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GENERAL

1. The NEC rules, which are the recommendations of the National Fire Protection Association (NFPA), should be followed in installing all interior wiring. These rules are revised every 3 years, and so it is inadvisable to include them entirely in this book. A copy of the rules can be obtained from any local inspection bureau or purchased from the NFPA. All statements are made in accordance with the 2008 edition of the Code. The Occupational Safety and Health Act (OSHA) adopted the 1971 National Electrical Code (initially the 1968 edition) as the electrical standard for employee safety in the workplace. NFPA has written a standard title “Electrical Safety Requirements for Employee Workplaces” (NFPA 70E®) that is intended to serve as an enforcement document by compliance officials of the Department of Labor.

2. There are local regulations covering the installation of wiring in force in many localities, which have been enacted by city and state governments. Sometimes these differ from the Code regulations, and so it is always well to be familiar with all the regulations in force before starting any work. The city and state rules are in reality laws and therefore take precedence over the NEC rules, which of themselves have no legal status.

3. Definitions (National Electrical Code). The NEC reserves Article 100 to cover the essential definitions required to properly apply its provisions. Not included are general terms that are commonly defined, or technical terms that are used in the same way as in related codes and standards. In addition, if a term is only used in one article, it will be defined within that article and not in Article 100. Part I of the article applies throughout the NEC; Part II covers definitions that only apply to installations operating over 600 V, nominal. Consult Article 100 if you are unclear as to how a specialized electrical term is defined that appears in the NEC.

There are four definitions, however, that are so widely used that they bear repeating here, along with some commentary, as follows:

a. **Amperes** The current, in amperes, that a conductor can carry continuously under the conditions of use without exceeding its temperature rating.

   This is covered extensively in Secs. 89 to 106 of Div. 3. Note that ampacity applies to electrical conductors. Other parts of an electrical system may have current ratings, such as switches, circuit breakers, motor contactors, etc., but only electrical conductors have an ampacity, and that ampacity changes with conditions. For example, 12 AWG THHN has an ampacity of 30 A at 30°C with three (or fewer) current-carrying conductors in a raceway. Raise the number of conductors, or raise the ambient temperature, or both, and the ampacity will decrease.

   The other three definitions cover the three methods of product acceptance recognized by the NEC. They are crucial to the proper application of the Code. Code making
panels have robust discussions every code cycle about which one to apply in a given situation.

b. **APPROVED** Acceptable to the authority having jurisdiction.

c. **IDENTIFIED** (as applied to equipment) Recognizable as suitable for the specific purpose, function, use, environment, application, etc., where described in a particular Code requirement.

d. **LISTED** Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that the equipment or material or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

**NOTE** The means for identifying listed equipment may vary for each organization concerned with product evaluation, some of which do not recognize equipment as listed unless it is also labeled. Use of the system employed by the listing organization allows the authority having jurisdiction to identify a listed product.

The word “approved” means acceptable to the inspectional authority (technically, the “authority having jurisdiction”), and nothing more or less. It does not mean “identified” unless the inspector chooses to use compliance with the definition of “identified” as the basis for his or her decision. Similarly it does not mean “listed” unless the inspector chooses that standard as the basis for his or her decision. For this reason, any statements in product literature (and they are common) that something is “approved” by some testing laboratory is necessarily fallacious. A product may be listed by a testing laboratory, but never approved.

The word “identified” is routinely confused with the normal usage in the English language of the word “marked.” It does not mean marked. It means what Article 100 says it means. It means generally recognizable as suitable for the specific application called out in the NEC requirement. This often comes from product literature generated by manufacturers. For an example of correct usage of this term in a Code rule, the NEC requires two-winding transformers reconnected in the field as autotransformers to be identified for use at elevated voltage. (Refer to the example in Sec. 117 of Div. 5 for the reasons why.) These transformers are frequently listed, but as two-winding transformers. They could not be listed as autotransformers because they do not leave the factory this way, and they have wide application as two-winding transformers. A listing would be excessive because the transformer manufacturers would have to run two production lines with two different labels for the same product. The installer needs to rely on product literature from the manufacturer to verify suitability for reconnection, and fortunately, these manufacturers all provide specific information on how to make the reconnections so the transformers will buck or boost the voltage as desired.

The word “listed” covers the most specific method of product acceptance, because it means that a qualified testing laboratory, usually with testing facilities that an inspector could not possibly duplicate, has performed exhaustive tests to judge the performance of the product under the conditions contemplated in a specific Code rule. The Code note that follows the definition needs some explanation as well. Although the note is written in a general and explanatory manner, in fact all qualified testing laboratories operating under the current North American electrical safety system do require a label as evidence of the listing. It follows, then, that if a label falls off, the product no longer has the status of being listed. Further, the only way a label can be reapplied is in the presence of an employee of the testing laboratory. Sending labels through the mail is not an option and will result in disciplinary action against the manufacturer by the testing laboratory. The testing laboratories will all send personnel into the field to witness the reapplication of labels.
4. Methods of installing interior wiring  (listed in the order of NEC coverage)

1. Armored cable, Type AC
2. Flat cable assemblies, Type FC
3. Flat conductor cable, Type FCC
4. Integrated gas spacer cable, Type IGS
5. Medium voltage cable, Type MV
6. Metal-clad cable, Type MC
7. Mineral-insulated, metal-sheathed cable, Type MI
8. Nonmetallic-sheathed cable, Type NM (and NMC and NMS)
9. Power and control tray cable, Type TC
10. Service-entrance cable, Type SE (and USE)
11. Underground feeder and branch-circuit cable, Type UF
12. Intermediate metal conduit, Type IMC
13. Rigid metal conduit, Type RMC
14. Flexible metal conduit, Type FMC
15. Liquidtight flexible metal conduit, Type LFMC
16. Rigid polyvinyl chloride conduit, Type PVC
17. High density polyethylene conduit, Type HDPE
18. Nonmetallic underground conduit with conductors, Type NUCC
19. Reinforced thermosetting resin conduit, Type RTRC
20. Liquidtight flexible nonmetallic conduit, Type LFNC
21. Electrical metallic tubing, Type EMT
22. Flexible metallic tubing, Type FMT
23. Electrical nonmetallic tubing, Type ENT
24. Auxiliary gutters
25. Busways
26. Cablebus
27. Cellular concrete floor raceways
28. Cellular metal floor raceways
29. Metal wireways
30. Nonmetallic wireways
31. Multioutlet assembly
32. Nonmetallic extensions
33. Strut-type channel raceways
34. Surface metal raceways
35. Surface nonmetallic raceways
36. Underfloor raceways
37. Cable trays
38. Concealed knob-and-tube wiring
39. Messenger-supported wiring
40. Open wiring on insulators
5. **Armored cable (Type AC)** includes Type AC. Type AC contains insulated conductors of a type accepted for general wiring applications to the NEC. The conductors are enclosed in an armor comprised of steel or aluminum interlocking tape. The armor is arranged with an internal bonding strip of aluminum or copper “in intimate contact with the armor for its entire length.” Type AC cable, which is commonly called BX, has largely been supplanted in the market by the interlocking-armor style of metal-clad cable. However, certain applications, especially patient care areas of health care facilities, require a wiring method where the outer margin of the wiring method, whether raceway or cable assembly, qualify as an equipment grounding return path, and Type AC cable inherently qualifies for this use.

6. **Flat cable assemblies (Type FC)** are comprised of a flat ribbon of 10 AWG conductors with a special stranding embedded in a flat nonmetallic assembly that is limited to 30-A branch circuits. The conductor ribbon is drawn into a raceway specially formed as an open channel to receive it. After the conductor assembly has been drawn in, special fittings that mount to the channel are added. These have sharp contacts that, when tightened, pierce the insulation mat supporting the conductors and make contact with the embedded conductors. The assembly is used to supply HID luminaires and other small power loads. The nonmetallic insulation is designed to be self-healing, and the tap mechanisms can be repositioned as needed.

7. **Flat conductor cable (Type FCC)** is a field-installed wiring system for branch circuits incorporated Type FCC cable and associated accessories for installation under carpet squares no larger than 914 mm (36 in.) square. FCC systems shall not be used outdoors or in other wet locations, where subject to corrosive vapors, in any hazardous location, or in residential, school, and hospital buildings.

8. **Integrated gas spacer cable (Type IGS)** is an assembly of 1 to 19 aluminum rods laid parallel, with kraft paper insulation over the bundle, inside a medium-density polyethylene jacket of 2, 3, or 4 trade size that is pressurized to a nominal 20 lb/sq in. (138 kPa) with sulfur hexafluoride (SF₆) gas. These assemblies are only permitted for use outdoors below grade or in tunnels, and must never be run in contact with a building.

9. **Medium-voltage (Type MV) cable** is a single or multiconductor cable with solid dielectric insulated conductors rated 2001 V or higher. Type MV cables are permitted to be used on power systems up to 35,000 V in wet or dry locations, in raceways, in cable trays, as permitted in Part II of NEC Article 396 covering messenger supported wiring, or directly buried when installed in accordance with Sec. 300.50 of the NEC. Type MV cables are not permitted in locations exposed to direct sunlight or in cable trays unless identified for these exposures. Type MV cables are permitted in exposed runs where suitable for the use and purpose, and without that qualification where accessible to qualified persons only. Type MV cable with an overall metallic sheath or armor is available with a dual “MV or MC” rating, and as such can be used where Type MC cable would be permitted.

10. **Type MC metal-clad cable** is a factory assembly of one or more conductors, each individually insulated and enclosed in a metallic sheath of interlocking tape or in a smooth or corrugated tube. The metallic covering may be a smooth metallic sheath, a welded and
corrugated metallic sheath, or interlocking metal-tape armor. This cable is widely used for concealed and exposed wiring when flexibility and ease of installation are important factors. Type MC cable is not permitted to be used when exposed to destructive corrosive conditions, such as direct burial in earth or in concrete or when exposed to cinder fills, strong chlorides, caustic alkalies, or vapors of chlorine or of hydrochloric acids, except when the metallic sheath is suitable for the conditions or is protected by material suitable for the conditions.

11. Mineral-insulated metal-sheathed cable (Type MI) consists of one or more electrical conductors insulated and separated by highly compressed refractory mineral insulation and protected from injury by enclosure in a liquidtight and gastight copper or nickel-clad copper sheath. The wires, insulation, and protective sheathing are manufactured as a unit. The method of installation is similar to that of metal-clad cable. Special approved fittings are used for terminating and connecting the cable to boxes and other equipment. At all points of termination of the cable an approved moisture seal must be provided.

12. Nonmetallic-sheathed cable (Types NM, NMC, and NMS) is made in three types, Types NM, NMC, and NMS. Type NM consists of two or more rubber- or thermoplastic-insulated wires bound together and protected by a plastic jacket. Type NMC cables are protected by an outer flame-retardant, moisture-resistant, fungus-resistant, and corrosion-resistant sheath which contains no cotton or paper. Type NMS cable is a factory assembly of insulated power, communications, and signaling conductors enclosed within a common sheath of moisture-resistant, flame-retardant, nonmetallic material. Nonmetallic cable may be run exposed on walls and ceilings, or concealed in the hollow spaces between partitions or between floors and ceilings. The cable is fastened directly to the surface of the walls, ceilings, or structural members with approved supports. Provision for outlets and switches is made by running the cable into outlet boxes. In most cases such cables contain an equipment-grounding conductor.

13. Power and control tray cable (Type TC) is an assembly of two or more insulated conductors, with or without associated bare of overed grounding conductors, under a nonmetallic jacket. It is not permitted to be made with a metallic cable armor either under or over the nonmetallic jacket; however, metal shielding is permitted, and where employed, the minimum bending radius of the cable must not be less than 12 times the cable diameter. Otherwise, the minimum allowable bend radius is based on the cable diameter, with a four times the diameter allowed for cables 1 in. (25 mm) or thinner, five times for cables up to 2 in. (50 mm), and six times for larger cables. In addition to cable tray usage, Type TC cable is permitted to run within raceways and on messenger wires, but for outdoor applications in direct sun it must be identified for that use. It may be directly buried, but also only if so identified.

Type TC cable is available with a more robust configuration that will meet the crush and impact tests that apply to metal-clad cable, Type MC. This form is identified as Type TC-ER. For industrial occupancies with qualified maintenance and supervision, Type TC-ER is permitted to exit a cable tray and run to utilization equipment or devices, provided also that it has continuous mechanical support, such as strut, angles, or channels. In addition, Type TC-ER is permitted to run unsupported between cable tray transitions, or from cable trays to utilization equipment or devices as long as the unsupported distance does not exceed 6 ft (1.8 m). Where the cable exits the tray, mechanical support must be provided so the required bend radius is maintained.
14. Service-entrance cable (Types SE and USE) (see Div. 2) normally is used for the conduit from the point of attachment of the service conductors on the outside of the building to the service switch, load center, or meter cabinet just inside the building. It may, however, also be employed for the interior wiring on the load side of the service switch. It is not commonly used for general interior wiring but is used for certain special portions of the wiring such as to supply large appliances like an electric range, as a feeder to a distribution panel elsewhere in the building, or as a service cable to other buildings. For unrestricted use all the conductors must be rubber- or thermoplastic-insulated. If an uninsulated neutral is used, the cable must have a final nonmetallic outer covering, the voltage to ground must not exceed 150 V, and it may be used to supply other buildings. The cable is fastened to the surface with straps spaced not over 1.4 m (4 ft 6 in.) apart.

15. Underground-feeder and branch-circuit cable (Type UF) resembles Type USE service-entrance cable in general appearance. The insulation employed may consist of a special synthetic plastic compound. When single-conductor cables are used, all conductors of the circuit must be installed in the same trench or raceway. For multiconductor cable installations all conductors of the circuit together with the protective covering of the cable are installed as a unit, just as in metal-clad or nonmetallic-sheath–cable installations. Provision for outlets is made by running the cable into suitable outlet boxes. Underground-feeder and branch-circuit cable wiring provides a convenient approved method for interior wiring in wet or corrosive locations. It may be installed underground in raceways or be buried directly in the earth. Multiconductor cables usually contain an equipment-grounding conductor.

16. Intermediate metal conduit (Type IMC) is the same as rigid metal conduit (following) except that, although threaded, it has a thinner wall. The alloy is such that it has essentially the same strength and it is permitted for the same uses as rigid metal conduit. The only real difference is that it is only made up to metric designator 103 (trade size 4) and no smaller than metric designator 16 (trade size 1/2).

17. In the rigid-metal-conduit (Type RMC) method of installing interior wiring the wires are supported and protected from mechanical injury by being installed in ferrous or nonferrous types of rigid metal conduits. Ferrous types are of wrought iron or steel with coatings such as black enamel, electrogalvanizing, hot-dip galvanizing, or similar material. Nonferrous types include aluminum or brass (silicon bronze) conduits. Various types of ferrous and nonferrous metal conduits are available with outer plastic coatings to provide optimum protection from corrosion.

Rigid or intermediate metal conduit may be run exposed, supported directly on walls, ceilings, or roof structures or on suitable hanger assemblies. It may also be concealed in partitions, ceilings, or floors. Provision for connection to the circuit at outlet and switch points is made by the insertion of sheet-steel, cast-metal boxes (steel or aluminum), or special conduit fittings in the conduit run. The special conduit fittings, LB, T, LL, LR, X, etc., are called by various trade names, such as Condulets or Unilets and defined as conduit bodies by the NEC. Although rigid metal conduits are usually employed with threaded fittings and connections, many threadless fittings are available for use without threading the conduit.

Conduit, fittings, and boxes are installed complete without wires. Then the wires are pulled into the conduit from fitting to fitting, box to box, or fitting to box. In hazardous locations only threaded connections (full five threads, or 41/2 threads in the case of threads made by the manufacturer on listed equipment) are permitted.
18. The flexible-metal-conduit method (Type FMC) of installing wires is used to a limited degree in frame buildings, or similar applications in which rigid raceways would be difficult to install and a pull-in, pullout conduit system is desirable. (Flexible metal conduit is often referred to as Greenfield.) It is available in metric designators 16 through 103 (trade sizes \(\frac{3}{8}\) through 4), with metric designator 12 (\(\frac{3}{8}\) trade size) available under special conditions, and as covered in Sec. 170. The runs of conduit, boxes, and fittings are installed first as a complete system. Then the wires are installed in the same manner as in rigid metal conduit. It is not permitted to be used in wet locations. The NEC states that flexible metal conduit may be used as a grounding means if the total ground return path in flexible conduits is no more than 1.8 m (6 ft) and both conduit and fittings are listed for grounding and the circuit conductors are protected by a 20-A overcurrent device or less. If they are not so listed, each run of flexible metal conduit must contain a bare or insulated grounding conductor, and this grounding conductor must be attached to each box or other equipment supplied by such conduit. The separate grounding conductor is also required if the installation requires flexibility after installations, such as for vibration isolation or for connection to moveable parts such as a swinging sign.

19. Liquidtight flexible metal (Type LFMC) has, in the case of LFMC, an outer liquidtight jacket. It is not intended for general-use wiring. Wiring of this kind is expressly permitted to be used for the connection of motors or portable or stationary equipment when flexibility of connection is required. There is no outright prohibition against other uses. It is available in the same sizes and under the same rules as for flexible metal conduit. When used, it must be provided with suitable terminal connectors approved for the purpose. It cannot be used where subject to physical damage, where subject to temperatures above its rating, or in any hazardous location, except for limited flexibility, and motor connection in Div. 2 areas, Class II dust areas, Class III fiber or flyings areas, and as permitted by Sec. 504.20 for intrinsically safe systems. See Tables 4 and 5 (and 5A) in Chap. 9 of the NEC for maximum sizes of conductors allowed. Where listed and marked for the purpose, it can be used for direct burial applications.

20. Rigid polyvinyl chloride conduit and fittings (Type PVC) are constructed of polyvinyl chloride, a polymeric (plastic) material that is resistant to moisture and chemical atmospheres. These conduits can be used above grade in exposed applications generally, and the very heavy wall Schedule 80 version can be used where exposed in areas of physical damage. Such conduits may also be embedded in concrete in buildings or installed in wet locations such as laundries or dairies. Complete lines of nonmetallic fittings and boxes are available. They may also be buried directly in earth. For underground applications refer to Div. 8.

21. High density polyethylene conduit (Type HDPE) is a tubular raceway of circular cross section. It is available in discrete lengths, and also in continuous lengths on a reel. It is available from metric designator 16 (trade size \(\frac{3}{8}\)) up to and including metric designator 155 (trade size 6). It must not be used above 50°C, either by reason of a high ambient temperature, or high operating temperatures of the enclosed conductors, or both. Polyethylene is flammable, and for that reason it is generally limited to direct burial applications. If not specifically prohibited, it is permitted above grade if encased in a concrete envelope not less than 2 in. (50 mm) thick. It is not permitted to be exposed, and it must not be used inside buildings. NEC Table 354.24 specifies the minimum bending radius for this...
material, which is more restrictive than most tubular raceways. The table begins with a 250 mm (10-in.) radius for metric designator 16 (trade size \(\frac{3}{4}\)) conduit, and rises to a 1.5 m (5 ft) minimum radius for the trade size 4 product. There is no table entry as of the 2008 NEC for metric designator 129 or 155 (trade size 5 or 6) conduit, so the manufacturer’s directions would need to be consulted for these sizes.

22. **Nonmetallic underground conduit with conductors (Type NUCC)** is the same product as Type HDPE conduit, and it follows the same installation rules, but conductors are preinstalled and shipped with the product by the manufacturer. Note that even though conductors arrive with the product preinstalled, it is still classified as a raceway, and the 360° maximum bends-in-the-run rule continues to apply.

23. **Reinforced thermosetting resin conduit (Type RTRC)** is the fiberglass entry in the nonmetallic conduit market. At one time it was only permitted for below-grade applications, but advances in chemistry have resulted in materials that meet above-grade fire resistance tests and it is now permitted for use in buildings where concealed in walls, floors, and ceilings, and also where exposed if identified for the application. It is stiffer than PVC and has a much lower coefficient of thermal expansion (about 45 percent of the value for PVC). Although the NEC uses the same support distance table as for PVC conduit, it does allow for longer support intervals if the product is listed for larger distances. It is more difficult to bend in the field, although an extensive range of different bend angle sweeps is available to accommodate field installation issues. It must not be used above 50°C unless listed for a higher temperature.

24. **Liquidtight flexible nonmetallic conduit (Type LFNC)** is a flexible nonmetallic raceway of circular cross section, available in three forms. Type LFNC-A has a smooth, seamless inner core and cover bonded together, with reinforcement between the core and cover layers. Type LFNC-B has a smooth inner surface together with reinforcement within the conduit wall. This is its most usual form. Type LFNC-C has a corrugated inner and outer surface, with no reinforcement in the wall. It is generally limited to 6-ft (1.8 m) lengths unless a longer length is required for the amount of flexibility called for at the point of use. However, the “B” style does not carry this length limitation. It can be used for direct burial and concrete encasement if listed and marked accordingly. It is available in the metric designator 16 through 103 (\(\frac{3}{8}\) through 4 trade) sizes, with the metric designator 12 (\(\frac{3}{4}\) trade size) available to enclose the leads of motors in some cases, and also in runs not over 1.8 m (6 ft) to luminaires as part of a listed assembly, or to utilization equipment.

25. **In the electrical-metallic tubing (Type EMT) method** of installing wiring the wires are installed in a thin-walled metallic tube or thin-walled conduit, as it is sometimes called. Electrical metallic tubing is similar to rigid conduit, except that it is constructed of much thinner material. Provisions for connecting outlets and switches to the circuit are made by means of special metallic-tubing fittings or by means of regular rigid-conduit fittings provided with an adapter. After the tubing and fittings have been installed as a complete system, the wires are pulled in from fitting to fitting as in the rigid-conduit method. Connectors and couplings are threadless types such as setscrew, compression, indenter, or tap-on.
26. **Flexible metallic tubing (Type FMT)** is a flexible metallic raceway intended to be used in protected locations such as suspended ceilings. Flexible metallic tubing in the \(\frac{3}{8}\) trade size is restricted to 1.8 m (6 ft) lengths and was developed for use in ducts or plenums through which the excursion of smoke or gases from the raceway needed to be controlled. The wiring method is otherwise available in trade sizes \(\frac{1}{2}\) and \(\frac{3}{4}\), the maximum permitted.

27. **Electrical nonmetallic tubing (Type ENT)** is a pliable, corrugated raceway of circular cross section with integral or associated couplings, connectors, and fittings listed for the installation of electric conductors. It is composed of a material that is resistant to moisture and chemical atmospheres and is flame-retardant. It is made of the identical PVC from which Type PVC conduit (Sec. 20) is made. It is sold in metric designators up to 53 (trade sizes up to 2), but in a corrugated wall construction that allows it to be bent by hand without the application of heat. It can be supplied in continuous lengths from a reel. It is even available as a prewired assembly with specified conductor combinations already pulled in place. However, it is not a cable, and it is subject to all the normal restrictions for raceways, including the \(360^\circ\) bend rule. It must be supported every 900 mm (3 ft), and within the same distance of terminations. It cannot be used outdoors or for direct burial; however, it can be used in cases where it runs in concrete, even if the concrete is below grade.

You can use the ENT wiring method either exposed or concealed in low-rise construction. However, in buildings that exceed three floors above grade, it must never be exposed, even in the first three floors. Instead, in other than fully sprinklered buildings, it needs to be behind a thermal barrier that has at least a 15-min finish rating as defined in listings of fire-rated assemblies. In the case of walls, this is fairly easy to arrange, since most \(\frac{1}{2}\)-in drywall used in commercial construction carries this rating. The same holds true above a drywall ceiling. However, if there is a suspended ceiling (common in commercial occupancies), check with the building inspector. The support grid and the ceiling panels need to be identified as a combination for this duty. For example, having 15-min panels would do no good if the T-bars dumped those panels onto the floor after 11 min of fire exposure.

The first floor is defined as the one with at least half its exterior wall area at or above grade level; one additional floor level at the base is allowed for vehicle parking or storage, provided it is not designed for human habitation. Beginning with the 2002 NEC, ENT can also be used in high-rise buildings (those over three floors above grade) without the use of a thermal barrier if the entire building has a complete fire sprinkler system in full compliance with NFPA 13, *Standard for the Installation of Sprinkler Systems*. The sprinkler system must cover all floors, not just the area where the use of ENT is being considered.

28. **Auxiliary gutters** differ from wireways only by the way they are applied in the field; they are usually listed for both purposes as they leave a manufacturer. They are available in both sheet metal and nonmetallic forms. They have hinged or removeable covers that allow for conductors to be laid in place after the system is complete. Their function is to supplement wiring spaces at meter centers, distribution centers, switchboards, and similar locations in a wiring system. They are not wireways, which are unlimited in length and intended as a circuit wiring method that connects a line and a load. An auxiliary gutter with a rectangular opening cut to match a similar opening cut in a panelboard, and used to contribute to the wire bending space in the panelboard would be an excellent example. This concept of why the auxiliary gutter article has current carrying limitations for busbars placed in the enclosure, but the wireway article does not address the topic. If a conductor needs to be pulled from the gutter through a nipple to a panel or switchboard, the use may be crossing over into the wireway article. That said, the basic field installation...
rules for conductor fill, derating thresholds, use as pull boxes, and distinctions between metallic and nonmetallic versions are similar. Refer to wireway topics in this division for more information.

29. **Busway systems** of wiring consist of bare or insulated busbars insulated from each other and supported and protected by a sheet-metal housing. The housing and busbars are assembled as a unit in 3.0-m (10-ft) or longer sections. The system is installed by supporting the housing from the ceiling, walls, or roof structure. Busway systems are extensively used for the feeder and main circuits in industrial plants. They are available in three general types: without provision for outlets, with provision for fixed outlets, and with provision for continuously moveable outlets for portable tools and electric-welding work. With the type which has provision for fixed outlets, openings are provided every few inches for branch taps. The connection of a tap to the busbars is accomplished through the insertion of a special power attachment plug in these openings. For the wiring of the branch circuit from the power plug to the apparatus to be supplied with power, flexible conduit, rigid conduit, or metal-clad cable may be employed. This method of wiring provides a very flexible system which meets in an economical manner the requirements of plants in which production conditions necessitate the frequent shifting or replacement of machinery.

30. **A cablebus system** is an approved assembly of insulated conductors mounted in spaced relationship in a ventilated metal protective supporting structure, including fittings and conductor terminations. Cablebus may be used at any voltage up to 35 kV or current for which the spaced conductors are rated. It is ordinarily assembled at the point of installation from components specified by the manufacturer. First, the supporting structure is installed in the same manner as in a cable-tray support system. Next, the insulated conductors, not less than 1/0 with insulation ratings at 75°C or higher, are inserted. After this, insulating supports are installed so that the conductors are properly separated and supported at intervals of not less than 900 mm (3 ft) for horizontal runs and 450 mm (1 1/2 ft) for vertical runs. Conductor ampacity is based on the values for open conductors.

31. **In cellular-concrete-floor-raceway wiring,** the floor is constructed of precast reinforced-concrete members. These precast members are provided with hollow voids which form smooth, round cells. The cells form raceways for the wires. Connections to the cells from a distribution center can be made by metal header ducts run horizontally across the precast slabs and embedded in the concrete fill over the slabs. Connection from these headers to the cells is made through handhole metal junction boxes. An outlet can be located at any point along a cell. An opening into the cell at the desired point is formed by drilling a hole through the concrete floor slab. The hole is then fitted with the proper outlet fitting, and the wires fished from a handhole junction box to the outlet.

32. **In cellular-metal-floor-raceway wiring,** the floor is constructed of special metal structural members containing hollow spaces or cells which form raceways for the wires. Provision for pulling in and splicing wires is made by locating special junction boxes in the floor between sections of the floor members. Outlet openings and fittings may be originally provided at regular intervals along the raceway formed by the cells, or outlets may be provided at any time after completion of the building construction simply by cutting a hole in the floor and cell wall and inserting a special floor-outlet fitting. After the
complete floor structure has been erected and finished over, the wires are pulled through the raceway formed by the floor cell structure and the junction boxes.

33. **In the metal wireway method** of wiring, the wires are supported and protected in a sheetmetal or nonmetallic trough. The trough is installed exposed, being mounted on the ceiling or walls or supported from the roof structure. One side of the trough is fitted with a sheet-metal cover so that access can be made to the interior sections of the trough throughout its length. After the wireway has been installed as a complete system, the wires are laid in the trough and the cover is installed. Mains and feeders are run in the wireways with taps for branches taken off at the most convenient point through rigid or flexible metal conduit, connected to the wireway through knockouts provided on three sides of the trough. This system provides a flexible distribution system.

34. **Nonmetallic wireways** are the nonmetallic version of metal wireways. There are some important differences, however. They must be securely supported at not greater than 900-mm (3-ft) intervals [1.2 m (4 ft) for vertical runs], which is far more frequent than the 1.5 m (5 ft) and 4.5 m (15 ft) distances allowed in sheet metal version. In addition, the derating penalties for mutual conductor heating apply to any current-carrying conductor fill above three. This is far more severe than for sheet metal wireways (with 30 or fewer, no penalty), but is justified because the metallic version is a far better heat sink. Refer to Sec. 351 for more information.

35. **Multioutlet assemblies** are a special form of surface raceway with built-in single receptacle outlets every few inches. The assembly is supported on the surface of walls or in or on top of baseboards. It is used for wiring in dwellings and commercial buildings to provide very convenient and adequate convenience outlets. The assembly is supplied with power through a cable or conduit run concealed in the walls and brought into the back or end of the assembly.

36. **A nonmetallic extension** is an assembly of two insulated conductors within a nonmetallic jacket or an extruded thermoplastic covering. The assembly is mounted directly on the surface of walls or ceilings. Nonmetallic extensions are permitted only if (1) the extension is from an existing outlet on a 15- or 20-A branch circuit and (2) the extension is run exposed and in a dry location. Nonmetallic extensions are limited to residential or office buildings that do not exceed three stories above grade. This category also includes concealable nonmetallic extensions, which are comprised of two, three, or four insulated circuit conductors that mount on wall and ceiling surfaces in a flat configuration that is capable of concealment behind paint, joint compound, wallpaper, etc. In this form, if identified for the purpose, concealable extensions are permitted in buildings of more than three stories.

37. **Strut-type channel raceways** use steel, stainless steel, or aluminum formed similar to construction strut, but with generally solid surfaces and listed as an electrical raceway. It can be mounted on a building surface or suspended, and must be fastened at least every 3.0 m (10 ft) and within 900 mm (3 ft) of terminations. The strut depth varies from $\frac{13}{16}$ to 3 in, (20.6 to 76 mm) with the allowable wire fill based on either 25 percent or
40 percent of the internal cross-sectional area, with the lesser fill mandated if the joiners between raceway sections are mounted internally. However, if the wire fill does not exceed 20 percent and the current-carrying conductor count does not exceed 30, then there is no ampacity derating for mutual conductor heating.

### 38. Surface metal raceways
Enclose wires that are inserted into a sheet-metal enclosure of various configurations. The raceway is installed exposed on interior building surfaces. The metal molding is made with a flattened-oval or rectangular cross section. Numerous fittings, adapters, and boxes, specially designed for this system, are readily available from major manufacturers of this wiring system. In some configurations the cover is separate from the base, and in others the cover and base are permanently joined and the wires are pulled in similar to tubular raceways. If the raceway exceeds 2500 mm² (4 in²) in cross section, the current-carrying conductor count does not exceed 30, and the wire fill does not exceed 20 percent, then mutual conductor heating derating penalties for wire fill are excused. Where different systems run in opposite halves of a divided raceway in order to accomplish the system segregation required by the NEC, such as communications circuits and power circuits, the separate compartments must be identified by imprinting, stamping, or color coding.

### 39. Surface nonmetallic raceways
Are the nonmetallic versions of surface metal raceways and have similar requirements. As in the case of other nonmetallic equivalents, these raceways are not effective heat sinks and the allowances for conductor fill without ampacity derating penalties do not apply to these raceways.

### 40. In the underfloor-raceway method
Of wiring the wires are installed in a sheet-metal or fiber casing which is embedded in the concrete or cement fill of the floor. Generally, the ducts or raceways are laid out in the floor to form a network. Provision is made at the intersections of the ducts for the pulling in and splicing of wires by means of special floor junction boxes. Sheet-metal–type raceways are provided with outlet openings spaced at regular intervals along the raceway. These outlet openings are either plugged or equipped with special floor-outlet fittings. With the fiber-duct type of raceway the raceway is first installed in the floor without any outlet openings. After the floor has been finished, outlets may be provided at any desired point along the duct runs simply by cutting a hole in the floor and duct and inserting a special floor-outlet fitting. In the underfloor-raceway systems the wires are pulled through the ducts in the same manner as for rigid-conduit work.

### 41. Cable tray
Is a unit or an assembly of units or sections and associated fittings made of metal or other noncombustible materials forming a continuous rigid structure used to support cables. The support system includes ladders, troughs, channels, and similar support systems. Cable tray is not a wiring method and may be used only as the mechanical support for approved raceways or multiconductor cable wiring methods or specially approved multiconductor cables designed for use in cable trays; or 1/0 AWG or larger single conductors in industrial establishments where conditions of maintenance and supervision assure that only qualified persons will service the cable-tray system. First, the cable tray is installed, and then the cables or raceways are installed and secured to the cable tray. This system has particular merit in industrial applications or similar uses for which many power, control, or signal cables are required and flexibility is a major consideration.
42. **Concealed knob-and-tube wiring** was one of the earliest methods of installing wiring. The wires were mounted on knobs and run through tubes where they pierced structural members of the building. They were then concealed by the wall and ceiling surface. This method is still allowed by the NEC but is not used very often because of the large amount of labor required to install the wiring. In addition, the wiring seldom includes an equipment grounding conductor, which is problematic in terms of meeting installation requirements for most metallic equipment.

43. **Messenger-supported wiring** encompasses the use of a messenger wire to support other wiring methods, or even individual conductors in some cases. The messenger must be supported at dead ends and at intermediate locations to assure that there will be no tension on the conductors, and that they will not come in contact with the messenger supports, or any structural members, walls, or pipes. The messenger supported wiring can be a factory assembled grouping, either as aerial cable or as a bare conductor twisted with ungrounded conductors such as duplex, triplex, or quadruplex makeups. The conductors can also run through rings or saddles, or they can be attached with a field lashing material. Acceptable wiring methods for messenger support include Types MC (Sec. 10), MI (Sec. 11), TC (both power and power limited cables, Sec. 13), UF (Sec. 15), multiconductor Type SE (Sec. 14) and other factory-assembled multiconductor cables identified for the application. In industrial occupancies with qualified maintenance and supervision, there are additional allowances covering ordinary building wires. If the messenger runs outdoors, such wires must be listed for wet locations and sunlight exposure as applicable. Type MV cable is also permitted assuming the exposed use is permitted by Article 300 (see Sec. 9).

44. **In the open-wiring method on insulators** of installing interior wiring the wires are run either concealed or exposed on the ceiling, roof structure, or walls. They are supported on porcelain insulators of either the knob (Figs. 4.139, 4.140, and 4.141) or the cleat type (Figs. 4.143 and 4.144) so as to provide the necessary clearance between the wires and the surface being wired over.

**OPEN WIRING ON INSULATORS**

45. **Open wiring on insulators** is one of the cheapest methods of installing wiring. It finds application in factories and mills for the installation of feeder circuits in places where appearance is of little consequence. The wires may contain rubber or thermoplastic insulation. Smaller wires must be supported at least every 1.4 m (4½ ft). Conductors 8 AWG and larger may be run across open spaces and supported at distances not greater than 4.5 m (15 ft) if approved noncombustible, nonabsorptive insulating separators providing not less than 65 mm (2½-in.) separation between conductors are installed at intervals of not over 1.4 m (4½ ft). For mill construction in locations where the conductors are unlikely to be disturbed, conductors 8 AWG and larger can be run between cross members on insulators such that the conductors are at least 150 mm (6 in.) apart. Industrial occupancies with a qualified maintenance force may use 250 kcmil or larger conductors supported at 9 m (30 ft) intervals.

46. **Knobs and methods of supporting conductors on them.** Knobs for supporting conductors in interior work are of porcelain. Split knobs or cleats may be used for supporting conductors smaller than 8 AWG. Some methods of securing wires to knobs are shown in Fig. 9.1. The line tie of I is made by winding the conductor once around the knob,
so both ends of the wire must be under tension to hold the wire in position. A tie wire is used at II; in making up the tie wire the slack can be drawn out of the conductor. A dead end, or termination, is shown at III. If it is necessary to change the direction of a run to get the conductor to an outlet or for any other reason, tap ties IV, V, and VI are used. It is not practicable to tie large conductors, so they may be supported as at VII.

For a discussion of types of knobs see Div. 4.

Nails used to support knobs must be not smaller than tenpenny and must be provided with cushion washers. When screws are used, they must penetrate the supporting wood to a depth equal to at least one-half the height of the knob or to at least the thickness of the cleat used.

47. **The wires** must have an insulation equal to that of the conductors they confine and may be used in connection with solid knobs for the support of wires of size 8 AWG or larger.

48. **The method of dead-ending on a cleat** at the end of a run is illustrated in Fig. 9.2. After the wire has been passed through the groove, the free end is given several short turns around the line. When a long run is dead-ended, it is often advisable to fasten two sets of cleats in such a way that one bears against the other so that both will assume the strain as shown at II. For types and dimensions of cleats see Div. 4.

49. **Methods of terminating heavy conductors.** At the ends of all important open-wire runs of wires larger than, say, 8 AWG, strain insulators engaging in some wire-tightening device should be used. Figure 9.3 illustrates some methods. Either tightening bolts or turnbuckles can be used. The insulator may be of the type extensively used in trolley-line construction as in I, II, and III, or it may be a heavy knob (IV) held to the tightening device with stout wire. When a run changes direction, a cable clamp can often be used with economy, particularly with large conductors. If a cable clamp is used, it is
unnecessary to cut the conductor to change its direction, and the need to make up turns about the line wire as in I and II is eliminated.

50. Different approved methods of exposed surface wiring are illustrated in Fig. 9.4. Which method should be used in any particular case is determined largely by the size of the wire involved and other local conditions.
51. Physical protection of exposed surface wiring. Wires must be protected on sidewalls from physical damage and, when crossing timbers where they might be disturbed, must be protected by guard strips or running board and guard strips as shown in Figs. 9.5 and 9.6. The guard strips must be at least 25 mm (1 in.) nominal thick and at least as high as the insulators. If a running board is used, it must be at least 13 mm (1/2 in.) thick and must extend at least 25 mm (1 in.) outside the conductors but not more than 50 mm (2 in.). The wires should also be protected by porcelain tubes when passing over pipes (Fig. 9.7) or any other members. Tie wires may be used in lieu of tape.

Conductors within 2.1 m (7 ft) from the floor shall be considered exposed to physical damage. Suitable protection on sidewalls therefore should extend not less than 2.1 m (7 ft) from the floor (Fig. 9.8). This protection may consist of substantial boxing, providing an air space of 25 mm (1 in.) around the conductors, closed at the top (the wire passing through porcelain-bushed holes), or of a conduit with fittings on each providing individual bushed holes for each wire (Fig. 9.8, III).
52. Methods of carrying exposed wiring around and through beams are illustrated in Fig. 9.4, which shows tube-and-cleat arrangements. In Fig. 9.9 are shown methods that can be used when wires are supported on knobs.

53. In steel-mill buildings heavy conductors may be carried on the lower chords of the roof trusses (Fig. 9.10). This is a good location because the conductors are out of the way and not apt to be disturbed. At each truss the conductors can be supported by one of the methods illustrated in Fig. 9.11. With the method of Fig. 9.11, I, the conductor merely rests in the insulator, and the entire longitudinal strain is taken by strain insulators attached to the tightening bolts or turnbuckles at the ends of the run. This method has the
disadvantage that if the conductor breaks at any point or is burnt in two, it will fall to the floor. The tie-wire method of II is seldom used, though it is satisfactory if cleats are not obtainable. (Split knobs or cleats must be used for conductors smaller than 8 AWG.) The cleat and through-bolt method of III is probably the best, all things considered. After the conductor has been drawn taut with the tightening bolts at the end of the run, the cleat bolts are tightened and each cleat then assumes its share of the stress. Tie wires, which are unreliable and may cut into the insulation of the conductor, are unnecessary. Leather washers should be used between the insulator and the bolt to prevent breakage.

54. For supporting conductors on steel angles the Universal Insulator Support (Figs. 9.12 and 9.13 and Table 42) is a convenient fitting. It is of malleable iron and can be clamped on the flanges of steel beams, angles, channels, and Z bars and on round, square, and flat bars. It can also be attached to gas and water pipes and to the edges plates and tanks. Two insulators can be fastened to each support when necessary. Cup-pointed, case-hardened setscrews are used. Leather washers should be used under the bolts that hold the insulators.
55. Dimensions of Universal Insulator Supports
(Steel City Division, Midland-Ross Corp., Pittsburgh)

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<thead>
<tr>
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<td>¾</td>
<td>½</td>
<td>¾</td>
<td>½</td>
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<td>½</td>
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<td>1</td>
<td>1</td>
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<td>3</td>
<td>½</td>
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<td>1½</td>
<td>¾</td>
<td>¾</td>
<td>¾</td>
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</tr>
</tbody>
</table>

56. For supporting conductors on steel columns a wooden baseboard for the cleats clamped to the column with hook bolts (Fig. 9.14) is a good arrangement. The board must be cut out in back for the rivet heads in the column. Strap-iron cleats through which the hook bolts pass prevent warping and splitting.

57. Wire racks are used to support conductors, principally heavy ones, when there are many conductors in the run. The conductors should have flameproof or slow-burning covering. A wire rack can be made of wood fashioned into a framework somewhat along the lines of the steel ones of Figs. 9.15 and 9.16. The cleats insulating the conductors are held to the frame with wood screws or, preferably, with machine or stove bolts. A commercial wire rack with a cast-iron base that can be bolted to any surface is shown in Fig. 9.17. Generally a steel-frame rack is preferable to a wooden one. The rack of steel angles of Fig. 9.15 was designed for installation in the top of a pipe tunnel. The insulators are held to the cross angles with bolts with a leather washer under the head of each. The structural-steel rack of Fig. 9.16, III, is arranged for supporting from a ceiling. Angle crossarms can be used as at I, or the crossarms can each be formed of two iron straps as at I. With the two-strap method, drilling for the cleat bolts is unnecessary, and the cleats can be shifted along the arm into any desired position and there clamped fast.
Strain insulators engaging in turnbuckles or tightening bolts should be used at the end of each straight run to assume the strain and to provide for tightening, or else the arms and cleats at the run ends should be reinforced to assume the stress that will come on them.

58. A method of supporting open wiring in concrete buildings is shown in Fig. 9.18. A round groove of \( \frac{3}{8} \)-in (9.525-mm) radius is cast in the faces of the beams, by having \( \frac{3}{4} \)-in (19.05 mm) half-round molding nailed in the forms.

59. When conductors pass through floors, walls, or partitions, they must always be protected. Openwork wires can be protected with porcelain tubes (Fig. 9.19). The tube or bushing must be long enough to bush the entire length of the hole in one continuous piece, or else the hole must first be bushed by a continuous waterproof sleeve of noninductive material and the conductor so installed that it will be absolutely out of contact with the sleeve.

60. A tube for protecting a wire where it crosses another wire should always be so placed that the tube will not force the unprotected wire against the surface supporting the conductors.

61. Flexible nonmetallic tubing, or “loom” (Fig. 9.20) is used mostly in connection with open wiring and concealed knob-and-tube wiring. When metal outlet boxes or switch boxes are used, flexible tubing is required from the last porcelain support, extending into the outlet box at least 6 mm (\( \frac{3}{8} \) in.), and held in place by an approved fitting such as a universal bushing or a clamp.
Another application for flexible tubing is in completed buildings where the wires are fished in between the walls and ceilings. Flexible nonmetallic tubing is used as a covering on such wires separately encased. In concealed knob-and-tube work it is frequently impracticable to place wires 75 mm (3 in.) apart and 25 mm (1 in.) from the surface wired over as required by the National Electrical Code, and in such cases the wires must be separately encased in flexible tubing. In open wiring when the amount of separation required by the Code from the surface wired over cannot be maintained, the wires may also be encased in flexible tubing.

The following is a list of places where flexible nonmetallic tubing is applicable: in open-work where wires are exposed nearer each other than 75 mm (3 in.); on wires crossing other wires; on wires crossing gas pipes, water pipes, iron beams, woodworking, brick, or stone; and at distributing centers or where space is limited and the 75 mm (3 in.) separation required cannot be maintained. Each wire must be separately encased in a continuous length of flexible nonmetallic tubing.

Only continuous (unspliced) lengths of flexible nonmetallic tubing can be used for wire protection at outlets.

### 62. Properties of Flexible Tubing or Loom

<table>
<thead>
<tr>
<th>$A$, inside diameter, in</th>
<th>$B$, outside diameter, in</th>
<th>Ft per coil</th>
<th>Largest wire, AWG or cmil</th>
<th>Weight, lb/1000 ft</th>
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<td>$2^{1/4}$</td>
<td>$2^{3/16}$</td>
<td>Odd lengths</td>
<td>1,100,000</td>
<td>810</td>
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</tbody>
</table>

### 63. When conductors cross damp pipes, they should be carried over rather than under so that drippings will not strike the wires. Porcelain tubes, securely taped to the conductors, should be placed on the conductors over the point where they cross.
64. **Rosettes for open surface wiring** are used to connect drop cords for incandescent lamps to the branch circuits. A rosette with protected (concealed) contact lugs is preferable to one with exposed lugs. Figure 9.21 shows one good type. Another good method of supporting drop cords, particularly if there is vibration, is with the ceiling button illustrated in Fig. 9.22.

![Figure 9.21: A cleat rosette.](image1)

![Figure 9.22: Ceiling buttons.](image2)

65. **Switches can be supported in exposed surface wiring** as shown in Fig. 9.23. The switch can be mounted on a commercial porcelain switch block.

![Figure 9.23: Support switches in exposed surface wiring.](image3)

66. **Entering damp or wet locations** (National Electrical Code). Conductors entering or leaving damp or wet locations shall have drip loops formed on them and shall then pass upward and inward from the outside of buildings or from the damp or wet location through noncombustible, nonabsorptive tubes.
CONCEALED KNOB-AND-TUBE WIRING

67. Concealed knob-and-tube wiring was used extensively at one time for the wiring of frame buildings when a low-cost installation was essential. It is still allowed by the National Electrical Code, but only for extensions of existing installations (or otherwise by special permission), and it is rarely used because more labor is required than with common cable systems. It has been superseded for low-cost installations by nonmetallic-sheathed cable.

68. Extensions of concealed knob-and-tube wiring are seldom practical today. (Adapted from Practical Electrical Wiring, 20th ed., © Park Publishing, 2008, all rights reserved.) Although this handbook extensively covers concealed knob-and-tube wiring because installers often come across it and need a reference source to help understand it, it is no longer routinely installed. The hardware is generally no longer available, and the existing knobs you might salvage from old jobs have internal spacings for old Type R conductor insulation that won’t work on today’s thinner insulation. Concealed knob-and-tube, as a wiring method, has no equipment grounding conductor carried with it. Over the generations, NEC provisions have changed to the point that it is almost impossible to wire anything legally without grounding it. For example, until the 1984 NEC, what is now 314.4 only required the grounding of metal boxes used with concealed knob-and-tube wiring if in contact with metal lath or metallic surfaces. Now all metal boxes must be grounded without exception. Meanwhile, grounding has been getting more difficult to arrange for remote extensions of concealed knob-and-tube outlets. Until the 1993 NEC you could go to a local bonded water pipe to pick up an equipment grounding connection, and then extend from there with modern wiring methods. Now NEC 250.130(C), which governs this work, requires that the equipment grounding connection be made on the equipment grounding terminal bar of the supply panelboard, or directly to the grounding electrode system or grounding electrode conductor. You are unlikely to be searching for a method of grounding concealed knob-and-tube wiring in a steel-frame building. Rather you will be attempting this in old wood-frame buildings, probably residential. In such occupancies, even if the water supply lateral is metallic, the water piping system ceases to be considered as an electrode beyond 1.5 m (5 ft) from the point of entry. This means fishing into the basement. If you can fish a ground wire down into the basement, you can fish a modern circuit up in the reverse direction and avoid the entire problem.

It is true that some geographical areas have more extensive use of slab-on-grade construction, and here interior water piping is sometimes permitted to qualify as electrodes because the pipes extend to grade for the minimum threshold distance of 10 ft and thereby allow interior connections. But in almost every case, trying to extend knob-and-tube wiring is like trying to erect a modern structure on a rotten foundation.

Add to these problems the fact that beginning with the 1987 NEC this wiring method cannot be used in wall or ceiling cavities that have “loose, filled, or foamed-in-place insulating material that envelops the conductors.” This effectively means that such cavities cannot be insulated, because you’d have to open all the walls to install board insulation products, and if you’d do that, you’d never consider trying to save this wiring method.

69. When changing from open wiring or concealed knob-and-tube wiring to conduit, electrical-metallic-tubing, nonmetallic-sheathed—cable, armored-cable, or surface-raceway wiring, a fitting or outlet box having a separately bushed hole for each conductor must be used.
RIGID-METAL-CONDUIT AND INTERMEDIATE-METAL-CONDUIT WIRING

70. **Rigid-metal-conduit wiring** is allowed for both exposed and concealed work and for use in nearly all classes of buildings. For ordinary conditions, wiring in metal conduit is probably the best, although it is the most expensive. The advantages of metal conduit are that (1) wires can be inserted and removed, (2) it provides a good ground path, (3) it is strong enough mechanically so that nails cannot be driven through it and so that it is not readily deformed by blows or by wheelbarrows being run over it, and (4) it successfully resists the normal action of cement when embedded in the partitions or walls of concrete buildings.

A recent innovation is intermediate metal conduit, which has a thinner wall and is acceptable whenever rigid metal conduit is permitted.

71. **When to use rigid-metal-conduit or intermediate-metal-conduit wiring.** In general, conduit wiring should be used whenever the job will stand the cost. Rigid conduit protects the conductors it contains and provides a smooth raceway, permitting ready insertion or removal.

Conduits and fittings exposed to severe corrosive influences shall be of corrosion-resistant material suitable for the conditions. If practicable, the use of dissimilar metals in contact anywhere in the system shall be avoided to eliminate the possibility of galvanic action.

Meat-packing plants, tanneries, hide cellars, casing rooms, glue houses, fertilizer rooms, salt storage, some chemical works, metal refineries, pulp and paper mills, sugar mills, roundhouses, textile bleacheries, plants producing synthetic staples, some stables, and similar locations are judged to be occupancies where severe corrosive conditions are likely to be present.

**Cinder Fill.** Conduit, unless of corrosion-resistant material suitable for the purpose, shall not be used in or under cinder fill where subject to permanent moisture unless protected on all sides by a layer of noncinder concrete.

**Wet Locations.** In portions of dairies, laundries, canneries, and other wet locations and in locations where walls are frequently washed, the entire conduit system, including all boxes and fittings used therewith, shall be so installed and equipped as to prevent water from entering the conduit, and the conduit shall be mounted so that there is at least 6 mm (1/4-in) air space between the conduit and the wall or other supporting surface.

All supports, bolts, straps, screws, etc., shall be of corrosion-resistant materials or be protected against corrosion by approved corrosion-resistant materials.

72. **Corrosion-resistant rigid conduit** is available in three general types: (1) aluminum, (2) red brass, and (3) plastic-coated.

Aluminum rigid conduit is useful in installations where there are present certain chemical fumes or vapors which have little effect upon aluminum but have a severe corrosive effect upon steel. It is widely used because its light weight reduces installation labor costs. Uncoated or unprotected aluminum conduit should not be embedded in concrete or buried in earth, particularly if soluble chlorides are present.

A conduit of red brass has special corrosive-resistance characteristics. Its use is advantageous for installations exposed to the weather, as on bridges, piers, and dry docks and
along the seacoast; in oil refineries and chemical plants; in sewage-disposal works; underground for water-supply works; and in wiring to underwater lighting fixtures for swimming pools.

Plastic-coated rigid conduit consists of standard galvanized-steel conduit over the surface of which seamless coatings of polyvinyl chloride plastic have been extruded. Thus a uniform nonporous protective coating is formed over the entire length of the raceway. All couplings and fittings should be covered with plastic sleeves or carefully wrapped with three thicknesses of standard vinyl electrical insulating tape. This plastic-coated conduit is flame-retardant and highly resistant to the action of oils, grease, acids, alkalies, and moisture; does not oxidize, deteriorate, or shrink when exposed to sunlight and weather; and provides excellent resistance to abrasion, impact, and other mechanical wear. Typical applications are meat-packing plants, malt-liquor industries, paper and allied industries, production plants for industrial organic and inorganic products, soap and related-products industries, tanneries and leather-finishing plants, canneries, food-processing industries, dairies, fertilizer plants, and petroleum industries.

73. **Dimensions of corrosion-resistant rigid conduit.**
The internal and external diameters for aluminum conduit are the same as those for rigid steel conduit (see Fig. 9.24). The internal diameter of plastic-coated rigid conduit, of course, is the same as that of standard rigid steel conduit. The outside diameter of the plastic-coated variety is slightly greater, as given in Table 75.

![FIGURE 9.24 Section of conduit.](image)

74. **Intermediate Metal Conduit**  
(Allied Tube & Conduit Corp.)

<table>
<thead>
<tr>
<th>Trade size, in</th>
<th>Nominal Minimum (−.005)</th>
<th>Maximum (+.005)</th>
<th>B. Length of finished conduit without coupling, in.</th>
<th>C. Wall thickness, in.*</th>
<th>Nominal weight per 100, lb$^{†}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{1}{8}$</td>
<td>0.815</td>
<td>0.810</td>
<td>0.820</td>
<td>119$/4</td>
<td>0.070</td>
</tr>
<tr>
<td>$\frac{3}{8}$</td>
<td>1.029</td>
<td>1.024</td>
<td>1.034</td>
<td>119$/4</td>
<td>0.075</td>
</tr>
<tr>
<td>1</td>
<td>1.290</td>
<td>1.285</td>
<td>1.295</td>
<td>119</td>
<td>0.085</td>
</tr>
<tr>
<td>$\frac{3}{4}$</td>
<td>1.638</td>
<td>1.630</td>
<td>1.645</td>
<td>119</td>
<td>0.085</td>
</tr>
<tr>
<td>1$\frac{1}{4}$</td>
<td>1.883</td>
<td>1.875</td>
<td>1.890</td>
<td>119</td>
<td>0.090</td>
</tr>
<tr>
<td>2</td>
<td>2.360</td>
<td>2.352</td>
<td>2.367</td>
<td>119</td>
<td>0.095</td>
</tr>
<tr>
<td>2$\frac{1}{2}$</td>
<td>2.857</td>
<td>2.847</td>
<td>2.867</td>
<td>118$/2</td>
<td>0.130</td>
</tr>
<tr>
<td>3</td>
<td>3.476</td>
<td>3.466</td>
<td>3.486</td>
<td>118$/2</td>
<td>0.130</td>
</tr>
<tr>
<td>3$\frac{1}{2}$</td>
<td>3.971</td>
<td>3.961</td>
<td>3.981</td>
<td>118$/2</td>
<td>0.130</td>
</tr>
<tr>
<td>4</td>
<td>4.466</td>
<td>4.456</td>
<td>4.476</td>
<td>118$/2</td>
<td>0.130</td>
</tr>
</tbody>
</table>

$^{*}$The wall thickness is $+.015$ and $-.000$ for IMC.

$^{†}$Because of the specification of tube dimensions, weight specifications are not part of Underwriters Laboratories (UL) Standard 1242 but have been included for comparative purposes. At regular production intervals, UL inspects wall thicknesses of all trade sizes with a micrometer to check consistency with the specified standard tolerance.
75. Plastic-Coated Rigid Conduit
(General Electric Co.)

<table>
<thead>
<tr>
<th>Size, in</th>
<th>Weight, lb/1000 ft</th>
<th>Ft per bundle</th>
<th>External diameter, in</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>1119</td>
<td>50</td>
<td>1.110</td>
</tr>
<tr>
<td>1</td>
<td>1701</td>
<td>50</td>
<td>1.375</td>
</tr>
<tr>
<td>1 1/4</td>
<td>2247</td>
<td>30</td>
<td>1.720</td>
</tr>
<tr>
<td>1 1/2</td>
<td>2688</td>
<td>10</td>
<td>1.960</td>
</tr>
<tr>
<td>2</td>
<td>3601</td>
<td>10</td>
<td>2.435</td>
</tr>
<tr>
<td>2 1/2</td>
<td>6132</td>
<td>10</td>
<td>2.935</td>
</tr>
<tr>
<td>3</td>
<td>7860</td>
<td>10</td>
<td>3.560</td>
</tr>
<tr>
<td>3 1/2</td>
<td>9433</td>
<td>10</td>
<td>4.060</td>
</tr>
</tbody>
</table>

76. Rigid steel conduit is made in several types, including white (galvanized), black (enameled), green (sheradized), and with an organic (plastic) coating. The white galvanized conduit is the type to be used where exposed to the weather, when embedded in concrete, or when installed in wet locations. The black conduit, which is coated with black enamel, is limited to indoor noncorrosive locations, and is seldom seen today. The green (sheradized) conduit has a special corrosion-resistant coating consisting of zinc applied in a way that alloys it to the underlying steel. It is the hardest of the zinc finishes and accepts paint without primers. Plastic coatings can be applied to the conventional galvanized product, or the sheradized finish for even more resistance to corrosion. Except for special conditions no size smaller than metric designator 16 (trade size 1/2) in. is allowed. The metric designator 12 (1/8 trade size) is allowed to enclose the leads of a motor, as covered in NEC 430.245(B).

77. Standard Rigid Wrought-Iron or Steel Conduit and Couplings

<table>
<thead>
<tr>
<th>Trade size, in</th>
<th>A, Approx. OD, in</th>
<th>B, Approx. ID, in</th>
<th>C, Approx. wall thickness, in</th>
<th>Thread per in</th>
<th>Approx wt per 1,000 ft, lb</th>
<th>J, OD, in</th>
<th>K, Length, in</th>
<th>Approx wt per 100 ft, lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>0.840</td>
<td>0.622</td>
<td>0.109</td>
<td>14</td>
<td>820</td>
<td>1.010</td>
<td>1/16</td>
<td>14</td>
</tr>
<tr>
<td>3/4</td>
<td>1.050</td>
<td>0.824</td>
<td>0.113</td>
<td>14</td>
<td>1,120</td>
<td>1.250</td>
<td>1/8</td>
<td>24</td>
</tr>
<tr>
<td>1</td>
<td>1.315</td>
<td>1.049</td>
<td>0.133</td>
<td>11 1/2</td>
<td>1,600</td>
<td>1.525</td>
<td>2</td>
<td>39</td>
</tr>
<tr>
<td>1 1/4</td>
<td>1.660</td>
<td>1.380</td>
<td>0.140</td>
<td>11 1/2</td>
<td>2,160</td>
<td>1.869</td>
<td>2/16</td>
<td>47</td>
</tr>
<tr>
<td>1 1/2</td>
<td>1.900</td>
<td>1.610</td>
<td>0.145</td>
<td>11 1/2</td>
<td>2,680</td>
<td>2.155</td>
<td>2/16</td>
<td>66</td>
</tr>
<tr>
<td>2</td>
<td>2.375</td>
<td>2.067</td>
<td>0.154</td>
<td>11 1/2</td>
<td>3,500</td>
<td>2.730</td>
<td>2/8</td>
<td>105</td>
</tr>
<tr>
<td>2 1/2</td>
<td>2.875</td>
<td>2.469</td>
<td>0.203</td>
<td>8</td>
<td>5,600</td>
<td>3.250</td>
<td>3/8</td>
<td>180</td>
</tr>
<tr>
<td>3</td>
<td>3.500</td>
<td>3.068</td>
<td>0.216</td>
<td>8</td>
<td>7,120</td>
<td>4.000</td>
<td>3/4</td>
<td>300</td>
</tr>
<tr>
<td>3 1/2</td>
<td>4.000</td>
<td>3.548</td>
<td>0.226</td>
<td>8</td>
<td>8,520</td>
<td>4.500</td>
<td>3/4</td>
<td>390</td>
</tr>
<tr>
<td>4</td>
<td>4.500</td>
<td>4.026</td>
<td>0.237</td>
<td>8</td>
<td>10,300</td>
<td>5.000</td>
<td>3/4</td>
<td>400</td>
</tr>
<tr>
<td>5</td>
<td>5.563</td>
<td>5.047</td>
<td>0.258</td>
<td>8</td>
<td>13,910</td>
<td>6.296</td>
<td>3/4</td>
<td>760</td>
</tr>
<tr>
<td>6</td>
<td>6.625</td>
<td>6.065</td>
<td>0.280</td>
<td>8</td>
<td>18,500</td>
<td>7.390</td>
<td>4</td>
<td>1075</td>
</tr>
</tbody>
</table>

Note: All tubes are threaded both ends, and 10 ft long inclusive of the coupling on one end.
78. Data on conduit couplings and elbows are given in Secs. 77, 81, and 86 (see Fig. 9.25). The weight columns are convenient for estimating transportation charges. The internal area is useful in determining the size of conduit for unusual combinations of conductors, as explained in Sec. 94. Dimensions of elbows and couplings are often used in laying out work on the drawing board or in estimating clearances in advance. Table 82 gives the dimensions of standard conduit threads. (See Fig. 9.26.)

Running threads are not allowed on conduit for connection at couplings.

![Conduit couplings](image1)

**FIGURE 9.25** Conduit couplings.

79. Rigid aluminum conduit. The use of rigid aluminum conduit has gained acceptance because of its light weight, excellent grounding conductivity, ease of threading, bending, and installation, and low losses for installed ac circuits. Installations of rigid aluminum conduit require no maintenance, painting, or protective treatment in many applications.

When aluminum conduit is buried in concrete or mortar, a limited chemical reaction on the conduit surface forms a self-stopping coating. This prevents significant corrosion for the life of the structure. However, calcium chloride or similar soluble chlorides sometimes are used to speed concrete setting. In limiting the use of such speeding agents, the American Concrete Institute and most building codes recognize that embedded metals can be damaged by chlorides. As a result, if aluminum conduit is to be buried in concrete, the installer should be absolutely sure that the concrete will contain no chlorides. If there is any doubt, rigid steel conduit should be used, because even though chlorides can damage steel conduit to some degree, this will not lead to cracking or spalling of concrete.

Although aluminum conduit can be buried safely in many soils, precautions are recommended because of unpredictable moisture, stray electric current, and chemical variations in almost every soil. To assure protection when buried directly in earth, aluminum or steel conduit should be coated with bituminous or asphalt paint, wrapped with plastic tape, or encased in a chloride-free concrete envelope.

Being a nonmagnetic metal, aluminum conduit reduces voltage drop in installed copper or aluminum wire up to 20 percent of a corresponding steel-conduit installation when ac circuits are involved.

Tables 80 and 81 list important data on rigid aluminum conduit.
80. Aluminum Rigid Conduit: Nominal 10-Ft Lengths

<table>
<thead>
<tr>
<th>Trade size</th>
<th>Lb per 100 ft*</th>
<th>No. per bundle</th>
<th>Lb per bundle*</th>
<th>Master shipping package</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>29.8</td>
<td>10</td>
<td>29.80</td>
<td>Bundles 20, pieces 200, Ft 2,000, Lb 596</td>
</tr>
<tr>
<td>3/4</td>
<td>39.8</td>
<td>10</td>
<td>39.80</td>
<td>Bundles 20, pieces 200, Ft 2,000, Lb 796</td>
</tr>
<tr>
<td>1</td>
<td>58.9</td>
<td>10</td>
<td>58.90</td>
<td>Bundles 10, pieces 500, Ft 1,000, Lb 589</td>
</tr>
<tr>
<td>11/4</td>
<td>79.8</td>
<td>5</td>
<td>39.90</td>
<td>Bundles 10, pieces 500, Ft 500, Lb 399</td>
</tr>
<tr>
<td>11/2</td>
<td>95.6</td>
<td>5</td>
<td>47.80</td>
<td>Bundles 10, pieces 500, Ft 500, Lb 478</td>
</tr>
<tr>
<td>2</td>
<td>128.8</td>
<td>5</td>
<td>64.40</td>
<td>Bundles 9, pieces 450, Ft 450, Lb 580</td>
</tr>
<tr>
<td>21/2</td>
<td>204.7</td>
<td>1</td>
<td>20.47</td>
<td>Loose 30, pieces 300, Ft 300, Lb 614</td>
</tr>
<tr>
<td>3</td>
<td>268.0</td>
<td>1</td>
<td>26.80</td>
<td>Loose 20, pieces 200, Ft 200, Lb 536</td>
</tr>
<tr>
<td>31/2</td>
<td>321.3</td>
<td>1</td>
<td>32.13</td>
<td>Loose 20, pieces 200, Ft 200, Lb 642</td>
</tr>
<tr>
<td>4</td>
<td>382.1</td>
<td>1</td>
<td>38.21</td>
<td>Loose 8, pieces 80, Ft 80, Lb 417</td>
</tr>
<tr>
<td>5</td>
<td>521.5</td>
<td>1</td>
<td>52.15</td>
<td>Loose 6, pieces 60, Ft 60, Lb 406</td>
</tr>
</tbody>
</table>

*Nominal shipping weights.

81. Aluminum Rigid Conduit Couplings

<table>
<thead>
<tr>
<th>Trade size</th>
<th>Outside diameter, in.</th>
<th>Length, in.</th>
<th>Nominal weight per 100 pieces, lb</th>
<th>Metric designator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>1/8/64</td>
<td>1.56</td>
<td>6.1</td>
<td>16</td>
</tr>
<tr>
<td>3/4</td>
<td>1/3/64</td>
<td>1.62</td>
<td>9.1</td>
<td>21</td>
</tr>
<tr>
<td>1</td>
<td>1/16</td>
<td>2.00</td>
<td>12.5</td>
<td>27</td>
</tr>
<tr>
<td>11/4</td>
<td>1/6/32</td>
<td>2.06</td>
<td>18.9</td>
<td>35</td>
</tr>
<tr>
<td>11/2</td>
<td>2/32</td>
<td>2.06</td>
<td>23.3</td>
<td>41</td>
</tr>
<tr>
<td>2</td>
<td>2/4</td>
<td>2.12</td>
<td>34.6</td>
<td>53</td>
</tr>
<tr>
<td>21/2</td>
<td>3/32</td>
<td>3.12</td>
<td>68.3</td>
<td>63</td>
</tr>
<tr>
<td>3</td>
<td>3/16</td>
<td>3.25</td>
<td>91.4</td>
<td>78</td>
</tr>
<tr>
<td>31/2</td>
<td>4/16</td>
<td>3.37</td>
<td>108.0</td>
<td>91</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>3.50</td>
<td>142.0</td>
<td>103</td>
</tr>
<tr>
<td>5</td>
<td>6/16</td>
<td>3.75</td>
<td>241.9</td>
<td>129</td>
</tr>
<tr>
<td>6</td>
<td>7/16</td>
<td>4.00</td>
<td>321.0</td>
<td>155</td>
</tr>
</tbody>
</table>
82. Standard Conduit: Dimensions of Threads

<table>
<thead>
<tr>
<th>Trade size of conduit</th>
<th>Number of threads per in.</th>
<th>Total length $L_4$ of threads, in.</th>
<th>Effective length $L_2$ of threads, in.</th>
<th>Pitch diameter $E_0$ at end of conduit, in.</th>
<th>Metric designator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4</td>
<td>18</td>
<td>0.59</td>
<td>0.40</td>
<td>0.477</td>
<td>†</td>
</tr>
<tr>
<td>3/8</td>
<td>18</td>
<td>0.60</td>
<td>0.41</td>
<td>0.612</td>
<td>12</td>
</tr>
<tr>
<td>1/2</td>
<td>14</td>
<td>0.78</td>
<td>0.53</td>
<td>0.758</td>
<td>16</td>
</tr>
<tr>
<td>5/8</td>
<td>14</td>
<td>0.79</td>
<td>0.55</td>
<td>0.968</td>
<td>21</td>
</tr>
<tr>
<td>11/32</td>
<td>11½</td>
<td>0.98</td>
<td>0.68</td>
<td>1.214</td>
<td>27</td>
</tr>
<tr>
<td>1¼</td>
<td>11½</td>
<td>1.01</td>
<td>0.71</td>
<td>1.557</td>
<td>35</td>
</tr>
<tr>
<td>1½</td>
<td>11½</td>
<td>1.03</td>
<td>0.72</td>
<td>1.796</td>
<td>41</td>
</tr>
<tr>
<td>2¼</td>
<td>11½</td>
<td>1.06</td>
<td>0.76</td>
<td>2.260</td>
<td>53</td>
</tr>
<tr>
<td>2½</td>
<td>8</td>
<td>1.57</td>
<td>1.14</td>
<td>2.720</td>
<td>63</td>
</tr>
<tr>
<td>3½</td>
<td>8</td>
<td>1.63</td>
<td>1.20</td>
<td>3.341</td>
<td>78</td>
</tr>
<tr>
<td>4¼</td>
<td>8</td>
<td>1.68</td>
<td>1.25</td>
<td>3.838</td>
<td>91</td>
</tr>
<tr>
<td>4½</td>
<td>8</td>
<td>1.73</td>
<td>1.30</td>
<td>4.334</td>
<td>103</td>
</tr>
<tr>
<td>5½</td>
<td>8</td>
<td>1.78</td>
<td>1.35</td>
<td>4.831</td>
<td>†</td>
</tr>
<tr>
<td>6½</td>
<td>8</td>
<td>1.84</td>
<td>1.41</td>
<td>5.391</td>
<td>129</td>
</tr>
<tr>
<td>7½</td>
<td>8</td>
<td>1.95</td>
<td>1.51</td>
<td>6.446</td>
<td>155</td>
</tr>
</tbody>
</table>

*A minus tolerance of one thread applies to the total length of threads. 
†A tolerance of ±0.005 in. applies to the pitch diameter.
†Dimension not currently recognized in the NEC; no metric designator assigned.

83. Bushings are required to protect wires from abrasion where a conduit enters a box or other fitting unless the design of the box or fitting is such as to afford equivalent protection.

Connections of rigid conduit to enclosures can be made by a single locknut (outside) and a single bushing (inside) if the bushing is tightly fitted against the wall of the enclosure. Double locknuts (one inside and one outside) and a bushing always make a better connection than the single-locknut–bushing method. The NEC requires the double-locknut method if the circuit voltage exceeds 250 V to ground or if wholly insulated bushings are utilized.

When ungrounded conductors of No. 4 and larger size enter a raceway in a cabinet, pull box, junction box, or auxiliary gutter, the conductors shall be protected by a substantial bushing providing a smoothly rounded insulating surface. Figures 9.27 and 9.28 show two types of bushings that provide insulation protection. The bushing in Fig. 9.27 is wholly insulated and constructed of a tough phenolic with reinforced fibers. The bushing in Fig. 9.28 is a metal grounding bushing with provisions for installing a bonding jumper from the bushing lug to a metal enclosure. The throat, or collar, is of insulating material to protect wires.
Tables 84 and 88 are useful when cutting knockouts into enclosures. The spacings listed in Table 84 allow enough room between adjacent knockouts for locknuts and bushings to be attached. (See Figs. 9.29, 9.30, and 9.31.)

FIGURE 9.27 Wholly insulated conduit bushing.

FIGURE 9.28 Metal grounding bushing with insulated throat. [Midwest Electric Mfg. Corp.]
84. Spacings for Conduit with Given Clearances and Punched-Steel Conduit Locknuts

(All dimensions in inches)

The clearance, $C$, values are based on the $D$ values given at the top of the next page.

**FIGURE 9.29** End view.

**FIGURE 9.30** Elevation.

**FIGURE 9.31** Conduit locknut.

<table>
<thead>
<tr>
<th>Size conduit</th>
<th>$\frac{1}{4}$</th>
<th>$\frac{3}{8}$</th>
<th>$\frac{1}{2}$</th>
<th>$\frac{5}{8}$</th>
<th>$\frac{3}{4}$</th>
<th>$1$</th>
<th>$\frac{1}{3}$</th>
<th>$\frac{5}{4}$</th>
<th>$2$</th>
<th>$\frac{3}{2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{3}{4}$</td>
<td>$A$</td>
<td>$0.59$</td>
<td>$0.58$</td>
<td>$0.56$</td>
<td>$0.56$</td>
<td>$0.52$</td>
<td>$0.52$</td>
<td>$0.52$</td>
<td>$0.52$</td>
<td>$0.52$</td>
</tr>
<tr>
<td>$\frac{3}{8}$</td>
<td>$A$</td>
<td>$0.59$</td>
<td>$0.58$</td>
<td>$0.56$</td>
<td>$0.56$</td>
<td>$0.52$</td>
<td>$0.52$</td>
<td>$0.52$</td>
<td>$0.52$</td>
<td>$0.52$</td>
</tr>
<tr>
<td>$\frac{3}{4}$</td>
<td>$B$</td>
<td>$0.58$</td>
<td>$0.56$</td>
<td>$0.56$</td>
<td>$0.56$</td>
<td>$0.52$</td>
<td>$0.52$</td>
<td>$0.52$</td>
<td>$0.52$</td>
<td>$0.52$</td>
</tr>
<tr>
<td>$\frac{5}{8}$</td>
<td>$B$</td>
<td>$0.56$</td>
<td>$0.56$</td>
<td>$0.56$</td>
<td>$0.56$</td>
<td>$0.54$</td>
<td>$0.54$</td>
<td>$0.54$</td>
<td>$0.54$</td>
<td>$0.54$</td>
</tr>
<tr>
<td>$\frac{3}{4}$</td>
<td>$1$</td>
<td>$0.55$</td>
<td>$0.55$</td>
<td>$0.55$</td>
<td>$0.55$</td>
<td>$0.55$</td>
<td>$0.55$</td>
<td>$0.55$</td>
<td>$0.55$</td>
<td>$0.55$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Look-out dimensions</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Nominal size of conduit, in. | Threads per in. | $A$, in.
--- | --- | ---
$\frac{3}{4}$ | $1$ | $0.701$
$\frac{3}{8}$ | $1$ | $0.811$
$\frac{1}{2}$ | $1$ | $1.144$
$\frac{5}{8}$ | $1$ | $1.488$
$\frac{3}{4}$ | $2$ | $1.727$
$\frac{1}{2}$ | $2$ | $2.228$
$\frac{5}{8}$ | $3$ | $2.830$
$\frac{3}{4}$ | $5$ | $5.241$

*The 3-in. look out is octagonal instead of hexagonal*
### 85. Conduit Chase Nipples

(See Fig. 9.32.)

<table>
<thead>
<tr>
<th>Trade size of nipple</th>
<th>$A, \text{ threads per in.}$</th>
<th>$B, \text{ diam of threads, in.}$</th>
<th>$C, \text{ in.}$</th>
<th>$D, \text{ in.}$</th>
<th>$E, \text{ in.}$</th>
<th>$F, \text{ in.}$</th>
<th>$G, \text{ in.}$</th>
<th>$H, \text{ in.}$</th>
<th>Metric designator of nipple</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1/2$</td>
<td>14.0</td>
<td>0.82</td>
<td>0.62</td>
<td>1.00</td>
<td>1.15</td>
<td>0.62</td>
<td>0.12</td>
<td>0.50</td>
<td>16</td>
</tr>
<tr>
<td>$3/4$</td>
<td>14.0</td>
<td>1.02</td>
<td>0.82</td>
<td>1.25</td>
<td>1.44</td>
<td>0.81</td>
<td>0.19</td>
<td>0.62</td>
<td>21</td>
</tr>
<tr>
<td>1</td>
<td>11.5</td>
<td>1.28</td>
<td>1.04</td>
<td>1.37</td>
<td>1.59</td>
<td>0.94</td>
<td>0.25</td>
<td>0.69</td>
<td>27</td>
</tr>
<tr>
<td>$1\frac{1}{2}$</td>
<td>11.5</td>
<td>1.63</td>
<td>1.38</td>
<td>1.75</td>
<td>2.02</td>
<td>1.06</td>
<td>0.25</td>
<td>0.81</td>
<td>35</td>
</tr>
<tr>
<td>$2\frac{1}{2}$</td>
<td>11.5</td>
<td>1.87</td>
<td>1.61</td>
<td>2.00</td>
<td>2.31</td>
<td>1.12</td>
<td>0.31</td>
<td>0.81</td>
<td>41</td>
</tr>
<tr>
<td>2</td>
<td>11.5</td>
<td>2.34</td>
<td>2.06</td>
<td>2.50</td>
<td>2.89</td>
<td>1.31</td>
<td>0.31</td>
<td>1.00</td>
<td>53</td>
</tr>
<tr>
<td>$2\frac{1}{2}$</td>
<td>8.0</td>
<td>2.82</td>
<td>2.46</td>
<td>3.00</td>
<td>3.46</td>
<td>1.44</td>
<td>0.37</td>
<td>1.06</td>
<td>63</td>
</tr>
<tr>
<td>3</td>
<td>8.0</td>
<td>3.44</td>
<td>3.06</td>
<td>3.75</td>
<td>4.33</td>
<td>1.50</td>
<td>0.37</td>
<td>1.12</td>
<td>78</td>
</tr>
<tr>
<td>$3\frac{1}{2}$</td>
<td>8.0</td>
<td>3.94</td>
<td>3.54</td>
<td>4.25</td>
<td>4.91</td>
<td>1.62</td>
<td>0.44</td>
<td>1.19</td>
<td>91</td>
</tr>
</tbody>
</table>

**FIGURE 9.32** Conduit chase nipple.
86. **Rigid Conduit Elbows**  
(See Fig. 9.33.)

**FIGURE 9.33** Conduit elbows: minimum radius for factory ells and ells made by a one-shot or a full-shoe bender.

### Standard-RADIUS Conduit Elbows

<table>
<thead>
<tr>
<th>Conduit trade size</th>
<th>Minimum radius to center of tube, in</th>
<th>Minimum straight length $L_s$ at each end, in</th>
<th>Metric designator</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{1}{2}$</td>
<td>4</td>
<td>$\frac{1}{2}$</td>
<td>16.</td>
</tr>
<tr>
<td>$\frac{3}{4}$</td>
<td>4$\frac{1}{2}$</td>
<td>$\frac{1}{2}$</td>
<td>21.</td>
</tr>
<tr>
<td>1</td>
<td>5$\frac{1}{4}$</td>
<td>$\frac{5}{8}$</td>
<td>27.</td>
</tr>
<tr>
<td>1$\frac{1}{4}$</td>
<td>7$\frac{1}{8}$</td>
<td>2</td>
<td>35.</td>
</tr>
<tr>
<td>1$\frac{1}{2}$</td>
<td>8$\frac{1}{8}$</td>
<td>2</td>
<td>41.</td>
</tr>
<tr>
<td>2</td>
<td>9$\frac{1}{2}$</td>
<td>2</td>
<td>53.</td>
</tr>
<tr>
<td>2$\frac{1}{2}$</td>
<td>10$\frac{1}{2}$</td>
<td>3</td>
<td>63.</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>$\frac{3}{8}$</td>
<td>78.</td>
</tr>
<tr>
<td>3$\frac{1}{2}$</td>
<td>15</td>
<td>$\frac{3}{4}$</td>
<td>91.</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>$\frac{3}{8}$</td>
<td>103.</td>
</tr>
<tr>
<td>5</td>
<td>24</td>
<td>$\frac{3}{8}$</td>
<td>129.</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>$\frac{3}{4}$</td>
<td>155.</td>
</tr>
</tbody>
</table>
### Conduit Nipples

See Fig. 9.34.

![Conduit Nipples](image)

**FIGURE 9.34** Conduit nipples.

<table>
<thead>
<tr>
<th>Size nipple, in</th>
<th>Length</th>
<th>Close Wt, lb per 100 pieces</th>
<th>Start Wt, lb per 100 pieces</th>
<th>2 in long Wt, lb per 100 pieces</th>
<th>3 in long Wt, lb per 100 pieces</th>
<th>4 in long Wt, lb per 100 pieces</th>
<th>5 in long Wt, lb per 100 pieces</th>
<th>6 in long Wt, lb per 100 pieces</th>
<th>8 in long Wt, lb per 100 pieces</th>
<th>10 in long Wt, lb per 100 pieces</th>
<th>12 in long Wt, lb per 100 pieces</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>1/8</td>
<td>7</td>
<td>1/2</td>
<td>9</td>
<td>12</td>
<td>19</td>
<td>25</td>
<td>32</td>
<td>38</td>
<td>51</td>
<td>64</td>
</tr>
<tr>
<td>3/4</td>
<td>1/4</td>
<td>11</td>
<td>2</td>
<td>17</td>
<td>...</td>
<td>26</td>
<td>34</td>
<td>43</td>
<td>51</td>
<td>68</td>
<td>85</td>
</tr>
<tr>
<td>1</td>
<td>1/2</td>
<td>19</td>
<td>2</td>
<td>25</td>
<td>...</td>
<td>38</td>
<td>51</td>
<td>63</td>
<td>76</td>
<td>102</td>
<td>127</td>
</tr>
<tr>
<td>1 1/4</td>
<td>1/4</td>
<td>28</td>
<td>2 1/2</td>
<td>43</td>
<td>...</td>
<td>61</td>
<td>69</td>
<td>86</td>
<td>103</td>
<td>138</td>
<td>172</td>
</tr>
<tr>
<td>1 1/2</td>
<td>1 1/4</td>
<td>36</td>
<td>2 1/2</td>
<td>51</td>
<td>...</td>
<td>62</td>
<td>82</td>
<td>103</td>
<td>124</td>
<td>165</td>
<td>206</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>55</td>
<td>2 1/2</td>
<td>69</td>
<td>...</td>
<td>83</td>
<td>111</td>
<td>139</td>
<td>167</td>
<td>228</td>
<td>278</td>
</tr>
<tr>
<td>2 1/2</td>
<td>2 1/2</td>
<td>110</td>
<td>3</td>
<td>132</td>
<td>...</td>
<td>...</td>
<td>176</td>
<td>220</td>
<td>264</td>
<td>353</td>
<td>441</td>
</tr>
<tr>
<td>3</td>
<td>2 1/4</td>
<td>151</td>
<td>3</td>
<td>173</td>
<td>...</td>
<td>...</td>
<td>231</td>
<td>288</td>
<td>346</td>
<td>462</td>
<td>577</td>
</tr>
<tr>
<td>3 1/2</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
88. **Malleable-Iron Conduit Bushings**  (See Fig. 9.35.)

![Conduit bushing](image)

**TABLE 9.35** Conduit bushing.

<table>
<thead>
<tr>
<th>Nominal size of conduit, in</th>
<th>A, in</th>
<th>B, in</th>
<th>C, in</th>
<th>D, in</th>
<th>E, in</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8</td>
<td>2y/32</td>
<td>2y/32</td>
<td>y/16</td>
<td>y/16</td>
<td>y/16</td>
</tr>
<tr>
<td>1/2</td>
<td>5/32</td>
<td>5/32</td>
<td>y/4</td>
<td>y/4</td>
<td>y/4</td>
</tr>
<tr>
<td>3/4</td>
<td>15/32</td>
<td>31/32</td>
<td>31/32</td>
<td>y/4</td>
<td>y/4</td>
</tr>
<tr>
<td>1</td>
<td>31/32</td>
<td>31/32</td>
<td>31/32</td>
<td>7/8</td>
<td>y/4</td>
</tr>
<tr>
<td>1 1/2</td>
<td>2y/32</td>
<td>2y/32</td>
<td>y/8</td>
<td>y/8</td>
<td>y/8</td>
</tr>
<tr>
<td>2 1/2</td>
<td>3y/32</td>
<td>3y/32</td>
<td>3y/32</td>
<td>9/8</td>
<td>y/8</td>
</tr>
<tr>
<td>3</td>
<td>3y/32</td>
<td>3y/32</td>
<td>3y/32</td>
<td>9/8</td>
<td>y/8</td>
</tr>
</tbody>
</table>

89. **Table 85, giving the dimensions of conduit chase nipples**, is since the function of the chase nipple is about the same as that of the bushing, used for the same purposes as the bushing table. The chase nipple screws into a coupling (see Fig. 9.30), while the bushing screws onto the threaded end of a length of conduit. The chase nipple is more compact than the bushing and hence is preferable for some work.

90. **Punched-steel locknuts are shown in Table 84.** Locknuts are used for conduit on the outside of the box whenever the conduit enters an outlet box, and their dimensions must often be known in laying out panel or outlet boxes so that proper turning clearances can be provided for the nuts.

91. **Table 84 of conduit spacings for different clearances between conduits and their locknuts or nipples** is exceedingly valuable to someone who is designing or erecting conduit work. From it the designer can determine directly just what the distance between centers of conduits should be for given clearances between nipples or conduit. These data are indispensable when laying out the centers of a row of holes through which conduit is to enter a panel box or in laying out the supports for a multiple-conduit run.

92. **Bends.** The NEC specifies that bends of rigid conduit shall be so made that the conduit will not be injured and that the internal diameter of the conduit will not be effectively reduced. The radius of the curve of the inner edge of any field bend using sequential benders such as hickey’s shall not be less than shown in Table 93. See Table 86 for the minimum radius permitted for field bends made by one-shot or full-shoe benders.
The NEC also specifies that a run of conduit between outlet and outlet, fitting and fitting, or outlet and fitting shall not contain more than the equivalent of four quarter bends (360° total), including bends located immediately at the outlet or fitting.

93. Minimum Radius of Conduit or Tubing Field Bends, Centerline Measurement. The former column for lead-sheathed conductors was deleted in the 2002 NEC code cycle because these conductors are no longer made.

<table>
<thead>
<tr>
<th>Raceway size,</th>
<th>One shot and</th>
<th>Other bends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric designator and (trade size)</td>
<td>full shoe benders</td>
<td></td>
</tr>
<tr>
<td>16 (1/2)</td>
<td>101.6 mm (4 in.)</td>
<td>101.6 mm (4 in.)</td>
</tr>
<tr>
<td>21 (3/4)</td>
<td>114.3 mm (4 1/2 in.)</td>
<td>127 mm (5 in.)</td>
</tr>
<tr>
<td>27 (1)</td>
<td>146.05 mm (5 3/4 in.)</td>
<td>152.4 mm (6 in.)</td>
</tr>
<tr>
<td>35 (1 1/4)</td>
<td>184.15 mm (7 3/4 in.)</td>
<td>203.2 mm (8 in.)</td>
</tr>
<tr>
<td>41 (1 1/2)</td>
<td>209.55 mm (8 1/4 in.)</td>
<td>254 mm (10 in.)</td>
</tr>
<tr>
<td>53 (2)</td>
<td>241.3 mm (9 1/2 in.)</td>
<td>304.8 mm (12 in.)</td>
</tr>
<tr>
<td>63 (2 1/2)</td>
<td>266.7 mm (10 1/4 in.)</td>
<td>381 mm (15 in.)</td>
</tr>
<tr>
<td>78 (3)</td>
<td>330.2 mm (13 in.)</td>
<td>457.2 mm (18 in.)</td>
</tr>
<tr>
<td>91 (3 1/2)</td>
<td>381 mm (15 in.)</td>
<td>533.4 mm (21 in.)</td>
</tr>
<tr>
<td>103 (4)</td>
<td>406.4 mm (16 in.)</td>
<td>609.6 mm (24 in.)</td>
</tr>
<tr>
<td>129 (5)</td>
<td>609.6 mm (24 in.)</td>
<td>762 mm (30 in.)</td>
</tr>
<tr>
<td>155 (6)</td>
<td>762 mm (30 in.)</td>
<td>914.4 mm (36 in.)</td>
</tr>
</tbody>
</table>

94. The NEC specifies the size of conduit to use, depending upon the number, type, and size of conductors to be installed therein. The proper size of conduit can be determined through a three-step process using the tables in NEC Chap. 9. First, determine the cross-sectional areas of the conductors to be installed by consulting Table 5 (or 5A for compact conductors), and develop the cross-sectional area of all the conductors taken together that will be part of the fill. Use the sizes in Table 8 if there are bare wires in the group. Note the fill factor from Table 1 that corresponds to the number of conductors involved. Finally, select the raceway size from Table 4, starting with the data for the raceway of choice and using the column that corresponds to the applicable fill factor; any raceway with a usable cross-sectional area equal to or larger than the conductor area will work. If all the conductors are the same size, Annex C has all the calculations done out ahead of time. Just look up the wiring method of choice and select the size that will hold the wires.

These tables incorporate Note 7 to Table 1, which says that if you divide the permitted fill area of a raceway by the area of the wires to be installed, and that calculation carried to one decimal place and truncated results in a decimal of 0.8 or larger, the fill can be rounded up to the next higher number of conductors, provided all the conductors are the same size.

95. Outlets for current-consuming equipment and wiring devices require the use of outlet boxes for concealed or exposed work, whereas conduit bodies (Fig. 9.38) are limited to exposed work.
96. **Outlet boxes** that are used for conduit wiring are of sheet steel, preferably coated with zinc. They not only hold the conduit ends firmly in position and form a pocket for enclosing wire joints but also constitute electrical connectors between the elements of the conduit system, all of which must be in good electrical contact. Each conduit run in an installation must terminate in an accessible outlet box. Outlet boxes are made in many different forms. For complete data and descriptions of outlet boxes see Div. 4. The required size of boxes is given in Sec. 345.

97. **All boxes should be installed** so that the outer edge of the box or the cover mounted on the box will come flush with the surface of combustible wall surfaces and 6 mm (¼ in.) set back in noncombustible wall surfaces. The top of an outlet or junction box must never be concealed, as the wire splices inside must be accessible for inspection. The conduit must be fastened securely to the box by using a locknut on the outside and a bushing on the inside of the box (see Sec. 83).

98. **Conduit junction boxes**, which in reality are nothing more than pull boxes on a large scale, are often very convenient at points where several conduit lines intersect, as for instance over a switchboard (Fig. 9.36) from which conduit lines radiate. The junction box is usually supported from the ceiling and is best made of sheet iron on an angle-iron frame. The sides should be held on with machine screws turning into tapped holes in the frame so that they can be readily removed. Round holes can be cut in the sheet-iron sides for the conduits. The conductors within the box can be carried from conduit outlet to conduit outlet in any direction desired, and the use of elbows and troublesome conduit crossings can thereby be avoided.

![Figure 9.36](image)
*FIGURE 9.36 A sheet-iron conduit junction box.*

99. **Pull boxes can often be advantageously substituted for elbows** (Fig. 9.37). Large elbows are expensive. If there are three or more right-angle turns in a run, a pull box should be inserted in any event. One pull box may be substituted for several elbows. Wire can be pulled in more readily when there are pull boxes. Pull boxes are generally made of sheet steel (Fig. 9.37, I). Boxes should be made and drilled in the shop, where proper tools are available, rather than on the job. The required size of pull boxes is given in Sec. 324.
100. **Conduit bodies** are fittings used to adapt conduit to different situations and conditions. Figure 9.38 shows some popular fittings, the applications of which are obvious. The NEC specifies that every conduit outlet must be equipped with an outlet box or approved fitting. Elbows, crosses, and tees can be obtained fitted with either metal or composition or porcelain wire-hole covers or with outlet or other devices. The fittings can be used as pull boxes, to support switches, or for a number of other purposes. Everyone interested in wiring should have the catalogs of the fitting manufacturers. These illustrate a great number of fitting combinations and applications.

Conduit fittings are made with their hubs for attachment to the conduit of either threaded or threadless types.

101. **Threadless fittings** (Fig. 9.39) can be used with unthreaded conduit. Tightening glands or setscrews clamp the conduit within the fitting. Threadless fittings materially reduce the labor cost of conduit installation in many instances.

The NEC requires that threadless fittings be made tight and that, if installed in wet places or if buried in masonry, concrete, or fill, they be of a type to prevent water from entering the conduit.

102. **Conduit should run as straight and direct as possible.** There should never be more than the equivalent of four right-angle bends between outlets or fittings.

103. **In installing exposed conduit runs** where there are several conduits in the run, it is usually better to carry the erection of all of them together rather than to complete one line before starting the others. If all are carried together, it is easier to keep all the raceways parallel, particularly at turns, and the chances are that the job will look better.
104. Galvanized-Iron Pipe Straps of the Two-Hole Type

<table>
<thead>
<tr>
<th>Nominal size of conduit, in</th>
<th>A, width of opening, in</th>
<th>B, width of opening, in</th>
<th>C, width of strap, in</th>
<th>D, distance between centers of screw holes, in</th>
<th>E, diam of screw hole, in</th>
<th>F, size of wood screw to use</th>
<th>Approximate number per lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4</td>
<td>9/16</td>
<td>7/32</td>
<td>1/8</td>
<td>1 1/16</td>
<td>0.20</td>
<td>No. in</td>
<td>75</td>
</tr>
<tr>
<td>5/32</td>
<td>1/8</td>
<td>7/32</td>
<td>1/8</td>
<td>1 1/16</td>
<td>0.20</td>
<td>8 × 1/8</td>
<td>40</td>
</tr>
<tr>
<td>1/2</td>
<td>11/16</td>
<td>7/16</td>
<td>1/8</td>
<td>2 1/8</td>
<td>0.22</td>
<td>8 × 1/16</td>
<td>29</td>
</tr>
<tr>
<td>5/8</td>
<td>11/16</td>
<td>7/16</td>
<td>1/8</td>
<td>2 1/8</td>
<td>0.22</td>
<td>10 × 1/8</td>
<td>21</td>
</tr>
<tr>
<td>3/4</td>
<td>13/16</td>
<td>7/16</td>
<td>1/8</td>
<td>2 1/8</td>
<td>0.22</td>
<td>10 × 1/16</td>
<td>18</td>
</tr>
<tr>
<td>1/2</td>
<td>13/16</td>
<td>7/16</td>
<td>3/16</td>
<td>3</td>
<td>0.22</td>
<td>10 × 1/16</td>
<td>14</td>
</tr>
<tr>
<td>1/2</td>
<td>7/16</td>
<td>7/16</td>
<td>3/16</td>
<td>3</td>
<td>0.22</td>
<td>10 × 1/16</td>
<td>12</td>
</tr>
<tr>
<td>3/4</td>
<td>13/16</td>
<td>7/16</td>
<td>4/16</td>
<td>4</td>
<td>0.25</td>
<td>11 × 1/16</td>
<td>6</td>
</tr>
</tbody>
</table>

105. Conduit can be supported on surfaces with pipe straps made in two-hole (Fig. 9.40) and one-hole (Fig. 9.41) types. On wooden surfaces, wood screws secure the straps in position. On masonry surfaces, machine screws turning into lead expansion anchors can be used. (Refer to Div. 4 for types of expansion anchors.) Wooden plugs should never be used because no matter how well seasoned a plug appears to be, it will usually dry out to some extent and loosen in the hole. The dimensions in Table 104 are valuable, when laying out multiple-conduit runs, to determine the spacings necessary between the conduits to permit proper placing of the straps. The screw-hole dimensions enable one to order, in advance, screws of the proper diameters to support the straps.

106. Location of conduit supports. The NEC states that rigid metal conduit shall be firmly secured within 900 mm (3 ft) of each outlet box, junction box, cabinet, or fitting. Such conduit shall be supported at least every 3 m (10 ft) except that straight runs of conduit made up with approved threaded couplings may be secured as indicated in Table 107, provided such fastening prevents transmission of stresses to termination when conduit is deflected between supports. In addition, the NEC allows the first support rule to be as far as 1.5 m (5 ft) from a termination in instances where there is no structural support available. This accommodates up to 5-ft spacings between bar joists without having to arrange intermediate support.

A new rule in the 2008 NEC covering all rigid tubular raceways (including RMC, IMC, EMT, PVC, and the now separate article for fiberglass type RTRC raceways) addresses the support of short nipples between enclosures. It requires direct support for...
108. Some commercial I-beam conduit hangers are shown in Figs. 9.42 and 9.43. The one at I is an I-beam clamp formed from wrought-iron strap. The hanger or clamp (the part that grips the beam) of that at II can be purchased of either stamped steel or malleable iron. The support (the yoke in which the conduits rest) is of malleable iron or spring steel and can be purchased to accommodate one or several conduits of different sizes.

109. Conduit hangers and supports. A variety of conduit hangers and supports and several applications are shown in Fig. 9.43. U-channel supports are ideal for supporting several runs of conduits. In laying out these supports consideration should be given to future conduit runs as well as those to be installed initially. It is a simple matter to provide U channels or trapeze hangers with additional space for future conduits. This procedure greatly reduces the cost of installing new conduit at a later date. With the U-channel system, as shown in Fig. 9.43, special clamps are slipped into the channel slot, and the top bolt of the clamp securely fastens the conduit to the U channel.

The U channel can be directly fastened to a wall or ceiling, or it can be attached to bolted threaded rod hangers, suspended from ceilings, roof structures, or similar members.

Another excellent application for the U channel is in suspended ceilings which contain lift-out ceiling panels. In modern construction these lift-out panels provide ready access to mechanical and electrical equipment within the suspended-ceiling area. Accordingly, it is important that conduits installed in such an area do not prevent the removal of panels or access to the area. Rod-suspended U channels provide the solution to conduit wiring in such areas.

Sections of U channel and associated fittings are available in aluminum or steel types. Another type of material that can be used for supports is slotted-angle-steel units. Numerous prepunched slots allow installers to bolt on rods, straps, and similar material without drilling holes. Slotted steel has unlimited applications in forming special structures, racks, braces, or similar items.

107. Spacing of Rigid-Metal-Conduits Supports

<table>
<thead>
<tr>
<th>Conduit size, in</th>
<th>Maximum distance between Rigid-Metal-Conduit supports, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 and 3/4</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>1 3/4 and 1 1/2</td>
<td>14</td>
</tr>
<tr>
<td>2 and 2 1/2</td>
<td>16</td>
</tr>
<tr>
<td>3 and larger</td>
<td>20</td>
</tr>
</tbody>
</table>

FIGURE 9.42 Commercial conduit clamps.
110. Conduit in concrete buildings (much of it, at any rate) can be installed while the building is being erected. The outlets should be attached to the forms, and the conduits between outlets should be attached to reinforcing steel with metal tie wires so that the conduit can be poured around them (Fig. 9.44). When several conduits pass through a wall, partition, or floor, a plugged sheet-metal tube (Fig. 9.45, I) should be set in the forms to provide a hole for them in the concrete. When a single conduit is to pass through, a nipple (Fig. 9.45, II) or a plugged sheet-metal tube can be set in the forms.
111. Conductors in Vertical Conduits must Be Supported within the conduit system as indicated in the following table.

<table>
<thead>
<tr>
<th>Conductor size</th>
<th>Aluminum or copper-clad aluminum</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not greater than</td>
<td>30 (100)</td>
<td>30 (100)</td>
</tr>
<tr>
<td>No. 18 through No. 8</td>
<td>30 (100)</td>
<td>30 (100)</td>
</tr>
<tr>
<td>No. 6 through No. 0</td>
<td>60 (200)</td>
<td>25 (80)</td>
</tr>
<tr>
<td>No. 00 through No. 0000</td>
<td>55 (180)</td>
<td>18 (60)</td>
</tr>
<tr>
<td>211,601 through 350,000 cmil</td>
<td>41 (135)</td>
<td>15 (50)</td>
</tr>
<tr>
<td>350,001 through 500,000 cmil</td>
<td>36 (120)</td>
<td>12 (40)</td>
</tr>
<tr>
<td>500,001 through 750,000 cmil</td>
<td>28.5 (95)</td>
<td>11 (35)</td>
</tr>
<tr>
<td>Above 750,000 cmil</td>
<td>26.5 (85)</td>
<td>11 (35)</td>
</tr>
</tbody>
</table>

The following methods of supporting cables will satisfy NEC requirements:

1. Approved clamping devices are constructed of or employ insulated wedges inserted in the ends of the conduits (Fig. 9.46). With cables having varnished cambric insulation, it may also be necessary to clamp the conductor.

2. Junction boxes may be inserted in the conduit system at the required intervals. Insulating supports of an approved type must be installed in them and secured in a satisfactory manner so as to withstand the weight of the conductors attached thereto. The boxes must be provided with proper covers.

3. The cables may be supported in junction boxes by deflecting them (Fig. 9.47) not less than 90° and carrying them horizontally to a distance not less than twice the diameter of the cable, the cables being carried on two or more insulating supports and additionally secured thereto by tie wires if desired. When this method is used, the cables shall be supported at intervals not greater than 20 percent of those mentioned in the preceding tabulation.
112. Properly bent conduit turns look better than elbows and are therefore preferable for exposed work (see Fig. 9.48). If bends are formed to a chalk line, drawn as suggested in Sec. 113, the conduits can be made to lie parallel at a turn in a multiple run as shown in Fig. 9.48, II. If standard elbows are used, it is impossible to make them lie parallel at the turns. They will have an appearance similar to that shown in I.

FIGURE 9.47 Supporting conductors in a vertical conductor run.

FIGURE 9.48 Right-angle turns with elbows and with bent conduit.
113. **Laying out a right-angle conduit bend.** Draw a chalk-line diagram of the contour of the bend on the floor as follows (see Fig. 9.49): Draw a base line CO of any length. Lay off AO 4 units long. (The units may be of any dimensions.) With a cord and piece of chalk with O as a center and a radius of 3 units describe the arc IJ. With A as a center and a radius of 5 units describe the arc EH. The line OD drawn from O through B, the intersection of the two arcs, will be at right angles with CO.

CO and OD can now be prolonged for any desired distance. The arc CD is drawn with the cord and chalk with any required radius R. The conduit bend should lie parallel to this arc when the bend is laid on the floor for inspection as shown in Fig. 9.50. The radius of curvature of the inner edge of any field bend is required by the NEC to be not less than shown in Table 93.

![Figure 9.49 Laying out a right angle.](image)

![Figure 9.50 Forming a conduit to chalk lines.](image)

114. **Conduit hickeys and benders** are used to hand-bend smaller sizes of rigid steel conduit, rigid aluminum conduit, and the new Type IMC (intermediate metal conduit) in 1/2-, 3/4-, and 1-in sizes, as well as in a 11/4-in size for small offsets (see Fig. 9.51.) Benders and hickeys for thin-wall electrical metallic tubing (EMT) are widely used for all types of bends in sizes from 1/2 to 11/4 in inclusive. A typical thin-wall conduit bender, shown in Fig. 9.52A, was invented by Jack Benfield of Delray Beach, Florida. Listed below are the features of this bender that have greatly improved the art of precision-bending conduit and EMT over the years:

1. Bold cast-in symbols not only are recessed but also are paint-filled to serve as permanent benchmarks or guide points for making accurate stub lengths, back-to-back bends, saddles, and offsets.
2. The Benfield formula for making precision offsets is printed in bold letters cast into the metal as a constant reference for the operator at point at use. The formula reads:

   \[
   \text{OFFSET DEPTH} \times \text{MULTIPLIER} = \text{DIST. NEEDED BTWN BENDS}
   \]

   A cast-in degree scale on one side and a cooperating cast-in multiplier scale on the opposite side of the tool guide the operator in this precision offset technique.
3. A patented inner-hook contour prevents the tool from slipping. It will not chew into or nick galvanized surfaces or gouge aluminum conduits.

![Figure 9.51 The standard conduit bicky.](image)
**FIGURE 9.52A** No. 1 Benfield bender for $\frac{1}{2}$-in electrical metallic tubing (EMT). This tool makes the minimum National Electrical Code radius. [Jack Benfield, patent holder]
4. The hook area also includes a back-pusher contour which allows the bender to grab on in reverse to remove an overbend or to shift the bend from side to side.

5. The back of the hook has a double-width outrigger ground flat (like a T square in relation to the bender groove). This flat shoulder provides stability and maintains floor contact long enough to set the course of the bend in a plane vertical to the working surface.

6. For purposes of safety the socket for a handle has recessed threads. The entire tool is cast of tough pearlitic-alloy malleable iron with heavy sections and guard points to protect the groove from damage.

7. The extended nonskid foot pedal invites foot pressure and increased leverage by 75 percent.

8. The Benfield No. 1 bender (Fig. 9.52A) is designed for bending 1/2-in EMT only. A similar model, No. 2, is used for 3/4-in EMT, and No. 3 is for bending 1-in EMT. All three tools bend to the minimum NEC radius. If larger radii are not objectionable, the No. 2 bender will bend 1/2-in rigid conduit. The No. 3 bender will bend 3/4-in rigid conduit.

The Benfield No. 6 Powr-Jack bender, shown in Fig. 9.52B, has every feature of the No. 2 bender plus an extended two-position power step that provides 200 percent more leverage, thereby extending the range for hand benders to include 1-in rigid or IMC conduit and 1 1/4-in EMT.

The Benfield No. 9 double-grooved bender (Fig. 9.52D) is a one-piece malleable-iron casting with no moving parts. One groove bends 1/2-in EMT only; the other groove is for 3/4-in EMT or 1/2-in rigid conduit (Fig. 9.52C). The No. 9 Benfield makes shorter radii than standard models, i.e., 3-in inside radius for 1/2-in EMT and a 4-in radius for 3/4-in EMT and 1/2-in rigid conduit or IMC. Handles are now available in IPS 3/4-, 1-, and 1 1/4-in sizes and are
factory-engineered ready for use. They are marketed complete with an applied mylar-coated weatherproof bumper-sticker-type Zip Guide to give the operator basic bending allowances at the point of use.

Relatively new to the industry is Type IMC (intermediate metal conduit). To provide the right NEC radii for IMC, a series of Benfield benders is marketed. These models bend all three types: rigid steel conduit, rigid aluminum conduit, and IMC intermediate metal conduit. Figure 9.52E, Benfield Model No. 16, shows an extra-heavy beefed-up hook plus extra-rugged sections throughout to withstand the rigors of bending rigid conduit and Type IMC conduit to the correct NEC radius. The No. 16 bends three conduit types: 1/2-in rigid steel, 1/2-in IMC, and 1/2-in aluminum rigid conduit. Larger models bend both rigid conduit and IMC in the 1/2- and 1-in sizes. The No. 16 series tools are not suitable for bending EMT.

Figure 9.52F, the Benfield Zip Guide, is an on-the-handle reference that speeds the work. This precalculated table for spacing between bends is accurate for any make of bender, whether hand-type, mechanical, or hydraulic. Zip Guides are a definite aid for the electrician.

The Benfield No. 7 one-shot hickey (Fig. 9.52G) bends 1/2- and 11/4-in rigid or IMC conduit. Model No. 8 bends 1- or 11/4-in rigid or IMC conduit. The unbreakable plumb bob swings free on a stainless-steel bolt as a constant degree-of-angle indicator. (Two shots are required for the No. 8 model.) Multiple shots may be used on both models for larger radii and concentric bending.

The Benfield No. 10 series stubber-hickey line (Fig. 9.52H) is unique. These tools are inch-along short-radius hickeys that bend both EMT and rigid or IMC conduit: No. 10 for 1/2- and 3/4-in rigid or IMC conduit. Model No. 8 bends 1- or 11/4-in rigid or IMC conduit. The unbreakable plumb bob swings free on a stainless-steel bolt as a constant degree-of-angle indicator. (Two shots are required for the No. 8 model.) Multiple shots may be used on both models for larger radii and concentric bending.
1/2-in EMT only, No. 11 for 1/2-in rigid IMC or 3/4-in EMT, No. 12 for 1/2-in rigid IMC or 1-in EMT, and No. 13 for 1-in rigid IMC or 11/4-in EMT.

These Benfield tools are available from wholesale electrical distributors throughout the United States and Canada. A 24-page basic training guide kit for any make of bender or hickey (whether hand type, ratchet type, hydraulic, or electrically powered) is available from Jack Benfield, P.O. Box 2735, Delray Beach, Florida 33447. This training kit dubbed in the trade “Back Pocket Bending Buddy” includes the booklet, a Zip-Guide 9-52E for the bender handle, and a wallet size offset-formula card. It is refreshingly nontechnical, replete with crystal clear diagrams and simple formulas for making stub-ups, back-to-band bends, offsets, concentric bends, and crossover saddles.

Benfield benders are produced in the United States by Klein Tools, Inc., of Chicago, Illinois. Klein Tools, Inc., franchises other manufacturers to market Benfield benders as follows:

1. Appleton Electric Company, Chicago, Illinois 60657
3. The Wiremold Company, West Hartford, Connecticut 06110
4. Appleton Electric Ltd., Cambridge, Ontario, Canada N3H 2N1

**SURFACE METAL MOLDING BENDERS** The Wiremold Benfield catalog No. 600-B (Fig. 9.52I) is a one-sweep bender with no moving parts. It makes 90° bends, offsets, and saddles in both No. 500 and No. 700 Wiremold surface metal raceway. The bender makes smooth sweeps flange-in or flange-out. An adapter that snaps into the bender groove is used to bend No. 200 Wiremold.

**NOTE** This tool will not bend this rectangular raceway sideways. To make sideway turns fittings must be used. Two separate degree scales are cast into the tool, one scale for No. 500 and the other for No. 700 Wiremold. Painted symbols serve as benchmarks to enable the operator to make precision bends as with EMT benders (Fig. 9.52I, and H). The 600-B comes complete with a two-piece handle of 1/2-in IPS coupled in the center (Fig. 9.52K). Applied to the handle is a weatherproof 3-in-by-6-in Zip-Guide instruction label, a basic reference at point of use.
FIGURE 9.52J  Action view.

FIGURE 9.52K  Side view with two-piece handle.

FIGURE 9.52I  Top view.
115. **Power conduit benders.** For larger EMT or conduit sizes, hydraulic benders similar to the one shown in Fig. 9.53 are used in modern practice. Such benders are operated by a hand pump or a motor-driven pump. In general, two types are available. One type utilizes the *progression-bend method*, in which bends are laid out in marked spacings. Then every few degrees the conduit is shifted to the next mark, and so on, until the bend is completed. The second type is called a *one-shot bender*, in which the bend can be made without shifting the conduit. A 90° bend made with a one-shot bender provides a radius about the size of a standard factory elbow. Various shoes are available for different EMT and conduit sizes and for different sweep sizes. Information on the proper use of hydraulic benders is available from manufacturers of such equipment, and their instruction books should be followed to obtain precision bends.

Figure 9.54A shows a Condumatic power bender for making precision bends with \(\frac{1}{2}\), \(\frac{3}{4}\), and 1-in rigid conduit. This motor-operated tool is extremely useful on large construction jobs for which many repetitive bends are required. The Greenlee power bender shown in Fig. 9.54B bends \(\frac{1}{2}\)- through 2-in conduit or EMT.

![FIGURE 9.53 Hydraulic conduit bender.](image)

![FIGURE 9.54A Condumatic power bender for \(\frac{1}{2}\), \(\frac{3}{4}\), and 1-in rigid metal conduit.](image)

![FIGURE 9.54B A power bender provides 90° bends for \(\frac{1}{2}\)" to 2" EMT, IMC, or rigid conduit.](image)

116. **A hydraulic pipe pusher** is used for underground installations of rigid metal conduit. The pusher eliminates tedious trenching operations. The conduit, which must be equipped with a cap or point, is driven through the ground laterally. A common application is under streets or roadways.
Pipe pushers can be operated at different pressures, depending on the conduit size and the type of ground through which the conduit is driven. Standard pipe pushers permit pushes up to 7 ft (2.1 m) without the pipe clamp being changed.

117. **Cable pullers and wire reels** (Fig. 9.55) are used for the installation of larger conductor sizes. Both are extremely useful on larger installations and save a great deal of time and labor. Multiple wire reels are also useful when a large number of small conductors are to be pulled into a single conduit. Figure 9.56 shows an electric-motor–operated cable puller which is also helpful in pulling in conductors with minimum effort.

118. **Threading conduit.** Dies for threading conduit are designed to produce a taper of 7/4 in. (19 mm)/ft as described in Sec. 82. It is usual practice when a lot of conduit is received to rethread all the ends, which may have become filled with paint or dirt or distorted by blows. Rethreading will save more than its cost in that it ensures rapid erection. Always reream conduit after cutting a thread on it. Pipe-threading machines for threading conduit, preferably those operated by motors, should be used on big jobs, as they will soon pay for themselves in the time that they save.

119. **Wrenches for turning conduit.** The form of wrench shown in Fig. 9.57, I, appears to be the most popular for turning conduit. Chain wrenches (II) are not as yet much used for conduit work, but when they have been tried, they have proved very satisfactory. Their advantages are that they can be used with one hand after the chain is around the conduit and that they can be used in confined places and close to walls where a Stilson wrench could not be utilized.
120. Conduit ends should always be reamed. A reamer like that of Fig. 9.58 which can be turned by a bit brace is a good tool for small and medium-size conduit. For conduit of the larger sizes, reamers which have long handles attached, giving the needed leverage can be obtained. When conduit is received and after it is cut, the ends are frequently turned in (Fig. 9.59, I) and, when screwed together in a coupling, form a knife-like edge which will abrade insulation. When the ends are properly reamed, they appear as shown in Fig. 9.59, II, but if they are screwed together too tightly, they may turn up as at I, defeating the purpose that reaming should accomplish. If no other tool is available, conduit can be reamed by hand with a half-round file.

121. The usual tool for cutting conduit is a hacksaw. Pipe cutters should not be used because they leave a large burr on the inside of the conduit, which takes time to ream out. While the conduit is being cut, it should be held in a vise. On jobs with a great deal of conduit to cut, the installation of a motor-driven cold-cutoff saw, such as is used for cutting structural steel and rails, will prove economical. A rapidly rotating steel disk without teeth cuts the pipe. Water must be sprayed on the disk to keep it cool. Other types of power saws are available, including portable band saws that will cut up to trade size 4 conduits.

122. Fishing wire is tempered-steel wire of rectangular cross section. It can be readily obtained at electrical supply houses. A fishing wire is sometimes termed a snake (see Table 126 and Fig. 9.60). So that a fishing wire will slide...
123. When fishing from two ends, as in Fig. 9.61, it is often advisable to tie a loop of cord, possibly 1 ft (0.3 m) long, in the hook of one wire and bend down the hook (Fig. 9.63). The other wire has an open hook which can be made to engage in the cord loop quite readily. It has been found that a fish wire will go through conduit more readily if prepared as in Fig. 9.64, by loosely winding the end with small wire or cord, so that the wire or cord cannot pull off.

124. Chain is used for vertical fishing. A small chain can be made to drop down a vertical wireway with little difficulty. Within a partition, the noise made by the lower end of a chain that is jiggled up and down will disclose its location almost exactly.
125. **Galvanized-steel wire can be used for fishing.** Any size from No. 14 up to, possibly, No. 6 may be utilized, but in nearly every case that flat steel ribbon wire is preferable.

126. **Dimensions of Steel Fish Wire**

Wire \( \frac{1}{8} \) in. wide is the size most frequently used. The wire is usually put up in coils of 50, 75, 100, 150, and 200 ft, and in some cases 240 ft (15.2, 22.9, 30.5, 45.7, and 61 m, and sometimes 130 m).

<table>
<thead>
<tr>
<th>Width, in</th>
<th>Thickness, in</th>
<th>Weight per 100 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{1}{8} )</td>
<td>0.015</td>
<td>11 oz</td>
</tr>
<tr>
<td>( \frac{1}{8} )</td>
<td>0.030</td>
<td>1 lb 4 oz</td>
</tr>
<tr>
<td>( \frac{3}{16} )</td>
<td>0.030</td>
<td>1 lb 14 oz</td>
</tr>
<tr>
<td>( \frac{1}{4} )</td>
<td>0.030</td>
<td>2 lb 8 oz</td>
</tr>
<tr>
<td>( \frac{3}{8} )</td>
<td>0.035</td>
<td>3 lb 8 oz</td>
</tr>
<tr>
<td>( \frac{1}{8} )</td>
<td>0.035</td>
<td>3 lb 12 oz</td>
</tr>
</tbody>
</table>

127. **In drawing wire into conduit** it is a mistake to use so much force that the wire cannot be withdrawn. Conduits should be big enough so that excessive force is not necessary. Small conductors (14 and 12 AWG) can be pulled in with the fish wire. Figure 9.65 shows how they can be attached to the fish wire, and Fig. 9.66 shows how the attachment should be served with tape to render pulling easy. It spoils any fishing wire to draw in with its conductors that pull hard.

For conductors larger than 14 and 12 AWG, unless the pulls are very easy, a pulling-in line which is drawn into the conduit with the fish wire should be used for hauling in the conductors. Number 10 or 12 Birmingham wire gage galvanized-steel wire makes a good pulling-in line and is probably better for heavy work than rope. Two strands can be used if necessary. Braided cord is better than twisted rope for a pulling-in line, because when tension is applied, rope tends to untwist. Sash cord is satisfactory for light work. Galvanized-steel pulling-in wire can be attached to fish wire as in Fig. 9.67. Nylon rope, attached to a foam piston or even an improvised parachute made from a plastic bag and a rag filler, and blown into conduits by a Jet-Line tool, is also recommended. A Kevlar measuring tape is available for this purpose that has measurements every foot marked on it, so the total length of pull can be anticipated exactly.
Three or four links from a chain of no greater diameter than the line should be made up in the end of a rope or cord pulling-in line. Wires to be drawn in or a fish line can be attached to the links (Fig. 9.68). One stranded conductor can be attached to a pulling-in line as in Fig. 9.69. The attachment should be taped over to make it smooth. If two conductors are to be pulled in, one of them is made up into a loop in the end of the pulling-in line, as shown in Fig. 9.69. The insulation is trimmed from this conductor for 6 in. (152.4 mm) or more, and the bared end of the other conductor is made up about the first one, forming a long, tapering connection. If a hard pull is expected, it is advisable to solder the connection. The whole should be served with tape as in Fig. 9.66. If three wires are to be drawn in instead of two, the attachment is the same, with the addition that the bared end of the third conductor is made up around the other two. The diameter at any section of the attachment must not exceed the overall diameter of the wires, and the attachment should be in the form of a conical wedge. It is sometimes necessary to cut off possibly half of the strands of the bared ends and make up only the strands that remain to ensure that the attachment will be of sufficiently small diameter. A flexible-metal basket grip (Fig. 9.70), available in many sizes, is also recommended. The weblike grip slips over the ends of cables, and when tension is applied, the grip tightens and the conductors are firmly secured.

---

**FIGURE 9.67** Attachment of pulling-in line to fish wire.

**FIGURE 9.68** Chain links in the end of pulling-in line.

**FIGURE 9.69** Attachment of stranded conductor to pull-in line.
128. Force for pulling-in wires is, in the case of easy pulls, supplied by the worker. Tackle blocks are permissible for heavy pulls. Snatch blocks can be used to guide the pulling-in line to some point at which it can be pulled either with the crane hook or by the crane in traveling along its runway. A lever can be used for hard pulls either by repeatedly fastening the pulling-in line to the lever or by gripping it with a pair of pliers and then prying against the pliers with the lever. Only a short pull is possible with each setting, a succession of settings and pries is necessary to draw the conductors in.

129. In feeding conductors into conduit, care must be taken that they go in symmetrically and without lapping or twisting. If one conductor crosses another, it may make a hump that will wedge in the conduit. Liquid paste, commonly known as wire lube, is widely used in modern cable-pulling operations. Although in a paste form during cable pulls, the substance dries into a powder form, which aids in withdrawing conductors later on. Newer versions are carefully formulated with water and polymers and do a much better job of reducing friction than previous products.

130. Pulling methods for nonmetallic raceways. Careful consideration must be used both during the design process and while setting up a pull in order to assure that the pulling method will not saw through the inner radius of a sweep. For steel raceways, this is not a major concern, but for nonmetallic raceways it can be very difficult. Some pulling winches use steel aircraft cable that will make short work of a nonmetallic elbow, especially if it is heavily loaded. For this reason, some wiring designs place steel conduit elbows in the middle of nonmetallic conduit runs.

This solves the pulling problem, but raises another issue because normally metal conduits have to be bonded to the equipment grounding conductor that runs with the circuit conductors (in the case of a service, to the grounded circuit conductor). This may be difficult to arrange in the field, particularly where the elbow will not be accessible. On an outdoor pole, the NEC makes an exception to the normal 6-ft (1.8 m) limit on these bonding conductors so the bonding conductor can continue up the pole and connect at the top of the riser. The NEC waives the bonding rule entirely if the elbow is buried so deep that the end nearest to the top of grade is still buried 18 in. (450 mm), or if the steel sweep is encased in not less than 2 in. (50 mm) of concrete.

If the steel sweep approach is impracticable another option is to pay close attention to the pull rope. A polypropylene rope will burn through the inner radius of a PVC sweep in a little over a minute under heavy pulling forces. On the other hand, a braided polyester rope will perform far better, and more than one manufacturer has taken this idea a step further by taking the braided polyester and forming it into a flat tape that distributes the pulling friction over a wide area. Studies have shown that this extends the burn-through time by about two orders of magnitude, such that what would burn through with polypropylene in about 1½ min would take over 2½ h under the same pulling conditions with the flat tape. The tape is available in different sizes with ratings up to 6000 lb.
131. Raceways must be proofed and conductors must be sized and coordinated so conductor insulation is not damaged during installation, by NEC rules. Statistics have shown that over 90 percent of failures to medium-voltage conductors in raceways stem from faulty installation practice during the process of pulling the conductors into the raceway. Statistics aren’t available for lower voltage applications, but undoubtedly a large percentage of failures at these voltages have a similar cause. Often these failures don’t show up for years, making it difficult to assign blame. It is very important to understand the factors that go into a successful installation that does not overstress the insulation.

The first step is to always proof the raceway by running equipment like that illustrated in Fig. 8.106 through it, so it will be clean and there will be no unexpected blockages. The force applied during cable pulling is primarily to overcome oppositional frictional forces, and therefore most of the cable-pulling calculations address the sources of the friction. However, raceway runs almost invariably involve bends. When cables move through a bend on a major pull, the pulling force on their leading end combined with the frictional forces behind the bend, including forces imposed by any prior bends, subject the insulation to enormous crushing forces. This crushing force is the sidewall bearing pressure, and it is a major factor in designing cable pulls. What follows are a series of calculations, all of which must be factored into the pulling analysis.

132. Start with the force required to unwind the reel. It requires force to unwind cable from a coiled orientation to straight as it enters the raceway, and there are also frictional forces in play as the reel turns over the support rollers or pay-off axle. A conservative value for this is \( T_{in} = \frac{25W}{H1005} \) where \( T_{in} \) is the tension applied on the cable entering the raceway, and \( W \) is the weight of the cable per foot. If there are multiple reels, the usual case, then multiply this number by the number of reels.

133. Now Analyze the Frictional Forces in the Raceway. The calculations that follow use terms defined in the following table:

<table>
<thead>
<tr>
<th>Defined term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D )</td>
<td>Inner diameter of the raceway, in inches</td>
</tr>
<tr>
<td>( d )</td>
<td>Outer diameter of one conductor (or cable assembly), in inches</td>
</tr>
<tr>
<td>( T_{in} )</td>
<td>Pulling tension into a specified section of the run, in pounds</td>
</tr>
<tr>
<td>( T_{out} )</td>
<td>Pulling tension out of a specified section of the run, in pounds</td>
</tr>
<tr>
<td>( \omega )</td>
<td>Weight correction factor (dimensionless)</td>
</tr>
<tr>
<td>( \mu )</td>
<td>Coefficient of dynamic friction (dimensionless)</td>
</tr>
<tr>
<td>( W )</td>
<td>Total weight of cables (or cable assembly) being pulled, in pounds/ft</td>
</tr>
<tr>
<td>( L )</td>
<td>Length of straight section, in feet</td>
</tr>
<tr>
<td>( \theta )</td>
<td>Rise or fall angle of straight section from horizontal</td>
</tr>
<tr>
<td>( \varphi )</td>
<td>Angle of bend, in radians (360° = 2\pi radians; 90° = 1.57 radians, etc.)</td>
</tr>
<tr>
<td>( R )</td>
<td>Bend radius measured to inner wall, in feet</td>
</tr>
<tr>
<td>( e )</td>
<td>Base for natural logarithms, a mathematical constant ( \approx 2.72 )</td>
</tr>
<tr>
<td>( SP )</td>
<td>Sidewall pressure in pounds/ft</td>
</tr>
</tbody>
</table>
The coefficient of dynamic friction ($\mu$) is the first and most important variable. It is important to remember that dynamic frictional coefficients are always smaller than static coefficients. In simpler words, it takes more force to break free a load at rest than to keep it moving once it is in motion. This is why cable pullers designed for the purpose keep the cable moving once the pull has begun, and why ad hoc methods like tractors, etc., that could allow the pull to stop and start are problematic. Major pulls involve forces on the order of 10,000 lb. An interrupted pull can easily result in a failed pull, because the increased force required to break the cable free may exceed the ratings of the pulling eyes, etc.

This coefficient can range from 0.1 to 1.0, or even higher for unlubricated runs. Many texts advise using a factor of 0.5 for lubricated work, and this analysis will start with this number as well. However, some modern cable lubricants, if properly applied, produce much lower coefficients. In addition, a major wire and cable manufacturer now has a pre-lubricated line of THHN/THWN conductors that have theoretical coefficients as low as 0.15 and has published data suggesting that a coefficient of 0.28 in steel and 0.24 in PVC is actually conservative for their product.

134. How the conductors arrange themselves in the raceway makes a difference. For these purposes there are four arrangements to consider, as shown in the table below. The first case is the trivial example of one cable in a raceway, and there is no correction factor required for this case. However, for all other cases because the friction is not equally distributed across all conductors, a correction factor must be applied in order for the force to be calculated correctly, as shown in the following table:

Weight Correction Factor Calculations

<table>
<thead>
<tr>
<th>Number of conductors</th>
<th>Configuration</th>
<th>Formula</th>
<th>Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Single</td>
<td>$\omega = 1$</td>
<td><img src="image" alt="Single" /></td>
</tr>
<tr>
<td>3</td>
<td>Cradled</td>
<td>$\omega = 1 + \frac{4}{3} \left( \frac{d}{D-d} \right)^2$</td>
<td><img src="image" alt="Cradled" /></td>
</tr>
<tr>
<td>3 (use for 2 also)</td>
<td>Triangular</td>
<td>$\omega = \frac{1}{\sqrt{1 - \left( \frac{d}{(D-d)} \right)^2}}$</td>
<td><img src="image" alt="Triangular" /></td>
</tr>
<tr>
<td>4 (use for 4 or more)</td>
<td>Diamond</td>
<td>$\omega = 1 + 2 \left( \frac{d}{(D-d)} \right)^2$</td>
<td><img src="image" alt="Diamond" /></td>
</tr>
</tbody>
</table>
The configuration generally follows from the conduit to cable diameter ratio (D/d ratio). The triangular configuration can always be used if the D/d ratio is less than 2.5. If the ratio runs from 2.5 to 3.0, the cables could lay either way and the cradled result should be used because it is conservative. For three conductors installed to NEC requirements, it can be demonstrated geometrically that the D/d ratio under worst case fill condition will be 2.65, so a cradled configuration will be the norm for applications covered here. If the ratio is above 3.0, the cradled configuration will almost certainly be the result. On the other hand, if the cable pull involves triplexed or quadruplexed assemblies, then the configuration follows the combined cable orientation for obvious reasons. For four cables, the diamond configuration will result in most cases where the D/d ratio is less than 3.0; otherwise the cradled configuration is likely. Here again, geometric analysis shows that the worst-case fill on an NEC compliant installation with four conductors will result in a D/d ratio of 3.08, so a cradled configuration will usually result unless the conductors are quadruplexed.

135. The required pulling force for straight sections of raceway can now be determined. There are several possibilities, as follows:

a. For horizontal straight sections, \( T_{out} = \omega WL + T_{in} \)

b. For inclined straight sections, \( T_{out} = \pm WL (\sin \theta \pm \omega \mu \cos \theta) + T_{in} \) where the “±” symbol is “+” for rising pulls and “−” for descending pulls.

c. For vertical applications same formula applies, however for these 90° angles the term “\( \sin \theta \)” is 1 and “\( \cos \theta \)” is 0, so for a straight up portion of the pull the tension added is \( WL \), and for a straight down portion the tension subtracted is \( WL \).

136. Raceway bends add significant friction. as follows. Exact bend calculations involve hyperbolic trigonometric functions and are extremely complex, especially where the bends are inclined and the effects of gravity enter the picture. Fortunately there is a relatively simple approximation that is sufficiently accurate for this work. The approximate effect of friction contributed by a bend is:

\[ T_{out} = T_{in} \times e^{\omega \mu \varphi} \]

137. How to handle natural logarithms and exponents. This type of mathematical expression will not be familiar to many of the users of this handbook. A logarithm of any number is the exponent, or power, to which a base number must be raised to give the first number. For example, the logarithm of 100 to base 10 is 2, because the base number, 10, raised to the second power is 100. Of course most logarithms don’t work out to be simple numbers. The base number 10 raised to the 0.30103 power is 2.0, etc., which means that the logarithm of 2.0, (written \( \log_{10} 2.0 \)) using base 10, is 0.30103.

The base number used in higher mathematics, given the designation “e” is derived from an evaluation of a certain area under a unit hyperbolic function using calculus. Its value has no perfect decimal representation, but it is approximately 2.72. This number turns out to be extremely useful as a base for logarithms in scientific work, and it also turns out to be essential in making pull calculations. Logarithms using this base are referred to as natural logarithms, and solutions for them are programmed into all scientific calculators. The usual designation for a natural logarithm is “ln.” For example “e” raised to the 0.69315 power is 2.0, so that is the natural logarithm of 2.0, written \( \ln 2 = 0.69315 \). The process can also be
inverted. Instead of finding the logarithm of a known number, if we know the base and the logarithm, the subject number can also be found. The pull calculation for a bend is exactly this type of work.

The formula gives the tension out of a pull \( (T_{ou}) \) by multiplying the incoming tension \( (T_{in}) \) by a number we will refer to as the bend multiplier. This number is “\( e \)” raised to a power, specifically the weight correction factor \( (\omega) \times \) the coefficient of friction \( (\mu) \times \) the angle of the bend in radians \( (\varphi) \). Radians are routinely used in higher mathematics, and unlike degree measurements, radians measure angles in terms of \( \pi \). Specifically, a semicircle of 180° contains 3.14159 (\( \pi \)) radians. Therefore a 90° angle contains half that amount, or 1.57 radians, and a 45° angle contains one quarter that amount, or 0.785 radians.

138. **Putting it all together.** First calculate the exponent in the formula by simply multiplying three numbers together \( (\omega) \times (\mu) \times (\varphi) \). This number is the natural logarithm of the bend multiplier, and we need to know what the bend multiplier actually is. To find this number, use the inversion of the process that finds a logarithm of a known number. The easy way to do this is to use a scientific calculator. They are commonly available, and one is built into most computer operating systems. Start the calculator, complete the multiplication \( (\omega \times \mu \times \varphi) \), select the invert key or checkbox (usually “INV”), and hit the natural logarithm button (usually “ln”). The result will be the bend multiplier. This result multiplied by the tension just before the bend \( (T_{in}) \) will give the tension out of the bend \( (T_{ou}) \).

This and all prior calculations generate the maximum force that must be applied by the end of the pull in order to complete the work. This will determine what form of pulling attachment is required, and whether the tensile strength of the conductors will stand up to the force, or whether the pull must be reengineered in terms of lubricant selected, or intermediate pull points provided. However, the bend calculations must be carefully recorded, at each stage in the pull, and the tension required (per these calculations) to be applied at the “out” side of each bend must be noted. This allows for the next set of calculations (below) to be performed.

139. **Sidewall bearing pressure** must be separately evaluated. Every time conductors are drawn through a bend, their insulation is compressed against the inner radius of the bend. The amount of force must not exceed the ability of the insulation to stand up to the pressure. Medium-voltage shielded cables are particularly vulnerable because if the shielding is permanently distorted, there may be a discontinuity that has no stress relief and results in a corona discharge under the outer jacket. If this occurs, the life of the cable will be dramatically curtailed. If the failure occurs within a raceway, the eventual fault will probably be sufficiently destructive to require the raceway to be replaced. Even 600 V applications, however, are susceptible to damage and must take sidewall pressure into account if the anticipated pulling force gets into the four figure range. The actual calculations must be done for each bend, based on the cable configuration and applicable out-of-bend tension, according to the following table:
9.62 DIVISION NINE

Determination of Sidewall Bearing Pressure

<table>
<thead>
<tr>
<th>Number of conductors</th>
<th>Configuration</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Single</td>
<td>( SP = \frac{T_{out}}{R} )</td>
</tr>
<tr>
<td>3</td>
<td>Cradled</td>
<td>( SP = \frac{(3\omega - 2) \times T_{out}}{3R} )</td>
</tr>
<tr>
<td>3 (use for 2 also)</td>
<td>Triangular</td>
<td>( SP = \frac{\omega \times T_{out}}{2R} )</td>
</tr>
<tr>
<td>4 (use for 4 or more)</td>
<td>Diamond</td>
<td>( SP = \frac{(\omega - 1) \times T_{out}}{R} )</td>
</tr>
</tbody>
</table>

In each case the table provides a result in the form of pounds of force per foot of bend radius. Frequently the sidewall bearing pressure will be more of a limiting factor than the pulling force limitations. The table below shows acceptable sidewall pressures from a variety of industry sources, including recent research on nylon-jacketed PVC-insulated 600 V conductors (THHN/THWN). Some of these values are higher than those published years ago and reflect current research.

Sidewall Bearing Pressure (SWBP) Limits, by Conductor Type

<table>
<thead>
<tr>
<th>Cable type</th>
<th>Max. SWBP (lb/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 V Nonshielded control cable, Type TC</td>
<td>300</td>
</tr>
<tr>
<td>600 V Nonshielded power cable, Types THHN, THWN, USE, RHW</td>
<td>1000</td>
</tr>
<tr>
<td>600 V XLPE power cable, Type XHHW</td>
<td>1000</td>
</tr>
<tr>
<td>PE and XLPE Type MV with concentric wire shield:</td>
<td></td>
</tr>
<tr>
<td>without jacket</td>
<td>1200(^{v})</td>
</tr>
<tr>
<td>with encapsulated jacket</td>
<td>2000</td>
</tr>
<tr>
<td>PE and XLPE insulation, LC shield, LDPE jacket</td>
<td>1500</td>
</tr>
<tr>
<td>PE, XLPE, EPR insulation, concentric wire or tape shield</td>
<td></td>
</tr>
<tr>
<td>LDPE and PVC sleeved jackets</td>
<td>2000(^{v})</td>
</tr>
<tr>
<td>Lead sheathed cable with and without jackets:</td>
<td></td>
</tr>
<tr>
<td>XLPE insulation</td>
<td>2000</td>
</tr>
<tr>
<td>EPR insulation</td>
<td>2000</td>
</tr>
<tr>
<td>XLPE insulation, copper ribbon shield, MDPE sleeved jacket</td>
<td>2000</td>
</tr>
</tbody>
</table>

\(^{v}\)For a pull of three single-conductor cables in the same raceway, a maximum of 750 lb/ft is recommended.

\(^{v}\)The recommended SWBP limit should be reduced to 1500 lb/ft where the jacket is not applied tightly to the cable core.

140. Internal clearance may need consideration. Some pulling analyses suggest a review of the internal headroom, for other than cradled configurations, between the top of the conductors pulled in and the upper wall of the raceway to assure at least \(\frac{1}{4}\)-in headroom on straight pulls and from \(\frac{1}{2}\)- to 1-in headroom where pulling through bends. It can be shown geometrically that any cable installation that complies with NEC fill limits will necessarily exceed a cable diameter in headroom. Since this analysis presumes NEC compliance, this issue is not considered further here. It may arise in some power-limited applications for which customary fill limits have no safety implication. The question usually arises for utility installations that substantially exceed NEC fill limitations.
141. **The tensile strength of the cable assembly** cannot be exceeded. If a pulling basket is used, any pulling forces above 1000 lb require careful review of the manufacturer’s data regarding the particular basket proposed. Therefore, if a basket will be used, the strength that can be applied is quite simply the rating of the basket. Although there are published ratings for insulation withstand to basket pulls, in general these values exceed the sidewall withstand numbers. Therefore, if the sidewall calculations have been done and the pull will satisfy the sidewall pressure ratings, go ahead and look for a basket of comparable strength.

142. **Baskets are often used for lead-covered cables,** and there is a special calculation that applies in these cases. The allowable applied force to a lead cable sheath has been found to be 1500 lb/square inch of sheath cross section. Since a sheath $t$ inches thick and $D$ inches outer diameter has an average circumference of $\pi(D - t)$, the sheath cross section will be a hollow cylinder with a total cross-sectional area equal to $\pi(D - t)$. If the dimensions are in inches, the allowable force on a lead sheath of diameter $D$ and thickness $t$ will be:

$$T = 1500\pi t(D - t) = 4712t(D - t)$$

143. **The conductor material itself is the ultimate test of strength** in a power cable pull. If a basket will not work, look to the conductor. The allowable tension that can be applied to a copper conductor is related directly to its cross-sectional area “$A$”. If that area is given in circular mils, the relation is as follows:

$$T = 0.008 \times A \text{ (in circular mils)}$$

Some hard-drawn aluminum alloys equal this strength, but since the NEC mandates the use of an AA-8000 series of alloy for almost all 600 V and lower applications, the constant for this alloy (0.006) is the one usually applicable. As a good example of these calculations at work, a 500 kcmil XHHW copper 600 V conductor will safely withstand 500,000 $\times 0.008 = 4000$ lb of tension. Multiply this result by the number of cables that will be in contact with the raceway surface and that will be the multiplier. In the case of a diamond pull of four conductors, use 60 percent of the entire group of conductors, or 2.4 times the result for a single conductor. This adequately allows for a disproportionate amount of force ending up on a few conductors, and applies to pulls with even higher numbers of conductors as well. Take care to compare such a result with the rating on the pulling eye; the maximum force will be the lesser of the two values.

Note that the tensile strength of different sized conductors differs, for obvious reasons. Pulling different sized conductors into one raceway, particularly on very difficult pulls, is therefore problematic because the smaller conductors will break more easily. Such pulls should be approached very cautiously, and if possible, limited to the tensile strength of the smaller conductors. Note also that if it is necessary to cut some of the strands to seat a large conductor in the pulling eye, judge the allowable tensile strength on the basis of the remaining strands.

144. **Example, Part I:** This example works through a number of the practical problems that arise when laying out large pulls. Assume a 480Y/277 V 3-phase 4-wire 400 A
feeder with a full-size neutral will be run with 600 kcmil THHN copper conductors through the following trade size 3 EMT components using conventional lubrication:

a. 10 ft up out of a switchboard
b. Through a 90° sweep (standard size, C/L radius = 13 in.)
c. Through a horizontal run of 300 ft
d. Through another standard sweep turned upwards at a 45° angle to produce an offset
e. Through a diagonal run of 10 ft
f. Through a 45° sweep (standard size, C/L radius = 13 in.)
g. Through a vertical run of 20 ft
h. Through a final 90° sweep (standard size, C/L radius = 13 in.) ending directly at the back wall of a panelboard

Solution:

(1) Assign a coefficient of friction; for these purposes use 0.5.
(2) Determine the tensile strength of the conductors for pulling purposes. Each cable is good for \( \frac{(0.008)(600,000)}{4800} \) lb. There are four cables, taken at 60 percent:

\[ 4800(4)(0.6) = 11,520 \text{ lb.} \]

(3) Look up the pulling capacity of the pulling eye and rope. For the purposes of this example, use 10,000 lb.

(4) Determine the unit cable weight per foot. From the data sheets provided by the manufacturer, the wire weighs 1987 lb/1000 ft, so the unit weight will be 1.99 lb/ft. Four wires in the pull bring the total to 3.96 lb/ft.

(5) Calculate the weight correction factor using the formula in the table, using the EMT and conductor diameters from Tables 4 and 5 of the NEC, as follows:

\[ \omega = 1 + \frac{4}{3} \left( \frac{d}{D - d} \right)^2 = 1 + \frac{4}{3} \left[ \frac{1.051}{(3.356 - 1.051)} \right]^2 = 1 + \frac{4}{3}(0.21) = 1.28 \]

(6) Using a scientific calculator, determine the bend multiplier for each angle in the pull. First multiply the weight correction factor by the friction coefficient by the bend angle in radians. In this case multiply the weight correction factor just calculated (1.28) by the coefficient of friction (0.5), and then by the bend angle in radians (1.57 for the 90° bends and 0.785 for the 45° bend). On a scientific calculator, enter these results one at a time (1.005 for the 90° bends and 0.502 for the 45° bend), activate the inversion key (or check box) and hit the “ln” button for each. The result will be 2.73 for the 90° bends, and 1.65 for the 45° bend.

(7) Determine the radius of the inner walls of the bends. Working from published data for standard trade size 3 sweeps, the centerline radius is 13 in, so the inner radius will be \( 13.000 \text{ in.} - \frac{1}{2}(3.356 \text{ in.}) = 11.322 \text{ in.} = 0.94 \text{ ft for all standard bends.} \)

(8) Move through the run, one segment at a time, as follows:

a. Reel unwind resistance for 4 reels, \( 25 \times 4 \times 3.96 = 396 \text{ lb} \)
b. 10 ft up, add \( W \times L = 3.96 \times 10 = 40 \text{ lb; T}_{\text{out}} = (396 + 40) = 436 \text{ lb} \)
c. First 90° sweep, \( T_{\text{out}} = 436(\text{bend multiplier}) = 436(2.73) = 1190 \text{ lb} \)
d. 300-ft run, horizontal, \( T_{\text{out}} = \omega \mu WL + 1190 \text{ lb; } (1.28)(0.5)(3.96)(300) + 1190 = 760 + 1190 = 1950 \text{ lb} \)
e. Second 90° sweep, \( T_{\text{out}} = 1950(\text{bend multiplier}) = 1950(2.73) = 5324 \text{ lb} \)
f. 10-ft sloping run, 45° rising: \( T_{\text{out}} = (3.96 \times 10)(\sin 45° + \omega \mu \cos 45°) + 5324 = 40(0.71 + 1.28 \times 0.5 \times 0.71) + 5324 = 47 + 5324 = 5371 \text{ lb} \)
g. 45° sweep: \( T_{\text{out}} = 5371(\text{bend multiplier}) = 5371(1.65) = 8862 \text{ lb} \\
h. 20 \text{ ft vertical: } W \times L = 3.96 \times 20 = 80 \text{ lb; } T_{\text{out}} = (8862 + 80) = 8942 \text{ lb} \\
i. Final 90° sweep, \( T_{\text{out}} = 8942(\text{bend multiplier}) = 7714(2.73) = 24,412 \text{ lb} \\

This result is unacceptable because neither the cables nor the pulling hardware would make it through the last bend.

145. Example, Part II: Assume the same layout as before, but as a solution to the previous result, make two key changes. First, reduce the coefficient of friction by using better quality lubrication or consider new formulations of THHN that are prelubricated from the factory, or both. Published data show that the coefficient of friction can be reduced below, often well below 0.30 by doing so. In this case, use the published value of 0.28. In addition, reverse the pull so it goes downhill and with the majority of the bends reduced below, often well below 0.30 by doing so. In this case, use the published value of 0.28. With the inversion key activated, hitting the “ln” key for these numbers gives bend multipliers of 1.76 for the 90° bend and 1.32 for the 45° bend. The combined results are dramatically different, as follows:

i. Reel unwind resistance, 25 × 4 × 3.96 = 396 lb \\
h. 90° sweep: \( T_{\text{out}} = 396(\text{bend multiplier}) = 396(1.76) = 697 \text{ lb} \\
g. 10 \text{ ft down, subtract } W \times L = 3.96 \times 10 = 40 \text{ lb; } T_{\text{out}} = (697 \times 40) = 657 \text{ lb} \\
f. 45° sweep: \( T_{\text{out}} = 657(\text{bend multiplier}) = 657(1.32) = 867 \text{ lb} \\
e. 10\text{-ft sloping run, 45° falling: } T_{\text{out}} = -(3.96 \times 10)(\sin 45° - \omega \mu \cos 45°) + 867 = -40(0.71 \times 1.28 \times 0.28 \times 0.71) + 8670 = -18 + 867 = 849 \text{ lb} \\
d. 90° sweep, \( T_{\text{out}} = 849(\text{bend multiplier}) = 849(1.76) = 1494 \text{ lb} \\
c. 300-\text{ft run, horizontal, } T_{\text{out}} = \omega \mu WL + 1494 \text{ lb} = (1.28)(0.28)(3.96)(300) + 1494 = 426 + 1494 = 1920 \text{ lb} \\
b. 90° sweep, \( T_{\text{out}} = 1920(\text{bend multiplier}) = 1920(1.76) = 3379 \text{ lb} \\
a. 10 \text{ ft down, subtract } W \times L = 3.96 \times 10 = 40 \text{ lb; } T_{\text{out}} = (3379 \times 40) = 3339 \text{ lb} \\

Both the cables and the hardware easily survive, but sidewall bearing pressure has yet to be evaluated and compared with the 1000 lb table limit for these conductors, as follows:

First (90°) sweep (now the initial, upper sweep):

\[
SP = \frac{(3\omega - 2) \times T_{\text{out}}}{3R} = \frac{(3\omega - 2)}{3} \times \frac{T_{\text{out}}}{R} = \left(\omega - \frac{2}{3}\right) \frac{T_{\text{out}}}{R} \\
= (1.28 - 0.67)\frac{T_{\text{out}}}{R} = (0.61)\frac{T_{\text{out}}}{R} = (0.61)\frac{697}{0.94} = 452 \text{ lb}
\]

The first bend is compliant; second (45°) sweep:

\[
SP = \left(\omega - \frac{2}{3}\right)\frac{T_{\text{out}}}{R} = (0.61)\frac{T_{\text{out}}}{R} = (0.61)\frac{867}{0.94} = 563 \text{ lb}
\]

The second bend is compliant; third (90°) sweep:

\[
SP = \left(\omega - \frac{2}{3}\right)\frac{T_{\text{out}}}{R} = (0.61)\frac{T_{\text{out}}}{R} = (0.61)\frac{1494}{0.94} = 970 \text{ lb}
\]
The third bend is compliant; fourth (90°) sweep:

\[ SP = \left( \omega - \frac{2}{3} \right) \frac{T_{out}}{R} = (0.61) \frac{T_{out}}{R} = (0.61) \frac{3379}{0.94} = 3595 \text{ lb} \]

This final result is not acceptable because it far exceeds the sidewall tolerance for this type of conductor. However, a final 90° bend over a switchboard with 10 ft of headroom very likely has enough room for a larger radius sweep. A sweep with a 3-ft radius (centerline measurement, readily available, inner radius 34.322 in. or \(2 + (10.322 \div 12) = 2.86 \text{ ft}\)) would solve the problem entirely, as follows:

\[ SP = \left( \omega - \frac{2}{3} \right) \frac{T_{out}}{R} = (0.61) \frac{T_{out}}{R} = (0.61) \frac{3379}{2.86} = 721 \text{ lb} \]

146. Strategies to reduce pulling resistance. In general, if a calculation shows that a pull will be difficult or impossible, consider the following strategies:

Reverse the Pull. Every bend takes all prior resistance and multiplies it by an exponential factor, so it is often better to set the pull so most of the bends are at the front end. In addition, all things being equal, it is better to work with gravity instead of against it.

Decrease the Coefficient of Friction. This can involve a better selection of lubricant, or the use of different conductors, or both.

Increase the Radius of Bends. Although this will not change the tensile strength required to make the pull, it will dramatically reduce the sidewall pressure. The sidewall bearing pressure will be the limiting factor in many cases. Frequently the last bend will be the source of difficulty, and it may be in an accessible location where it could be changed.

Staff the Cable Reels. If helpers are turning the reels and actively guiding the cables into the raceway, much or all of the unwinding resistance can be eliminated. Since this occurs at the very beginning of the pull, it will have a disproportionately positive effect in reducing the pulling force and sidewall pressures.

If all of the foregoing options fail, then the run will need to be redesigned with fewer bends or one or more intermediate pull points provided as required. Keep in mind that the NEC requires that all raceways be continuous between established pull points prior to conductor insertion. Do not attempt opening the raceway at an intermediate point and pulling the full length of conductors through and beyond that location, all in the hope of resuming the pull at that intermediate point, and then reassembling the raceway to create the appearance of an end-to-end pull.

147. Potential cable jams on three-conductor pulls require special care. When tabular raceways are bent, they do not retain a perfectly circular form through the bend. Inevitably they become slightly elliptical in cross section in the process. If a three-conductor pull begins in a triangular configuration, and the conductor sizes are in a certain ratio to the diameter of the raceway, they may assume a cradled configuration when passing around the bend, with the midpoint of the cradle falling along the inside radius of the bend. When the leading part of the pull moves beyond the bend, the raceway resumes its circular cross section, and the conductors will try to resume their triangular configuration. If the conductors
cross over each other in the process, the result will be a jam if the inner diameter of the raceway, in its normal circular form, is smaller than approximately three times the diameter of the conductors. Conductors appreciably larger than this will not lose their orientation even when they pass through an oval section of the raceway, and conductors appreciably smaller than this ratio can slip back and forth between relative positions without difficulty.

For these reasons, the NEC has identified three-conductor pulls where the D/d (raceway diameter to cable diameter) ratios run between 2.8 and 3.2 as deserving of special care, because any attempt to pull through such a jam will likely damage the insulation. When making this calculation, increase the raceway diameter by 5 percent (multiply by 1.05) to account for out-of-round raceway problems. The NEC does not prohibit these ratios from being used, but cautions the installer to be alert. It is advisable to mark the cable to be drawn in, or pull in measuring tape with the conductors so if a jam occurs, and the tape measurement corresponds to the position of a known bend, the pull can be temporarily halted before the conductors are damaged. Often pulling back and then repulling will allow the conductors to resume their proper alignment.

148. **For bends, the pulling radius is not the same as the training radius.**

The NEC addresses how conductors will be maneuvered into the positions in pull boxes or at terminations that will be maintained for the foreseeable future. For example, single conductors must not be bent more sharply than 8 times their diameter if nonshielded and 12 times their diameter if shielded. This is a specification of the allowable **training radius** of a conductor, and it must not be confused with a conductor’s allowable **pulling radius**, which will vary with the unique conditions of every installation because it is a function of the allowable sidewall bearing pressure. As the pulling forces increase to overcome friction in the pull, these forces will increase to the point of exceeding the allowable sidewall force, unless the raceway radius increases proportionately. The example above provides a good example of this principle at work, where three of the bends can be standard radius, but one of them at the end of the pull had to be increased.

In addition, the minimum pulling radius directly affects the sizes of intermediate pulling sheaves in instances where a cable is pulled directly through a manhole into another conduit not on the opposite wall. Such sheaves must be well lubricated so the rollers will freely follow the passage of the cable. Otherwise, the sidewall bearing pressure must be calculated based on the radius of the intermediate pulling sheave, just as in fixed portions of the raceway system.

Often a compound roller system will be required for this purpose, including when large conductors are pulled into a complicated cable tray layout. No portion of a bend exceeding 20° should ever be made across a single roller. Therefore, to achieve a 90° bend during a pulling operation using compound rollers, a minimum of five rollers must be used. Arrangements that use just two rollers, one at each conduit end point, impose two sharp 45° bends through small radii on the cable and must never be used, because they defeat the purpose of maintaining a large radius during the pull.

**INTERIOR OR ABOVEGROUND WIRING WITH RIGID NONMETALLIC CONDUIT**

149. **Rigid nonmetallic conduit** of the Schedule 40 polyvinyl chloride (PVC) type may be used in walls, floors, and ceilings and for:

1. Portions of dairies, laundries, canneries, and other wet locations
2. Locations where walls are frequently washed
3. Locations subject to severe corrosive influences
4. Damp or dry location not prohibited by Sec. 147
5. Locations subject to chemicals for which the PVC material is specifically approved

It may also be used for exposed work when it is approved for the purpose and is not exposed to physical damage, unless identified for such locations. Schedule 80 is so identified, and may also be used aboveground on poles.

150. **Heavy-wall PVC conduit must not be used:**
1. In hazardous locations, except as specifically permitted in the articles of the Code that cover those locations.
2. Where exposed to physical damage unless identified for such use, as noted above.
3. For the support of fixtures or other equipment, with the exception of conduit bodies of a trade size not larger than the trade size of the largest entering conduit. Such conduit bodies are only for the purpose of changing the conduit direction, and must not support luminaires or devices beyond incidental splicing equipment employed in unusual instances where the conduit body contains splices.
4. Where subject to ambient temperatures, or conductor operating temperatures, exceeding those for which the conduit is listed.
5. PVC Schedule 40 and Schedule 80 are suitable for use aboveground and underground and for direct burial without encasement in concrete except as required by 300.50(B) of the NEC for over 600 V installations.

151. **Underwriters Laboratories** lists rigid nonmetallic PVC conduit for aboveground applications with two different labels, as shown in Fig. 9.71. The conduits are manufactured in sizes from 1/2 to 6 in. The extra-heavy-wall–type Schedule 80 conduit is utilized for special applications which require additional physical protection, such as pole risers or similar uses when conduit is subject to physical damage.

![FIGURE 9.71 Identification of aboveground PVC conduits.](image)

152. **Manufacturers’ classifications** for rigid nonmetallic PVC conduit are:
1. Type A. Thin-wall for underground, encased in concrete
2. Type 40. Heavy-wall for direct burial in earth and limited aboveground installations
3. Type 80. Extra-heavy-wall for direct burial in earth and aboveground installations for general applications and when subject to physical damage as indicated in Sec. 151

From the classifications indicated in Secs. 147 and 148 it should be noted that only heavy-wall (Type 40) and extra-heavy-wall (Type 80) PVC conduits are suitable for aboveground
applications. The Type A PVC conduit is limited to underground installations when encased in concrete, and such installations should be installed as indicated for underground work in Div. 8.

153. **PVC conduit fittings** are shown in Fig. 9.72. Also available are a wide variety of outlet boxes constructed of polyvinyl chloride or fiber-reinforced Bakelite.

![FIGURE 9.72 Fittings and accessories for PVC conduit.](image)

154. **Cutting PVC conduit.** This conduit can be easily cut with a fine-tooth handsaw. For sizes from 2 through 6 in. a miter box or similar saw guide should be used to keep the material steady and assure a square cut. After cutting, deburr the conduit ends and wipe off dust, dirt, and plastic shavings. Deburring can be readily accomplished with a pocketknife. Sizes up to 1 1/4 trade size can be cut easily with special cutting tools that fit in one hand and advance a sharp blade connected to a ratchet mechanism steadily through the conduit.

155. **Joining PVC conduit.** The conduit should be wiped clean and dry. Then apply a coat of cement (use a natural-bristle brush or aerosol-spray cement) to the end of the conduit, including the length of the fitting socket to be attached. Finally, push conduit and fittings firmly together, and then rotate the conduit in the fitting about a quarter turn to
distribute the cement evenly. The cementing and joining operation will not require more
than 1 min. Many manufacturers supply brush-top cans of PVC solvent cement, which may
be used as timesaving expedients. In adapting PVC conduit to existing or metal equipment,
a complete range of threaded adapters is available. Standard metallic locknuts are used at
these termination points, and bushings normally are not necessary.

156. **Bending PVC conduit.** Although a complete line of factory elbows (90, 45, or
30°) are available (Fig. 9.72), heat-bending of PVC conduit in the field can be easily accom-
plished. The most accepted method for sizes from \( \frac{1}{2} \) through 2 in. is with electric blankets
of varying sizes and ratings which consist of a 115-V, heating element that wraps around
the conduit. Large sizes of conduit utilize hot boxes that will accept the larger conduit sizes.
The conduit can be rotated to assure even heating.

The larger sizes of PVC conduit require interior support when being bent because their
walls, while hot, are not capable of withstanding the force of the bending process, and will
collapse. The usual way to provide this support is to insert air-tight plugs into both ends of
the conduit section being heated, while the conduit is still cold. As the conduit heats, the air
trapped inside heats with it, and becomes pressurized. The result is that the bends can be
completed without collapsing the conduit. If bending plugs are not available, and the
required bend is not a standard configuration as shown in Fig. 9.72, such as 90°, 45°, or
30° another option is to place a PVC sweep elbow in an oven, set at about 300°F. The
manufactured elbow, when it gets hot and pliable, will begin to “remember” its previous
form (a straight tube). Wearing gloves, remove the segment from the oven when it relaxes
to the desired angle and freeze it in place with a rag wet with cold water.

Under normal conditions a complete bend can be made in less than 1 min. When exact
measurements are required, preheat a length of PVC conduit and then form it in place. This
is possible because PVC conduit will remain pliable for at least 3 min after it has been
heated. Never use flame-type devices as a heat application to PVC conduit, because this
excessive heat can ruin the conduit.

The newest method of bending PVC raceways in the smaller trade sizes is to insert spe-
cial coiled springs specially sized to prevent kinking into the part of the conduit that must
be bent, and then bending without heating the conduit, often with a bender such as the one
illustrated in Fig. 9.52E. The spring is then withdrawn after the bend is complete.

157. **Expansion and contraction.** In applications in which the conduit installation
will be subject to constantly changing temperatures and the runs are long, considera-
tion must be given to expansion and contraction of PVC conduit. In such instances an expa-
nsion coupling, such as shown in Fig. 9.72, should be installed near the fixed end of the run
to take up any expansion or contraction that may occur. The coupling shown in Fig. 9.72
has a normal expansion range of 6 in. (152.4 mm). The coefficient of linear expansion of
PVC conduit is given in Table 352.44 of the NEC, and exceeds the expansion coefficient
of steel by a factor of five. Without properly applied expansion fittings, an aboveground
installation subject to the usual range of outdoor temperatures will fail. If the job is installed
on a cold winter day, and the conduit cannot freely move when the hot weather arrives, the
result will look like an accordion. If the same job is installed on a hot day, come the winter
months the conduit will contract to the point of pulling out of glue joints and exposing the
conductors within.

In addition, when PVC conduit is exposed to direct sun, it absorbs even more heat than
the surface wired over. A leading maker of PVC conduit recommends that at least 140°F be
used as the upper temperature design parameter for this reason. If the minimum temperature
were 0°F, that change in temperature would cause a 100-ft (30 m) length of conduit to
expand and contract through a range of almost 6 in. (150 mm). The wiring system must be arranged with this in mind. Of course, some parts of the system will handle this movement without difficulty. For example, a service riser running straight up from a meter socket and ending at a weatherhead, if properly supported with clamps designed to allow movement, can expand and contract at will.

Expansion couplings may be used in either underground or exposed applications. In underground or slab applications such couplings are seldom used, because expansion and contraction may generally be controlled by bowing the conduit slightly or by immediate burial. After the conduit has been buried, expansion and contraction cease to be a factor. Care should be taken, however, to assure that contraction does not take place in a buried installation if the conduit should be left exposed for an extended period of time during widely variable temperature conditions.

**158. Support of Rigid Nonmetallic Conduit** should be not less than specified in the following NEC table:

<table>
<thead>
<tr>
<th>Maximum spacing between conduit size, in</th>
<th>Supports, m (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2-1</td>
<td>0.9 m (3)</td>
</tr>
<tr>
<td>11/4-2</td>
<td>1.5 m (5)</td>
</tr>
<tr>
<td>21/2 and 3</td>
<td>1.8 m (6)</td>
</tr>
<tr>
<td>31/2 to 5</td>
<td>2.1 m (7)</td>
</tr>
<tr>
<td>6</td>
<td>2.5 m (8)</td>
</tr>
</tbody>
</table>

In addition, rigid nonmetallic conduit shall be supported within 900 mm (3 ft) of each box, cabinet, or other conduit termination.

**159. Number of conductors.** The number of conductors permitted in a single nonmetallic conduit is determined in the manner described in Sec. 94. In many instances nonmetallic conduits will contain equipment-grounding conductors to ground metal-enclosed equipment or grounding-type receptacles supplied by such conduits. If bare equipment conductors are used, the cross-sectional areas of these conductors, as listed in Table 57 of Div. 12, may be used in sizing the conduit. Accordingly, smaller conduit sizes may be permitted if bare instead of insulated grounding conductors are used.

It should be noted that extra-heavy-wall PVC conduit (Type 80) has a reduced cross-sectional area available for wiring space. Table 4, Chap. 9 of the NEC can be utilized to calculate conduction fill. The NEC now provides fill tables for Schedule 80 PVC in its Annex C, so if all the wires are of the same size, the permitted fill can be read out of the Code.

**160. The number of bends** in any run of conduit between outlet and outlet, fitting and fitting (LB, T, X), or outlet and fitting shall not contain more than the equivalent of four quarter bends (360°), including bends located immediately at the outlet or fitting.

**161 Nonmetallic conduit lengths** are normally available in 10-ft (3-m) lengths. However, lengths up to 30 ft (9.1 m) may be obtained for special applications. The longer lengths require fewer coupling connections and save time and labor.
162. **Weight of Heavy-Wall (Type 40) Rigid Nonmetallic PVC Conduit**

<table>
<thead>
<tr>
<th>Trade size, in</th>
<th>Weight, lb/100 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>16</td>
</tr>
<tr>
<td>3/4</td>
<td>21</td>
</tr>
<tr>
<td>1</td>
<td>31</td>
</tr>
<tr>
<td>1 1/4</td>
<td>42</td>
</tr>
<tr>
<td>1 1/2</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>67</td>
</tr>
<tr>
<td>2 1/2</td>
<td>106</td>
</tr>
<tr>
<td>3</td>
<td>139</td>
</tr>
<tr>
<td>3 1/2</td>
<td>168</td>
</tr>
<tr>
<td>4</td>
<td>197</td>
</tr>
<tr>
<td>5</td>
<td>268</td>
</tr>
<tr>
<td>6</td>
<td>348</td>
</tr>
</tbody>
</table>

163. **PVC is a nonmagnetic conduit,** and being nonmetallic, it provides less voltage drop and fewer reactance losses than are possible with metallic conduits with corresponding conductors used on ac circuits.

164. **Other types of rigid nonmetallic conduits,** such as thin-wall PVC, fiber, asbestos cement, soapstone, fiberglass epoxy, and high-density polyethylene, are designed solely for use in underground work. At one time they were recognized in the NEC for underground use, but today all conduit wiring methods must be listed, and the only other methods recognized are high-density polyethylene (Type HDPE, Sec. 21) and its sister with preinstalled conductors (Type NUCC, Sec. 22) for strictly underground use, and reinforced thermosetting resin conduit (Type RTRC, Sec. 23) that can be used above and below grade. These conduits and installation procedures, where used underground, are described in the underground-wiring sections of Div. 8. For systems of 600 V or less all types of rigid nonmetallic conduits must be 450 mm (18 in.) below the surface if buried directly in earth. Lesser depths 300 mm (12 in.) are permitted if the conduit is run below 50 mm (2 in.) of concrete. Refer to Part II of Article 300 in the NEC for minimum burial depths for high voltages.

165. **Conduits emerging from grade have special rules.** In addition to accommodating expansion and contraction due to heating and cooling, the wiring must accommodate ground movement, whether upthrust due to frost, or downward pressure due to ground settlement. Generally an expansion fitting as shown in Fig. 9.72 will do the job nicely. In addition, where direct burial conductors enter a riser from below grade, they should have an “S” loop arranged at the entry point so ground movement will not disturb the conductors where they arrive at the upper end of the riser and terminate.

Although the usual wiring method for these transitions is PVC conduit, it is important to note that ground movement affects all raceways equally, and a steel conduit pushed past concentric knockouts and through the bottom of a meter socket through frost action could be even more dangerous than a nonmetallic wiring method. The rules only relate to the potential for ground movement, and not temperature variations. Therefore these rules [NEC 300.5(J)] apply equally to both metallic and nonmetallic conduits in such locations.
FLEXIBLE-METAL-CONDUIT WIRING

166. Flexible metal conduit can be used for many kinds of wiring, being in some cases preferable to rigid conduit (see Fig. 9.73). Its installation is much easier and quicker than the installation of rigid conduit, the latter coming in short pipe lengths, whereas flexible conduit may be had in lengths of 25 to 250 ft (7.6 to 76.2 m), depending on the size of the conduit. The rules governing the insulation on the wires are the same as for rigid conduit: outlet or switch boxes must be installed at all outlets or switches, and the conduit must be continuous from outlet to outlet and be securely fastened to the boxes.

Flexible metal conduit shall not be used (1) in wet locations; (2) in hoistways, except as provided in Sec. 620.21(A)(1) of the NEC; (3) in storage-battery rooms; (4) in any hazardous location, except as permitted by the hazardous location Code articles; (5) where exposed to oil, gasoline, or other materials having a deteriorating effect on the installed conductors; (6) underground or embedded in poured concrete or aggregate or where subject to physical damage.

Flexible metal conduit consists of a single strip of aluminum or galvanized steel, spirally wound on itself and interlocked so as to provide a round cross section of high mechanical strength and great flexibility. Its flexibility together with the continuous length procurable makes its use practicable when rigid conduit would be out of the question. For this reason it can be employed to advantage in finished frame buildings in place of the other forms of wiring so largely employed in these structures. The conduit is easily fished and requires no elbow fittings. These can be made with the conduit itself, but care should be exercised in properly fastening the conduit at elbows (Fig. 9.74). There are on the market fittings whereby changes from other forms of wiring can be easily made to flexible-conduit wiring. Iron plates should be used to protect the conduit from nails where it passes through slots in floor beams or studding.

167. Standard Sizes of Flexible Steel Conduit

<table>
<thead>
<tr>
<th>B, nominal inside diameter, in</th>
<th>A, minimum OD, in</th>
<th>Bending radius in</th>
<th>Approximate ft per coil</th>
<th>Minimum weight, lb/1000 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/16</td>
<td>0.470</td>
<td>1/4</td>
<td>250</td>
<td>150</td>
</tr>
<tr>
<td>3/8</td>
<td>0.560</td>
<td>2</td>
<td>250</td>
<td>255</td>
</tr>
<tr>
<td>1/2</td>
<td>0.860</td>
<td>3</td>
<td>100</td>
<td>470</td>
</tr>
<tr>
<td>3/4</td>
<td>1.045</td>
<td>4</td>
<td>100</td>
<td>595</td>
</tr>
<tr>
<td>1</td>
<td>1.300</td>
<td>5</td>
<td>50</td>
<td>1020</td>
</tr>
<tr>
<td>11/16</td>
<td>1.550</td>
<td>6/16</td>
<td>50</td>
<td>1250</td>
</tr>
<tr>
<td>11/2</td>
<td>1.850</td>
<td>7/12</td>
<td>25</td>
<td>1625</td>
</tr>
<tr>
<td>2</td>
<td>2.350</td>
<td>10</td>
<td>25</td>
<td>2125</td>
</tr>
<tr>
<td>21/2</td>
<td>2.860</td>
<td>12/12</td>
<td>25</td>
<td>2630</td>
</tr>
<tr>
<td>3</td>
<td>3.360</td>
<td>15</td>
<td>25</td>
<td>3130</td>
</tr>
<tr>
<td>31/2</td>
<td>3.860</td>
<td>17/12</td>
<td>25</td>
<td>3220</td>
</tr>
<tr>
<td>4</td>
<td>4.360</td>
<td>20</td>
<td>25</td>
<td>3740</td>
</tr>
</tbody>
</table>
168. **Installation of flexible metal conduit.** If exposed, flexible metal conduit can be fastened to the surface with single-hole or two-hole straps (Figs. 9.40 and 9.41). The conduit must be secured at intervals not exceeding 1.4 m (4 1/2 ft) and within 300 mm (12 in.) from every outlet box or fitting except 900 mm (3 ft) lengths at terminals where flexibility is required, and 1.8 m (6 ft) lengths from a fixture terminal connection for tap connections to a lighting fixture. If concealed, the conduit can be fished into place just as any concealed conductors are fished in. In making bends, care must be exercised that the conduit is not damaged.

169. **The number and size of conductors to be installed in flexible metal conduits** is governed, as in the case of all tubular raceways, by Table 1 of Chap. 9 of the NEC. For metric designator 12 (trade size 3/8) conduit, NEC Table 348.22 has a separate wire fill table for this size conduit.

170. **The minimum size of flexible conduit** that is allowed by the NEC is metric designator 16 (trade size 1/2), except for metric designator 12 (trade size 3/8) as allowed by the Code for limited motor wiring, or for a connection which is not over 1.8 m (6 ft) in length, for taps to luminaires (lighting fixtures), or for utilization equipment, or for manufactured wiring systems, or for listed assembly of wired luminaire (lighting fixture) sections or in hoistways.

171. **Flexible metal conduit is joined** with couplings as illustrated in Fig. 9.75. Short lengths can be coupled to longer pieces with the clamp of I and waste thereby be prevented. The clamp at II is used for coupling rigid to flexible conduit.

![FIGURE 9.75 Couplings for flexible steel conduit.](image)

172. **When elbows are formed in flexible conduit,** some provision must be made to prevent the conduit from straightening out and thereby preventing the withdrawal of the conductors. Pipe straps can be used in some cases, and in others an elbow clamp (Fig. 9.73) can be applied.

173. **Flexible metal conduit can be connected into steel boxes** with the connector illustrated in Fig. 9.76. It is clamped to the armor with a bolt which provides a connection between armor and steel box. Figure 9.77 shows flexible metal conduit connected into an outlet box.

174. **To cut flexible metal conduit** a fine hacksaw should be used. Special vises have a slot across their jaws to guide the saw blade, the conduit being held between grooves in the jaws. Always cut flexible conduit straight across to ensure a proper fit into connectors.
175. For reaming flexible metal conduit a special reamer (Fig. 9.78) has been made, but inasmuch as the burr resulting from the hacksaw cut is very small, it can be readily removed with a three-cornered scraper made from a three-cornered file, or it can be removed with an ordinary file. The reamer illustrated is for conduit with a diameter of 1\(\frac{1}{4}\) in. or less.

176. Fish plugs for pulling in flexible conduit (Fig. 9.79) are furnished by the conduit manufacturer for \(\frac{5}{16}\)-, \(\frac{1}{2}\)-, and \(\frac{3}{4}\)-in flexible conduit. After the conduit has been cut off square in a vise with a hacksaw, the fish plug is screwed into the tube and the fish or drawing-in wire attached to the plug for pulling in.

177. Pulling in conductors. Conductors are pulled into flexible conduits in much the same manner as in rigid conduits (refer to Sec. 122) with fish tapes or similar pulling means. It should be emphasized that the number of bends in any one run of flexible conduit should never exceed the equivalent of four quarter bends (360\(^\circ\)), and preferably there should not be more than two quarter bends in a run. A fish tape which is to be inserted into a flexible conduit to pull in conductors should contain a ball or oval end instead of a hook.
A rounded tip permits the tape to be inserted without hanging onto convolutions of the flexible conduit.

**178. Flexible metal conduit and fittings** cannot generally be used as a grounding means. The only acceptable applications where they are so recognized is where all of the following conditions are met:

1. No enclosed conductor has overcurrent protection above 20 A.
2. The total length of the all flexible metal conduits, either ordinary flexible metal conduit or liquidtight flexible metal conduit or flexible metallic tubing or one or more of them together, in any equipment grounding return path must not exceed 1.8 m (6 ft).
3. The flexible metal conduit must not be subject to movement after the installation process is complete, such as for vibration isolation or for connections to a swinging sign, etc.

**LIQUIDTIGHT FLEXIBLE-METAL-CONDUIT WIRING**

**179. Liquidtight flexible metal conduit** is similar to regular flexible metal conduit, except that it is covered with a liquidtight plastic sheath (Fig. 9.80). It is not intended for general-purpose wiring but has definite advantages in many cases for the wiring of machines and portable equipment. Its use is restricted by the NEC as follows:

1. It is allowed in exposed or concealed locations where conditions of installation, operation, or maintenance require flexibility or protection from liquids, vapors, or solids. It is permitted for direct burial where listed and marked for the purpose.
2. Its use is not allowed (a) when subject to physical damage; (b) under any combination of ambient and conductor temperature conditions such that its operating temperature exceeds the rating of the material; and (c) in any hazardous location except as expressly permitted in the relevant Code articles.

Care must be exercised in its installation to employ only suitable terminal fittings that are approved for the purpose. Liquidtight flexible metal conduit in metric designators 41 (trade sizes 1 1/2 in.) and larger shall be bonded in accordance with Sec. 250.118 of the NEC. Metric designator 35 (trade sizes of 1 1/4 in.) and smaller are suitable for grounding in any ground return path of 1.8 m (6 ft) or less if metric designators 12 and 16 (trade sizes 3/8 and 1/2) are protected at 20 A or less, and 60 A or less for metric designators 21 through 35 (trade sizes 3/4 in through 1 1/4) and the fittings are listed for grounding.

The Code specifies that the maximum size used must not be larger than the metric designator 103 (4 trade size).
### Table 180. Dimensions of Liquidtight Flexible Metal Conduit

<table>
<thead>
<tr>
<th>Metric designator, conduit</th>
<th>Actual</th>
<th>ID, in</th>
<th>OD, in</th>
<th>Metric designator, conduit</th>
<th>Actual</th>
<th>ID, in</th>
<th>OD, in</th>
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<td>Maximum</td>
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<tr>
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</tr>
</tbody>
</table>

### 181. Conductor size.

The NEC specifies that the maximum number of conductors installed in liquidtight flexible metal conduit is governed, as in the case of all tubular raceways, by Table 1 of Chap. 9 of the NEC. For metric designator 12 (trade size 1/4) conduit, NEC Table 348.22 controls the wire fill for this size conduit.

### METAL-CLAD–CABLE WIRING: TYPES AC AND MC

**182. Type AC cable** is a fabricated assembly of insulated conductors in a flexible metallic enclosure.

**183. Type AC cables** (generally referred to as *armored cable*) are branch-circuit and feeder cables with armor or flexible metal tape (Fig. 9.81). Cables of the AC type must have an internal bonding strip of copper or aluminum in intimate contact with the armor for its entire length. Most manufacturers use a flat aluminum ribbon as the bonding strip. At terminations, the bond wire is simply folded back without connection to the enclosure or other such conductors. Being in intimate contact with the metal armor, the bond wire is intended to reduce the overall impedance of the cable armor during the performance of its electrical function as an equipment grounding return path. For cables of the AC type, insulated conductors must be one of the types listed in NEC Table 310.13(A). In addition, the conductors must have an overall moisture-resistant and fire-retardant fibrous covering. For ACT (thermoplastic conductors), a moisture-resistant fibrous covering is required only on the individual conductors.

When not subject to physical damage, Type AC cable may be installed in both exposed and concealed work. Type AC cable may be used in dry locations and may be embedded in...
plaster finish on brick or other masonry, except in damp or wet locations. It is permitted to
be fished in air voids or masonry block or tile walls where such walls are not exposed or
subject to excessive moisture or dampness. It must not be used where subject to corrosive
fumes or vapors, or in any wet locations, including direct burial in the earth.

184. **Manipulating Type AC cable.** Type AC cable must never be spliced except at
outlets. Many methods of fastening cable in outlet boxes are in vogue. Clamps or box con-
nectors can be used. Outlet and switch boxes containing internal cable clamps designed for
this wiring can be used. Special cutters are available. Type AC cable must not be bent more
sharply than a radius of five times the outer diameter of the cable, with the radius measured
to the inner side of the bend.

185. **For cutting the cable to length,** a shear, bolt cutter, or hacksaw can be used.
At each outlet or junction box the armor must also be cut back about 8 in. (203.2 mm) in
order to leave sufficient free ends of wire for splicing. This cutting is done with a hacksaw
held so as to cut across the armor at an angle of about 60° with the axis of the cable. Great
care must be taken not to cut into the insulation on the conductors.

Seatek Co., has developed a Flex Splitter rotary tool (Fig. 9.82) that is far superior for
cutting Type AC cable. An adjustment knob varies the depth of the cut and a rotary crank
easily cuts the sheath.

![Figure 9.82](image)

**FIGURE 9.82** Method of cutting armor back from the end of cable. [Seatek
Co., Inc.]

186. **The wires at the ends of Type AC cable** should be protected by fiber bush-
ings. The fiber bushings employed for this purpose are called *antishort insulating bushings*
(Fig. 9.83). The split bushing is pinched together and slipped over the wires inside the
armor, as illustrated in Fig. 9.84. It protects the insulation of the wires from the rough edges
of the cut ends of the armor.
187. **For fastening Type AC cable to outlet boxes** a connector (Fig. 9.85) can be slipped over the end of the cable. The setscrew is tightened down against the armor. The threaded end of the connector slips into standard conduit knockouts, and the locknut is then put on, holding the connector tight to the box. Another method is to use outlet boxes of the type shown in Fig. 9.86, which contain built in cable clamps in which the clamp tightens down against the armor and holds it firmly in place.

188. **Type AC cable for old-building wiring.** Type AC cable can be used to great advantage in this work. It can be run with almost utter disregard of its contact with pipes or other materials and can be fished for long distances. Its own weight is sufficient to carry it down partitions, and it is stiff enough to fish between joists without the use of a fish wire. It or nonmetallic-sheathed cable can also be installed more quickly and with less cutting of walls, floors, etc., than can wires in flexible tubing.

189. **The loop system of wiring** is nearly always used for concealed work in order to avoid the use of junction boxes. The cables loop from one outlet to the next outlet, and splices are made only at outlet boxes. All splices must be accessible for inspection, and if a junction box is used, the cover must be left accessible.

190. **Supports.** Type AC cable must be secured by approved staples, straps, hangers, or similar fittings so designed and installed as not to injure the cable. The cable may be installed on the underside of floor joists in basements when it is supported at each joist and is so located as not to be subject to physical damage. The cable must be secured within
300 mm (12 in.) of every terminating location. This means it must be prevented from movement through the use of a staple or clip. This is different from elsewhere in the run, where mere support is required. For example, it is permitted to entrain the cable through holes in studs or joists, as long as a staple, clip, or equal is set within a foot of terminations. However, when it is run through an accessible ceiling, the last 1.8 m (6 ft) prior to a termination is permitted without additional securement. The cables must be supported not less than every 1.4 m (4 1/2 ft) in the middle of the run in all other locations.

191. Through studs, joists, and rafters. Type AC cable can be run through bored holes in studs, joists, or rafters. The holes must be bored at the approximate centers of the wood members or at least 32 mm (1 1/4 in.) from the nearest edge when practical. If there is no objection because of weakening of the structure, the Code will allow the cable to be laid in notches in the studding or joists, provided that the cable is protected against the driving of nails into it by having the notch covered with a steel plate at least 1.6 mm (1/16 in.) thick (or thinner if so listed) before the building finish is applied.

Type AC or MC cables installed in other than vertical runs through bored or punched holes in wood or metal framing members, or through notches in wooden framing members and protected by a steel plate at least 1.6 mm (1/16 in.) thick, shall be considered supported and secured where such support does not exceed 1.4 m (4 1/2 ft).

192. In accessible attics. Type AC and MC cables in accessible attics shall be installed as follows:

1. If run across the top of floor joists, or within 2.1 m (7 ft) of the floor or floor joists across the face of rafters or studs, in attics or roof spaces which are accessible, the cable shall be protected by substantial guard strips which are at least as high as the cable. If this space is not accessible by permanent stairs or ladders, protection will be required only within 1.8 m (6 ft) of the nearest edge of the scuttle hole or attic entrance.

2. If cable is carried along the sides of rafters, studs, or floor joists, neither guard strips nor running boards shall be required.

193. Ampacity. Where run in thermal insulation, the cable construction must employ conductors rated for 90°C, but the usable ampacity is to be taken under the 60°C column in NEC Table 310.16. This accommodates the deleterious effect that thermal insulation has on the ability of electrical conductors to dissipate heat developed during operating conditions. Refer to the coverage on this topic under “interior wiring with service-entrance cable” for more information on this subject.

194. Type MC cables are power and control cables (Fig. 9.87) limited in size to conductors not smaller than No. 18 AWG and larger for copper and No. 12 AWG and larger for aluminum. The metal enclosure shall be either a smooth metallic sheath, corrugated metallic sheath, or interlocking metal tape armor. Supplemental protection of an outer covering of corrosion-resistant
material must be provided when such protection is required by Sec. 300.6 of the NEC. The cables must provide an adequate path for grounding purposes, either over their armor or by incorporating one or more additional grounding conductors within the assembly. For cables of the MC type, insulated conductors must be of a type listed in NEC Table 310.13(A), and 18 and 16 AWG may employ a fixture-wire insulation.

Except as otherwise specified in the Code and where not subject to physical damage, circuits, services, or feeders in both concealed and exposed work as follows.

The cable may be used in partially protected areas, as in cable trays and the like, in dry locations; and when any of the following conditions are met, it may be used in wet locations:

1. The metallic covering is impervious to moisture.
2. A lead sheath or moisture-impervious jacket is provided under the metal covering.
3. The insulated conductors under the metallic covering are approved for use in wet locations and a corrosion-resistant jacket is provided over the metallic armor. If identified for the use, Type MC cable may be directly buried (Fig. 9.88).

![FIGURE 9.88](image)

**FIGURE 9.88** Interlocking-armor Type MC cable in smaller branch-circuit sizes. The upper cable has an outer nonmetallic jacket that is suitable for direct burial, and is so marked.

195. **Type MC cable connectors require care in selection.** At all points where Type MC cable terminates, suitable fittings designed for use with the particular wiring cable and the conditions of service must be used (see Fig. 9.89). For Type MC cable, this requires great attention to detail. For example, the armor of interlocking armor MC cable is thinner than the corresponding armor for Type AC cable, and in general a single-screw clamp of the type shown in Fig. 9.85 will not be listed for such thinner armor. Acceptable designs use wraparound clamps as in Fig. 9.89, or some form of two-screw saddle or double-grip fastener will be used in order to properly distribute the pullout forces, in accordance with listings. In addition, connectors will be listed in reference to specific cable diameters and styles, or numbers of conductors. Because these markings are so complex, the information cannot be marked on the connector, and is permitted to be shown on the smallest unit carton.

![FIGURE 9.89](image)

**FIGURE 9.89** Connectors for Type MC cables.
196. **Bends.** All bends shall be so made that the cable will not be damaged; and the radius of the curve of the inner bend of any bend must not be less than 7 times the diameter of Type MC cable with an interlocked or corrugated sheath, and 10 times the diameter of a smooth sheath of a size not more than 19 mm (7/8 in.), 12 times the diameter for cables larger than 19 mm (7/8 in.) but not more than 38 mm (1 1/2 in.), and 15 times the diameter for cables more than 38 mm (1 1/2 in.) in diameter. For shielded conductors, as are routinely used in medium voltage work, the inner radius must be at least 12 times the overall diameter of an individual shielded conductor or 7 times the overall diameter of a multiconductor cable, whichever is greater. Type AC cable carries a minimum bending radius of five times the cable diameter, also measured to the inner radius of the cable assembly.

197. **Equipment grounding.** In general, interlocking-armor type MC cables require equipment grounding conductors as part of the cable assembly. Larger cables often have this conductor subdivided into three or more segments. Smooth-type and corrugated-type MC cables usually have enough metal in a sheath that is not wound in convolutions so the armor can serve as an equipment grounding conductor. Figure 9.90 shows two such examples. Although the upper cable appears to have an interlocking tape armor, it is actually a continuous tube merely formed in a way that superficially resembles an interlocking metal tape. It does, however, contain a full-sized green-insulated conductor. This feature allows it to be used in patient-care areas of health care facilities, which require both the outer margin of the wiring method and an incorporated conductor to qualify for equipment grounding.

There is a new form of interlocking-armor Type MC cable on the market that has a full-sized bare aluminum equipment grounding conductor run outside of the Mylar sheath that is placed over the circuit conductors, such that it is in constant contact with the aluminum cable armor. In this it is comparable to the bonding strip in Type AC cable. This cable does not need to have this conductor brought into an enclosure for terminations, also like Type AC cable. However, some enclosures such as panelboards and other cabinets equipped with concentric knockouts may not qualify for equipment grounding continuity, particularly for circuits operating over 250 V to ground. In such cases, instead of being cut off, the bare aluminum wire is carried into the enclosure and terminated in the same location as the green wire in conventional interlocking-armor Type MC cables.

**FIGURE 9.90** Corrugated Type MC cable comes in several configurations. Both these cables have an outer armor that is fully qualified as an equipment grounding return path; however, the upper cable has an additional grounding conductor for other reasons.
SURFACE-RACEWAY WIRING

198. **Wiring in surface metal raceway** can be used for exposed work for branch-circuit or feeder conductors. It may be installed in dry locations. It shall not be used (1) where concealed except under raised floors of information technology equipment; (2) when subject to severe physical damage unless approved for the purpose; (3) when the voltage is 300 V or more between conductors unless the metal has a thickness of not less than 1.02 mm (0.040 in.); (4) when subject to corrosive vapors; (5) in hoistways; or (6) in any hazardous location, except as expressly permitted in those specialized articles. The number of conductors installed in any raceway shall be no greater than the number for which the raceway is designed. Metal raceway must be continuous from outlet to outlet, junction box, or approved fittings designed especially for use with metal raceway. All outlets must be provided with approved terminal fittings which will protect the insulation of conductors from abrasion unless such protection is afforded by the construction of the boxes or fittings. Metal raceway should not be used in damp places.

When combination raceways are used for the installation of signal, power, and lighting circuits, each system shall be run in a separate compartment of the raceway.

Raceways may be extended through dry walls, dry partitions, and dry floors if in unbroken lengths where passing through, and provided access to the conductors is maintained on both sides of the partition.

199. **Surface nonmetallic raceway** is intended as a raceway for baseboard receptacles and other circuit supplies. It also serves a dual function as an attractive baseboard trim and replaces conventional baseboards.

Basically, the baseboard system contains a plastic backplate which is secured directly to the wall. Where receptacles are to be located, a metal bracket is attached through the backplate into the wall with wood screws or other fastening devices. Wires are then pulled in, and receptacles are mounted in place and wired. The wires are held in place along the raceway by a retaining clip strip, which is fastened to the wall of the raceway about every 1.5 m (5 ft). This holds the wiring in place. Finally, the external baseboard cover and receptacle cover are snapped into place. Covers over receptacles are doubly anchored by means of a flange and a 6-32 screw into the outlet body.

The material used in this system is the same as is used with rigid PVC conduit. End caps and inside or outside corners are available. One side of each of these fittings is cemented to the baseboard cover.

National Electric Code rules state that surface nonmetallic raceway and fittings must be of suitable nonmetallic material which is resistant to moisture and chemical atmospheres. It must also be flame-retardant and resistant to impact and crushing, distortion due to heat under conditions likely to be encountered in service, and resistant to low-temperature effects.

Surface nonmetallic raceways may be installed in dry locations. They must not be used (1) when concealed, (2) when subject to severe physical damage, (3) when the voltage is 300 V or more between conductors unless listed for higher voltage, (4) in hoistways, (5) in any hazardous location, except as permitted by the applicable specialized code articles, (6) when subject to ambient temperatures exceeding the listing, or (7) for conductors whose insulation exceeds those for which the nonmetallic raceway is listed.

Other Code rules such as the number and size of conductors are the same as for surface metal raceways.

200. **Wiremold metal raceways** are made in three general types by the Wiremold Co. These types are designated as (1) Wiremold surface raceway, used for general surface-raceway wiring systems; (2) Pancake overfloor raceway, used for overfloor surface-raceway wiring;
and (3) Plugmold raceway, used primarily for multioutlet-assemblies wiring (see Sec. 303). Plugmold can be used without receptacles as a general high-capacity surface-wiring raceway. The Wiremold surface raceway is a unit assembly, while the other two types consist of two separable parts, the base and the cover. (See Figs. 9.91 and 9.92.)

FIGURE 9.91  A flat 90° turn.

FIGURE 9.92  Inside 90° turn; outside turns are comparable.
The appearance and dimensions of the different types and sizes are shown in Fig. 9.93. The wire capacities are given in Secs. 201 to 204 inclusive. Wiremold No. 2000 is made in 5-ft (1.5-m) lengths. The standard length for the other types is 10 ft (3.05 m), although some types are available also in 5-ft lengths.

**FIGURE 9.93** Types and dimensions of Wiremold raceways. [The Wiremold Co.]
Wiremold surface metal raceway consists of a metal capping with its edges crimped over a slightly curved base. The capping is crimped on the base at the factory so that capping and base are installed as a unit. The wires are pulled through the raceway from fitting to fitting in a manner similar to that employed in conduit work. The lengths are fastened together with a coupling (Fig. 9.94, I), which is fastened to the wall surface with a wood screw or toggle bolt. The base of the raceway is slipped under the end of the coupling before the screw or bolt is drawn up tight. A connection cover (Fig. 9.94, II) snaps over the ends of the raceway, closing the joint. Each section of raceway is secured at one or two intermediate points between the couplings by means of either one- or two-hole straps (Fig. 9.94, III and IV) screwed or bolted to the wall surface. The fittings and capping of Wiremold were traditionally finished in a neutral brown tint which blended well with most surroundings. Although that color is still available, it is now usually shipped in an off-white or ivory color that is more popular. The larger profiles (such as 4000 and 6000), formerly only available in an industrial shade of gray, are now also routinely available in the same off-white or ivory color. The base of the raceway and the baseplates of all fittings are given a special zinc treatment to prevent corrosion.

Pancake overfloor raceway consists of two steel parts, a base and a cover. The parts have a natural galvanized finish. When this raceway is installed, the base is fastened to the floor by the appropriate means of wood screws, expansion shields, toggle bolts, etc. The conductors are then laid flat in the base of the raceway. After the connections have been completed, the cover is snapped in place over the base.

Plugmold raceway consists of two steel parts, a channel base and a snap-on cover. Both base and cover are available in the standard brown Wiremold finish or in a gray finish. When this raceway is installed, the channel base is fastened to the supporting structure with the appropriate means. The conductors are laid in the channel base, the necessary connections made, and the installation completed by snapping the cover over the base.

A very complete line of fittings, outlets, and receptacles is available for the different Wiremold raceways to meet the varied needs of installation.
201. Wire Capacities for Nos. 500 to 3000 Wiremold Raceways
(For not more than the number of wires of sizes and types indicated when no wiring devices are mounted on or in raceway)

<table>
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<th>Catalog numbers</th>
<th>Wire size</th>
<th>Cross-sectional area, in²</th>
<th>Types</th>
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202. Wire Capacities for Nos. 1500 and 2600 Overfloor Wiremold
(For use on floors in dry locations not subject to excessive mopping or scrubbing; raceway to be used with not more than the number of wires of sizes and types indicated)

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203. Wire Capacities for Wiremold Nos. 2000 to 3000 Plugmold, with Devices

(For use with Wiremold attachment-plug receptacles designed for mounting in raceway; raceway to be used with not more than the number of wires of sizes and types indicated)

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<th>Catalog No. 2400 wire capacity, undivided</th>
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</thead>
<tbody>
<tr>
<td>Type of wire</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>With receptacles</td>
</tr>
<tr>
<td>Without devices</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Catalog No. 2400 wire capacity, divided,* 2/3 (1/3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No devices</td>
</tr>
</tbody>
</table>

*Raceway is available permanently divided by the manufacturer, with the divider permanently located 1/3 of the way across.

<table>
<thead>
<tr>
<th>Catalog No. 2100 wire capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types THHN/THWN</td>
</tr>
<tr>
<td>Device no.</td>
</tr>
<tr>
<td>No. 10</td>
</tr>
<tr>
<td>2126</td>
</tr>
<tr>
<td>2127GA</td>
</tr>
<tr>
<td>2127GT</td>
</tr>
<tr>
<td>IG2127GT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Catalog No. G-3000 wire capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of wire</td>
</tr>
<tr>
<td>Wire types</td>
</tr>
<tr>
<td>With duplex receptacles</td>
</tr>
<tr>
<td>With surge/GFCI devices</td>
</tr>
<tr>
<td>Large single receptacles</td>
</tr>
</tbody>
</table>
204. Wire Capacities for Nos. 4000 and 6000 Wiremold Raceways

(For use with not more than the number of wires of sizes and types indicated)

**NOTE** For undivided 4000 and both divided and undivided 6000 Wiremold [i.e., where the raceway cross-sectional area exceeds 2500 mm² (4.0 in²), derating for multiple current-carrying conductors in a common raceway may be avoided if the number of current-carrying conductors does not exceed 30 and the wire fill does not exceed 20 percent, or ½ of the number shown in the wire fill columns, which have been calculated based on the usual 40 percent fill.]

<table>
<thead>
<tr>
<th>Catalog No. G-4000 wire capacities, THHN/THWN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single-conductor</strong></td>
</tr>
<tr>
<td><strong>Without devices</strong></td>
</tr>
<tr>
<td><strong>With devices</strong></td>
</tr>
<tr>
<td><strong>Device types</strong></td>
</tr>
<tr>
<td><strong>No.</strong></td>
</tr>
<tr>
<td><strong>With divider:</strong></td>
</tr>
<tr>
<td>Power compartment only:</td>
</tr>
<tr>
<td>NO DEVICES</td>
</tr>
<tr>
<td>Duplex receptacles</td>
</tr>
<tr>
<td>Surge/GFCI devices</td>
</tr>
<tr>
<td>Large single recept.</td>
</tr>
<tr>
<td><strong>Without divider:</strong></td>
</tr>
<tr>
<td>NO DEVICES</td>
</tr>
<tr>
<td>Duplex receptacles</td>
</tr>
<tr>
<td>Surge/GFCI devices</td>
</tr>
<tr>
<td>Large single recept.</td>
</tr>
<tr>
<td><strong>Communications and signal wiring, with divider</strong></td>
</tr>
<tr>
<td><strong>Number of cables at 40% fill</strong></td>
</tr>
<tr>
<td><strong>2-Pair</strong></td>
</tr>
<tr>
<td>Telephone cable</td>
</tr>
<tr>
<td>Optical fiber</td>
</tr>
<tr>
<td>Unshielded twisted pair</td>
</tr>
<tr>
<td>Coaxial</td>
</tr>
<tr>
<td>90</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>27</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>28</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>24</td>
</tr>
<tr>
<td><strong>Communications and signal wiring, without divider</strong></td>
</tr>
<tr>
<td><strong>Telephone cable</strong></td>
</tr>
<tr>
<td>Optical fiber</td>
</tr>
<tr>
<td>Unshielded twisted pair</td>
</tr>
<tr>
<td>Coaxial</td>
</tr>
<tr>
<td>187</td>
</tr>
<tr>
<td>21</td>
</tr>
<tr>
<td>55</td>
</tr>
<tr>
<td>83</td>
</tr>
<tr>
<td>58</td>
</tr>
<tr>
<td>62</td>
</tr>
<tr>
<td>50</td>
</tr>
</tbody>
</table>

**Note:** Other configurations have been evaluated. Refer to manufacturer’s literature.
### Catalog No. G-6000 wire capacities, THHN/THWN

<table>
<thead>
<tr>
<th>Device types</th>
<th>No. 2</th>
<th>No. 3</th>
<th>No. 4</th>
<th>No. 6</th>
<th>No. 8</th>
<th>No. 10</th>
<th>No. 12</th>
<th>No. 14</th>
<th>With divider:</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO DEVICES</td>
<td>24</td>
<td>29</td>
<td>34</td>
<td>56</td>
<td>78</td>
<td>136</td>
<td>216</td>
<td>296</td>
<td></td>
</tr>
<tr>
<td>Surge/GFCI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large single</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duplex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receptacles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without divider:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO DEVICES</td>
<td>55</td>
<td>65</td>
<td>77</td>
<td>126</td>
<td>174</td>
<td>303</td>
<td>481</td>
<td>659</td>
<td></td>
</tr>
<tr>
<td>Surge/GFCI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large single</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duplex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receptacles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Additional ratings exist for even larger conductors provided no devices are installed, for undivided and (divided) raceways, as follows:

- 1 AWG, 40 (18); 1/0 AWG, 34 (15); and 2/0 AWG, 28 (12).

### Communications and signal wiring, with divider

<table>
<thead>
<tr>
<th>Number of cables at 40% fill</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Pair</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Telephone cable</td>
</tr>
<tr>
<td>Optical fiber</td>
</tr>
<tr>
<td>Unshielded twisted pair</td>
</tr>
<tr>
<td>Coaxial</td>
</tr>
</tbody>
</table>

### Communications and signal wiring, without divider

<table>
<thead>
<tr>
<th>Number of cables at 40% fill</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Pair</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Telephone cable</td>
</tr>
<tr>
<td>Optical fiber</td>
</tr>
<tr>
<td>Unshielded twisted pair</td>
</tr>
<tr>
<td>Coaxial</td>
</tr>
</tbody>
</table>

**Note:** Other configurations have been evaluated. Refer to manufacturer’s literature.
205. Cross-Sectional Areas of Wiremold Raceways

<table>
<thead>
<tr>
<th>Raceway</th>
<th>Area, in²</th>
<th>Raceway</th>
<th>Area, in²</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>0.19</td>
<td>2600</td>
<td>.72</td>
</tr>
<tr>
<td>700</td>
<td>0.26</td>
<td>G-3000</td>
<td>3.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G-4000</td>
<td>7.20 (undivided)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.50 (each compartment when raceway is divided)</td>
</tr>
<tr>
<td>1500</td>
<td>0.22</td>
<td>G-6000</td>
<td>15.82</td>
</tr>
<tr>
<td>2000</td>
<td>0.80</td>
<td></td>
<td>7.20 (each compartment when raceway is divided)</td>
</tr>
<tr>
<td>2100</td>
<td>0.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2400</td>
<td>1.39</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ELECTRICAL-METALLIC-TUBING WIRING**

206. Wiring employing electrical metallic tubing (EMT) is widely used for commercial and industrial wiring systems. The NEC allows the installation of EMT, either concealed or exposed, when either during construction or afterward it will not be subject to severe physical damage. Electrical metallic tubing may be supported in buildings of fire-resistive construction on the face of masonry or other material of which walls or ceilings are composed. It may then be buried in concrete or plaster finish. Connections between lengths of tubing and between tubing and any fitting shall provide adequate mechanical strength and electrical continuity.

In installations having cinder concrete or fill, EMT must be protected on all sides by a layer of noncinder concrete at least 50 mm (2 in.) thick unless the tubing is at least 450 mm (18 in.) under the fill. In general, EMT should not be used for direct burial applications because of limitations in its listing. If directly buried in earth, it generally requires additional corrosion protection applied over and above the galvanizing. Although asphalt paint or something comparable might be used for this purpose, it should be noted that testing laboratories do not recognize any specific nonmetallic supplementary coating for this purpose, which leaves it entirely in the hands of the inspector as to whether or not any particular coating will be approved.

In installations in which corrosive fumes or vapors may exist, as in meat-packing plants, tanneries, hide cellars, casing rooms, glue houses, fertilizer rooms, salt storage, some chemical works, metal refineries, pulp mills, sugar mills, roundhouses, some stables, and similar locations, EMT requires additional protection that must be approved for the corrosive exposure in question.

When installed in wet locations, such as dairies, laundries, and canneries, and in locations where the walls are frequently washed, the entire tubing system, including all its boxes and other fittings, shall be installed and equipped so as to prevent water from entering the tubing system, and the tubing shall be mounted so that there is at least a 6 mm (1/4 in.) air space between it and the wall or other supporting surface. For these installations all the supporting materials, such as straps, bolts, and screws, must be of corrosion-resistant material or be protected against corrosion by approved materials.

The rules regarding bends, minimum size, and allowable number of conductors are the same as for rigid metal conduit. The maximum allowable size of tubing is 4 in.
207. **Table 208 gives the sizes and weights of electrical metallic tubing.** Since the inside diameters are the same as those for rigid metal conduit, the same tables of number of allowable wires in a conduit apply to the tubing. The wall is thinner, however, and the outside diameters of tubing are less than those for conduit. The regular metallic tubing has a round cross section and is made of galvanized steel. However, sizes over metric designator 53 (trade size 2) have the same outside diameters as corresponding sizes of rigid metal conduit. Accordingly, the internal diameters of these larger sizes are slightly greater than those of other types of conduit.

208. **Electrical Metallic Tubing**

<table>
<thead>
<tr>
<th>Metric designator</th>
<th>Trade size</th>
<th>Approximate weight per 1,000 ft, lb</th>
<th>Diameter, in</th>
<th>Wall thickness, in</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>1/2</td>
<td>295</td>
<td>0.622</td>
<td>0.042</td>
</tr>
<tr>
<td>21</td>
<td>3/4</td>
<td>445</td>
<td>0.824</td>
<td>0.049</td>
</tr>
<tr>
<td>27</td>
<td>1</td>
<td>650</td>
<td>1.049</td>
<td>0.057</td>
</tr>
<tr>
<td>41</td>
<td>1 1/4</td>
<td>960</td>
<td>1.380</td>
<td>0.065</td>
</tr>
<tr>
<td>53</td>
<td>1 1/2</td>
<td>1,110</td>
<td>1.610</td>
<td>0.065</td>
</tr>
<tr>
<td>63</td>
<td>2</td>
<td>1,410</td>
<td>2.067</td>
<td>0.065</td>
</tr>
<tr>
<td>78</td>
<td>2 1/2</td>
<td>2,300</td>
<td>2.731</td>
<td>0.072</td>
</tr>
<tr>
<td>91</td>
<td>3</td>
<td>2,700</td>
<td>3.356</td>
<td>0.072</td>
</tr>
<tr>
<td>103</td>
<td>4</td>
<td>4,000</td>
<td>4.334</td>
<td>0.083</td>
</tr>
</tbody>
</table>

209. **All outlet boxes and fittings** for use with EMT must be of the threadless type, since owing to the thin wall it is not permissible to thread the tubing. Special threadless fittings similar to those employed for standard rigid conduit are manufactured for tubing. Standard rigid conduit fittings can be used with tubing if an adapter is employed. Sections of tubing can be joined by means of threadless couplings, which are available in steel, malleable-iron, and diecast construction. Tubing is connected to outlet boxes by means of connectors. One end of the connector is made for threadless attachment to the tubing, and the other end is threaded and supplied with a locknut for attachment to the box through a knockout. Raintight connections can be made to the tubing with some couplings and connectors. Standard 90° elbows (Fig. 9.95) are attached to the tubing by means of the above-described couplings. The dimensions of standard elbows are given in Sec. 210. Raintight elbows and angle-box connectors are available with the ends fitted with threadless fittings.

![FIGURE 9.95 Standard radius, 90° elbow.](image)
210. Standard 90° Elbows for EMT

<table>
<thead>
<tr>
<th>Metric designator of tubing</th>
<th>Trade size of tubing</th>
<th>Smallest acceptable radius $R$ to center line of tubing</th>
<th>Shortest acceptable length $L_s$ of each straight end portion of tubing</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>$\frac{1}{2}$</td>
<td>4</td>
<td>$1\frac{1}{2}$</td>
</tr>
<tr>
<td>21</td>
<td>$\frac{5}{8}$</td>
<td>4</td>
<td>$1\frac{1}{2}$</td>
</tr>
<tr>
<td>27</td>
<td>1</td>
<td>5</td>
<td>$1\frac{1}{4}$</td>
</tr>
<tr>
<td>35</td>
<td>$1\frac{1}{4}$</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>41</td>
<td>$1\frac{1}{2}$</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>53</td>
<td>2</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>63</td>
<td>$2\frac{1}{2}$</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>78</td>
<td>3</td>
<td>13</td>
<td>$3\frac{1}{3}$</td>
</tr>
<tr>
<td>103</td>
<td>4</td>
<td>16</td>
<td>$3\frac{1}{3}$</td>
</tr>
</tbody>
</table>

211. Threadless couplings and connectors for EMT are of setscrew, compression, indenter, tap-on, two-piece, or squeeze-types. Such fittings are classified as concrete-tight only, or raintight and concrete-tight. Accordingly, only fittings that are classified as being raintight can be used outdoors exposed to the weather or in wet locations. Except for indenter-type fittings, EMT couplings and connectors can be installed with common hand tools. Indenter-type fittings require a special tool, and these fittings are made only up to metric designator 27 (trade size 1).

In the past, it has been routinely assumed that any split-ring compression connector (as opposed to indenter or set-screw designs) provided a watertight connection. This has proven false, and now connectors and couplings that are in fact watertight and suitable for wet locations are marked accordingly. They usually have an inner nonmetallic gland of some sort, although one manufacturer has a solid (not split) compression ring design that requires the application of a torque wrench to a crow’s-foot end and special calculations in order to correctly seat the ring.

212. Support for EMT. The NEC requires EMT to be securely fastened in place at least every 3 m (10 ft) and within 900 mm (3 ft) of each outlet box, junction box, cabinet, or fitting. Methods of support are similar to those described for rigid metal conduit. Figure 9.96 shows the use of spring clips to secure EMT to U-channel supports. If there are no available structural support points, the permitted distance to termination points increases to 1.5 m (5 ft), just as for rigid metal conduit and intermediate metal conduit (see Sec. 106), but with one significant difference: the tubing must be unbroken. If there is a coupling near the box or conduit body, then the maximum distance remains at 900 mm (3 ft) EMT used as a pipe nipple between enclosures is also subject to the new restrictions on support in such applications; review Sec. 109 for more information.

213. Bending EMT. Bends in EMT must also be made so that the tubing will not be injured and the internal diameter of the tubing will not be effectively reduced. The radius of the curve of the inner bend or any field bend shall not be less than shown in Secs. 86 and 93. For metric designators 16 through 35 (trade sizes $\frac{1}{2}$ through $1\frac{1}{4}$) EMT, a hand bender, as shown in Fig. 9.97, I, is used. The EMT hickey shown in Fig. 9.97, II, is only for making
9.94  DIVISION NINE

INTERIOR WIRING

214. Installation methods. The techniques of installation described in the sections for rigid metal conduit will apply, in general, to EMT. Such items as junction or pull boxes, number of conductors permitted in a single raceway, and support hardware apply to both these wiring methods.

NONMETALLIC-SHEATHED–CABLE WIRING

215. Nonmetallic-sheathed cable is used for the wiring of new and old residences and for small offices and stores. For decades it was only permitted in one- and two-family dwellings or in multifamily dwellings or other structures not exceeding three floors above grade. This limitation was significantly relaxed in the 2002 NEC, as described at the
end of this section. This cable is frequently employed for extensions to existing installations and is commonly used in small apartment houses. Nonmetallic-sheathed cable can be run either exposed on ceilings and walls or concealed in hollow partitions or between floors and ceilings. It provides a reasonably safe and reliable wiring installation of low first cost. It is made in three types: Type NM, Type NMC, and Type NMS. Conductors are copper, aluminum, or copper-clad aluminum.

Types NM and NMS may be used only in normally dry locations which are free from corrosive vapors or fumes. It may be run or fished in air voids in masonry-block or tile walls where not exposed or subject to excessive moisture or dampness. Types NM and NMS must not be embedded in masonry, concrete, fill, or plaster or run in a shallow chase in masonry, concrete or adobe and covered with plaster, adobe or similar finish.

Type NMC is moisture- and corrosion-resistant, so that its use is allowed in dry, moist, damp, or corrosive locations and in outside and inside walls of masonry block or tile. If embedded in plaster or adobe or run in a shallow chase in masonry walls and covered with plaster or adobe, it shall be protected against damage from nails by a cover of corrosion-resistant coated steel at least 1.59 mm (1/16 in.) thick, or a listed alternative verified to be of equal or better hardness, under the final surface finish.

Neither Types NM and NMC, nor Type NMS is allowed to be used (1) as service-entrance cable, (2) in commercial garages, (3) in theaters and similar locations except as provided in Article 518 of the NEC, (4) in motion-picture studios, (5) in storage-battery rooms, (6) in hoistways, or on elevators or escalators, (7) in any hazardous location except as permitted by specific allowances in the hazardous location articles, or (8) embedded in poured cement, concrete, or aggregate. The cable is also not permitted to be run exposed above a suspended ceiling in other than one- or two-family dwellings. Since the definition of “exposed” in NEC Article 100 includes areas behind lift-out panels, this effectively precludes the use of this wiring method above such ceilings, even if it is firmly attached to structural members at all points.

The NFPA Standards Council made a dramatic change in the allowable uses of Type NM cable when it released the 2002 NEC. The Council agreed that Type NM cable could now be used in any building permitted to be of Types III, IV, or V construction, even if actually constructed as Type I or II, provided (for nonresidential uses) the cable is located behind the same sort of thermal barrier normally required for ENT (Sec. 27) in high-rise buildings. There is no NEC waiver for buildings with a sprinkler system; however, building codes generally permit more extensive buildings to be constructed as Type III, IV, or V if a full sprinkler system is in place. The Council action was based on the entire record before it, including NFPA fire statistics that showed no association between Type NM cable and fire prevalence, and the report of the NFPA Toxicity Advisory Committee to the effect that in a fire the contribution of Type NM cable jacketing materials is a negligible fraction of the total smoke load.

This is the first time the NEC has put building construction types at the center of a rule governing the use of a wiring method, although some rules on transformer installations include these references. Refer to Annex E, Types of Construction in the NEC for the complete descriptions. They can be roughly summarized as follows:

Type I—All structural members are noncombustible (or limited-combustible) and have fire ratings generally of 3 or 4 h (less in some cases), depending on the specific usage.

Type II—All structural members are as in Type I but the fire resistance generally drops to 2 or 1 h (less in some cases), depending on the specific usage.

Type III—All exterior bearing walls are noncombustible (or limited combustible) and have fire ratings of at least 2 h, but interior structural elements can be of approved combustible material.
Type IV—All exterior and interior bearing walls are noncombustible (or limited combustible) and interior columns, beams, girders, arches, trusses, floors, and roofs are of heavy timber construction without concealed spaces.

Type V—Buildings constructed of approved combustible material, that for some structural elements is subject to a minimum 1-h fire resistance rating.

216. Nonmetallic-sheathed cable, with grounding wires, is manufactured in two-, three-, and four-conductor cables in sizes running from 14 up to 2 AWG. (See Fig. 9.98.) Each wire is insulated with rubber or thermoplastic of the same thickness as required on single wires, except that the cable will have an approved size of covered or bare conductor for grounding purposes only. In Type NM cable the conductors have an outer flame-retardant and moisture-resistant coverings. Type NMC cable is similar in construction to Type NM cable except that it is protected by an outer covering that is flame-retardant and moisture-, fungus-, and corrosion-resistant. Type NMS cable can contain power, communications, and signaling conductors enclosed within a common sheath of moisture-resistant, flame-retardant, nonmetallic materials. Although part of the cable assembly, these other conductors must be firmly separated from the power conductors by the cable sheath, and thereby respect the system separation rules in the NEC.

![FIGURE 9.98](image)

**FIGURE 9.98** Type NM cable marked NM-B has insulation rated 90°C with a final cable ampacity that given in NEC Table 310.16 for 60°C conductors.

217. When nonmetallic-sheathed cable is installed exposed, it is supported directly on the walls or ceiling with straps or staples. The distance between supports must not be greater than 1.4 m (4 1/2 ft), and there must be a support within 300 mm (12 in.) of each outlet box or fitting. The cable must follow the surface of the wall or ceiling and not break from beam to beam. Whenever nonmetallic-sheathed cable does not follow the building finish, it must be protected from physical damage. This protection may consist of a wooden running board or metal protecting strip or a piece of conduit or EMT. It is preferable to use either conduit, especially Schedule 80 rigid PVC conduit, or EMT, especially where the cable passes through floors.

218. When nonmetallic-sheathed cable is installed concealed in new buildings, the cable is fastened to the joists or beams by means of staples. The distance between supports should not be greater than 1.4 m (4 1/2 ft). In wiring finished buildings, when it is impracticable to support the cable between outlets, it can be fished from outlet to outlet in the same manner as Type AC cable. Where the cable is run through holes bored in studs, joists, etc., no protection is required. The holes should be bored as near to the center of the timber as possible and not less than 32 mm (1 1/4 in.) from the nearest edge when practical. There are cable supports that have slots to hold the cables parallel to and away from the framing member, allowing the 32 mm (1 1/4-in.) spacing to be maintained for multiple cables even on narrow framing members. An approved method of installing nonmetallic-sheathed cable in a new building is shown in Fig. 9.99.
219. No joints or splices should be made in nonmetallic-sheathed–cable wiring except in outlet or junction boxes. This rule applies to both exposed and concealed installations. The loop system is employed generally for concealed work. The cable is looped from outlet to outlet, and the use of junction boxes is avoided.

220. Bends in cable (National Electrical Code) shall be so made and other handling shall be such that the protective coverings of the cable will not be injured, and no bend shall have a radius less than five times the diameter of the cable.

221. An approved outlet box or fitting must be provided at all outlets or switch locations. The cable must be attached to the box with some form of approved device which will substantially close the opening in the box. This connection of the cable to the box can be accomplished by means of a box with a built-in clamp, or a clamp connector (Fig. 9.100) can be employed with a box having conduit knockouts. For data on metal boxes, see Sec. 115 of Div. 4.


FIGURE 9.100 Nonmetallic-sheathed cable attached to outlet box by means of clamp connectors.
222. **NEC rules require that outlet boxes be grounded.** and most receptacles and switch yokes must be grounded as well. This means the equipment grounding wire in Type NM cable must be terminated properly so the required grounding connections can be made. This grounding wire is covered by the same 6-in (150 mm) minimum-length-of-conductor rule as the insulated conductors, and 8 in. (200 mm) is an advisable minimum length for workability. If outlet boxes with built-in clamps are employed, the required contact between the box and the grounding wire can be made by means of a small grounding clip. The connection is made by fastening the clip over the grounding wire and box (Fig. 9.101). These copper grounding clips are commonly called G clips. The wire can also be connected to the box with a ground screw that has no other function.

![Grounding clip attached to metal box.](image)

**FIGURE 9.101** Grounding clip attached to metal box. In actual practice, both the circuit conductors and the grounding conductor must not be less than 6 in. (150 mm) in length from the point where they emerge from the cable jacket, and they must be long enough to extend out of the box by at least 3 in. (75 mm). [Electrical Construction and Maintenance]

223. **Boxes of insulating material** (Fig. 4.156 of Div. 4) can be used with nonmetallic-sheathed cable instead of metal boxes. With these boxes, grounding is limited, and it is not necessary to connect each box to a grounding conductor. The boxes shown in Fig. 4.156 of Div. 4 are made of plastic. Cables shall be secured to the box except that size 2 1/4 in. by 4 in. and smaller may be fastened within 200 mm (8 in.) of the box measured along the sheath. Thin sections of material are knocked out to provide openings to bring the cable into the box. In the case of nonmetallic boxes, the bare wires are spliced together and to jumpers extending to grounding terminals on receptacles and snap switch yokes.

224. **A line of outlets for surface mounting** with exposed nonmetallic-sheathed–cable wiring is available (Fig. 9.102). They are made of porcelain or plastic; a clamp inside the case holds the cable. There are terminal screws near each end so that cables can be brought in from both ends. NEC requirements for these devices are given in Sec. 225.

225. **Devices of insulating material.** Switch, outlet, and tap devices of insulating material may be used without boxes in exposed cable wiring and for concealed work for rewiring in existing buildings when the cable is concealed and fished. Openings in such devices shall form a close fit around the outer covering of the cable, and the device shall fully enclose that part of the cable from which any part of the covering has been removed. If connections to conductors are by binding screw terminals, there shall be available as many terminals as conductors.
226. Methods of installing nonmetallic-sheathed cable in accessible attics or roof spaces are shown in Fig. 9.103. When the cable is carried across the top of floor beams or across the face of rafters within 2.1 m (7 ft) of the floor, the cable should be protected by guard strips, as shown at B. If the attic is accessible only through a scuttle hole without permanent stairs or ladders, the protection is required only within 1.8 m (6 ft) of the edge of the scuttle hole. The cable may be supported along the sides of rafters, studs, or floor joists without any additional protection, as at D.

227. Methods of installing nonmetallic-sheathed cable in unfinished cellars or basements are shown in Fig. 9.104. The cable may be run through bored holes in the floor joists and along the sides or faces of joists without any additional protection such as running boards or guard strips, as shown at A and B. When the cable is run at angles across the bottom faces of floor joists, the cable must be supported on the underside of running boards as shown in C. Assemblies containing not smaller than two No. 6 or three No. 8 conductors may be secured directly on the bottom of the joists. Cables run through or parallel to framing members or furring strips must be at least 1 1/4 in. (32 mm) from their front edges, or else protected with steel at least 1/16 in. (1 mm) thick (or listed as equivalent), or sleeved in listed conduit or tubing equipped with a bushing where the cable
enters. The cable must be secured within 12 in. (300 mm) of where it enters the raceway, and the cable jacket must remain intact through the length of the raceway and into the box not less than 1/4 in. (6 mm).

228. Special rules apply to Type NM cable ampacities. (Adapted from Practical Electrical Wiring, 20th ed., © Park Publishing, 2008, all rights reserved.) Although the individual conductors must have a 90°C temperature rating, the final allowable ampacity must not exceed that given in the 60°C column in NEC Table 310.16 (reproduced in Table 18 of Div. 12). This applies after adjustments for ambient temperature and for mutual conductor heating have been factored. Although mutual conductor heating may seem odd, you must apply this to all the conductors in a group of cables if those cables are “bundled” for longer than 24 in. This includes routing more than one cable through a succession of single bored holes; the NEC now requires the use of derating penalties if multiple cables are run together through thermal insulation. You need to consider this requirement in a basement, for example, where you might be tempted to run large numbers of cables back to the panelboard through a set of holes lined up through the floor joists and ending at the panel. The derating penalties in NEC 310.15(B)(2)(a) (see Div. 12, Sec. 17, item 5) apply to this condition, as well as to any instance in which more than two cables with two or more wires pass through a common opening in wood framing that is caulked or fire- or draft-stopped.

In addition, a special restriction (which also applies to any wiring method) prevents making use of the general permission to round up to the next higher overcurrent protective device if a branch circuit supplies multiple receptacle outlets. These two conditions mean that for any branch circuits supplying multiple receptacle outlets, if the resulting derated ampacity drops below the branch circuit size even by a single ampere, then you must separate the conductors. For example, the ampacity of 12 AWG in the 90°C column is 30 A, and for 14 AWG it is 25 A. Suppose just five 2-wire cables run through a common set of bored holes. Since the derating penalty is 50 percent, the resulting diminished ampacity condemns any 14 AWG cables on 15-A circuits, and any 12 AWG cables on 20-A circuits—the usual assumption. You could, of course, increase the wires by a cable size, but normally it is better to bore a parallel set of holes.

MINERAL-INSULATED METAL-SHEATHED–CABLE WIRING

229. Mineral-insulated metal-sheathed cable (Type MI) was developed to fill the need for an electrical cable which would have high heat and water resistance and would not be bulky or difficult to install. It provides a general wiring system which is suitable for a great variety of applications for systems with voltages up to and including 600 V. Type MI is approved for use in almost any type of installation. The NEC states that MI cable may be used for services, feeders, and branch circuits in both exposed and concealed work, in
dry or wet locations, and embedded in plaster finish on brick or other masonry. It may be used where exposed to weather or continuous moisture, for underground runs and embedded in masonry, concrete, or fill, in buildings in the course of construction or where exposed to oil, gasoline, or other conditions not having a deteriorating effect on the metal sheath. The sheath of mineral-insulated metal-sheathed cable exposed to destructive corrosive conditions, such as some types of cinder fill, must be protected by materials suitable for those conditions. In addition, MI cable is approved for installation in all hazardous locations.

Type MI cable is composed of only two materials, which are assembled as three components: the conductor, the insulation, and the outer sheath. The conductors are fabricated from high-conductivity copper. The insulation is a specially selected, highly compressed pure magnesium oxide which is processed to maintain permanently the excellent electrical characteristics inherent in this material. The sheath is a round, seamless copper or steel tube which provides the requirements of heat and flame resistance, mechanical protection, and ductility. The wires, insulation, and protective copper or alloy steel sheath are manufactured as a unit, as shown in Fig. 9.105. MI cable is available in single-, two-, three-, four-, and seven-conductor assemblies. Refer to Sec. 100 of Div. 2 for data. The cable possesses exceptional ability to withstand severe mechanical abuse, as shown in Sec. 230 by the summary of mechanical properties as determined from tests.

![Type MI cable](General Cable Co.)

Both ends of each coil of cable are factory-sealed to prevent ingress of moisture into the cable. It is advisable to reseal unused cable in coils that will stand around for any length of time and to apply permanent seals to each cable run as promptly as possible. Should moisture enter cable ends during field handling and installation, the affected insulation will normally be discarded in the process of stripping back and terminating the cable. If necessary, the cable can be further dried by careful application of a torch over approximately a 2-ft (0.6-m) section of cable adjacent to the end. Insulation-resistance measurements checked by an insulation tester should indicate adequate dryness.

The general method of installation is similar to that of metal-clad cable. Standard junction or outlet boxes may be used at each point of termination or when two lengths of cable are to be joined. The tap size of these units should be the same as listed under “Corresponding Conduit Size,” as given in Sec. 96 of Div. 2.

### 230. Summary of Mechanical Tests on Mineral-Insulated Cable

<table>
<thead>
<tr>
<th></th>
<th>Type MI</th>
<th>Metal-clad cable</th>
<th>EMT Type T</th>
<th>Rigid conduit Type T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact</td>
<td>B</td>
<td>D</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>Crushing</td>
<td>A</td>
<td>D</td>
<td>C</td>
<td>B</td>
</tr>
</tbody>
</table>

**Notes.** Performance is indicated by the letter “grades”; A signifies best performance. EMT is electrical metallic tubing. Type T refers to Underwriters’ Code Grade thermoplastic-insulated conductors. In the impact test, the cable was laid over an anvil hardy having a smoothly rounded edge with a 1/8 in. radius. Weights of 50, 20, and 10 lb were dropped on the cable, and the length of drop determined which produced not more than two failures in 10 separate blows. In the crushing test the cable was crushed against the same anvil hardy used in the impact test by a flat steel plate in a compression-testing machine. The force required to crush the cable to 50 percent of its original diameter was determined.
231. Installation of MI cable. It is suggested that the MI be trained into position where the installation allows. The cable can also be snaked and fished into and through congested areas. In some cases, a simple rotating X frame has been used to advantage, facilitating paying off the cable as it is snaked through barriers. After training to position, the cable can be secured with one-hole clips, as offered by many manufacturers of conduit clips, multicable gang straps, channel and spring-set clip-supporting arrangements, cable trays, conduit hangers, and spacing bars and straps.

The cable can be trained into final position by hand in most cases. True alignment can be ensured by tapping the cable lightly along its axis with a wooden mallet. True round sweeps can be made in the larger-sized cable runs with a hand hickey, but this usually is not necessary.

**NOTE** NEC requires that the radius of bends (at the inner edge of the bend) shall be not less than five cable diameters for cable not more than 20 mm (3/4 in.) in external diameter and 10 times cable diameters greater than 20 mm (3/4 in.) in external diameter. Cable (except where fished) is to be supported at intervals not exceeding 1.8 m (6 ft).

The copper itself being in an annealed condition, MI is easily worked. Keeping the cable straight when unwinding the coil facilitates final training. The cable is cut after measurement, allowing for conductor tails (stretching steel wire over the proposed run is an ideal method of measuring). MI can be terminated before or after it is laid in position. If undue stressing and sharp bending are avoided during preliminary handling and roughing in work, hardening of the cable will be minimized, resulting in a more readily installed system.

In portions of dairies, laundries, canneries, and other wet locations and in locations where walls are frequently washed, the entire wiring system, including all boxes and fittings used therewith, shall be made watertight, and the cable shall be mounted so that there is at least 6 mm (1/4 in.) air space between it and the wall or other supporting surface.

The Code states that at all points where mineral-insulated metal-sheathed cable terminates, a seal shall be provided immediately after stripping to prevent the entrance of moisture into the mineral insulation and that, in addition, the conductors extending beyond the sheath shall be insulated with an approved insulating material. Also, when Type MI cable is connected to boxes or equipment, the fittings shall be identified for such use. MI cable terminal fittings (Fig. 9.106) are designed to seal the cable ends hermetically to prevent the entrance of moisture into the cable as well as secure mechanically the cable to the outlet box, motor, or other apparatus. The complete terminal consists of an end seal and a threaded gland.

![FIGURE 9.106 Standard termination for mineral-insulated cables suitable for use at temperatures up to 85°C [General Cable Co.]]
## 232. Termination Dimensions

(Dimensions in Inches)

<table>
<thead>
<tr>
<th>Group size</th>
<th>A</th>
<th>B</th>
<th>C*</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type O gland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/2</td>
<td>1/16</td>
<td>3/16-18</td>
<td>7/16-14</td>
<td>7/16</td>
<td>3/16</td>
<td>7/16</td>
<td>17/32</td>
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<tr>
<td>3/4</td>
<td>1/4</td>
<td>3/16-14</td>
<td>7/16-14</td>
<td>1/2</td>
<td>1/8</td>
<td>1/8</td>
<td>3/16</td>
</tr>
<tr>
<td>1</td>
<td>1/8</td>
<td>1-14</td>
<td>1-11/16</td>
<td>1/16</td>
<td>1/8</td>
<td>1/8</td>
<td>3/16</td>
</tr>
<tr>
<td>Type G gland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/4</td>
<td>3/4</td>
<td>3/16-16</td>
<td>7/16-14</td>
<td>7/16</td>
<td>3/16</td>
<td>7/16</td>
<td>17/32</td>
</tr>
<tr>
<td>1</td>
<td>2/2</td>
<td>1/8</td>
<td>1-11/16</td>
<td>1/16</td>
<td>1/8</td>
<td>1/8</td>
<td>3/16</td>
</tr>
</tbody>
</table>

*STD electrical conduit pipe thread.
†This dimension is 25/16 on sizes 637 and 684.
### 233. Termination Selection Chart

<table>
<thead>
<tr>
<th>Application</th>
<th>Designation</th>
<th>Sleevings</th>
<th>Sealants</th>
<th>Glands</th>
</tr>
</thead>
<tbody>
<tr>
<td>General use up to 85°C, wet and dry location—UL listed</td>
<td>Type O</td>
<td>PVC</td>
<td>Type O plastic</td>
<td>Type O</td>
</tr>
<tr>
<td>Hazardous locations, wet and dry up to 85°C—UL listed epoxy</td>
<td>Type H</td>
<td>PVC</td>
<td>Type H plastic</td>
<td>Type G</td>
</tr>
<tr>
<td>Low temperatures (below −10°C)</td>
<td>Low</td>
<td>temperature</td>
<td>Silicone rubber (Fiberglass reinforced)</td>
<td>Type O</td>
</tr>
<tr>
<td>High temperatures (up to 125°C)</td>
<td>High</td>
<td>temperatures</td>
<td>Silicone rubber (Fiberglass reinforced)</td>
<td>Type O epoxy</td>
</tr>
</tbody>
</table>

Ceramic-to-metal seals are available for temperature in excess of 125°C.

**NOTES.**
1. Type G glands may be used as an alternative for Type O glands in any application.
2. Silicone rubber Fiberglass-reinforced sleeving may be used as an alternative for PVC sleeving in any general-use application.
3. Type H epoxy may be used as an alternative sealant in any application.
4. Type O Plastic and Type O epoxy may be used as alternative sealants in Class I, Group B, and Class II, Groups E, F, and G, hazardous location.

### 234. Termination procedure for MI cable

**Cable End Seal.** Basic parts of the cable-seal termination and the complete seal are shown in Fig. 9.107. The following parts are required for making the seal.

1. Screw-on pot, a self-thread brass cylinder
2. Silicone rubber or PVC tubing, for insulating the exposed conductor ends
3. Insulating cap
4. Sealing compound, a soft plastic material or two-part epoxy compound
5. Crimping and stripping tools

The cable-seal termination is made by removing the copper sheath with the stripping tool to expose the length of conductors needed for the connections, screwing the self-threading screw-on pot onto the end of the cable sheath, filling the pot with sealing compound, slipping the insulating tubing and cap assembly over the exposed conductors and pressing the cap down into the end of the screw-on pot, and, finally, securing in place by crimping the edge of the pot down over the insulating cap. This insulates the end of each exposed conductor and provides a moisture seal over the insulation.
Threaded Gland. Figure 9.108 shows the parts of the threaded gland, with the gland in place before tightening and, finally, with the gland locked in the final position. The following parts are included:

1. Gland body
2. Compression ring
3. Gland nut

These gland parts are slipped over the end of the cable before the termination is applied, in the order of first the gland nut, then the compression nut, and finally the gland body. When the gland nut is screwed into the gland body over the compression ring, the ring is compressed onto the cable sheath, which anchors it into position. This can be applied at any point on the cable, but usually it is brought clear up to the end with the cable-seal termination seated into the counterbored end of the gland body. The outer end of the gland body is threaded for locknuts.

Assembly Tools

1. One hand vise
2. One screwdriver or nut driver
3. One copper tube cutter
4. One diagonal cutting pliers
5. Two pipe wrenches
6. One crimping and compressing tool
7. One stripping tool
235. Details of termination procedure for MI cable
(General Cable Co.)

1. Mark sheath only with a pencil at point which will expose desired conductor length.

2. Use diagonal cutters to start the rip.

3. Use wrist motion to tear up "tag."

4. Engage the tag in the slot of the rod and twist it around the cable. Wrist motion is continued as rod revolves about cable axis.

5. Keep rod at about 45° to the line of the cable. Keep bare rod against sheath and 45° will be regulated. Do not force tearing.

6. Bring stripping tool perpendicular to axis of cable. Then ring the cable sheath at the pencil mark using a copper tube cutter. The depth of the cut should be approximately one half the thickness of the cable sheath. Do not cut through sheath.

7. After ringing, continue stripping as shown in Fig. 5 and tear off squarely at the ring. Remove any burrs at the end of the cable sheath with diagonal cutters.
236. Type MV cable is a single-conductor or multiconductor cable with extruded solid dielectric insulation. The cable may have an extruded jacket, a metallic covering, or a combination of both over the single conductors or the cabled conductors. (See Figs. 9.109, 9.110, and 9.111.)
237. **Type MV cables are rated** from 2001 V up to 35,000 V. The ampacities are governed by Sec. 310.60 of the National Electrical Code.

238. **The construction of Type MV cable** shall be in accordance with Article 310 of the NEC and may have aluminum, copper, or copper-clad aluminum conductors.
239. **Power systems** up to 35,000 V use Type MV cable, which is permitted in wet or dry locations, in raceways, in cable trays if identified for such use in messenger-supported wiring, or directly buried, installed in accordance with Sec. 300.50 of the NEC.

**UNDERGROUND-FEEDER AND BRANCH-CIRCUIT–CABLE WIRING**

240. **Underground-feeder and branch-circuit cable** provides an economical wiring system for wet and corrosive installations. Single-conductor Type UF cable resembles Type USE service-entrance cable in general appearance. The insulation employed consists of a plastic compound, NEC statements with respect to its use are: Underground-feeder and branch-circuit cable may be used underground, including direct burial in the earth, as feeder or branch-circuit cable where provided with overcurrent protection not in excess of the rated current-carrying capacity of the individual conductors. If single-conductor cables are installed, all cables of the feeder circuit, subfeeder circuit, or branch circuit, including the neutral and equipment grounding conductor, if any, shall be run together in the same trench or raceway. If the cable is buried directly in the earth, the minimum burial depth permitted is 600 mm (24 in.) if the cable is unprotected and 450 mm (18 in.) when a supplemental covering, such as a 50 mm (2 in.) concrete pad, metal raceway, pipe, or other suitable protection, is provided. Type UF cable may be used for interior wiring in wet, dry, or corrosive locations under the recognized wiring methods of the Code, and where installed as nonmetallic-sheathed cable it shall conform to the provisions of Article 334 and be of a multiconductor type. It must also be of a multiconductor type if installed in cable tray.

This type of cable shall not be used (1) as service-entrance cable, (2) in commercial garages, (3) in theaters, (4) in motion-picture studios, (5) in storage-battery rooms, (6) in hoistways, (7) in any hazardous location, (8) embedded in poured cement, concrete, or aggregate except as provided in Article 424 of the Code, and (9) where exposed to direct sunrays, unless identified as sunlight-resistant (Fig. 9.112).

![Figure 9.112](https://www.digitalengineeringlibrary.com) Type UF two-conductor cable suitable for direct burial.

**INTERIOR WIRING WITH SERVICE-ENTRANCE CABLE**

241. **Service-entrance cable of Type SE or Type USE** may be employed for interior wiring, installed either concealed or exposed. The construction of these cables is described in Sec. 244. Cables with all the conductors insulated may be used for general interior wiring. Those without insulation on the grounded conductor may be used only on systems not exceeding 150 V to ground as branch circuits to existing ranges and clothes dryers. The cables with uninsulated grounding conductors must have a final nonmetallic outer covering. Cables which are used for interior wiring must be installed in accordance
with the rules for nonmetallic sheathed cable discussed in Secs. 215 to 228. In such cases the uninsulated wire becomes an equipment grounding conductor only, and is not allowed to be a circuit conductor.

242. Ampacity rules change; effects of thermal insulation. An exemption from the Type NM requirement that the final ampacity be based on the 60°C ampacity column (see Sec. 228) was removed in the 2008 NEC cycle. The results, where enforced, will be dramatic. For example, 4/0 AWG Aluminum Type SE cable made with three insulated conductors and a smaller bare conductor has been in common use for decades as a 200 A feeder run to dwelling unit panels in multifamily housing. It has an ampacity of 180 A under the 75°C ampacity column. Since the next higher standard-size overcurrent device is 200 A, it could have been used for this purpose unless the actual load ran in the 180 to 200 A window, a very unusual circumstance. Now it must be taken as a 60°C conductor, reducing the ampacity to 150 A.

The change in the ampacity rule is technically questionable in most instances; however, there is one application where the change is entirely justified, and might even not go far enough. When wiring is embedded in thermal insulation, the ampacity is significantly degraded. The results tend to get progressively worse for larger cable sizes, because larger cables are generally installed to meet an expectation of higher current draw. The heat generated by a conductor is $I^2R$. Larger cables carrying larger currents reduce the heat by the first power due to larger radiating surface areas, and increase the heat by the square of the current increase. This means that large cables tend to be worse than smaller ones, because the latter increase in heat ($+\Delta P$) usually overwhelms the former decrease ($-\Delta R$). The present rule for 60°C works well for branch circuits, but not as well for large feeders.

In the 1987 NEC cycle, this was confirmed by actual NEMA testing, with dramatic results. The test used 2 AWG aluminum Type SE cable of the “SEU” style (two insulated conductors and the grounded conductor configured as a spirally-wrapped conductor around the ungrounded conductors). This cable is used routinely for 100 A residential services [due to the special ampacity accorded for this purpose by 310/15(B)(6)]. It was run through thermal insulation under controlled test conditions. Specifically, the cable was run embedded in cellulose insulation with 7 in above it. Thermocouples were placed on the cable, and the various loads under test were maintained for long periods. This cable has a Table 310.16 ampacity (terminations not considered for this purpose) of 100 A. When the cable was loaded to 100 A, the cable jacket was “completely charred” as well as adjacent “charred wood members,” all while the cable was operating within its table ampacity limitations. In fact, the testing showed (65 A caused 96°C operation) the cable exceeded its rated operating temperature at any time the continuous current exceeded about two-thirds of the table ampacity.

These results strongly demonstrate the fact that the ampacity of a conductor is not necessarily what a table may predict. The ampacity of a conductor is its ability to carry current continuously under the conditions of use. This is determined by thermodynamics. The ampacity of 2 AWG aluminum XHHW configured as 2/3 Al SEU cable and embedded in cellulose insulation is approximately 60 A. Actually, the ampacity corresponding to Table 310.16 would be even less than that, because Table 310.16 is structured around three current-carrying conductors and this testing only used two of the three conductors in the test circuit.

This testing focused on Type SE cable, but a test run using 6 AWG copper in metal conduit embedded in foam insulation overheated those conductors as well. There is no ampacity table for thermal insulation, and it would be impossible to create one, because variations in $R$ factors significantly change end results. However, it is fair to say, for example, that the ampacity of 4/0 Al SE cable (table ampacity of 205 A) embedded in thermal insulation is...
far less than even the 60°C table result of 150 A would predict. The NEC, in 310.10, requires that no conductor may be operated above the temperature limitations of its insulation. That is the only NEC rule that covers this point, and it is referenced in a number of cable articles for this reason. To the extent practicable, good practice is to route larger circuits in such a way as to avoid contact with thermal insulation.

243. The principal use of service-entrance cable for interior wiring in dwellings is for branch circuits supplying ranges or water heaters and in farm wiring as feeders from the master service to supply the other buildings that are wired for electricity. It is also commonly used for both indoor and outdoor feeders, even for 3-phase 4-wire commercial applications. The cable is supported on the building structure by means of single-hole or two-hole cable straps made in different sizes to accommodate the size of cable. They are similar in appearance to those used for rigid conduit. Connection to switch or outlet boxes is made by means of a connector (Fig. 9.113), which is made in watertight and nonwatertight types. A typical range installation is shown in Fig. 9.114.

244. Types of cables, indoor-use exclusion. Two common types of cables are shown in Figs. 9.115 and 9.116. The three-conductor Type SE cable in Fig. 9.115 consists of two insulated conductors and one concentric-stranded insulated conductor (generally used as the grounded-neutral conductor). This cable is limited to services that do not exceed 150 V to ground, such as a 120/240-V single-phase supply. If used as a three-wire 120/240-V branch circuit to a range, wall-mounted oven, counter-mounted cooking unit, or clothes dryer, this cable must originate at the service equipment. In such instances, the uninsulated neutral conductor may be used to ground the metal frame of the equipment supplied, but such application is limited to existing branch-circuit installations only.

FIGURE 9.115 Four-conductor Type SE cables uses three insulated conductors and a bare equipment ground.
Figure 9.116 shows a single-conductor 4/0 aluminum Type USE cable. This cable, if it has no other designation, is limited to underground applications with an allowance for an outdoor only, above-grade termination. It must never be brought into a building unless it also has a building wire classification to go along with the USE designation. For example, it is not uncommon to see a Type USE/RHW cable that has been evaluated for use within buildings as well as for direct burial. When used in direct-burial applications, such a cable has a 75°C rating. The ampacity ratings of conductors are listed in Tables 19 through 23 of Div. 12. For underground applications Type USE cable should be buried not less than the depths specified for Type UF cables in Sec. 240. For over 600 V refer to Sec. 131 of Div. 8.

**UNDERFLOOR-RACEWAY WIRING**

245. **Underfloor-raceway systems** are used principally in office buildings for the installation of the wiring for telephone and signal systems and for convenience outlets for electrically operated office machinery. They provide a flexible system by which the location of outlets may be easily changed to accommodate the rearrangement of furniture and partitions. The NEC allows their use when embedded in the concrete or in the concrete fill of floors. Their installation is allowed only in locations which are free from corrosive or hazardous conditions. No wires larger than the maximum size approved for the particular raceway shall be installed. The voltage of the system must not exceed 600 V. The total cross-sectional area of all conductors in a duct must not be greater than 40 percent of the interior cross-sectional area of the duct.

246. **An underfloor-raceway system** consists of ducts laid below the surface of the floor and interconnected by means of special cast-iron floor junction boxes. The ducts for underfloor-raceway systems are made of either fiber or steel. Fiber ducts are made in two types, the open-bottom type and the completely enclosing type. Steel ducts are always of the completely enclosing type, usually having a rectangular cross section. In the underfloor-raceway system, provision is made for outlets by means of specially designed floor-outlet fittings which are screwed into the walls of the ducts. When fiber ducts are employed, the duct system is laid on the floor with or without openings or inserts for outlets. After the floor has been poured and finished as desired, the outlet fittings are installed into inserts or at any points along the ducts at which outlets are required. The method of installing outlet fittings is described in Sec. 261. When steel ducts are employed, provision for the outlet fittings must be made at the time that the ducts are laid, before the floor or floor fill is poured. The steel ducts are manufactured with threaded openings for outlet connections at regularly spaced intervals along the duct. During the installation of the raceway and the floor these outlet openings are closed with specially constructed plugs whose height...
can be adjusted to suit the floor level. The shapes and dimensions of the different types of ducts for underfloor raceways are shown in Fig. 9.117. For telephone and similar circuits, much wider ducts can be obtained.

247. General rules for the installation of underfloor raceways. In general, underfloor raceways should be installed so that there is at least 20 mm (3/4 in.) of concrete or wood over the highest point of the ducts (see Figs. 9.118 and 9.119). However, in offices approved raceways may be laid flush with the concrete if covered with linoleum or equivalent floor covering (see Fig. 9.120). When two or three raceways are installed flush with the concrete, they must either be contiguous with each other and joined to form a rigid assembly. Flat-top ducts over 100 mm (4 in.) wide but not over 200 mm (8 in.), spaced less than 25 mm (1 in.), must be covered with at least 38 mm (1 1/2 in.) of concrete (see Fig. 9.121). It is a standard practice to allow 200 mm (3/4 in.) clearance between ducts run side by side. The centerline of the ducts should form a straight line between junction boxes. If the spacing between raceways is 1 in. or more, the raceway may be covered with only 1 in. of concrete. All joints in the raceway between sections of ducts and at junction boxes should
be made waterproof and with good electrical contact so that the raceways will be electrically continuous. Metal raceways must be properly grounded.

248. **Wires of signal or telephone systems** must not be run in the same duct as wires of fighting systems. Combination junction boxes accommodating the two or three ducts of multiple-duct systems may be employed, provided separate compartments are furnished in the boxes for each system. (See Fig. 9.122.) It is best to keep the same relative location of compartments for the respective systems throughout the installation.

All joints or taps to the conductors must be made in the junction boxes. No joints or taps should be made in the ducts of the raceway or at outlet insert points. (See Figs. 9.123, and refer to Figs. 9.136, and 9.137.)
249. **Junction boxes for use with underfloor raceways** are specially constructed metal boxes. They are available in single-compartment types and in combination boxes to accommodate multiple-duct systems having two or three raceways run side by side. The general construction of the junction boxes is similar for both fiber- and steel-duct systems. Most boxes are equipped with leveling screws so that they can be leveled up with the duct runs. The covers of the boxes also are adjustable with respect to height so that they can be accurately leveled to agree with the surface of the finished floor. Different types of covers that will be suitable for the different types of floor finishes are available. With plain cement-finished floors a plain brass cover set flush with the floor (Fig. 9.124) is sometimes used. In other cases a recessed cover filled with cement is employed. For linoleum- or cork-covered floors a cover with a recess for a cork or linoleum insert is provided, as illustrated in Fig. 9.125. For marble or hardwood floors a recessed cover with a marble insert (Fig. 9.126) may be employed. With the recessed covers only a thin ring of brass shows in the finished floor, marking the location of the junction box.
250. **Fittings must be installed** at every end of a line of raceway with a marker extending through the floor to show the line of the duct. All dead ends of raceway must be closed with a suitable fitting.

251. **In installing raceways** every effort should be made to avoid low points which could form traps for water.

   All connections to a raceway except those made through the inserts provided in the raceway shall be made by means of flexible metal conduit where not installed in concrete, rigid conduit, intermediate metal conduit, EMT, or a special approved fitting (refer to Fig. 9.127). Where a metallic underfloor raceway system provides for the termination of an equipment grounding conductor, rigid nonmetallic conduit, electrical nonmetallic tubing, or liquidtight flexible nonmetallic conduit where not installed in concrete unless so listed may be used.

252. **Inserts** (National Electrical Code) shall be leveled to the floor grade and sealed against the entrance of concrete. Inserts used with metal raceways shall be metal and shall be electrically continuous with the raceway. Inserts set in or on fiber raceways before the floor has been laid shall be mechanically secured to the raceway. Inserts set in fiber raceways after the floor has been laid shall be screwed into the raceway. In cutting through the raceway wall and setting inserts, chips and other dirt shall not be allowed to remain in the raceway, and tools shall be so designed as to prevent the tool from entering the raceway and injuring conductors that may be in place.

253. **Reinsulation of conductors in underfloor raceways prohibited.** When an outlet is discontinued, the conductors supplying the outlet shall be removed from the raceway. The general practice is to loop wire intermediate receptacles between the header and the end of the run. This requirement assures that reinsulated conductors will not be resting in the raceway below an abandoned outlet. This in turn prevents a fish wire inserted afterward from a downstream location from getting caught on a reinsulated conductor, with very destructive consequences. It is often advisable to wire each outlet on its own pair of conductors back to the header or other junction point. Then, when an outlet is abandoned, the associated pair of conductors can be withdrawn without disrupting other outlets on the run. Take care, however, to keep track of the total number of conductors at all portions of the duct, because the ampacity derating factors for mutual conductor heating (Div. 12, Sec. 17, item 5) will apply. Some jurisdictions provide limited waivers to these derating factors in underfloor applications; however, in order to encourage this practice and thereby discourage the reinsulation of conductors. When the conductors are withdrawn, leave a pull string in their place so the outlet can be easily reactivated in the future as necessary.
Steel-duct raceways are made for two types of underfloor electrical distribution systems:

1. The two-level system, recommended for use when electrical growth and expansion of facilities are anticipated
2. The single-level system, recommended for underfloor wiring installations when cost and design limitations are a factor

The features of a two-level system showing raceways, junction boxes, typical supports, and other fittings are given in Fig. 9.127. Duct details are shown in Fig. 9.128.

The features of a one-level system showing raceways, junction boxes, typical supports, and other fittings are given in Fig. 9.129. Duct details for the raceway of one manufacturer
FIGURE 9.128  Duct and duct insert for a two-level raceway system. [General Electric Co.]

are given in Fig. 9.130. For dimensions of ducts available from other manufacturers refer to Fig. 9.117 and the catalogs of such manufacturers.

255. Installation of steel-duct raceways. The method of installing Walker-duct, the steel-raceway system manufactured by the Walker Systems, Inc., in the concrete fill of floors is illustrated in Fig. 9.131. The ducts are supported by saddle supports, which consist, as shown in Fig. 9.132, of two detachable parts, a base and a saddle. These supports are available for single-duct runs and in various combinations for supporting multiple-duct runs. Support should be located not more than 5 ft (1.5 m) apart. After the locations of junction boxes and duct runs have been marked out, the bases of the saddle supports are fastened to the floor by expansion bolts for concrete construction or by special toggle wires for hollow-tile work (see Fig. 9.131). The saddle is then assembled to the base, and the ducts fastened to the saddle by tie wires. The complete raceway is then leveled and adjusted to the proper height by means of the height-adjusting bolts of the saddles and the leveling screws of the couplings and junction boxes. The adjacent sections of duct are fastened together by duct couplings (Fig. 9.133). The pointed set-screws of the couplings fasten the duct to the coupling and at the same time provide an electrical ground connection between the duct and the coupling. Special fittings are available for connecting ducts and junction boxes to conduit, for connecting ducts directly to distribution cabinets, for blanking off the ends of ducts, etc.

256. The outlet openings in the ducts are closed by means of outlet plugs whose height can be adjusted to coincide with the floor level. A marker screw can be inserted in one plug of each 10-ft (3-m) length of duct if it is desired to facilitate the location of the outlets. The appearance of a duct after the installation of the floor fill with an outlet opening
closed by means of an outlet plug is as shown in Fig. 9.134. When the floor is covered with linoleum, rubber, cork, etc., the outlets are not extended through the covering until needed. It is a good practice to indicate the location of the outlet inserts by means of an escutcheon marking screw in the plugs on each side of the junction boxes. (See Fig. 9.135.) Wood or marble floors can be laid over the outlet inserts and the outlets are not extended through the finished floor until actually needed.
257. **When the raceway is installed in the concrete of the floor,** the ducts are supported from the forms by saddle supports, and the whole system is accurately leveled and adjusted for the proper height, by means of the leveling screws and bolts on the fittings and saddle supports, before the floor is poured. In concrete-joist construction when building codes will not allow the saddle support to be mounted directly on the concrete pans, a saddle bridge must be used to support the duct saddles.

258. **Installation of outlet fittings in steel-duct–raceway systems.** When a duct outlet is to be used for service, the small amount of concrete is removed from the top depression of the outlet plug. The plug is removed by unscrewing it from the duct with a plug-removal wrench. The removal of the plug forms a neat preformed passage through the concrete to the duct-outlet opening. The necessary wires are pulled in from the nearest junction box and threaded through the service fitting. The service fitting is then screwed into the duct-outlet opening, and the floor flange adjusted. Figures 9.136 and 9.137 illustrate this process.

When it is desired to locate an outlet at a point in a raceway where there is no preset insert plug, an afterset insert for the outlet can be made by the use of special tools available from the manufacturer. The method of making an afterset insert is illustrated in Fig. 9.138.
FIGURE 9.137 Flush service fittings for single service power or low voltage applications. [Walker Systems, Inc.]

FIGURE 9.138 Method of making an outlet with an afterset insert. [General Electric Co.]
259. **Trenchduct.** Several makes of steel underfloor raceways are suitable for use with Trenchduct. Figure 9.139 shows a section of Trenchduct supplying two runs of underfloor steel raceways. Trenchduct is available in standard 6-ft (1.8-m) lengths at a depth of 2 7/8 in. (53.975) mm. Other depths are available on special order. Ducts are shipped complete with three 18-in- (457.2-mm-) long cover sections. Cover plates are 1/4-in- (6.35-mm-) thick roller-leveled steel. The Trenchduct is used to extend branch circuits from a panelboard to the underfloor raceways, and the Trenchduct shown in Fig. 9.139 has a cross-sectional area of 22 1/2 in² (145.15 cm²) which allows many more conductors than a conduit feed.

Cover plates for Trenchducts are adjustable upward to 3/8 in. (9.525 mm) and downward to 3/8 in. from a standard position by means of leveling screws flush with the top surface cover. Adjustment to finished-floor height is made by a screwdriver from the top.

Side-feed connectors provide bushed openings for feeds into the side of the Trenchduct. When specified, openings in Trenchduct are precut by the manufacturer.

![Figure 9.139 Typical components of a Trenchduct used in connection with an underfloor steel raceway.](Triangle Conduit & Cable Co., Inc., subsidiary of Triangle Industries, Inc.)
The Trenchduct is, in effect, a continuous junction box, because the cover plates are flush with the finished floor and one or more sections can be easily removed as required.

Vertical elbows turn the Trenchduct system up to a panelboard with full duct capacity. Figure 9.139 shows typical components of the system.

260. **Installation of completely enclosing fiber-duct raceways.** Completely enclosing fiber-duct underfloor raceways may be installed in either the concrete or the concrete fill of floors in a manner similar to that described for steel-duct raceways in Sec. 255. With fiber-duct raceways there are preinserted provisions for outlets, or they can be provided without any openings for outlets. After the finished floor has been laid, an outlet may be provided at any preset insert or at any point desired along the duct runs, as described in Sec. 261. The main component parts of a fiber-duct underfloor-raceway system are illustrated in Figs. 9.140 and 9.141. The different sections of duct are clamped together by means of a combination steel coupling and support provided with leveling screws for leveling the runs and adjusting to the proper height.

261. **Installation of outlet fittings in fiber-duct-raceway systems.** To establish outlets in a preset system after the finish is in place, it is necessary to determine the location of the insert. This can be done by means of an insert finder. Then the flooring is chipped down to expose the insert cap. The cap is removed and a hole cut in the duct so that wires can be fished through and connected to the receptacle.

**FIGURE 9.140** Component parts of a completely enclosed fiber underfloor-raceway installation.
The procedures shown in Fig. 9.142 should be employed in installing an outlet fitting at any point in a fiber underfloor raceway of the completely enclosing type. The special tools provided by the manufacturers for this purpose should be used to ensure satisfactory workmanship.

262. Layout of underfloor-raceway systems. A very simple layout for an underfloor-raceway system, called the single-runaround layout, is shown in Fig. 9.143. Such a layout provides only the minimum of flexibility in the location of outlets. It is satisfactory for certain types of buildings when the installation cost must be limited and desks will be located only around the sidewalls. This layout will provide outlets only for telephone and signal systems. A similar layout is shown in Fig. 9.144. This layout, having two separate raceways, provides outlets for electrically operated office machines from one raceway and outlets for telephones and signal systems from the other raceway.

FIGURE 9.141 Junction box and associated fittings for a completely enclosed fiber underfloor-raceway system.

FIGURE 9.142 Method of installing afterset inserts into fiber underfloor raceways.
FIGURE 9.143  Single-runaround layout for an underfloor raceway.

FIGURE 9.144  Double-runaround layout for an underfloor raceway.
263. **To provide greater flexibility** in the possible location of outlets over the entire area than is accomplished with the runaround layouts, grid layouts are employed. A typical single-grid layout is shown in Fig. 9.145, and a double-grid layout in Fig. 9.146. The flexibility provided for the location of outlets depends upon the distance between parallel duct lines. For maximum flexibility the parallel lines of ducts should be located approximately 5 ft (1.5 m) apart with the outside runs located 3 ft (0.9 m) from the outside walls. The distance between rows of junction boxes should be from 20 to 60 ft (from 6.1 to 18.3 m), depending upon the estimated number of outlets that will be required at any one time between junction boxes.

**FIGURE 9.145** Single-grid layout for an underfloor raceway.

**FIGURE 9.146** Double-grid layout for an underfloor raceway.
264. Wireways may be installed only for exposed work, except as extensions to pass transversely through walls. They must not be used where they will be subjected to severe physical damage or to corrosive vapors or in any hazardous location, except as specifically permitted in the hazardous location articles in the NEC. Wireways for outdoor use shall be of approved raintight construction. Their chief application is for the installation of mains and feeders in industrial plants or other locations where a flexible means of supplying branch circuits is advantageous or where many wires must be located in one run. They permit access to the wires and cables at all points in the system for tapping, splicing, rerouting, inspection, installation of additional wiring, or other changes, all without disturbing the existing work. Three long sides (and the ends) may or may not be provided with knockouts for wiring entries. The fourth long side consists of a removable cover which may be hinged or secured with screws, and provides access for installing wires and making splices. Multiple lengths can be coupled together with nuts and bolts running through a connecting coupling. A typical use of wireway is shown in Fig. 9.147. Note the use of a power distribution block for splicing purposes in this wireway section. The wire bending space must comply with Div. 12, Table 34 limits for the conductors terminated, and all uninsulated live parts must be protected as shown so they will not be exposed whether or not the wireway cover is in place.

Wireways are available in sizes 2, 21/2, 3, 31/2, 4, 41/2, 5, 6, 8, 10, and 12 in. (50.8, 63.5, 76.2, 88.9, 102, 114, 127, 152, 203, 254, 305 mm) square. No conductor larger than that for which the wireway is designed shall be installed in wireways, provided that the sum of the cross-sectional area of all the conductors at any cross section does not exceed 20 percent of the interior area of the wireway. Splices and taps may be located within the wireway, provided the cover is left accessible. The conductors including the splices must not fill the wireway to more than 75 percent of its area at that point. The wireway must not contain more than 30 conductors at any point except for signaling circuits or for control conductors between a motor and its starter, used only for starting duty. More than 30 current-carrying conductors may be installed in a wireway, at a 20 percent maximum fill, if the reduction factors specified in 310.15(B)(2)(a) (Div. 12, Sec. 17, item 5) are applied. Figure 9.148 shows a more elaborate application where three wireway sections connect four panelboards to a pull box at the upper left that has been field-modified to serve as a common junction point. By distributing the approximately 85 current-carrying circuit conductors leaving the four panelboards over the three wireway runs, the installation avoids derating entirely.

Horizontal runs of wireways must be supported at each end and every 1.5 m (5 ft) unless specifically listed for supports at greater intervals, but in no case shall the distance between supports exceed 3 m (10 ft). Vertical runs of wireway shall be securely supported...
at intervals not exceeding 4.5 m (15 ft) and shall not have more than one joint between supports. Adjoining wireway sections shall be securely fastened together to provide a rigid joint. An unbroken length of wireway may extend transversely through walls. Very short wireway sections are often bought and placed in service as a rectangular pull box. This is permitted but the required wire bending space and conduit spacings that apply to pull boxes generally (see Sec. 349) apply to these applications.

265. **Cross-Sectional Areas of Wireways**

<table>
<thead>
<tr>
<th>Wireway size, in</th>
<th>Cross-sectional areas, in²</th>
<th>100%</th>
<th>75%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2(\frac{1}{2}) × 2(\frac{1}{2})</td>
<td>6.25</td>
<td>4.68</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>4 × 4</td>
<td>16.00</td>
<td>12.00</td>
<td>3.20</td>
<td></td>
</tr>
<tr>
<td>6 × 6</td>
<td>36.00</td>
<td>27.00</td>
<td>7.20</td>
<td></td>
</tr>
<tr>
<td>8 × 8</td>
<td>64.00</td>
<td>48.00</td>
<td>12.80</td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 9.148** Metal wireways can often avoid derating penalties for mutual conductor heating.
266. In computing the proper size of wireway, refer to Secs. 264 and 265. Then determine the total cross-sectional area of the conductors to be installed from Table 5 in NEC Chap. 9.

267. Nonmetallic wireways are available and are very helpful in areas where metal wireways would likely corrode. They follow essentially the same rules as metal wireways with one major exception. Because nonmetallic materials do not work as well as metal in their ability to function as a heat sink, the contained conductors, even if fewer than 30, are always subject to derating penalties for mutual conductor heating, just as if they were running in a conduit.

**BUSWAY WIRING (NEMA)**

268. Busway is a modern system of power distribution. It provides a flexible means for distributing power and light in industrial and commercial buildings and/or connecting branch motor circuits to the mains so that the location of the branch taps can be readily and economically changed to suit the conditions of rearrangement of machines. This system finds wide use in industrial plants when the layout of machines must be continually changed to meet changing manufacturing conditions because busway’s flexibility in accommodating such change is its greatest advantage. (See Fig. 9.149.)
By definition (NEMA standard BU1) a busway is a prefabricated electric distribution system consisting of busbars in a protective enclosure, including straight lengths, fittings, devices, and accessories. Busways are of the following types:

1. **Feeder busway.** A feeder busway is a busway without plug-in openings which is intended primarily for conducting electric power from the source of supply to centers of distribution but which can have provisions for bolt-on devices (see Fig. 9.150).

   ![Feeder busway](image1)

   **FIGURE 9.150** Feeder busway.

2. **Plug-in busway.** A plug-in busway is a busway having plug-in openings on one or both sides at spaced intervals, offering means for electrical connection of plug-in or bolt-on devices to the busbars. Such plug-in or bolt-on devices (bus plugs) may incorporate switches, circuit breakers, transformers, motor controllers, or other auxiliary equipment (see Fig. 9.151).

   ![Fusible bus plug](image2)

   **FIGURE 9.151** Fusible bus plug installed on a plug-in busway.

269. **Major requirements related to the application and testing of low-voltage busway.** This material is intended to assist in understanding the application and testing of low-voltage busway by summarizing the principal codes and standards applicable to the product. Since all codes and standards are revised from time to time and requirements vary from locality to locality, contact your local inspection authority and the manufacturer for the latest requirements applicable to your installation.

Groups which maintain standards enumerating busway construction and installation practices include:

1. Underwriters Laboratories Inc.
2. The National Electrical Manufacturers Association
3. The National Fire Protection Association (The National Electrical Code)
4. State and local electrical codes
5. Power companies, which frequently specify minimum conductor sizes and spacing for connection to their equipment.
Underwriters Laboratories Requirements. Busway bearing the Underwriters Laboratories listing mark must pass a series of performance tests (see UL 857). Among the tests which may be required here are:

Heating (temperature-rise) test. Busway with suitably plated joint connections must carry its rated current continuously without any part showing a temperature rise above ambient of more than 55°C. Tests are conducted on three 10-ft (3-m) sections bolted together, at any convenient voltage, at design frequency, with rated current flowing.

Resistance-to-impact test. The resistance-to-impact test will ordinarily not be required for nonventilated busway if its construction conforms to the specifications spelled out in Table A. However, all other busway must be tested to ensure that no hazardous condition will exist after any side of the enclosure has been subjected to a blow from a 50-lb weight suspended from a 30-in- (762-mm-) long pendulum arm going through a 60° angle from the vertical.

### TABLE A  Thickness of Sheet Metal

<table>
<thead>
<tr>
<th>Maximum inside width of widest surface</th>
<th>Minimum acceptable thickness of sheet metal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>Zinc-coated</td>
</tr>
<tr>
<td>in</td>
<td>mm</td>
</tr>
<tr>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>12*</td>
<td>305</td>
</tr>
<tr>
<td>18</td>
<td>457</td>
</tr>
<tr>
<td>30</td>
<td>762</td>
</tr>
<tr>
<td>More than 30</td>
<td>More than 762</td>
</tr>
</tbody>
</table>

*18 in if enclosure does not support the weight of the busbar assembly.

Dielectric test. A busway shall withstand for 1 min without breakdown of the application of a 60-Hz potential of 1000 V plus twice the maximum rated voltage between live parts and the enclosure and between live parts of opposite polarity.

Resistance-to-bending test. Busway intended for a spacing of not more than 5 ft (1.5 m) between mounting supports will ordinarily be accepted without a bending test. However, to qualify for horizontal mounting on a 10-ft (3-m) support basis or on 16-ft (4.9-m) centers in vertical risers, a busway must withstand for 5 min without rupture of the joint, appreciable permanent distortion, or short-circuiting or grounding of the phase or neutral busbars a bending moment equivalent to the weight of a 10-ft section plus an additional 100-lb (45.36-kg) force applied at the end of the 10-ft section.

Resistance-to-crushing test. Busway intended to employ a spacing of not more than 5 ft (1.5 m) between mounting supports and whose construction is in accordance with Table A will ordinarily be accepted without a crushing test. However, if the busway does not meet these spacing or construction requirements, it shall be tested to ensure that it will be able to withstand a crushing force of 200 lb (90.7 kg) plus 3 times the weight of a 10-ft (3-m) section.

Busbar pullout test. Busway intended for mounting in a vertical run shall be capable of supporting a downward force equal to 4 times the weight of an individual busbar in a 10-ft (3-m) section applied simultaneously to each of the busbars without rupture or permanent distortion of busbar supports.

Insulation-resistance and dielectric-strength test after exposure to rain. Outdoor busway must withstand a simulated rain for 8 h per day for 5 successive days without dielectric breakdown.
Short-circuit test. All busway and fittings rated 100 A or less and having a short-circuit current rating of more than 5000 A shall be tested and marked with their respective rating(s). Busway and fittings rated over 100 A and having a short-circuit current rating over 10,000 A shall be tested and marked with their respective ratings. To verify these rating(s), representative samples of the busway shall be subjected to phase-to-phase, phase-to-enclosure, and phase-to-ground conductor (when applicable) short-circuit tests. Tests may be conducted either with or without fuse or circuit-breaker protection ahead of the busway being tested, and the ratings and markings will so indicate.

Tests when busway enclosure is used as an equipment-grounding conductor. For the busway enclosure to be accepted as an equipment-grounding conductor, the busway shall be subjected to the short-circuit tests described above. In addition, two other conditions shall be met: (1) the busway enclosure shall comply with minimum cross-sectional-—area requirements, and (2) a maximum resistance of 0.005 Ω is allowed when passing a direct current of 30 A between adjacent busway sections.

National Electrical Manufacturers Association Standards. In addition to the Underwriters Laboratories tests listed above, the NEMA standard for busways specifies the following:

Short-circuit current ratings. There are no minimum or maximum standards on short-circuit current ratings specified by Underwriters Laboratories. The minimum rating depends upon the maximum short-circuit available at the line and of the installed busway run. However, NEMA recommends the following minimum ratings:

<table>
<thead>
<tr>
<th>Continuous current rating of busway, A</th>
<th>Short-circuit current ratings, symmetrical amperes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plug-in busway</td>
</tr>
<tr>
<td>100</td>
<td>10,000</td>
</tr>
<tr>
<td>225</td>
<td>14,000</td>
</tr>
<tr>
<td>400</td>
<td>22,000</td>
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<td>1600</td>
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<td>85,000</td>
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</tbody>
</table>

Voltage drop. There are no minimum or maximum standards on voltage drop since these values may vary considerably depending upon several factors, including (1) the design, (2) the conductor material, (3) the continuous-current rating, (4) the current load, (5) the power factor of the load, (6) the operating temperatures, (7) the length of the run, and (8) the distribution of the load. Actual values of voltage drop in given situations can best be determined by obtaining the necessary data from a busway manufacturer and applying it to the specific situation. In general, the line-to-line voltage drop of fully loaded, three-phase busway will usually be less than 6 V/100 ft. Voltage drops for plug-in busway are
based upon an evenly distributed load along the run and are one-half that of a load concentrated at one end.

Resistance, reactance, and impedance. There are no minimum or maximum values of resistance, reactance, or impedance since these values vary considerably with different ratings and busway constructions. Busway manufacturers can supply these data for their particular products. These data are used for calculating the voltage drop for a specific application.

Unusual service conditions. For applications in which the ambient temperature is higher than 40°C, the busway current rating should be derated in accordance with the manufacturer’s recommendations, if furnished, or the following:

| TABLE B |
|-----------------|------------------|
|                 | Ambient-temperature limits | NEMA standards publication no. |
| Busway lengths and fittings | −30°C through +40°C | NEMA BU 1 |
| Low-voltage-power circuit breakers | Not to exceed +40°C | NEMA SG 3 |
| Molded-case circuit breakers | 0°C through +40°C | NEMA AB 1 |
| Enclosed switches | −30°C through +40°C | NEMA KS 1 |
| Low-voltage cartridge fuses | See applicable UL standards | NEMA ICS 1 |
| Electromagnetic and manual motor controls at 6000 ft and less | 0°C through +40°C maximum | ICS 2 |
|                 | ICS 3 |

270. National Electrical Code requirements. The National Electrical Code, which is sponsored by the National Fire Protection Association, outlines the general guidelines which are necessary for the safe application of electrical equipment. Article 368 of the Code specifically applies to busways, although other articles in the Code are applicable in certain situations. Thorough familiarization with the NEC requirements for busways is recommended before attempting to apply busways to specific applications.

Some of the major requirements for safe application of busways as outlined in the 2008 NEC are as follows:

368.10. Uses permitted

a. Exposed. Busways shall be permitted to be located in the open where visible, except as permitted in 368.10(C).

b. Concealed. Busways shall be permitted to be installed behind access panels, provided the busways are totally enclosed, of nonventilating-type construction, and installed so that the joints between sections and at fittings are accessible for maintenance purposes. Where installed behind access panels, means of access shall be provided, and either of the following conditions shall be met:
   1. The space behind the access panels shall not be used for air-handling purposes.
   2. Where the space behind the access panels is used for environmental air, other than ducts and plenums, there shall be no provisions for plug-in connections, and the conductors shall be insulated.

c. Through walls and floors. Busways shall be permitted to be installed through walls and floors in accordance with (C)(1) and (C)(2).
   1. Walls. Unbroken lengths of busway shall be permitted to be extended through walls.
   2. Floors. Floor penetrations shall comply with (a) and (b).
      (a) Busways shall be permitted to be extended vertically through dry floors if totally enclosed (unventilated) where passing through and for a minimum distance of 1.8 m (6 ft) above the floor to provide adequate protection from physical damage.
(b) In other than industrial establishments, where a vertical riser penetrates two or more dry floors, a minimum 100 mm (4 in.) high curb shall be installed around all floor openings for riser busways to prevent liquids from entering the opening. The curb shall be installed within 300 mm (12 in.) of the floor opening. Electrical equipment shall be located so that it will not be damaged by liquids that are retained by the curb.

368.12. Use not permitted. Busways shall not be installed (1) where subject to severe physical damage or corrosive vapors; (2) in hoistways; (3) in any hazardous (classified) location, unless specifically approved for such use; or (4) outdoors or in wet or damp locations unless identified for such use.

Lighting busway and trolley busway shall not be installed less than 2.5 m (8 ft) above the floor or working platform unless provided with a cover identified for the purpose.

368.30. Support. Busways shall be securely supported at intervals not exceeding 1.5 m (5 ft) unless otherwise designed and marked.

300.21. Spread of fire or products of combustion. Electrical installations in hollow spaces, vertical shafts, and ventilation or air-handling ducts shall be so made that the possible spread of fire or products of combustion will not be substantially increased. Openings around electrical penetrations through fire-resistance–rated walls, partitions, floors, or ceilings shall be fire-stopped by using approved methods to maintain the fire-resistance rating.

368.17(B). Reduction in ampacity size of busway. Overcurrent protection shall be required where busways are reduced in ampacity.

Exception: For industrial establishments only, omission of overcurrent protection shall be permitted at points where busways are reduced in ampacity, provided that the length of the busway having the smaller ampacity does not exceed 15 m (50 ft) and has an ampacity at least equal to 1/3 the rating or setting of the overcurrent device next back on the line, and provided further that such busway is free from contact with combustible material.

State and Local Electrical Codes. Many states and cities have electrical codes which supplement the National Electrical Code. Before attempting to apply or install busway as well as any other type of electrical equipment, contact your local electrical inspection authority for a copy of the latest requirements applicable to the location of the installation.

Electric-Power-Company Requirements. Busways are commonly used for the main services of buildings, in which case they are usually connected to one or more distribution transformers owned by the local electric power company. This connection may be made by either cable or busbars, depending upon local practices. Since the various electric power companies throughout the United States often prefer different methods of connection to busway services, it is recommended that the local company supplying the power be contacted before applying or installing a service-entrance busway run.

Contacting Busway Manufacturers. Since the practical applications and uses of busway are nearly unlimited, it is not possible to outline here all the technical information available pertaining to busway. For this reason, it is advisable to contact one or more of the manufacturers of busway for more specific information whenever a possible application for busway is contemplated. All companies in the industry have technical experts who will assist in properly selecting and applying the busway system best suited to the specific requirements.
271. **Busway layout.** Present-day busway systems are designed for flexibility of layout and can be applied on applications such as a simple straight run of plug-in busway fed from a cable-tap box or a complex run with multiple feeders and plug-in devices for a high-rise building. However simple or complex, the system must be planned in advance.

The purpose of this section is to show how to plan the layout in an easy, step-by-step approach. A number of examples and details of how the busway is applied, as well as specific details on how to coordinate the installation of busway with other products, are included.

This section should be used as a reference guide only. The final decision on any system must be dictated by the particular details of the application.

When busway manufacturers receive orders for busway, an approval drawing is generally required. Experience has shown that a complete, detailed approval drawing as shown in Fig. 9.152 expedites release for manufacture. It is therefore important that the information sent to the manufacturer be as nearly complete as possible. If it is incomplete, a great deal of time can be wasted in obtaining missing information.

![Diagram of typical customer-approval drawing](image-url)
The following is some of the information typically missing from sketches or drawings received by busway manufacturers:

1. Front location of switchgear, switchboards, transformers, or other cubicles
2. Floor heights and floor thicknesses on risers
3. Location of busway risers in relation to closet walls
4. Location of plugs on a riser in relation to closet walls
5. Location of walls and wall thickness

The approval drawing that is sent back to the field for approval may require additional dimensions for the complete busway layout. The electrician will be required to fill in these dimensions after field-measuring the job, approve the drawing for manufacture, and submit it through channels to the busway manufacturer.

*Guidelines for Getting Basic On-Site Measurements.* Before even looking at a busway job, you should have these basic materials for measuring: a sketch pad, a 50- or 100-ft (15- or 30-m) measuring tape, an 8- or 10-ft (2.4- or 3-m) folding wood rule, chalk and chalk line, plumb bob and string, and a yellow lumber crayon. Armed with these tools, you are prepared to lay out a busway system successfully.

First, it is always a good practice to walk through the entire facility to get an idea of general routing. While walking through, watch for obstructions, both vertical and horizontal. At the same time, try to establish one elevation so that offsets are not required. To do so, you must check floor elevations between rooms or various parts of the building. Otherwise, the busway installed at a specific elevation in one part of the building might be too high or too low at another point.

After the walk-through, you are ready to begin measuring the system. For reference points, use structures already available in the building, such as walls or columns. To save time, don’t attempt to break the run down into specific lengths of busway. A busway manufacturer’s engineer will do this and at the same time prepare an erection drawing to show the breakdown.

Actual measurement should start in the area where the switchboard or switchgear is located. If the switchboard has not been installed, chalk in the specified location and the point of entry for the busway. At this time, if the service entrance run is part of the job, you can measure its location.

One of the most important steps in planning a large busway layout is coordination between the trades. This is a good time for the electrician to meet with plumbing, heating, ventilating, and sprinkler-system trades to establish a definite right of way throughout the construction area. Once this has been established, hours of frustrating rerouting can be saved. Immediately after the right of way has been determined, electricians will often install busway hangers to claim and identify their areas.

The next step is to establish the busway elevation, then start horizontal measurements using the following examples as a guide. The examples indicate the dimensions required (see Figs. 9.153 through 9.162).
FIGURE 9.153 Basic site dimensions required before starting busway layout.
FIGURE 9.154 Service entrance run from power-center transformer, pad-mount transformer, and weatherhead.
FIGURE 9.155 Elevation.
FIGURE 9.156  Horizontal offset.

FIGURE 9.157  Vertical offset.
FIGURE 9.158 Vertical drop into an MCC.

FIGURE 9.160  Double-run distribution system.

FIGURE 9.161  Using columns as reference points.
FIGURE 9.162  Multifloor.
272. **Busway-riser applications.** Several conditions will dictate the number of plug-in units that will fit physically on each floor: floor height, size of plugs, maximum height of plug-operating handle, other equipment or walls in close proximity to the busway riser, and orientation and phasing. Let’s consider each of these conditions in turn.

**Floor-Height Measurements.** The basic dimensions (height from finished floor to finished floor plus floor thickness) required for every busway riser are shown in Fig. 9.163. Do not assume that all floors are of the same height.

*NOTE* See NEC rule in Sec. 270. If a curb is to be supplied around the floor opening, specify the height of the curb.

**Floor Height.** The individual planning the riser should realize that clearance above the floor must be maintained to install vertical mounting hangers and joint-cover plates. Generally, a distance of 15 to 24 in. (381 to 609.6 mm) above the floor to the centerline of the joint is required.

273. **Size of plug-in devices.** The floor height will dictate the number of plug-in openings physically possible for each riser on each floor. If the floor height is less than 12 1/2 ft (3.8 m) and floor thickness remains at 6 in. (152.4 mm), it is impossible to use a 10-ft (3.05-m) straight length of plug-in busway. Instead, a shorter straight length would be used.

Using the manufacturer’s plug-in unit dimensions, you can experiment with plugs to be supplied and determine the number that can fit on each floor.

**Maximum Height of Plug-Operating Handles.** Generally, there is no maximum height for plug-in units when a suitable means of operating such as a hook stick, rope, or chain is provided (see Sec. 404.8(A) Exception No. 1 in the NEC). However, since requirements

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*FIGURE 9.163* Basic height measurements required for risers.
vary from locality to locality, contact the local inspection authority and busway manufacturer for the latest requirements applicable to your installation.

**Other Equipment or Walls in Close Proximity to the Busway Riser.** Applying busway with plug-in or bolt-on units in a vertical riser requires preplanning. See Figs. 9.164, 9.165, and 9.166 for examples of busway risers in an electrical closet. Busway with plug-in or bolt-on units must be arranged to clear other equipment and walls in the wiring closet. In particular, make sure that the plug-in or bolt-on hinged cover can be opened fully for maintenance.

**Orientation and Phasing.** To ensure that plug-in units are properly located, consult the manufacturer for coordination of busway orientation and phasing.

**FIGURE 9.164** Examples of busway risers in an electrical closet.
Busway Connections from Switchgear through Wall and Floor Openings. Wall and floor openings (see Fig. 9.167) for busway should be at least 1 in. (25.4 mm) larger than the outside dimensions of the busway. In some areas where there is doubt about the accuracy of the measurement, a flange must be installed through a wall, the hole must be large enough for the largest dimension.

Special Conditions. Certain conditions require preplanning to circumvent installation problems. Figure 9.168 is an example. If the X or Y dimensions are below the minimum needed to permit a joint between the elbow and the walls or floor, the joints must fall as shown. It then follows that openings in the walls or floors must be made large enough to install the busway. (See Fig. 9.169.) Wall thickness must also be considered.
**Busway Plug-in Application.** When plug-in units are to be installed, consideration must be given to providing adequate clearance from the plug-in busway to obstructions to allow the plug-in unit to swing in place. Consult the manufacturer for specific requirements. (See Fig. 9.170.)

**Customer Erection Drawings.** Prior to shipment of busway from the factory, the installer will receive a customer drawing. A sample appears in Fig. 9.171. This drawing contains a complete layout of the entire installation and a bill of material that includes (1) an item number which can be correlated with the drawing and a description of each piece and (2) the identification number and quantity of each piece.
274. **Busway installation (see Fig. 9.172)**

*General.* To ensure maximum reliability and long life for a busway system proper installation is imperative. Manufacturers supply installation drawings on all but the simplest busway layouts. Study these drawings carefully. If drawings are not supplied, make your own. Verify actual components on hand against those shown on installation drawings to ensure that there are no missing items. Manufacturers’ drawings identify components by catalog number and specify their location in the installation. Catalog numbers appear on nameplates and carton labels. Read the manufacturers’ instructions for installation of the individual components. If you are still in

**FIGURE 9.171** Typical drawing sent by a busway manufacturer to an installer.

**FIGURE 9.172** Installing busway.
doubt, ask for more information; never guess. Almost all busway sections are built with a busway joint on one end. Refer to the installation drawing to orient each component properly. Pay particular attention to “Top” labels and other orientation marks where applicable.

Storage and Handling. Busway sections and fittings which are not to be installed and energized immediately upon receipt should be stored in a clean, dry place that has a uniform temperature to prevent condensation. Preferably, they should be stored in a heated building having adequate air circulation and protected from dirt, fumes, water, and physical damage. Because of moisture it is extremely risky to store busway outdoors. If busway must be stored outdoors, it must be securely covered for protection from weather and dirt. Temporary electrical heating should be installed beneath the cover to prevent condensation.

Indoor busway must always be protected from exposure to moisture, plaster, and other types of contaminants. This is extremely important during initial installation when the busway may be exposed to higher levels of dust and moisture.

Outdoor busway must be treated exactly the same as indoor busway until it is installed. It is not weather-resistant until it is completely and properly installed. Care must be used in unpacking. Band cutters should be used on all banding securing the package. If a crane is employed to install busway, use nylon straps and distribute, or balance, the weight of each lift. If cables are employed, spurs should be used to avoid damage to the metal housing. Do not drag busway across the floor. When installing vertical sections, it is easier to lower the busway from the floor above where it will be installed. Vertical sections are often stored on the floor above their final location to facilitate lowering them into position.

Supports and Hangers. Use the hangers or the hanging recommendations supplied by the manufacturer in the manner prescribed to afford a secure installation and proper hanger spacing. A busway which is mounted horizontally should be supported at 5-ft (1.5-m) intervals and not more than 10-ft (3-m) intervals if it is marked as being suitable for such intervals. Consider sway bracing for plug-in busway. Caution must be emphasized when all plug-in units are used on one side of a busway or when there are more plugs on one side than the other. Large plug-in units are cubicles which have considerable weight and when mounted on a horizontal run of busway should be separately supported from the building structure to prevent twisting or deformation of the busway. A busway which is to be mounted vertically should be marked to indicate that it is suitable for that purpose. When the distance between floor supports is more than that for which the busway is marked as suitable, the manufacturers’ recommendation regarding intermediate supports should be followed; however, support intervals should not exceed 16 ft (4.9 m). Busway cubicles and bus plugs should be separately supported by the building structure when so recommended by the manufacturer. (See Figs. 9.173 and 9.174.)
Testing. Be sure to recheck all steps to ensure that you have followed the manufacturer’s recommendations for installation and that you have not forgotten anything. At this point the busway installation should almost be complete. Before energizing it, the complete installation should be properly tested. The testing procedures should first verify that the proper phase relationships exist between the busway and associated equipment. This phasing and continuity test can be performed in the same manner as similar tests on other pieces of electrical equipment on the job. All busway installations should then be tested with a megohmmeter or high-potential-voltage tester to be sure that excessive leakage paths between phases and ground do not exist. Megohmmeter values depend on busway construction, type of installation, size and length of busway run, and atmospheric conditions. Acceptable values for a particular busway should be obtained from the manufacturer.

Energizing. When the equipment is energized for the first time, qualified electrical personnel should be present. Energizing a run of busway for the first time is potentially dangerous. If faults caused by damage or poor installation practices have not been detected in the checkout procedure and corrected, serious damage can result when the power is turned on. There should be no load on the busway when it is energized. Since busway typically extends through several rooms and floor levels, care should be taken to see that all devices fed from the busway are switched to the off position. The equipment should be energized in sequence by starting at the line end of the system and working toward the load end. In other words, energize the main devices, then the feeder devices, and then the branch-circuit devices. Turn the devices on with a firm, positive motion. Protective devices which are not quick-acting should not be teased into the closed position. After all the devices have been closed, loads such as lighting circuits, contactors, heaters, and motors may be turned on. Busway, when operating properly, will have a moderate 60-Hz hum. However, excessive noise may be an indication of hardware that has not been tightened or of metal parts that have been improperly assembled. Occurrence of sparking at any joint along the busway is an abnormal condition. The busway should be deenergized until the sparking condition has been corrected.

275. Busway-system inspection and maintenance

Warning. Turn off power ahead of the busway before performing any of the following maintenance operations. Check incoming line terminals with a voltmeter prior to proceeding with work. Do not attempt to work on energized busway.

276. Busway should be inspected once each year or after any severe electrical faults. Look for any moisture or signs of previous wetness or dripping onto the busway or onto connection boxes from leaky roofs, pipes, sprinklers, or other sources of moisture. Look for any recent changes in sprinklers or other plumbing that might now be a source of trouble to the busway. Eliminate the source of any liquids dripping onto the busway and any other source of moisture (indoor busway). Replace or thoroughly dry and clean any insulating material which is damp or wet or shows accumulation of deposited material from previous wettings. If there is an appreciable accumulation of dust and dirt, clean it off by using a brush, vacuum cleaner, or clean, lint-free rags. To avoid blowing dust into busway joints, circuit breakers, or other equipment do not use a blower or compressed air. Carefully inspect all visible electrical joints and terminals, checking for tightness of bolts, nuts, etc., in accordance with the manufacturers’ instructions (see Fig. 9.175). If joints or terminations appear to be badly discolored, corroded, or pitted or show evidence of having been subjected to high temperatures, the parts should be disassembled and replaced or cleaned. Do not remove plating on aluminum parts, joints, or terminations. Damaged
aluminum parts should normally be replaced. Check the insulation resistance prior to reenergizing the busway. A permanent record should be kept of resistance readings. If readings decrease appreciably with time, deterioration is taking place. If resistance readings are below recommended manufacturer’s values, contact the busway manufacturer for the appropriate corrective action.

277. Busway plugs and protective devices. Check the operation of all mechanical components. Check all switch-operator mechanisms and external operators of circuit breakers. Make sure that each operator mechanism quickly and positively throws contacts fully on and fully off. Check the mechanisms of all electrical and mechanical interlocks and padlocking means. Check for missing or broken parts, proper spring tension, free movement, rusting or corrosion, dirt, and excessive wear. Examine all readily accessible arc chutes and insulating parts for cracks or breakage and for arc spatter, sooty deposits, oil, or tracking. Clean off arc spatter, oil, and sooty deposits. Replace the device if appreciable material has burned away or if parts are charred or cracked. Closely examine the fuse clips. If there is any sign of overheating or looseness, check the spring pressure, tightness of clamps, etc. Replace the fuse clips if the spring pressure compares unfavorably with that of identical fuse clips and other equipment. Look for any signs of deterioration in insulating material or melting of the sealing compound. Replace such insulating parts and assemblies where the sealing compound has melted. Be sure that the condition which caused the overheating has been corrected. Lubricate the operating parts of switch mechanisms, etc., according to the manufacturer’s instructions. Use a clean nonmetallic light grease or oil as instructed. Do not oil or grease parts of molded-case circuit breakers (see Fig. 9.176). If no instructions are given on the devices, sliding copper contacts, operating mechanisms, and air locks may be lubricated with clean, light grease. Operate the switch or circuit breakers several times to make sure that all mechanisms are free and in proper working order. Retighten all wire connections. Check fuses to make sure that they have the proper ampere rating and interrupting rating. Make sure that non-current-limiting fuses are not used as replacements for current-limiting fuses. If the bus plug has been removed from the busway, check the insulation resistance of the device prior to its reinstallation.

278. Specific-purpose busway. Lighting busway and trolley busway are considered to be special-purpose busway. Lighting busway provides a low-cost, flexible power-distribution system for supplying low-capacity loads. It provides maximum flexibility for these low-capacity loads, since a power tap-off can be located at any point along the busway. It is used effectively as a power supply system for lighting fixtures, small power
tools, and machines in industrial and assembly plants, office and commercial buildings, department stores, vocational schools, garages, warehouses, truck and rail terminals, shipping docks, museums, and galleries. Trolley busway provides a completely mobile and flexible power-distribution system for such applications as cranes, hoists, monorails, conveyors, assembly lines, observatories, rotating restaurants, industrial trolley cars, and portable tools.

Lighting busway (Fig. 9.177) provides the greatest flexibility in the location of outlets for low-current-capacity loads. Several ampere ratings (20, 30, 35, 50, and 60 A) are available in two-, three-, and four-wire systems, with a maximum voltage rating of 300 V, ac or dc, to ground. Lighting busway may be used as a branch-circuit or feeder circuit as defined in Article 100 of the National Electrical Code, subject to the ampere limitations in Sec. 210.23. It may be utilized in exposed areas except in unsuitable locations where subject to mechanical injury, corrosive vapors, hoistways, battery rooms, outdoors, or in wet or hazardous locations (see Sec. 368.12 of the NEC).

Standard straight sections are typically available in 4- and 10-ft (1.2- and 3-m) lengths, while nonstandard sections are typically available in lengths of 1, 2, 3, 5, 6, 7, 8, and 9 ft (0.3, 0.6, 0.9, 1.5, 1.8, 2.1, 2.4, and 2.7 m). In this type of busway, the steel housing serves as the ground path. A continuous narrow opening or slot along the bottom of the housing provides power tap-off capability along the entire length of the busway run by allowing the insertion of plugs at any point. If required, a rubber slot closure which can be field-cut to length is available to close off openings between plugs to prevent the entrance of dust or other objects.

Standard components, along with straight sections, include coupling for joining section to section, feed-in devices for supplying power to individual runs, and caps to terminate a run, various types of hangers and heavy-gage–steel channels to suspend and support lighting runs with fixtures attached, and a variety of tap-off devices in both terminal and receptacle types with or without circuit protectors (fuses or circuit breakers).

Couplings (Fig. 9.178) serve three functions: first, to connect electrically the circuit conductors between sections; and, second, to join section housing rigidly and securely to section housing. A third function is available with a trolley-entrance coupling which allows the insertion of a trolley-type tap-off device for moveable-load applications.

Feed-in boxes serve to power lighting busway circuits and are designed to attach at the end (Fig. 9.179) or in the center of a run (Fig. 9.180).

End caps serve to terminate or seal off the end of a run (Fig. 9.181). Similar in design to couplings, they snap into place and can be easily removed and reused when extending a lighting busway run.

FIGURE 9.177 Example of a lighting busway.

FIGURE 9.178 Couplings.
Methods of Suspension. (Figs. 9.182 and 9.183) Lighting busway can be suspended by various methods. Manufacturers provide a variety of hangers for flush or surface mounting, drop-rod suspension, or the messenger-cable method. The distance between points of suspension depends on the weight loads directly supported by the busway, building truss or beam locations, and manufacturers’ allowable limits. Hangers can be positioned anywhere along the busway housing. When heavy loads (such as high-bay lighting fixtures) are to be supported or when building trusses are spaced beyond standard allowable limits, a supplementary steel support channel (hat section) can be provided by busway manufacturers. By using the support channel and roller-type rod hangers, lighting busway can be rolled into position, with lighting fixtures prepositioned (installed on the busway and electrically connected), from one of a building.
279. **Power tap-off devices** (twistouts and trolleys; Figs. 9.184, 9.185, and 9.186) are typically available as follows:

1. **Without circuit protection.** Polarized.
2. **Receptacle twistouts.** Rated 15 A at 125 V, ac or dc; for three-wire (line, neutral, and ground) convenience gaps.
3. **Terminal twistouts.** Rated 20 A at 125 V, ac or dc, and 15 A at 300 V ac; for three-wire (line, neutral, and ground) permanent connection to electrical devices.
4. **Terminal trolleys.** Rated 20 A at 300 V, ac, for three-wire (line, neutral, and ground) permanent connection to electrical devices.
Lighting busway can be furnished in two-, three-, or four-pole configuration. All are polarized, use conductors rated at 300 V, ac or dc, with four available ampere ratings: 20, 35, 50, and 60 A. Neutrals are sized at 100 percent cross-sectional area of the conductor bars.

For single-circuit loads, two-pole lighting busway is normally used for low-initial-cost installations. It can be used for 120-, 240-, or 277-V ac systems or dc systems up to 300 V.

Three-pole lighting busway is used for most applications, as it offers two-circuit capability at only slightly higher installed cost and provides greater load-carrying capacity. While a two-pole system rated at 277 V, 60 A can carry 16.6 kVA, a three-pole system of the same rating can carry 33.2 kVA.

Four-pole lighting busway may be used where there is a need to serve both single-phase and three-phase loads.

Three-pole systems are normally operated at either 120/240 or 120/208 V, ac or dc, up to 300 V. They can also be connected to a 480Y/277-V system provided the ungrounded legs are all connected to the same phase or that the maximum voltage between any two conductors never exceeds 300 V, the maximum rating of lighting busway.

In effect, three-pole lighting busway provides two independent circuits in the same housing, thus providing greater switching capability, extra circuits at low cost, and greater service continuity.

Independently controlled circuits are desirable whenever it is necessary to control separate loads or separate portions of the same load. For example, a department store may require two different lighting circuits, depending on the material displayed, and an industrial plant may require one circuit for work periods and another for maintenance crews. By using single-pole switching in each of the hot legs with a grounded neutral, it is easy to obtain maximum flexibility with three-pole lighting busway.

In most distribution systems, normal day-lighting circuits are paralleled by other branch circuits. These additional circuits supply night lighting, convenience outlets, small offices
or washrooms, heaters, fans, portable tools, etc. If two-pole busway is used, other loads
must be supplied by other independent circuits, which may be either lighting busway or
wire and conduit. In many instances, a considerable saving can be effected by using three-
wire lighting busway to supply two, three, or more of these circuits.

If service continuity is essential, as in emergency lighting systems, it is desirable to split
the loads in a three-pole, two-circuit single housing. Then, if a temporary overload should
occur on one circuit, the single-pole breaker protecting that circuit may trip but the other
circuit will be left in operation. Thus, only a portion of the load will be shut down, and all
production will not be lost.

280. Typical installation procedures for lighting busway. After the suspension
method has been put into place and hangers located as required, the installer may select any
desired location along the designated run to install the first section of lighting busway. A
coupling can first be installed by snapping it onto the end of a section. A tab on the coupling
engages a square slot on the top of the section housing which locks it into place. As no tools
are required, couplings can be attached after a section has been installed on the hangers.

To install lighting busway, simply slide each section through the hanger(s), snap the
sections together at the coupling, and repeat the process until the run has been completed.
Lighting fixtures and tap-off devices, as well as end or center feed-ins and end caps, can be
installed at the same time.

Lighting busway is designed for simplicity of installation and reusability. It can be
removed and reinstalled, affording flexibility and cost savings for future changes.

Trolley Busway. (Fig. 9.189) This is a modern enclosed, mobile power-distribution sys-
tem designed to provide moving-current tap-off for applications such as cranes, hoists,
maintenance hanger doors, and rotating platforms. Automobile plants, for example, use
trolley busway to provide mobile power for portable assembly tools and parts carrying
monorail systems. Direct-current trolley busway is also used for testing the vehicle electri-
cal system as it moves down the assembly line. Appliance manufacturers use trolley
busway for assembly and testing of their products. When compared with a bare bar or cable
used in the same application, trolley busway offers not only lower installed cost but greatly
reduced maintenance in addition to safety, as the conductor bars are enclosed and protected
in a single steel housing.

Two- and three-pole trolley busway (Fig. 9.190) is available in continuous ampere rat-
ings of 100, 225, 375, 400, 500, 600, and 800 A. All have 150 percent intermittent ratings
based on 1-min-on, 1-min-off duty cycles and can be used on system voltages up to 600 V ac
(50, 600, 400, or 800 Hz) or 250 V dc. Four-pole trolley busway is rated 100/150 A at 480 V ac or 250 V dc. All use copper conductor bars. In this type of busway the steel housing serves as the ground path. Trolley busway is usually furnished in standard 10-ft (3-m) straight sections. However, section lengths from 1 ft 2 in. to 10 ft (0.35 to 3 m), in any increments, are available as well as horizontal or vertical curved sections (Fig. 9.191). For exceptionally long straight runs or where rigidly supported on the building structure or at both ends of the run or where a run crosses a building expansion joint, a trolley busway expansion section should be included.

Polarized dropout sections, which provide trolley access points, may be built into a standard section and may be installed at any convenient location along the run. Sections can also be sectionalized (for circuit isolation) or be provided busless for trolley return on closed-loop applications. When switching trolleys from one run to another run, insulated flared ends are installed on the end of each facing section. These serve to align trolleys when transferring from one run to the other.

Accessories include couplings, hangers, and plates, feed-ins, and a variety of trolleys. 

*Couplings* are used to join section to section together mechanically and electrically (Fig. 9.192) and also serve as the hanger. Intermediate hangers are used on long-radius curves or straight sections subject to heavy hanging loads between couplings. [Trolleys can support up to 25-lb (11.3-kg) loads.]

**FIGURE 9.190** Typical section of a trolley busway.

**FIGURE 9.191** Horizontal and curved section.

**FIGURE 9.192** Coupling.
End plates close off or terminate a trolley-busway run and prevent trolleys from traveling beyond the end of a run.

Feed-in adapters attach to the top of a coupling and provide means to power a run at the ends or at any coupling location in between. This permits feeding a run in several locations to control voltage drop or to maintain or increase system capacity, as, for example, on assembly test lines.

Trolleys serve as the power tap-off and transverse inside the trolley-busway housing. Contacts on the trolley move along the copper busbars for power collection. Trolleys are available in several types and should be selected in accordance with the application and tap-off–ampere requirement. Contacts (button, roller, and shoe types) are typically made of an alleged graphite-impregnated bronze and are replaceable, as they are intended to wear instead of the copper busbars. Contact life varies depending on the severity of the duty and working atmospheric conditions. To prevent incorrect phasing, trolleys are polarized. The number and type of contacts determine trolley tap-off capacities. Ampere ratings range from 30 to 200 A, 600 V or less, ac or dc. Trolleys can be close-coupled and interconnected for higher-rating applications (Fig. 9.193).

The steel carriages on trolleys are equipped with sealed ball-bearing wheels which support and guide the trolley inside the trolley-busway housing. Side wheels, which are of copper-impregnated steel, provide positive ground contact between trolley and busway housing. Undercarriage wheels prevent the trolley from riding up and down when being pushed or towed in either direction.

Accessory boxes, which attach directly to trolley carriages, can be equipped with fuses, circuit breakers, receptacles, contactors, starters, timers, pilot lights, and pushbuttons (Fig. 9.194). A tool hanger with wiring box is also available (Fig. 9.195).
Nylon-brush cleaning trolleys are used to clean the copper conductor bars when a trolley busway is subject to dusty conditions. An abrasive cleaning trolley can be used intermittently to resurface the copper conductor bars if they become rough or coated from severe operating conditions.

Trolley busway, being manufactured in bolt-together sections, can easily be disassembled and moved to a new location within a facility or a new operation.

281. Definitions from NEMA BU1

**ACCESSORY**    Non-current-carrying component of a busway system used to mount or adapt the busway to the building structure.

**ADAPTER**    Fitting which permits the joining together of lengths and fittings of different shapes or designs.

**AMBIENT TEMPERATURE**    Temperature of the surrounding air that comes in contact with the outside of the busway enclosure, device, or fitting.

**ASYMMETRICAL CURRENT**    Alternating current having a waveform which is offset with respect to the zero axis. The offset occurs at the initiation of a short circuit or other change in current. It usually decays quickly until steady-state conditions are reached and the current becomes symmetrical. Asymmetrical current is composed of the alternating symmetrical component. It is expressed in rms asymmetrical amperes at a specific time (normally one-half cycle) after initiation of a short circuit or other change in current. Peak current refers to the maximum instantaneous amperes within this first half cycle.

**AVAILABLE SHORT-CIRCUIT CURRENT**    Maximum current which a circuit is capable of delivering at the system terminals ahead of the apparatus being supplied. Available short-circuit current may be expressed in either rms symmetrical amperes or rms asymmetrical amperes.

**BOLT-ON DEVICE**    Power takeoff means which can be bolted to the busways at a joint between lengths and fittings, at the end of a run, or at any predetermined location, and which makes electrical connection to the busbars.

**Busbars**    Conductors which carry current through busway lengths and fittings and which have one of the following arrangements: (1) single-bar arrangement, which refers to a busway having one conductor per pole; and (2) multibar arrangement, which refers to a busway having two or more conductors for one or more of its poles.

**Busway**    Prefabricated electric distribution system consisting of busbars in a protective enclosure, including straight lengths, fittings, devices, and accessories. Busways are of the following types: (1) feeder busway, a busway that has no plug-in openings and is intended primarily for conducting electric power from the source of supply to centers of distribution but can have provisions for bolt-on devices; and (2) plug-in busway, a busway having plug-in openings on one or both sides at spaced intervals, offering means for electrical connection of plug-in or bolt-in devices to the busbars.

**Center Cable Tap Box**    Fitting or device which provides for the attachment of cables at a location other than the end of a busway run.

**Circuit Breaker**    Device designed to open and close a circuit by nonautomatic means and to open the circuit automatically on a predetermined overcurrent without injury to itself when properly applied within its rating.
CONTINUOUS-CURRENT RATING Designated maximum direct current or alternating current in rms amperes at rated frequency which a busway can carry continuously without exceeding its temperature-rise limits when subjected to specified heating tests.

CROSS Fitting suitable for connection in four directions.

CUBICLE Enclosure attached to a length or fitting for the purpose of enclosing electrical components.

DEVICE Enclosed component used on rather than in a run of a busway system. The device may carry current from the busway system to supply a load circuit or be a nonload-supplying unit, such a ground detector.

ELBOW Angular fitting.

END CABLE-TAP-BOX Fitting which provides for the attachment of cables and conduits at the end of the busway run.

END CLOSURE Fitting which terminates and closes the end of a busway run.

EQUIPMENT-GROUNDING CONDUCTOR Conductor which is used to connect noncurrent-carrying metal parts of the busway.

EXPANSION FITTING Fitting which accommodates expansion and contraction of the busway or building.

FITTING (BUSWAY) Component in a run of a busway system, other than a straight length. It may be either current-carrying, such as an elbow, tee, or cross, or noncurrent-carrying, such as an end closure.

FLANGED END (OR SWITCHBOARD STUB) Fitting which provides means for mechanically and electrically connecting a busway run to other apparatus.

FLOOR FLANGE Accessory on the outside of a busway enclosure that provides means for the installer to cover the floor opening penetrated by the busway.

INDOOR Suitable for installation within a building which protects the busway from exposure to the weather.

NEUTRAL CONDUCTOR Conductor which is connected to the midpoint of a three-wire single-phase system, center point of a Y-connected three-phase system, or midpoint of one side of a delta-connected three-phase system.

OFFSET Fitting providing two or more angles.

OUTDOOR So constructed that exposure to the weather will not interfere with successful operation. NOTE Outdoor busway is not suitable for outdoor use until completely and properly installed as recommended by the manufacturer.

PLUG-IN CIRCUIT BREAKER Plug-in device containing an externally operable circuit breaker.

PLUG-IN DEVICE (OR BUS PLUG) Power takeoff means which can be plugged into a plug-in busway and which makes electrical connection to the busbars.

PLUG-IN FUSIBLE SWITCH Plug-in device containing an externally operable fusible switch. A handle-operated switch is a switch which is externally operated without opening or closing the cover; a cover-operated switch is a switch which is operated by opening and closing the cover.

PLUG-IN GROUND DETECTOR Plug-in device which indicates a ground on any of the normally ungrounded busway conductors.

PLUG-IN POTENTIALIZER (OR NEUTRALIZER) Plug-in device having means for limiting the potential difference between a busway enclosure and the busbars.
**RATING** Designated limit(s) of the rated operating characteristic(s) of a busway length, fitting, or device. **NOTE** Such operating characteristics as current, voltage, frequency, etc., may be given in the rating.

**REDUCER** Fitting designed for connection between lengths and fittings of different ampere ratings.

**ROOF FLANGE** Accessory on the outside of a busway enclosure that provides means for the installer to weatherproof the roof opening penetrated by the busway.

**STRAIGHT LENGTH** Straight section of a busway system.

**SWITCH** Device for opening and closing or for changing the connection of a circuit.

**SYMMETRICAL CURRENT** Alternating current having no offset or transient component and therefore having a waveform essentially symmetrical about the zero axis. Symmetrical current is expressed in rms amperes.

**TEE** Fitting suitable for connection in three directions.

**TOTALLY ENCLOSED** So constructed as to prevent the free exchange of air between the inside and outside of a housing but not sufficiently enclosed to be termed airtight.

**TRANSFORMER FITTING** Fitting wherein busbar positions are interchanged to equalize the impedance of the different phases or to change the phase relationship.

**TRANSFORMER TAP** Fitting having busbars extended through its housing or end barrier for connections by open cable to terminals of the transformer(s).

**TRANSFORMER THROAT** Fitting which provides enclosed busbar connections to transformer terminals.

**TRANSVERSE BARRIER** Dividing barrier or other means of restricting the free flow of either air or moisture through the inside of a busway.

**VAULT TERMINATION** Fitting having open busbars extending from one end which provides for connections to vault equipment.

**VENTILATED** So constructed as to provide for the circulation of external air through an enclosure to remove heat.

**VOLTAGE DROP** Arithmetical difference between voltages at the load and supply ends.

**WALL FLANGE** Accessory on the outside of a busway enclosure that provides means for the installer to cover the wall opening penetrated by the busway.

**CELLULAR-METAL-FLOOR–RACEWAY WIRING**

282. **Cellular-metal-floor raceways** are formed by employing for the floor construction of the building structural members made of corrugated sheet steel. Seven types of cellular steel floor, as made by the H. H. Robertson Co. of Pittsburgh, are shown in Fig. 9.196. Cross-sectional views of completed floors and their adaptation for the installation of the electric wiring system are given in Figs. 9.197 and 9.198.
FIGURE 9.196  Types of cellular-steel floors. [H. H. Robertson Co.]
283. The cells which are not filled with concrete from the raceways for wiring and piping. In all types the cells are 6 in. (152.4 mm) apart on centers, and the members are manufactured four cells wide with varying lengths to suit the span between beams. The cells are cross-connected by headers formed over the beams in the space left between adjacent lengths of flooring. When headers connected to alternate cells are used, one raceway system can be formed for signal wires and another for power wires, with both systems kept entirely separate from each other. If any cells are used for piping, those cells must not be interconnected to the electrical raceway system.

FIGURE 9.197 Model illustrating cellular-metal-floor–raceway wiring. [H. H. Robertson Co.]

FIGURE 9.198 Model illustrating typical 5-ft (1.5-m) staggered module of cellular-metal-floor raceway. [H. H. Robertson Co.]
284. In forming these floors, close cooperation is required between the structural and the electrical workers. The structural workers lay the floor members across the spans from beam to beam, fastening them to the beams and leaving about 4 1/2 in. (114.3 mm) of space on top of the beams between the abutting ends of the floor members for formation of the header.

The raceway headers are formed by the electrical workers in the space between members on top of the floor beams. A line of cells which is to form a raceway is interconnected at the ends of the sections by locating an access unit (Fig. 9.199) between the open ends of the aligning cells of adjacent sections.

The other cells are closed off with connecting units (Fig. 9.200) so as to form a continuous header across the beam to the raceway line of cells. When one raceway system is to be built for power wiring and another for telephone wiring, the header for one system is built on one junction of floor beams and the header for the other system on another junction (Fig. 9.201). The wires for one system will pass through the lower portion of its cells under the header for the other system. The joints at the edges of the header units are sealed with a cold-flowing asphaltic compound.
285. The connection from a header to a panelboard is made from special fittings as shown in Fig. 9.202. Connection to the header is made with an adapter (Fig. 9.203, II) to which is connected the vertical elbow (Fig. 9.203, I). Straight sections of duct 1 ft (0.3 m) long (Fig. 9.203, IV) coupled together with couplings (Fig. 9.203, V) form the vertical run up the wall. The final section to the panelboard is cut to length with a hacksaw. The box connector (Fig. 9.203, III) holds the duct to the panelboard. It requires an opening 1 7/8 by 5 3/4 in. (47.625 by 146.05 mm) in the bottom of the panelboard box.

286. Method of installing floor outlets. A hole of 1 1/8-in (41.275-mm) diameter is cut in the center of a cell with a saw-type drill (Fig. 9.204, I). A forming tool (Fig. 9.204, II) is turned into the hole to prepare the hole for reception of the outlet tap. For floors with a concrete fill of 2 to 3 1/4 in. (50.8 to 82.55 mm) a standard adjustable tap (Fig. 9.205, I) is then screwed into the hole. For fills of 1 to 2 in. (25.4 to 50.8 mm) a special tap is available. For fills of less than 1 in a shallow tap (Fig. 9.205, IV) is set in the hole and held in place with three No. 12 self-tapping screws. Holes for the screws must be drilled in the cell with a No. 9 drill. The top of the standard tap can be adjusted in height to the floor level, and a blanking cover (Fig. 9.205, II) installed until after the floor is poured. When a floor outlet is installed, the blanking cover is removed, and an extension (Fig. 9.205, III) is screwed into the tap. The floor outlet is then screwed onto the extension, using a Warnock wrench (Fig. 9.204, III) or other type of fabric wrench to avoid marring the fitting. With the shallow tap (Fig. 9.205, IV) the fitting screws onto the tap directly without the use of the extension. The complete outlet assembly is shown in Fig. 9.206. A duplex convenience outlet is shown in Fig. 9.207.
FIGURE 9.204 Tools for installing outlets in cellular-metal-floor raceways. [H. H. Robertson Co.]

FIGURE 9.205 Fittings for cellular-metal-floor raceways. [H. H. Robertson Co.]

FIGURE 9.206 Assembly of floor outlets with cellular-metal-floor raceway. [H. H. Robertson Co.]
287. **Cell markers** should be located on the center of each cell near the opposite side of the room from the header to facilitate future location of cells when outlets are not installed initially. The access units in the header will identify the cell locations at the header. A straight line between the center of an access unit and a cell marker will then identify the cell so that an outlet can be located accurately at any time in the future. Several types of cell markers are shown in Fig. 9.208. The double-slot screw (Fig. 9.208, I) can be used to identify power-wire cells, and the single-slot one (Fig. 9.208, II) to identify telephone-wire cells. In installing these markers (Fig. 9.209) a hole is drilled and tapped in the top of the cell for a 12-24 screw before the floor fill is laid. The brass marker with a headless screw is then fastened in place and adjusted in height to the level of the finished floor. The marker should then be grouted in place. After the floor has been poured and the finished floor covering laid, the headless screw is replaced with one of the grommeted brass screws (Fig. 9.208, I or II).

**FIGURE 9.207** Outlets for use with cellular-metal-floor raceways. [H. H. Robertson Co.]

**FIGURE 9.208** Markers for cellular-metal-floor raceways. [H. H. Robertson Co.]

**FIGURE 9.209** Detail showing cell marker. [H. H. Robertson Co.]
288. **Underside (ceiling) headers** (Fig. 9.210) are generally used with Types FK inverted, UK inverted, RK, and UK floors of Fig. 9.196 because there is not sufficient room for the other headers in the shallow floor fill. Two sizes are available:

1. 2½ in. (63.5 mm) deep and 5 in. (127 mm) wide
2. 4 in. (101.6 mm) deep and 6 in. (152.4 mm) wide

A ceiling header mounted in the corner formed by the ceiling and wall so as to be as inconspicuous as possible is shown in Fig. 9.211. It is held in place with No. 12 self-tapping screws which pass through holes drilled in the bottom of the raceways. Connection to a panelboard is made with a special cell (Fig. 9.212, II), as shown in Fig. 9.213. Connection between the cells and the header is made by drilling a 2-in (50.8-mm) hole in the cell to line up with the pilot opening in the header. A grommet (Fig. 9.212, I) with the locknut removed is then inserted in the hole diagonally, as shown in Fig. 9.214. After the grommet has been adjusted to its proper position, the locknut is screwed on and holds the grommet firmly in place. At least two markers, as explained in Sec. 287, should be located on top of the floor for each cell which does not have outlets installed initially.
Ceiling lighting fixtures can be hung and wired from cellular-metal-floor raceways as shown in Fig. 9.215. At I is shown a fixture-stud mounting using the stud illustrated in Fig. 9.216, I. The fixture stud is inserted through a 2-in (50.8-mm) hole cut in the cell similar to the grommet assembly of Fig. 9.214. A mounting for fixtures which fasten on the cover of a 4-in (101.6-mm) box is shown in Fig. 9.215, II. The box (Fig. 9.216, II) is held in place with a grommet. The knockouts in the box can be used for surface conduit wiring if desired. A conduit-hung fixture is supported from the cell by means of a hanger as shown in Fig. 9.215, III. The hanger (Fig. 9.216, III) is held in place with a locknut in the same way as the grommet.
290. Trench header duct. A trench header duct can be used in lieu of the standard headers shown in Figs. 9.197 and 9.198. A typical trench-header-duct installation is shown in Fig. 9.217. It is run across the floor cells at right angles, and access to each cell is made through a grommet connection. The trench header duct shown in Fig. 9.217 contains barriers so that feeders, branch circuits, and telephone circuits are separated. The cover is flush with the floor, and flush screws secure the cover to the header duct. Each cover section is 3 to 6 ft (0.9 to 1.8 m) long.

Trench header duct is made in widths of 9 to 36 in. (228.6 to 914.4 mm) and arranged to accept standard floor tiles or similar floor coverings. This header system makes a neat installation, and access openings to the header duct are practically unnoticeable after the covers have been installed. One or more cover sections can be easily removed when access to the trench duct or floor cells is necessary.

291. The cellular raceways are wired by fishing the wires from the access units to the outlets. No conductor larger than No. 1/0 may be installed except by special permission.
The number of conductors in a cell is not limited as long as the total cross-sectional area of the conductors and cables does not exceed 40 percent of the internal area of the header or cell. All splices and taps must be made in the trench header duct or at junction boxes. So-called loop wiring (continuous, unbroken conductors) is not considered a splice or tap. The internal areas of the raceways are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Entire area, sq in</th>
<th>40 percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>K cells</td>
<td>20.25</td>
<td>8.10</td>
</tr>
<tr>
<td>RK cells</td>
<td>11.25</td>
<td>4.50</td>
</tr>
<tr>
<td>FK, FK inverted</td>
<td>14.62</td>
<td>5.85</td>
</tr>
<tr>
<td>UK, UK inverted</td>
<td>5.62</td>
<td>2.24</td>
</tr>
<tr>
<td>DK cells</td>
<td>29.24</td>
<td>11.70</td>
</tr>
</tbody>
</table>

All junction boxes and inserts must be leveled to the floor grade and sealed against the entrance of concrete. They must be made of metal and so installed that they will be electrically continuous with the raceway. In cutting a cell and in setting inserts great care must be exercised so that chips or other dirt will not remain in the raceway. Only tools which are specially designed so that they will not enter the cell and injure the conductors should be used.

The NEC requires that when an outlet is discontinued, the conductors supplying it must be removed from the raceway, as discussed in depth in Sec. 253. Connections to cabinets and extensions from cells to outlets unless made by approved fittings must be made by means of flexible metal conduit where not installed in concrete rigid, intermediate, or electrical metallic tubing. Where there are provisions for the termination of an equipment grounding conductor, nonmetallic conduit, electrical nonmetallic tubing, or liquidtight flexible nonmetallic conduit where not installed in concrete may be used.

**292. Cellular-metal-floor–raceway wiring is not allowed** in any hazardous location except Class I, Div. 2 locations as permitted by express allowances in the appropriate articles of the NEC or where subject to corrosive vapors. It is not allowed in commercial garages except for supplying ceiling outlets or extensions to the area below the floor but not above. Any cell or header that is used for electrical conductors may not be used for any other service, such as steam, water, air, gas, and drainage.

**293. Cellular-metal-floor raceways are used** principally for office buildings in which the needs of the tenants for wiring outlets are not known definitely in advance and in which a high quality of adequacy and convenience of outlets and interior appearance without exposed wiring is desired. The position of the raceways may be varied in 6-in (152.44-mm) increments, and a very flexible system of outlets for telephones, business machines, and desk lamps provided, with all outlets located under the desks out of sight. The cost may be lower than would be incurred if a standard floor with a large number of underfloor raceways were installed. The wiring for ceiling-lighting outlets is also simplified by use of a type of floor in which the underside of the raceways serves as the ceiling.
**CELLULAR-CONCRETE-FLOOR–RACEWAY WIRING**

294. *Cellular-concrete-floor raceways* provide a complete underfloor electrical distribution system. For this system the floor is constructed of precast reinforced-concrete members (Fig. 9.218). These precast members are provided with hollow voids which form smooth, round cells. The cells form raceways for the electrical wires. Connections to the cells from a distribution center are made by means of metal header ducts which are run horizontally across the precast slabs and embedded in the concrete fill over the slabs. Connection from these headers to the cells is made through handhole metal junction boxes. An outlet can be located at any point along a cell. An opening into the cell at the desired point is formed by drilling a hole through the concrete floor slab. The hole is then fitted with the proper outlet fitting, and the wires fished from a handhole junction box to the outlet.

295. The National Electrical Code describes “cellular concrete floor raceways” in the scope of Article 372 as “the hollow spaces in floors constructed of precast cellular-concrete slabs, together with suitable metal fittings designed to provide access to the floor cells.” A *cell* is defined in NEC Sec. 372.2 as a single, enclosed tubular space in a floor made of precast cellular-concrete slabs, the direction of the cell being parallel to the direction of the floor member. A *header* is defined in the same section as transverse metal raceways for electrical conductors, providing access to predetermined cells of a precast cellular-concrete floor, thereby providing for the installation of electrical conductors from a distribution center to the floor cells.

296. Use of cellular-concrete-floor–raceway wiring (National Electrical Code). Conductors shall not be installed in precast-cellular-concrete-floor raceways (1) where subject to corrosive vapor; (2) in hazardous locations except as specifically permitted in the hazardous location articles in the NEC; or (3) in commercial garages except for supplying ceiling outlets or extensions to the area below the floor but not above. No electrical conductors shall be installed in any cell or header which contains a pipe for steam, water, air, gas, drainage, or any service other than electrical, as set forth in NEC Sec. 300.8.

FIGURE 9.219 Electrical distribution with cellular-concrete-floor-raceway wiring. [The Flexicore Co., Inc.]

The precast slabs are available in two sizes as shown in Fig. 9.222. Flexicore Hi-Stress Deck is available in five sizes, as shown in Fig. 9.223. Headers are available in different sizes. The NEC makes the following specifications for headers: The headers shall be installed in a straight line, at right angles to the cells. It shall be mechanically secured to the top of the precast cellular-concrete floor. The end joints shall be closed by metallic closure fittings and
sealed against the penetration of concrete. The header shall be electrically continuous throughout its length and be electrically bonded to the enclosure of the distribution center.

The method of making connection to cabinets or other enclosures is shown in Figs. 9.219, 9.220, and 9.224.

When the panel box or cabinet is located at right angles to the header (Types A and B, Fig. 9.224), the connection is made by an elbow and riser duct to the panel box. This is simply a continuation of the header up to the panel box.

When the panel box is parallel to the header (Type C), the connection is made with a T junction box, a short piece of header duct, an elbow, and a riser.

When parallel to the header, telephone and intercom cabinets are usually connected to the header as shown by Type D. The wire drops from the header through a handhole junction into a cell, through the cell, up through a jack junction box, and then to the cabinet.

FIGURE 9.223 Flexicore Hi-Stress Deck. [The Flexicore Co., Inc.]

FIGURE 9.224 High-capacity system with trench header ducts. [The Flexicore Co., Inc.]
The NEC requires that these connections be made by means of listed metal raceways and listed fittings.

Handhole junction boxes and their relation to the header and concrete cells are shown in Fig. 9.224. The NEC requires that junction boxes be leveled to the floor grade and sealed against the free entrance of water or concrete. Junction boxes shall be of metal and be mechanically and electrically continuous with the header.

Markers (Figs. 9.224 and 9.225) are installed along each cell for the determination of its location and to mark the location of all hidden access points between a header and a cell which is intended for future use. These markers must extend through the floor covering, and a suitable number must be used to locate the cells and provide for system identification.

298. **High-capacity system.** The system shown in Fig. 9.226 is designed to handle eighty-two 100-pair plus one hundred thirty-seven 25-pair telephone cables, or the equivalent in other sizes. The cables feed from the panel through the channel slab, transversely through the 24-in (609.6-mm) trench header duct, then down into the cells of the Flexicore deck. Wiring can run in either direction to telephone floor outlets located at any point along the cells. Every second cell is assigned to telephones, providing lines of availability only 16 in. (406.4 mm) apart.

Electrical distribution is handled through the high-capacity trench-header-duct system shown. Many variations of both systems are possible.
FIGURE 9.26: Installation of outlets and markers. [The Flexicore Co., Inc.]
299. **Inserts for the location of outlets** can be located at any point along a cell. Typical outlets and their installation are shown in Figs. 9.224, 9.225, 9.227, and 9.228. The procedure in installing an outlet is as follows:

1. Mark location of outlet. Use cell markers to line up center of cell.

2. Drill hole for outlet using 17/8-in (47.625-mm) core bit.
3. Drive in outlet drive plug.

4. Screw in floor-outlet nipple.

5. Fish wire to outlet location.
6. Install outlet box. Floor outlets can be installed at any time during the life of the building.

300. NEC requirements for inserts are as follows: Inserts shall be leveled to the floor grade and sealed against the entrance of concrete. They shall be of metal and be fitted with receptacles of the grounded type. A grounding conductor shall connect the insert receptacles to a positive ground connection provided on the header. In cutting through the cell wall for setting inserts or other purposes (such as providing access openings between header duct and cells), chips and other dirt shall not be allowed to remain in the raceway, and the tool used shall be so designed as to prevent it from entering the cell and damaging the conductors.

301. Discontinued outlets (National Electrical Code). When an outlet is discontinued, the conductors supplying the outlet shall be removed from the header and cell. No splices or reinsulated conductors such as abandoned loop wiring shall be allowed in raceways. Refer to Sec. 253 for more information on this topic.

302. Conductors (National Electrical Code). No conductor larger than No. 1/0 shall be installed except by special permission. The total cross-sectional area of all conductors or cables in a header or in an individual cell shall not exceed 40 percent of the interior cross-sectional area of the header or cell.

Splices and taps shall be made only in header-duct access units or junction boxes.

WIRING WITH MULTIOUTLET ASSEMBLIES

303. Multioutlet assemblies consist of a metallic or nonmetallic assembly with convenience outlets built in every few inches. In one type made by the Wiremold Co. (Fig. 9.229) the outlets may be spaced as desired along the raceway and connected by wires laid in the raceway. In another type (Fig. 9.230) the outlets are built in at fixed intervals and connected by copper strips which terminate in terminal screws at each end of each length of raceway.

This type is made in three styles according to the position in which it is to be used: (1) the chair-rail style for flat-surface mounting, (2) the baseboard-cap style for mounting on the top of baseboards or in the corners of mantels and cabinets, and (3) the baseboard-insert style for
recessing in the baseboard or in a plastered wall. Blank sections through which standard-type wires may be run to join plug-in sections are available for use behind radiators or for other inaccessible places where the expensive plug-in strip is not needed. Multioutlet assemblies are used to provide adequate plug receptacles for the utmost convenience in the use of appliances, in dwelling-type use, and for industrial and commercial applications. The multioutlet assembly classification also includes the vertical assemblies that are fed from above a suspended ceiling and anchored to the floor to provide power or communications or both to any desired location, particularly on commercial office environments (Fig. 9.231).

NEC specifications for the use of multioutlet assemblies are as follows: A multioutlet assembly may be used in dry locations. It shall not be used (1) when concealed; (2) where subject to severe physical damage; (3) where the voltage is 300 V or more between conductors unless the assembly is of metal having a thickness of not less than 1.02 mm (0.040 in.); (4) where subject to corrosive vapors; (5) in hoistways; or (6) in hazardous locations, except as specifically allowed by the hazardous location articles of the NEC. A metal multioutlet assembly may be extended through (not run within) dry partitions, provided arrangements are made for removing the cap or cover on all exposed portions and no outlet falls within the partitions.

FIGURE 9.229 Installation of multioutlet assembly of the Plugmold-Snapicoil type: (1) Remove knockout (from inside out) for feed connection and fasten 1/2-in connector into base with a locknut A. No special fittings are needed: there is plenty of room to spin the locknut. (2) At the end of the run, install a No. 2010B blank-end fitting in the base, B and C. (3) Mount base to surface through screw piercings or knockouts, using No. 6 flathead screws. (Some types of surfaces require other methods of fastening.) (4) Lay out Snapicoil, and cover sections to avoid having outlet directly in a corner or over a feed connection. (5) Splice feed wires into Snapicoil conductors D. NOTE In a three-wire harness, black wire with yellow lettering should be used for the switch leg. (6) Snap Snapicoil receptacles into 2000C Holecut cover, E and F: a wire clip can be used to cover G or base to keep wires inside raceways. (7) Snap cover, complete with receptacles, into base. [The Wiremold Co.]

FIGURE 9.231 The relocatable pole assembly diagrammed here is also classified as a multisoutlet assembly.
304. **Various ways of mounting the chair-rail style** on plastered walls are shown in Fig. 9.232. Toggle bolts are used unless a wood strip is available, as in III, when wood screws can be used. The chair-rail style is intended for mounting on flat surfaces at a considerable height above the baseboard. The curved surfaces on the top and bottom give the installation a neat appearance.

![Figure 9.232](image-url) Methods of mounting chair-rail style of plug-in strip.

305. **The baseboard-cap type** has a flat surface on one edge and is curved on the other edge. It is used as illustrated in Fig. 9.233, when there is a corner against which the flat edge can be placed. The curved edge gives a finished appearance to the corner. In this type of mounting, there is usually a wood background so that wood screws can be used for fastening.

![Figure 9.233](image-url) Methods of mounting baseboard-cap style of plug-in strip.
306. **The baseboard type** is set into the wall so that the surface of the strip is flush with the wall surface. When finished buildings are wired with this type, the molding on top of the baseboard is removed, the plug-in strip is placed on top of the baseboard, and the molding is placed against the plug-in strip (Fig. 9.234, III). For new installations a channel can be left in tile, glass, or marble surfaces as shown in Fig. 9.234, I and II, or the plaster can be channeled as shown in Fig. 9.234, IV.

![Figure 9.234](image)

**FIGURE 9.234** Methods of mounting baseboard-insert style of plug-in strip.

307. **Plug-in strip is made in various lengths** from 6 in. to 9 ft (from 152.4 mm to 2.7 m). The lengths are joined together as shown in Fig. 9.235. Copper links connect the terminal screws on two adjoining lengths of plug-in strip (Fig. 9.235, I). Then insulating plates are placed over the terminals (Fig. 9.235, II), and the joint is covered with a coupling of the same exterior finish as the plug-in strip.

![Figure 9.235](image)

**FIGURE 9.235** Method of coupling plug-in strips together.
309. **Heavier-duty multioutlet assemblies.** The types of multioutlet assemblies discussed in the preceding sections are of the light-duty type. Heavier-duty multioutlet assemblies are available in the following types:

1. Two-wire grounding strip for grounding of equipment
2. 20-A receptacle type
3. 30-A receptacle type
4. 50-A receptacle type
5. Combination raceway and multioutlet assembly (Fig. 9.237)

Baseboard types of combination multioutlet assembly and surface raceway are available. Two types are shown in Figs. 9.238 and 9.239.

**FIGURE 9.236** Method of bringing supply circuit into plug-in strip.

**FIGURE 9.237** Combination raceway and multioutlet assembly. Up to three No. 12 Type TW electric conductors can be installed in the raceway space located beneath the standard plug-in-stripe assembly. The additional conductors may be wired either three-phase or single-phase.
FIGURE 9.238  Installation of Plugmold baseboard: (1) Remove knockout (from inside out) for feed connection and fasten \( \frac{1}{2} \)-in connector into base with a locknut A. No special fittings are needed. (2) At the end of the run, install No. 2410B blank-end fitting in the base, B and C. (3) Mount base to surface through screw piercings or knockouts, using No. 6 flathead screws. (Some types of surfaces require other methods of fastening.) (4) Lay out Snapicoil, and cover sections to avoid having outlet directly in a corner or over a feed connection. This method is also available with the receptacles already installed. (5) Splice feed wires onto Snapicoil conductors D. NOTE In a three-wire harness, black wire with yellow lettering should be used for the switch leg. (6) Insert Snapicoil receptacles into 2400C Holecut cover, and snap device clip in place, E and F. The clip can also be used in the base to keep wires inside raceways. (7) Snap cover, complete with receptacles, into 2400B base G. [The Wiremold Co.]

FIGURE 9.239  Base duct.
CABLEBUS WIRING

310. Cablebus is an approved assembly of insulated conductors mounted in a spaced relationship in a ventilated metal protective supporting structure including fittings and conductors. Typical components are shown in Fig. 9.240, which also includes some of the major NEC rules for cablebus.

![Diagram of Cablebus System]

**FIGURE 9.240** Elements of a typical cablebus system and major National Electrical Code requirements. *Electrical Construction and Maintenance*

The original manufacturer of the cablebus wiring system was Husky Products, Inc., subsidiary of Burndy Corp. The system is highly desirable in industrial applications for larger feeders or branch circuits at 600 V or less and in higher distribution voltages of 5 or 15 kV. It can also be used for primary feeders in high-rise buildings or commercial buildings in which load-center unit substations are to be used. Cablebus can be used indoors or outdoors in wet or dry locations. The entire system is factory-fabricated with bottom support blocks (Fig. 9.240) in place.
The sizes of cablebus structures will vary according to the number of conductors. Figure 9.241 shows the four sizes of some of the insulator blocks that are presently available: 3-conductor, 6-conductor, 12-conductor, and 18-conductor; 24- and 27-conductor blocks are also available. Phase arrangements for three-phase circuits are also shown in Fig. 9.241 to provide a closely balanced impedance. Because of carefully selected conductor spacing, transposition of conductors is not required. Controlled spacing also assures low impedance and low voltage drop. The cablebus framework is an all-welded construction for maximum strength, and 12-ft (3.7-m) spacing of supports is standard, but 20-ft spacing is also available. High-pressure splice joints between framework sections provide an excellent path or ground, and the installed framework serves as a grounding conductor.

![Figure 9.241 Sizes of insulating blocks and three-phase conductor arrangements.](image)

311. Types of conductor. The manufacturer of cablebus recommends that only thermoplastic or thermosetting conductors be used in cablebus. At the present time, combining the insulation’s electrical and physical qualities with the cost, the preferred insulation is cross-linked polyethylene. Since cablebus is a ventilated enclosure and conductors are separated by insulating blocks, conductor ampacities may be determined on the basis of single conductors in free air, as in Tables 19 and 22 of Div. 12. Generally, 90°C-rated conductors are recommended and 75°C is the minimum permitted.

312. Installation procedures. The basic installation of the cablebus framework is similar to that of a cable-tray system (Sec. 314). Typical arrangements are shown in Fig. 9.242, in which cablebus is used for primary and secondary feeders and circuits. The conductor-pulling tools are the same as those shown in Fig. 9.248 for cable tray. Conductors are pulled in after the basic framework has been completely installed. After conductors have been pulled in and arranged in proper phase sequence, they are secured to the insulating blocks. The final step is the installation of top covers.
313. National Electrical Code rules. The following Code rules apply to cablebus:

1. Cablebus shall be installed only for exposed work. It may be installed outdoors or in corrosive, wet, or damp locations if identified for such use.
2. Cablebus shall not be installed in hoistways or hazardous locations unless specifically approved for such use.

FIGURE 9.242 Typical cablebus runs for primary and secondary distribution. [Husky Products, Inc., subsidiary of Burndy Corp.]
3. If adequately bonded, cablebus framework may be used as the equipment-grounding conductor for branch circuits and feeders.

4. Cablebus may be used for systems in excess of 600 V, nominal.

5. The current-carrying conductors in cablebus shall have an insulation rating of at least 75°C and be of an approved type.

6. The size and number of conductors shall be that for which the cablebus is designed, and in no case less than 1/0.

7. Insulated conductors shall be supported on blocks or other mounting means designed for the purpose.

8. The individual conductors in a cablebus shall be supported at intervals not greater than 900 mm (3 ft) for horizontal runs and 450 mm (1 1/2 ft) for vertical runs. Vertical and horizontal spacing between conductors shall be not less than one conductor diameter at the points of support.

9. Where the ampacity of cablebus conductors does not correspond to a standard rating of the overcurrent device, the next-higher-rated overcurrent device may be used, only if the rating does not exceed 800 A.

10. Cablebus shall be securely supported at intervals not exceeding 3.7 m (12 ft). Where spans greater than 12 ft are required, the structure shall be specifically designed for the required span length.

11. Cablebus may extend transversely through partitions or walls, other than fire walls, provided the section within the wall is continuous, protected against physical damage, and unventilated.

12. Except when fire stops are required, cablebus may extend vertically through dry floors and platforms and in wet locations where (a) there are curbs or other suitable means to prevent water flow through the floor or platform opening and (b) the cablebus is totally enclosed at the point where it passes through the floor or platform and for a distance of 1.8 m (6 ft) above the floor or platform.

13. Except when fire stops are required, cablebus may extend vertically through dry floors and platforms, provided the cablebus is totally enclosed at the point where it passes through the floor or platform and for a distance of 1.8 m (6 ft) above the floor or platform.

14. Cablebus shall utilize approved fittings for changes in the horizontal or vertical direction of the run, dead ends, terminations in or on connected apparatus or equipment or the enclosures for such equipment, and additional physical protection where required, such as guards for severe mechanical protection.

15. Approved terminating means shall be used for connections to cablebus conductors.

16. Sections of cablebus shall be electrically grounded and bonded.

17. Each section of cablebus shall be marked with the manufacturer’s name or trade designation and the maximum diameter, number, voltage rating, and ampacity of conductors to be installed. Markings shall be so located as to be visible after installation.

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**CABLE TRAYS**

314. A cable-tray system is a unit or an assembly of units or sections, with associated fittings, forming a rigid structural system used to support cables and raceways. Cable trays include ladders, troughs, channels, solid-bottom trays, and similar structures.
The National Electrical Code allows cable tray to contain any approved conduit or raceway with its contained conductors; mineral-insulated metal-sheathed cable (Type MI); armored cable (Type AC); metal-clad cable (Type MC); power-limited tray cable (Type PLTC); nonmetallic-sheathed cable (Types NM, NMC, and NMS); multiconductor service-entrance cable (Types SE and USE); multiconductor underground-feeder and branch-circuit cable (Type UF); power and control tray cables (Type TC); instrument tray cable (Type ITC); and other factory-assembled multiconductor control, signal, or power cables which are specifically approved for installation in cable trays. In practice, the most common types used in cable trays are Type MC metal-clad cable (Fig. 9.87) and Type TC tray cables (Figs. 9.243, 9.244, and 9.245) listed by Underwriters Laboratories Inc. for cable-tray systems. The cable shown in Fig. 9.243 is a polyvinyl chloride- and nylon-insulated 600-V power cable with three 2/0 conductors and a grounding conductor. The cable shown in Fig. 9.244 has the same insulation and contains 19 No. 12 stranded conductors, suitable for 600-V power or control circuits. Figure 9.245 also has the same insulation, and contains three 4/0 power conductors and four No. 12 control conductors, all suitable for 600 V. Cables similar to these can be obtained with a wide variety of conductor sizes. These nonmetallic cables and Type MC metal-clad cables can be installed in cable trays much more easily than other types of cables. Refer to Sec. 13 for a discussion of required wiring configurations for Type TC cable where it exits a cable tray system.

315. Types of cable tray. There are several manufacturers of cable tray, and the types shown in Figs. 9.246 and 9.247 are manufactured by the Globe Division of United States Gypsum. These drawings show various types of cable tray (channel type, solid-cover type, louvered-cover type, ladder type, and solid-bottom type). Also illustrated are a variety of fittings used with the support system, such as elbows or offsets, blind ends, tees, crosses, reducers, dividers, and box connectors. As can be seen in Figs. 9.246 and 9.247, cable trays provide a highly flexible system in any application in which a number of power and/or control cables are required. Cable trays are secured in a manner similar to that described in the sections on rigid metal conduit and busways.
FIGURE 9.246 Typical components of a CABLE-STRUT system. [Globe Division, United States Gypsum Co.]
FIGURE 9.247  Typical components of a CABLE-STRUT system. [Globe Division, United States Gypsum Co.]
An excellent feature of the cable-tray system is that cables can be added, revamped, or removed with minimum effort. When laying out such systems, it is well to plan for future needs by obtaining trays larger than necessary for the initially installed cables. Manufacturers offer many different widths and lengths for each section of cable-tray system, and it is recommended that representatives of these firms be approached when such installations are contemplated.

316. Installation aids. The tools shown in Fig. 9.248 to simplify the pulling of cables into cable trays are typical of those offered by manufacturers of these systems. Locating rollers and pulleys at the proper locations in the system speeds up the installation of cables and prevents damage to them during installation. After cables have been installed, they should be spaced and supported as indicated in Sec. 317.

317. National Electrical Code rules for cable trays are as follows:

1. They shall have suitable strength and rigidity to provide adequate support for all contained wiring.
2. They shall not present sharp edges, burrs, or projections injurious to the insulation or jackets of the wiring.
3. If made of metal, they shall be adequately protected against corrosion or shall be made of corrosion-resistant material.
4. They shall have side rails or equivalent structural members.
5. They shall include fittings or other suitable means for changes in direction and elevation of runs.

6. Nonmetallic cable trays shall be made of fire-retardant material.

7. Cable trays shall be installed as a complete system. Field bends or modifications shall be so made that the electrical continuity of the cable-tray system and support for the cables shall be maintained. In instances where a tray segment is not mechanically continuous, either to the next tray segment or to the equipment where the conductors will terminate, the distance cannot exceed 1.8 m (6 ft), the conductors or cable assemblies must be secured to the cable tray at the transition points, and the open run must not be subject to physical damage. This must be assured through guarding or by location.

8. Each run of cable tray shall be completed before the installation of cables.

9. Supports shall be provided to prevent stress on cables where they enter another raceway or enclosure from cable-tray systems. Cable trays shall be supported at intervals in accordance with the installation instructions.

10. In portions of runs where additional protection is required, covers or enclosures providing the required protection shall be of a material compatible with the cable tray.

11. Multiconductor cables rated 600 V or less shall be permitted to be installed in the same cable tray.

12. Cables rated over 600 V shall not be installed in the same cable tray with cables rated 600 V or less except where separated by either solid fixed barriers of a material compatible with the cable tray or by the metallic cable armor in the case where the cables over 600 V are Type MC.

13. Cable trays shall be permitted to extend transversely through partitions and walls or vertically through platforms and floors in wet or dry locations where the installations, complete with installed cables, are made in accordance with the requirements of Sec. 300.21 of the Code.

14. Cable trays shall be exposed and accessible except as permitted by Par. 13.

15. Sufficient space shall be provided and maintained around cable trays to permit adequate access for installing and maintaining the cables.

16. Metallic cable trays which support electrical conductors shall be grounded as required for conductor enclosures in Article 250 of the Code.

17. When steel or aluminum cable-tray systems are used as equipment-grounding conductors, all the following provisions shall be complied with:
   a. The cable-tray sections and fittings shall be identified as an equipment grounding conductor.
   b. The minimum cross-sectional area of cable trays shall conform to the requirements in Table 392.7(B) of the NEC.
   c. All cable-tray sections and fittings shall be legibly and durably marked to show the cross-sectional area of metal in channel-type cable trays or cable trays of one-piece construction and the total cross-sectional area of both side rails for ladder or trough-type cable trays.
   d. Cable-tray sections, fittings, and connected raceways shall be bonded in accordance with Sec. 250.96 of the NEC, using bolted mechanical connectors or bonding jumpers sized and installed in accordance with Sec. 250.102 of the Code.

18. Cable splices made and insulated by approved methods shall be permitted to be located within a cable tray provided they are accessible. The splices are now permitted to project above the side rails, provided their location does result in exposure to physical damage.

19. In other than horizontal runs, the cables shall be fastened securely to transverse members of the cable trays.
20. A box shall not be required where cables or conductors are installed in bushed conduit or tubing used for support or for protection against physical damage.

21. Where single-conductor cables comprising each phase or neutral of a circuit are connected in parallel as permitted in Sec. 310.4 of the NEC, the conductors shall be installed in groups consisting of not more than one conductor per phase or neutral in order to prevent current unbalance in the paralleled conductors due to inductive reactance.

   Single conductors shall be securely bound in circuit groups to prevent excessive movement due to fault-current magnetic forces, unless single conductors are twisted together, as in triplexed assemblies.

22. Single conductors installed in ladder or ventilated trough cable trays that are 1/0 through 4/0 AWG shall have all single conductors installed in a single layer. Conductors that are bound together to comprise each circuit group can be installed in other than a single layer. For ladder-type tray, the rung spacing under these conductors must not exceed 225 mm (9 in). Single-conductor equipment grounding conductors are permitted to be as small as 4 AWG.

23. A cable tray is not a wireway without a cover. Single conductors in cable trays are only permitted in very restricted circumstances. Specifically, single conductors are only permitted in industrial occupancies with qualified maintenance and supervision, in sizes 1/0 AWG and larger. Medium-voltage conductors run as Type MV cable are permitted to run as single conductors provided they follow the same rules.

GENERAL REQUIREMENTS FOR WIRING INSTALLATIONS

CONDUCTOR REQUIREMENTS

318. Size of conductors. No wire smaller than 14 AWG is allowed for general interior-wiring work. Wires of 18 or 16 AWG may be used for fixture wiring, flexible cords, and some other special applications as given in Sec. 32 of Div. 3. Although 14 AWG wire is allowed for branch circuits, it is a good practice not to use wire smaller than 12 AWG. The larger 12 AWG wire costs only about 20 percent more than 14 AWG, can usually be placed in the same-size conduit or raceway, will have greater mechanical strength, and will reduce the voltage drop and the $I^2R$ heating loss in the wires by approximately 40 percent. Solid conductors of larger size than 10 AWG are not allowed to be used in conduit or raceways. For ease in handling, it is a good practice to use stranded conductors in the larger sizes for open wiring also. The size of wire required, according to the amount of current to be carried by the circuit, is discussed in Sec. 31 of Div. 3, and the ampere current-carrying capacities are given in Tables 18 to 23 of Div. 12.

319. All ungrounded conductors must be protected by fuses or circuit breakers rated in accordance with the allowable ampacity of the conductors as given in Sec. 320 and located at the point where the conductor receives its supply, with the following exceptions. What follows are what is known as the tap rules in the NEC, and one must never be applied to another. That is, it is never permitted to “tap a tap”:

1. For building-service conductors the overcurrent protection is located at the same point as the other service-entrance equipment, which may be at the load end of the service-entrance conductors or at the outer end.

2. The overcurrent protection may be omitted provided the overcurrent unit farther back on the circuit is rated not greater than the ampacity of the smaller conductor.
3. Taps to individual outlets and circuit conductors supplying what constitutes collectively a single household electric range, as in the case of a separate wall-mounted oven and a counter cooktop, shall be considered to be protected by the branch-circuit overcurrent devices when in accordance with the requirements of Sec. 210.19(A)(3) Exception No. 1 of the NEC.

4. If a feeder tap conductor or transformer secondary is not over 3 m (10 ft) long, does not extend beyond the switchboard, panelboard, disconnecting means or control devices which it supplies, is enclosed in a raceway, and has an ampacity not less than the sum of the computed loads of the circuits which it supplies, not less than the rating of the device supplied by the tap conductor, or not less than the rating of the overcurrent protective device at the termination of the tap conductors, it need not be separately protected. For field installations where the tap conductors leave the enclosure or vault in which the tap is made, the rating of the overcurrent device on the line side of the tap conductors shall not exceed 10 times the ampacity of the tap conductor.

5. If the feeder tap conductor is not over 7.5 m (25 ft) long, is protected from physical damage, has an ampacity not less than one-third the rating of the feeder overcurrent device, and terminates in a single circuit breaker or set of fuses that will limit the load to the ampacity of the tap conductors. This device may supply any number of additional overcurrent devices on its load side.

6. For individual motor branch circuits, refer to Sec. 385, Div. 7.

7. For feeders or main conductors supplying more than one motor, refer to Sec. 390, Div. 7.

8. Protection of fixture wires and cords. Where flexible cord used in listed extension cord sets is connected to a branch circuit of Article 210 of the NEC, a 16 AWG or larger conductor may be protected by a 20 A circuit.
   Flexible cord or a tinsel cord approved for use with specific listed appliances or portable lamps shall be considered to be protected by the overcurrent device of the branch circuit of Article 210 of the NEC where applied within the listing requirements.
   Fixture wire shall be considered to be protected by the overcurrent device of the branch circuit of Article 210 of the NEC when conforming to the following:
   - 20-A circuits: 18 AWG up to 15 m (50 ft)
   - 20-A circuits: 16 AWG up to 30 m (100 ft)
   - 20-A circuits: 14 AWG and larger
   - 30-A circuits: 14 AWG and larger
   - 40-A circuits: 12 AWG and larger
   - 50-A circuits: 12 AWG and larger

9. Feeder Taps Supplying a Transformer (Primary Plus Secondary Not Over 7.5 m [25 ft] Long). Conductors supplying a transformer shall be permitted to be tapped, without overcurrent protection at the tap, from a feeder where all the following conditions are met:
   a. The conductors supplying the primary of a transformer have an ampacity at least 1/3 of the rating of the overcurrent device protecting the feeder conductors.
   b. The conductors supplied by the secondary of the transformer shall have an ampacity that, when multiplied by the ratio of the secondary-to-primary voltage, is at least 1/3 of the rating of the overcurrent device protecting the feeder conductors.
   c. The total length of one primary plus one secondary conductor, excluding any portion of the primary conductor that is protected at its ampacity, is not over 7.5 m (25 ft).
   d. The primary and secondary conductors are suitably protected from physical damage.
   e. The secondary conductors terminate in a single circuit breaker or set of fuses that will limit the load current to not more than the conductor ampacity that is permitted by Sec. 310.15 of the NEC.
10. Busway Taps. Busways and busway taps shall be permitted to be protected against overcurrent in accordance with Secs. 368.17 of the NEC.

11. Conductors from Generator Terminals. Conductors from generator terminals that meet the size requirements of 445.13 are to be protected against overload by the generator overload protective device required by 445.12 of the NEC.

12. Feeder Taps Over 25 ft (7.62 m) Long. Conductors over 7.5 m (25 ft) long shall be permitted to be tapped from feeders in high bay manufacturing buildings over 7 m (25 ft) 11 m (35 ft) high at walls, where conditions of maintenance and supervision ensure that only qualified persons will service the systems. Conductors tapped, without overcurrent protection at the tap, to a feeder shall be permitted to be not over 7.5 m (25 ft) long horizontally and not over 30 m (100 ft) total length where all the following conditions are met:
   a. The ampacity of the tap conductors is not less than 1/3 of the rating of the overcurrent device protecting the feeder conductors.
   b. The tap conductors terminate at a single circuit breaker or a single set of fuses that will limit the load to the ampacity of the tap conductors. This single overcurrent device shall be permitted to supply any number of additional overcurrent devices on its load side.
   c. The tap conductors are suitably protected from physical damage or are enclosed in a raceway.
   d. The tap conductors are continuous from end-to-end and contain no splices.
   e. The tap conductors are sized 6 AWG copper or 4 AWG aluminum or larger.
   f. The tap conductors do not penetrate walls, floors, or ceilings.
   g. The tap is made no less than 9 m (30 ft) from the floor.

13. Transformer Secondary Conductors for Industrial Installations. Under conditions of qualified maintenance and supervision, conductors shall be permitted to be connected to a transformer secondary for industrial installations, without overcurrent protection at the connection, where all the following conditions are met:
   a. The length of the secondary conductors does not exceed 7.5 m (25 ft).
   b. The ampacity of the secondary conductors is not less than the secondary current rating of the transformer, and the sum of the ratings of the overcurrent devices does not exceed the ampacity of the secondary conductors. Since taps cannot be tapped, as a practical matter this provision would be limited to tap conductors arriving at the main lugs of a switchboard. A motor control center would not qualify, because overcurrent protection in the form of a singular device is required in accordance with the rating of the common power bus.
   c. All overcurrent devices are grouped.
   d. The secondary conductors are suitably protected from physical damage.

14. Outside Feeder Taps of Unlimited Length. Outside conductors shall be permitted to be tapped to a feeder or to be connected at the transformer secondary, without overcurrent protection at the tap or connection, where all the following conditions are met:
   a. The conductors are suitably protected from physical damage.
   b. The conductors terminate at a single circuit breaker or a single set of fuses that will limit the load to the ampacity of the conductors. This single overcurrent device shall be permitted to supply any number of additional overcurrent devices on its load side.
   c. The tap conductors are installed outdoors, except at the point of termination.
   d. The overcurrent device for the conductors is an integral part of a disconnecting means or shall be located immediately adjacent thereto.
   e. The disconnecting means for the conductors are installed at a readily accessible location either outside of a building or structure, or inside nearest the point of entrance of the conductors. If it is necessary to extend power conductors into a
building beyond where their disconnecting means and overcurrent protection would normally be located, the NEC allows such conductors to continue to be considered, for enforcement purposes, outside the building under any of the following four conditions. The point of entry is artificially extended where the wiring is (1) below at least a 50-mm (2-in) concrete slab under a building, or (2) if installed encased in not less than 50 mm (2 in.) of concrete or brick, or (3) if run within a transformer vault that meets the fire protection requirements of Article 450 Part III, and as covered in Div. 5, Secs. 142 to 148, or (4) run in conduit and placed at least 450 mm (18 in.) of earth beneath a building or other structure.

320. Rating of the overcurrent protective devices. The rating of the overcurrent protective device must be as given below except for the exceptions referred to in Pars. 6 to 8 of Sec. 319. Fuses or circuit breakers shall have ratings not greater than the allowable ampacity of the conductor which they protect, except that when the standard ampere ratings and settings of overcurrent devices do not correspond with the allowable ampacity of conductors, the next-higher standard rating and setting may be used in ratings of 800 A or less.

The effect of the temperature on the operation of thermally controlled circuit breakers should be taken into consideration in the application of such circuit breakers when they are subjected to extremely low or extremely high temperatures.

The allowable ampacity of wires is given in Tables 18 to 23 of Div. 12, and the common sizes of fuses and circuit breakers in Table 38 of Div. 12 and Sec. 240.6 of the NEC.

321. Grounded conductors must not be fused and must not have a circuit breaker in them unless the circuit breaker opens all the wires of the circuit at the same time. The size of a grounded conductor may be changed whenever the sizes of the other conductors are changed, provided the other conductors are protected as outlined in Secs. 319 and 320 (see Div. 8, Sec. 137, for an explanation of the reason for grounding one conductor of a wiring system).

322. Overcurrent devices in parallel. Except for fuses or circuit breakers which are factory-assembled and listed as a single unit, overcurrent devices must not be arranged or installed in parallel.

323. Enclosures for protective devices (National Electrical Code). Overcurrent devices shall be enclosed in cutout boxes or cabinets unless they are a part of an assembly which affords equivalent protection or unless they are mounted on open-type switchboards, panelboards, or control boards, they shall be located in rooms or enclosures free from easily ignitable material and dampness and accessible only to qualified personnel. The operating handle of a circuit breaker may be accessible without opening a door or cover.

Damp or Wet Locations. Metallic enclosures for overcurrent devices in damp or wet locations shall be mounted so there is at least a 6 mm (1/4 in.) air space between the enclosure and the wall or other supporting surface. Enclosures installed in wet locations shall be weatherproof. Nonmetallic enclosures must also comply with the air space rule if the surface on which they are mounted is absorbent, such as wood. The space is not required for nonmetallic enclosures on tile, concrete, or similar surfaces.
**Vertical Position.** Enclosures for overcurrent devices shall be mounted in a vertical plane unless in individual instances this is shown to be impracticable and the handle position is clearly identified as to “on” and “off” in accordance with Sec. 240.81 of the NEC.

**Disconnection of Fuses before Handling.** Disconnecting means shall be provided on the supply side of all fuses in circuits of more than 150 V to ground and cartridge fuses in circuits of any voltage, if accessible to other than qualified persons, so that each individual circuit containing fuses can be independently disconnected from the source of electrical energy, except that a single disconnecting means may be used to control a group of circuits each protected by fuses under the conditions described in Secs. 430.112 and 424.22(C) of the NEC and current-limiting devices on the supply side of the service disconnecting means permitted by 230.82 of the NEC.

**Arcing or Suddenly Moving Parts.** Arcing or suddenly moving parts shall comply with the following:

1. **Location.** Fuses and circuit breakers shall be so located or shielded that persons will not be burned or otherwise injured by their operation.

2. **Suddenly moving parts.** Handles or levers of circuit breakers and similar parts which may move suddenly in such a way that persons in the vicinity are likely to be injured by being struck by them shall be guarded or isolated.

**Flexible cords are used for wiring fixtures,** for the connection of pendants, wiring of luminaires (fixtures) or portable lamps, portable and mobile signs, or appliances, for elevator cables, for the wiring of cranes and hoists, for the connection of stationary equipment to facilitate their frequent interchange, to prevent transmission of noise or vibration, or to facilitate the removal of fixed or stationary appliances for maintenance or repair and the appliance is intended or identified for flexible cord connection, for data processing cables, and connection of moving parts, or for temporary wiring as permitted in 590.4(B) and (C) of the NEC. If the load connected to them is not greater than their carrying capacity, they are considered to be sufficiently protected by the branch-circuit overcurrent device of the branch circuit from which they are tapped. For the ampacity of fixture wire see Table 25, Div. 12. Cords must be connected to devices so that tension in a cord will not be taken by the terminal screws. This can be accomplished by knotting the cord inside the device (Fig. 9.249), by winding it with tape, or by using a clamp fitting. When flexible cords pass through the cover of an outlet box, the hole must have a smooth, well-rounded surface; when they enter lampholders, they must be protected by insulating bushings. Flexible cords shall be installed in continuous lengths without splice or tap. For voltages between 300 and 600,

![FIGURE 9.249 Method of tying a supporting knot in flexible cord (see Sec. 299 for description).](image-url)
9.202  DIVISION NINE

Cords of No. 10 and smaller shall have at least 1.14 mm (45 mils) of thermoset or thermoplastic insulation on each conductor unless Type S, SO, SE, SEO, SEOO, SOO, STO, STOO, or ST cord is used.

In the wiring of fixtures, use conductors having insulation suitable for the current, voltage, and temperature to which they will be subjected. The splice between the fixture conductors and the circuit conductors must be easily accessible for inspection without requiring disconnection of the wiring. (See Fig. 9.250.) This is accomplished by making the canopy so that it will slide down the fixture stem (Fig. 9.251).

325. Splicing of conductors. Conductors in conduit or raceway systems must be continuous from outlet to outlet and must not be spliced or tapped within the raceway or conduit itself, except in wireways or auxiliary gutters. Instructions for the proper splicing of conductors are given in Div. 2.

326. Conductors may be placed in parallel in sizes 1/0 and larger, provided they are of the same length and size and have the same type of insulation and conductor material. The conductors shall be arranged and terminated at each end in such a manner as to ensure equal division of the total current between all the parallel conductors. If the parallel circuits should be carried in different conduits or raceways, at least one wire of each phase must be carried in each conduit or raceway.

327. Induced currents in metal enclosures (National Electrical Code). In metal enclosures, the conductors of circuits operating on alternating current shall be so arranged as to avoid overheating of the metal by induction. When the capacity of a circuit is such that it is impracticable to run all conductors in one enclosure, the circuit may be divided and two or more enclosures may be used, provided each phase conductor of the circuit and the neutral conductor, when one is used, are installed in each enclosure. The conductors of such an installation must conform to the provisions of Sec. 326 for paralleled conductors.
Induced currents in an enclosure can be avoided by so grouping the conductors in one enclosure that the current in one direction will be substantially equal to the current in the opposite direction.

Where the conductors of a circuit pass through individual holes in the wall of a metal cabinet, the effect of induction may be minimized by passing all the conductors in the circuit through an aluminum wall or insulating block used to cover a hole in the metal cabinet sufficiently large for all the conductors of the circuit.

328. At outlets and switch locations at least 150 mm (6 in.) of free conductor must be left for the making of joints and the connection of wiring devices, except when conductors are intended to loop without joints through boxes and fittings. The distance is to be measured from the point the conductors emerge from the enclosing cable sheath in the box, or from the bushing or connector in the case of a raceway. In addition, in the case of deep boxes or boxes with several extension rings, there is an additional requirement that the free conductor be long enough to extend at least 75 mm (3 in.) into the open beyond the box or plaster ring opening. This assures that the conductors will be able to be spliced in a sound manner. This additional rule is waived in the event that all dimensions of the box opening equal or exceed 200 mm (8 in.), because such a large opening allows for a person to work the splice with both hands in the enclosure.

329. When ungrounded conductors of No. 4 and larger enter a cabinet, junction, or pull box, they shall be protected by a smoothly rounded insulating bushing unless they are separated from the raceway fitting by substantial insulating material securely fastened in place. If conduit bushings are constructed wholly of insulating material, a locknut to which the conduit is attached shall be provided both inside and outside the enclosure. If the conductors enter the cabinet vertically, a wiring space must be provided with a width as specified in Sec. 85, Div. 4.

330. Conductors of different systems

1. Conductors of light and power systems of 600 V or less may occupy the same enclosure, without regard to whether the individual circuits are alternating-current or direct-current, only if all conductors are insulated for the maximum voltage of any conductor within the enclosure.

2. Conductors of light and power systems of over 600 V shall not occupy the same enclosure with conductors of light and power systems of 600 V or less.

3. Secondary wiring to electric discharge lamps of 1000 V or less may occupy the same enclosure as the branch-circuit conductors.

4. Control, relay, and ammeter conductors used in connection with any individual motor or starter may occupy the same enclosure as the motor-circuit conductors.

5. Primary leads of electric discharge lamp ballasts, insulated for the primary voltage of the ballast, when contained within the individual wiring enclosure may occupy the same luminaire (fixture) sign, or outline lighting enclosure as the branch-circuit conductors.

331. When conductors or cables are run through bored holes in studs and joists, the holes should be bored at the approximate centers of wood members or at least 32 mm (1¼ in.) from the nearest edge when practical. If there is no objection because of
weakening the building structure, cables or raceways may be laid in notches in the studding or joists if the cable at those points is protected against the driving of nails into it by having the notch covered with a steel plate at least 1.6 mm (1/16 in.) thick before the building finish is applied. Plates made of harder steel alloys that have equivalent resistance to penetration may be used, provided they have been listed for this purpose.

332. Conductors in vertical raceways (any metallic enclosure for conductors) must be supported at intervals not greater than those given in Sec. 111.

333. Wiring in ducts, plenums, and other air-handling spaces (National Electrical Code). No wiring systems of any type shall be installed in ducts used to transport dust, loose stock, or flammable vapors; nor shall any wiring system of any type be installed in any duct, or shaft containing only such ducts, used for vapor removal or ventilation of commercial-type cooking equipment.

Only wiring methods consisting of mineral-insulated metal-sheathed cable, Type MC cable employing a smooth or corrugated impervious metal sheath without an overall nonmetallic covering, electrical metallic tubing, flexible metallic tubing, intermediate metal conduit, or rigid metal conduit without an overall nonmetallic covering shall be installed in ducts or plenums specifically fabricated to transport environmental air. Flexible metal conduit shall be permitted, in lengths not to exceed 1.2 m (4 ft), to connect physically adjustable equipment and devices permitted to be in these ducts and plenum chambers. The connectors used with flexible metal conduit shall effectively close any openings in the connection. Equipment and devices shall be permitted within such ducts or plenum chambers only if necessary for their direct action upon, or sensing of, the contained air. Where equipment or devices are installed and illumination is necessary to facilitate maintenance and repair, enclosed gasketed-type luminaires shall be permitted.

Only totally enclosed, nonventilated insulated busways having no provisions for plug-in connections and wiring methods consisting of mineral-insulated metal-sheathed cable, Type MC cable without an overall nonmetallic covering, and Type AC cable and other factory-assembled multiconductor control or power cable which is specifically listed for the use or listed prefabricated cable assemblies of metallic manufactured wiring systems without a nonmetallic sheath shall be used for wiring in systems installed in other space used for environmental air. Other types of cables and conductors and raceways shall be permitted to be installed in electrical metallic tubing, flexible metallic tubing, intermediate metal conduit, rigid metal conduit without an overall nonmetallic covering, flexible metal conduit, or where accessible metal surface raceway or metal wireway with metal covers or solid bottom metal cable tray with solid metal covers.

Electric equipment with a metal enclosure or with a nonmetallic enclosure listed for the use and having adequate fire-resistant and low-smoke–producing characteristics, and associated wiring material suitable for the ambient temperature may be installed in such other space unless prohibited elsewhere in the NEC. Integral fan systems are permitted where specifically identified for such use.

Habitable rooms or areas of buildings the prime purpose of which is not air handling are not considered ducts or plenums. The space above a suspended ceiling that is used as a collection point for environmental air returning to an air handler is a good example of the space in which these provisions apply.

NFPA Standard for the Installation of Air Conditioning and Ventilating Systems, No. 90A, sets forth requirements of building used for ducts and plenums.

The wiring systems used for information technology equipment and located within air-handling areas created by raised floors are permitted in accordance with Article 645 of the NEC.
334. The approved types of insulation of conductors for different installations are given in Div. 2, Secs. 25 to 36.

335. Insulation resistance. To provide a reasonable factor of safety against short circuits and grounds, completed wiring systems should undergo an insulation-resistance test. The proper instrument for making this test is a megohmmeter. The NEC formerly contained recommended values of resistance for various circuit sizes. However, these values were deleted from the Code because they were misleading. Cable and conductor installations provide a wide variation of conditions with respect to the resistance of insulation. These variations are due to the many types of insulating materials used, insulation thickness, voltage rating, and the length of the circuit. Long circuits may be subject to wide variations in temperature, and this can influence the insulation-resistance values in a test.

While insulation-resistance readings are quantitative, they are also relative and comparable. Accordingly, such readings can be used to indicate the presence of moisture, dirt, and deterioration. Although the operation of a megohmmeter insulation tester is fairly simple, one must know how to interpret the results, and instructions provided for such instruments should be carefully followed.

Because a discussion of all the factors involved with these instruments and various test methods is beyond the scope of this book, anyone interested in this subject should review an instruction manual for insulation testers. Such manuals include instructions for connecting and operating Megger insulation-testing instruments, directions for making insulation-resistance tests on various types of electrical equipment, supplementary instructions and explanations to assist the person who makes the test, and valuable material on how to interpret insulation-resistance readings.

336. Grounded conductor. Every interior-wiring system must have a grounded conductor except as allowed by the Code for certain specific conditions. The grounded conductor must be continuously identified throughout the system.

If a neutral (grounded) conductor is run to a lampholder or any other screw-shell device, the neutral (grounded) conductor must be connected to the screw shell. This requirement does not apply to screw shells that serve as fuseholders.

GENERAL INSTALLATION REQUIREMENTS

337. Working space about electric equipment, 600 V or less (National Electrical Code). Sufficient access and working space shall be provided and maintained around all electric equipment to permit ready and safe operation and maintenance of such equipment. Enclosures housing electrical apparatus that are controlled by lock and key shall be considered accessible to qualified persons.

1. Working Clearances. Except as elsewhere required or permitted in the NEC the dimension of the working space in the direction of access to live parts operating at 600 V or less and likely to require examination, adjustment, servicing, or maintenance while energized shall not be less than indicated in Table 337A. In addition to the dimensions shown in Table 337A, the work space shall not be less than 762 mm (30 in.) wide in front of the electric equipment. Distances shall be measured from the live parts if such are exposed or from the enclosure front or opening if such are enclosed.
The conditions are as follows:

**Condition 1.** Exposed live parts on one side and no live or grounded parts on the other side of the working space, or exposed live parts on both sides effectively guarded by suitable wood or other insulating materials. Insulated wire or insulated busbars operating at not over 300 V shall not be considered live parts.

**Condition 2.** Exposed live parts on one side and grounded parts on the other side. Concrete, brick, or tile walls shall be considered as grounded.

**Condition 3.** Exposed live parts on both sides of the work space (not guarded as provided in Condition 1) with the operator between.

**Dead-Front Assemblies.** Working space shall not be required in back of assemblies such as dead-front switchboards or motor-control centers where there are no renewable or adjustable parts such as fuses or switches on the back and where all connections are accessible from locations other than the back or sides. Where rear access is required to work on nonelectrical parts on the back of enclosed equipment, a minimum working space of 762 mm (30 in.) horizontally shall be provided.

**Low Voltage.** By special permission smaller spaces may be permitted where all uninsulated parts are at a voltage no greater than 30 V rms, 42 V peak, or 60 V dc.

**Existing Buildings.** In existing buildings where electrical equipment is being replaced, Condition 2 working clearance shall be permitted between dead-front switchboards, panelboards, or motor control centers located across the aisle from each other where conditions of maintenance and supervision ensure that written procedures have been adopted to prohibit equipment on both sides of the aisle from being open at the same time and qualified persons who are authorized will service the installation.

2. **Clear Spaces.** Working space required by this section shall not be used for storage. When normally enclosed live parts are exposed for inspection or servicing, the working space, if in a passageway or general open space, shall be suitably guarded.

3. **Access and Entrance to Working Space.** At least one entrance of sufficient area shall be provided to give access to the working space about electric equipment. For equipment rated 1200 A or more and over 1.8 m (6 ft) wide, containing overcurrent devices, switching devices, or control devices, there shall be one entrance to and egress from the required working space not less than 610 mm (24 in.) wide and 2.0 m (6 1/2 ft) high at each end of the working space.

**Unobstructed Exit.** Where the equipment location permits a continuous and unobstructed way of exit travel one means of exit is permitted.

**Extra Work Space.** Where the work space required by Sec. 110.26(A)(1) of the NEC is doubled, only one entrance to the working space is required and it shall be so located that the edge of the entrance nearest the equipment is the minimum clear distance given in Table 337A away from such equipment.

### Table 337A: Working Clearances*
(Table 110.26(A)(1), 2008 NEC)

<table>
<thead>
<tr>
<th>Voltage to ground</th>
<th>Condition 1</th>
<th>Condition 2</th>
<th>Condition 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–150</td>
<td>914 mm (3)</td>
<td>914 mm (3)</td>
<td>914 mm (3)</td>
</tr>
<tr>
<td>151–600</td>
<td>914 mm (3)</td>
<td>1.07 m (3 1/2)</td>
<td>1.22 m (4)</td>
</tr>
</tbody>
</table>

*Reprinted with permission from NFPA 70-2008. National Electrical Code®. Copyright © 2007. National Fire Protection Association. Quincy, Massachusetts 02269. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety.
4. **Illumination.** Illumination shall be provided for all working spaces about service equipment, switchboards, panelboards, or motor control centers installed indoors. Additional lighting fixtures shall not be required where the work space is illuminated by an adjacent light source or as permitted by 210.70(A)(1), Ex. 1 of the NEC for switched receptacles. In electrical equipment rooms, the illumination shall not be controlled by automatic means only.

5. **Headroom.** The minimum headroom of working spaces about service equipment, switchboards, panelboards, or motor control centers shall be 2.0 m (6 1/2 ft). Where the electrical equipment exceeds 2.0 m (6 1/2 ft) in height, the minimum headroom shall not be less than the height of the equipment.

   *Exception.* Service equipment or panelboards in existing dwelling units that do not exceed 200 A.

338. **All cables and raceways** must be continuous from outlet to outlet and from fitting to fitting and must be securely fastened in place. Fittings must be mechanically secured to conduits, raceways, and boxes; and the entire metallic enclosure system must form an electrically continuous conductor. If different portions of a conduit or raceway system or sleeving for cables are exposed to widely different temperatures, as in refrigerating or cold-storage plants, or for passages from outdoors to indoor areas using conditioned air, provision must be made to prevent circulation of air through the raceway from a warmer to a colder section by sealing.

339. **Protection against corrosion and deterioration.** Raceways, cable trays, cablebus, auxiliary gutters, cable armor, boxes, cable sheathing, cabinets, elbows, couplings, fittings, supports, and support hardware shall be of materials suitable for the environment in which they are to be installed.

1. Ferrous raceways, cable trays, cablebus, auxiliary gutters, cable armor, boxes, cable sheathing, cabinets, metal elbows, couplings, fittings, supports, and support hardware shall be suitably protected against corrosion inside and outside (except threads at joints) by a coating of approved corrosion-resistant material, such as zinc, cadmium, or enamel. If protected from corrosion solely by enamel, they shall not be used outdoors or in wet locations as described in Par. 4. Where boxes or cabinets have an approved system of organic coatings and are marked “Raintight,” “Rainproof,” or “Outdoor type,” they may be used outdoors. Where corrosion protection is necessary and conduit is threaded in the field, the threads shall be coated with an approved electrically conductive, corrosion-resistant compound. Stainless steel is not required to have protective coatings.

   Unless made of materials judged suitable for the condition or unless corrosion protection approved for the condition is provided, ferrous or nonferrous metal raceways, cable armor, boxes, cable sheathing, cabinets, elbows, couplings, nipples, fittings, supports, and support hardware shall not be installed in concrete or in direct contact with the earth or in areas subject to severe corrosive influences.

2. Aluminum raceways, cable trays, cablebus, auxiliary gutters, cable armor, boxes, cable sheathing, cabinets, elbows, couplings, nipples, fittings, supports, and support hardware embedded or encased in concrete or in direct contact with the earth shall be provided with supplementary corrosion protection.

3. Nonmetallic raceways, cable trays, cablebus, auxiliary gutters, boxes, cables with a nonmetallic outer jacket and internal metal armor or jacket, cable sheathing, cabinets,
elbows, couplings, nipples, fittings, supports, and support hardware shall be made of material approved for the condition. Where exposed to sunlight, the materials shall be either listed or identified as sunlight resistant. Where subject to exposure to chemical solvents, vapors, splashing, or immersion, materials or coatings shall be either inherently resistant to chemicals based on their listing or be identified for the specific chemical reagent.

4. In portions of dairies, laundries, canneries, and other indoor wet locations, and in locations where walls are frequently washed or where there are surfaces of absorbent materials, such as damp paper or wood, the entire wiring system where installed exposed, including all boxes, fittings, conduits, and cable used therewith, shall be mounted so that there is at least a 6 mm (¼ in.) air space between it and the wall or supporting surface except for nonmetallic boxes and raceway systems installed on nonabsorbent surfaces such as concrete, masonry, or tile.

340. Outlet boxes (see Div. 4) must be provided at each outlet, switch, or junction point for all wiring systems except open wiring. The boxes must be made of metallic material, except that for open wiring on insulators, concealed knob-and-tube wiring, nonmetallic-sheathed or similar cables with entirely nonmetallic sheaths, flexible cords, or nonmetallic raceways the boxes may be of nonmetallic construction. Nonmetallic boxes are permitted with metallic wiring methods if internal bonding is provided between all entries, such as the use of bonding bushings on metallic conduit or tubing entries. In addition, specialized nonmetallic boxes with integral bonding provisions, such as those with embedded metal framework in fiberglass enclosures developed for hazardous locations that are also corrosive, are permitted with metal wiring methods. These boxes must have a means provided within the enclosure to attach an equipment bonding jumper. Whenever a change is made from open or concealed knob-and-tube wiring to one of the other types of wiring, a box or terminal fitting which has a separately bushed hole for each conductor must be used. In terminating conduit wiring at switchboards and control-apparatus locations an insulating bushing instead of a box may be used. If conductors are lead-covered, the bushing need not be insulated.

Care must be exercised in installing boxes and fittings in damp or wet locations so that they are either placed or equipped to prevent moisture or water from entering and accumulating within the box or fitting. In wet locations the boxes or fittings must be listed for use in wet locations.

Round outlet boxes are not allowed when conduits or connectors requiring the use of locknuts or bushings are to be connected to the side of the box.

341. Supports. Boxes shall be securely and rigidly fastened to the surface upon which they are mounted or securely and rigidly embedded in concrete or masonry. Except as otherwise provided in this section, boxes shall be supported from a structural member of the building either directly or by using a metal, polymeric, or wooden brace. If of wood, the brace shall not be less than nominal 25 mm × 50 mm (1 in. × 2 in.) thickness. If of metal, it shall be corrosion-resistant and shall be not less than 0.51 mm (0.020 in.) uncoated.

When mounted in new walls in which no structural members are provided or in existing walls in previously occupied buildings, boxes shall be affixed with approved anchors or clamps so as to provide a rigid and secure installation.

Enclosures not exceeding 1650 cm (100 in³) in size which do not contain devices, receptacles, or switches and do not support luminaires (fixtures) may be considered adequately supported if two or more conduits are threaded into the box wrenchtight and are supported.
within 900 mm (3 ft) of the box on two or more sides; or boxes or conduit bodies containing devices or supporting luminaires may be supported by the connecting conduit when at least two connecting conduits are threaded into the box and rigidly supported within 450 mm (18 in.) of the junction box. The conduit entries must be at hubs that are an integral part of the box or that are identified for the purpose if added in the field. Conduit bodies that are no larger than the largest entering raceway and contain no splices do not require independent support.

342. Ceiling outlet boxes may be supported with wood screws projecting through the holes in the bottom of the box, in frame construction when a wood background is available. If boxes must be supported between wooden beams, bar hangers as shown in Sec. 119 of Div. 4 are used. The hangers are fastened with nails or wood screws to the beams. The box is fastened to the hanger by means of the fixture stud or with two bolts. With concealed conduit wiring in reinforced-concrete ceilings the conduits and the edges of the backing plate of the concrete boxes, bearing against the concrete, support the box. With terra-cotta ceilings a tee made of 3/8-in pipe substantially bearing on the top of the terra-cotta should be used (Fig. 9.250). The pipe projects through the fixture-stud knockout in the back of the box and forms the fixture stud. For exposed wiring on concrete ceilings, screws and lead expansion sleeves should be used. For exposed wiring on steelwork the box should be bolted or clamped to the steel. For exposed wiring on plastered ceilings the box may be fastened on the surface with toggle bolts.

343. Wall outlet boxes in frame construction are fastened to the studs with side hangers which form part of the box (see Sec. 117, Div. 4). With concealed wiring in concrete or brick walls the masonry, being built tight around the box, supports it. The conduit prevents the box from coming loose from the wall. If a pocket has been cut in a brick wall to receive an outlet box and the wall has been channeled for the conduit, the box should be fastened to the wall by two expansion sleeves. With concealed wiring in concrete construction, for the support of a fixture which is too heavy to be safely hung on an ordinary 3/8-in fixture stud, the outlet box should be supported by a pipe support similar to that of Fig. 9.250, embedded in the concrete. For exposed wiring on concrete and brick walls the box may be fastened with wood screws in lead expansion sleeves.

344. Luminaires (lighting fixtures) are usually supported from the fixture stud in the outlet box (Fig. 9.251). A hickey is screwed onto the fixture stud, and the fixture stem is screwed into the hickey. The fixture wires are brought out of the fixture stem through the holes in the hickey and spliced to the circuit wires. The canopy is then slipped up against the ceiling and fastened to the fixture stem with a setscrew. In many cases it is preferable to use outlet boxes which have the fixture stud made integral with the back of the box. In case that type of box is not available, a separate fixture stud (Fig. 9.252) may be installed. The no-bolt type (Fig. 9.252, I) is used for supporting the box from a bar hanger. The body of the stud is on the back of the hanger with the threaded portion projecting through the hanger and through a hole in the center of the box. The nut is screwed on the stud inside the box and holds the box to the hanger. The bolted type (Fig. 9.252, II) either is bolted to the back of the box or, when the box is supported from a wooden member, is held in place with wood screws. The NEC requires that a fixture

![Figure 9.252](https://www.digitalengineeringlibrary.com)
which weighs more than 3 kg (6 lb) or exceeds 400 mm (16 in.) in any dimension must not be supported by the screw shell of the lampholder. Small lighting fixtures consisting of a lampholder and a small shade may be supported from a pendant cord. In this case a box cover with a round hole in the center is used. A knot is tied in the cord inside the box (Fig. 9.249) so that the knot will bear against the cover and support the weight of the fixture. With exposed conduit wiring, elbow or tee conduit fittings are frequently used. The fixture is supported with a short length of conduit which threads into the fixture and into the hub which projects down from the fitting. Sometimes the upper part of the fixture is designed to be fastened as the cover on a 3½- or 4-in outlet box. A fixture which weighs more than 23 kg (50 lb) must be supported independently of the outlet box unless the outlet box is listed for the weight to be supported. Figure 9.253 shows a typical method of attaching a lightweight fixture to a nonmetallic box.

345. **Number of conductors in outlet, device, and junction boxes, and conduit bodies.** Boxes and conduit bodies shall be of sufficient size to provide free space for all enclosed conductors. In no case shall the volume of the box, as calculated in 1. below, be less than the fill calculation as calculated in 2. below. The minimum volume for conduit bodies shall be as calculated in 3. below.

The provisions of this section shall not apply to terminal housings supplied with motors. Boxes and conduit bodies enclosing conductors, size No. 4 or larger, shall also comply with the provisions of Sec. 314.28 of the NEC.

1. **Box volume calculations.** The volume of a wiring enclosure (box) shall be the total volume of the assembled sections, and, where used, the space provided by plaster rings, domed covers, extension rings, etc., that are marked with their volume or are made from boxes the dimensions of which are listed in Table 314.16(A) of the NEC.
   a. **Standard Boxes.** The volumes of standard boxes that are not marked with a cubic inch capacity shall be as given in Table 314.16(A) of the NEC.
   b. **Other Boxes.** Boxes 1650 cm$^3$ (100 in$^3$) or less, other than those described in Table 314.16(A) of the NEC, and nonmetallic boxes shall be durably and legibly marked by the manufacturer with their volume. Boxes described in Table 314.16(A) of the NEC.
that have a larger volume than is designated in the table shall be permitted to have their volume marked as required by this section.

2. **Box fill calculations.** The volumes in paragraphs a. through e. below, as applicable, shall be added together. No allowance shall be required for small fittings such as lock-nuts and bushings.

   a. **Conductor Fill.** Each conductor that originates outside the box and terminates or is spliced within the box shall be counted once, and each conductor that passes through the box without splice or termination shall be counted once. The conductor fill, in cubic inches, shall be computed using Table 314.16(B) of the NEC. A conductor, no part of which leaves the box, shall not be counted.

      Exception. Where an equipment grounding conductor or not over four fixture wires smaller than No. 14, or both, enter a box from a domed luminaire (fixture) or similar canopy and terminate within that box, it shall be permitted to omit these conductors from the calculations.

   b. **Clamp Fill.** Where one or more internal cable clamps, whether factory or field supplied, are present in the box, a single volume allowance in accordance with Table 314.16(B) of the NEC shall be made based on the largest conductor present in the box. No allowance shall be required for a cable connector with its clamping mechanism outside the box.

   c. **Support Fittings Fill.** Where one or more luminaire (fixture) studs or hickeys are present in the box, a single volume allowance in accordance with Table 314.16(B) of the NEC shall be made for each type of fitting based on the largest conductor present in the box.

   d. **Device or Equipment Fill.** For each yoke or strap containing one or more devices of equipment, a double volume allowance in accordance with Table 314.16(B) of the NEC shall be made for each yoke or strap based on the largest conductor connected to a device(s) or equipment supported by that yoke or strap. If the supported item is wide enough such that it cannot be installed in a single-gang box as listed in Table 314.16(A), such as 3-pole 4-wire grounding 125/250-V, 30- or 50-A receptacles commonly used for ranges and clothes dryers, then the allowances will be calculated based on the required number of gangs. In the example given a two-gang box would be required for mounting, and therefore there would be a double allowance for each of the two required gangs, for a total of four allowances.

   e. **Equipment Grounding Conductor Fill.** Where one or more equipment grounding conductors enters a box, a single volume allowance in accordance with Table 314.16(B) of the NEC shall be made based on the largest equipment grounding conductor present in the box. Where an additional set of equipment grounding conductors, as permitted by Section 250.146(D) in the NEC is present in the box, an additional volume allowance shall be made based on the largest equipment grounding conductor in the additional set.

3. **Conduit Bodies.** Conduit bodies enclosing No. 6 conductors or smaller other than short radius conduit bodies as described in Sec. 314.5 of the NEC shall have a cross-sectional area not less than twice the cross-sectional area of the largest conduit or tubing to which it is attached. The maximum number of conductors permitted shall be the maximum number permitted by Table 29 of Div. 12 for the conduit to which it is attached.

   Conduit bodies shall not contain splices, taps, or devices unless they are durably and legibly marked by the manufacturer with their volume. The maximum number of conductors shall be computed using the same procedure for similar conductors in other than standard boxes. Conduit bodies shall be supported in a rigid and secure manner.
346. **Conductors entering boxes or fittings** (National Electrical Code). Conductors entering boxes, conduit bodies, or fittings shall be protected from abrasion and conform to the following:

1. **Openings to be closed.** Openings through which conductors enter shall be adequately closed.
2. **Metal boxes and conduit bodies.** If metal outlet boxes, or conduit bodies, are used with open wiring or concealed knob-and-tube work, conductors shall enter through insulating bushings or, in dry places, through flexible tubing extending from the last insulating support and firmly secured to the box or conduit body. Where raceway or cable is used with metal outlet boxes or conduit bodies, the raceway or cable shall be secured to such boxes and conduit bodies.

**Nonmetallic Boxes.** Nonmetallic boxes shall be suitable for the lowest-temperature-rated conductor entering the box. Where nonmetallic boxes are used with open wiring or concealed knob-and-tube wiring, the conductors shall enter the box through individual holes. Where flexible tubing is used to encase the conductors, the tubing shall extend from the last insulating support to no less than 6 mm (£\(\frac{1}{4}\) in.) beyond any cable clamps inside the box. Where nonmetallic-sheathed cable or multiconductor type UF is used, the cable assembly, including the sheath, shall extend into the box no less than \(\frac{1}{4}\) in. through a nonmetallic-sheathed cable clamp. Where nonmetallic-sheathed cable is used with nominally sized 57 by 100 mm (2\(\frac{1}{2}\)-by-4-in.) boxes mounted in walls or ceilings and the cable is fastened within 200 m (8 in.) of the box measured along the sheath and where the sheath extends into the box no less than 6 mm (\(\frac{1}{4}\) in.), securing the cable to the box shall not be required. In all instances all permitted wiring methods shall be secured to nonmetallic boxes. Conductors 4 AWG and larger are covered in Sec. 300.4(G) of the NEC.

347. **Location.** Conduit bodies and junction, pull, and outlet boxes shall be so installed that the wiring contained in them can be rendered accessible without removing any part of the building or, in underground circuits, without excavating sidewalks, paving earth, or other substance that is to be used to establish the finished grade.

**Exception.** Listed boxes shall be permitted where covered by gravel, light aggregate, or noncohesive granulated soil if their location is effectively identified and accessible for excavation.

In walls or ceilings of concrete, tile, gypsum, plaster or other noncombustible material (National Electrical Code), boxes shall be so installed that the front edge of the box will not set back of the finished surface more than 6 mm (\(\frac{1}{4}\) in.). In walls and ceilings constructed of wood or other combustible material, outlet boxes shall be flush with the finished surface or project therefrom.

348. **Covers and canopies** (National Electrical Code). In completed installations each outlet box shall be provided with a cover, faceplate, lampholder, or luminaire fixture canopy, except where the installation complies with 410.24(B).

1. Nonmetallic or metal covers and plates may be used with nonmetallic outlet boxes. Where metal covers or plates are used, they are subject to the grounding requirements of Sec. 404.9(B) of the NEC.
2. If a luminaire (fixture) canopy or pan is used, any combustible wall or ceiling finish exposed between the edge of the canopy or pan and the outlet box shall be covered with noncombustible material.

3. Covers of outlet boxes and conduit bodies having holes through which flexible-cord pendants pass shall be provided with bushings designed for the purpose or shall have smooth, well-rounded surfaces on which the cords may bear. So-called hard-rubber or composition bushings shall not be used.

349. Pull and junction boxes (National Electrical Code). Boxes and conduit bodies used as junction boxes shall conform to the following:

1. **Minimum Size.** For raceways containing conductors of 4 AWG or larger (if required to be insulated), and for cables* containing conductors of 4 AWG or larger, the minimum dimensions of a pull or junction box installed in a raceway or cable run shall conform to the following:
   a. **Straight pulls.** In straight pulls the length of the box shall be not less than 8 times the trade diameter of the largest raceway.
   b. **Angle or U pulls, or Splices.** Where angle or U pulls, or splices are made, the distance between each raceway entry inside the box and the opposite wall of the box shall not be less than 6 times the trade diameter of the largest raceway in a row. This distance shall be increased for additional entries by the amount of the sum of the diameters of all other raceway entries in the same row on the same wall of the box. Each row shall be calculated individually, and the single row that provides the maximum distance shall be used.

   Exception. Where a raceway or cable entry is in the wall of a box or conduit body opposite a removable cover and where the distance from that wall to the cover is in conformance with the column for one wire per terminal in Table 312.6(A) in the NEC.

   The distance between raceway entries enclosing the same conductor shall not be less than 6 times the trade diameter of the larger raceway.
   c. Boxes or conduit bodies of lesser dimensions than those required in Subpars. a and b of this section may be used for installations of combinations of conductors that are less than the maximum conduit or tubing fill (of conduits or tubing being used) permitted by Table 1 of Chap. 9 of the NEC, provided that the box has been listed for and is permanently marked with the maximum number of conductors and the maximum AWG size permitted.

   Exception. Terminal housings supplied with motors which shall comply with the provisions of Sec. 430.12 of the Code.

2. **Conductors in Pull or Junction Boxes.** In pull boxes or junction boxes having any dimension over 1.8 m (6 ft), all conductors shall be cabled or racked up in an approved manner.

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*When transposing cable size into raceway size in Subpars. a and b, the minimum trade-size raceway required for the number and size of conductors in the cable shall be used.
3. **Covers.** All pull boxes, junction boxes, and conduit bodies, shall be provided with covers compatible with the box or conduit body construction and suitable for the conditions of use. Where metal covers are used, they shall comply with the grounding requirements of Sec. 250.110 of the NEC.

4. **Permanent Barriers.** Where permanent barriers are installed in a box, each section shall be considered as a separate box.

### 350. Cabinets, cutout boxes, and meter socket enclosures.

The field-wiring requirements of the NEC with respect to cabinets, cutout boxes, and meter socket enclosures are as follows:

1. **Damp or Wet Locations.** In damp or wet locations, surface-type enclosures shall be so placed or equipped as to prevent moisture or water from entering and accumulating within the cabinet or cutout box and shall be mounted so there is at least a 6 mm (1/4 in.) air space between the enclosure and the wall or other supporting surface. Enclosures installed in wet locations shall be weatherproof. Nonmetallic cabinets and cutout boxes may be installed without the air space on a concrete, masonry, tile, or similar surface. Raceways or cables entering enclosures in wet locations must use entrance fittings listed for wet locations if the entry point is above the level of uninsulated live parts.

2. **Position in Wall.** In walls of concrete, tile, or other noncombustible material, cabinets shall be so installed that the front edge of the cabinet will not set back of the finished surface more than 6 mm (1/4 in.). In walls constructed of wood or other combustible material, cabinets shall be flush with the finished surface or project therefrom.

3. **Repairing Noncombustible Surfaces.** Noncombustible surfaces that are broken or incomplete shall be repaired so there will be no gaps or open spaces greater than 3 mm (1/8 in.) at the edge of the cabinet or cutout box employing a flush-type cover.

4. **Conductors Entering Cabinets or Cutout Boxes.** Conductors entering cabinets or cutout boxes shall be protected from abrasion and shall conform to the following:
   a. **Openings to be closed.** Openings through which conductors enter shall be adequately closed.
   b. **Metal cabinets cutout boxes and meter socket enclosures.** If metal enclosures are used with open wiring or concealed knob-and-tube wiring, conductors shall enter through insulating bushings or, in dry locations, through flexible tubing extending from the last insulating support and firmly secured to the cabinet, cutout box or meter socket enclosure.
   c. **Cables.** Where cable is used, each cable shall be secured to the enclosure. An elaborate exception to this rule covers the acceptable use of a raceway sleeve to entrain a group of nonmetallic cables into an enclosure. These rules are covered in detail in Sec. 85 of Div. 4.

5. **Deflection of Conductors.** Conductors at terminals or conductors entering or leaving cabinets or cutout boxes and the like shall conform to the following:
   a. **Width of wiring gutters.** Conductors in parallel shall be judged on the basis of the number of conductors in parallel. Conductors shall not be deflected within a cabinet or cutout box unless a gutter having a width in accordance with Table 312.6(A) of the NEC is provided. Conductors in parallel in accordance with 310.4 shall be judged on the basis of the number of conductors in parallel.
   b. **Wire Bending Space at Terminals.** Wire bending space at each terminal shall be provided in accordance with 1. or 2. below.
      1. **Conductors Not Entering or Leaving Opposite Wall.** Table 312.6(A) of the NEC (see Div.12, Table 33) shall apply where the conductor does not enter or leave the enclosure through the wall opposite its terminal.
2. **Conductors Entering or Leaving Opposite Wall.** Table 312.6(B) of the NEC (see Div. 12, Table 34) shall apply where the conductor enters or leaves the enclosure through the wall opposite its terminal. This table requires greater spacings, but there are two exceptions:

a. Where the distance between the wall and its terminal is in accordance with Table 312.6(A), a conductor shall be permitted to enter or leave an enclosure through the wall opposite its terminal provided the conductor enters or leaves the enclosure where the gutter joins an adjacent gutter that has a width that conforms to Table 312.6(B) of the NEC for that conductor.

b. A conductor not larger than 350 kcmil shall be permitted to enter or leave an enclosure containing only a meter socket(s) through the wall opposite its terminal, provided the terminal is a lay-in type where either:
   1. The terminal is directed toward the opening in the enclosure and is within a 45° angle of directly facing the enclosure wall, or
   2. The terminal is directly facing the enclosure wall and offset is not greater than 50 percent of the bending space specified in Table 312.6(A) of the NEC.

   **NOTE:** Offset is the distance measured along the enclosure wall from the axis of the centerline of the terminal to a line passing through the center of the opening in the enclosure.

c. **Insulated fittings.** In accordance with NEC 300.4(G), where raceways contain 4 AWG insulated circuit conductors and these conductors enter a cabinet, box, enclosure, or raceway, the conductors shall be protected by a substantial bushing providing a smoothly rounded insulating surface unless the conductors are separated from the raceway fitting by substantial insulating material securely fastened in place. If conduit bushings are constructed wholly of insulating material, a locknut shall be provided both inside and outside the enclosure to which the conduit is attached. The insulating bushing or insulating material shall have a temperature rating not less than the insulation temperature rating of the installed conductors.

   **Exception.** Where threaded hubs or bosses that are an integral part of a cabinet, box enclosure, or raceway provide a smoothly rounded or flared entry for conductors.

d. Wire bending space in enclosures for motor controllers with provisions for one or two wires per terminal is covered by Sec. 430.10(B) of the NEC.

6. **Space in Enclosures.** Cabinets and cutout boxes shall conform to the following:

a. Cabinets and cutout boxes shall have sufficient space to accommodate all conductors installed in them without crowding.

b. **Enclosures for Switches or Overcurrent Devices.** Enclosures for switches or overcurrent devices shall not be used as junction boxes, auxiliary gutters, or raceways for conductors feeding through or tapping off to other switches or overcurrent devices unless adequate space for this purpose is provided. The conductors shall not fill the wiring space at any cross section to more than 40 percent of the cross-sectional area of the space, and the conductors, splices, and taps shall not fill the wiring space at any cross section to more than 75 percent of the cross-sectional area of that space.

7. **Side- or Back-Wiring Spaces or Gutters.** Cabinets and cutout boxes shall be provided with back-wiring spaces, gutters, or wiring compartments as required by Sec. 312.11(C) and (D) of the Code.

351. **Auxiliary gutters** (National Electrical Code). Auxiliary gutters, used to supplement wiring spaces at meter centers, distribution centers, switchboards, and similar points of wiring systems, may enclose conductors or busbars but shall not be used to enclose...
switches, overcurrent devices, appliances, or other similar equipment. Refer to Sec. 28 for general information, including distinctions between auxiliary gutters and wireways. They are available in both sheet metal and flame-retardant nonmetallic forms. The enclosures have hinged or removable covers for housing and protecting electrical wires, cables, and busbars. The enclosures are designed for conductors to be laid in place after the enclosures have been installed as a complete system.

1. **Uses not Permitted.** An auxiliary gutter shall not extend a greater distance than 9 m (30 ft) beyond the equipment which it supplements, except in elevator work. Any further extension shall comply with the rules for wireways or busways. Auxiliary gutters must not be used to enclose switches, overcurrent devices, appliances, or other similar equipment.

2. **Supports.** Sheet metal gutters shall be supported throughout their length at intervals not exceeding 1.5 m (5 ft). Nonmetallic auxiliary gutters shall be supported at intervals not to exceed 900 mm (3 ft) and at each end or joint, unless listed for other support intervals. In no case shall the distance between supports exceed 3 m (10 ft).

3. **Covers.** Covers shall be securely fastened to the gutter.

4. **Number of Conductors.** The sum of the cross-sectional areas of all contained conductors at any cross section of sheet metal and nonmetallic auxiliary gutters shall not exceed 20 percent of the interior cross-sectional area of the gutter. Sheet metal auxiliary gutters shall not contain more than 30 conductors at any cross section unless the conductors are made subject to the derating factors in 310.15(B)(2)(a). Signaling circuit or controller conductors between a motor and its starter and used only for starting duty are not considered current-carrying conductors. Nonmetallic auxiliary gutters are subject to the same fill limitations.

5. **Ampacity of Conductors.** Where the number of current-carrying conductors contained in a sheet metal auxiliary gutter is 30 or fewer, the adjustment factors specified in 310.15(B)(2)(a) of the NEC, shall not apply. If the number of current-carrying conductors, including neutral conductors classified as current carrying under the provisions of 310.15(B)(4), exceeds 30, the derating factors specified in 310.15(B)(2)(a) of the NEC, shall be applicable to all current-carrying conductors in the sheet metal auxiliary gutter. The current carried continuously in bare copper bars in auxiliary gutters shall not exceed 1.5 A/mm² (1000 A/in²) of cross section of the conductor. For bare aluminum bars, the current carried continuously is limited to 1.09 A/mm² (700 A/in²). Nonmetallic auxiliary gutters do not have any exemption from the 310.15(B)(2)(a) derating factors, so for them, derating applies anytime the current-carrying conductors exceed three, just as for tubular raceways.

6. **Clearance of Bare Live Parts.** Bare conductors shall be securely and rigidly supported so that the minimum clearance between bare current-carrying metal parts of different potential mounted on the same surface shall be not less than 50 mm (2 in.) or less than 25 mm (1 in.) for parts that are held free in the air. A spacing not less than 1 in. shall be secured between bare current-carrying metal parts and any metal surface. Adequate provision shall be made for expansion and contraction of busbars.

7. **Splices and Taps.** Splices and taps shall conform to the following:
   a. Splices or taps, made and insulated by approved methods, may be located within gutters if they are accessible by means of removable covers or doors. The conductors, including splices and taps, shall not fill the gutter to more than 75 percent of its area.
   b. Taps from bare conductors shall leave the gutter opposite their terminal connections and conductors shall not be brought in contact with uninsulated current-carrying parts of different potential.
c. All taps shall be suitably identified at the gutter as to the circuit or equipment which they supply.

d. Tap connections from conductors in auxiliary gutters shall be provided with overcurrent protection in conformity with the provisions of Secs. 319 and 320.

8. **Construction and Installation.** Auxiliary gutters shall comply with the following:

   a. Gutters shall be so constructed and installed that adequate electrical and mechanical continuity of the complete raceway system will be secured.

   b. Gutters shall be of substantial construction and shall provide a complete enclosure for the contained conductors. All surfaces, both interior and exterior, shall be suitably protected from corrosion. Corner joints shall be made tight, and if the assembly is held together by rivets, bolts or screws, these shall be spaced not more than 300 mm (12 in.) apart.

   c. Suitable bushings, shields, or fittings having smooth, rounded edges shall be provided where conductors pass between gutters, through partitions, around bends, between gutters and cabinets or junction boxes, and at other locations where necessary to prevent abrasion of the insulation of the conductors.

   d. Where insulated conductors are deflected within the auxiliary gutter, either at the ends or where conduits, fittings, or other raceways or cables enter or leave the gutter, or where the direction of the gutter is deflected more than 30\(^\circ\), dimensions correspond to those required for one wire per terminal in cabinets and cutout boxes as given in Sec. 312.6(A) of the Code (reproduced in Div. 12, Table 33). If a short section of the auxiliary gutter is used as a pull box, the spacing rules in Sec. 349 apply for both straight and angle pulls.

   e. Sheet metal auxiliary gutters installed indoors or outdoors in wet locations shall be suitable for such locations.

      1. Nonmetallic auxiliary gutters installed outdoors shall:
         a. Be listed and marked as suitable for exposure to sunlight; and
         b. Be listed and marked as suitable for use in wet locations; and
         c. Be listed for the maximum ambient temperature of the installation, and marked for the installed conductor insulation temperature rating.

      d. Have expansion fittings installed where the expected length change due to expansion and contraction due to temperature change is more than 6 mm (0.25 in.).

   2. Nonmetallic auxiliary gutters installed indoors shall:

      a. Be listed for the maximum ambient temperature of the installation and marked for the installed conductor insulation temperature rating.

      b. Have expansion fittings installed where expected length change due to expansion and contraction due to temperature change is more than 6 mm (0.25 in.).

9. **Grounding.** Grounding shall be in accordance with Article 250.

352. **There are two types of grounds in interior-wiring systems:**

   1. System grounds (grounding electrode conductors)

   2. Equipment and conductor-enclosure grounds

   A system ground refers to the condition of having one wire of a circuit connected to ground. The reason for doing this is explained in Secs. 132 and 133, Div. 8.

   An equipment or conductor-enclosure ground refers to connecting the noncurrent-carrying metal parts of the wiring system or equipment to ground. This is done so that the metal parts with which a person might come in contact are always at or near ground potential. With this condition there is less danger that a person touching the equipment or conductor
enclosure will receive a shock. Also metal conduit, raceways, and boxes may be in contact with metal parts of the building at several points. If an accidental contact occurs between an ungrounded conductor and its metal enclosure, a current may flow to ground through a stray path made up of sections of metal lath, metal partitions, piping, or other similar conductors. If the equipment is grounded, the resistance of the path through the grounding conductor will usually be much less than the resistance through the stray path, and not much current will flow through the stray path. Sufficient current will usually flow through the grounded path to blow the circuit fuse or trip the circuit breaker and thus open the circuit until repairs can be made. On the other hand, if the equipment is not grounded, sufficient current may flow through the stray path to heat up some section to a sufficient temperature to ignite wood or other flammable material with which it is in contact. The current may not be sufficient to operate the fuse or circuit breaker, especially if the contact occurs on large-size feeders.

353. The following items of equipment and conductor enclosures must be connected to the equipment grounding conductor:

1. **Metal Conductor Enclosures.** Unless exempted by the provisions of 3i, in general all such enclosures shall be connected to the equipment grounding conductor. There are limited exceptions, including runs of less than 7.5 m (25 ft), that are extensions of existing installations comprising wiring methods that do not include an equipment grounding conductor, that are free from probable contact with ground, grounded metal, metal lath, or other conductive material, and that are guarded against contact by persons. Short sections of metal enclosures or raceways used to provide support or protection of cable assemblies from physical damage need not be grounded, and metal elbows installed in nonmetallic raceway runs need not be grounded if the metal elbow is isolated from contact by direct burial to a depth of not less than 450 mm (18 in.) measured from all points of the elbow, or by concrete encasement not less than 50 mm (2 in.) thick.

2. **Fixed Equipment: General.** Under any of the following conditions, exposed noncurrent-carrying metal parts of fixed equipment, which are likely to become energized, shall be connected to an equipment grounding conductor

   a. Where equipment is supplied by means of a wiring method that provides an equipment grounding conductor except as noted in 1. above.
   b. Where equipment is located in a wet or damp location and is not isolated.
   c. Where equipment is located within 2.5 m (8 ft) vertically and 1.5 m (5 ft) horizontally of grounded objects or ground and within reach of persons.
   d. Where equipment is in a hazardous location.
   e. Where equipment operates with any terminal at more than 150 V to ground.

   f. The following are exceptions to these rules requiring grounding connections:

      (1) Metal frames of electrically heated appliances, exempted by special permission, in which case these metal frames shall be permanently and effectively insulated from ground
      (2) Transformers and capacitor cases and other distribution apparatus mounted on wooden poles at a height of more than 2.5 m (8 ft) from the ground
      (3) Listed equipment protected by a system of double insulation, or its equivalent, is not required to be grounded. Where such a system is used, the equipment shall be distinctively marked.

3. **Fixed Equipment: Specific.** Exposed noncurrent-carrying metal parts of the kinds of equipment listed in a through k, and enclosures listed in l and m even where not exposed, shall be connected to the equipment grounding conductor regardless of voltage:
a. Switchboard frames and structures supporting switching equipment, except that frames of 2-wire dc switchboards need not be grounded where effectively insulated from ground.

b. Generator and motor frames in an electrically operated pipe organ unless effectively insulated from ground and the motor driving it.

c. Frames of motors as specified in Sec. 430.242 of the Code.

d. Enclosures for motor controllers unless attached to ungrounded portable equipment.

e. Electric equipment of elevators and cranes.

f. Electric equipment in commercial garages, theaters, and motion-picture studios, except pendant lampholders on circuits of not more than 150 V to ground.

g. Electric signs, outline lighting, and associated equipment.

h. Motion-picture projection equipment.

i. Equipment supplied by Class 1 circuits shall be grounded unless operating at less than 50 V. Equipment supplied by Class 1 power-limited circuits, by Class 2, and Class 3 remote-control and signaling circuits and by fire alarm circuits shall be grounded when Part II or VIII of Article 250 of the Code requires system grounding of those circuits.

j. Luminaires (lighting fixtures) as provided in Part V of Article 410 of the NEC.

k. Permanently mounted electrical equipment and skids on skid-mounted equipment grounded with an equipment bonding jumper sized per 250.122.

l. Motor-operated water pumps including the submersible type.

m. Metal well casings where a submersible pump is used shall be bonded to the pump circuit equipment grounding conductor.

4. Nonelectrical Equipment. The following metal parts shall be connected to the equipment grounding conductor:

a. Frames and tracks of electrically operated cranes and hoists

b. The metal frame of a nonelectrically driven elevator car to which electric conductors are attached

c. Hand-operated metal shifting ropes or cables of electric elevators

NOTE If extensive metal in or on buildings may become energized and is subject to personal contact, adequate bonding and grounding will provide additional safety.

5. Equipment Connected by Cord and Plug. Under any of the following conditions, exposed noncurrent-carrying metal parts of cord- and plug-connected equipment which are likely to become energized shall be connected to the equipment grounding conductor:

a. In hazardous locations (see Articles 500 to 517 of the Code).

Exception. Listed tools, listed appliances, and listed equipment covered in “b” through “d” and protected by a system of double insulation or its equivalent need not be grounded. Where such a system is employed, the equipment shall be distinctively marked.

b. Where operated at more than 150 V to ground, except:

(1) Motors, where guarded

(2) Metal frames of electrically heated appliances exempted by special permission, in which case the frames shall be insulated from ground.

c. In residential occupancies, (1) refrigerators, freezers, and air conditioners; (2) clothes-washing, clothes-drying, and dish-washing machines, waste disposers, information technology equipment, sump pumps, and electrical aquarium equipment; and (3) hand-held, motor-operated tools and motor-operated appliances of the following types: hedge clippers, lawn mowers, snowblowers, and wet scrubbers; and (4) portable hand lamps.

Portable tools or appliances are not intended to be used in damp, wet, or conductive locations unless they are grounded, double-insulated, or supplied by an isolation transformer.
In other than residential occupancies, (1) refrigerators, freezers, and air conditioners; (2) clothes-washing, clothes-drying, and dish-washing machines, information technology equipment, sump pumps, and electrical aquarium equipment; (3) hand-held, motor-operated tools, stationary and fixed motor-operated tools, and light-industrial motor-operated tools; (4) motor-operated appliances of the following types: hedge clippers, lawn mowers, snowblowers, and wet scrubbers; (5) portable hand lamps; (6) cord- and plug-connected appliances used in damp or wet locations or by persons standing on the ground or on metal floors or working inside metal tanks or boilers; (7) tools that are likely to be used in wet and conductive locations.

Exception. Tools and portable hand lamps that are likely to be used in wet and conductive locations need not be grounded when supplied through an isolating transformer with an ungrounded secondary of not over 50 V.

354. The types of wiring systems required to have a system ground are as follows:

1. Two-wire dc systems of not more than 300 V supplying premises wiring unless the system supplies industrial equipment in limited areas and is equipped with a ground detector as described in Div. 1. A system operating at 50 V or less between conductors need not be grounded.
   Rectifier-derived dc systems supplied by an ac system complying with Sec. 250.20 of the Code and dc fire alarm circuits having a maximum current of 0.030 A need not be grounded.
2. Three-wire dc systems supplying premises wiring.
3. AC systems, provided the grounded conductor can be so arranged that the maximum voltage to ground is between 50 and 150 V. Systems that are three-phase wye-connected with the neutral conductor used as a current-carrying conductor must be grounded, and three-phase delta-connected systems where the midpoint of one phase winding is used as a circuit conductor, must be grounded. Any uninsulated service conductor must be grounded. AC systems of 1 kV and higher must be grounded when they are used to supply mobile or portable equipment. High-impedance grounded systems are permitted as in Sec. 356.
4. AC systems of less than 50 V if supplied by transformers from systems of more than 150 V to ground, or if the transformer supply system is ungrounded, or if run overhead outside buildings.
5. AC systems of 50 to 1000 V supplying premises wiring of the following types are not required to be grounded; in all instances such ungrounded systems must employ ground detectors:
   a. Electric systems used exclusively to supply industrial electric furnaces for melting, refining, tempering, and the like.
   b. Separately derived systems used exclusively for rectifiers supplying only adjustable-speed industrial drives.
   c. Separately derived systems supplied by transformers that have a primary voltage rating less than 1000 V, provided that all the following conditions are met:
      (1) The system is used exclusively for control circuits.
      (2) The conditions of maintenance and supervision assure that only qualified persons will service the installation.
      (3) Continuity of control power is required.
   d. Other systems not required to be grounded in accordance with item (3) above.
355. **Circuits which must not be grounded.** Circuits for electric cranes operating over combustible fibers in Class III hazardous locations as provided in 503.13 of the NEC (refer to Sec. 383 for description of hazardous locations), isolated circuits in health care facilities, and circuits to electrolytic cells and secondary circuits of lighting systems as provided in 411.5(A) of the NEC.

356. **High-impedance grounded-neutral systems** (Adapted from Practical Electrical Wiring, 20th ed., © Park Publishing, 2008, all rights reserved) combine the best features of the ungrounded systems in terms of reliability, and the best features of the grounded systems in terms of their ability to dissipate energy surges due to their grounding connection. This procedure is covered in NEC 250.36.

These systems behave like ungrounded systems in that the first ground fault will not cause an overcurrent device to operate. Instead, alarms required by NEC 250.36(2) will alert qualified supervisory personnel. Remember, a capacitor is two conductive plates separated by a dielectric. A plant wiring system consists of miles and miles of wires, all of which are separated by their insulation. This means that a plant wiring system is a giant though very inefficient capacitor, and it will charge and discharge 120 times each second. The resistance is set such that the current under fault conditions is only slightly higher than the capacitive charging current of the system. Since a fault will often continue until an orderly shutdown can be arranged, the resistor must be continuously rated to handle this duty safely.

As shown in Fig. 9.254, the grounding impedance must be installed between the system neutral and the grounding electrode conductor. Where a system neutral is not available, the grounding impedance must be installed between the neutral derived from a grounding transformer and the grounding electrode conductor. The neutral conductor between the neutral point and the grounding impedance must be fully insulated. Size it at 8 AWG minimum. This size is for mechanical concerns; the actual current is on the order of 10 A or less.

Contrary to the normal procedure of terminating a neutral at a service disconnecting means enclosure, when the system is high-impedance grounded, the grounded conductor is prohibited from being connected to ground except through the grounding impedance. In addition, the neutral conductor connecting the transformer neutral point to the grounding impedance is not required to be installed with the phase conductors. It can be installed in a separate raceway to the grounding impedance. The normal procedure (usually performed by the utility) of adding a grounding electrode outside the building at the source of a grounded system (should one be used as the energy source for an impedance-grounded system) must *not* be observed, because any grounding currents returning through the earth to the outdoor electrode will bypass and therefore desensitize the monitor.

An equipment bonding jumper must be installed unspliced from the first system disconnecting means or overcurrent device to the grounded side of the grounding impedance. The grounding electrode conductor can be attached at any point from the grounded side of the grounding impedance to the equipment grounding connection at the service equipment of the first system disconnecting means.
This drawing shows a likely retrofit on a formerly ungrounded installation, with its neutral conductor created through a zig-zag grounding autotransformer. Note that the size of the equipment bonding jumper depends on the end to which the grounding electrode conductor is connected. A connection at the line (left) end makes the bonding jumper a functional extension of the grounding electrode conductor, and it must be sized accordingly. A connection at the load (right) end makes the bonding jumper a functional extension of the neutral, normally sized at 8 AWG.
357. Location of the system ground  (Fig. 9.255)

1. For off premise dc systems the ground must be at the supply station and nowhere else.
2. For ac systems there must be a ground at the secondary of the transformer supplying the system. There must be another ground at each building service to the grounded service conductor at an accessible point from the point of connection of the service drop or service lateral conductor to the service disconnecting means.
3. For multiple buildings served by a single service in one of them, and with other buildings supplied by feeders or branch circuits or both, the system ground must be located at the service. System grounding connections are generally prohibited at all electrically downstream locations from the service connection. Instead, an equipment grounding conductor run with the other supply circuit conductors provides the grounding protection for wiring and equipment in each building. For “existing premises wiring systems only,” a special exception allows downstream system grounding connections, provided there are no parallel metallic return paths that would allow current that should flow over the grounded circuit conductor to instead return to the service through other paths. Examples include an equipment grounding conductor, including a wiring method to the second building that is itself an equipment grounding conductor, such as rigid metal conduit. In such a case a system grounding connection in the second building would send normal circuit current through the conduit in parallel with the enclosed grounded circuit conductor (usually a neutral). Another example would be a metallic water piping system common to both buildings; since such systems must be bonded to the grounding systems in each building the water pipes would become parallel conductors for the same reason.
4. For a separately derived system the common main grounding conductor shall be made at the transformer, generator, or other source of supply or at the switchboard, panelboard, or other disconnecting means location, on the supply side of the first switch controlling the system.

358. The conductor to be grounded. For alternating-current premises-wiring systems the conductor to be grounded shall be as follows:

1. Single-phase two-wire: the grounded-circuit conductor
2. Single-phase three-wire: the neutral conductor
3. Multiphase systems having one wire common to all phases: the common conductor
4. Multiphase systems where one phase is grounded: one phase conductor
5. Multiphase systems in which one phase is used as in Par. 2: the neutral conductor

Grounded conductors shall be identified by the means specified in Article 200 of the NEC.
359. The noncurrent-carrying metallic parts of fixed equipment are considered to be satisfactorily grounded under any one of the following conditions (fixed equipment includes boxes, cabinets, and fittings):

1. They are metallically connected to grounded cable armor or the grounded metal enclosure of conductors in accordance with the applicable provisions of Sec. 250.118 for the wiring method employed.

2. By a grounding conductor run with circuit conductors, this conductor may be uninsulated, but if an individual covering is provided for this conductor, it shall be finished to show a green color.

3. DC electrical equipment secured to and in contact with the grounded structural metal frame of a building may be considered to be grounded; this option is prohibited for ac equipment. On dc circuits, the equipment grounding conductor may run in a separate location than the circuit conductors. Equipment grounding conductors added as part of modern wiring extended from older circuits that have no equipment grounding conductor available may be connected to a remote grounding location as provided in NEC 250.130(C). In such cases the equipment grounding conductor may, of necessity, run apart from the circuit conductors.

4. Metal car frames supported by metal hoisting cables attached to or running over metal sheaves or drums of elevator machines shall be deemed to be grounded if the machine is grounded in accordance with 250.134 of the Code.

360. Portable and/or cord- and plug-connected equipment. The noncurrent-carrying metal parts of cord- and plug-connected equipment required to be grounded may be grounded in one of the following two ways:

1. By means of a grounding conductor run with the power supply conductors in a cable assembly or flexible cord that is properly terminated in a grounding-type attachment plug having a fixed grounding contact.

   Exception. The grounding contacting pole of grounding-type ground-fault circuit interrupters may be of the moveable self-restoring type on circuits operating not over 150 V between any two conductors or over 150 V between any conductor and ground.

2. A separate flexible wire or strap, insulated or bare, connected to an equipment grounding conductor and protected as well as practicable against physical damage may be used where part of the equipment.

361. Bonding at service equipment. The electrical continuity of the grounding circuit for the following equipment and enclosures shall be assured by one of the means given in Sec. 362.

1. The service raceways, cable trays, or service cable armor or sheath, except as provided in Sec. 250.84 of the Code for underground service cable

2. All service equipment enclosures containing service-entrance conductors, including meter fittings, boxes, or the like, interposed in the service raceways or armor
362. **Continuity at service equipment.** Electrical continuity at service equipment shall be assured by one of the following means:

1. Bonding equipment to the grounded service conductor in a manner provided in Sec. 250.8 of the Code
2. Threaded couplings and threaded bosses on enclosures with joints made up wrenchtight
3. Threadless couplings and connector made up tight for rigid and intermediate metal conduit metal-clad cables, and electrical metallic tubing
4. Other listed devices such as bonding locknuts and bushings, or bushings with bonding jumpers

Bonding jumpers meeting the other requirements of NEC Article 250 shall be used around concentric or eccentric knockouts which are punched or otherwise formed so as to impair the electric connection to ground. Standard locknuts or bushings shall not be the sole means used for the bonding required by this section.

363. **Intersystem bonding termination provisions** must be made at service locations to connect bonding and grounding conductors from other systems, such as telephone and CATV systems. These provisions must also be made at the main disconnecting means for each other building on the premises. The bonding means must be external to service or building disconnect enclosures, accessible for inspections and for system connections, and it must allow for no fewer than three such system connections. It must be so installed that any enclosure on which it is installed, if any, can still be opened for inspection or maintenance. The intersystem bonding termination may be any of the following three items:

a. A set of terminals listed as grounding and bonding equipment and securely mounted to the meter socket, and electrically connected thereto
b. A bonding bar near the service equipment enclosure, meter enclosure, or raceway for service conductors, and connected to the equipment grounding bar for the service disconnect or building disconnect as applicable with a bonding conductor not smaller than 6 AWG copper
c. A bonding bar near the grounding electrode conductor, and connected to the grounding electrode conductor with a bonding conductor not smaller than 6 AWG copper

Existing buildings and structures with comparable intersystem bonding means already installed may continue to use those earlier methods.

364. **The equipment and conductor-enclosure ground** should be located as close to the service entrance or source of supply as practicable. This ground must be so located that no system is grounded through a grounding electrode conductor smaller than required by Table 366. A common method is to run the grounding electrode conductor from the service-switch enclosure. As far as practicable, all other equipment is then connected to ground by electrically continuous conductor enclosures or by separate equipment grounding conductors from the service switch. Bonding jumpers or ground wires are used to connect isolated equipment to grounded equipment. Figure 9.256 shows a single common grounding conductor which grounds a grounded system and the metallic equipment of both an ungrounded system and the grounded system.
365. Rules for sizing system grounding conductors

1. For dc systems: not smaller than the largest conductor supplied by the system and in no case smaller than No. 8. An exception to this rule is a system supplied by a balancer set. In such installations, if the grounded circuit conductor is a neutral derived from a balancer winding or a balancer set with overcurrent protection in accordance with 445.12(D) of the NEC, the size of the grounding electrode conductor shall not be less than that of the neutral conductor but in no case smaller than No. 8.

2. For ac systems and service equipment as follows:
   a. The size of the grounding electrode conductor for an ac system shall not be less than is given in Sec. 366.
   b. If the wiring system is not grounded at the premises, the size of a grounding conductor for a service raceway, for the metal sheath or armor of a service cable, and for service equipment shall be not less than is given in Sec. 366.
   c. Grounding electrode conductors run to the three categories of grounding electrodes below need not be larger than that given by the following specific provisions, whether the system is ac or dc:
      (1) Where connected to rod, pipe, or plate electrodes that portion of the grounding electrode conductor connected solely to such an electrode need not be larger than 6 AWG.
      (2) Where connected to a concrete-encased electrode, that portion of the grounding electrode conductor connected solely to such an electrode need not be larger than 4 AWG.
      (3) Where connected to a ground ring, that portion of the grounding electrode conductor connected solely to such an electrode need not be larger than the conductor that comprises the ground ring.
### 366. Sizing Grounding Electrode Conductors for AC Systems*
(Table 250.66, 2008 NEC)

<table>
<thead>
<tr>
<th>Size of largest service-entrance conductor or equivalent for parallel conductors,† AWG or 1000 cmil</th>
<th>Size of grounding electrode conductor, AWG or 1000 cmil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>Aluminum or copper-clad aluminum</td>
</tr>
<tr>
<td>2 or smaller</td>
<td>1/0 or smaller</td>
</tr>
<tr>
<td>1 or 1/0</td>
<td>2/0 or 3/0</td>
</tr>
<tr>
<td>2/0 or 3/0</td>
<td>4/0 or 250 kcmil</td>
</tr>
<tr>
<td>Over 3/0</td>
<td>Over 250 kcmil</td>
</tr>
<tr>
<td>through 350 kcmil</td>
<td>through 500 kcmil</td>
</tr>
<tr>
<td>Over 350 kcmil</td>
<td>Over 500 kcmil</td>
</tr>
<tr>
<td>through 600 kcmil</td>
<td>through 900 kcmil</td>
</tr>
<tr>
<td>Over 600 kcmil</td>
<td>Over 900 kcmil</td>
</tr>
<tr>
<td>through 1100 kcmil</td>
<td>through 1750 kcmil</td>
</tr>
<tr>
<td>Over 1100 kcmil</td>
<td>Over 1750 kcmil</td>
</tr>
</tbody>
</table>

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†This table also applies to the derived conductors of a separately derived ac system.

²See installation restrictions in Sec. 250.64(A) of the NEC.

**NOTE** Where there are no service-entrance conductors, the size of the grounding electrode conductor shall be determined by the equivalent size of the largest service-entrance conductor required for the load to be served. Where multiple sets of service-entrance conductors are used as permitted in Sec. 230.40, Exception No. 2, of the NEC, the equivalent size of the largest service-entrance conductor shall be determined by the largest sum of the areas of the corresponding conductors of each set.
### 367. Size of Equipment Grounding Conductors for Grounding Raceway and Equipment*

*(Table 250.122, 2008 NEC)*

<table>
<thead>
<tr>
<th>Rating or setting of automatic overcurrent device in circuit ahead of equipment, conductor, etc., A not exceeding:</th>
<th>Size of wire, AWG or 1000 cmil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Copper</td>
</tr>
<tr>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>100</td>
<td>8</td>
</tr>
<tr>
<td>200</td>
<td>6</td>
</tr>
<tr>
<td>400</td>
<td>3</td>
</tr>
<tr>
<td>600</td>
<td>1</td>
</tr>
<tr>
<td>800</td>
<td>1/0</td>
</tr>
<tr>
<td>1000</td>
<td>2/0</td>
</tr>
<tr>
<td>1200</td>
<td>3/0</td>
</tr>
<tr>
<td>1600</td>
<td>4/0</td>
</tr>
<tr>
<td>2000</td>
<td>250 kcmil</td>
</tr>
<tr>
<td>2500</td>
<td>350 kcmil</td>
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<tr>
<td>3000</td>
<td>400 kcmil</td>
</tr>
<tr>
<td>4000</td>
<td>500 kcmil</td>
</tr>
<tr>
<td>5000</td>
<td>700 kcmil</td>
</tr>
<tr>
<td>6000</td>
<td>800 kcmil</td>
</tr>
</tbody>
</table>

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†See installation restrictions of Sec. 250.120 of the NEC.

NOTE: Equipment grounding conductors may need to be sized larger than specified in this table in order to comply with Sec. 250.4(A)(5) or (B)(4) of the NEC.

### 368. NEC specifications for the material and installation of grounding conductors

are as follows:

1. **Material**
   
   a. For grounding electrode conductor. The grounding electrode conductor of a wiring system shall be of copper, aluminum, or copper-clad aluminum. The material selected shall be resistant to any corrosive condition existing at the installation, or shall be suitably protected from corrosion. Aluminum and copper-clad aluminum conductors must not be used in direct contact with the earth or masonry, and where used outside, these conductors must not be terminated within 450 mm (18 in.) of the earth. The conductor may be solid or stranded, insulated, covered or bare. The grounding electrode conductor must be without joint or splice throughout its length, unless it is spliced using exothermic welding or irreversible compression connectors. Busbar sections are permitted to be bolted together for obvious reasons.

   If there are multiple service enclosures, the unbroken conductor rule applies to the conductor that runs to the general service location. If the service consists of two to
six disconnects supplied from separate service laterals joined only at their supply ends in accordance with NEC 230.2 and 230.40 Exception No. 2, or connected to separate sets of service entrance conductors extending from a single service drop or lateral in accordance with 230.40 Exception No. 2, the grounding electrode conductor will be arranged with taps extending into each service enclosure. In this case the tap connections shall be made using exothermic welds or with connectors listed as suitable for grounding and bonding, and those taps must leave the common grounding electrode conductor without a joint or splice. If multiple service enclosures are supplied from a common location, such as a wireway above the multiple enclosures, the grounding electrode conductor will run to this enclosure and taps will extend into each enclosure using connectors listed for grounding and bonding connections, or the exothermic welding process can be used. If desired, separate grounding electrode conductors may be run to the grounding electrode system from each disconnecting means.

b. For conductor enclosures and equipment only. The equipment grounding conductor for equipment and for conduit and other metal raceways or enclosures for conductors may be a conductor of copper, aluminum, or copper-clad aluminum, stranded or solid, insulated, covered or bare, in the form of a wire or busbar of any shape, or one of thirteen qualifying wiring methods, as follows:

1. Rigid metal conduit
2. Intermediate metal conduit
3. Electrical metallic tubing
4. Flexible metal conduit, provided it and its fittings are listed, and the overcurrent protection ahead of any circuit contained in the run does not exceed 20 A. The flexible metal conduit must not be installed where flexibility is required after the installation is complete, such as for vibration isolation or connections to moveable equipment. The total length of flexible raceways covered in items (4), (5), and (6) of this list cannot exceed 1.8 m (6 ft) in any equipment grounding return path. The wiring method can be used for larger or longer applications, but a wire in accordance with the first paragraph above must be added.
5. Liquidtight flexible metal conduit, provided it and its fittings are listed, and the overcurrent protection ahead of any circuit contained in the run does not exceed 20 A in the metric designator 12 through 16 (trade size \(\frac{3}{8}\) through \(\frac{1}{2}\)) sizes, and 60 A in the metric designator 21 through 35 (trade sizes \(\frac{3}{4}\) through \(1\frac{1}{2})\) sizes. The liquidtight flexible metal conduit must not be installed where flexibility is required after the installation is complete, such as for vibration isolation or connections to moveable equipment. The total length of flexible raceways covered in items (4), (5), and (6) of this list cannot exceed 1.8 m (6 ft) in any equipment grounding return path. The wiring method can be used for larger or longer applications, but a wire in accordance with the first paragraph above must be added.
6. Flexible metal tubing, provided it and its fittings are listed, and the overcurrent protection ahead of any circuit contained in the run does not exceed 20 A. The total length of flexible raceways covered in items (4), (5), and (6) of this list cannot exceed 1.8 m (6 ft) in any equipment grounding return path. The wiring method can be used for larger or longer applications, but a wire in accordance with the first paragraph above must be added.
7. Armor of type AC cable, where manufactured so as to provide a suitable fault return path in accordance with NEC 320.108.
8. The copper sheath of mineral-insulated, metal-sheathed cable.
9. Type MC cable where listed and identified for grounding using one of the two possible approaches. For the interlocking-metal tape form, the armor
and grounding conductor in combination are evaluated. For the smooth and corrugated tube forms the metallic sheath is evaluated, together with any enclosed grounding conductors if any and as required to meet the required performance criteria.

(10) Cable trays as permitted in NEC 392.3 and 392.7.
(11) Cablebus framework as permitted in 370.3.
(12) Other listed electrically continuous metal raceways and listed auxiliary gutters.
(13) Surface metal raceways listed for grounding.

All bolted and threaded connections at joints and fittings shall be made tight by the use of suitable tools.

2. Installation
   a. Grounding electrode conductor. A grounding electrode conductor, 4 AWG or larger, may be attached to the surface on which it is carried without the use of knobs, tubes, or insulators. It need not have protection unless exposed to severe physical damage. A 6 AWG grounding conductor, which is free from exposure to physical damage, may be run along the surface of the building construction without metal covering or protection when it is securely fastened to the construction; otherwise it shall be in rigid metal conduit, intermediate metal conduit, rigid nonmetallic conduit, electrical metallic tubing, or cable armor. Grounding conductors smaller than No. 6 shall be in rigid metal conduit, intermediate metal conduit, rigid nonmetallic conduit, electrical metallic tubing, or cable armor. Ferrous metal enclosures for grounding conductors shall be electrically continuous from the point of attachment to cabinets or equipment to the grounding electrode and shall be securely fastened to the ground clamp or fitting. Ferrous metal enclosures which are not physically continuous from cabinet or equipment to the grounding electrode shall be made electrically continuous by bonding each end to the grounding conductor. Where a raceway is used as protection for a grounding conductor, the installation shall comply with the appropriate raceway article of the Code. The requirement to bond both ends of ferrous metal enclosures is critical for grounding electrode conductors in ac systems because the current only goes one way, so there is no opportunity for magnetic field cancellation. Any current will attempt to flow over the outer perimeter of the wiring method, which in this case would be the steel conduit. Actual testing shows, for example, that with a 100 ft run of 3/4-in rigid metal conduit enclosing 6 AWG copper wire, if 100 A is flowing through this system, 97 A will be flowing through the raceway, and only 3 A will flow over the copper wire. If this natural process is obstructed through a failure to bond both ends, the 100 A will flow through the wire, but at over double the impedance.
   b. Conductor enclosures and equipment only. An equipment grounding conductor for conductor enclosures and equipment must run with or enclose the associated circuit conductors, with two exceptions. DC circuit equipment grounding conductors may be run in separate locations. Equipment grounding conductors installed to provide grounding connections for receptacles added to or replaced on, or branch-circuit extensions made from branch circuits that do not contain an equipment grounding conductor must connect to the grounding electrode system or to suitable grounding terminations in upstream panelboards, etc. These conductors are often fished through walls, and where so located away from sources of physical damage, they may run without a raceway enclosure regardless of the conductor size. If an equipment grounding conductor does run in the open for any reason, it is subject to the size and raceway protection rules that apply to grounding electrode conductors, as covered in a above.
369. **Cord-connected equipment**. (National Electrical Code). The equipment grounding conductor in flexible cord must not be smaller than 18 AWG and not smaller than the circuit conductors for all cord assemblies up to and including 10 AWG conductors. Cord assemblies with larger conductors are permitted to have the size of the equipment grounding conductor reduced in size, but not smaller than the size shown in Table 367.

370. **Grounding electrode system.** If present on the premises at each building or structure served, each item Nos. 1. through 7. shall be bonded together to form the grounding electrode system. The bonding jumpers shall be sized in accordance with Sec. 365, installed in accordance with Sec. 368 (2a) and shall be connected in the manner specified in Sec. 372. However, for an existing building, a concrete-encased electrode does not have to be made part of the grounding electrode system where the reinforcing steel is not accessible without disturbing the concrete.

Metal underground gas-piping systems and aluminum electrodes of any form shall not be used in a grounding electrode system. Where practicable, rod, pipe, or plate electrodes shall be embedded below permanent-moisture level, and they shall be free from nonconductive coatings, such as paint or enamel. If more than one electrode system is used (including systems used for lightning rods), each electrode of one grounding system shall not be less than 1.83 m (6 ft) from any other electrode of another grounding system. Two or more electrodes that are effectively bonded together are to be treated as a single grounding electrode system in this sense. This rule pertains to the electrodes of different systems so they can function as designed. It does not prohibit bonding different systems together, and the NEC specifically requires that lightning protection system grounding terminals shall be bonded to the premises wiring grounding electrode system.

Rod, pipe, or plate electrodes shall, if practicable, have a resistance to ground not to exceed 25 Ω. If the resistance is not as low as 25 Ω, an additional electrode connected in parallel shall be used. Such additional electrodes must be spaced not less than 1.8 m (6 ft) apart. If two such electrodes in parallel result in a net resistance to ground in excess of 25 Ω, however, the NEC does not require any additional steps to decrease the resistance to ground. Continuous metallic underground water systems, particularly those using cast iron street mains, in general have a resistance to ground of less than 3 Ω. Metal frames of buildings and local metallic underground piping systems, metal well casings, and the like have, in general, a resistance substantially below 25 Ω.

1. A metal underground water pipe in direct contact with the earth for 3 m (10 ft) or more (including any metal well casing bonded to the pipe) and electrically continuous (or made electrically continuous by bonding around insulating joints or sections or insulating pipe) to the points of connection of the grounding electrode conductor and the bonding conductors. Continuity of the grounding path or the bonding connection to interior piping shall not rely on water meters or filtering devices and similar equipment. A metal underground water pipe shall be supplemented by an additional electrode of a type specified in Pars. 2 through 8. Interior metal water piping located more than 1.52 m (5 ft) from the point of entrance to the building shall not be used as a part of the grounding electrode system in some cases. In industrial, institutional, and commercial occupancies only, an exception allows remote connections to the water piping system, provided there is qualified maintenance and supervision, and provided the entire length of water pipe used in the connection to earth is exposed other than incidental short sections passing directly through walls, ceilings, etc. Note that the area above a suspended ceiling with removable panels is exposed within the NEC definition.
2. The metal frame of the building, where connected to earth in one or more of the following methods: (a) A 3.0 m (10 ft) length of structural steel is in direct contact with earth, or encased in concrete that is in direct contact with earth; or (b) connected to a concrete-encased electrode as in Par. 3 below or to a ground ring as in Par. 4 below; or (c) bonded to rod, pipe, or plate electrodes as covered in Par. 5 or Par. 7 below that meet the resistance provisions given at the end of this section; or (d) connected using some other means that has been approved by the authority having jurisdiction.

3. An electrode encased by at least 50 mm (2 in.) of concrete, located horizontally within and near the bottom of a concrete foundation or footing, or vertically within that portion of a concrete foundation or footing that is in direct contact with the earth, consisting of at least 6 m (20 ft) of one or more bare or zinc galvanized or other electrically conductive coated steel reinforcing bars or rods of not less than 13 mm (1/2-in) diameter or consisting of at least 6.0 m (20 ft) of bare copper conductor not smaller than No. 4 AWG. If multiple such electrodes are present, it is sufficient to make connections to only one of them. If no reinforcing steel is present at the bottom of a foundation, there is no requirement to add this electrode. However, it is one of the very best electrodes, and even with no steel in the footing, if the timing can be worked out, the alternative of 6.0 m (20 ft) of bare copper laid into an open footing should be strongly considered. The result will be far better than rod, pipe, or plate electrodes with lower material cost and less time to install. Be sure to prop the wire up on stones or other supports so the concrete will be able to fully encase the bare copper.

4. A ground ring encircling the building or structure, in direct contact with the earth, consisting of at least 6 m (20 ft) of bare copper conductor not smaller than No. 2 AWG. It must be installed at least 750 mm (30 in.) below grade.

5. Rod and pipe electrodes. Rod and pipe electrodes shall not be less than 2.44 m (8 ft) in length, shall consist of the following materials, and shall be installed in the following manner:
   a. Electrodes of pipe or conduit shall not be smaller than metric designator 21 (3/4 trade size) and, where of iron or steel, shall have the outer surface galvanized or otherwise metal-coated for corrosion protection.
   b. Electrodes of stainless steel and copper or zinc coated steel rods of steel shall be at least 15.87 mm (5/8 in.) in diameter, unless listed and not less than 12.7 mm (1/2 in.) in diameter.
   c. If rock bottom is not encountered, the electrode shall be driven to a depth of 2.5 m (8 ft). If rock bottom is encountered, the electrode may be driven at an oblique angle not exceeding 45° from the vertical. If the rock bottom does not permit the electrode to be driven as described, then the electrode shall be buried in a trench at least 750 mm (21/2 ft) deep. The upper end of the electrode shall be flush with or below ground level unless the aboveground end and the grounding electrode conductor attachment are protected against physical damage as specified in Sec. 250.10 of the NEC. Since the minimum driven distance is 2.5 m (8 ft), an above grade attachment is only possible if the electrode exceeds 8 ft in length.

6. Other listed grounding electrodes are permitted. These include specially fabricated and chemically enhanced electrodes featuring heavy-wall copper tubing packed with electrolytic salts that slowly percolate into the surrounding soil to reduce soil resistivity in difficult areas.

7. Plate electrodes. Each plate electrode shall expose not less than 0.186 m² (2 ft²) of surface to exterior soil. Electrodes of iron or steel plates shall be at least 6.35 mm (1/4 in.) in thickness. Electrodes of nonferrous metal shall be at least 1.52 mm (0.06 in.) in thickness. They must be installed at least 750 mm (30 in.) below grade.

8. Other local metal underground systems or structures, such as piping systems, underground tanks, and underground metal well casings that are not bonded to a metal water pipe.
371. Location of connection to grounding electrode  
(National Electrical Code)

1. **To Water Pipes.** System or common grounding conductors shall be attached to a waternpiping system on the street side of the water meter or on a cold-water pipe of adequate ampacity as near as practicable to the water service entrance to the building. If the source of the water supply is a driven well in the basement of the premises, the connection shall be made as near as practicable to the well. The point of attachment shall be accessible. If the point of attachment is not on the street side of the water meter, the water-piping system shall be made electrically continuous by bonding together all parts between the attachment and the street side of the water meter or the pipe entrance which are liable to become disconnected, as at meters, valves, and service unions.

2. **To Other Electrodes.** The grounding conductor shall be attached to other electrodes permitted in Sec. 370 at a point which will assure a permanent ground.

372. Attachment of grounding conductors  
(National Electrical Code)

**Attachment to Wiring Components and Equipment.** Connections that depend solely on solder shall not be permitted. Grounding connections must employ one of the following 8 methods:

1. Listed pressure connectors
2. Terminal bars
3. Pressure connectors listed for grounding and bonding equipment
4. The exothermic welding process
5. Machine screw-type fasteners that engage no fewer than two threads in the enclosure or are secured with a nut
6. Thread-forming machine screws that engage no fewer than two threads in the enclosure
7. Connections that are part of a listed assembly
8. Other listed means

**Attachment to Electrodes.** The grounding electrode conductor shall be attached to the grounding electrode by means of exothermic welding, listed lugs, listed pressure connectors, listed clamps, or other listed means, except that connections which depend upon solder shall not be used. Not more than one conductor shall be connected to the grounding electrode by a single clamp or fitting unless the clamp or fitting is of a type listed for multiple conductors. One of the following methods shall be used.

1. A listed bolted clamp of cast bronze or brass or of plain or malleable iron
2. A pipe fitting, plug, or other approved device, screwed into the pipe or into the fitting
3. For indoor telecommunications purposes only, a listed sheet-metal-strap-type ground clamp having a rigid metal base that seats on the electrode and having a strap of such material and dimensions that it is not likely to stretch during or after installation, or
4. Other equally substantial approved means

**Ground Clamps.** Ground clamps for use on copper water tubing and copper, brass, or lead pipe should preferably be of copper, and those for use on galvanized or iron pipe should preferably be of galvanized iron and so designed as to avoid physical damage to pipe. Ground clamps used with aluminum grounding conductors should be listed for the
purpose. Note that limitations in the listing process for clamps require that clamps that will be used on copper water tubing must be marked for this service. Clamps that will be used on reinforcing steel must be marked accordingly, including the size of the reinforcing bar(s) for which the clamp was listed. Any clamp used for direct burial in earth or where embedded in concrete must be marked “direct burial” or “DB” as the available space allows.

Protection of Attachment. Ground clamps or other fittings shall be approved for general use without protection and shall be protected from ordinary physical damage.

Figure 9.257 shows some types of grounding clamps. For the smaller ground wires, which must be enclosed in conduit, the type in Fig. 9.257, I, is used. For bare ground wire connected to a water pipe, use the type in Fig. 9.257, II. The type in Fig. 9.257, III, is for a bare wire to be attached to a ground rod.

373. On grounded wiring systems the circuit conductor which is connected to ground must be identified throughout the system. This grounded conductor is referred to as the identified conductor.

1. Insulated conductors of 6 AWG or smaller, except conductors of Type MI cable and multiconductor cables covered under Sec. 200.6(E) of the NEC, fixture wires and multiconductor varnished-cloth-insulated cables, shall have an outer identification of white or gray color along its entire length. The grounded conductors of Type MI cable shall be identified by distinctive marking at the terminals during the process of installation, as is the case for varnished cloth multiconductor cables. A single-conductor, sunlight-resistant, outdoor-rated cable used as a grounded conductor in photovoltaic power systems as permitted by Sec. 690.31 of the NEC shall be identified at the time of installation by a distinctive white marking at all terminations. Three continuous white stripes on other than green insulation is permitted. Aerial cables can be identified with the customary white or gray coloring on the grounded conductors, or they can use a ridge running along the conductor to be grounded. Multiconductor cables operating under conditions of qualified maintenance and supervision are permitted to have a colored conductor permanently identified at the time of installation by a distinctive white marking or equal.

2. Insulated conductors larger than No. 6 shall have an outer identification of white or gray color or shall be identified by distinctive white marking at terminals during the process of installation, which shall encircle the conductor. Multiconductor flat cable No. 4 or larger may employ an external ridge on the grounded conductor. Three continuous white stripes on other than green insulation is permitted.
3. Where grounded conductors of different systems are installed in a common cable, raceway, box, or other enclosure, each grounded conductor shall be identified by system. Since white and gray are both permitted color choices for a grounded conductor, this is one way to distinguish voltage systems. For example, many installations use white as the identified conductor of a 208Y/120-V system and gray as the identified conductor of a 480Y/277-V system. If additional systems are present in common enclosures, white or gray wire with a colored stripe (other than green) can be used. Whatever method is used, it must be permanently posted at each branch-circuit panelboard.

4. The continuity of a grounded circuit conductor must not depend on connections to enclosures, raceways, or cable armor. This problem frequently arises in service panelboards with multiple busbars. Figure 9.258 shows an example of the problem, and how to correct it. The NEC Committee has spent considerable effort in recent years trying to assure that normal circuit current is confined to recognized conductors, and does not pass over raceways and enclosures that were never designed to be current-carrying conductors.

5. In general, conductors colored white or gray, or colored with three continuous white stripes, or identified with white or gray markings at terminations, must be used as grounded circuit conductors and for no other purpose. There are a few limited exceptions to this principle, as follows:
   a. On circuits of less than 50 V, wires using white or gray markings may be used for other purposes, unless system grounding is required by 250.20(A). Refer to Sec. 354 (4) for when this is the case. If it does apply, then the use of an identified conductor follows.
   b. On circuits of 50 V or more, a white or gray wire that is part of a cable assembly may be used as an ungrounded conductor provided it is reidentified as some color other than white or gray (or green) at all terminations and other locations where it is visible and accessible. The same procedure holds for a cable used in a switch loop, with the added proviso that the wire running to the load will not be reidentified, only the one supplying the switch, or running between 3- and 4-way switches where used. Flexible cord is also permitted to have its white or gray wires used as ungrounded conductors for appliance and equipment connections, without the necessity of reidentifying its white or gray wires.

6. For approximately 75 years (since 1923) the NEC described the customary identification rule in terms of “white or natural gray” coloring. This originally referred to the color of latex insulation and the unbleached muslin put over it. It wasn’t exactly either white or gray, but installers knew what it was. It was never intended to be the controlled color gray, and conductors manufactured in this way have not been produced for many decades. In fact, the controlled color gray could always have been used, and occasionally
was used as an ungrounded conductor. However, with the advent of 480Y/277-V sys-
tems, the controlled color gray was increasingly used as an identified conductor based
on an improper interpretation of the old terminology “natural gray.” The 2002 NEC rat-
tified what had become the convention, dropped the term “natural gray” completely, and
recognized the controlled color gray as a permitted color for identified conductors for
the first time. However, since gray wires were permitted, at least theoretically, for use
as ungrounded conductors the NEC advises caution when working with gray wires on
existing systems.

7. At the terminals of wiring devices the grounded conductor must be connected to the
nickel- or zinc-colored terminal, which must have a whitish appearance in contrast to
the copper or brass-colored terminals. Alternatively, the grounded terminal may be
marked “W” or by the use of the word “white,” and this marking is mandatory in cases
where the actual terminals are not visible and only the conductor entry hole can be seen.
On screw-shell lampholders the grounded conductor must be connected to the screw
shell itself. Appliances with a single-pole switching device shall have means to identify
the appropriate terminal for the grounded circuit conductor (if any). No single-pole
switch or circuit breaker and no fuse shall be used in a grounded conductor.

374. Identification of grounded conductors in flexible cord and fixture wire
is different than for ordinary building wire. Identification for the grounded circuit con-
ductor in flexible cord must comply with one of the following six methods:

1. A braid finished to show a white or gray color provided the braid on the other conduc-
tor(s) is finished to show readily distinguishable color(s).

2. A tracer in a braid of any color contrasting with that of the braid, and no tracer in the
braid of any other conductor. No tracer shall be used in the braid of any conductor of a
cord containing a conductor with a braid finished to show white or gray. Cord types C
and PD, however, have the identified conductor as solid white or gray, and all other con-
ductors with a colored tracer in the braid.

3. A white or gray insulation on one conductor and insulation of a readily distinguishable
color(s) on the other conductor(s) for cords having no braids on the individual conduc-
tors. For jacketed cords furnished with appliances, one conductor having its insulation
finished light blue, and with the other conductors having insulation of a readily distin-
guishable color other than white or gray. This limitation does not apply to cords with
the insulation on the individual conductors integral with the jacket. The insulation is
permitted to be covered with an outer finish to provide the desired color.

4. A white or gray separator on one conductor and a separator of a readily distinguishable
solid color on the other conductor(s) of cords having insulation on the individual con-
ductors integral with the jacket.

5. One conductor having the individual strands tinned and the other conductor(s) having
the strands untinned for cords having insulation on the individual conductors integral
with the jacket.

6. One or more ridges, grooves, or white stripes located on the exterior of the cord so as to
identify one conductor for cords having insulation on the individual conductors integral
with the jacket.

Fixture wires intended for use as grounded circuit conductors shall be identified by one
or more continuous white stripes on other than green insulation, or by one of the means
above for flexible cord.
375. Permitted colors for ungrounded conductors. All ungrounded conductors must be finished in black or red or any color contrasting to white, gray, or green. Where more than one nominal voltage system exists in a building, each ungrounded system conductor shall be identified by phase or line, and by system, at all termination, connection, and splice points. The specific code is left to the owner, but each panelboard must have the code in use for circuits originating in that panelboard. Alternatively, for facilities with sophisticated recordkeeping, the code can be “documented in a manner that is readily available.”

   If, on a four-wire delta-connected secondary, the midpoint of one phase is grounded to supply lighting and similar loads, that phase conductor having the higher voltage to ground shall be indicated by the color orange or by tagging or other effective means at any point at which a connection is to be made if the grounded conductor is present. In addition, every switchboard and panelboard must be field marked with a warning label “Caution ___ Phase Has ___ Volts to Ground.”

SERVICE-ENTRANCE REQUIREMENTS AND INSTALLATION

376. Service entrances for the electrical system of a building may be supplied by means of overhead or underground service conductors. The source of energy for any service is an electrical utility. If the source is an on-premises source, then there is no service, only a separately derived system. A service consists of the service conductors and the service equipment. The service conductors are the conductors which supply a building with electrical energy from an electric power system outside the building. They consist of that portion of the supply conductors which extend from the street distribution main or distribution transformer to the service equipment of the building. The service conductors may be located overhead or underground. For overhead conductors the service conductors include the conductors from the last line pole to the service equipment. The service conductors of an overhead service are further classified into two parts: the service-drop conductors and the service-entrance conductors. The service-drop conductors are the overhead service conductors from the last line pole or other aerial support to and including the splices, if any, connecting to the service-entrance conductors at the building or other structure. The service-entrance conductors of an overhead service are that portion of the service conductors between the terminals of service equipment and a point usually outside the building, clear of the building walls, where they are joined by tap or splice to the service drop.

377. The service equipment must consist of an externally operated disconnecting device and overcurrent protective device. The disconnecting device must provide a readily accessible means for disconnecting all the service conductors from the source of supply. It may consist of a single switch or manually operated circuit breaker or not more than six switches or six manually operated circuit breakers. In Fig. 9.259, if there had been only six occupants in the building, the main service switch would not have been required. In multiple-occupancy buildings each occupant must have access to his or her disconnecting means except where maintenance is under continuous building management supervision. Circuit breakers may be equipped with electrical remote control, provided that the breaker has in addition a manually operable handle. The disconnecting means must be of a type which will plainly indicate whether it is in the open or the closed position. The service switch or breaker must be located as close as is feasible to the point of entrance of the service conductors to the building. It may be located either outside or inside the building. If the switch or breaker does not open the grounded conductor, other means must be provided.
at the service entrance for disconnecting the grounded conductor of the supply from the
interior wiring. The connection to a neutral terminal bar in the service switch will consti-
tute a satisfactory disconnecting means.

A service switch must have a rating which is not less than the fuseholder in series
with it, and the rating must be at least as great as the minimum allowable load (refer to
Sec. 52 of Div. 3). Except in special cases of very small occupancies, it is not a good
practice to install a service switch or circuit breaker that has a rating less than 60 A. A
30-A switch should not be used for a two-wire service supplying more than two branch
circuits. A one-family dwelling shall have a service disconnecting means rated not less
than 100 A, 3-wire.

Each ungrounded service conductor must be provided with overcurrent protection. The
protection may consist of a single set of fuses or circuit breakers or not more than six sets
of fuses or six circuit breakers. For the rating of fuses or the setting of circuit breakers, refer
to Secs. 319 and 320. No overcurrent device shall be inserted in a grounded conductor,
except a circuit breaker which simultaneously opens all conductors of the service. The pro-
tective devices must be located at the same point as the disconnecting means or be located
immediately adjacent thereto.

In addition to the disconnecting means and the protective devices, when the building is
supplied directly from public-utility mains, the service equipment will include the kilo-
watt-hour meter for the measurement of power consumption. For small or multiple-
occupancy buildings, the branch-circuit distribution equipment frequently is grouped along
with the service equipment (see Fig. 9.259). If the service overcurrent protective devices
are locked or sealed or otherwise not readily accessible, the branch-circuit overcurrent
devices must be installed as close as is practicable to the load side of the service equipment.
They must be in a readily accessible location and be of a lower rating than the service over-
current device.

The construction and types of service equipment are discussed in Div. 4.

FIGURE 9.259  Arrangement of meters and service for a multitenant building.
378. There are six possible different arrangements or sequences for service equipment consisting of switch, fuses, and meter, as follows:

1. Switch-fuse-meter
2. Switch-meter-fuses
3. Fuses-switch-meter
4. Fuses-meter-switch
5. Meter-switch-fuses
6. Meter-fuses-switch

When circuit breakers are employed, there are, of course, only two possible sequences: meter–circuit breaker or circuit breaker–meter.

The proper order for placing the switch, fuses, and meter in the circuit has been the subject for much dispute and not enough standardization, each power company reserving for itself the decision on the proper method. Each method has its advantages, and it has been a matter for local decision as to which advantage seems most important to the individual power company.

379. A main service is a service which supplies more than one building under single management. If the buildings are supplied from a private distribution system, the services should be installed in accordance with the general requirements for services from a public utility. In installations which include properties with their own generating plant, the conductors running from one building to another are not considered service conductors.

The supply to each building must be separately controlled and properly protected by overcurrent devices. The control should consist of an externally operable enclosed safety switch or a circuit breaker. Refer to Div. 8, Sec. 71, topic 24 for an analysis of NEC rules covering this topic, particularly where they differ from the rules presented here on actual services. Garages and outbuildings of residences and farms come under this class of installation. Methods of meeting these requirements are illustrated in Figs. 9.260 and 9.261. The protection for each building should have a lower rating or setting than the protection at $F$ in the figures, so that in case of trouble the protection of any one building will function without operating the device at $F$.

No service should supply one building from another unless they are under the same management.

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**FIGURE 9.260** Two buildings under single management. No service fuses are required in building 2 if fuses $F$ are of proper rating to protect conductors $C$. A switch $S_2$ must be installed to control conductor $C$.

**FIGURE 9.261** Three buildings under single management. If properly protected by fuses $F$, conductors $C$ require no other fuse protection. A switch $S_2$ must be provided to control the wiring in building 2, and a switch $S_3$ to control the wiring in building 3. Because wire $C$ is not controlled by $S_2$, it must not pass through Building no. 2.
380. No building should be supplied by more than one set of service conductors from the same secondary distribution system or from the same transformer except as follows:

1. **Fire Pumps.** If a separate service is required for fire pumps.

2. **Continuity of Power.** If a separate service is required for emergency, legally required standby, optional standby, or parallel power production systems, or systems designed for the connection of multiple sources of supply for the purposes of enhanced reliability.

3. **Capacity Requirements.** If capacity requirements make multiple services necessary, due to capacity exceeding 2000 A at a supply voltage of 600 V or less, or where the load requirements of a single-phase installation exceed what the serving agency normally supplies through one service, or in other cases by special permission from the authority having jurisdiction.

4. **Buildings of Large Area.** By special permission, if more than one service drop is necessary owing to the area over which a single building extends.

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**FIGURE 9.262** Two sets of service-entrance conductors tapped from one service drop.

**FIGURE 9.263** Four sets of service-entrance conductors tapped from one set of main service conductors.
5. **Multiple-Occupancy Buildings.** By special permission, in multiple-occupancy buildings where there is no available space for service equipment accessible to all the occupants. See Figs. 9.262 and 9.263 for multiple metering supplied by one service drop.

6. **When Additional Services Are Required for Different Classes of Use.** These include needs for different voltage, frequency, or phase or different rate schedules for different types of use of electric power.

7. Underground conductors 1/0 or larger, connected at their supply ends but not at their load ends, and serving two to six disconnecting means that are grouped in one location and that supply multiple loads are considered a single service and are therefore permitted.

Separate services may be brought into a single building for power and light, respectively, when the lighting is supplied from a separate secondary distribution main, as shown in Fig. 9.264. Separate services may be brought into a single building for power and light, respectively, if each service is supplied through a separate transformer (Fig. 9.265) or if the lighting service is supplied from one transformer of a polyphase bank of transformers supplying the power.

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**381. Size of service conductors.** Service conductors must have an ampacity sufficient to supply the load of the building (refer to Div. 3) and regardless of the actual load must have an ampacity not less than that required by the minimum load requirements of Div. 3. They must have a minimum size in some cases for mechanical strength. They must also have a minimum size corresponding to the minimum rating of the service disconnecting means as required for certain specified loads. Therefore, no service conductor can be...
smaller than the following (adjusted for aluminum if applicable), and may be larger if required by the actual load:

<table>
<thead>
<tr>
<th>Conductors</th>
<th>Minimum allowable copper size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service entrance for all installations, except ones specified below</td>
<td>6 AWG (to supply a 60 A minimum disconnect size using 75°C terminations)</td>
</tr>
<tr>
<td>Service entrance supplying a single branch circuit</td>
<td>14 AWG (to supply a 15 A minimum disconnect size)</td>
</tr>
<tr>
<td>Service entrance supplying a two-circuit installation</td>
<td>10 AWG (to supply a 30 A minimum disconnect size)</td>
</tr>
<tr>
<td>Service entrance supplying a single-family house</td>
<td>4 AWG [to supply a 100 A minimum disconnect size, using 310.15(B)(6)]</td>
</tr>
<tr>
<td>Service drop or lateral</td>
<td>12 AWG (overhead: hard-drawn) for a single circuit installation</td>
</tr>
<tr>
<td>Service drop or lateral</td>
<td>8 AWG, for other installations</td>
</tr>
<tr>
<td>Service of over 600 V</td>
<td>No. 6, except that in multiconductor cables No. 8 may be used</td>
</tr>
</tbody>
</table>

382. Splicing of service conductors. Service conductors in the form of underground service laterals and all service entrance conductors are permitted to be spliced as long as the splicing method complies with the usual rules in the NEC for general wiring of comparable size and location. The NEC does not expressly cover splices in overhead service drops, but given the other rules as long as the splice meets industry standards for strain tolerance and workmanship, it would normally be permitted subject to the judgment of the authority having jurisdiction.

383. Typical service installations of proper and improper construction are shown in Fig. 9.266. Overhead services to occupancies having relatively small loads, such as residences and small stores, are generally made with one of the installations shown in Fig. 9.266, II and III. The installation in Fig. 9.266, I, violates Code rules because the service head is not located above the point of attachment of the service-drop conductors to the building. The present trend is toward installations of the types shown in Figs. 9.266, II and III, and 9.267. A good service installation for a low-roof building is shown in Fig. 9.267. Occasionally the service switch is also mounted outside the building along with the meter.

In congested city residential districts an underground service using underground service-entrance cable is frequently run from overhead lines when a change to underground distribution is planned at a later date. This procedure facilitates the changeover, as the part of the cable which is aboveground may in the future be taken down and placed underground and run directly into the underground distribution box. In cities where the distribution is all underground, direct-burial cable or nonmetallic raceway is the most common method of running services. The advantage of the conduit system is that in case the service needs to be replaced for any reason, the cable may be pulled out of the conduit and another one installed without having to dig up the pavement or sidewalk. For apartment-house service a meter trough in which are mounted the meter sockets, one for each apartment, in one or more horizontal rows (Fig. 9.259), is installed. Directly under each meter is a branch-circuit distribution panel containing fuses or circuit breakers for the branch-circuit protection for the apartment. In some cases a service switch is provided for each apartment, and a feeder is run to the apartment with the branch-circuit distribution panel located in the apartment.
384. For commercial or industrial services the maximum demand is usually metered as well as the kilowatthours. When the demand is of the order of a few kilowatts, this may be done with a single meter which has a demand-indicating pointer as well as the usual meter dials (Fig. 9.268). For larger installations a separate indicating-demand meter is installed (Fig. 9.269). A recording type of demand meter may also be employed for larger installations; Current transformers are usually required on larger installations to reduce the current which the meter has to handle; self-contained metering is currently available up to 400 A, although the cut-off point is a matter for the local utility to decide. For an underground service from an urban network system, the service equipment consists of a main fused switch or circuit breaker, a set of current transformers in a sheet-metal cabinet, and meters as outlined above. If the supply comes from a radial feeder system, a transformer bank with an oil circuit breaker and disconnect switches is installed at the building ahead of the above service equipment. For an overhead service a transformer bank is installed just
outside the building, on a concrete foundation on the ground or on an elevated platform between two poles. The bank will contain high-voltage fuses and lightning arresters in addition to the transformers. The service conductors are then brought into the building in conduit or as individual wires to the service equipment. Sometimes the metering is installed so as to measure the input to the transformers so that the customer pays directly for the transformer losses. When this is done, high-voltage current and potential transformers are installed in the leads to the primary of the transformers. The meters may then be located in a weatherproof cabinet outside the building or located inside the building wall, as before, with a conduit to carry the secondary leads from the instrument transformers.

385. Connections ahead of the service disconnect. The National Electrical Code, in Sec. 230.82, allows eight types of equipment to be connected ahead of the service disconnecting means, as follows:

1. Cable limiters or other current-limiting devices.
2. Meters or meter sockets nominally rated not in excess of 600 V, provided all metal housings and service enclosures are grounded in accordance with Part VII and bonded in accordance with Part V of Article 250.
3. Meter disconnect switches nominally not rated in excess of 600 V that have a short-circuit current rating equal to or greater than the available short-circuit current, provided all metal housings and service enclosures are grounded in accordance with Part VII of Article 250 and bonded in accordance with Part V of Article 250. A meter disconnect switch shall be capable of interrupting the load served.
4. Instrument transformers (current and voltage), high-impedance shunts, load management devices, surge arresters, and Type 1 surge-protective devices.
5. Taps used only to supply load management devices, circuits for standby power systems, fire pump equipment, and fire and sprinkler alarms, if provided with service equipment and installed in accordance with requirements for service-entrance conductors.
6. Solar photovoltaic systems, fuel cell systems, or interconnected electric power production sources.
7. Control circuits for power-operable service disconnecting means, if suitable overcurrent protection and disconnecting means are provided.

8. Ground-fault protection systems or Type 2 surge-protective devices, where installed as part of listed equipment, if suitable overcurrent protection and disconnecting means are provided.

CRANE WIRING

386. Wiring for cranes consists of the following elements:

1. Collector switch
2. Main collector contact conductors
3. Cab main-line switch
4. Bridge collector contact conductors
5. Motor-circuit wiring

387. A collector switch or circuit breaker must be installed in every circuit feeding crane wires. A fused switch is most frequently used to provide overload protection, although in important installations, where reliability is essential (where equipment must be placed back in service after an accident, in minimum time), circuit breakers are used. From an electrical standpoint the best location for the switch is at the center of the run.

The switch must be readily accessible and operable from the ground or floor, be within view of the runway contact conductors, and be of a type which can be locked in the open position. It shall open all ungrounded conductors simultaneously.

388. The main collector contact conductors are bare copper trolley wires or structural-steel conductors that are erected parallel to the crane runway. The location of the conductors is determined by conditions. Sometimes the crane builder specifies that the conductors must be located in a certain position, and in other cases the purchaser selects and specifies the position of the conductors, and the crane manufacturer arranges the current collectors on the crane accordingly.

389. Trolley wire for cranes is hard-drawn copper, the same as used in electric traction. Hard-drawn wire must be used to prevent excessive stretching. Round wire is erected when the method of support adopted does not involve the use of trolley ears for holding it at intermediate points between the ends of the run. When trolley ears are used, figure-eight or, preferably, grooved trolley wire should be used, because it can be readily held in screw-clamp trolley ears. Round wire can be used with trolley ears, but the ear flanges of these must be hammered down around the wire, a time-consuming operation requiring some skill; also, a round-wire ear introduces a hump on the wire and makes the trolley wheel jump and draw an arc when the wheel passes over the raised place. Either 1/0, 2/0, 3/0, or 4/0 AWG wire is usually required. The wire size required is ordinarily specified by the crane builder, but in any case it should be large enough so that the voltage drop in it will not much exceed 3 or 4 percent of the line voltage with all the crane motors operating at full load. In no case should the wires be smaller than the minimum allowable sizes given in Sec. 400 for bridge collector conductors.
390. Trolley rails of structural steel are being used to some extent instead of copper trolley wire to supply current to cranes and other moving electrical machinery. The steel rails are made sufficiently heavy so that they cannot break and fall, as copper wires occasionally do. Sometimes strap-steel bars are used, but more frequently a section such as an angle or a tee, which has considerable stiffness in all directions, is adopted. Steel conductors should be painted, except on the contact edge or face, to prevent corrosion. Either a shoe or a trolley wheel can be used to collect current from a steel conductor rail. A shoe or spoon, which makes a rubbing contact, is probably preferable for the average application. Trolley-wheel collectors that travel at high speeds are not successful for current collection from steel conductors, because the wheel tends to bounce and jump from the rigid rail at joints and uneven places.

391. The main collector contact conductors must be isolated by elevation or provided with suitable guards so that persons cannot inadvertently touch the live parts while in contact with the ground or with conducting material connected to the ground. If the crane travels over easily ignitable combustible fibers and materials, the collector conductors must be protected by barriers so arranged as to prevent the escape of sparks or hot particles. Probably the best location for the collector conductors on a bridge-crane runway is between the flanges of and parallel to one of the crane girders. Here the conductors are out of the way and well protected and can be readily supported. It is not often that they are erected in any other position. Occasionally the trolley wires can be supported from the roof trusses above the crane runway and are installed similarly to the trolley wires for trolley cars. A pole collector with a wheel at its upper end, exactly like a trolley-car pole but much shorter, is used. When the spacing between roof trusses is very great, this method may not give good results because of the wire swinging and the trolley coming off. The main contact conductors, when carried along runways, should normally be supported on insulating supports at intervals not exceeding 6 m (20 ft) and separated from each other at least 150 mm (6 in.), except that a spacing of not less than 75 mm (3 in.) may be used for monorail hoists. If wires are used, they should be secured at the ends with approved strain insulators and so mounted on intermediate insulators that the extreme displacement of the wires will not bring them closer than 38 mm (1/2 in.) from the surface wired over. If necessary, the intervals between supports may be increased up to 12 m (40 ft), provided that the separation between conductors is increased proportionately. All sections of the conductors must be so joined that a continuous electrical connection is provided. The collector conductors must not supply any equipment other than that of the crane or cranes which they are designed to serve.

392. Methods of supporting crane trolley wires differ with conditions. If the crane is provided with hook-shoe collectors (Fig. 9.270), which slide under and carry the weight of the trolley wire, the wire is rigidly held only at the terminations at the ends of the run and is kept from sagging by intermediate insulating brackets like those shown in Fig. 9.270. If trolley-wheel current collectors are used, the tension in the wire is taken by the terminations, and the wire is also rigidly held by trolley ears at intermediate points.
393. **Terminations** are made as shown in Fig. 9.271. Strain insulators separate the trolley wire electrically from the building members, and either a turnbuckle or an eyebolt with a long thread can be used for pulling the slack from the wire and adjusting its tension. The terminations should be depended upon to assume the entire tension of the wire. The intermediate supports are placed merely to prevent excessive sagging. The members which take the stresses of the eyebolts at the terminations should be very substantial or thoroughly braced, because on them depends the reliability of the entire installation. The eyebolts, turnbuckles, and strain insulators should be not smaller than the \( \frac{5}{8} \)-in size.

![FIGURE 9.271](image)

**FIGURE 9.271** Trolley supports at ends of run.

394. **Intermediate supports for crane trolley wires**, the supports installed between the terminations to prevent sagging, can be arranged as shown in Figs. 9.270, 9.272, and 9.273. The bracket of Fig. 9.270 is, as above explained, applicable only if the crane has hook-shoe collectors. The block of wood that supports the insulating spools should be thoroughly dry and treated with an insulating paint. The bolt holes in it should be deeply countersunk to eliminate the possibility of grounds. The spools should be of porcelain. Porcelain tubes with porcelain knobs at the ends to form flanges will do. The length of the insulator between flanges should be at least 4 in. (101.6 mm). Spools turned from fiber are sometimes used. The spools should be so arranged that there will be at least a \( \frac{1}{2} \)-in (12.7-mm) clearance between them and the hook shoe when it passes along.

In a fireproof building, when the crane has trolley-wheel collectors, the wires can be supported by trolley ears as in Fig. 9.273. The wooden supporting block must be thoroughly painted, and the bolt holes in it deeply countersunk to prevent the possibility of grounds. Tap bolts, screwing in from the rear, support the screw-clamp trolley ears which seat against washers. Figure-eight or,

![FIGURE 9.272](image)

**FIGURE 9.272** Trolley hanger support.
preferably, grooved trolley wire is used. The wire should be drawn tightly at the terminations, and the ears should be installed every 8 or 10 ft (2.4 or 3 m).

For an outdoor crane, as well as for indoor applications, the wires can be supported in some cases as shown in Fig. 9.272. Standard street-railway–type trolley hangers and ears, which provide excellent insulation, are used. The hangers can, provided a proper location of the trolley wires results, be bolted directly to the crane girder.

395. There are almost numberless ways in which steel conductor rails can be arranged and supported. The arrangement of a structural-steel tee conductor or trolley rail is shown in Fig. 9.274. Although the arrangement illustrated was developed for serving monorail cranes, which travel on the lower flanges of I beams, only minor modifications in the supporting forging would be required to adapt it for serving bridge cranes or other similar traveling electrical machines. Note that a feature of the method is that no drilling or close fitting is required in the field. The only piece that is different for different jobs is the supporting forging, which can be formed and drilled in the shop. The only tools required to erect the rail are a hacksaw for cutting the tee, which is purchased in 30-ft (9.1-m) lengths, and a wrench for setting the bolts. No bolt smaller than 5/8-in diameter is used, because smaller ones than this can be twisted asunder too easily. A 1 1/2- by 1 1/2- by 3/16-in T bar was selected, because this is about the smallest size that is rigid enough to sustain itself effectively between supports. A T bar of this size has a conductivity equivalent to that of a 109,800-cmil copper conductor, that is, a copper conductor between Nos. 1/0 and 2/0 in size.

The insulating hanger (Fig. 9.274, II) is similar to a trolley hanger but smaller. A malleable-iron bell encloses the molded material that supports and insulates the hanger stud. The splicing plate (IV) and the clamp (V) are castings, preferably of malleable iron, and the only machine work on them is the drilling and tapping of the holes. The section insulator (VI) consists of two castings, a fiber dividing block, and two wrought-iron clamping plates. Directions for spacing the insulating supports when erecting the conductor are given on the illustration. The terminal lug (VIII) is forked instead of annular so that it can be readily disconnected for isolating circuits for testing without taking out a bolt.

Rigid collector conductors must have insulating supports spaced at intervals of not more than 80 times the vertical dimension of the conductor, but in no case greater than 4.5 m (15 ft), and spaced apart sufficiently to give a clear electrical separation of conductors or adjacent collectors of not less than 25 mm (1 in.).
FIGURE 9.274 Steel trolley rail.
396. **Track as circuit conductor** (National Electrical Code). Monorail, tramrail, or crane-runway tracks may be used as a conductor of current for one phase of a three-phase ac system furnishing power to the carrier, crane, or trolley, provided the following conditions are fulfilled:

1. The conductors for supplying the other two phases of the power supply shall be insulated.
2. The power for all phases shall be obtained from an insulating transformer.
3. The voltage shall not exceed 300 V.
4. The rail serving as a conductor shall be bonded to the equipment grounding conductor at the transformer and may also be grounded by the fittings used for the suspension or attachment of the rail to a building or structure.

397. **In computing the resistance of steel trolley rails** the area in square inches of the section involved can be taken from one of the steel companies’ handbooks, such as those issued by the Cambria and Carnegie steel companies; the area in circular mils can then be obtained by using the rule given below. By dividing this area by 6.14, which is the approximate ratio of the resistance of mild steel to that of copper, the equivalent copper area of the steel conductor results. Then by using the standard formula for the resistance of a copper conductor, the actual resistance of the steel is obtained.

![Figure 9.275](image)

**EXAMPLE** What is the resistance of 160 ft of 1 1/2- by 1 1/2- by 1 1/2- by 1/8-in steel angle? (See Fig. 9.275 for a picture of the section.)

**SOLUTION** By referring to a handbook, it will be noted that the area of 1 1/2- by 1 1/2- by 1/8-in steel angle is 0.53 in². Then, to find its area in circular mils,

\[
Cmil = \frac{\text{area in in}^2}{0.000,000,785.4} = \frac{0.53}{0.000,000,785.4} = 674,800 \text{ cmil}
\]

Equivalent in copper

\[
\text{Equivalent in copper} = \frac{\text{cmil area of steel}}{6.14} = \frac{674,800}{6.14} = 109,800 \text{ cmil}
\]

Then the resistance of the 160-ft length will be

\[
\text{Resistance (for copper)} = \frac{11 \times \text{ft}}{109,800} = 11 \times \frac{160}{109,800} = 0.016 \Omega
\]

The resistance, therefore, of 160 ft of 1 1/2- by 1 1/2- by 1/8-in steel angle is 0.016 Ω. It is evident from the equivalent copper area of the steel (109,800 cmil) that the conductivity of the steel section will lie between the conductivities of No. 1/0 (105,500 cmil) and No. 2/0 (133,100 cmil) copper wire.
The equivalent copper area in circular mils can be used in any of the wiring formulas for computing drop in a steel conductor, just as the actual area of a copper conductor is used in the same formulas, and the result will be a correct one for the steel section. Obviously the above method is approximate because the constants are approximate, but it is quite accurate enough for wiring computations, which always involve necessarily inaccurate assumptions.

398. Disconnecting means for cranes and monorail hoists (National Electrical Code). A motor-circuit switch, molded-case switch, or circuit breaker shall be provided in the leads from the runway contact conductors or other power supply on all cranes and monorail hoists. The disconnecting means shall be capable of being locked in the open position. The provision for locking or adding a lock to the disconnecting means shall be installed on or at the switch or circuit breaker used as the disconnecting means and shall remain in place with or without the lock installed. Portable means for adding a lock to the switch or circuit breaker shall not be permitted.

Where a monorail hoist or hand-propelled crane bridge installation meets all of the following, the disconnecting means shall be permitted to be omitted:

1. The unit is controlled from the ground or floor level
2. The unit is within view of the power supply disconnecting means
3. No fixed work platform has been provided for servicing the unit

Where the disconnecting means is not readily accessible from the crane or monorail hoist operating station, means shall be provided at the operating station to open the power circuit to all motors of the crane or monorail hoist.

The continuous ampere rating of the switch or circuit breaker specified above shall be not less than 50 percent of the combined short-time ampere ratings of the motors nor less than 75 percent of the short-time ampere rating of the motors required for any single motion.

Note that the NEC crane article (Art. 610) uses the wording “in view” in several places instead of “in sight” consciously in order to avoid the 15 m (50 ft) limitation built into the NEC definition of “in sight”. Many large industrial cranes to too big to make the 15 (50 ft) limit workable.

399. Contact conductors are required across the crane bridge for carrying the circuit to the carriage and hoist motors. They are usually made of bare copper wires supported in the general way described in Secs. 391 to 394, except that bridge collector conductors shall be kept at least 65 mm (21/2 in.) apart, and if the span exceeds 25 m (80 ft), insulating saddles shall be placed at intervals not exceeding 15 m (50 ft).

400. Contact conductors. The National Electrical Code requires that the size of contact wires shall be not less than the following:

<table>
<thead>
<tr>
<th>Distance between end strain insulators or clamp-type intermediate supports, ft</th>
<th>Size of wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 9.0 m (30 ft)</td>
<td>6 AWG</td>
</tr>
<tr>
<td>9.0 m–18 m (30–60 ft)</td>
<td>4 AWG</td>
</tr>
<tr>
<td>Over 18 m (60 ft)</td>
<td>2 AWG</td>
</tr>
</tbody>
</table>
401. **The motor-circuit wiring** must be enclosed in raceways or Type AC cable with insulated grounding conductor, Type MC cable, or Type MI cable unless otherwise permitted for specific conditions. Contact conductors and short lengths of exposed conductors at resistors, collectors, and other equipment shall not be required to be in raceways. Conductors exposed to external heat or connected to resistors shall have a flame-resistant outer covering or be covered with a flame-resistant tape individually or as a group.

The conductors must be of a size as given in Table 610.14(A) of the NEC. When flexible connections to motors or controllers are necessary, flexible metal conduit, liquidtight flexible metal conduit, liquidtight flexible nonmetallic conduit, multiconductor cable, or an approved nonmetallic flexible raceway may be used. Short runs for control equipment in the cab or on the bridge may be enclosed in auxiliary gutters. A common-return conductor may be used for the several motors of a single crane or hoist. The ampacities of conductors used with crane motors are as given in Table 610.14(A).

402. **Motor control and protective equipment.** The hoist of cranes must be provided with a limit switch which will control the upper limit of travel. It is best practice to arrange the control levers of all traveling cranes, in any one installation, in the same relative position in all the cages of the different cranes. The NEC allows two motors with their leads, which operate a single hoist, carriage, truck, or bridge and are controlled as a unit by one controller, to be protected by a single overload device. The device should be located in the cab if there is one.

403. **A crane-wiring diagram** is given in Fig. 9.276, which is typical for a dc, three-motor, traveling bridge crane. Variations in crane wiring and control schemes are practically numberless. For dc cranes, series motors are almost invariably used, while for ac cranes, wound-rotor motors are used.

![Direct-current crane-wiring diagram](image)
WIRING FOR CIRCUITS OF OVER 600 VOLTS

404. For wiring circuits operating at more than 600 V, the conductors must have an insulation sufficient for the particular voltage employed. The aboveground conductors must be installed in rigid or intermediate metal conduit, in rigid nonmetallic conduit, in electrical metallic tubing, as busways, in cable trays, as busways, as cablebus, in other identified raceways, or in open runs of metal-clad cable suitable for the use and purpose, except that in locations accessible to qualified persons only, open runs of Type MV cable, bare conductors, and bare busbars may also be used. Open runs of braid-covered insulated conductors must have flame-retardant braid, or the braid covering must be treated with a flame-retardant saturant after installation. The braid covering must be stripped back at conductor terminals to a safe distance according to the operating voltage, and is not less than 25 mm (1 in.) for each kilovolt of the conductor-to-ground voltage.

The metallic and semiconducting insulation shielding components of shielded cables shall be stripped back to a safe distance according to the circuit voltage at all terminations of the shielding, as in potheads and joints. At such points, suitable methods such as the use of potheads, terminators, stress cones, or similar devices shall be employed for stress reduction, and the metallic shielding tape and semiconducting components shall be connected to a grounding conductor, grounding busbar, or a grounding electrode.

405. Circuit interrupting devices for medium-voltage applications are covered in 490.21 of the NEC. Specific devices covered in this code section are as follows:

(A) Circuit breakers
(B) Power fuses and fuseholders
(C) Distribution cutouts and fuse links
(D) Oil-filled cutouts
(E) Load interrupters

406. Isolating means (National Electrical Code). Means shall be provided to isolate an item of equipment completely. The use of isolating switches is not necessary if there are other ways of deenergizing the equipment for inspection and repairs, such as draw-out-type metal-enclosed switchgear units and removable truck panels. Isolating switches not interlocked with an approved circuit-interrupting device shall be provided with a sign warning against opening them under load. A fuseholder and fuse designed for the purpose may be used as an isolating switch.

407. Space separation. The NEC requires that a minimum air separation in field fabricated installations between live conductors and between such conductors and adjacent grounded surfaces be not less than the values given in Table 490.24 of the NEC. These spacings do not apply to equipment designed, manufactured, and tested to accepted national standards.

408. Work space and guarding. The National Electrical Code requires the following protection:
1. **Working Space.** The minimum clear working space in front of electrical equipment likely to require examination, adjustment, servicing, or maintenance while energized shall not be less than set forth in Table 110.34(A) of the NEC unless otherwise specified in the Code. Distances shall be measured from the live parts if such are exposed, or from the enclosure front or opening if such are enclosed.

   The conditions are as follows:
   
   a. Exposed live parts on one side and no live or grounded parts on the other side of the working space or exposed live parts on both sides effectively guarded by insulating materials.
   
   b. Exposed live parts on one side and grounded parts on the other side. Concrete, brick, or tile walls will be considered grounded surfaces.
   
   c. Exposed live parts on both sides of the work space.

   **Exception.** Working space is not required in back of equipment such as dead-front switchboards or control assemblies where there are no renewable or adjustable parts (such as fuses or switches) on the back and where all connections are accessible from locations other than the back. Where rear access is required to work on deenergized parts on the back of enclosed equipment, a minimum working space of 762 mm (30 in.) horizontally shall be provided.

2. **Separation from Low-Voltage Equipment.** Where switches, cutouts, or other equipment operating at 600 V, nominal, or less are installed in a vault, room, or enclosure where there are exposed live parts or exposed wiring operating at over 600 V, the high-voltage equipment shall be effectively separated from the space occupied by the low-voltage equipment by a suitable partition, fence, or screen.

   **Exception.** Switches or other equipment operating at 600 V, nominal, or less and serving only equipment within the high-voltage vault, room, or enclosure shall be permitted to be installed in the high-voltage enclosure, room, or vault if accessible to qualified persons only.

3. **Locked Rooms or Enclosures.** The entrances to all buildings, rooms, or enclosures containing exposed live parts or exposed conductors operating at over 600 V, nominal, shall be kept locked, except where such entrances are at all times under the observation of a qualified person at all times.

   Where the voltage exceeds 600 V, permanent and conspicuous warning signs shall be provided, reading substantially as follows: “DANGER—HIGH VOLTAGE—KEEP OUT.”

4. **Illumination.** Illumination shall be provided for all working spaces around electrical equipment. The lighting outlets shall be arranged so that persons changing lamps or making repairs on the lighting system are not endangered by live parts or other equipment. The points of control shall be located so that persons are not likely to come into contact with any live part or moving part of the equipment while turning on the lights.

409. **Isolation by elevation.** The National Electrical Code requires that the distances above working spaces to unguarded live parts be not less than those specified in Table 110.34(E).
WIRING FOR CIRCUITS OF LESS THAN 50 VOLTS

410. For wiring circuits of less than 50 V, conductors not smaller than 12 AWG must be used. If the conductors supply more than one appliance or appliance receptacle, they must not be smaller than 10 AWG. Receptacles must be rated at not less than 15 A; in kitchens, laundries, and other locations where portable appliances are likely to be used, the receptacles must be rated at not less than 20 A.

WIRING FOR HAZARDOUS (CLASSIFIED) LOCATIONS

411. Hazardous location classifications (Adapted from Practical Electrical Wiring, 20th ed., © Park Publishing, 2008, all rights reserved) arise because of the presence or handling of explosive gases, liquids, flammable dusts, or easily ignitable fibers. The basic rules for wiring in such locations are covered by NEC Articles 500 through 506, and more specific information is covered in Articles 510 through 517—altogether more than 88 pages. This handbook can discuss only the barest details of this intricate subject.

The NEC uses three basic classes to indicate the type of hazard involved, and those classes (I, II, and III) are further subdivided into divisions (1 and 2) to indicate the prevalence of hazard, and also into lettered groupings to specify the exact type of hazard. Area classifications are seldom performed by an electrical inspector; they are done by qualified engineers subject to review. The reviewer may be the chief of the fire department or some other official. The NEC now requires that hazardous (classified) locations be completely documented, and that those documents be made available to the inspector.

412. Class I locations are those “in which flammable gases, flammable liquid-produced vapors, or combustible liquid-produced vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures.” Combustible liquids will burn, but have flash points (the temperature at which enough liquid vaporizes to create an ignitable fuel-air mixture at the surface of the liquid) at or above 38°C (100°F). Note that the flash point of a liquid is much different than the ignition temperature of its vapor.

Class I, Division 1 locations are those in which hazardous concentrations of gas (1) exist continuously or intermittently under normal operations, (2) exist frequently because of maintenance or leakage, or (3) might exist because of breakdowns or faulty operation that might also result in simultaneous failure of electric equipment in such a way as to cause the electrical equipment to become an ignition source. Examples are paint-spraying areas, systems that process or transfer hazardous gases or liquids, portions of some cleaning and dyeing plants, and hospital operating rooms in countries that still use ethers and related flammable anesthetic agents. These anesthetizing materials are no longer used in the United States, but they are still used in some countries.

Class I, Division 2 locations are locations (1) in which flammable gases or volatile flammable liquids are normally confined within containers or closed systems from which they can escape only in case of breakdown, rupture, or abnormal operation; (2) in which the hazardous concentrations are prevented by mechanical ventilation from entering but which might become hazardous upon failure of the ventilation; or (3) that are adjacent to a Class I, Division 1 location and might occasionally become hazardous unless prevented by positive-pressure ventilation from a source of clean air by a ventilation system that has effective safeguards against failure. Examples are storage in sealed containers and piping without valves.
Class II locations are those having combustible dust. Class II, Division 1 locations are those in which combustible dust is or may be in suspension in the air in sufficient quantity to produce an explosive or ignitable mixture (1) continuously or intermittently during normal operation, (2) as a result of failure or abnormal operation that might also provide a source of ignition by simultaneous failure of electric equipment, or (3) in which combustible dust that is electrically conductive may be present. Examples are grain elevators, grain-processing plants, powdered-milk plants, coal-pulverizing plants, and magnesium-dust-producing areas.

Class II, Division 2 locations are those in which combustible dust is not normally in suspension in the air and is not likely to be under normal operations in sufficient quantity to produce an explosive or ignitable mixture but in which accumulations of dust (1) might prevent safe dissipations of heat from electric equipment or (2) might be ignited by arcs, sparks, or burning material escaping from electric equipment. Examples are closed bins and systems using closed conveyors and spouts.

Class III locations are those in which there are easily ignitable fibers or flyings, such as lint, but in which the fibers or flyings are not in suspension in the air in sufficient quantity to produce an ignitable mixture. Class III, Division 1 locations are those in which easily ignitable fibers or materials that produce combustible flyings are manufactured, used, or otherwise handled, such as textile mills, cotton gins, and woodworking plants. Class III, Division 2 locations are those in which such fibers are stored, such as a warehouse for baled cotton, yarn, and so forth.

Groups. Equipment for use in Class I locations is divided into Groups A, B, C, and D; for Class II into Groups E, F, and G. Each group is for a specific type of hazardous material, which you can determine by consulting your copy of the NEC. All equipment for hazardous locations must be marked to show the class and the group for which it is approved; some equipment is suitable for more than one group and is so marked. Note that for Group E, which encompasses the electrically conductive metallic dusts, there are no Division 2 locations. These dusts are so hazardous that if they are present in any quantities, no matter how infrequently, the location must be wired to Class II, Division 1 standards, using equipment evaluated for Group E exposure.

Basic principles apply to hazardous (classified) location equipment. Enclosures for equipment in Class I, Division 1 locations and enclosures for devices with ignition-capable arcing contacts in Class I, Division 2 locations must be explosionproof. This does not mean that explosive gases or vapors cannot enter into them. The eventual entrance of such gases or vapors is assumed to be inevitable, resulting in ignition, but the enclosure is made to withstand and contain the force of the explosion. Moreover, the hot exploded gas does escape, but not until it has passed through a tight joint that is either threaded or has a wide ground-finish flange. In either case, before it finally escapes to the outside of the enclosure, it has cooled to a temperature below the ignition temperature of the gas in the surrounding atmosphere. The cooling takes place while the gas passes through the long circuitous path of a threaded joint, or across the wide, tight-fitting, ground-finish flange.

For Class II locations, enclosures must be dust-ignition-proof. Dust can be prevented from entering enclosures by means of gaskets, and enclosures can be made with large exposed surfaces for more rapid heat dissipation.
If a Class II dust-ignition-proof enclosure is used in a Class I location, gas can get in, explode, and blow the enclosure to pieces, possibly setting off a larger explosion in the general area, leading to fire or injury. Likewise, if a Class I explosionproof enclosure is installed in a Class II location, it can overheat when blanketed with dust and start a fire.

For a Class III location, equipment only has to be totally enclosed to prevent the entry of fibers and flyings, and to prevent the escape of arcs, sparks, or hot particles.

417. Other protective approaches may work better. The best approach is to use ingenuity and keep electrical equipment out of the hazardous environment. Failing that, another approach is to keep the power circuits somewhere else, and just maintain sensors near the combustible material. If the energy level can be assured to be sufficiently low, any failure in the wiring system won’t be ignition capable. These energy levels are very low. For example, an energy level of just 1/4 milliwatt-second (mW-s) will ignite methane, and levels one-tenth of that will ignite unsaturated hydrocarbons like ethylene. Nevertheless, many sensors can and do function on what are called intrinsically safe circuits (covered in NEC Article 504). These circuits use zener diodes in their supplies, arranged so that even a direct short circuit with its associated potential arcing and heating would not be ignition capable. These circuits can be used with ordinary wiring methods in hazardous (classified) locations for which they are rated.

Nonincendive wiring is closely related to intrinsically safe wiring. Under all normal operating conditions it can’t produce ignition-capable energy, but under very unusual (but foreseeable) operating conditions, might produce such an effect. These circuits are allowed in ordinary wiring in Division 2 locations, but not Division 1. The principle here is that given two low-likelihood probabilities, the probability of them occurring at the same moment is infinitesimal—the two low probabilities in this case being a Division 2 vapor release and a nonincendive circuit failing in a way that is ignition capable.

Another strategy is to exclude all gases and vapors through positive pressure, called “purged and pressurized” in the NEC. This equipment must be connected to a source of clean air under constant pressure. It must be arranged with automatic means to disconnect power if the air supply fails, and it must be equipped with a time-delay function so that its interior can purge prior to the restoration of power. There are three levels of purged and pressurized enclosures. Type X purging reduces a Division 1 environment to unclassified, Type Y purging reduces from Division 1 to Division 2, and Type Z purging goes from Division 2 to unclassified.

Other strategies involve hermetic seals to exclude the hazardous atmosphere, and oil-immersed contacts, which also exclude the hazardous gas or vapor. These two methods are allowable in Division 2 locations only.

418. Zone classification system (NEC Article 505) is a new approach. A number of international standards take the Class and Division system a step further, dividing Division 1 into areas where the specified environment exists routinely and areas where it would exist only for brief periods, probably not long enough to be taken up into the interior of a wiring system and exploding, conditions for which Division 1 equipment must be designed. The result is the Zone system, which is now in the NEC as a parallel classification system. Zone 0 is the worst case, and all power wiring is excluded from it. Zone 1 gets the balance of the traditional Division 1, and since the routine or continual exposure doesn’t apply, most explosionproof requirements do not apply to Zone 1 either. Zone 2 is essentially the same as Division 2.

An occupancy can be designed to the Zone system, or to the Class and Division system, but there must be no overlap or intersection between them, except that Zone 2 and
Division 2 locations can adjoin but not overlap. It is permitted to reclassify an existing Class- and Division-classified area under the Zone system, provided the entire space classified on the basis of a single flammable gas or vapor is reclassified under Zone system requirements. The Zone system classifications and equipment selection must be under the control of a qualified person.

The 2005 NEC (Article 506) extended the zone concept to environments with combustible dust, comparable to Class II under the traditional system, with supervisory requirements comparable to Article 505 applications. The traditional Class and Division system has proven very durable, however, in large part because Zone 2 and Division 2 are functionally identical. The principal economic benefit of the Zone system derives from the more lenient treatment of Zone 1 wiring in comparison to Division 1. However, the overwhelming majority of hazardous (classified) locations today are Division 2, because environmental concerns have made the sort of chemical releases that create Division 1 environments largely nonexistent, or confined to extremely small areas from which it is quite practical to exclude most wiring other than instrumentation. Many facilities are finding no net benefit in changing classification systems.

419. Proper installation and maintenance is essential. In all cases, enclosures such as luminaires and panelboard enclosures must be kept reasonably cleaned of accumulations of residue, fibers, dust, or whatever is contained in the atmosphere. And they must be properly installed. For example, if one of four screws in the cover of an explosionproof switch enclosure is left untightened, or if the flanged joint of a cover or box is scratched, exploded gas will escape before it has sufficiently cooled, and an explosion or fire could result.

A threaded joint must have at least five full threads fully engaged (four and a half threads if factory threaded). Figure 9.277 shows an explosionproof box with threaded hubs for threaded metal rigid conduit, and a threaded cover. Figure 9.278 shows an explosionproof receptacle and plug. The box containing the receptacle has a ground-finish flange joint with four screws, and a threaded hub for conduit. The plug and receptacle are designed so the plug can be withdrawn only part of the way, which breaks down the circuit; an arc, if it forms, will explode the small amount of vapor in the interior. This takes place during the brief time it takes to twist the plug before it can be withdrawn.

Many plugs and receptacles are designed so the plug cannot be inserted or removed unless a switch is in the off position, and the switch cannot be turned on unless the plug is fully inserted.
An explosionproof HID luminaire is shown in Fig. 9.279. Explosionproof fluorescent luminaires are also available, as are explosionproof panelboards, disconnecting means, circuit breakers, motors, and various other equipment—even telephones.

**FIGURE 9.279** An explosionproof luminaire.

420. **Sealing fittings** compartmentalize the wiring system. Explosive gases or vapors can pass from one enclosure to another through conduit. The conduit itself can contain a substantial amount of such material, and without seals to compartmentalize the system the quantity of fuel available to an internal explosion will be enough to cause a rupture, a phenomenon known as *pressure piling*. To avoid these outcomes, sealing fittings of the general type shown in Fig. 9.280 must be installed. The sealing fitting is installed in the conduit adjacent to the enclosure, and thereby completes the enclosure. Then after the wires are pulled into place, the fitting is filled with a sealing compound that effectively prevents explosive or exploded gases from passing from one part of the electrical installation to another, or from passing from a hazardous location to a nonhazardous location where unexploded gases might reach a source of ignition. Note the qualification of the word “prevents.” The actual NEC text uses the term “minimizes” because seals will pass some gases over time, particularly if the gas is pressurized. The principal function of these seals is to isolate sections of conduit or enclosures in the event of an internal explosion; seepage over long periods must be addressed through other approaches. A worker was killed and a catastrophic fire resulted from a disconnect being opened in an enclosure that had accumulated a hazardous quantity of gas resulting from this type of seepage.
The fitting shown in Fig. 9.280 is for a vertical run of conduit. A different type consists of a T-shaped explosionproof fitting or box with a screw-on cover having a spout, with a plug to close the end of the spout. This kind (Fig. 9.281) can be used in either vertical or horizontal runs of conduit. Seals must always be accessible after installation. Seals are also required at hazardous (classified) location boundaries, but those at the boundary between a Division 2 and an unclassified location need not be explosionproof, but must be identified for the purpose of minimizing the passage of gasses under normal operating conditions.

The product standards for seal fittings were reorganized under the 1968 NEC, which at the time set a limit of 25 percent wire fill for new work, and 40 percent for old work. Since seals cannot be opened and reused, the standards presumed a 25 percent fill. When the NEC changed to allow 40 percent fill for even new installations, these standards were overlooked until comparatively recently. The NEC now requires seals to be figured on the basis of 25 percent fill unless listed otherwise. A number of manufacturers now have seals with larger bodies that will accommodate a 40 percent fill. In addition, the seal in Fig. 9.281 clearly allows for easy spreading of the conductors, solving the major problem of undersized seals.
A seal with two wires touching, and the seal compound incomplete at that point, is no seal at all. A major manufacturer has developed a new sealing compound, however, that can be squirted into its seal fitting with no damming or conductor separation, and it will harden into an acceptable seal. This should be very beneficial.

421. **Wiring methods** for hazardous locations are limited. Threaded rigid metal conduit, intermediate metal conduit, and Type MI cable are acceptable in all locations. Rigid nonmetallic conduit is permitted for underground use below 600 mm (24 in.) of cover, with steel conduit ends over the final 600 mm (24 in.) of the run in both directions, allowing a conventional threaded steel end to mate a seal to, because in many cases the hazardous environment is assumed to extend to the point of conduit emergence. In industrial locations with restricted public access, a special type of Type MC cable with a gas/vapor-tight corrugated aluminum armor under a nonmetallic jacket can be used in hazardous locations. Where flexibility is required, there are explosionproof flexible fittings. If additional flexibility is required, extra-hard-usage cord is permitted under conditions of qualified maintenance and supervision, guarding or equivalent protection, and suitable seals where terminated.

In Division 2 locations, most metal-clad or metallic wiring methods are permitted. Where flexibility is required, the usual metallic flexible wiring methods are allowable, along with extra-hard-usage flexible cord. Heavy-wall nonmetallic conduits (Type PVC, Schedule 80, and fiberglass Type RTRC, marked “–XW”) are allowed where very corrosive environments are anticipated in industrial occupancies, but only with qualified service and supervision and restricted public access.

422. **Commercial repair garages** are covered by NEC Article 511. A commercial garage is a location used for servicing and repairing self-propelled vehicles that use flammable liquid fuels, including cars, trucks, buses, or tractors. The 2005 NEC greatly revised many key portions of this material in order to correlate it with the NFPA 30A standard covering these facilities, and the 2008 NEC rewrote 511.3 to simplify the area classification process. Under NFPA 30A, repair garages fall into one of two principal types, described as “major” and “minor.” A minor facility does tune-ups, oil and other fluid changes, brake repairs, tire rotations, etc. This classification includes the popular “quick lube” type of facility. In contrast, a major facility does (in addition) engine overhauls, body and painting work, and (most critically in terms of area classification) repairs that require draining of a fuel tank. Area classification for these facilities focuses on three areas (floor, ceiling, and subfloor pits), and the requirements in each depend on whether specified ventilation is provided.

To summarize, make three assessments: (1) Are you in a major, or minor, repair garage? (2) Are you considering a ceiling, floor, or a pit? (3) Is the space you are considering ventilated per the applicable code specification? In 511.3, the NEC breaks the garage classifications out first (major vs. minor) in lettered subsections. Then it breaks out the locations in numbered paragraphs under each. Finally, under each of those headings come two lettered paragraphs (ventilation provided or not provided).

**Major Repair Garages.** The general floor areas in major repair garages are considered as Class 1, Division 2 to a height of 450 mm (18 in.) above the floor unless the space is ventilated to provide at least four air changes per hour, or 0.028 m³/min (1 cfm) of fresh air per 0.093 m² (ft²) of floor area. The ventilation must be taken from no higher than 300 mm (1 ft) above the floor, and arranged to exchange air across the entire floor area. Ceiling areas are classified to the same extent (i.e., unclassified if there is 1 cfm/ft² ventilation provided,
otherwise, Div. 2), except the 450 mm (18 in.) measurement for Div. 2 extends down from
the ceiling. The classification does not apply if the facility will not be working on vehicles
using lighter-than-air fuels such as hydrogen or natural gas. If classification does apply, the
exhaust port must be within 450 mm (18 in.) from the ceiling high point. For pit areas, their
classification is reduced from Div. 1 to Div. 2 if, and only if, they are ventilated at the rate of
at least six air changes per hour.

**Minor Repair Garages.** The general floor areas in minor repair garages are unclassified as
long as there are no subfloor work areas or pits. If the work area includes these subfloor
areas, the floor areas are classified exactly the same as in the case of major repair garages.
Ceiling areas are unclassified unless lighter-than-air fuels are transferred. For pit areas, they
are unclassified if they are separately exhausted in a similar manner as major repair garages.
Pits not so ventilated in a minor repair garage become Class I, Division 2 locations.

Office areas, stock rooms, toilets, etc., are all classified as nonhazardous locations if they
have at least four air changes an hour, or if they are effectively cut off from the repair area
by partitions. Areas that are adjacent to the repair area but not cut off by partitions and do
not have four air changes an hour may be classified as nonhazardous locations if they have
either sufficient ventilation for ordinary needs, an air pressure differential, or spacing that
presents no hazard in the judgment of the authority having jurisdiction. [A pressure differ-
ential means that the air pressure is slightly higher in the adjacent area than in the hazardous
(repair) area so that no vapors will flow from the hazardous area to the adjacent area.]

**Wiring Methods.** The wiring in nonhazardous areas of commercial garages may be any
type discussed in this division.

*Exceptions:* In an area above a hazardous location that is not cut off by a ceiling, the
wiring must be in a metal raceway, rigid nonmetallic conduit, ENT, Type AC or MC or MI
cable, or manufactured wiring systems, or Type TC cable, or for signaling purposes, Type
PLTC. EMT is very commonly used in such areas.

Luminaires in the area above vehicle lanes must be not less than 3.7 m (12 ft) above the
floor, or be constructed in a way that prevents sparks or hot particles from falling to the floor.
Where fluorescent lighting is used and the luminaires are neither 3.7 m (12 ft) above the
floor nor equipped with a glass or plastic bottom, there are plastic sleeves and similar
devices available to hold a broken fluorescent tube (lamp) and prevent the hot cathode ends
of the lamp from falling to the floor. Other equipment above the hazardous location, such
as motors or switches, must be totally enclosed if less than 3.7 m (12 ft) above the floor.
Drop lights, unless restrained against coming within 450 mm (18 in.) of the floor, must be
suitable for Class I, Division 1 locations.

Wiring in the hazardous location must be of a type specifically described in this part of
Div. 9 for Class I, Division 1 or Division 2 (whichever it is). A sealing fitting is required to
be installed where the wiring enters or leaves the hazardous location so that there is no cou-
pling or other fitting between the sealing fitting and the boundary between the hazardous and
the nonhazardous locations. A sealing fitting is also required at an equipment enclosure,
such as a receptacle or switch box, that is within the hazardous location, but it is common
practice to keep all such wiring and equipment above the 450 mm (18-in) level where prac-
tical. Equipment can almost invariably be kept above the 450 mm (18-in) level, but some-
times the wiring is brought in from underground or installed in the floor slab. In all such
cases, install threaded rigid metal conduit, use gasoline- and oil-resistant wire, and seal the
conduit so there is no coupling or other fitting between the sealing fitting and the 450 mm
(18-in) level. Install a sealing fitting at the panelboard end as the last fitting above grade.

Battery chargers and their control equipment must not be installed in the hazardous
location. If batteries are charged in a separate compressor room, tire-storage room, or similar
area, the room must be well ventilated to allow dissipation of the hydrogen gas. (There is not enough hydrogen gas involved for a battery room to be classified as a hazardous location, but the small amount that is developed must be allowed to dissipate.)

423. Service stations are covered in the NEC as “Motor Fuel Dispensing Facilities” in Article 514. The service area (such as a “lubritorium”), office, storage room, toilets, etc., are treated the same as similar areas in a commercial garage. The gasoline-dispensing areas are classified as follows:

The area within the gasoline dispenser (pump) is no longer classified by language in the NEC; due to differences in modern dispenser designs, this area classification is now left to the product standards as part of the listing process. However, any pit or below-grade space that extends upward into a classified location within the dispenser is Class I, Division 1. In addition, the entire area within 450 mm (18 in.) horizontally of the dispenser enclosure, or of any liquid-handling components within the enclosure, is Class I, Division 2. Moving outward from the dispenser, the entire area extending 6.0 m (20 ft) horizontally in all directions from the dispenser enclosure and extending up to 18 in. above grade is a Class I, Division 2 location. This includes any indoor area not suitably cut off by partitions. The below-grade area is unclassified because there is not enough air to support combustion. However, conduits routed beneath these areas can accumulate fumes and must be sealed.

The requirement to seal applies to the point of conduit emergence from grade. This allows the seal, which must always be accessible and usually within a conduit length of the required location, to be at a convenient point. Otherwise installers would be installing handholes in areas of unbroken pavement to accommodate sealing requirements.

The area within 3.0 m (10 ft) horizontally of a storage-tank fill pipe (for a loose-fill connection) or 1.5 m (5 ft) horizontally of the tight-fill connections more common today because of environmental concerns, and extending to 450 mm (18 in.) above grade is a Class I, Division 2 location; the below-grade area beneath this is a Class I, Division 1 location. For storage tank vent pipes, the spherical volume within a 900-mm (3 ft) radius of the discharge point of a storage-tank vent pipe is a Class I, Division 1 location; the spherical volume between the 0.90-m and 1.5-m (3-ft and 5-ft) radius is a Class I, Division 2 location. Any wiring to pole lights, signs, etc., must be kept out of the hazardous locations or be made to comply with the rules for the location, which include a sealing fitting at each end of a conduit that passes through a hazardous area. It also means that any below-grade wiring within any hazardous location must be in rigid metal conduit and be nylon-covered gasoline- and oil-resistant wire, since gasoline can and often does get into below-grade conduit in hazardous locations. (Under some conditions, as noted in the general discussion, rigid nonmetallic conduit and Type MI cable may also be installed underground.) For wiring to a gasoline dispenser, a sealing fitting must be the first fitting in the conduit where the conduit emerges from below grade at the dispenser and also where the conduit emerges from below grade at the panelboard. An explosionproof flexible fitting is frequently required between the sealing fitting and the equipment inside the dispenser, since the conduit may not quite line up with the internal fittings, and there is not much room for bending rigid metal conduit underneath the dispenser.

Any branch circuit supplying a dispenser or passing through a dispenser (such as to supply a lighting standard near the dispenser) must have a circuit breaker or switch that disconnects all conductors of the circuit, including the grounded (white) conductor. There are special circuit breakers made for this specific purpose; they have a switching pole for the grounded conductor as well as for the ungrounded conductor, but there is no overcurrent device in the grounded conductor pole of the breaker. If such a circuit breaker is not used, a switch without a fuse in the grounded conductor, but that opens all conductors (including the grounded conductor) simultaneously, must be used.
424. Paint-spraying booths are covered in NEC Article 516, which include paint-spraying booths and areas. Some repair garages have a body shop with a paint-spraying booth. No electric equipment, and no wiring except threaded rigid metal (or intermediate metal) conduit, or Type MI cable, or metal boxes (or fittings), provided they contain no splices or terminal connections, are permitted in a paint-spraying booth unless the equipment and the splice and terminal enclosures are approved for both Class I, Division 1, Group D locations, and for accumulations of readily ignitable residues. Luminaires are the only equipment available (as of this writing) meeting both these requirements. To wire such a booth, proceed as follows:

Luminaires (in conjunction with transparent baffles, exhaust-air movement, and careful placement) can often be installed where they will not be covered with paint residue, but it is sometimes difficult to do and not always acceptable to some inspectors. So use luminaires that are approved for both Group D and for paint residue. Then wire them with threaded rigid (or intermediate) metal conduit (or Type MI cable) without splice boxes or switches inside the booth. Explosionproof boxes, as shown in Fig. 9.277, may be used as long as there are no splices in the box; and switches must be installed outside the booth.

If luminaires other than the type that are approved for residue are used, install them outside the booth so that light will enter the booth interior through extra-strength glass panels in the roof or sides of the booth (or both). Wire these luminaires as required for the garage location in which they are located.

The exhaust fan (which must have nonferrous blades, that is, not iron or steel but rather aluminum or brass) must have the fan motor installed outside the exhaust stack and connected to the fan by a metal shaft or by a staticproof belt. Wire the motor as required for the location. That is, if it is inside the garage repair area, wire it accordingly; if it is outdoors, wire it for an outdoor location. (In some cases one wall of a booth may be the exterior building wall; so in some cases, the motor could be outdoors.)

**INSTALLATION OF APPLIANCES**

425. Connection to circuit and protection. A portable appliance may be connected only to a receptacle having a rating at least as great as the appliance. The standard duplex convenience-outlet receptacle is rated at 15 A and may supply a single 15-A fixed appliance or a 12-A portable appliance if used on a 15-A branch circuit. Heavy-duty receptacles rated at 20, 30, and 50 A may be obtained for higher-current appliances. On new installations all 15- and 20-A receptacles must be of the grounding type. (Refer to Div. 4 for a description of receptacles.) Most household appliances, such as toasters, hot plates, percolators, flatirons, waffle irons, refrigerators, radiant heaters, roasters, portable ovens, etc., are rated at less than 12 A, so that they may be used in the standard outlet on a 15-A circuit.

Appliances other than motor-operated ones are not generally required to have individual overload protection.

426. In wiring appliances one of the approved types of cords listed in Div. 2 should be used. If the appliance is rated at more than 50 W and temperatures of more than 121°C (250°F) are produced on surfaces with which the cord is apt to be in contact, one of the types of heater cords must be used. Every heating appliance which is intended to be applied to combustible material as a smoothing iron must be equipped with a stand, which may be separate or a part of the appliance. Each heating appliance intended to be located in a fixed location.
position must have ample protection provided between the appliance and adjacent combustible material.

427. Disconnecting means (National Electrical Code). Each appliance shall be provided with a means for disconnection from all ungrounded conductors as follows:

1. Portable Appliances. For portable appliances (including household ranges and clothes dryers) a separable connector or an attachment plug and receptacle may serve as the disconnecting means. The rating of a receptacle or of a separable connector shall not be less than the rating of any appliance connected thereto, except that demand factors authorized elsewhere in the NEC may be applied. Attachment-plug caps and connectors shall conform to the following:
   a. Exposed parts. They shall be so constructed that there are no exposed current-carrying parts, except the prongs, blades, or pins. The cover for the wire terminations shall be a part that is essential for the operation of an attachment plug or connector (dead-front construction).
   b. Rating. The rating of a receptacle or of a separable connector shall not be less than the rating of any appliance connected thereto.
   c. Noninterchangeability. They and their mating receptacles shall be constructed such receptacles or cord connectors do not accept an attachment plug with a different voltage or current rating from that for which the device was intended. However, a 20-A T-slot receptacle or cord-connector shall be permitted to accept a 15-A attachment plug of the same voltage rating. Nongrounding receptacles and connectors shall not accept grounding-type attachment plugs.

   For cord- and plug-connected appliances, where the separable connector or plug and receptacle are not accessible, the appliance shall be provided with a disconnecting means in accordance with the provisions for permanently connected appliances. For household electric ranges, a plug-and-receptacle connection at the rear base of a range, if it is accessible from the front by removal of a drawer, is considered as meeting the intent of the accessibility rule.

2. Permanently Connected Appliances. For permanently connected appliances rated not over 300 VA or \(\frac{1}{2}\) hp, the branch-circuit overcurrent device may serve as the disconnecting means. For permanently connected appliances of greater rating, the branch-circuit switch or circuit breaker within sight from the appliance, or is capable of being locked in the open position, may serve as the disconnecting means.

3. Unit Switches with a Marked “Off” Position. Switches that are a part of an appliance and that disconnect all ungrounded conductors shall not be considered as taking the place of the single disconnecting means required by this section unless there are other means for disconnection as follows:
   a. Multifamily dwellings. In multifamily (more than two families) dwellings, the disconnecting means shall be within the apartment or on the same floor as the apartment in which the appliance is installed and may control lamps and other appliances.
   b. Two-family dwellings. In two-family dwellings, the disconnecting means may be outside the dwelling in which the appliance is installed. This will permit an individual switch for the dwelling to be used and shall also be permitted to control lamps and other appliances.
   c. One-family dwellings. In one-family dwellings, the service disconnecting means may be used.
   d. Other occupancies. In other occupancies, the branch-circuit switch or circuit breaker, if readily accessible to the user of the appliance, may be used for this purpose.
4. **Switch or Circuit Breaker to Be Indicating.** Switches or circuit breakers used as disconnecting means shall be of the indicating type.

5. **Motor-Driven Appliances.** A switch or circuit breaker which serves as the disconnecting means for a permanently connected motor-driven appliance of more than 1/8 hp shall be located within sight of the motor controller.

Exception. A switch or circuit breaker that serves as the other disconnecting means as required in Par. 3 shall be permitted to be out of sight from the motor controller of an appliance which is provided with a unit switch or switches with a marked-off position and which disconnects all ungrounded conductors.

428. **Portable appliances need to be grounded as specified in Sec. 250.114 of the NEC.**

429. **Signals and temperature-limiting devices for heated appliances.** In other than dwelling-type occupancies, each electrically heated appliance or group of electrically heated appliances intended to be applied to combustible material shall be provided with a signal unless the appliance is provided with an integral temperature-limiting device.

430. **Overcurrent protection for nonmotor-operated appliances** must not exceed the marking on the appliance (if any). If the appliance is not marked, the overcurrent protection must not exceed 20 A on appliances rated 13.3 A or less, and must not exceed 150 percent of the rating of larger appliances. Rounding up to the next higher standard sized overcurrent device is permitted.

Electric ranges, cooktops, and similar appliances with surface-type heating elements that present a load in excess of 60 A after the application of the demand factors in Table 2 in Div. 12 shall have that load subdivided into two or more circuits. The resulting circuits shall have overcurrent protection rated at not over 50 A.

**ELECTRIC COMFORT CONDITIONING**

431. **Introduction.** As a practical guide to electric comfort conditioning, these sections are designed to provide a general understanding of when to use electric heating and cooling systems, how to estimate heat loss, what type of equipment is available, and where comfort conditioning equipment should be located.

432. **When to use electric heating and cooling.** Electric heating and cooling systems are used in all types of buildings, and there are outdoor spot-heating systems in addition to snow-melting and deicing systems.

433. **Residential buildings.** Electric heating and cooling systems for single-family dwellings and many multifamily dwellings, widely accepted at one time throughout the United States, are now used far less frequently due to the cost of energy. Whether such a
system is most desirable economically, a personal preference, or a luxury depends upon its usage by the occupants, the construction of the building, and the local electric utility rates (cost per kilowatthour of electricity for heating).

1. **Advantages of Electric Heating** include individual room control, long life of the equipment, space-saving features, cleanliness, and safety. However, the user can abuse these advantages by leaving doors, windows, or fireplace chimney flues open; overheating; or improper building construction or insulation. Improper usage by the occupant is usually the reason for excessive utility bills.

2. **Insulation.** If electric heat is to be operated economically, it is important to consider the value of insulation. A well-insulated residence requires less equipment and incurs lower operating costs. Savings in equipment cost and annual operating costs generally pay for the increased cost of added insulation, storm windows, and storm doors.

3. **Selecting Insulation.** It is important to consider the effectiveness of insulation in terms of resistance to heat transfer and not just thickness. The effectiveness of insulation (for ceilings, walls, and floors) is judged in terms of its $R$ (resistance) value. The insulation manufacturer will indicate the $R$ value for a given thickness. For buildings with electric comfort conditioning, the National Mineral Wool Insulation Association at one time specified a minimum resistance as follows: ceilings = $R_{19}$; walls = $R_{11}$; floors = $R_{13}$. Building codes today generally move these numbers far higher, and should be consulted prior to designing an installation.

4. **Construction of the Wall or Ceiling Roof.** The construction is not very significant if the minimum $R$ value is provided. Storm windows (and doors) or double-glazed glass more than double the $R$ value of the glass area.

5. **House with a Heated Basement.** Such a house need not have insulation under the floor, but there should be insulation under a floor which is over an exposed crawl space. The most effective insulation for concrete slabs is around the exposed outside edge. Perimeter-slab insulation can be extended down vertically about 24 in. (609.6 mm) or can be installed around the edge of the slab at about the same distance.

6. **Insulation Protection.** To protect insulation from the negative effect of moisture from within the house, a vapor barrier on the inside face of the insulation is recommended. The vapor barrier must be protected from damage, and any tears or holes must be repaired.

7. **Well-Insulated Buildings.** A well-insulated building may become an excessively humid building. To avoid excessive humidity buildup, a humidistat should be used to control one or more exhaust fans or a fresh-air ventilator. The humidistat closes the circuit to the fans when the relative humidity exceeds the preselected humidistat setting.

   The operation of a humidistat is similar to that of a thermostat, except that the sensing element responds to humidity instead of heat. Also, the element in a humidistat most commonly consists of a series of human hairs, which respond to changes in the relative humidity. In a home the relative humidity rises because of the use of dishwashers, dryers, washing machines, showers, sinks, and similar sources when use of water or production of moisture occurs.

8. **Heat Loss.** A residential building, insulated to the previously indicated specification, will have a heat loss of about 10 W/ft$^2$ (0.93 W/m$^2$) or 1 W/ft$^3$ (0.028 W/m$^3$).

9. **Heat-Loss Survey.** Before actual load requirements are determined, a heat-loss survey of all exposed rooms should be made. If, for example, in the New York City area, with an outside design temperature of 0°F (−18°C) and an inside design temperature of 70°F (18°C), the heat loss is to be determined for a frame residence, the loss for each exposed room can be calculated in the same manner as in the following example for a 12- by 10- by 8-ft (3.7- by 3- by 2.4-m) corner bedroom (bedroom A).
10. Steps in Calculating Heat Loss

b. Multiply the total square-foot area for all exposed areas by this factor. (Deduct exposed-glass and door area from the gross wall area to determine the net wall area.)
c. Multiply the cubic-foot volume by the infiltration or air-change factor.
d. Add all products for the total heat loss of the room.
e. Add the heat loss of all the rooms to determine the total heat loss of the house. See the following example:

<table>
<thead>
<tr>
<th></th>
<th>Sq-ft</th>
<th>Factor</th>
<th>Heat loss, W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross outside wall windows (and doors)</td>
<td>176</td>
<td>× 12</td>
<td>288</td>
</tr>
<tr>
<td>Net outside walls</td>
<td>152</td>
<td>× 1.6</td>
<td>243</td>
</tr>
<tr>
<td>Ceiling</td>
<td>120</td>
<td>× 1.0</td>
<td>120</td>
</tr>
<tr>
<td>Floor</td>
<td>120</td>
<td>× 2.0</td>
<td>240</td>
</tr>
<tr>
<td>Infiltration</td>
<td>960</td>
<td>× 0.4</td>
<td>384</td>
</tr>
<tr>
<td>Total heat loss</td>
<td></td>
<td></td>
<td>1,275</td>
</tr>
</tbody>
</table>

11. Determining Annual Operating Cost. Check with the local utility for the conversion factor for kilowatthours. If the heat loss is 7370 W and the conversion factor is 1.4, multiply the heat loss of 7370 W by 1.4, which equals 10,318, the total number of kilowatthours required to provide a 70°F (18°C) indoor temperature during the heating period. A similar heat-gain study can be made to determine the cooling load. Once the kilowatthour consumption is estimated, multiply 10,318 kilowatthours by 0.0458 (4.58 cents), the 1985 base rate for electric heating in Chicago. The product is $472.56, which is the estimated annual operating cost for electric heating. On the basis of an 8-month heating season, the average operating cost per month is $59.07. Today’s unit energy costs are frequently double this number or even more, so make a proportional increase based on local energy costs. Heat-loss calculations of this type may also be made for apartment buildings, small commercial buildings, and other small buildings. For large commercial or institutional buildings, other factors, particularly that of fresh-air changes, must be considered.
434. Commercial or industrial buildings. Many factors are involved in considering the use of electric heating in a commercial, industrial, or institutional building. Usually, a consulting engineer or heating specialist will perform a feasibility study which compares electric heating with other types of heating systems. The study will compare not only the cost of fuel but also the annual capital costs and maintenance costs over a period of years. The selection of electric heating, however, will generally depend upon the cost of electricity.

435. Types of equipment. There are many types of electric heaters, varieties of housings, heating elements, and methods of distributing the heat into the heated area.

1. Electric Heaters. There are convector, fan-forced, or radiant types of heaters. Each heater contains a resistance element which heats air or water. All such heaters provide both radiant and convection heat. The ratio depends upon the type of heater. Radiant heaters provide the highest radiation-to-convection ratios.

2. Residential Buildings. A centralized system may be an electric furnace, boiler, or heat-pump system. A decentralized system could include the use, entirely or in combination, of baseboard heaters, wall heaters, floor-drop-in heaters, ceiling heaters, or ceiling panels or heating cables. The decentralized systems permit individual room control. Central systems have central control but often have the advantage of combining heating and cooling in the same duct system. The conversion of a fossil-fuel–fired hot-air or hot-water system can be readily accomplished by replacing the existing furnace or boiler with an electric furnace or hot-water boiler.

3. Commercial Buildings. Central systems are available with large banks of electric duct heaters in conjunction with air handlers. Electric hot-water or steam boilers are available in large kilowatt capacities. Central heating and cooling systems can be used in conjunction with perimeter-baseboard–type heaters. Perimeter heaters will counteract external-wall heat loss and allow control of the heaters in modular sections.

4. Unitary Systems. In commercial buildings unitary systems permit combinations of heating and cooling with control of each room or area.

5. Through-the-Wall Heating and Air-Conditioning Units. Particularly in school buildings, such units help to reduce engineering and maintenance costs. Unitary-equipment breakdown affects only a single room or area instead of the entire building or large section that is affected when a central system becomes defective.

6. Rooftop Equipment. Such equipment saves building space in low-ceiling commercial buildings while providing large-capacity electric heat and cooling into a ceiling plenum or duct system.

7. Electrically Heated Buildings. Most such buildings will use electricity for domestic hot water. All-electric kitchens complete the application of electricity in the total-electric concept.

8. Partial-Building Heat. This is another common application for unitary heaters.

9. Infrared Heaters. These provide spot heating for indoor or outdoor heating applications. Electric-heating cables or mats for snow melting, deicing, or pipeline heating offer convenience and reduction of costs unavailable in other systems.

436. Equipment capacities. The following equipment is described for various applications in Secs. 437 to 443.
437. Electric furnaces (Figs. 9.282 and 9.283) are made in capacities of 4 to 35 kW at 240 V, single-phase or three-phase.

This heating assembly is a compact package heating system for new buildings or conversion applications in homes, apartments, or small commercial buildings. The furnace can be positioned in the ducts so that it can be used for upflow, downflow, or horizontal discharge in basements, attics, utility rooms, or utility closets.

Heating elements can be internally wired to be energized in 5-kW stages, at 60-s intervals, to prevent power surges. As part of the electric-furnace system, summer air conditioning or an electronic air cleaner may be added at any time without changing the blower or duct system. Some units are designed to be used with a split-system air conditioner. Low-voltage wall-mounted controls are usually installed in a central part of the building.

438. Hydronic boilers have capacities from 6 to 30 kW at 240 V, single-phase. These wall-mounted hot-water boilers are compact in size (between 2 and 8 ft³, or between 0.057 and 0.227 m³) and weigh about 120 lb (54.4 kg). A typical boiler has incremental stages (5 kW or less), which sequence at 30- to 45-s intervals to eliminate a large power surge. Centrally located low-voltage wall-mounted controls operate the boiler.

439. Heat pump

Capacities range from 23,000 to 236,000 Btu for heating and 2 to 20 tons for cooling, single-phase or three-phase, at several voltage ratings.
The residential heat pump is a boxlike unit which is installed inside or outside the building, although it is usually outside with air-to-air heat transfer. The heat pump designed for outdoor installation is roof-mounted, through-the-wall, or remote-mounted. In cold climates (below 20°F, or −7°C, outdoor design) supplementary space-heating equipment is used in conjunction with the heat pump. An accessory kit is available for low-ambient operation.

The heat pump is regarded as a low-operating-cost heating and cooling system with a centrally mounted combination heating-cooling thermostat. Figure 9.284 shows a 3-ton residential central condensing unit for an air conditioning system; heat pumps run in the cooling mode will have comparable capacities. Large-capacity heat pumps are sometimes used for commercial or industrial buildings.

**FIGURE 9.284** A 3-ton residential central air-conditioning condensing unit.

### 440. Residential unitary systems

include several types of electric heaters or combination units:

1. **Baseboard Heaters.** Figure 9.285 shows a typical unit of these commonly used heaters. Capacities range from 375 to 3500 W at 120, 208, or 240 V.

   These heaters are usually surface-mounted convector units with finned-tubular or cast-aluminum (Fig. 9.285) heating elements. Ratings are in terms of watt density. Low watt density is about 175 W/ft, medium watt density is about 225 W/ft, and high watt density is about 275 W/ft.

**FIGURE 9.285** Baseboard heating section. [King Electrical Mfg. Co.]
Heater lengths range from 2 to 12 ft (from 0.6 to 3.7 m), and heights are usually from 6 to 9 in. (from 152.4 to 228.6 mm). The heaters are controlled by integral line-voltage thermostats, thermostat sections, line-voltage wall thermostats, or low-voltage wall thermostats.

These heaters are most commonly used to provide perimeter heating, particularly under the windows of outside walls. They can be easily installed in both new or existing buildings. Many baseboard heaters provide a full-length wireway. They have knockouts in the bottom, side, and back for electrical-supply connections. A plastic seal can be provided on the back of the heater to maintain a neat appearance when the heater is installed against an uneven wall. An air deflector directs heated air away from the wall. A free-floating element reduces expansion and contraction noises.

Heater accessories include blank sections which can be cut on the job for wall-to-wall installations. A thermostat section is available with or without duplex receptacles, although a receptacle section itself is available with some heaters. A control section, with or without a thermostat, may be used to switch the same source of power from an off position to a heat position or to a cool position. A room air conditioner is plugged into the top of this section. Also available is a section that contains a relay or transformer-relay for use with a low-voltage thermostat.

2. **Radiant Wall Heaters.** These heaters are also widely used. Capacities range from 500 to 6000 W at 120, 208, or 240 V.

   Residential units of this type are for surface or recessed mounting. Small-capacity (500- to 1500-W) heaters are used in bathrooms or other small rooms. Large-capacity (2- to 6-kW) heaters are designed for add-on rooms, new construction, or existing room areas. The radiant heater may have a resistance element or glass panel with embedded resistance material. A typical glass unit, rated at 750 W, is shown in Fig. 9.286.
This heater features a built-in thermostat and shallow depth for recessed applications (2 in. or 50.8 mm, in some cases). For ease of installation, there are knockouts on the back, bottom, or side.

3. **Forced-Air Wall Heaters.** Such a heater is shown in Fig. 9.287. Capacities range from 660 to 4000 W at 120, 208, 240, or 277 V.

   These residential units can be recessed, semirecessed, or surface-mounted. Most commonly, this type of heater has a built-in thermostat with a positive off position. The lower-capacity heaters (660 to 1500 W) are used in bathrooms and other small rooms. The higher-capacity heaters (2 to 4 kW) are commonly used in basements, recreation rooms, or add-on rooms. The larger heaters offer several options. Some units have a fan-delay switch, a built-in safety switch, a fuse-disconnect, or a low-voltage transformer. A self-lubricating motor is common in the larger heaters. Also, a permanent type of filter is available in large-capacity heaters.

   Some of these heaters utilize the counterflow principle of heat and air distribution. They may be controlled by a separate line- or low-voltage thermostat in conjunction with an integral or remote relay. A fan switch permits summer operation.

4. **Convector Wall Heaters.** Such a heater is shown in Fig. 9.288. Capacities range from 500 to 5000 W at 120, 208, or 240 V.

   These convector units can be surface- or recess-mounted with integral or remote controls. Low wattage heaters can be used in shops, corridors, breezeways, and basements. Larger-wattage convectors can be used to heat basements, attics, or any area where limited wall space prevents the use of baseboard heaters.
5. **Fan-Forced Kick-Space or Baseboard Heaters.** Such a heater is shown in Fig. 9.289. Capacities range from 750 to 2000 W at 208 or 240 V.

Such heaters can be surface- or recess-mounted. They are well suited to locations where baseboard radiation is desired but only limited space is available. The kick-space heater has a quiet tangential blower and is particularly suitable for kitchens or bathrooms where adequate wall space is not available. It is recessed into the kick-space area under a cabinet or counter. Control is by a separate wall-mounted line-voltage thermostat.

![Fan-forced recessed kick-space heater](image)

**FIGURE 9.289** Fan-forced recessed kick-space heater. [Chromalox, Wiegand Industrial Division of Emerson Electric Co.]

6. **Wall-Mounted Electric Fireplaces.** Such a fireplace is shown in Fig. 9.290. Capacities range from 2000 to 5000 W at 240 V.

This unit is a forced-air surface-mounted heater designed to look like a fireplace. It has a glowing grate with realistic logs in a steel cabinet which is finished in matte black or copper-tone enamel. It is ideal for dens, beach and mountain cabins, offices, motels, restaurants, and lounges. The electric fireplace can have a built-in thermostat and fan-delay control; it is also available with a remote wall-mounted low-voltage thermostat.

![Wall-mounted electric fireplace](image)

**FIGURE 9.290** Wall-mounted electric fireplace.
7. **Radiant-Heat Ceiling Units.** Such a unit is shown in Fig. 9.291. The capacity of the heater is 1500 W at 120 V. Lighting consists of two 60-W incandescent lamps, and the small exhaust fan is rated at 60 ft³/min (0.028 m³/s).

This unit is recessed in the ceiling of bathrooms. A wall-mounted switch or time-control switch provides individual control of the heater and lamps.

![Radiant heater with fan circulation for ceiling mounting.](image)

8. **Radiant and Forced-Air Ceiling Heaters.** These heaters are available in capacities of 600 to 1250 W at 120 V.

A typical unit is attached directly to a flush 3½- or 4-in ceiling outlet box. This heater is commonly used in small bathrooms, playrooms, and powder rooms. A small fan is used to force heat away from the ceiling; the primary heat is radiant. In some heaters, a center-mounted 100-W incandescent lamp is available for lighting.

9. **Forced-Air Ceiling Heaters.** Such heaters range in capacities from 1000 to 1525 W at 120, 208, or 240 V.

Forced-air units can be surface-mounted on a standard flush 3½- or 4-in ceiling outlet box. Commonly used in bathrooms or powder rooms, the fan-forced heater is approved for standard 60°C supply wires, such as Type TW. It is available with adjustable mounting brackets and an automatic plug-in connection. Control is by a wall-mounted thermostat.

10. **Radiant Ceiling Heaters.** These range in capacities from 600 to 1500 W at 120, 208, or 240 V.

The ceiling-mounted residential radiant heater can be recessed or surface-mounted on a standard flush 3½- or 4-in ceiling outlet box. Available with a center-located 100-W incandescent lamp and plug-in connections, the heaters are approved for 60°C supply wires. The radiant ceiling heater is commonly used in bathrooms, powder rooms, or other small rooms. Control is by a wall-mounted thermostat.

11. **Radiant Ceiling Panel Heaters.** These heaters range in capacities from 235 to 1000 W at 120, 208, or 240 V.

The residential radiant ceiling panel is constructed of laminated glass, gypsum drywall, or radiant metal. It can be surface-mounted, recessed, or used in a T-bar construction module, usually in panels 2 to 4 ft (0.6 to 1.2 m) wide and 3 to 12 ft (0.9 to 3.7 m) long. The depth of the heater is ½ to 1 in. (19.05 to 25.4 mm). The surface finish can be painted. A typical unit contains a 4-in terminal box and a 3-ft (0.9-m) flexible metal conduit. Controlled by a separate wall-mounted thermostat, the ceiling panel may be used for small rooms, spot heating, or complete area heating.

12. **Ceiling Heating Cable.** A typical run of this cable is shown in Fig. 9.292. Capacities range from 200 to 5000 W at 120, 208, or 240 V, and lengths are from 75 to 1800 ft (from 22.9 to 548.6 m).

Ceiling cable is embedded in plaster or laminated ceiling construction for individual rooms or complete house heating. Color-coded cables are electrically insulated and
resistant to high temperature, water absorption, aging effects, and chemical action. The cables are usually rated at 9 W/m (2 1/2 W/ft). They must not be cut in the field, and identification labels must not be removed.

Nonheating lead wires, 2.1 m (7 ft) or longer, extend to the thermostat or a junction box. For installation (Fig. 9.293), the cable is stapled to a nonmetallic fire-resistant surface at least every 400 mm (16 in.). After the first plaster coat has been applied, cables should be tested for continuity and for insulation resistance (at least 100,000 Ohms measured to ground).

Minimum spacing between cable runs is 38 mm (1 1/2 in.) on centers with the closest spacing near the outside walls. Cables should clear lighting fixtures by at least 200 mm (8 in.). General electrical wiring (for lights, etc.) should be run over the thermal insulation and at least 50 mm (2 in.) over the heated ceiling surface.

13. Floor Heating Cable. Such cable has unlimited heat capacities which vary with the conductor resistance, type of cable, and length of cable. Ratings are from 120 to 600 V. In residential occupancies ratings are 120, 208, or 240 V.

Heating cables are used in floors to form radiant panel systems. Cables most commonly used are polyvinyl chloride–sheathed cables or mineral-insulated (MI) copper-sheathed cables. In concrete, cables must be of a material that is resistant to any chemical action in the concrete. Cables may be interwoven as part of a properly
grounded prefabricated mat. They may be of predesigned lengths which are spaced to provide a desired radiant-heat output. Cables such as Type MI are available at several different resistances. Single- or two-conductor cables at specified lengths will have varied heat capacities, depending upon the applied voltage. Heating cables may be installed in one or two pours with adjacent runs not less than 25 mm (1 in.) on centers and with adequate spacing between cable runs and metallic bodies embedded in the floor. Nonheating leads must be protected when they leave the floor by rigid metal conduit, IMC, or EMT or, with MI cable, by approved current-carrying non-heating cable sections. Control of floor heating systems is by a thermostat with a capillary and sensing element attached. The sensing bulb is embedded in the slab so that it will respond to typical temperature changes.

14. **Floor Drop-In Heaters.** Such a heater is shown in Fig. 9.294. Capacities range from 300 to 2000 W at 120, 208, 240, or 277 V.

Residential floor drop-in heaters are resistance convector units, fan-forced units, or units that have a chamber with antifreeze water sealed in and heated electrically. They are best applied to counteract downdrafts from floor-to-ceiling windows or sliding glass doors. They can be installed in wood or concrete floors. A fan-forced heater may have an integral thermostat, but the control for most units is by a line- or low-voltage wall thermostat.
441. Central systems for commercial-type occupancies are of the types described in the following paragraphs.

1. Outdoor Roof-Mount Heating and Cooling Units. Such a unit is shown in Fig. 9.295. Electric-heating capacities are custom-designed for a particular installation. Cooling capacities range from 2 to 200 tons at 208 V, single- or three-phase; 277 V, single-phase; and 480 V, single- or three-phase.

   All-electric heating and cooling machines are designed for roof-mount outdoor conditions. Custom fabrication provides machines with job-specified heating and cooling capacities. Multizone staging from a remote monitoring panel can establish the roof-mount machine as the heating and cooling plant for a one- or two-story building. Supermarkets, office buildings, laboratories, warehouses, machine shops, and aircraft plants are good applications for roof-mount equipment. Space-saving economy is a major feature of such equipment. Staged or step control for the heating section, with fresh-air damper control, provides a well-balanced automated system.

2. Commercial Steam or Hot-Water Boilers (Fig. 9.296). These boilers are available in capacities up to 3000 kW at 208, 240, and 480 V, single- or three-phase.

   Commercial steam or hot-water boilers are designed for conversion of electric energy to heat in the form of steam or hot water. Hot-water boilers are used as a replacement for fuel-fired boilers; as the heating component for a chilled water-cooling system; as a safe method of heating a hazardous area; or as a side-arm–faucet water heater. A typical boiler is provided with a low-water cutoff, a safety relief valve, temperature control, a water gage, a high-temperature limit switch, contactors, internal fusing, full insulation, and an enameled-steel jacket. The electric boiler occupies a much smaller floor area than other types of boilers and does not require retubing, flue cleaning, burner cleaning, damper adjusting, or chemical additives.

   Steam boilers are available with 1/2 to 30 boiler hp (4.9 to 294.3 kW), 1 to 250 lb/in², and are built to ASME and Underwriters Laboratories standards. Boilers include a safety valve, a boiler steam pressure gage, a pressure regulator, a low-water cutoff, an automatic-feed control, a control switch, a pilot light, outlet valves, and drain valves. A condensate tank is recommended to reuse the condensed steam.
### 442. Commercial unitary systems

are described in the following paragraphs.

1. **Infrared Heaters.** Such a heater is shown in Fig. 9.297. Capacities are 500 to 7600 W at 120, 208, 240, 277, 440, 480, and 600 V.

![An infrared heater with quartz lamps.](image)

**FIGURE 9.297** An infrared heater with quartz lamps. [Chromalox, Wiegand Industrial Division of Emerson Electric Co.]
The heating elements consist of metal-sheathed units, quartz tubes, or quartz lamps. The following table describes the characteristics of these three infrared sources:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Quartz lamp</th>
<th>Quartz tube</th>
<th>Metal sheath</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative heat intensity</td>
<td>Very high</td>
<td>Low to medium high</td>
<td>Medium to high</td>
</tr>
<tr>
<td>Splash resistance</td>
<td>Very good</td>
<td>Very good</td>
<td>Very good</td>
</tr>
<tr>
<td>Color blindness</td>
<td>Fair</td>
<td>Very good</td>
<td>Very good</td>
</tr>
<tr>
<td>Life expectancy</td>
<td>5,000 h or more</td>
<td>5,000 h or more</td>
<td>Consult manufacturers</td>
</tr>
<tr>
<td>Visible light</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Heat-up and cool-down time</td>
<td>A few seconds</td>
<td>2 min or more</td>
<td>About 2 min</td>
</tr>
<tr>
<td>Relative cost per kW</td>
<td>Medium high</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Filament or source temperature</td>
<td>About 4,000°F</td>
<td>About 1,200 to</td>
<td>About 1,200 to</td>
</tr>
<tr>
<td>Vibration resistance</td>
<td>Medium</td>
<td>Medium</td>
<td>Very good</td>
</tr>
</tbody>
</table>

Infrared heaters are used for complete indoor heating, spot heating, outdoor heating, and outdoor snow melting. For outdoor heating and snow melting it is preferable to use the quartz lamp and to shield the element and fixture from strong winds as much as possible. Rapid cooling of the element diminishes radiation effectiveness. For spot heating, use two fixtures aimed at the center of the target area at about a 45° angle. Do not irradiate outside walls or surfaces over 6 ft (1.8 m) above the floor. For complete comfort heating, install 1/2 W for each degree of operational temperature desired above the minimum ambient ever reached in a specific area. For spot heating provide 1 W/ft²/degree of temperature difference. For outdoor heating provide 2 W/ft²/degree of temperature difference. If, for example, the area to be heated is a storefront sidewalk 100 ft (30.5 m) long by 10 ft (3 m) wide in New York City, proceed as follows (assuming an outside design of 0°F and a desired temperature of 50°F):

\[
100 \times 10 = 1000 \text{ ft}^2 \\
\times 2 \text{ W/ft}^2 \\
\times \frac{2000}{50} \\
100,000 \text{ W}, \text{ or } 100 \text{ kW}
\]

Select fixtures in accordance with the manufacturers’ recommendations. The radiation patterns are determined by the reflector design and the resulting beam pattern. Beam patterns range from a 30° to a 90° angle. They may be symmetrical or asymmetrical. Fixtures may have one, two, or three elements. Marquee-type heaters are recessed into an overhead masonry canopy. For snow-melting applications, twice the suggested outdoor capacity is recommended. Provide 150 to 200 W/ft² of area for most applications. Control of infrared heaters is by switch, input control, ambient-temperature thermostat, or any combination of these devices. A high-limit thermostat is recommended for most applications.

2. **Horizontal Unit Heaters.** Such a heater is shown in Fig. 9.298. Capacities range from 1.5 to 50 kW at 120 or 208 V, single- and three-phase; 240 V, single- and three-phase; 277 V, single-phase; and 480 or 600 V, single- and three-phase.

Horizontal unit heaters can be installed on the wall or hung from the ceiling with bracket or swivel adjustments. They are ideal for use in warehouses, factories, or entranceways. Unit heaters are normally located along the outside wall with the direction...
of airflow in a circular fashion. Large-capacity heaters can be provided with duct collars or deflectors. Unit heaters are commonly controlled by a remote thermostat and may have remote or built-in contactors. A fan-delay switch can be provided to prevent the fan from operating until the heating elements have reached the desired temperature. An explosionproof model is available to conform with Class I, Group D, requirements.

3. **Vertical Unit Heaters.** Several types of these heaters are shown in Fig. 9.299. Capacities are 10 to 50 kW at 208 and 480 V, single- or three-phase. The ceiling-suspended vertical unit heater has integral relays and one- or two-stage remote control. It can be surface-mounted or recessed with air discharge through four optional louver arrangements which permit virtually any desired air pattern at the floor level. Diffusers are of the radial, cone, anemostat, or louver type. Internally mounted automatic-control relays and overheat and motor-overload protection are usually provided. These heavy-duty units can be used in factories, garages, and warehouses, with high-bay mounting up to 33 ft (10.1 m) above the floor.

4. **Auditorium Unit Ventilators.** Such a ventilator is shown in Fig. 9.300. Capacities are 12 to 400 kW; 1200 to 15,000 ft³/min (0.57 to 7.08 m³/s), and 208, 240, or 480 V, three-phase. This unit ventilator provides the proper heating, ventilating, and natural cooling required in school auditoriums, gymnasiums, libraries, and other areas where large-capacity systems and quiet operation are essential. It may be installed for horizontal, upright, or inverted operation on the ceiling, wall, or floor; directly in the area to be
served; or in an adjacent location and connected by ductwork. Such a unit features a special attenuator and an enclosed motor and drive designed for quiet operation. Step control is frequently used.

5. **Wall Convector Units.** A typical unit is shown in Fig. 9.301. Capacities are 750 to 4000 W at 208, 240, and 480 V, single- and three-phase. Commercial wall convectors can be surface-mounted or recessed with front or top discharge. These units are used in commercial, industrial, or institutional buildings in offices, corridors, and entrances. Cabinet convectors are available with integral or remote controls.

![FIGURE 9.300 Auditorium unit ventilator, 15 kW.](image)

![FIGURE 9.301 Wall convector unit for surface mounting. [King Electrical Mfg. Co.]](image)
6. **Commercial Forced-Air Wall Heaters.** This type of heater is similar to the heater shown in Fig. 9.287. Capacities are 1.5 to 4 kW at 120, 208, 240, or 277 V, single-phase. The commercial forced-air heater can be surface-mounted or recessed. Tamperproof construction makes this unit ideal for entryways, lobbies, corridors, stairwells, and rest rooms in all types of commercial buildings. Fan and discharge louvers direct air downward, keeping the floor warm and dry.

7. **Sill-Line Convector Units.** Such a unit is shown in Fig. 9.302. Capacities are 120 to 750 W/ft at 208, 240, 277, and 480 V, three-phase, in one- or two-stage control. Commercial sill-line heaters are available at different heights and many different wattage outputs. Lengths vary from 2 to 8 ft (0.6 to 2.4 m) to provide modular or wall-to-wall design. Units of this type are available with blank sections, filler sections, matching sleeves, end caps, inside and outside corners, and conduit covers. Sill-line heaters are surface-mounted with front or top discharge when perimeter radiation is desired. They should be mounted at least 2 in. (50.8 mm) above the floor. Built-in controls may be integral to the unit, or they can be provided in a filler section. The filler section can contain a relay for a 120-V remote-control circuit, a disconnect switch, or a circuit breaker.

8. **Pedestal Convector Heaters.** Such a heater is shown in Fig. 9.303. Capacities range from 500 to 3500 W at 208, 240, and 277 V, single-phase. This heater is a convector which is used to heat floor-to-ceiling glass areas. It can be mounted on a new concrete floor or be bolted to the surface of an existing floor. Pedestal-type heaters can be installed individually or end to end in continuous runs. They provide a basic perimeter system designed especially for corridors, lobbies, foyers, and entryways, particularly for hard-to-heat areas where floor-to-ceiling glass creates cold downdraft problems and prohibits the use of wall-mounted equipment. This special downdraft heater is controlled by a separate wall-mounted thermostat with an optional integral relay for remote control by a time clock.
9. **Draft-Barrier Wall Heaters.** Such a heater is shown in Fig. 9.304. Capacities are 100 to 200 W/ft at 120, 208, 240, and 277 V, single-phase. The draft-barrier wall heaters are low-silhouette units (3 to 6 in, or 25.4 to 76.2 mm, high) designed to counteract down-draft at window areas. They are mounted under the sill, from wall to wall at floor level, or within modular confines in commercial office buildings. Electric connections can be made from either end on some units or through the back. Built-in thermal relays and thermostats are available.

![FIGURE 9.304 An architectural electric convection heater provides a draft barrier when installed along glass curtain walls. [Chromalox, Wiegand Industrial Division of Emerson Electric Co.]](image)

10. **Commercial Baseboard Heaters.** These heaters are similar to the unit shown in Fig. 9.304. Capacities are 300 to 1250 W at 120, 208, 240, and 277 V, single-phase. Commercial-grade baseboard heaters are available in lengths of 2, 5, and 8 ft (0.6, 1.5, and 2.4 m). They are surface-mounted 2 in. (50.8 mm) off the floor. These units can be controlled by an attached thermostat section or by a wall-mounted line- or low-voltage thermostat. End caps, blank sections, and inside and outside corners for wall-to-wall installation are available as required.

11. **Cabinet Unit Heaters.** Such a heater is shown in Fig. 9.305. Capacities are 1.5 to 30 kW at 208, 240, 277, and 480 V, single-phase or three-phase.

The commercial cabinet unit heater can be used freestanding, wall-mounted, or ceiling-mounted. Surface or recessed installation is applicable to wall- or ceiling-type heaters. An inverted model is available for unusual installations. The cabinet unit heater can be provided with tamperproof integral or remote wall-mounted controls. A two- or three-speed fan motor, providing 200 to 1250 ft³/min (0.094 to 0.59 m³/s), may have a fan selector switch to provide quiet operation. A fan-delay thermostat is used to prevent circulation of unheated air. This type of heater is designed primarily for

![FIGURE 9.305 Cabinet unit heater with top discharge and front inlet. [Chromalox, Wiegand Industrial Division of Emerson Electric Co.]](image)
entranceways, corridors, and lobbies in offices, airport terminals, schools, and retail stores. There are some units which can provide a choice of 25 or 100 percent outside air with dampers for ventilation cooling and air filters that can be cleaned.

12. **Unit Ventilators and Air Conditioners.** Such a ventilator and air conditioner is shown in Fig. 9.306. Heating capacities are 1.3 to 36 kW at 208, 240, 277, and 480 V, single- or three-phase. Cooling capacities range from 8000 to 27,000 Btu.

The packaged electric unit ventilator and its companion unit, the unitary air conditioner, are through-the-wall machines. The electric unit ventilator is installed under windows, has a wall sleeve and louvered opening in the wall, and is designed for use in school classrooms, auditoriums, gymnasiums, offices, libraries, or other high-occupancy areas. It heats, cools, and ventilates with outdoor air (600 to 1500 ft³/min, or 0.28 to 7.08 m³/s). Usually, there is internal wiring for step-control switching. An optional built-in electric demand limiter is available. Controls may be integral or remote; electric, electronic, or pneumatic. The controls of one unit (the master) may be used in the same area to control other units (slaves). The unit ventilator is usually installed against an outside wall, though it may also be ceiling-mounted. The through-the-wall heating and cooling unit may have an integral cooling (compressor) section, or it may be remote-mounted.

13. **Duct Heaters.** A typical heater is shown in Fig. 9.307. Wattage combinations are virtually unlimited with single- and three-phase connections and multistage control at 120 to 600 V. Electric duct heaters are used in ducts, plenums, or air handlers for primary heat, terminal booster heat, or air-conditioning reheat. Open-coil or metal-sheathed finned tubular heaters (Fig. 9.307) are available for insertion into an existing duct or, with a flange, as part of a new duct. To conform to duct sizes, heaters are manufactured in different horizontal and vertical dimensions for mounting on the side or bottom of the duct. Integral controls may include automatic reset of thermal cutouts, built-in relays, a transformer, fuses or circuit breakers, a fan interlock relay, pilot switches, and pilot lights. The NEC specifies a maximum 60-A branch circuit for overcurrent protection with a maximum connected load of 48 A, and zero clearance, automatic reset of thermal overload, and separate manual reset for a backup thermal overload system. Duct heaters are controlled by duct stats or remote wall controls. For large-capacity heaters a step controller is used.
443. **Electric snow-melting systems** consist of resistance-type wire or cable embedded in concrete or asphalt. The design of snow-melting systems depends on the area, geographical conditions, wind conditions, and expectations of the user (see Table 30 of Div. 12). Generally, for melting snow at temperatures between 32 and 0°F (between 0 and –16°C), the system will be designed at 40 to 60 W/ft². Depending on wind factor, temperature, and the rate of snowfall, the area will be kept free and clear of any snow formation if the system is energized about 30 min prior to a snowfall.

The heat-transfer environment may be asphalt or concrete, and the heating element may be in the form of a mat or a heating cable. In asphalt, install the mats 12 in. (304.8 mm) from the edge with the largest mats on a straight run. Mats may be installed on an existing slab with a 2-in (50.8-mm) blacktop surface cover. The surface asphalt should be fine-grain with no stones larger than 5/8-in (9.525-mm) diameter.

In concrete, the mats or cable should be located within expansion joints generally no farther than 20 ft (6.1 m) apart. The concrete slab should contain crushed-rock aggregate (not river gravel) and should be at least 4 in. (101.6 mm) thick. There should be a well-prepared base with adequate drainage and suitable reinforcement.

Junction boxes for connection of feeders to cables or mat lead wires should be located out of the area or in a nearby wall. They should not be installed flush with the snow-melting–surface area. Mats or cables should be installed from 1½ to 2 in. (from 38.1 to 50.8 mm) below the surface. If they are installed in two pours of concrete, a binder or bonding agent should be used between pours. Cables should be tested before installation, during installation, and on completion of installation.

Snow-melting mats for walkways, driveways, or steps (Fig. 9.308) are made of resistance wires embedded in a polyvinyl chloride sheath, interwoven in chicken wire or plastic webbing. The wire may have a copper overbraid for positive grounding.

Single- or two-conductor Type MI (mineral-insulated) cable with varied resistances is factory-fabricated at specified lengths of heating leads and nonheating leads. Hot-to-cold wire connectors and end caps are factory-brazed. Type MI cable is semirigid and can be hand-bent at the construction site to conform to desired spacing (usually 3 to 9 in, or 76.2 to 228.6 mm). It has the advantage of being durable in different asphalt or concrete environments.

Heating cables may be controlled by switch or by automatic snow control (Fig. 9.309). It is recommended that a high-limit thermostat be installed in the slab to prevent the system from operating at higher temperatures (50°F, or 10°C, or more).
444. **Electric-heating controls.** Electric space-heating equipment may be specified with a built-in thermostat and relay or with a wall thermostat. Commercial installations often require the use of a contactor. Step controllers or solid-state controls may be used with electric comfort heating equipment. For safety, most heaters are provided with spot or linear overheat protection.
445. Sizing room air conditioners. As a general rule, room air conditioners are sized on the basis of 30 Btu/hr/ft² of space in a given room. Room air conditioners are rated in Btu (British thermal units) of cooling capacity. Units are available at 120-V ratings up to 12,000 Btu in most cases. Current ratings range from 7 1/2 to 12 A for 120-V units. In planning outlets, however, it is important to know whether the room air conditioner (window or through-the-wall type) will be 120 or 240 V, because some manufacturers provide 240-V ratings for units of 9000 Btu or more.

446. Code rules for fixed space-heating equipment. Article 424 of the NEC covers installations of fixed electric space-heating equipment. The following paragraphs describe the major provisions of this article.

1. Branch Circuits. All circuits for space-heating, snow-melting, and deicing equipment are considered continuous loads. As such, the load on any single or multioutlet branch circuit cannot exceed 80 percent of the branch-circuit rating (12 A on a 15-A circuit, 16 A on a 20-A circuit, etc.). Generally, space-heating equipment can be connected to 15-, 20-, or 30-A multioutlet branch circuits. Infrared systems can be connected to 15-, 20-, or 30-A multioutlet branch circuits. In other than residential occupancies, fixed infrared heating equipment can be supplied from branch circuits rated not over 50 A. Refer to Div. 3 for feeder or service calculations for a group of heaters.

2. Controllers and Disconnecting Means
   a. Thermostats and thermostatically controlled switching devices which indicate an off position and which interrupt line current shall open all ungrounded conductors when the control device is manually placed in this off position.
   b. Thermostats and thermostatically controlled switching devices which do not have an off position are not required to open all ungrounded conductors.
   c. Remote-control thermostats need not meet the requirements of Pars. a and b. These devices shall not serve as the disconnecting means.
   d. Switching devices consisting of combined thermostats and manually controlled switches that serve both as controllers and disconnecting means shall open all ungrounded conductors when manually placed in the off position or be so designed that the circuit cannot be energized automatically after the device has been manually placed in the off position.

3. Duct Heaters
   a. Means shall be provided to assure uniform and adequate airflow over the heater.
   b. Means shall be provided to ensure that the fan circuit is energized when the first heater circuit is energized. However, time- or temperature-controlled delay in energizing the fan motor shall be permitted.
   c. Each duct heater shall be provided with an integral approved automatic-reset temperature-limiting control or controllers to deenergize the circuit (or circuits). In addition, an integral, independent, supplemental control or controllers shall be provided in each duct heater which will disconnect enough conductors to interrupt current flow. This control shall be manually resettable or replaceable.
   d. Duct-heater controller equipment shall be either accessible with the disconnecting means installed at or within sight of the controller except as permitted by Sec. 424.19(A) of the Code.

447. Other reference material. With the continued development of the electric-heating market, reference should be made to the latest NEMA standards and publications of the Electric Heating Association (EHA).
448. Types of signs. Electric signs or outline lighting may consist of incandescent lamps or gaseous-discharge tubing (commonly called neon signs). Today light-emitting diodes (LEDs) are increasingly used given their long life and efficient use of energy. Installing a brand new sign using incandescent lamps with mechanical flashers would be almost unheard of. However, this equipment is still in use, and will be covered so users will have a reference source in case they are called upon to service it. Refer to Div. 10 for a discussion of lamps and tubing.

449. Methods of wiring incandescent electric signs (National Electric Light Association, Data on Electric Signs). Lamps burning in multiple may be connected either two-wire or three-wire, as shown in Fig. 9.310. In series wiring, lamps may be connected in either straight series or multiple series, as shown. If transformers (see Sec. 60 of Div. 5 for information on sign transformers) are used to obtain low voltage, lamps may be connected either two-wire or three-wire as in standard multiple wiring, the transformer reducing the voltage from the regular 120- or 240-V circuits to the voltage required by the lamp. The ordinary multiple wiring can be changed to straight series wiring by merely clipping the alternate connections between lamps (Fig. 9.311).
In a large sign any combination of series or multiple series may be used. With straight series wiring, should one lamp in the series burn out, all the lamps in that series will be out. If the lamps are connected in multiple series, the failure of one lamp does not cause any of the other lamps to go out. However, there should not be less than 8 to 10 lamps in each multiple group, or the failure of one lamp will cause too much current to flow through the other lamps of the same group, thus shortening their lives.

450. Different effects of flashing or motion can be obtained with incandescent signs by the use of a sign flasher. Cams or a drum are mounted on a shaft that is rotated by a small electric motor (Fig. 9.312). The circumferences of the cams or drums are so cut that, in brush-type flashers, the brushes will make contact only during certain predetermined portions of a revolution and thereby complete the electric circuit through the sign lamps only during that period. In the carbon-type flashers the cams, instead of carrying current and making and breaking the contacts directly, operate to open and close carbon-break contact switches which control the sign lamps. The possible variations in arrangement of cams and drums for producing different effects are almost numberless. Flashers are available for high- or low-voltage circuits.

451. Method of wiring neon-lamp signs. Neon lamps used for signs are of the high-voltage type (see Div. 10). The lamps are supplied from ordinary lighting circuits through small step-up transformers. The voltage required depends upon the length of neon-lamp tubing used in the sign. The maximum voltage employed on the lamps is 15,000. When the length of tubing is greater than can be illuminated with 15,000 V, two or more transformers are employed as required. Practically always, neon signs are completely wired and installed by the manufacturers, the purchaser simply providing the necessary outlets from the general-lighting system. Also, the servicing and maintenance of the signs generally are handled by specialists. Section 460 includes requirements for this type of equipment.

452. The installation of all signs or outline lighting, whether of the incandescent, LED, or the gaseous-discharge type, must meet the following requirements: All electric
signs, section signs, and outline lighting, whether fixed, mobile or portable, shall be listed unless exempted by special permission. However, field-installed skeleton tubing is not required to be listed if installed per NEC rules, and outline lighting need not be listed as a system if it consists of listed luminaires wired using Chap. 3 methods. All equipment and devices used with signs must be enclosed in metal boxes, unless the enclosures are listed. All devices, such as switches, flashers, and similar devices controlling transformers shall be either rated for controlling inductive loads or must have a current rating which is not less than twice the current rating of the transformer supplying the sign. The circuits should be so arranged that none will have a load of more than 16 A.

453. Marking of signs and outline lighting systems are identified by the manufacturers name, trademark, or other means of identification, and maximum wattage per lamp for incandescent lamp illuminated signs, and input voltage and current rating for electric-discharge signs. Section signs must be marked to indicate that field wiring and installation instructions are required.

454. Branch circuits must comply with the following:

1. A 20-A outlet supplying no other loads, for each commercial building and each commercial occupancy accessible to pedestrians, located at each entrance to each tenant space.

2. The maximum rating is 20 A for circuits supplying incandescent, fluorescent forms of illumination. For neon tubing, the maximum rating is 30 A. HID light sources are not addressed in the NEC sign article; however if they have heavy-duty mogul lampholders (most do) per 210.21(A) they could be used for 30 A circuits as well.

3. Each required branch circuit shall be computed at a minimum of 1200 VA.

4. Any suitable wiring method in Chap. 3 of the NEC may be used and must terminate within a sign or outline lighting enclosure.

455. A disconnect must be provided for each sign or outline lighting installation, consisting of an externally operable switch or circuit breaker that opens all ungrounded conductors, except a disconnect is not required for exit directional signs located within buildings, or cord-connected signs. In addition, signs and outline lighting systems must comply with the following:

The disconnect must be located within the sight of the sign. If any of the sections of a sign are out of sight of the disconnecting means, then the disconnecting means must be capable of being locked in the open position. A similar rule applies when the sign is operated by a remote controller; the disconnect must be placed within sight of the controller, and the disconnect must be capable of being locked in the open position.

456. The location of signs or outline lighting systems is restricted as follows:

1. Areas accessible to vehicles, unless protected from physical damage, shall be located at least 4.3 m (14 ft) above the vehicle area.

2. Areas readily accessible to pedestrians shall have neon tubing protected from physical damage, except for portable signs in dry locations.
3. Adjacent combustible materials shall not be subjected to temperatures exceeding 90°C (194°F), and HID lamps or lampholders shall be located at least 50 mm (2 in.) from wood or other combustibles.

4. Signs and outline lighting system equipment for wet location use, other than listed watertight type, shall be weatherproof and have drain holes neither smaller than 6 mm (1/4 in.) nor larger than 13 mm (1/2 in.). Every low point or isolated section must have at least one drain hole. The drain holes must be positioned so that there will be no external obstructions.

457. **Portable or mobile signs** must be installed as follows:

1. Signs must be adequately supported and be readily moveable without the use of tools.
2. An attachment plug shall be provided.
3. In wet or damp locations, a GFCI located in the supply cord must be provided. The cord must include an equipment grounding conductor and must be rated for hard service or junior hard service.
4. In dry locations, the cord length is limited to 4.5 m (15 ft). The cord shall be type SP-2, SPE-2, SPT-2, or heavier.

458. **Ballasts shall be listed** and identified for the use and shall be thermally protected. Ballasts, transformers, and electronic power supplies are to be installed as follows:

1. They are to be located where accessible and securely fastened in place.
2. The ballasts, transformers, and electronic power supplies are to be located as near to the lamps or neon tubing as is practicable.
3. Ballasts, transformers, and electronic power supplies used in wet locations shall be weatherproof type or of the outdoor type where protected from the weather.
4. Ballasts, transformers, and electronic power supplies require a working space at least 900 mm (3 ft) high, 900 mm (3 ft) wide, by 900 mm (3 ft) deep where not installed in a sign.
5. Power supplies may be located in an attic or soffit, provided they meet the access requirements of Sec. 600.21(E) of the NEC. There must be an access door at least 900 mm by 562.5 mm (36 in. by 22 1/2 in.), a passageway at least 900 mm (3 ft) high by 600 mm (2 ft) wide, and a permanent walkway at least 300 mm (12 in.) wide extending from the point of entry to each component.
6. Power supplies may be located above suspended ceilings if securely fastened in place and not dependent on the suspended ceiling grid for support.

459. **Transformers and electronic power supplies** must be listed and identified for the use. They must meet the following criteria:

1. Transformers and electronic power supplies must have secondary-circuit ground-fault protection. Transformers with isolated ungrounded secondaries and with a maximum open circuit voltage of 7500 V, or transformers with integral porcelain or glass secondary housing for the neon tubing and requiring no field wiring on the secondary side are exempted from this rule.
2. The secondary voltage must not exceed 15,000 V, nominal, under any load condition. The maximum voltage to ground of any transformer secondary circuit output terminals must not exceed 7500 V under any load condition.

3. The secondary current rating must not exceed 300 mA.

4. Secondary circuit outputs must not be connected in parallel or series.

5. Transformers and power supplies must be marked to indicate that they have secondary-circuit ground-fault protection.

6. Class 2 power supplies and power sources must be listed for use with electric signs and outline lighting systems, and meet the requirements for Class 2 power sources in NEC 725.121. Metal parts of signs and outline lighting systems must meet the grounding and bonding requirements for signs generally. Secondary circuit wiring must either use one of the conventional wiring methods in Chap. 3 of the NEC, or meet the requirements for power-limited circuits in NEC 725.130(B).

460. **Field installed skeleton tubing** must meet the following specific requirements:

1. Neon secondary circuit conductors of 1000 V or less are to comply with the following:
   a. Use any wiring methods in Chap. 3 of the NEC that is suitable for the conditions.
   b. Conductors shall be insulated, listed for the purpose, and not smaller than No. 18.
   c. Raceways are limited to the conductor fill permitted by Table 1 in Chap. 9 of the NEC.
   d. Conductors are to be installed so they are not subject to physical damage.
   e. Bushings are to be used to protect wires passing through an opening in metal.

2. Neon secondary circuit conductors over 1000 V are to comply with the following:
   a. Conductors can be installed, in rigid metal conduit, intermediate metal conduit, PVC or RTRC nonmetallic conduit, liquidtight flexible nonmetallic conduit, electrical metallic tubing, flexible metal conduit, liquidtight flexible metal conduit, electrical nonmetallic tubing, metal enclosures, on insulators in metal raceways, or other equipment listed for the purpose. Only one conductor can be installed per length of conduit or tubing, which must not be smaller than metric designator 16 (trade size 1/2). Metal parts of a building cannot be used as a grounded or equipment grounding conductor.
   b. Conductors shall be insulated, listed for the purpose, rated for the voltage, not smaller than No. 18, and have the minimum temperature rating of 105°C (221°F).
   c. Conductors are not to be subjected to physical damage.
   d. Sharp bends in insulated conductors are to be avoided.
   e. Other than at insulators or neon tubing, or between a conductor and the inner wall of its enclosing raceway, conductors must have 38 mm (1½ in.) spacing from each other and all other objects. Other than the points of connection to a metal enclosure or sign body, nonmetallic raceways containing a conductor operating at 100 Hz or less must be separated at least 38 mm (1½ in.) from grounded or bonded parts, with the distance increasing to 45 mm (1¾ in.) at higher frequencies.
   f. Insulators and bushings for conductors are to be listed.
   g. The insulated portions of conductors in metal raceways must extend not less than 65 mm (2½ in.) beyond the end of the raceways.
   h. Conductors may run from the leads of neon tubing to the grounded midpoint of a transformer or electronic power supply listed for the purpose and provided with terminals at the midpoint. The conductors should be as short as possible.
   i. Dwelling occupancy equipment is limited to an open circuit voltage of 1000 V.
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j. High voltage cable run in a metal raceway or tubing from a transformer or electronic power supply to the first neon tube electrode is limited to 6 m (20 ft) lengths. Similar cables in nonmetallic raceways or tubing is limited to 15 m (50 ft).

k. Splices in high-voltage secondary circuit conductors shall be made in listed enclosures rated over 1000 V. The enclosures shall be accessible after installation and shall be listed for the location where they are used.

3. Neon tubing is to comply with the following:
   a. The length and design of the tubing should be such that transformers or electronic power supplies are not subjected to continuous overcurrent beyond their design loading.
   b. Listed tubing supports shall be used.
   c. Other than at its support, neon tubing shall have a spacing of 6 mm (1/4 in.) from the nearest surface. The tubing shall be supported within 150 mm (6 in.) from the electrode connection.
   d. Field-installed skeleton tubing is not to be subject to physical damage. If readily accessible to other than qualified persons, it shall be provided with suitable guards or protected by other approved means.

4. Electrode connections are to comply with the following:
   a. Where high-voltage secondary conductors emerge from the wiring methods in 2a above, they shall be enclosed in a listed assembly.
   b. Unqualified persons are not to have access to the terminals of an electrode.
   c. Connections to an electrode are to be made by a connection device, twisting the wires together, or by the use of an electrode receptacle. An enclosure listed for the purpose shall be used and the connections shall be electrically and mechanically secure.
   d. Neon secondary conductors are to be supported within 150 mm (6 in.) from the electrode connection to the tubing.
   e. Electrode receptacles are to be listed for use in signs.
   f. Bushings listed for signs are to be used where electrodes penetrate enclosures, unless receptacles are provided.
   g. If receptacles penetrate a building at a wet location, a listed cap shall be used to close the opening. If bushings or neon tubing penetrate a building, the opening between neon tubing and the bushing shall be sealed.
   h. Electrode enclosures shall be listed. For dry locations an enclosure listed for use in either dry or damp or wet locations may be used. For damp or wet locations the enclosure must be listed and identified accordingly.

461. Current-carrying capacities of flashers. Double-pole flashers are made in four sizes that will carry respectively 15, 30, 45, or 60 A per switch. Single-pole carbon flashers that will carry 5 A per switch are made. Brush-type flashers are rated at from 2 to 5 A on each brush and are not reliable for greater currents.

Switches, flashers, and similar devices controlling transformers and electronic power supplies shall be rated for controlling inductive loads or have a current rating at least twice the current rating of the transformer.

462. Grounding and bonding of signs and outline lighting systems must meet special requirements that, in some cases, supersede the provisions in Article 250. The grounding or bonding requirements that differ in some way, or that have a different focus from conventional NEC rules are as follows (refer to NEC 600.7 for the complete provisions):
1. Metal parts and equipment of signs and outline lighting systems shall be bonded together and to the associated transformer or power supply, together with the equipment grounding conductor of the supply circuit. Portable signs are permitted to be exempt from this rule if they are protected with a system of double insulation and are marked accordingly. Small metal parts not exceeding 50 mm (2 in.) in any dimension, not likely to be energized, and spaced at least 19 mm (3/4 in.) from neon tubing need not be bonded. Where listed, flexible metal conduit or listed liquidtight flexible metal conduit is used to enclose the secondary circuit conductor from a transformer or power supply for use with neon tubing; it may be used as a bonding method provided the total accumulative length does not exceed 30 m (100 ft).

2. Metal parts of a building are prohibited from use as either a secondary return conductor or an equipment grounding conductor, or for bonding together the metal parts and equipment of signs or outline lighting systems, or for bonding such parts to the transformer or to the equipment grounding conductor of the supply circuit.

REMOTE-CONTROL, SIGNALING, AND POWER-LIMITED CIRCUITS

463. A remote-control circuit is any electric circuit that controls any other circuit through a relay or an equivalent device.

464. Class 1 circuit power source. Remote control or signaling circuits in this classification are either power-limited, or not. The Class 1 power-limited circuits are supplied from sources limited to 30 V and 1000 VA. The nonpower-limited Class 1 circuits are limited to 600 V, but the source output power is unlimited.

465. A signal circuit is any electric circuit that energizes signaling equipment. Such circuits include circuits for doorbells, buzzers, code-calling systems, signal lights, and the like.

466. Safety-control devices. Remote-control circuits to safety-control devices, the failure of operation of which would introduce a direct fire or life hazard, shall be considered Class 1 circuits.

Room thermostats, service hot-water temperature-regulating devices, and similar controls used in conjunction with electrically controlled domestic heating and air conditioning equipment are not considered to be safety-control devices.

467. Remote-control, power-limited, and signal circuits in communication cables. Class 2 and 3 remote-control, power-limited, and signal circuits, which use conductors in the same cable with communication circuits, shall, for the purpose of this discussion, be classified as communication circuits and meet the requirements of such circuits (refer to Article 800 of the NEC).

468. Hazardous locations. Any remote-control or signal circuit or any circuit considered such by the Code which is installed in a hazardous location must meet the Code
requirements for hazardous-location installation in addition to the requirements for remote-control circuits. Cables installed in hazardous locations shall be Type PLTC.

469. **Remote-control, power-limited, and signal circuits are divided** by the NEC into two power-limited classes (in addition to the Class 1 classification described in Sec. 464) as follows:

1. **CLASS 2** Systems in which the voltage and power is limited in accordance with Sec. 725.121 of the NEC. A Class 2 circuit considers safety from a fire initiation standpoint and provides acceptable protection from electric shock.

2. **CLASS 3** Systems in which the voltage and power are limited, also in accordance with Sec. 725.121 of the NEC. A Class 3 circuit considers safety from a fire initiation standpoint, however, since higher levels of voltage and current than for Class 2 are permitted, additional safeguards are specified to provide protection from an electric shock hazard that could be encountered.

**CLASS 1 SYSTEMS**

470. **The installation of Class 1 systems** must be in accordance with general NEC requirements for the installation of electrical circuits except as stated in the special Code specifications given in Secs. 471 to 480 inclusive.

471. **Conductor sizes.** Numbers 18 and 16 AWG conductors may be used if installed in a raceway, an approved enclosure, or a listed cable. Flexible cords shall comply with the provisions of Article 400 of the Code.

472. **Conductor insulation.** Conductors larger than 16 AWG may be any of the conductors listed in Article 310 of the NEC for general wiring. Conductors of 18 and 16 AWG shall have an insulation of a type listed in Sec. 725.49(B) of the NEC.

473. **Number of conductors in raceways.** The number of conductors of remote-control or signal circuits in a raceway must be determined according to the conventional wire-fill rules in the NEC using the information in Chap. 9. Section 310.15(B)(2) of the NEC applies only to continuous loads (3 h or more) in excess of 10 percent of the ampacity of the conductor.

474. **Conductors of different systems.** Conductors of two or more Class 1 remote-control and/or signal circuits may occupy the same cable, enclosure or raceway without regard to whether the individual systems or circuits are ac or dc, provided all conductors are insulated for the maximum voltage of any conductor in the cable, enclosure or raceway. Class 1 circuits and power circuits may occupy a common raceway only where the equipment powered is functionally associated.

475. **Physical protection of remote-control circuits.** If damage to a remote-control circuit would introduce a hazard as covered in Sec. 466, all conductors of such
remote-control circuits shall be installed in rigid metal conduit, intermediate metal conduit, rigid nonmetallic conduit, electrical metallic tubing, Type MI cable, or Type MC cable or be otherwise suitably protected from physical damage.

476. **Overcurrent protection.** Conductors shall be protected against overcurrent in accordance with the general Code requirements except for 18 and 16 AWG conductors, which shall not exceed 7 A for No. 18 and 10 A for No. 16 except when other articles of the Code have other protection requirements.

477. **Location of overcurrent protection.** Overcurrent devices shall be located at the point where the conductor to be protected receives its supply unless the overcurrent device protecting the larger conductor also protects the smaller conductor in accordance with the current-carrying capacity tables of Div. 12; or the overcurrent protection is provided in accordance with other specific NEC rules, such as 430.72 for motor control circuits and 610.53 for cranes and hoists. Where a control circuit is tapped from the light or power circuit that the control circuit is affecting, the overcurrent protection is permitted to be for short-circuit and ground-fault protection only, defined for these purposes as not exceeding 300 percent of the Class 1 circuit conductor ampacity. For two-winding transformers, with only one winding connection on the primary side and one on the secondary side, the overcurrent protection can be on the primary side with its effective value as adjusted by the transformer winding ratio. Electronic source output conductors supplied from listed equipment is generally permitted to rely on the overcurrent protection ahead of the electronic power source.

478. **Circuits extending beyond one building.** Class 1 circuits which extend aeri-ally beyond one building shall also meet the requirements of Article 225 of the Code.

479. **Grounding.** Class 1 remote-control and signal circuits shall be grounded as required by Sec. 250.20 of the Code for ac circuits, and 250.162 for dc circuits. If system grounding does apply to one of these control circuits, refer to the discussion in Sec. 487 for direction on how to proceed.

480. **Transformers.** Transformers used to supply power-limited Class 1 circuits shall comply with Article 450 of the NEC and the power limitations of Sec. 725.41 of the NEC.

**CLASS 2 AND CLASS 3 SYSTEMS**

481. **NEC requirements for the installation of Class 2 and Class 3 systems** are given in the following Secs. 482 to 487, inclusive.

482. **Overcurrent protection.** If current is limited in Class 2 and Class 3 systems by means of overcurrent protection, such overcurrent protection devices shall not be interchangeable with protection of a higher rating. The overcurrent protection may be an integral part of the power supply.
483. Power limitations. Protection for power-limited circuits shall comply with Sec. 725.121 of the NEC.

484. On the supply side of overcurrent protection, transformer, or current-limiting devices. Conductors and equipment on the supply side of overcurrent protection, transformers, or current-limiting devices shall be installed in accordance with the appropriate requirements of Chaps. 1 through 4 of the Code. Transformers or other devices supplied from electric-light and power circuits shall be protected by an overcurrent device with a rating or setting not exceeding 20 A, except the input leads of a transformer or other power source supplying Class 2 and Class 3 circuits may be smaller than 14 AWG, but not smaller than 18 AWG if they are not over 300 mm (12 in.) long and if they have insulation that complies with Sec. 725.49(B) of the NEC.

485. On the load side of overcurrent protection, transformer, or current-limiting devices. Conductors on the load side of overcurrent protection, transformer, or current-limiting devices shall be insulated and shall comply with Sec. 725.179 and not less than the requirements of Secs. 725.133 and 725.154 of the Code. The cables must be listed with respect to fire resistance, and generally applied in accordance with a four-level hierarchy based on that criterion. The level is evidence by the cable marking, which for remote-control and signaling circuits is CL2 or CL3 as applicable. This determines the power level, and the marking has space for an additional letter that determines the permitted locations. A suffix of “X” (as in “CL2X” for doorbell wire) is the least rigorous, and it indicates suitability for low-intensity dwelling use, such as short lengths in nonconcealed spaces generally and in concealed spaces only in one- and two-family dwellings only. CL2 with no suffix is generally suitable for commercial work whether concealed or exposed. CL2R is the next better grade of cable, and it can be used in risers from floor to floor. The top of the hierarchy is the cables, marked CL2P, which can run in plenum cavities used for environmental air such as above a suspended ceiling that connects to the intake of a large air handler. Better cables can always substitute for poorer cables, as shown in NEC Table 725.154(G). For example, CL3R can substitute for CL2R, which can substitute for CL2, etc.

486. Circuits extending beyond one building. Class 2 and Class 3 circuits which extend beyond one building and are so run as to be subject to accidental contact with light or power conductors operating at a potential exceeding 300 V to ground shall also meet the requirements of Secs. 800.44, 800.50, 800.53, 800.93, 800.100, 800.170(A), and 800.170(B) for other than coaxial conductors for communication circuits in the Code and 820.44, 820.93, and 820.100 for coaxial conductors used in CATV systems.

487. Grounding. Class 2 and Class 3 circuits and equipment shall be grounded as required by Sec. 250.20(A) of the NEC for ac circuits, and 250.162 for dc circuits. Note that ac systems of less than 50 V must be connected as grounded systems complete with a grounded circuit conductor (usually colored white, etc.) if supplied by transformers whose primaries are connected to systems of more than 150 V to ground, or if the transformer supply system is ungrounded, or if the transformer primary circuit is run overhead outside buildings.

The overwhelming majority of power-limited control circuits are fed from transformers with 120-V primaries running on grounded systems, and are therefore unaffected by these
system grounding requirements. However, there are numerous applications, such as 277-V duct heaters supplied with Class 2 transformers for thermostat connections, and some power supplies for 277-V lighting applications, where these rules will be important.

Should such an application arise, there are additional considerations. Such a grounded system must be connected to a grounding electrode, although this is seldom a problem because the systems normally qualify as separately derived, and NEC 250.30(A)(3) Exception No. 3 generally allows the use of the equipment grounding conductor connection for the supply transformer (limited in the exception to 1 kVA) to function as a grounding electrode conductor in such cases. Another wrinkle is the requirement in 250.112(I) that these systems incorporate an equipment grounding conductor. Such a conductor must normally be colored green; however, 250.119 Exception [erroneously written as though 250.112(I) didn’t exist] allows green wire for other than grounding purposes in power-limited cabling, so the color is at best unclear. What is clear is that some conductor in the cable must be an equipment ground, and green is obviously the best choice. Note also that the size of this wire can be the same as the others in the circuit because 250.122(A) never requires an equipment grounding conductor to be larger than the associated circuit conductors. The likely result is two wires in the power-limited cable assembly (white and green) will have code required functions and connections at odds with the traditional color code for HVAC wiring diagrams. Take care to plan accordingly.

488. Power-limited circuits must be neat and workmanlike. They must be supported so they will not be damaged by normal building use. They can use ordinary cable ties or similar fittings designed and installed so as to not damage the cable for securement, but they must not be tied to electrical raceways or cables except as noted in Sec. 489. Abandoned cables must be removed to the extent they are accessible. A cable is defined as abandoned if it is not terminated, and not identified for future use with a tag. The tag must have sufficient durability to withstand the environment involved.

489. System separation. Class 2 and Class 3 conductors must be divorced from Class 1 and power conductors. The general rule allowing conductors of differing voltages to run in a common raceway as long as all conductors are insulated for the maximum voltage present does not apply to power-limited circuits, because you must never rely on conductor insulation alone, no matter how robust, to provide the system separation required by the NEC for over 70 years. For this reason the general prohibition against tying cables to a raceway is relaxed to allow a power-limited cable tied to a raceway where the systems are functionally associated. A good example of this principle at work is running the thermostat cable for an oil burner down a conduit (or tubing) riser for a furnace.

However, there are times when power-limited conductors must land on equipment with power connections, and the NEC has evolved many complicated rules, now covered in Sec. 725.136, to cover the topic. For example, suppose a Class 2 circuit will run to the coil of a relay that controls the activity of a power circuit. Both power levels will necessarily enter a common enclosure, and 725.136(D)(1) allows this provided the two systems are routed to maintain a 6 mm (1/4 in.) of air separation between them. Another example, commonly used in industrial settings, is to reclassify the power-limited circuit as a Class 1, allowing it to enter the wiring channels in an industrial control panel. Take care, however, before applying this technique, because once the circuit is reclassified, all devices connected thereto must be fully rated for Class 1 standards. For industrial control components that may be feasible, but for commercial or residential use it may be unrealistic, such as for a conventional thermostat that must be connected to a Class 2 control circuit under the terms of its listing.
WIRING FOR SPECIAL OCCUPANCIES

490. The NEC should be consulted for special rules on installations in the following special occupancies or for the following special equipment or conditions:

- Commercial garages
- Aircraft hangars
- Motor fuel dispensing facilities
- Bulk-storage plants
- Spray application, dipping, and coating processes
- Health care facilities
- Assembly occupancies
- Theaters, audience areas of motion picture and television studios, performance areas, and similar locations
- Control systems for permanent amusement attractions
- Carnivals, circuses, fairs, and similar events
- Motion-picture and television studios and similar locations
- Motion-picture projection rooms
- Manufactured buildings
- Agricultural buildings
- Mobile homes, manufactured homes, and mobile home parks
- Recreational vehicles and recreational vehicle parks
- Park trailers
- Floating buildings
- Marinas and boatyards
- Temporary installations
- Electric signs and outline lighting
- Manufactured wiring systems
- Office furnishings (consisting of lighting accessories and wired partitions)
- Cranes and hoists
- Elevators, dumbwaiters, escalators, moving walks, platform lifts, and stairway chairlifts
- Electric vehicle charging systems
- Electrified truck parking spaces
- Electric welders
- Audio signal processing, amplification, and reproduction equipment
- Information technology equipment
- Sensitive electronic equipment
- Pipe organs
- X-ray equipment
- Induction and dielectric heating equipment
- Electrolytic cells
Electroplating
Industrial machinery
Electrically driven or controlled irrigation machines
Swimming pools, fountains, and similar installations
Natural and artificially made bodies of water
Integrated electrical systems
Solar photovoltaic systems
Fuel cell systems
Fire pumps
Emergency systems
Legally required standby systems
Optional standby systems
Interconnected electric power production sources
Critical operations power systems (COPS)
Circuits and equipment operating at less than 50 V
Class 1, class 2, and class 3 remote-control, signaling, and power-limited circuits
Instrumentation tray cable, Type ITC
Fire alarm systems
Optical fiber cables and raceways
Communications circuits
Radio and television equipment
Community antenna television and radio distribution systems
Network-powered broadband communications systems

**DESIGN OF INTERIOR-WIRING INSTALLATIONS**

**491. Factors affecting wiring layouts** *(Standard Handbook for Electrical Engineers).* In conduit work the space available often dictates that feeders be split into two or more feeder lines so as to guard against complete shutdown should anything happen to one feeder.

In reinforced-concrete floors a cross section of the floor must be studied to see that there will be sufficient space for the reinforcing rods, conduit or raceways, and necessary thickness of concrete. This is especially true when conduits cross. The local building code should be consulted to see what restrictions are placed on floor installations. A minimum thickness of 1 in. (25.4 mm) of concrete over conduits and raceways should be used to prevent cracking.

**EXAMPLE** The building code may allow floors 4 in. (101.6) thick with \( \frac{3}{4} \)-in reinforcing rods located with 1 in. (25.4 mm) of concrete covering the underside (Fig. 9.313). This would mean that there is a minimum space of \( \frac{1}{4} \)-in. (31.75 mm) between the top of the reinforcing rods and the top of any conduit. For this installation, \( \frac{3}{4} \)-in conduit, which has an outside diameter of 1.05 in. (Sec. 63), would be the largest size allowable. There could be no crosses of conduit because even two \( \frac{1}{4} \)-in conduits would take up \( 2 \times 0.84 = 1.68 \) of space, which is more than the \( \frac{1}{4} \)-in. available.
In brick walls there must be two thicknesses of brick to conceal conduits, and the distance between them must be studied to determine the maximum size for vertical runs of conduit. These are only a few of the possible examples in which space for wiring must be considered. Very often the mistake of installing feeders just large enough to carry the present load is made, and when additions are called for, the feeders are overloaded and additional feeders must be installed at great expense. Conduits for feeders and mains should be of sufficient size to permit the installation of feeders or mains of a carrying capacity of 150 percent of the present connected load. Also, spare conduits can be installed.

492. **Wiring methods to be used are determined** by a consideration of national and local code requirements, reliability, appearance, and cost. Those planning a wiring installation should decide which methods of wiring are allowable for the particular occupancy and electric system being considered. Then the cost of each allowable method should be weighed against the appearance, the degree of protection afforded, reliability, and probable years of service that will be realized. Both cost of material and cost of labor must be considered.

1. **Residences.** Type MC cable concealed in partitions is very practical, giving good reliability at moderate cost. If a less expensive installation is desired, nonmetallic-sheathed cable may be used. Sometimes this is used for a few large-size circuits such as a circuit to the electric range if the difference in cost is considerable, even if the rest of the wiring is metal-clad cable. The expense of metal raceways is usually not justified except in very large residences of the highest grade of construction. When the highest degree of adequacy for convenience outlets is desired, multioutlet assemblies should be employed for this part of the wiring.

2. **Rewiring Old Buildings of Residential or Commercial Occupancy.** Surface raceways, Type AC cable, nonmetallic-sheathed cable, and electrical metallic tubing are the usual expedients in rewiring. Surface raceways give the best appearance if the wiring must be exposed. Type AC cable or nonmetallic-sheathed cable is the most practical for that part of the wiring which can be fished through the partitions.

3. **Small Commercial Buildings and Apartment Buildings.** For buildings of frame or brick and frame construction, Type MC cable, nonmetallic-sheathed cable, or electrical metallic tubing concealed in the partitions is generally the most practical.

4. **Office and Public Buildings.** For buildings of steel, concrete, terra-cotta, or similar construction, the cost of wiring is only a small percentage of the total cost of the building. To keep the offices rented to business firms, the electric system should provide the very best in appearance and adequacy of service. Therefore the wiring should be concealed, and rigid metal conduit, intermediate metal conduit, or electrical metallic tubing be employed for ceiling lights and feeders, and under-floor raceways or cellular-floor raceways for desk outlets for power and signaling circuits.

5. **Industrial Buildings.** Metal raceways are generally used for branches, with busways, metal-clad cables, or conduits for feeders.

6. **Large-Sized Main Feeders.** The method of wiring should be considered very carefully because the high unit costs may make a considerable difference in the total cost of the installation.
Very often, combinations of wiring methods are used in the same building, each method being used where its advantages make it desirable.

493. In rewiring buildings using existing conduits, the use of new insulations with thinner insulations permits more conduit fill, depending on the type and size of conductors (see Tables 4 and 5 of Chap. 9 of the NEC.).

494. The branch circuits used in interior wiring may be classified as follows:

**Type 1** This is a branch circuit that supplies only one utilization equipment.

**Type 2** This is a branch circuit that supplies two or more outlets. Such branch circuits are further classified by the NEC according to the rating of the fuse or circuit breaker that protects the circuit. The Code recognizes five types of these multioilet branch circuits. They are 15-, 20-, 30-, 40-, and 50-A branch circuits, respectively. The Code provides certain restrictions on the rating of outlets, size of wire, and equipment to be supplied, as given in Sec. 497.

495. Maximum loads for branch circuits. Type 1 branch circuits may supply loads of any capacity. If the load consists of a motor-operated appliance, the load must not exceed 80 percent of the branch-circuit wires. Also the load must not exceed 80 percent of the rating of the branch circuit when any load will continue for 3 h or more. For details of the requirements for motor branch circuits refer to Div. 7.

Branch circuits are required by the Code to have maximum loads which conform to the following:

1. **Appliances consisting of motors and other loads** When a circuit supplies only motor-operated appliance loads, Article 430 of the Code shall apply (refer to Div. 7). For other than a portable appliance, the branch-circuit size shall be calculated on the basis of 125 percent of motor load if the motor is larger than 1/8 hp plus the sum of the other loads.

2. **Other loads** The total load shall not exceed the branch-circuit rating and shall not exceed 80 percent of the rating when the load will continue for 3 h or more, as for store lighting and similar loads. In computing the load of lighting units that employ ballasts, transformers, or autotransformers, the load shall be based on the total of the ampere rating of such units and not on the wattage of the lamps.

   *Exception:* range loads. See Note 4 of Table 2 in Div. 12.

496. Permissible loads for Type 2 branch circuits are specified by the NEC as follows:

1. **15- AND 20-A BRANCH CIRCUITS** Lighting units and/or appliances: the rating of any one portable appliance shall not exceed 80 percent of the branch-circuit rating; the total rating of fixed appliances shall not exceed 50 percent of the branch-circuit rating if lighting units or portable appliances are also supplied.

2. **30-A BRANCH CIRCUITS** Fixed lighting units with heavy-duty lampholders in other than dwelling occupancies or utilization equipment in any occupancy: the rating of any one portable appliance shall not exceed 24 A.
3. 40- AND 50-A BRANCH CIRCUITS  Fixed lighting units with heavy-duty lampholders or infrared heating appliances or utilization equipment in other than dwelling occupancies or fixed cooking appliances in any occupancy.

4. Branch circuits larger than 50 A shall supply only nonlighting loads.

The term fixed as used in this section recognizes cord connections when otherwise permitted.

### 497. Lighting and Appliance Branch Circuits

(Table 210.24, 2008 NEC)

<table>
<thead>
<tr>
<th>Circuit rating, A</th>
<th>15</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductors (minimum size):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circuit wires</td>
<td>14</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Taps</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Fixture wires and cords</td>
<td>Refer to Sec. 240.5 of Code</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overcurrent protection, A</td>
<td>15</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Outlet devices:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lampholders permitted</td>
<td>Any type</td>
<td>Any type</td>
<td>Heavy-duty</td>
<td>Heavy-duty</td>
<td>Heavy-duty</td>
</tr>
<tr>
<td>Receptacle rating, A&lt;sup&gt;c&lt;/sup&gt;</td>
<td>15 maximum</td>
<td>15 or 20</td>
<td>30</td>
<td>40 or 50</td>
<td>50</td>
</tr>
<tr>
<td>Maximum load, A</td>
<td>15</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Permissible load</td>
<td>...&lt;sup&gt;d&lt;/sup&gt;</td>
<td>...&lt;sup&gt;d&lt;/sup&gt;</td>
<td>...&lt;sup&gt;e&lt;/sup&gt;</td>
<td>...&lt;sup&gt;f&lt;/sup&gt;</td>
<td>...&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

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<sup>b</sup>These gages are for copper conductors.

<sup>c</sup>Refer to Sec. 410.30(C) of the NEC for receptacle rating of cord-connected electric discharge fixtures.

<sup>d</sup>Refer to Sec. 210.23(A).

<sup>e</sup>Refer to Sec. 210.23(B).

<sup>f</sup>Refer to Sec. 210.23(C).

498. The minimum required loads for which branch circuits and feeders must be supplied shall meet the Code requirements as determined from Table 5, Div. 12. If the maximum load of a branch circuit will continue for 3 h or more, as with store lighting and similar loads, the minimum unit loads specified in Table 5 of Div. 12 shall be increased by 25 percent so that the wiring system may have sufficient branch-circuit and feeder capacity to ensure safe operation. Refer to Secs. 89 to 107 in Div. 3 for a comprehensive analysis of this topic.

499. Branch circuits required. The NEC requires that branch circuits shall be installed as follows:

1. LIGHTING AND APPLIANCE CIRCUITS For lighting and for appliances, including motor-operated appliances, not specifically provided for in Par. 2, branch circuits shall be provided for a computed load not less than that determined by Part II of Article 220 of the Code.

The number of circuits shall be not less than that determined from the total computed load and the capacity of circuits to be used, but in every case the number shall be sufficient
for the actual load to be served, and the branch-circuit loads shall not exceed the maximum loads specified in Secs. 495 to 497.

Where the load is calculated on a volt-amperes per unit area basis, the wiring system up to and including the branch-circuit panelboard(s) shall be provided to serve not less than the calculated load. This load shall be evenly proportioned among mult OUTLET branch circuits within the panelboard(s). Branch circuit overcurrent devices and circuits shall be required to be installed only to serve the connected load.

2. SMALL-APPLIANCE BRANCH CIRCUITS: DWELLING OCCUPANCIES For the small-appliance load, including refrigeration equipment, in kitchen, pantry, dining room, or similar area of dwelling occupancies, two or more 20-A small-appliance branch circuits in addition to the branch circuits specified in Par. 1 of this section shall be provided for all wall and floor receptacle outlets covered by NEC 210.52(A) and counter receptacle outlets covered by 210.52(C) in these rooms, and such circuits shall have no other outlets except clock outlets or supplemental equipment and lighting on gas-fired ranges, ovens, or counter-mounted cooking units. In addition to the required receptacles, switched receptacles are permitted in lieu of lighting outlets in other than the kitchen and bathroom.

Receptacle outlets supplied by at least two appliance-receptacle branch circuits shall be installed in the kitchen to serve countertop surfaces.

At least one 20-A branch circuit shall be provided for a laundry receptacle (or receptacles) required in Sec. 210.52(F) of the Code.

Receptacle outlets installed solely for the support of and the power supply for electric clocks may be installed on lighting branch circuits or small appliance circuits.

A 120/240-V multiwire branch circuit is the equivalent of two 120-V receptacle branch circuits.

When a grounding receptacle is required as in Sec. 406.3(A) of the Code, the branch circuit shall include or provide an equipment grounding conductor to which the grounding contacts of the grounding receptacle shall be connected. Refer to Sec. 368, sub-heading 1b, for the list of acceptable equipment grounding conductors.

3. OTHER CIRCUITS For specific loads not otherwise provided for in Pars. 1 or 2, branch circuits shall be as required by other sections of the Code.

500. Feeder loads should be determined in accordance with instructions given in Div. 3. Instructions for determining the minimum allowable loads required by the Code are given in Sec. 5, Div. 12.

501. The size of conductors required with respect to both carrying capacity and voltage drop is discussed in Div. 3. For Type 2 branch circuits also refer to Sec. 497 of this division.

502. Overcurrent protection of circuits. In general, the rating of the overcurrent protective devices of a circuit shall not be in excess of the carrying capacity of the circuit conductor. However, there are many examples where this general principle is not workable and the Code either allows for limited exceptions from, or imposes additional limitations on this general principle:

a. Overload protection, but not short-circuit protection, may be omitted where the operation of a circuit protective device due to overload would cause a greater hazard, as in the case of fire pump circuits.
b. For overcurrent devices rated 800 A or less, when the ampacity of a conductor does not coincide with a standard rating of an overcurrent device, the next higher standard size may be used. Note that this does not allow a conductor to be knowingly operated in the window between its ampacity and the next higher standard size device. For example, the ampacity of 4/0 aluminum Type SE cable for load connection purposes (refer to Div. 3 for a detailed analysis of termination ratings, etc.) is 180 A. The next higher standard size overcurrent device is 200 A. Although the cable can be protected with the 200 A device, if the actual load (as determined by NEC Article 220) is expected to run above 180 A, then a 250 kcmil aluminum Type SE cable would be required. In addition, the next-higher standard-size allowance does not apply to a multioutlet branch circuit supplying receptacles for cord-and-plug-connected portable loads.

c. There are special allowable ampacity values established for small conductors, unless specifically permitted for tap conductors or for specific applications as covered in item f below. The values are as follows:

1. 18 AWG copper is 7 A provided any continuous loads do not exceed 5.6 A, and there is special overcurrent protection provided by branch-circuit-rated circuit breakers or fuses listed and marked for use with 18 AWG copper wire, or Class CC, J, or T fuses are used for this purpose.
2. 6 AWG copper is 10 A provided any continuous loads do not exceed 8 A, and there is special overcurrent protection provided by branch-circuit-rated circuit breakers or fuses listed and marked for use with 16 AWG copper wire, or Class CC, J, or T fuses are used for this purpose.
3. 14 AWG copper is 15 A.
4. 12 AWG aluminum and copper-clad aluminum is 15 A.
5. 12 AWG copper is 20 A.
6. 10 AWG aluminum and copper-clad aluminum is 25 A.
7. 10 AWG copper is 30 A.

d. Tap conductors, and secondary conductors from transformers with no overcurrent protection at the point of supply, all as covered in Sec. 319.

e. Specific applications covered in specialized Code articles, as follows:

1. Air conditioning and refrigeration equipment conductors, as covered in Div. 7 in Secs. 400 to 402.
2. Capacitor circuit conductors, as covered in Sec. 138 of Div. 4.
3. Control and instrumentation circuit conductors using the special protocol allowed in NEC Article 727, as covered in NEC Sec. 727.9. This method is not covered in this handbook.
4. Electric welder circuit conductors, as covered in NEC Sec. 630.12 and 630.32. These details are not covered in this handbook.
5. Fire-alarm circuit conductors, as covered in NEC Sec. 760.43, 760.45, 760.121, and Chap. 9, Tables 12(A) and 12(B). For nonpower-limited circuits, the rules generally follow the provisions for comparable conductors of signaling circuits covered in Sec. 477, although the 300 percent allowance does not apply. For power-limited circuits, the overcurrent protection is generally governed by the activities of the listing agencies because the applicable tables in Chap. 9 effectively only apply to a listing evaluation.
6. Motor conductors, both power and control, and motor-operated appliances are entirely governed by provisions in Article 430, as covered in Div. 7. Note that those provisions do not generally follow the small conductor limitations covered here. For example, the table allowable ampacity of a 14 AWG conductor under the usual termination conditions is 20 A. The rating of a 1 hp 115-V single phase motor per Div. 12, Table 8 is 16 A. The minimum ampacity for a motor conductor in this case (refer
to Sec. 387 of Div. 7) is 125 percent of full load, or 20 A for this motor. Assume that
the motor will be protected by an inverse-time circuit breaker. As covered in Table 43
of Div. 12, the allowable protection ratio is 250 percent, allowing for a 50-A circuit
breaker ahead of 14 AWG conductors to this motor. This assumes the motor has
appropriate running overload protection, generally set at not over 125 percent of full-
load current, or 20 A in this case.

7. Phase converter supply conductors, as covered in Sec. 371 of Div. 7.

8. Remote-control, signaling, and power-limited circuit conductors, as covered in NEC
Sec. 725.43, 725.45, 725.121, and Chap. 9, Tables 11(A) and 11(B). For nonpower-
limited circuits, the rules are covered in Sec. 477. For power-limited circuits, the
overcurrent protection is generally governed by the activities of the listing agencies
because the applicable tables in Chap. 9 effectively only apply to a listing evaluation.

9. Secondary tie conductors, as covered in Sec. 126 of Div. 5.

503. The voltage on branch circuits supplying lampholders within their voltage rat-
ings, auxiliary equipment of electric discharge lamps, and cord-and-plug-connected or per-
manently connected utilization equipment shall not exceed 120 V between conductors;
however, higher voltages are permitted in a number of cases, subject to the occupancy lim-
itation in Sec. 504.

Branch circuit voltages exceeding 120 V between conductors but not exceeding 277 V
to ground (which allows for 480 V supplies on 480Y/277-V systems) are permitted to sup-
ply listed electric discharge luminaires (fixtures) and a special form of listed incandescent
luminaire with an integral stepdown autotransformer between the supply and the screw
shell. This voltage bracket is also permitted to supply luminaires with mogul-base screw-
shell lampholders or other lampholders applied within their voltage rating, auxiliary equip-
ment of electric-discharge lamps, and cord-and-plug-connected or permanently connected
utilization equipment.

Conductors running up to 600 V between conductors, and with no voltage to ground
limitation, are permitted to supply the ballasts for electric discharge lamps mounted in per-
manently installed fixtures on poles for the illumination of areas, such as highways, roads,
bridges, athletic fields, parking lots, at a height not less than 6.7 m (22 ft), or on other struc-
tures such as tunnels at a height not less than 5.5 m (18 ft) shall not exceed 600 V between
conductors. They are also permitted to supply luminaires powered from dc systems that
incorporate listed dc ballasts that provide isolation between the dc source and the lamp cir-
cuit and shock protection during relamping operations. This allowance is designed for dc
photovoltaic output circuits (Sec. 551) that often approach this voltage, and this allows for
directly-connected lighting without the inherent inefficiencies of a central inverter.

The above limitations do not apply to lampholders of industrial infrared heating appli-
cances as covered in NEC Sec. 422.14, nor do they apply to railway properties where a lim-
ited permission is available to power equipment from a trolley wire system with a ground
return. Medium voltages (over 600 V) are permitted to supply utilization equipment in
occupancies with qualified maintenance and supervision of the electrical system. For
example, many industrial occupancies use very powerful motors in ranges of thousands of
horsepower and operating at 4.8 or even 13.8 kV.

504. In dwelling occupancies, and guest rooms or suites of hotels and motels, the
voltage between conductors supplying luminaires (lighting fixtures), and cord- and plug-
connected loads 1440 VA, or less, or less than ¼ hp shall not exceed 120 V between con-
ductors. This limitation is by occupancy and therefore supersedes allowances for higher
voltages generally, as covered in Sec. 503.
505. **General considerations.** The following recommendations for wiring for residential outdoor lighting have been taken from a booklet on the subject published by the Construction Materials Division of the General Electric Co.

Factors that must be considered before making any outdoor wiring installation are family habits and the facilities that the family wishes to enjoy, the style and construction of the house, the size and topography of the property, and, most important of all, whether spare circuits are available at the panelboard or new circuits must be added, and the length of the circuits required for the various outdoor lighting and outlet installations.

In general, it will probably be found that permanently installed outdoor wiring to be used beyond the house should be run underground from the point where it emerges from the house to the point where the equipment is to be used. There are, of course, exceptions. When the house is multistoried, overhead wiring may be used. In almost all other cases, from the viewpoint of both safety and aesthetics, underground circuits will be preferable. Sometimes a combination of overhead and underground wiring will be most satisfactory.

Any circuit installed in an existing dwelling for outdoor use should be a new circuit originating at the panelboard rather than an extension of an existing circuit. In all cases circuits for outdoor use should be restricted to this purpose only.

In laying out new outdoor wiring, it should be recognized that even though the homeowner considers that the primary purpose of the new circuits is to provide lighting only, this cannot be taken for granted. Once the circuits are installed and outdoor outlets are available, there will probably be a heavy demand from this source for power for appliances and tools. Not less, therefore, than two 20-A circuits or one three-wire 120/240-V circuit should be installed.

506. **Running the circuits from panelboard to the outside.** The style and construction of the house will determine how the circuits are run from the panelboard to the outside. Most installations will be either (1) from a basement when the walls are concrete or cement-block or (2) from above ground level when the panelboard is located either in the garage or in another interior location at first-floor level.

1. **When the Panelboard is in the basement** In this situation, wiring is generally brought to the outside either through the masonry wall of the basement or through the sill on top of the foundation. Factors to be considered are whether the installation is to be underground or overhead. If it is underground, going directly through the basement wall and coming out below ground level (Fig. 9.314) on the outside is the least conspicuous. If convenient shrubbery will hide the conduit, it may be easier to come out through the sill (Fig. 9.315).
Either of these methods may be chosen when the wiring is to be overhead. In this case, since a length of conduit will have to run up the side of the house, it is well to come out of the basement at a point where shrubbery will partially conceal the installation. Occasionally, in frame construction, the circuit for overhead wiring can be fished up through the walls to a point of departure at the desired elevation of the house.

2. When the Panelboard Is in the Garage or the House. In many newer houses, especially those without basements, the panelboard is installed in the attached garage or in some other handy but inconspicuous part of the house. In such cases, the circuit is run from the panelboard through the wall of the garage or house (Fig. 9.316) at the most convenient point. Thought should be given to the point selected so that the installation is as unobtrusive as possible.

507. Underground Circuits. Circuits run underground offer a number of advantages to the homeowner. They are not subject to damage from storms or exposed to mechanical damage. Most important, such circuits are invisible and do not, therefore, mar the appearance of the grounds and gardens.

The most economical underground installation for both feeders and branch circuits is Type UF (underground-feeder) cable. This cable is approved by the NEC for direct burial in the ground without additional protection.

Underground cable is laid in a trench at least 600 mm (24 in.) or (12 in.) 300 mm (12 in.) deep if 20 A or less and protected with a GFCI to prevent possible damage from normal spading. The bottom of the trench should be free from stones. This is easily accomplished by using a layer of sand or sifted dirt in the bottom of the trench (Fig. 9.317). Cable is laid directly on top of this layer. When cable enters the building or leaves the ground, slack should be provided in the form of an S curve to permit expansion with extreme changes in temperature. After the cable has been installed, fill all openings through the foundation with sealing compound so that water from rain or melting snow cannot follow the cable into the building.

It is desirable that underground-feeder cables be installed in continuous lengths from outlet to outlet and from fitting to fitting. Splices can be made only without a splice box in accordance with Sec. 110.14(B) of the NEC. Note that the individual conductors of Type UF cable are not listed for direct burial; only the complete cable assembly has that rating. Therefore, any cable splices for this wiring method must run complete from intact cable sheath to intact cable sheath. There are twist-on wire connectors with direct burial ratings, and that are suitable for single-conductor Type USE cables, but they cannot be used for the customary Type UF cable underground.

In some areas of a yard, when it is felt that digging might accidentally occur to the depth of the cable, a concrete pad or a 1- by 2-in (25.4- by 50.8-mm) running board can be laid.
over the cable before the trench is filled (Fig. 9.317). Under driveways or roadways or where heavy loading might occur, it is also desirable to use a board, concrete pad, or conduit.

For outdoor wiring in sections of the United States that are known to be termite-infested or subject to attack by rodents, or whenever extra protection to the Type UF underground circuits is required, rigid galvanized-steel conduit may be used for mechanical protection. When rigid conduit for the complete circuit run is used, feeders and branch circuits may be of any approved type of moisture-resistant wire such as Types TW, RHW, or THWN.

508. Multiple-family buildings or apartments. The recommendations for residences can be applied to individual apartments for lighting and convenience outlets, and switch locations. If central heating is supplied, it is unlikely that an electric heater will be used in the bathroom or that many heavy-duty appliances will be used at one time. Therefore the two 20-A small-appliance branch circuits supplying convenience outlets in the dining room and kitchen generally will be sufficient. It is recommended that a three-wire, 120/240-V, No. 8 range circuit be installed for each apartment.

For nonrentable areas under the control of the building management the following rules from the *Handbook of Interior Wiring Design*, prepared by the Industry Committee on Interior Wiring Design, represent good practice:

1. **Entrances**
   a. Sufficient outlets shall be installed to provide electrical service consistent with the general architectural treatment, but in no case shall there be less than one outlet for an outside lantern or two for outside wall brackets.
   b. At least one ceiling outlet shall be installed for each 150 ft² (13.9 m²) of vestibule space.
   c. At least one wall outlet shall be installed over each group of letter boxes covering a lineal distance of 8 ft (2.4 m) or less.

2. **Lobby or Main Hallway**
   a. At least one ceiling outlet per 125 ft² (11.6 m²) of floor area shall be installed provided:
      (I) No area has outlets spaced more than 15 ft (4.6 m) apart.
      (2) No elevator door or stairwell is more than 6 ft (1.8 m) from the nearest ceiling outlet.
   b. At least one convenience outlet shall be installed for every 12 ft (3.7 m) of wall space for portable lamps and general-utility purposes (vacuum cleaners, floor polishers, and so on). Hallways 10 ft or longer require a minimum of one convenience outlet.
   c. Provision shall be made for additional outlets to furnish such illumination as is demanded by the architectural treatment. This may be in the form of decorative wall brackets, urns, pedestals, built-in units, etc.

3. **Upper Hallways**
   a. At least one ceiling outlet shall be installed per 150 ft² (13.9 m²) of floor area, provided that:
      (I) No area has ceiling outlets spaced more than 15 ft (4.6 m) apart if they are arranged on alternate circuits or 30 ft (9.1 m) if adjacent outlets are on the same circuit.
      (2) No elevator door or staircase is located more than 6 ft (1.8 m) from the nearest ceiling outlet.
      (3) No section of a hallway not in a straight line from another shall be without at least one ceiling outlet.
   b. At least one convenience outlet shall be installed per floor, with additional outlets spaced so that no point in a hallway is located more than 25 ft (7.6 m) from a convenience outlet, and a minimum of one for hallways 10 ft or longer.
4. **Hall Switches**
   a. All ceiling outlets plus the outlets for entrance lighting shall be controlled by switches.
   b. When all ceiling outlets on any one floor are controlled by a single switch, this switch shall be of a type or shall be located so as to be inaccessible to the general public.
   c. When more than one switch controls the ceiling outlets on a particular floor, at least one switch shall be inaccessible to the general public. This switch shall control outlets installed under the following provisions:
      1. It must control the outlet nearest the stairwell or the elevator door.
      2. It must control outlets so that the spacing between any two is not greater than 30 ft (9.1 m).
      3. It must control an outlet in every space not in a direct line from the outlet near the stairwell or the elevator door.

5. **Stairwells**
   a. When enclosed stairwells are installed (as in masonry construction), there shall be an outlet for lighting on each landing.
   b. If exit lights are required, they shall be installed in accordance with all rules and regulations covering their use.
   c. Interior stairways with six risers or more require a wall switch at each floor level.

6. **Basement Areas.** Lighting outlets shall be provided in basement areas on the basis of at least one ceiling outlet per 200 ft² (18.6 m²), plus additional outlets and necessary switch control if such basement areas are available to tenants for laundry, storage, or other purposes.

7. **Oil Burners, Air-Conditioning Equipment, etc.** Circuits shall be individually provided for each such piece of equipment in accordance with the size and rating of each motor or heater.

8. **Elevators.** Power and light feeders for elevator service shall be of the size required by the elevator manufacturer.

509. **The arrangement of the service and feeders** will depend on the system of metering employed. When each apartment is to be metered and billed for all its power, a meter service switch and meter should be provided for each apartment and one or two for the building management. These should be located in rows along the walls in the basement. Each apartment must be on an individual feeder from the meter service switch. The load on the feeder should be computed in accordance with the instructions given in Div. 3. If an electric range is supplied, three-wire feeders should be used. When the power company will bill the building management on a lower rate for power than it does for lighting, two meters with separate circuits for each should be provided. If there are more than six meter service switches, the service must be brought in through a single circuit breaker or fused service switch, the size to be determined in accordance with the instructions of Div. 3. When the power company bills the building management and included in the rent, the circuit is brought in through a single circuit breaker or fused service switch as before.

   Circuits for either one or two meters, depending on whether the power company bills the power on a separate rate from the lighting, should be provided. A distribution center with a safety enclosed fused knife switch or circuit breaker for each feeder should be installed. With steadily increasing energy costs at hand, the trend is toward including all tenant loads on a tenant meter. This also promotes energy conservation, since a tenant pays directly for any energy wasted. The method of wiring is with Type MC cable or nonmetallic-sheathed cable for small buildings permitted to be of frame construction. Conduit or tubing wiring is often employed, at least for feeders, for larger buildings of masonry construction.
510. With any of the above plans each apartment should have its own distribution panelboard containing circuit breakers for the branch circuits. Circuit breakers can be easily reset and are unlikely to provoke a service call by a tenant squeamish about changing a cartridge fuse. Note that every tenant must have ready access to his branch-circuit overcurrent devices, regardless of how a rental agreement may have been worded. He must also have ready access to his feeder and service devices unless there is continuous supervision by building management, and the management is responsible for electrical maintenance. This exemption only applies in multiple-occupancy buildings; a tenant in a single-family house must have this access regardless of how a rental agreement may describe the electrical maintenance responsibility.

WIRING FOR COMMERCIAL AND INDUSTRIAL OCCUPANCIES

511. Electrical distribution systems for commercial and industrial use (Joseph F. McPartland, *Electrical Systems Design*). In any electrical system, the distribution system involves the methods and equipment used to carry power from the service equipment to the overcurrent devices protecting the branch circuits. The distribution system carries power to lighting panelboards, power panelboards, and motor-control centers and to the branch-circuit protective devices for individual motor or power loads. Depending upon the type of building, the size and nature of the total load, various economic factors, and local conditions, a distribution system may operate at a single voltage level or may involve one or more transformations of voltage. A distribution system might also incorporate a change in frequency of ac power or rectification from ac to dc power.

Design of a distribution system, therefore, is a matter of selecting circuit layouts and equipment to accomplish electrical actions and operations necessary for the conditions of voltage, current, and frequency. This means relating such factors as service voltage, distribution voltage or voltages, conductors, transformers, converters, switches, protective devices, regulators, and power-factor corrective means to economy, load conditions, continuity of service, operating efficiency, and future power requirements. Of course, the factors of capacity, accessibility, flexibility, and safety must be carefully included in design considerations for distribution.

Basically, distribution systems are classified according to the voltage level used to carry the power either directly to the branch circuits or to load-center transformers or substations at which feeders to branch circuits originate. The most common types of distribution systems based on voltage are discussed in Div. 3.

512. Types of electrical distribution systems. The descriptions and discussions of the different types of electrical distribution systems given in this section and Secs. 513 to 524 inclusive are reproduced from *Westinghouse Architects’ and Engineers’ Electrical Data Book* through the courtesy of the Westinghouse Electric Corporation.

In the great majority of cases, power is supplied to a building at the utilization voltage. In practically all these cases, the distribution of power within the building is achieved through the use of a simple radial distribution system. This system is the first type described on the following pages from the low-voltage bus to the loads.

When service is available at the building at some voltage higher than the utilization voltage to be used, the system design engineer has a choice of a number of types of systems.
This discussion covers seven major types of distribution systems and practical modifications of several of them.

Simple radial
Loop-primary radial
Banked-secondary radial
Primary-selective radial
Secondary-selective radial
Simple network
Primary-selective network

513. Simple radial system. The conventional simple radial system receives power at the utility supply voltage at a single substation and steps the voltage down to the utilization level. Low-voltage feeder circuits run from the substation bus to switchgear assemblies and panelboards that are located with respect to the loads as shown in Fig. 9.318. Each feeder is connected to the substation bus through a circuit breaker. Relatively small circuits are used to distribute power to the loads from the switchgear assemblies and panelboards.

Since the entire load is served from a single source, full advantage can be taken of the diversity among the loads. This makes it possible to minimize the installed transformer capacity. However, the voltage regulation and efficiency of this system are poor because of the low-voltage feeders and single source. The costs of the low-voltage feeder circuits and their associated circuit breakers are high when the feeders are long and the peak demand is above 1000 kVA.

A fault on the substation bus or in the substation transformer will interrupt service to all loads. Service cannot be restored until the necessary repairs have been made. A low-voltage feeder-circuit fault will interrupt service to all loads supplied over that feeder circuit.
A modern and improved form of the conventional simple radial system distributes power at a primary voltage. The voltage is stepped down to utilization level in the several load areas within the building through power-center transformers. The transformers are usually connected to their associated load bus through a circuit breaker, as shown in Fig. 9.319. Each power center is a factory-assembled unit substation consisting of a three-phase liquid-filled or air-cooled transformer, an integrally mounted primary switch, and low-voltage metal-enclosed circuit breakers. Circuits are run to the loads from these circuit breakers.

Since each transformer is located within a specific load area, it must have sufficient capacity to carry the peak load of that area. Consequently, if any diversity exists among the load areas, this modified system requires a greater transformer capacity than the basic form of the simple radial system. However, because power is distributed to the load areas at a primary voltage, losses are reduced, voltage regulation is improved, feeder-circuit costs are reduced substantially, and the large low-voltage feeder circuit breakers are eliminated. In many cases the interrupting duty imposed on the load circuit breakers is reduced.

This modern form of the simple radial system will usually be lower in initial investment than any other type of distribution system for buildings in which the peak load is above 1000 kVA. It is poor, however, from the standpoints of service continuity and flexibility. A fault on the primary feeder circuit or in one transformer will cause an outage to all loads. In the case of the feeder fault, service is interrupted to all loads until the trouble has been eliminated. When a transformer fault occurs, service can be restored to all loads except those served by the faulty transformer by opening the transformer primary switch and reclosing the primary feeder breaker.

Reducing the number of transformers per feeder by adding primary feeder circuits will improve the flexibility and service continuity of this system. This, of course, increases the investment in the system but minimizes the extent of an outage due to a transformer or feeder fault.

If one primary feeder is used per transformer, as in Fig. 9.320, the system is comparable in service continuity to the single substation form of the simple radial system. This
system arrangement will usually be very expensive. The cost can be materially reduced, however, by replacing the automatic feeder circuit breakers with manually operated breakers or load-break switches and by backing up a number of these switches with one automatic circuit breaker.

In this modified form of the simple radial system, a primary feeder fault interrupts service to all loads. Service can be restored to all loads except those associated with the faulted system element by opening the load-break switch on the faulted circuit and closing the circuit breaker. Service can be restored to the remaining loads when the necessary repairs are made.

514. Loop-primary radial system. This system is similar in principle to the modern form of simple radial system. It provides for quick restoration of service when a primary feeder or transformer fault occurs, as does the modified simple radial system of Fig. 9.320, and at a lower investment. A sectionalized primary loop controlled by a single primary feeder breaker as shown in Fig. 9.321 is used rather than a radial primary feeder.

Manually operated load-break switches are installed in the feeder for sectionalizing purposes. Two are located where the feeder branches to form the loop, and the others are located at the transformers. This makes it possible to disconnect any transformer and its associated section of loop from the rest of the system.

When a transformer or primary-feeder fault occurs, the main feeder breaker opens and interrupts service to all loads. Increasing the number of primary loop feeders will reduce the extent of the outage from a fault but will also increase the system investment. The faulty section of loop and its associated transformer can be disconnected from the system by the load-break switches. Service can then be restored to all but the disconnected portion of the system by closing the primary feeder breaker. Service cannot, however, be restored to the loads in the area where the transformer or primary loop section is in trouble until the necessary repairs have been made.
The cost of this system as illustrated is only slightly more than that of the modern simple radial system of Fig. 9.319. The primary-cable cost is a little greater, and there are two additional load-break switches in the system. The load-break switches associated with the transformers will cost little more than the disconnecting switches in the primary leads of the transformers of the simple radial system.

515. Banked-secondary radial system. This system permits quick restoration of service to all loads following a primary-feeder or transformer fault. It uses a secondary loop, as shown in Fig. 9.322, to provide an emergency supply when a fault occurs in a transformer or a section of the primary loop. The primary-circuit arrangement is the same as that in the loop-primary radial system of Fig. 9.321.

The primary-feeder arrangement of the simple radial system of Fig. 9.320 can be used to give the same results, but it usually will be more costly.

A primary-feeder or transformer fault causes the main breaker to operate and drop all load. Service can be restored by opening the two load-break switches and the low-voltage breaker of the transformer adjacent to the fault and closing the primary feeder breaker. When the primary feeder breaker is reclosed, service is restored to all loads. Those loads connected to the load bus associated with the disconnected transformer are supplied over the secondary loop from adjacent load buses.

The secondary loop gives a number of important advantages other than providing an emergency supply to restore service. It helps equalize the loads on all transformers and thus makes it unnecessary to match the transformer capacity at each load center to the load connected to each load bus.

Balancing transformer capacity and load in each load area may be a real problem on all other types of radial systems, except the radial system of Fig. 9.318. The secondary loop permits 1 kVA rating of transformer to be used throughout the system, and load circuits can be run directly from the nearest bus to the loads.
Advantage is taken of the diversity among the loads because all transformers are connected in parallel. As a result, there usually is a saving in transformer capacity over that required in any other form of radial system except the simple radial system of Fig. 9.318. Also, this system is better adapted for across-the-line starting of relatively large motors than is any other type of radial system because the starting current is supplied through several transformers in parallel rather than through a single transformer. Thus, if the starting of large motors is involved, the use of this system may result in a saving in the cost of motor-starting equipment. Likewise, it is the most satisfactory type of radial system for combined light and power secondary circuits.

In the banked-secondary radial system, fault current flows not only through the transformer associated with a faulted load bus or circuit but also through other transformers and over the secondary loop to the fault. The resulting increase in fault current may require the use of load circuit breakers having a higher interrupting rating than needed in other types of modern radial systems. This possible increase in cost may or may not be offset by savings in transformer capacity and secondary conductors.

It is difficult to make a general cost comparison between this system and the loop-primary radial system. In some buildings the additional cost of the secondary loop will be offset by the saving in transformer capacity and secondary conductors. In other buildings, because of lack of diversity and a relatively uniform distribution of load, these savings are very small, and the system will cost more than the loop-primary radial system by about the cost of the secondary loop. However, the advantages of quick restoration of service to all loads, greater flexibility, higher efficiency, and better voltage conditions may justify the extra cost.

516. Primary-selective radial system. The primary-selective radial system, as shown in Fig. 9.323, differs from the systems previously described in that it employs at least two primary-feeder circuits in each load area. It is designed so that when one primary circuit is out of service, the remaining feeder or feeders have sufficient capacity to carry the total load. While three or more primary feeders may be used, usually only two feeders are employed. Half of the transformers are normally connected to each of the two feeders.
When a fault occurs on one of the primary feeders, only half of the load in the building is dropped. In the systems discussed previously a primary-feeder fault causes an outage to all loads in the building.

Double-throw or primary selector switches are used with all transformers so that when a primary-feeder fault occurs, the transformers normally supplied from the faulted feeder can be switched to the good feeder and restore service to all loads.

The short-circuit duty on the load circuit breakers is less than in the banked-secondary radial system and is about the same as for all other types of radial systems using transformers within the load areas.

If a fault occurs in one transformer, the associated primary-feeder breaker opens and interrupts service to half of the load in the building, just as when a primary feeder fails. The faulted transformer is disconnected by moving its primary selector switch to the open position. Service is then restored to all loads except those normally supplied by the defective transformer by closing the primary-feeder breaker.

Service cannot be restored to the loads normally served by the faulted transformer until the transformer is repaired or replaced.

Cost of the primary-selective radial system is greater than that of the simple radial system of Fig. 9.319 because of the additional primary-feeder breaker, the use of primary selector switches, and the greater amount of primary-feeder cable required. The benefits derived from the reduction in the amount of load dropped when a primary-feeder or transformer fault occurs, plus the quick restoration of service to all or most of the loads, may more than offset the greater cost.

The primary-selective radial system, however, is not so good as the banked-secondary radial system from the standpoint of restoring service to the loads after a primary-feeder or transformer fault. It is only a little better than the loop-primary radial system in this respect. In some cases, particularly in fairly large buildings with medium- or light-load density, about the same quality of service can be rendered at less cost by using the loop-primary radial system employing two separate loops instead of one. In this case, half of the transformers are connected to each loop of the system. (See Fig. 9.323.)
Secondary-selective radial system. This system uses the same principle of duplicate feed from the power supply point as the primary-selective radial system. In this system, however, the duplication is carried all the way to each load bus on the secondary side of the transformers instead of just to the primary terminals of the transformers. This arrangement permits quick restoration of service to all loads when a primary-feeder or transformer fault occurs, as does the banked-secondary radial system.

The usual form of secondary-selective radial system is shown in Fig. 9.324. Each load area in the building is supplied over two primary feeders and through two transformers. The capacity of each of these transformers must be such that it can safely carry the entire load in the area served by both transformers. Each transformer is connected through a transformer breaker to a secondary bus section to which half of the radial load circuits are connected.

A bus-tie breaker is provided for connecting the two secondary or load-bus sections at each load center. Normally this bus-tie breaker is open, and the system operates as two parallel systems entirely independent of each other beyond the power supply points. The bus-tie breaker is interlocked with the two transformer breakers so that it cannot be closed unless one of the transformer breakers is open. This is done to keep the interrupting duty imposed on the load circuit breakers to a minimum.

A primary-feeder fault causes half of the load in the building to be dropped, as with the primary-selective radial system. Service can be restored by opening the transformer breakers associated with the faulted feeder and closing all bus-tie breakers. When this is done, the entire load is fed over one primary feeder and through half of the transformers. Therefore, both primary feeders must be capable of carrying the entire load, as with the primary-selective radial system, and a much greater transformer capacity is required.

A fault in a transformer causes the associated primary feeder breaker to trip and interrupts service to half of the building load. Service can be restored by opening the disconnecting switch on the primary and the circuit breaker on the secondary of the faulted transformer, closing the associated bus-tie breaker, and reclosing the primary-feeder breaker. This manual switching restores the system to normal operating conditions, except that the faulted transformer is deenergized and its load is being supplied through the adjacent transformer.
Cost of the secondary-selective radial system usually will be considerably more than that of the radial systems previously discussed with the exception of the system shown in Fig. 9.318, which uses one large substation and low-voltage feeders, and the banked-secondary radial system of Fig. 9.322. This is due chiefly to the large amount of transformer capacity required to provide complete duplicate power supply to the secondary load buses. Because of this spare transformer capacity, the regulation provided by the secondary-selective radial system under normal conditions is better than that of the systems previously discussed, with the possible exception of the banked-secondary radial system.

From the standpoint of voltage fluctuation when a load such as a relatively large motor is thrown on the system, this system is not as good as the banked-secondary radial system. The advantage that the secondary-selective radial system offers over the banked-secondary radial system is that a primary-feeder or transformer fault causes only one-half of the load to be dropped instead of all the load in the area. Both systems permit the quick restoration of service to all loads when a primary-feeder or transformer fault occurs.

The banked-secondary radial system has greater flexibility and can be more readily adapted to changing load conditions than can the secondary-selective radial system.

A modified form of secondary-selective radial system that will often be less costly than the common form previously described as shown in Fig. 9.325. In this system there is only one transformer at each load center instead of two. Pairs of adjacent load buses are connected by secondary cables or bus and thus permit picking up the load of any bus when a primary-feeder or transformer fault occurs.

Each tie circuit is connected to each of its two load buses through a secondary-tie circuit breaker. Each secondary-tie breaker is interlocked so that it cannot be closed unless one of the two transformer breakers is open.

There are two ways in which this single-transformer-substation form of secondary-selective radial system can be handled. One is to use the same number and rating of transformers as in the usual form of the system. Essentially, this results in twice as many load areas with half as much load in each area. This arrangement has the advantage of reducing the average length of the radial load circuits and thereby lowering the cost of the secondary

![FIGURE 9.325 Modified secondary-selective radial system.](image-url)
conductors. When compared with the other types of distribution systems, both this and the usual form of secondary-selective radial system introduce the problem of balancing the loads on twice the usual number of load buses.

The other way in which the system can be handled is to use the same number of load areas as in Fig. 9.324. With one transformer of twice the kVA rating at each load center, the result is half of the number of transformers but the same total transformer capacity. Because of the smaller number of transformers of larger rating, this will often be the lowest-cost form of secondary-selective radial system.

Basically, the single-transformer-substation form of secondary-selective radial system, regardless of the number and size of the transformers used, functions as described in connection with the more usual form of this system.

518. Simple network system. The ac secondary network system is the system that has been used for many years to distribute electric power in the high-density, downtown areas of cities. Modifications of this type of system make it applicable to serve loads within buildings.

The best-known advantage of the secondary network system is continuity of service. No single fault anywhere on the system will interrupt service to more than a small part of the system load. Most faults will be automatically cleared without interrupting service to any load. Another outstanding advantage that the network system offers is its flexibility to meet changing and growing load conditions at minimum cost and with minimum interruption of service to the other loads. In addition to flexibility and service reliability, the secondary network system provides exceptionally uniform and good voltage regulation, and its high efficiency materially reduces the cost of losses.

Three major differences between the network system and the simple radial system account for the outstanding advantages of the network. First, a network protector is connected in the secondary leads of each network transformer in place of the usual transformer secondary breaker, as shown in Fig. 9.326. Second, the secondaries of all transformers are connected together by a ring bus or secondary loop from which the loads are supplied over

![FIGURE 9.326 Simple network system.](image-url)
short radial circuits. Third, the primary supply has sufficient capacity to carry the entire building load without overloading when any one primary feeder is out of service.

A network protector is a specially designed, motor-closed, and shunt-tripped air circuit breaker controlled by network relays. The network relays function to close the breaker automatically only when voltage conditions are such that the associated transformer will supply load to the secondary loop and to open the breaker automatically when power flows from the secondary loop to the network transformer. The purpose of the network protector is to protect the secondary loop and the loads served from it against transformer and primary-feeder faults by disconnecting the defective feeder-transformer unit from the loop when a back feed occurs.

The chief purpose of the secondary loop is to provide an alternative supply to any load bus when the primary feeder which normally supplies it is deenergized, so as to prevent any service interruption when a transformer or feeder fault occurs. The use of the loop, however, gives at least four other important advantages. First, it saves transformer capacity. It permits lightly loaded transformers to help those which are more heavily loaded and thus tends to equalize the load on all transformers. Second, it saves secondary load circuit conductors and conduit. The secondary loop makes it unnecessary to match the load supplied from any one load bus with the transformer capacity at that point. Loads can be served from the loop at load buses located between network transformers, and the load circuits can be run directly to the loads from the nearest load bus. This permits the use of very short radial circuits and results in a considerable saving in secondary cable and conduit when compared with the load circuits of a simple radial system. Third, the use of the loop gives lower system losses and greatly improved voltage conditions. The voltage regulation on a network system is such that both lights and power can be fed from the same load bus. Much larger motors can be started across the line than on a simple radial system. This factor often results in greatly simplified motor control and permits the use of relatively large low-voltage motors with their less expensive control.

The fourth important advantage resulting from the use of the secondary loop is the much greater system flexibility it provides. New or relocated loads can be supplied directly from the nearest load bus without the necessity of reconnecting other loads to keep within the transformer capacity of the secondary substation to which the load is to be added. Complete network power centers or load-bus units can be relocated in the loop, or new units can be added to the loop to meet changing load conditions. The loop capacity requires no change when additional network power centers are connected to it if each new transformer is of no larger rating than those originally used. The loop permits these system changes to be made without interrupting service to existing loads. This greater flexibility of the network system permits the system to be changed more easily, more quickly, and at less cost to meet changing load conditions that can be done with a radial system.

Since the length of the secondary loop (which is in essence an extended bus) is considerably longer than the buses used with the usual radial systems, the probability of faults on it is greater. It therefore becomes necessary to protect the system against faults on this bus or loop so that a fault on it will be automatically disconnected without interrupting service. To accomplish this, the secondary loop should consist of a minimum of two three-phase circuits. These separate circuits should be bused at each point where power is supplied to the loop through a transformer and at each point where a radial load circuit is supplied to the loop through a transformer and at each point where a radial load circuit is served from the loop. Each individual loop circuit should be connected to these bus points through limiters.

A limiter is a device for disconnecting a faulted cable from a distribution system and for protecting the unfaulted portions of that cable against serious thermal damage. Although fusible, they are rated by the size of the conductors they protect and not a specified current in amperes. They function by means of a circuit-opening member which is heated and
destroyed by the current passing through it. The fusible circuit-opening member is completely enclosed so that there is no visible flame or smoke when the limiter operates. Limiters for building networks are suitable for use on circuits of 600 V and below and have an interrupting rating of 200,000 A. Limiters are designed for use with various sizes of cable and are rated in cable size. The largest limiter is rated at 1000 kcmil. The minimum fusing current of a limiter is about 3 to 3 1/2 times the NEC continuous-current rating of the cable with which it is designed to be used. This value of fusing current is necessary to ensure positive selectivity among the limiters in the secondary loop. If limiters having appreciably lower values of fusing current were used, those on both the good conductors and the faulted conductor would function on the minimum definite time portion of other time-current curves for high fault currents. This means that not only the limiters in the faulted loop conductor but a number of those in the good conductors would blow almost instantly and in some cases cause unnecessary interruptions of service. In addition to preventing unnecessary limiter blowings, the high fusing-current value of limiters also has the advantage of keeping the normal temperature of the limiter terminals relatively low so that the associated cable can safely carry its rated current.

If loads are to be supplied from the secondary loop at points other than those at which the network transformers are connected to the loop, the current rating of the loop should be equal to the full-load current of one of the transformers supplying the loop. The current rating of the loop can be safely reduced to 67 percent of the above value if loads are supplied from the loop only at transformer locations. If more than 1 kVA rating of network transformer is used, the current rating of the loop should be based on the full-load current of the largest network transformer connected to the loop. When loads are served from the loop at points other than transformer locations, the maximum amount of load which should be supplied from the loop between any two adjacent transformers should not exceed the full-load rating of the larger of the two transformers.

To obtain satisfactory selectivity between limiters under all fault conditions, a minimum of two similar single-conductor cables per phase should be used in the secondary loop. The size and number of conductors used in any case should be selected to give the lowest installed loop cost. However, the conductors used should not be larger than about 600,000-cmilm cable.

Loads are served from the secondary loop at conveniently located load buses over relatively short radial circuits. These load circuits are taken off the load buses through air circuit breakers. The breakers should provide adequate overload protection for their associated circuits and should be capable of interrupting the fault current available at that point on the system. The average interrupting duty on the load breakers in a network system will often be higher than the duty on the load breakers in a radial system having the same connected transformer capacity.

The optimum size and number of primary feeders can be used in the secondary network system because the loss of any primary feeder and its associated transformers does not result in the loss of any loads. In spite of the spare capacity required in primary feeders, this will often result in a saving in primary-feeder and switchgear cost when compared with a radial system. This saving is due to the fact that in many radial systems more and smaller feeders are often used to keep down the extent of the outage when a primary-feeder fault occurs.

When a fault occurs on a primary feeder or in a transformer, the fault is isolated from the system through the automatic tripping of the primary feeder circuit breaker and all the network protectors associated with that feeder circuit. This operation does not interrupt service to any loads. When the necessary repairs have been made, the system is restored to normal operating conditions by closing the feeder circuit breaker. All network protectors associated with that feeder will close automatically.

The simple network system sometimes takes a form commonly known as a spot-network system. With this system, emergency capacity to prevent a service interruption
when a primary-feeder or transformer fault occurs is provided by making a spare primary cable and transformer available at each load center instead of tying the load areas together by a secondary loop, as in the usual simple network.

The simple spot-network system resembles the secondary-selective radial system in that each load area is supplied over two or more primary feeders through two or more transformers. In this system, however, the transformers are connected through network protectors to a single load bus, as shown in Fig. 9.327. Since the transformers at each load bus operate in parallel, a primary-feeder or transformer fault does not cause any service interruption. The transformers supplying each load bus will normally carry equal loads, whereas equal loading of the two transformers supplying a load center in the secondary-selective radial system is difficult to obtain. The interrupting duty imposed on the load circuit breakers will be greater with the simple spot-network system than with the secondary-selective radial system.

Simple spot-network systems are more economical than the other forms of network systems for buildings in which there are heavy concentrations of load covering small areas, with considerable distances between these concentrations and very little load in the areas between them. The chief disadvantage of spot-network systems is that they are not nearly so flexible for growing and shifting loads as are the other forms of network systems. Simple spot-network systems are used when a high degree of service continuity is required, flexibility is of minor importance, and their cost is less than that of the network systems using a secondary loop. The simple spot-network system is most economical when three or more primary feeders are required. This is true because supplying each load bus through three or more transformers greatly reduces the spare cable and transformer capacity that is required.

519. Primary-selective network. This is the most generally applicable and widely used form of industrial secondary network system. It is similar in principle to the simple network system, offers almost all its advantages, and is the lowest-cost network system for
buildings or load areas requiring only two or three primary feeders. Saving in first cost when compared with the simple network system is accomplished by using the principle of duplicate or alternate feed to each transformer, as with the primary-selective radial system. This procedure practically eliminates the necessity for spare transformer capacity and reduces the interrupting duty imposed on the load circuit breakers but not the spare primary-feeder capacity required.

Each transformer in the primary-selective network system is equipped with a primary selector switch. Two primary feeders are run to each transformer, as shown in Fig. 9.328. In a building requiring two primary feeders, each feeder must be capable of supplying the entire load in the building. Each transformer is connected to a load bus through a network protector. The radial circuits serving the loads are connected to the load bus through circuit breakers. A secondary loop, as is used in the banked-secondary radial and the simple network systems, connects each load bus to the two adjacent load buses. One-half of the network transformers are normally connected to each primary feeder.

A primary-feeder fault causes the faulty feeder and its transformers to be disconnected from the system by the automatic operation of the primary-feeder breaker and associated network protectors. The entire building load is then carried over the remaining primary feeder and one-half of the network transformers. The transformers associated with the faulty feeder can be connected to the good feeder by manually operating their selector switches. This relieves the overload on the transformers normally associated with the good feeder.

A transformer fault is isolated from the system by the operation of the primary-feeder breaker and the network protectors associated with the primary feeder. The defective transformer can be disconnected from the primary feeder by opening its selector switch. The feeder and its good transformers can be immediately returned to service. A primary-feeder or transformer fault will not cause any interruption of service to the load.
Cost of the primary-selective network system compares very favorably with that of the secondary-selective radial system. In buildings in which the load is quite uniform and there is little diversity among load centers, the secondary-selective radial system usually will be lower in initial investment than the network system. However, in buildings in which the load is nonuniform and there is appreciable diversity among load centers, the primary-selective network system often will be lower in first cost than the secondary-selective radial system.

It is a common practice to supply the radial circuits only from the load buses to which the network transformers are connected. At times a reduction in system cost can be made by serving loads from the loop at points between transformers. When this is done, the loop cables should preferably be paralleled and the loads taken off through load-bus units. Each load-bus unit should be similar to those used when network transformers connect to the loop; it consists of a load bus, two limiter buses with load-break switches and limiters, and load circuit breakers. Connecting loads to the secondary loop in this manner reduces the average length of the secondary load circuits.

By tapping all loads from the secondary loop at the nearest point, the amount of secondary load circuit conductors can be reduced to a minimum. This cannot be done practically when using a cable secondary loop if limiters are installed in the loop conductors at each load takeoff point. Such a form of network system is practical, however, if two or more parallel runs of plug-in bus duct are used for the secondary loop.

In this system, the transformers connect to a bus through network protectors, as in Fig. 9.328, except that there usually will be no load circuit breakers in the bus units. All loads usually are supplied through the load-break switches to the limiter buses and then through the limiters into the bus ducts that tie the adjacent bus units together.

This form of network system requires larger conductors in the secondary loop than those using the cable loop previously described. It also sacrifices something in service continuity when compared with network systems in which the loads are fed from load-bus units connected in a cable loop. This is true because a fault in a section of the bus-duct loop will cause an outage to the loads served from that section.

As with the simple network system, the primary-selective network may also take the form of a spot-network system. Each transformer in the primary-selective spot-network system is equipped with a primary selector switch and arranged for connection to either of two primary feeders, as shown in Fig. 9.329. This largely eliminates the necessity for spare transformer capacity, and the system is ordinarily designed without providing for such capacity.

Primary-feeder and transformer faults on this system are cleared without any interruption of service to the loads as in the simple spot-network system. When a primary feeder is deenergized because of a feeder fault, the transformers associated with the good feeder will carry as high as 160 to 200 percent of their rated kVA until the transformers normally associated with the defective feeder are switched to the good feeder by operation of their primary selector switches. After this switching operation has been completed, all the overloads on the system are relieved.

When a spot-network system of this design is used, a transformer failure requires a reduction in the load served from its load bus to prevent serious overloading of the remaining transformer connected to that bus. A transformer failure will occur so infrequently, however, that the cost of providing spare transformer capacity throughout the system cannot be justified to eliminate the remote probability of having to reduce load on one bus. If the possibility of having to reduce load is objectionable, it will cost less to use the simple spot-network system than to provide the necessary spare capacity in the primary-selective spot-network system. The primary-selective spot-network system, when designed without spare transformer capacity, will cost less than the simple spot-network system if two primary feeders and two transformers per load bus are used. If three or more primary feeders
are required, the simple spot-network system will be lower in cost than the primary-selective spot-network system.

520. Influence of buildings on design. Building distribution systems are too often selected on the basis of using the system having the lowest initial investment. This practice usually results in the installation of a system which is neither the best nor the most economical for the building when all the factors are considered and properly evaluated.

All the major characteristics of the different types of distribution systems should be evaluated in the light of the building load requirements, in order to select the best system. The six major characteristics are initial investment, flexibility, service continuity, voltage regulation, efficiency, and cost of operation and maintenance.

The best system is that which gives the greatest value per dollar of investment and provides adequate electric service. This is rarely the system with the lowest initial investment. Flexibility is the system’s ability to be adapted to changing load conditions with the minimum of service interruptions and minimum cost of necessary changes.

Service continuity is measured in terms of the amount of load dropped with faults at different locations in the system, taking into account the likelihood of faults in the various locations.

Under voltage regulation, the change in voltage with load variations, the uniformity of this change at the various load points throughout the system, and the change in voltage resulting from suddenly applied loads should be considered.

The overall efficiency of the system from the power supply point or points to the utilization devices should be taken into account for both light-load and heavy-load conditions of operation.

Operating and maintenance costs are influenced by the nature and amount of equipment in the system and the ability to inspect, test, and maintain the equipment with minimum interruption of service.
The general arrangement and choice of the type of system depend upon the type and purpose of the building. In this discussion buildings shall be considered as belonging to one of these five classifications:

1. Large vertical buildings less than about 12 stories high
2. Tall (high-rise) commercial buildings
3. Large horizontal buildings such as shopping centers and large one-floor offices
4. Groups of small buildings such as hospitals and educational institutions
5. Industrial plants

The quality of service required by the loads varies somewhat within each of these classifications, depending upon the purposes of the buildings and the activities carried on within them.

521. Large vertical buildings. Large vertical buildings, such as office buildings, stores, apartments, hospitals, and hotels, require a high quality of electric service because the operation of essential equipment in the buildings depends directly on a reliable supply of electric power. Network systems are recognized as the best means of assuring satisfactory electric service in large buildings. However, in some cases, such as warehouses, interruptions of service for inspection and maintenance or as a result of faults may not interfere with the function of the building or cause hazards. In these cases, simple radial, primary-selective radial, or secondary-selective radial systems are used, depending upon the extent and duration of interruptions that can be tolerated and the importance of small savings in initial cost.

The network system is generally accepted as the most desirable form of distribution system for large buildings because it is the most economical method of providing reliability and good voltage characteristics. It is essential to have these characteristics in the distribution system for most large buildings because the activities in the buildings usually depend on a continuous supply of electric power with good voltage characteristics. Reliability is important because a failure of power that may stop elevators, pumps, and ventilating systems not only halts the activities in the buildings but may endanger the occupants. Obviously, good voltage regulation is essential to obtain the most effective output from lamps and other utilization devices. Good voltage regulation becomes particularly important when the same system supplies both the lighting and the power loads.

The relatively high load demands in large buildings encourage the use of large undesirable concentrations of transformer capacity in secondary substations with the result that very high fault currents are available in many cases. This requires expensive switchgear equipment to give adequate protection to the system against all possible faults in low-voltage circuits within the system. The power supply in buildings should be carefully designed to limit the fault currents to reasonable values so that less expensive equipment can be used. Several small substations instead of a few big substations can be used to reduce interrupting duties.

The interrupting duty on the low-voltage breakers in the substations directly affects the cost of the distribution system. High-interrupting-capacity breakers are more expensive than low-interrupting-capacity breakers. In general, the cost of the distribution system will materially increase if the interrupting duty exceeds 50,000 A. Therefore, it is desirable to plan the distribution system so that the interrupting duty does not exceed this value. In buildings in which the total load is not more than a few hundred kVA, it is not difficult to keep the interrupting duty below this value, and frequently it is possible to limit the interrupting duty below this value, and frequently it is possible to limit the interrupting duty to 25,000 A. The difference in cost between a substation using 25,000-A breakers and one using 50,000-A breakers is a relatively small part of the total cost of the substation.
Therefore, it is not economical to make extensive special arrangements to reduce the interrupting duty when it is between 25,000 and 50,000 A. On the other hand, when it is necessary to install switchgear having an interrupting capacity higher than 50,000 A, the switchgear may become a large part of the total cost, and considerable expenditures to reduce the interrupting duty to 50,000 A may be justified. Relatively small substations distributed throughout the building generally mean that the low-voltage feeders will be short and that the voltage regulation will be better. Furthermore, the small substations can be installed in smaller spaces. Frequently, it will be easier to find several small spaces for substations than to find or provide one large space in the building for one substation. Another advantage of using a number of small substations is that it is easier to find space to carry the low-voltage feeder conduits away from the substation.

The form of the network system most frequently used in large buildings is the simple spot-network system. However, a simple network system having several interconnected secondary substations is used in some cases.

When the distribution system in a building is continuously supervised by capable operators, the total transformer capacity sometimes can be reduced by using high-voltage selector switches instead of disconnecting switches on the network transformers. When four or more primary feeders are available, it is generally as economical to use disconnect switches and provide the necessary reserve transformer capacity as to use the more expensive selector switches. Selector switches should not be used whenever it is likely that they may not be operated promptly in an emergency.

The distributed type of simple network system is primarily applicable to very large buildings in which the low-voltage feeders can be materially shorter with this type of network than if a spot network were used. In such applications, the extra cost of the secondary ties may be more than offset by savings in low-voltage feeder circuits because the substations are located closer to the load centers. This form of network system may also provide better voltage conditions at the load centers than could be provided by a spot network and relatively long low-voltage feeder circuits.

The spot network is particularly applicable to medium-size buildings having only a few floors. In these cases, the savings in low-voltage feeders that could be obtained by using two or more small substations in a distributed form of network usually do not justify the expense of the secondary ties and their protective equipment. The spot network, of course, gives the same degree of reliability as does the distributed form of network. Obviously, two or more spot networks can be used in larger buildings with the same resulting savings in low-voltage feeder circuits. However, this means that there would be a greater number of smaller transformers and a correspondingly greater number of network protectors. The smaller units generally have a higher cost per kVA than the larger units, so that a number of small spot networks may cost more than a distributed network in an extensive system.

522. **Tall buildings.** Tall buildings are generally built in the densely loaded areas of cities. Almost without exception, the loads in these areas are served by secondary network systems. This makes it practical and economical to use some form of network system in a tall building. The nature of such a building practically requires a network system. Access to the major part of the building is accomplished almost entirely by elevators. Hence, it is imperative that power be continuously available for the operation of the elevators to avoid the hazard of panic or serious inconvenience resulting from a power outage. Furthermore, fire protection, water supply, heating, and ventilating depend for their operation on the availability, at all times, of an electric power supply. These considerations practically limit the choice of a distribution system to some form of secondary network. Usually three or more primary feeders are available within the area to supply the building, so that either a simple spot-network system or a simple network system is feasible. Various arrangements
In most modern tall commercial buildings there is likely to be a large air-conditioning load. When this load and the other power loads such as elevators, ventilating and heating equipment, fire pumps, water pumps, and related auxiliaries are taken into account, the power demand is likely to be more than the lighting load and may be as much as 3 or 4 times the lighting load. This proportion of power and lighting loads should be considered in the choice of utilization voltage. The power load will usually be the principal factor in the choice of locations for the distribution equipment.

Generally speaking, the practical maximum height that 208Y/120-V circuits can be carried in a tall building is about 12 stories. This limitation depends to a considerable extent on the relative cost of space for the distribution equipment in various parts of the building. The limitation of about 12 stories is based on including in the cost of the distribution system a charge for all the space used above the basements equal to the value of the same amount of commercially usable space. On this basis there is a thumb rule that major distribution centers will occur about every 25 floors in a tall office building. This is a very general rule, and the locations of the elevator equipment and major air-conditioning loads and other power loads in the building may make other locations of the distribution equipment more economical. The locations of the secondary substations involved in the distribution system in the building should be very carefully considered. Some specific comparisons have indicated that a much closer spacing of the secondary substations than 25 stories is economical. A closer spacing of the units improves the voltage conditions within the building and reduces losses in the system.

The simplest form of network system for a tall building is the simple spot-network system. In this system, a spot-network substation comprising the necessary number of network transformers and the associated low-voltage switchgear equipment is located at or near the major loads in the building. Therefore, the spot-network substation in the basement is generally the biggest of the various secondary substations. The locations of the power loads in the basement area or a logical segregation of the load may make two or more spot-network substations feasible. In this form of the network system, several primary-feeder circuits are carried up through the building to the various spot-network substation locations where the corresponding network transformers are connected to the primary feeders.

In many locations where tall buildings are built, it is practical to operate the building distribution system as part of the low-voltage secondary network in the area around the building. This involves the use of a simple network system within the building with secondary-tie circuits between the various network substations and the secondary-main system in the area around the building. The ties between the secondary mains of the utility network system and the building distribution system permit interchange of power between the two systems. This augments the reliability of the network system within the building and to some extent may improve the voltage conditions within the building. Since the same primary feeders that supply the building may also supply network units in the area around the building, there is some advantage in interconnecting the two systems to make sure that all the network equipment functions in the same manner. The desirability of interconnecting the building network system with a surrounding local network system may offset some of the advantages of a 460-V system within the building. The network system in the area around the building will be a 208Y/120-V system in most cases.

The simple network system involves some variations of the secondary ties between the network substations within the building. In their simplest form, these ties are purely tie circuits and do not supply loads at any time except by interchange of power from one substation to another. When this form of secondary tie is used, it generally will have only about two-thirds as much carrying capacity as the rated current of the largest of the associated network transformers. This provides enough capacity to make up for the outage of one
transformer at one of the network substations. Generally, the carrying capacity of the tie circuits is practically independent of the number of network units at any load bus. The secondary ties between the building system and the surrounding network system usually have about the same capacity as the ties between network substations within the building.

The capacity of the secondary ties can be increased to provide for tapping loads directly from the secondary ties between network substations. Basically, such a tie can be treated in two general ways. One way is to form load buses at every point along the tie where loads are tapped, as indicated in Fig. 9.330. If this is done, the capacity of the tie circuit will depend on the amount of load tapped off the circuit and the size of the network units associated with the tie. The capacity should be enough to carry all the loads tapped from the circuit, from one end of the circuit, as well as a reasonable amount of

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**FIGURE 9.330** Three arrangements of secondary-tie circuits between network substations in tall commercial buildings.
power interchanged between the network substations. In a simple case in which single-transformer network substations are interconnected by a tie circuit of this type, the total capacity of the circuit should be about equal to the rated current of one of the associated network transformers.

If load buses are not established in the tie circuit and the loads are tapped from one or another of the parallel branches of the tie circuit, the total carrying capacity of the tie circuit should be correspondingly increased. The reason for this is that it is unlikely that the load can be equally divided among the parallel branches of the tie circuit. Even if an equal division of connected load were possible, the diversity among the loads would mean that the load on one branch would not always be the same as that on another. Therefore, in this type of circuit the total carrying capacity should be at least 1 1/3 times the rated current of one of the associated transformers when there is only one transformer in each of the interconnected network substations.

The forms of the secondary-tie circuit illustrated in Fig. 9.330 consider only the use of paralleled three-phase circuits to form the tie circuit. This is because practical and convenient sizes of conductors can be used and overcurrent protection for the circuits can be economically provided. It is possible, of course, to use a single conductor per phase, such as a heavy bus, to form the tie circuit. To get the necessary carrying capacity in this way is likely to be expensive, and providing overcurrent protection for such a circuit is expensive and requires heavy protective equipment.

Another form of tie circuit that has been used is a secondary bus running the full height of the building. This form of tie circuit in effect is an extended spot network with the spot-network bus extending from the basement of the building to the uppermost network unit. In this arrangement the load circuits at the various floors are connected directly to the riser bus through protective devices or through a switchboard connected to the riser bus through a suitable protective device. The major disadvantage of this arrangement is the length of the spot-network bus. It is necessary to install this bus in such a way that there is practically no possibility of a fault on it. This can be accomplished by segregating the phases by barriers between the buses. However, such an installation is expensive. The capacity of such a bus should be somewhat more than the total load connected to the bus between adjacent network transformers. Some excess above this total load value would be required for the interchange of power between network units when one of the primary-feeder circuits is out of service.

The distribution of power within a tall building necessarily involves the use of transformers within the building. It is very important to choose transformers that minimize the possibility of fire or other damage to the building or injury to people in the building resulting from a transformer failure. For this reason, ventilated or sealed dry-type transformers are used in buildings. These types of transformers eliminate the hazard of fire and explosion damage resulting from a transformer failure.

523. Large horizontal buildings. Under the classification of large horizontal buildings, probably the most important with respect to numbers, size, and magnitude of load are shopping centers.

Shopping centers may be classified into three types with regard to size. They are the neighborhood shopping center that is designed to serve 5000 to 20,000 people, the district shopping center that serves 20,000 to 100,000 people, and the regional shopping center that serves a market of over 100,000 people.

Shopping centers will usually take one of five general physical arrangements. The simplest type, usually associated with the neighborhood shopping center, is the strip layout. A common variation of this simple layout is the L-shape layout. The mall, the
court, and the ring are three layouts that are used mostly in the district shopping center. The fifth type, the group or cluster of buildings, is generally used for large regional shopping centers.

The physical layout of a shopping center will influence the design of the electric distribution system. For instance, a system utilizing a loop-secondary circuit can be used to advantage in the mall-, ring-, or group-type shopping centers but may not be economical for the strip or court arrangement. The large loads in a shopping center will usually dictate where the power-center transformers must be located. If power centers must be located at these large loads, the loads in between them may be served over radial circuits from the power centers. However, if the distance between the power centers becomes great, using a system that permits the tapping of services off a secondary circuit running between power centers would be advantageous.

The selection of the utilization voltage or voltages to be used in shopping centers should not be limited to the choice of 120/240 V single-phase, 480 V three-phase, or 208Y/120 V three-phase. The magnitude, locations, and characteristics of the loads in shopping centers make it appear that the use of a three-phase, four-wire, grounded-Y, 480Y/277-V system would prove to be more economical in many cases.

Table 524 compares the distribution systems discussed previously for several magnitudes of load in each of the five types of shopping centers. The comparisons are made on a column basis, and it is not intended that the ratings in different columns should be compared.

The ratings take into account initial investment, service continuity, flexibility to handle new or changing loads, operation and maintenance costs, voltage regulation, and efficiency. Each of these factors has been weighted in proportion to its relative importance for each load magnitude and type of shopping center. The A ratings indicate that analysis of the system has shown it to rate at the top of the 12 systems compared in each column. The other quality ratings are given in terms of percentage of value of the A system:

<table>
<thead>
<tr>
<th>Rating</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>81–90</td>
</tr>
<tr>
<td>C</td>
<td>71–80</td>
</tr>
<tr>
<td>D</td>
<td>61–70</td>
</tr>
<tr>
<td>E</td>
<td>51–60</td>
</tr>
<tr>
<td>F</td>
<td>41–50</td>
</tr>
</tbody>
</table>
### Comparison of Distribution Systems for Several Types of Shopping Centers

<table>
<thead>
<tr>
<th>Type of shopping center, loads in kVA</th>
<th>Strip or L Mall</th>
<th>Ring</th>
<th>Court</th>
<th>Mall</th>
<th>Group or cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>100–1,000</td>
<td>1,000–2,500</td>
<td>100–1,000</td>
<td>1,000–2,500</td>
<td>100–1,000</td>
<td>1,000–2,500</td>
</tr>
<tr>
<td>1,000–5,000</td>
<td>2,500 and up</td>
<td>1,000–5,000</td>
<td>2,500 and up</td>
<td>1,000–5,000</td>
<td>2,500 and up</td>
</tr>
</tbody>
</table>

#### Type of Distribution System
- **Conv. simple-radial**
- **Modern simple-radial**
- **Modified modern simple-radial**
- **Loop-primary radial**
- **Banked-secondary radial**
- **Primary-selective radial**
- **Secondary-selective radial**
- **Modified secondary-selective radial**
- **Simple network**
- **Primary-selective network**
- **Simple spot-network**
- **Primary-selective spot network**

#### Legend
- A
- B
- C
- D
- E
- F
525. **Methods of supplying power to individual motor loads.** The layout of the last stage of a motor distribution system will depend upon the type of building, construction characteristics of the building, motor size, types of motors to be served, and the flexibility desired in order to take care of changing location of loads. In one type of layout the branch circuit to each motor is run from a power panel. In another type the branch circuits to individual motors are tapped from a feeder. The features of the different types of motor distribution layouts are shown in Fig. 9.331.

The following discussion of the application of these methods is reproduced from *Electrical Systems Design*, by Joseph F. McPartland.

Miscellaneous motor loads in most commercial and institutional buildings and in many industrial buildings are usually circuited from power panels to which feeders deliver power. This type of distribution is a standard method of motor circuiting, generally limited to handling a number of motors of small integral-horsepower or fractional-horsepower sizes, located in a relatively small area such as a fan room or a pump room. The feeder to a power panel may be a riser in a multistory commercial or institutional building, run from a basement switchboard. In a one-level industrial area, the feeder to a power panel may be run from a main or load-center switchboard or from a load-center substation in a high-voltage distribution system. In commercial and industrial buildings, motor feeders may be run from a main switchboard or a load-center substation to a motor-control center serving a large group of motors in a machine room or in any compact area where the motors are relatively

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**FIGURE 9.331** Methods of power distribution to individual motors. *Electrical Systems Design*
close together and close to the control-center assembly. The motor-control center contains all the control, protection, and disconnecting means for the motor circuits supplied.

In industrial buildings, in which a large number of motors are used over a large area, distribution of power to the individual motor loads generally follows the method of tapping motor branch circuits from the feeder. Such circuits may be tapped in several ways, with various combinations of branch-circuit overcurrent protection and motor control and disconnect means. The feeder in such an arrangement may originate from a main switchboard or from a load-center substation. In multistory buildings, such as office buildings or institutions, taps to motor branch circuits on a particular floor may be taken from a subfeeder originating in a load-center switchboard which is fed by a riser from the main switchboard in the basement. The feeder-tap method of supplying motor branch circuits is, of course, the basis for plug-in busway distribution to spread-out motor loads. In the system, the plug-in busway may be a feeder or a subfeeder, depending upon its origin. From a main switchboard, it would be a feeder; from a load-center switchboard, it would be a subfeeder. However, from a load-center substation, the plug-in busway would be a feeder—a secondary feeder derived from the transformation down from the primary feeder to the substation.

526. Adequate wiring for lighting and convenience outlets in commercial, public, and industrial structures. It is very important in designing the interior wiring for a building to make adequate provision not only for present demands but also for probable future demands. The levels of illumination demanded by industry and commerce are being constantly increased. In order that a building may keep pace with this advancement without excessive expense in the reconstruction of its wiring, the wiring must be more than adequate to provide merely for present needs. Double carrying capacity can be provided in the original wiring installation for less than 25 percent additional cost. To provide a guide for adequate wiring, the following recommendations from the Handbook of Interior Wiring Design are given:

1. Outlet Location: Commercial and Public Occupancies
   a. Ceiling outlets for general illumination. Whenever possible, ceiling outlets should be uniformly spaced and located so that the spacing will be approximately the same in both directions. In offices and schoolrooms, the spacing between adjacent outlets shall not exceed the distance from floor to ceiling. In other interiors, the space may be extended to 1 3/4 times the ceiling height. The space between an outlet and a wall should not exceed one-half of the average distance between outlets. In halls and corridors, spacing should not exceed 20 ft (6.1 m).

   In locating outlets on any floor plan, construction features should be considered, especially ceiling beams. These are not always shown on the floor plans, yet they may seriously affect a lighting layout. This is particularly true for indirect lighting.

   b. Stores: convenience outlets. There shall be installed at least one convenience outlet for each 400 ft² (37.2 m²) of floor area or major part thereof; these outlets need to be uniformly distributed over the entire area. Preference shall be given to the placing of these outlets in supporting columns and sidewalls, but no part of the floor area shall be more than 15 ft (4.6 m) from an outlet.

   c. Stores: outlets for window illumination. Provision for show-window illumination shall be made by (1) a junction box on a wall or column at a suitable height above the transom bar or possible false ceiling to which all circuits of show-window reflectors or spotlights can be connected or (2) individual outlets spaced as recommended below. The NEC now requires receptacle outlets for every 3.7 linear m (12 linear ft) or major fraction of show window, located not more than 450 mm (18 in.) below the top.

   For medium-base lampholders, outlets for show-window reflectors should be located 12 to 18 in. (304.8 to 457.2 mm) apart. For mogul-base lampholders, outlets
for show-window reflectors should be located 15 to 24 in. (381 to 609.6 mm) apart; for fluorescent lamps, as required by the lighting layout. The specific layout is to be governed by the standard loads of Sec. 527. Whenever more than one circuit per window is necessary, adjacent outlets should be on different circuits.

For spot or floodlights, at least two outlets per window shall be symmetrically placed, with an additional outlet for every 8 ft (2.4 m) or major fraction in excess of 16 ft (4.9 m).

d. Stores: convenience outlets in show windows. In or near the floor of each window, there shall be installed at least one convenience outlet for each 50 ft² (4.6 m²) of platform or floor area used for window display, but in no case shall there be fewer than two convenience outlets per window.

e. Stores: outlets for case lighting. Outlets shall be provided in the floor or wall for termination of the circuits for showcase and wall-case lighting. Such outlets shall be suitably located for connection to the lighting equipment and shall be governed by the standard loads as listed in Table 527.

f. Offices and schools: convenience outlets. In each separate office room with 400 ft² (37.2 m²) or less of floor area, there shall be installed at least one convenience outlet for each 20 ft (6.1 m) of wall space. In each separate office with more than 400 ft² of floor area, there shall be installed at least four convenience outlets for the first 400 ft² of floor area and at least two outlets for each additional 400 ft² or major fraction thereof. Outlets should be placed at suitable locations to serve all parts of the office space. Certain offices, for example, professional and display offices, require many more outlets than are specified above, and the wiring needs must be individually studied if such probable occupancy is known.

For typical schoolrooms at least one convenience outlet shall be placed along the front wall and at least one along the rear wall.

g. Offices and stores: fans. Unless made unnecessary by provision for complete air conditioning, outlets for fans shall be installed on the basis of at least two for each 400 ft² (37.2 m²) or major portion thereof. Such outlets shall be placed approximately 7 ft (2.1 m) above the floor and shall be of a type from which the fan may be mechanically suspended.

h. Stores: signs. If no other equivalent provision is made for sign lighting, a rigid metal conduit or electrical metallic tubing, not smaller than 1 in., shall be run to the front face of the building for each intended or probable individual store occupancy. Such a raceway shall terminate outside the building at a point suitable for connection to the sign and shall terminate inside the building at a cabinet. Feeder capacity to this cabinet and service capacity shall be based upon a sign load of not less than 50 W/ft of store frontage, only the frontage on the principal street being considered if the store faces more than one street. Space provision shall be allowed for the connection and placement of a time switch to the sign circuit.

2. Outlet Location: Industrial Occupancies

a. Ceiling outlets for general illumination. The many special considerations of industrial lighting make it necessary to develop the outlet locations around the lighting layout. Local lighting units frequently supplement general illumination; special directional overhead sources are often necessary. In planning outlet locations, these must be considered as part of the complete installation. In halls and corridors lighted from a single row of outlets, the spacing between outlets shall not exceed 20 ft (6.1 m).

b. Convenience outlets. There should be at least one convenience outlet in each bay in both manufacturing and storage spaces.

3. Standard Loads for General Illumination The number of branch circuits and the capacities of the feeders and service shall be based upon the loads specified in Tables 527 and 528 as a minimum. If a known load that will exceed the loading here specified is to be supplied, the circuits, feeders, and service shall be based upon such known load.
The tabulated values represent the present acceptable standards of Illuminating Engineering Society foot-candle values. From these, the watts per square foot for each occupancy were determined by considering average conditions found in such occupancy, together with the accepted methods and equipment used in providing such illumination levels. In certain cases the standard loads include allowance for convenience outlets as well as for general illumination. The calculated wattage standards were based on the use of fluorescent and mercury-vapor equipment for large areas and incandescent equipment for local and supplementary lighting.

4. Branch Circuits* The minimum number of branch circuits shall be based on the present connected load as follows:
   a. For two-wire 15-A circuits, the load per circuit shall not exceed 1000 W.
   b. For multiwire 15-A circuits, the load shall not exceed 1000 W between each outside wire and the neutral.
   c. For circuits designed for heavy-duty lampholders, the load per circuit shall not exceed 1500 W for No. 10 wire, 2500 W for No. 8, and 3000 W for No. 6.

The following considerations of wire size and circuit runs shall apply:
   d. No wire smaller than No. 12 shall be used for any circuit.
   e. When the run from a panelboard to the first outlet of a lighting branch circuit exceeds 50 ft (15.2 m), the size of wire used shall be at least one size larger than that determined by any of the above considerations. The calculated size may be used between outlets.
   f. When the run from a panelboard to the first outlet of a convenience-outlet circuit exceeds 100 ft (30.5 m), No. 10 wire or larger shall be used for such run.
   g. No runs longer than 100 ft (30.5 m) between the panelboard and the first outlet of a lighting branch circuit shall be made unless the intended load is so small that the voltage drop can be restricted to 2 percent between the panelboard and any outlet on that circuit. To avoid this condition, panelboards should be relocated or additional panelboards installed.

The following considerations in regard to combinations of outlets shall apply:
   h. No convenience outlet shall be supplied by the same branch circuit that supplies ceiling or show-window lighting outlets.
   i. Outlets for show-window spotlights shall be on separate circuits from general show-window outlets.
   j. The number of convenience outlets included on one circuit shall be based on the listing in the following table.

<table>
<thead>
<tr>
<th>Outlets per Circuit</th>
<th>Maximum number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barbershops, beauty parlors, etc.</td>
<td>2</td>
</tr>
<tr>
<td>Medical, dental, and similar offices</td>
<td>2</td>
</tr>
<tr>
<td>Store show windows (for spotlights)</td>
<td>3</td>
</tr>
<tr>
<td>Store show windows (at floor)</td>
<td>6</td>
</tr>
<tr>
<td>Display areas in retail stores</td>
<td>6</td>
</tr>
<tr>
<td>School classrooms</td>
<td>6</td>
</tr>
<tr>
<td>Manufacturing spaces</td>
<td>6</td>
</tr>
<tr>
<td>Office spaces</td>
<td>8</td>
</tr>
<tr>
<td>Storage spaces</td>
<td>10</td>
</tr>
</tbody>
</table>

*These standards are based upon 15-A protection of branch circuits. If local regulations limit the load on branch circuits to less than these requirements, the wattage and area limits herein specified must be proportionately reduced.
5. **Circuit Control** Suitable provision shall be made for the control of all circuits except those supplying convenience outlets only, and control of the latter circuits is recommended. Circuits may be controlled individually, in groups, or by a combination of both methods.

In a retail store, individual control at the panelboards by means of circuit switches or circuit breakers is usually preferable. In most other occupancies, control should be provided by means of local switches or circuit breakers. Frequently it is necessary to provide two or more switches for the local control of outlets supplied by a single branch circuit.

Provision shall be made for control of all circuits supplying a single sign by means of an external manually operable switch or circuit breaker, and in each case a suitable time switch shall also be provided to effect the same control.

In a retail store, each circuit supplying outlets in one or more show windows shall be individually controlled, and provision shall be made for the installation of a time switch for group control of all such circuits.

Group control of circuits for general illumination or for special decorative effects, by means of remote-control switches, is desirable in certain large spaces such as large offices, large reading rooms, museums, art galleries, and ballrooms.

6. **Panelboards** The number and location of panelboards shall be based on the number of branch circuits and the distance or runs as specified in Par. 4 of these adequacy standards.

On each panelboard one spare circuit shall be provided for each five circuits utilized in the initial installation. When flush-type cabinets are used, provision shall be made for bringing a corresponding number of circuit conductors to the ceiling of the story served, the ceiling of the story immediately below, or both points. Such provision may consist of circuit conductors or of empty raceways terminating in boxes suitably located for future extensions.

Provision shall be made for control of show-window lighting by such grouping of circuits to a panelboard as to enable a time switch to be suitably installed.

7. **Feeders**
   a. **Carrying capacity.** The carrying capacity of each feeder or subfeeder shall be based on the number of separate circuits which it supplies, computed as follows:
      (1) *Overhead lighting circuits.* These are assumed as having 1000 W for each 15-A circuit and 1500 W for each 20-A circuit.
      (2) *Convenience-outlet circuits.* The assumed load is 1000 W per circuit.
      (3) *Spare panelboard circuits.* The assumed load is 500 W.
      (4) *Nonitemized and heavy-duty additional circuits.* The capacity is based on the specific load for which they are designed.

To the total of these four, such demand factors as permitted by the NEC may be applied. Refer to Div. 3 for additional information.

b. **Provision for the future.** In all determinations of feeder size, consideration should be given to increasing the capacity of the initial system by 50 percent to provide for future growth at a minimum of unwarranted expense. If an ultimate feeder size does not exceed No. 4 wire, the excess capacity should be installed immediately. In other cases, one of the following methods should be made a part of the original layout:
   (1) The installation of oversize raceways, so that the conductors installed can be withdrawn at any time and replaced by conductors of a suitable larger size.
   (2) The installation or arrangement of the installed equipment so that additional feeders can be installed later at minimum expense to furnish the ultimate capacity.
   (3) The installation of feeders of excess size.
c. **Voltage drop.** Feeder and subfeeders shall be of such size that the total voltage drop from any panelboard to the point where connection is made to the lines of the utility supplying services shall not exceed 1 percent (see Div. 3 for method of calculation). To compute such a drop, the ultimate demand as calculated above shall be used whenever the wire size based on such demand is installed immediately. If provision for the future is made in some other way (oversize raceways, etc.), the voltage drop shall be computed on the basis of the carrying capacity of the wire used.

8. **Feeder Distribution Center** A feeder distribution center in the form of a panelboard, switchboard, or group of enclosed switches or circuit breakers shall be provided for the control and protection of each feeder.

   Except when oversize feeders are provided in the original installation as recommended in the preceding section, provision shall be made at the feeder distribution center for the connection and suitable protection of feeders of increased size or of supplemental feeders. This can be accomplished by providing additional protective devices as part of the original installation, or by so designing the original equipment that space, bus capacity, and facilities for making connections will be available.

9. **Service-Entrance Adequacy Standards (75°C Rated Copper Conductors)**

   | Initial load, A | Service switch, A | Initial load, A | Service switch, A | Conductor size, gage No. or cir mils
---|---|---|---|---|---
1–23 | 60 | 8 | 118–133 | 200 | 4/0
24–33 | 60 | 6 | 134–150 | 400 | 4/0
34–47 | 100 | 4 | | | |
48–60 | 100 | 2 | 151–167 | 400 | 250,000
61–67 | 100 | 1 | 168–183 | 400 | 300,000
| | | 184–200 | 400 | 350,000
68–83 | 200 | 1/0 | 201–217 | 400 | 400,000
84–100 | 200 | 2/0 | 218–267 | 400 | 500,000
101–117 | 200 | 3/0 | | | |

10. **Service Conductors and Equipment** The minimum capacity of the service required for the initial load depends on the total number of feeders supplied by it, whose individual loads are determined as specified in Par. 7. When applicable, demand factors as permitted by the NEC may be used (see Sec. 44 of Div. 3). To determine the probable required ultimate capacity of the service conductors and equipment, 50 percent should be added to the calculated initial load.

   When the calculated initial load does not exceed 267 A, service conductors and equipment having the capacity needed for the ultimate load should be included as part of the original installation. The recommended equipment for various initial loads is tabulated in Par. 9. When the initial load exceeds 267 A, a study should be made of each individual case to determine what provision should be made for a future increase in the load.
These values should be understood in terms of relative load densities and not absolute design criteria. Current building codes generally impose energy conservation standards that substantially reduce these numbers in absolute terms.

### 527. **Standard Loads for Lighting in Commercial Buildings**

<table>
<thead>
<tr>
<th>Occupancy</th>
<th>VA/sq-ft</th>
<th>Occupancy</th>
<th>VA/sq-ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armories: drill sheds and exhibition halls. (This does not include lighting circuits for demonstration booths, special exhibit spaces, etc.)</td>
<td></td>
<td>Looker rooms</td>
<td>2</td>
</tr>
<tr>
<td>Art galleries:</td>
<td></td>
<td>Fencing, boxing, etc.</td>
<td>5</td>
</tr>
<tr>
<td>General</td>
<td></td>
<td>Handball, squash, etc.</td>
<td>5</td>
</tr>
<tr>
<td>On paintings—50 W per running foot of usable wall area</td>
<td>5</td>
<td>Halls and interior passageways—20 W per running foot</td>
<td></td>
</tr>
<tr>
<td>Auditoriums</td>
<td>4</td>
<td>Hospitals:</td>
<td></td>
</tr>
<tr>
<td>Automobile showrooms</td>
<td>6</td>
<td>Lobby, reception room</td>
<td>3</td>
</tr>
<tr>
<td>Banks:</td>
<td></td>
<td>Corridors—20 W per running foot</td>
<td></td>
</tr>
<tr>
<td>Lobby</td>
<td>4</td>
<td>Wards, including allowance for convenience outlets for local illumination</td>
<td>3</td>
</tr>
<tr>
<td>Counters—50 W per running foot including service for signs and small motor applications, etc.</td>
<td></td>
<td>Private rooms, including allowance for convenience outlets for local illumination</td>
<td>5</td>
</tr>
<tr>
<td>Offices and cages</td>
<td>5</td>
<td>Operating room</td>
<td>5</td>
</tr>
<tr>
<td>Barber shop and beauty parlors. (This does not include circuits for special equipment.)</td>
<td></td>
<td>Operating tables or chairs:</td>
<td></td>
</tr>
<tr>
<td>Billiards:</td>
<td></td>
<td>Major surgeries—3,000 W per area</td>
<td></td>
</tr>
<tr>
<td>General</td>
<td>3</td>
<td>Minor surgeries—1,500 W per area</td>
<td></td>
</tr>
<tr>
<td>Tables—450 W per table</td>
<td></td>
<td>This and the above figure include allowance for directional control.</td>
<td></td>
</tr>
<tr>
<td>Bowling</td>
<td></td>
<td>Special wiring for emergency systems must also be considered.</td>
<td></td>
</tr>
<tr>
<td>Alley runway and seats</td>
<td>5</td>
<td>Laboratories</td>
<td>5</td>
</tr>
<tr>
<td>Pins—300 W per set of pins</td>
<td></td>
<td>Lobby, not including provision for conventions, exhibits</td>
<td>5</td>
</tr>
<tr>
<td>Churches:</td>
<td></td>
<td>Dining room</td>
<td>5</td>
</tr>
<tr>
<td>Auditoriums</td>
<td>2</td>
<td>Kitchen</td>
<td>4</td>
</tr>
<tr>
<td>Sunday-school rooms</td>
<td>5</td>
<td>Bedrooms, including allowance for convenience outlets</td>
<td>5</td>
</tr>
<tr>
<td>Pulpit or rostrum</td>
<td>5</td>
<td>Corridors—20 W per running foot</td>
<td></td>
</tr>
<tr>
<td>Club rooms:</td>
<td></td>
<td>Writing room, including allowance for convenience outlets</td>
<td>3</td>
</tr>
<tr>
<td>Lounge</td>
<td>2</td>
<td>Library</td>
<td>5</td>
</tr>
<tr>
<td>Reading rooms</td>
<td>5</td>
<td>Reading rooms. This includes allowance for convenience outlets.</td>
<td></td>
</tr>
<tr>
<td>The above two uses are so often combined that the higher figure is advisable. It includes provision for convenience outlets.</td>
<td></td>
<td>Stack room—12 W per running foot of facing stacks</td>
<td>6</td>
</tr>
<tr>
<td>Courtrooms</td>
<td>5</td>
<td>Motion-picture houses and theaters:</td>
<td></td>
</tr>
<tr>
<td>Dance halls (No allowance has been included for spectacular lighting, spots etc.)</td>
<td>2</td>
<td>Auditoriums</td>
<td>2</td>
</tr>
<tr>
<td>Drafting rooms</td>
<td>7</td>
<td>Foyer</td>
<td>3</td>
</tr>
<tr>
<td>Fire-engine houses</td>
<td>2</td>
<td>Lobby</td>
<td></td>
</tr>
<tr>
<td>Gymnasiums:</td>
<td></td>
<td>(Continued)</td>
<td></td>
</tr>
<tr>
<td>Main floor</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shower rooms</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
527. Standard Loads for Lighting in Commercial Buildings (Continued)

<table>
<thead>
<tr>
<th>Occupancy</th>
<th>VA/sq-ft</th>
<th>Occupancy</th>
<th>VA/sq-ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Museums:</td>
<td></td>
<td>Schools:</td>
<td>3</td>
</tr>
<tr>
<td>General</td>
<td></td>
<td>Auditoriums</td>
<td></td>
</tr>
<tr>
<td>Special exhibits—supplementary lighting</td>
<td>2</td>
<td>If to be used as a study hall— 5 W/sq-ft</td>
<td></td>
</tr>
<tr>
<td>Office buildings:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private offices, no close work</td>
<td>5</td>
<td>Class and study rooms</td>
<td>3</td>
</tr>
<tr>
<td>Private offices, with close work</td>
<td></td>
<td>Drawing room</td>
<td></td>
</tr>
<tr>
<td>General offices, no close work</td>
<td>5</td>
<td>Laboratories</td>
<td>5</td>
</tr>
<tr>
<td>General offices, with close work</td>
<td>7</td>
<td>Manual training</td>
<td>7</td>
</tr>
<tr>
<td>File room, vault, etc.</td>
<td>5</td>
<td>Sewing room</td>
<td>5</td>
</tr>
<tr>
<td>Reception room</td>
<td>7</td>
<td>Sight-saving classes</td>
<td>5</td>
</tr>
<tr>
<td>Post office:</td>
<td>3</td>
<td>Showcases—25 W per running foot</td>
<td>7</td>
</tr>
<tr>
<td>Lobby</td>
<td>2</td>
<td>Large cities:*</td>
<td></td>
</tr>
<tr>
<td>Sorting, mailing, etc.</td>
<td></td>
<td>Brightly lighted district—700 W per running foot of glass</td>
<td></td>
</tr>
<tr>
<td>Sorting, file room etc.</td>
<td>3</td>
<td>Secondary business locations— 500 W per running foot of glass</td>
<td></td>
</tr>
<tr>
<td>Professional offices:</td>
<td>3</td>
<td>Neighborhood stores—250 W per running foot of glass</td>
<td></td>
</tr>
<tr>
<td>Waiting rooms</td>
<td>3</td>
<td>Neighborhood stores—250 W per running foot of glass</td>
<td></td>
</tr>
<tr>
<td>Consultation rooms</td>
<td></td>
<td>Small cities:*</td>
<td></td>
</tr>
<tr>
<td>Operation offices</td>
<td>3</td>
<td>Medium cities:*</td>
<td></td>
</tr>
<tr>
<td>Dental chairs—600 W per chair</td>
<td>5</td>
<td>Brightly lighted district—500 W per running foot of glass</td>
<td></td>
</tr>
<tr>
<td>Railway:</td>
<td>7</td>
<td>Secondary business locations—250 W per running foot of glass</td>
<td></td>
</tr>
<tr>
<td>Depot-waiting room</td>
<td></td>
<td>Neighborhood stores—250 W per running foot of glass</td>
<td></td>
</tr>
<tr>
<td>Ticket offices—general</td>
<td></td>
<td>Small cities and towns—300 W per running foot of glass</td>
<td></td>
</tr>
<tr>
<td>On counters 50 W per running foot</td>
<td>3</td>
<td>Lighting to reduce daylight</td>
<td></td>
</tr>
<tr>
<td>Rest room, smoking room</td>
<td></td>
<td>Window reflections—1,000 W</td>
<td></td>
</tr>
<tr>
<td>Baggage, checking office</td>
<td>5</td>
<td>per running foot of glass</td>
<td></td>
</tr>
<tr>
<td>Baggage storage</td>
<td>3</td>
<td>per running foot of glass</td>
<td></td>
</tr>
<tr>
<td>Concourse</td>
<td>3</td>
<td>per running foot of glass</td>
<td></td>
</tr>
<tr>
<td>Train platform</td>
<td>2</td>
<td>per running foot of glass</td>
<td></td>
</tr>
<tr>
<td>Restaurants, lunchrooms, and cafeterias:</td>
<td>2</td>
<td>Stores, large department, and specialty:</td>
<td></td>
</tr>
<tr>
<td>Dining areas</td>
<td>2</td>
<td>Main floor</td>
<td>6</td>
</tr>
<tr>
<td>Food displays—50 W per running foot of counter (including service aide)</td>
<td>6</td>
<td>Other floors</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stores in outlying districts</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wall oases—25 W per running foot</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE** Figures based on use of fluorescent equipment for large-area application, incandescent for local or supplementary lighting.

*Wattages shown are for white light with incandescent filament lamps. Where color is to be used, wattages should be doubled.
### 528. Standard Loads for General Lighting in Industrial Occupancies

(Refer to the note in Table 527, which also applies to these values.)

<table>
<thead>
<tr>
<th>Occupancy</th>
<th>VA/sq-ft</th>
<th>Occupancy</th>
<th>VA/sq-ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aisles, stairways, passageways 10 W per running foot</td>
<td></td>
<td>Foundries:</td>
<td></td>
</tr>
<tr>
<td>Assembly:</td>
<td></td>
<td>Charging floor, tumbling, cleaning, pouring, shaking out</td>
<td>2.0</td>
</tr>
<tr>
<td>Rough</td>
<td>3.0</td>
<td>Roug... molding and core making</td>
<td>2.0</td>
</tr>
<tr>
<td>Medium</td>
<td>4.5</td>
<td>Fine molding and core making</td>
<td>4.0</td>
</tr>
<tr>
<td>Fine</td>
<td>*4.5</td>
<td>Garages:</td>
<td></td>
</tr>
<tr>
<td>Extra fine</td>
<td>*4.5</td>
<td>Storage</td>
<td>2.0</td>
</tr>
<tr>
<td>Automobile manufacturing:</td>
<td></td>
<td>Repair and washing</td>
<td>*3.0</td>
</tr>
<tr>
<td>Assembly line</td>
<td>*4.5</td>
<td>Glassworks:</td>
<td></td>
</tr>
<tr>
<td>Frame assembly</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body assembly</td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body finishing and inspecting</td>
<td>*4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bakeries</td>
<td>4.0</td>
<td>Fine grinding, polishing, beveling, etching, inspecting, etc.</td>
<td>*4.5</td>
</tr>
<tr>
<td>Book binding:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Folding, assembling, pasting</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cutting, punching, stitching, embossing</td>
<td>4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breweries:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brewhouse</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiling, leg washing, etc.</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottling</td>
<td>4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Candy making</td>
<td>4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canning and preserving</td>
<td>4.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical works:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand furnaces, stationary driers, and crystallizers</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical driers and crystallizers, filtrations, evaporators, bleaching</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tanks for cooking, extractors, percolators, nitrators, electrolytic cells</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay products and cements:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grinding, filter presses, kiln rooms</td>
<td>2.0</td>
<td>Light</td>
<td>2.0</td>
</tr>
<tr>
<td>Moldings, pressing, cleaning, trimming</td>
<td>2.0</td>
<td>Dark</td>
<td>4.5</td>
</tr>
<tr>
<td>Enameling</td>
<td>3.0</td>
<td>Forming, sizing, pouncing, flanging, finishing, and ironing:</td>
<td></td>
</tr>
<tr>
<td>Glazing</td>
<td>4.0</td>
<td>Light</td>
<td>3.0</td>
</tr>
<tr>
<td>Ice making, engine, and compressor room</td>
<td></td>
<td>Dark</td>
<td>6.0</td>
</tr>
<tr>
<td>Cloth products:</td>
<td></td>
<td>Sewing:</td>
<td></td>
</tr>
<tr>
<td>Cutting, inspecting, sewing:</td>
<td></td>
<td>Light</td>
<td>4.5</td>
</tr>
<tr>
<td>Light goods</td>
<td>4.5</td>
<td>Dark</td>
<td>*4.5</td>
</tr>
<tr>
<td>Dark goods</td>
<td>*4.5</td>
<td>Leather manufacturing:</td>
<td></td>
</tr>
<tr>
<td>Pressing, cloth treating (oil cloth, etc.):</td>
<td></td>
<td>Rouch</td>
<td>3.0</td>
</tr>
<tr>
<td>Light goods</td>
<td>3.0</td>
<td>Fine</td>
<td>*4.5</td>
</tr>
<tr>
<td>Dark goods</td>
<td>6.0</td>
<td>Extra fine</td>
<td>*4.5</td>
</tr>
<tr>
<td>Coal breaking, washing, screening</td>
<td>2.0</td>
<td>Vats</td>
<td>2.0</td>
</tr>
<tr>
<td>Dairy products</td>
<td>4.0</td>
<td>Cleaning, tanning, and stretching</td>
<td>2.0</td>
</tr>
<tr>
<td>Engraving</td>
<td>*4.5</td>
<td>Cutting, fleshing, and stuffing</td>
<td>3.0</td>
</tr>
<tr>
<td>Forge shops, welding</td>
<td>2.0</td>
<td>Finishing and scarfing</td>
<td>4.5</td>
</tr>
</tbody>
</table>

(Continued)
### 528. Standard Loads for General Lighting in Industrial Occupancies (Continued)

<table>
<thead>
<tr>
<th>Occupancy</th>
<th>VA/sq-ft</th>
<th>Occupancy</th>
<th>VA/sq-ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plating</td>
<td>2.0</td>
<td>Polishing and burnishing</td>
<td>3.0</td>
</tr>
<tr>
<td>Power plants, engine rooms, boilers: Boilers, coal and ash handling, storage-battery rooms</td>
<td>2.0</td>
<td>Auxiliary equipment, oil switches, and transformers</td>
<td>2.0</td>
</tr>
<tr>
<td>Switchboard, engines, generators, blowers, compressors</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Printing industries: Matrixing and casting</td>
<td>2.0</td>
<td>Miscellaneous machines</td>
<td>3.0</td>
</tr>
<tr>
<td>Presses and electrotyping</td>
<td>4.5</td>
<td>Lithographing</td>
<td>*4.5</td>
</tr>
<tr>
<td>Linotype, monotype, typesetting, imposing stone, engraving</td>
<td>*4.5</td>
<td>Proofreading</td>
<td>*4.5</td>
</tr>
<tr>
<td>Receiving and shipping</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rubber manufacturing and products: Calendars, compounding mills, fabric preparation, stock cutting, tubing machines, solid tire operations, mechanical goods, building, vulcanizing</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bead building, pneumatic-tire building and finishing, inner-tube operation, mechanical-goods trimming, treading</td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheet-metal works: Miscellaneous machines, ordinary bench work</td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Punches, presses, shears, stamps, welders, spinning, medium bench-work</td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspecting and sorting raw material, cutting, and stitching: Light</td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dark</td>
<td>*4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lasting and welting</td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soap manufacturing: Kettle houses, cutting, soap chip, and powder</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stamping, wrapping and packing, filling and packing soap powder</td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Steel and iron mills: bar, sheet, and wire products:
- Soaking pits and reheating furnaces: 2.0
- Charging and casting floors: 2.0
- Muck and heavy rolling, shearing (rough by gage), pickling, and cleaning: 2.0
- Plate inspection, chipping: *4.5
- Automatic machines, light and cold rolling, wire drawing, shearing (fine by line): 4.5

Stone crushing and screening:
- Belt-conveyor tubes, main-line shafting spaces, chute rooms, inside of bins: 2.0
- Primary breaker room, auxiliary breakers under bins: 2.0
- Screens: 3.0

Storage-battery manufacturing, molding of grids: 3.0

Store- and stock rooms:
- Rough bulky material: 2.0
- Medium or fine material requiring care: 3.0
- Structural-steel fabrication: 3.0
- Sugar grading: 5.0

Testing:
- Rough: 3.0
- Fine: 4.5
- Extra-fine instruments, scales, etc.: *4.5

Textile mills:
- Cotton:
  - Opening and lapping, carding, drawing roving, dyeing: 3.0
  - Spooling, spinning, drawing, warping, weaving, quilling, inspecting, knitting, slashing (over beam end): 4.5

<table>
<thead>
<tr>
<th>Occupancy</th>
<th>VA/sq-ft</th>
<th>Occupancy</th>
<th>VA/sq-ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silk:</td>
<td></td>
<td>Winding, throwing, dyeing</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quilling, warping, weaving,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>finishing:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Light goods</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dark goods</td>
<td>6.0</td>
</tr>
<tr>
<td>Woolen:</td>
<td>*4.5</td>
<td>Carding, picking, washing, combing</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Twisting, dyeing</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drawing-in, warping:</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Light goods</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weaving:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Light goods</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dark goods</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knitting machines</td>
<td>4.5</td>
</tr>
<tr>
<td>Tobacco products:</td>
<td></td>
<td>Drying, stripping, general</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grading and sorting</td>
<td>*4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Toilet and washrooms</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upholstering, automobile, coach, furniture</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Warehouse</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Woodworking:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rough sawing and bench work</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sizing, planing, rough sanding, medium machine and</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>bench-work, gluing, veneering, cooperage</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine bench- and machine work, fine sanding, and finishing</td>
<td>6.0</td>
</tr>
</tbody>
</table>

The figures given in this table are average design loads for general lighting. In those cases marked with an asterisk (*), the load values provide only for large-area lighting applications. Local lighting must then be provided as an additional load.

The figures given are based on the use of fluorescent and mercury-vapor equipment of standard design. Adjustments can be made for use of higher or lower efficiency equipment. For equal lighting intensities from incandescent units, the figures must be at least doubled.

Use of these figures in computing number and loading of circuits and feeders should always be checked against the conditions and requirements of the particular area. The figures are not substitutes for lighting design.

In any case, need for particular color quality of light, special intensities, or control of light must be determined as part of the lighting design, and wattages and circuit requirements must be provided accordingly.
529. **Allowance for growth in feeders** *(Electrical Systems Design)* should begin with the spare capacity designed into the branch circuits. For all circuits loaded to 50 percent of capacity, it can be assumed that there is an allowance for growth of each circuit load by an amount equal to 30 percent of the circuit capacity. This allowance is based on Code limitation of 80 percent load on circuits which are in operation for 3 hours or longer or on circuits which supply motor-operated appliances in addition to other appliances and/or lighting. The 30 percent growth allowance in each circuit should be converted to a total watts figure and added to the total load on the feeder as calculated above. This grand total then represents the required feeder capacity to handle the full circuit load on the panelboard. The next step is to provide capacity in the feeder for anticipated load growth (plus some amount for possible unforeseen future requirements).

From experience, modern design practice dictates the sizing of feeders to allow an increase of at least 50 percent in load on a feeder when analysis reveals any load-growth possibilities. Such an analysis depends upon the type of building, the work performed, the plans or expectations of management with respect to expansion of facilities or growth of business, the type of distribution system used, locations of centers of loads, permanence of various load conditions, and particular economic conditions. Depending upon a thorough study of all these factors, the advisability of spare capacity can be determined for each feeder in a distribution system. But if study demands extra capacity in a feeder, substantial growth allowance (50 percent) is generally essential to realize the sought-after economy of future electrical expansion. Skimpy upsizing of feeder conductors or raceways has proved a major shortcoming of past electrical design work. This is particularly true in tall office buildings, apartment houses, and other commercial buildings in which the elimination of riser bottlenecks represents a large part of the total modernization cost.

Spare capacity in feeders may be provided in one or more of several ways. If the anticipated increase in feeder load is to be made in the near future, the extra capacity should usually be included in the conductor size and installed as part of the initial electrical system. In many small office or commercial buildings and apartment houses, extra capacity should automatically be included in the initial size of the feeder conductors, provided the size is not greater than No. 2 after adding the 50 percent of extra capacity. Other methods of providing for growth in feeder load are as follows:

1. **Selection of raceways larger than required by the initial size and number of feeder conductors.** With this provision, the conductors can be replaced with larger sizes if required at a later date. The advisability of this step should be carefully determined in the case of risers or underground or concealed feeder raceway runs. In some cases, a compromise can be made between providing spare capacity in the feeder conductor size and upsizing the feeder raceway.

2. **Including spare raceways in which conductors can be installed at a later date to obtain capacity for load growth.** Such arrangements of multiple raceways must be carefully laid out and related to the existing overall system. The types of feeder-distribution centers or main switchboards and the layouts of local branch-circuit panelboards must be able to accommodate future expansion of distribution capacity based on the use of spare raceways, with modification and regrouping of feeder loads.

530. **Control of groups of receivers (other than hall or night lights) from the main switchboard.** If it is desirable to control a group of receivers from the main switchboard in the basement, a separate feeder must be carried from it to each group to be so controlled. Usually the feeder system can be laid out without regard to the control of the room lights, because, as a rule, they need not be controlled from the switchboard. It is usually advisable to have each of the lower floors, up to and including the ground floor, on a separate switch, as these floors often require light when the others do not. Special lighting
appliances such as sign, clock-dial, and outside dome lights require separate feeders from the switchboard, because they are turned on and off at set times from the switchboard. Certain motors may require similar control. In hotels the feeder switches are never opened except in case of accident, so from a control standpoint only it is not necessary to subdivide hotel feeders. When tenants of portions of buildings pay for the light they use, it is often desirable to carry a separate feeder from the switchboard to each tenant’s suite so that all meters can be located together at the switchboard. Suites can be metered separately by cutting meters in the mains at the suites, but this may be undesirable.

531. The control of hall lights from the main switchboard is an important consideration. In private dwellings it does not usually pay to install a separate feeder for the hall lights, and it may not be necessary in a hotel, where attendants are constantly passing in the halls. In a majority of public buildings, however, separate control of the hall lights is very desirable, if not necessary. The usual problem, then, is whether there shall be one or two sets of hall-light feeders. With two sets of feeders for hall lights, local switches can be eliminated and control effected entirely from the main switchboard. Two sets of hall feeders increase the cost of installation, but the saving in energy usually justifies them. By arranging two sets of feeders, one set serving, say, one-third of the hall lights and the other the remaining two-thirds, the smaller group can be used for dark days and for an all-night circuit, and a saving in energy will result. When there are two sets of hall lights thus controlled, the wiring of outlets should be such that there will be a uniform distribution of light whichever set is lighted. When tenants pay for the energy used in their suites, a separate feeder for the hall lights is indispensable.

FARM WIRING

532. Wiring. The use of electric power on the farm is continually increasing. So that the farm electrical system may be adequate and give the best results in expenditure of money and satisfactory service, it is essential that the system be properly and wisely planned, that good materials and equipment be employed throughout, and that good workmanship be employed in its installation. In most cases the best installation will be achieved by the use of a power pole, as shown in Fig. 9.332. The power pole will be the central distribution point of the electrical system, which is why the NEC defines it as the “distribution point” and it will be so described in the remainder of this discussion. The power company will run its supply lines from its main pole line to the distribution point of the farm and down the pole to its meter. From the distribution point, the consumer will distribute the electric power by overhead or underground lines to the different buildings. In rare instances, it may not be possible to erect a distribution point. In such cases the power lines from the public utility will terminate at a building, probably the farmhouse. The meter will then be installed at this point. This method introduces some complications and is recommended only when the erection of the distribution point is very difficult or impossible.

The first step in planning the farm electric system is to determine the power demands for each building. The diversity of farm work makes it impossible to set down definite load requirements to fit all farms. Every kind of farming has its own needs insofar as power, machinery, and appliances are concerned. However, a number of wiring requirements are fundamental to the various farm buildings. No matter where the farm is located or how the buildings are constructed, certain minimum standards of wiring must be followed to obtain satisfactory electrical service. The following sections specify proper wiring for average conditions. They take into consideration the correct number of outlets, the proper switching, modern lighting, and adequate wire sizes for the machinery and appliances that are normally used in specific farm buildings. They are intended as a basic guide. If more equipment is to
be installed than is included in these specifications or if the farming operations are of a special nature, the specifications must be varied to suit the special needs.

### 533. Typical Computed Loads and Probable Maximum Demands

<table>
<thead>
<tr>
<th>Building</th>
<th>Computed load</th>
<th>Probable demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm residence</td>
<td>19 kW</td>
<td>13 kW</td>
</tr>
<tr>
<td>Dairy barn, medium rice, including milk house and one 5-hp motor</td>
<td>20 kW</td>
<td>12 kW</td>
</tr>
<tr>
<td>Dairy barn, large size, including milk house and one 7½-hp motor</td>
<td>27 kW</td>
<td>15 kW</td>
</tr>
<tr>
<td>Same, two 7½-hp motors</td>
<td>36 kW</td>
<td>24 kW</td>
</tr>
<tr>
<td>Milk house barn with milk house</td>
<td>7.5 kW</td>
<td>5.8 kW</td>
</tr>
<tr>
<td>Milk house only</td>
<td>6.0 kW</td>
<td>4.8 kW</td>
</tr>
<tr>
<td>Beef-cattle, horse, sheep, and hog barns, medium size, with 5-hp motor</td>
<td>14 kW</td>
<td>10 kW</td>
</tr>
<tr>
<td>Same, large size, with 7½-hp motor</td>
<td>20 kW</td>
<td>15 kW</td>
</tr>
<tr>
<td>Poultry laying house:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,000 sq-ft</td>
<td>1.8 kW</td>
<td>1.8 kW</td>
</tr>
<tr>
<td>4,000 sq-ft</td>
<td>8.7 kW</td>
<td>6.4 kW</td>
</tr>
<tr>
<td>8,000 sq-ft</td>
<td>15.2 kW</td>
<td>11.7 kW</td>
</tr>
<tr>
<td>Brooder house, per brooder:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrared</td>
<td>2.25 kW</td>
<td>2 kW</td>
</tr>
<tr>
<td>Standard brooder</td>
<td>1.25 kW</td>
<td>1 kW</td>
</tr>
<tr>
<td>Farm shop, with welder</td>
<td>17 kW</td>
<td>10 kW</td>
</tr>
<tr>
<td>Sweet-potato curing and storage</td>
<td>1.5 W/cu-ft or 4 W/bu</td>
<td>1.5 W/cu-ft or 4 W/bu</td>
</tr>
<tr>
<td>Machinery sheds, stock shelters, and miscellaneous buildings</td>
<td>1 W/sq-ft or floor area</td>
<td>1 W/sq-ft or floor area</td>
</tr>
</tbody>
</table>

*Source: “Farmstead Wiring Handbook.”*
534. Other loads. (Design Manual on Steel Electrical Raceways, published by American Iron and Steel Institute). Over and beyond the electrical requirements of individual buildings are a number of other loads for which provision must be made. These include such diverse items as water pumps (water system and irrigation), immersion heaters, water warmers, hay dryers and hoists, forage handlers, silo unloaders, and other miscellaneous equipment. Some idea of typical loads encountered is given by the following selected examples:

Forage handling:
- Blower type 20-hp motor
- Inclined elevator 2- to 3-hp motor
- Silo unloaders 30- to 5-hp motor
- Bulk-milk coolers Varies with size and type; 1 to 5 hp for one or more motors

Such additional loads should be kept in mind when surveying a farm operation for initial wiring or rewiring, and provisions made in the system design to handle such equipment.

535. Specifications for dairy barn

Lights. In back of cows there should be one lighting outlet every 12 ft (3.7 m), and in front of cows one approximately every 20 ft (6.1 m). There should be one or two lights on top of the silo, so installed that they will light the silo and chute. Only general illumination is needed in the haymow. Floodlights above the hay line on opposite walls of the barn will therefore give the required lighting.

Convenience Outlets. Outlets should be placed approximately 15 ft (4.6 m) apart in a row in back of the cows. If the cows face in, outlets should be on the wall, up high enough so that cattle cannot come in contact with them. If the cows face out, outlets should be suspended from the ceiling on heavy-duty cords. They must be hung so that they can be reached easily yet high enough not to obstruct traffic.

In open spaces a convenience outlet should be installed for each 600-ft² (55.7-m²) area.

Switches. It is best to install separate switches for each row of lights in the barn. In small barns, however, all lights in back of the cows may be on one switch. When two or more entrances are used frequently, at least one row of lights should be controlled by three-way switches. The switch for the lights in the haymow should be mounted at a convenient location on the barn floor and also be equipped with a pilot light. To have a visible indication when the light is burning in the silo, a switch with a pilot light mounted at the entrance of the silo chute is recommended.

Circuits. The service-entrance panel for the barn must be adequate to take care of the load. Since some of the equipment needs special circuits, it is important to have an entrance panel of the proper capacity. The following number of circuits is recommended as a minimum. However, additional equipment or a change in the barn layout may make it necessary to deviate from this recommendation.

- Lights 2 circuits (depending on size of barn)
- Milking machine 1 circuit (230 V)
- Feed grinder 1 circuit (230 V)
- Utility motor 1 circuit (230 V)
Convenience outlets 1 circuit (depending on size of barn)
Fans 1 or more (depending on size of barn)
Hay dryer 1 circuit (230 V)

536. Specifications for milk house

Lights. In most cases a center light will be sufficient unless the milk house is unusually large. Then additional lights will be necessary over the work areas, especially where the utensils are washed.

Convenience Outlets. At least one convenience outlet for general use should be installed at a convenient location in the milk house. It is advisable to put this outlet on a heavy-duty 20-A circuit.

Switches. All lights should be controlled by a switch at the entrance.

Circuits. When the milk house is connected to the barn, its circuits may be included in the barn entrance panel. When the milk house is separate, a special entrance panel must be installed.

The following circuits are recommended as a minimum:
- Lights and outlets 1 circuit
- Milk cooler 1 circuit
- Water heater 1 circuit (230 V)
- Sterilizer 1 circuit (230 V)
- Ventilating fan 1 circuit (if fan is small, it may be connected to light and outlet circuit)

537. Specifications for workshop, garage, and machine shed. Frequently the workshop, garage, and machine shed are one building, subdivided to serve all three purposes. The wiring for this building must therefore be arranged to suit this special condition.

Lights

Workshop. A well-lighted workshop is absolutely necessary for doing good work. Two types of lighting are needed: general lighting for the entire workshop and localized lighting over the workbench and near permanently located equipment.

For this reason, a ceiling light must be installed for every 200 ft² (18.6 m²) of floor area, at least one and possibly two lights over the workbench, and conveniently located lights over the stationary tools such as the drill press, plane, forge, or saw.

Garage. One light over the front of the cars and another one at the rear will permit making minor repairs to the car and other equipment.

Machine shed. One or two ceiling lights, depending on the size of the shed, give sufficient general illumination. Lights must be properly placed for best results.

Convenience Outlets

Workshop. Convenience outlets in the workshop must serve many different purposes. There must be a sufficient number, properly located, to facilitate the work. Install at least two convenience outlets over the workbench and other outlets throughout the workshop for
the connection of the electric tools. A heavy-duty outlet must be installed for the portable welder.

**Garage.** A convenience outlet at the rear wall of the garage permits the use of portable tools, a battery charger, and extension lights.

**Machine shed.** Since the welder may frequently be used in the machine shed, a heavy-duty outlet should be provided. Other convenience outlets should be considered for the connection of portable tools such as drills and soldering irons.

**Switches**

**Workshop.** The ceiling lights in the workshop should be controlled by a single-pole switch near the entrance. The lights over the workbench and fixed equipment can be controlled by pull-chain switches inside the fixture.

**Garage.** A single-pole switch near the entrance of the garage is needed for the control of the ceiling lights.

**Machine shed.** The same type of switch control should be used here as in the garage.

**Circuits.** As in the barn and milk house, the service-entrance panel for the workshop must have the correct capacity for the load. Since all the equipment will never be used at the same time, a reasonable diversity factor may be taken into consideration.

The number of circuits depends, of course, on the equipment and machinery installed. However, the following minimum should be carefully considered:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lights</td>
<td>1 circuit</td>
</tr>
<tr>
<td>Convenience outlet</td>
<td>1 circuit</td>
</tr>
<tr>
<td>Wood saw and planer</td>
<td>1 circuit (No. 12 wire)</td>
</tr>
<tr>
<td>Portable welder</td>
<td>1 circuit (230 V)</td>
</tr>
</tbody>
</table>

**538. Specifications for poultry house**

**Lights.** Lighting in the poultry house serves to increase egg production in addition to providing light for seeing. One light should be installed for each 200 ft² (18.6 m²) of floor area, but if pens are smaller than 200 ft², at least one light per pen must be provided for. The same general-lighting arrangement should also be kept in the poultry-house workroom with additional local lighting for egg cleaning, grading, poultry scalding, waxing, etc.

Since ultraviolet light promotes healthier, stronger birds, sunlamps should be installed over feeding troughs. Full spectrum fluorescent tubes that closely match outdoor light should be used. With a color rendering index of 96 (outdoor light 100) and color temperature of 5500 K matching natural outdoor light, poultry and other livestock confined to a building can benefit from the ultraviolet and visible spectrum of the lighting. It is also recommended that at least one germicidal fixture for each 100 ft² (9.3 m²) of floor area of laying pens be installed. These lamps should be on a separate switch so that they can be turned off when someone is working in the pen.

**Convenience Outlets.** To connect the water warmer in the laying pens, at least one convenience outlet should be installed for every 200 ft² (18.6 m²) of floor area. The outlets are best located at the ceiling and should be equipped with the locking type of receptacle.

In the brooder house, the same arrangement of receptacles is recommended to serve brooders and water warmers. In the workroom, convenience outlets must be installed for the egg cleaner, candler, grader, poultry scalders, and waxer.

The feed-grinder and feed-mixer motors must have special heavy-duty outlets on a 230-V circuit.
Switches. Lights for all the laying pens should be connected to a regular switch as well as to an automatic time switch. The time switch will make morning lights to control egg production possible. The ceiling lights in the workroom should be on a separate switch from the lights in the laying pens. The local lighting over the work areas can be controlled by wall switches or by pull-chain switches in the fixtures. Germicidal lamps, being on at all times, do not need a switch.

Circuits. The following circuits are recommended for the poultry house as a minimum:

- Lights: 1 circuit (depending on size of poultry house)
- Ultraviolet lamps: 1 circuit (depending on size of poultry house)
- Germicidal lamps: 1 circuit (depending on size of poultry house)
- Convenience outlets: 1 circuit
- Brooder outlets: 1 circuit each brooder
- Feed mixer: 1 circuit (230 V)
- Feed grinder: 1 circuit (230 V)

539. Specifications for hog house or sheep shed. For general illumination, a lighting outlet every 20 ft (6.1 m) along the passageways should be sufficient. These lights should be controlled by a single-pole switch near the entrance. Convenience outlets are needed in the farrowing pen for the connection of the pig brooders. This outlet should be about 3 ft (0.9 m) above the floor and in a corner of the pen.

540. Specifications for granary and corncrib. Lights over the center of the drive spaced 20 ft (6.1 m) apart are needed in the granary and corncrib. These lights should be controlled with a switch at the entrance. Upstairs, a light is needed for approximately every 200 ft² (18.6 m²) of storage area with a switch and pilot light installed downstairs near the stairs. At least one power outlet is needed downstairs for the connection of the grain elevator.

541. Specifications for farmyard. In the farmyard, electricity serves many important functions. Lights properly switched help in performing the evening chores. Outlets are needed throughout the yard for connection of the portable utility motor. Therefore, a plan for the wiring of a farm should include proper lighting and outlets outdoors. In general, the following simple rules will be sufficient:

- Lights. Install at least three lights in the yard: one at the house, one at the barn, and one at the workshop or garage. They should be at least 15 ft (4.6 m) above the ground to allow a wide spread of light.

- Outlets. Heavy-duty weatherproof outlets are needed for the connection of the utility motor. One should be mounted at the barn near the silo, and others at all places where farm chores will employ the utility motor. If the pump house is located adjacent to the yard, a separate circuit to the pump motor should be provided.

- Switches. To make it possible to turn the lights on or off from several different points, three- and four-way switches must be installed. A switch at the house, one at the barn, and a third one at another convenient place are recommended for maximum efficiency.
Planning the farm wiring system. After the required loads have been determined, the wiring system can be planned. The system will be considered in three parts: (1) the distribution point, (2) distribution feeders, and (3) interior wiring of each building.

Distribution point. (Secs. 543 to 545; adapted from *Practical Electrical Wiring*, 20th ed., © Park Publishing, 2008, all rights reserved) Locate the pole as near as practical to the buildings that use the greatest amount of power; on modern farms, the house rarely has the greatest load. By locating the pole so the largest wires will be the shortest wires, you will find it relatively simple to solve the problem of excessive voltage drop without using wires larger than would otherwise be necessary for the current to be carried. Total cost is kept down when the large expensive wires to the buildings with the big loads are the shorter wires, and the smaller less expensive wires to buildings with the smaller loads are the longer wires.

Figure 9.333 shows a modern farm distribution point. The disconnecting means may be provided by the utility or by the owner, depending on local practice. The switch has no overload protective devices within it, thereby varying from the normal rule for services in NEC 230.91. The NEC classifies this device as a “site isolating device” to distinguish it from a service disconnect. Even if supplied and maintained by the utility, and therefore beyond the scope of the NEC, the NEC avoids needless duplication by recognizing it as a disconnecting means, provided it meets the requirements in NEC 547.9(A). Since it is not an actual service disconnect, it follows that the wiring that leaves this device still has the status of service conductors and must meet the wiring method and clearance requirements in Article 230. Although nothing technically prevents a farm from establishing a conventional service at the distribution pole, and then routing conventional overcurrent-protected feeders to each building, the arrangement shown here is widely used for overall cost effectiveness. Note that although the switch is at the top of the pole, it can be operated from a readily accessible point through the permanently installed linkage shown in Fig. 9.333. In addition, a grounding electrode conductor must be installed at this point and run it from the neutral block of the switch to a suitable electrode at the pole base.

If there are two or more distribution points located closer together than 500 ft (measured in a straight line), each location must have reciprocal labeling setting out the location of the other point(s) and the buildings or structures served by each.

Equipotential planes. Due to the sensitivity of livestock to very small “tingle” voltages, the NEC now requires an equipotential plane in livestock (does not include poultry) confinement areas, both indoors and out, if they are concrete floored and contain metallic equipment accessible to animals and likely to become energized. These areas must include wire mesh or other conductive elements embedded in (or placed under) the concrete floor, and those elements must be bonded to metal structures and fixed electrical equipment that might become energized, as well as to the grounding electrode system in the building. In the case of dirt confinement areas, the equipotential plane may be omitted. For outdoor areas the plane must encompass the area in which the livestock will be standing while accessing equipment likely to become energized.

Remember that the grounding system to which equipotential planes should be connected is usually (refer to the distribution feeder discussion of this topic) electrically separated from neutral return currents. The idea is to minimize voltage gradients. Due to the well-grounded environment, the NEC also requires all general purpose 15- and 20-A, 125-V receptacles in the area of an equipotential plane to have GFCI protection. This GFCI protection requirement also applies to similar receptacles in all damp or wet locations, including outdoors, and for dirt confinement areas whether indoors or out. Receptacles for
specified (not general purpose) loads are not covered by this requirement, but where GFCI protection is omitted, a GFCI-protected receptacle must be installed within 3 ft of the unprotected receptacle.

545. Distribution feeders. From the pole top, go to the buildings that need to be supplied from this point. Review the discussion in Sec. 357 Par. 3 about regrounded neutrals. As a general rule the farmhouse can be supplied by a three-wire service, with its neutral regrounded at the house just as if the utility had made a direct termination. The farmhouse must not, however, share a common grounding return path with the barn. If it does, as in the case of a common metallic water piping system, the house (1) has to be supplied with
a four-wire service and (2) have all instances of electrical contact between the neutral and
the local equipment grounding system removed.

Although the barn, arguably, could also be wired like the house (three-wire), a three-
wire hookup would mean that the neutral and the equipment grounding system in the barn
would be bonded together at the barn disconnect. That in turn would mean the neutral, in
the process of carrying current across its own resistance, would constantly elevate the volt-
age to ground of all barn equipment by some finite amount relative to local ground, espe-
cially from the perspective of farm animals where they stand. The feet of livestock, being
in close contact with moisture, urine, and other farm chemicals, are conductively rather
well coupled to local earth. Most livestock are much more sensitive to voltage gradients
than are people. A potential difference in the range of a fraction of a volt can take a cow out
of milk production, which no farmer can afford.

The NEC addresses this in two ways. First, it establishes the unique rules on farm dis-
tributions being covered here. Second, it establishes an equipotential plane for these envi-
ronments, discussed later in this chapter. The service to the barn is normally wired
four-wire, and that is (1) customary because of the reasoning discussed in the previous
paragraph, and (2) mandatory unless there are no parallel grounding return paths over water
systems, etc., a necessary condition to comply with NEC 250.32(B) Exception. There is an
additional condition attached to the four-wire scheme that is unique to agricultural build-
ings. The separate equipment grounding conductor must be fully sized. That is, if the run
to the barn is 3/0 AWG copper for a 200-A disconnect, and the neutral is 1/0 AWG copper
(both sized on the basis of load), the equipment grounding conductor is not 6 AWG as nor-
mally required by NEC Table 250.122; nor is it 4 AWG, the size for a grounding conduc-
tor on the supply side of a service using 3/0 AWG wires; nor is it 1/0 AWG, the size of the
neutral. It must not be smaller than the largest ungrounded line conductor, or 3/0 AWG.
When this wire arrives at the barn, it must arrive at a local distribution with the neutral com-
pletely divorced from any local electrodes or equipment surfaces requiring grounding.

546. Wiring of buildings. Normally the power-distribution feeder for the distribu-
tion point to a building is secured to the building with an insulator bracket (see Div. 8). Brackets
should be mounted high enough so that the power feeders are never suspended lower than 5.5 m (18 ft) over driveways, for clearance of loaded wagons, and 3 m (10 ft) over footwalks.

From the insulator bracket service-entrance conductors are run down the side of the
building to a point where they enter the building and connect to the service-entrance panel.
Copper service-entrance cable is recommended for this purpose. This cable with its tough
nonmetallic outer covering protects cattle from coming in contact with metallic parts of the
wiring system. The table in Sec. 547 will give an idea of the size of service-entrance panels
required (refer to Secs. 376 to 385 for information on service entrances).

It is recommended that Types UF, NMC, Copper SE, jacketed Type MC, rigid non-
metallic conduit (either PVC or RTRC), liquidtight flexible nonmetallic conduit, or other
cables or raceways suitable for the location be employed for the interior wiring of the build-
ings (refer to preceding sections of this division for information on wiring, and refer to
Secs. 535 to 541 of this division for information on requirements for lights, convenience
outlets, switches, and circuits).

At each building the wiring system must be grounded. This provision is in addition to
the ground at the distribution point. Grounds must be established at each point of entrance
to each building, and, if possible, all these grounds should be tied together on driven
grounds. Also, for added safety, the farm water system should be tied at each building to
the driven ground for that building. This is important. A well-grounded wiring system adds
to the safety of the entire installation.
### 547. Service-Entrance Requirements

<table>
<thead>
<tr>
<th>Type of building</th>
<th>Installation</th>
<th>Service-entrance conductors, A (All services are 9-wire, 115/230-V, unless otherwise specified)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy barn (complete barn, including milk room) up to 2,500 sq-ft</td>
<td>Normal amount of lighting, ventilation, milker, milk cooler, water pump, dairy water heater, milk house heater, gutter cleaner (3 hp), hay drier, or utility motor (5 hp)</td>
<td>100</td>
</tr>
<tr>
<td>Same, above 2,500 sq-ft</td>
<td>Normal amount of lighting, ventilation, milker, milk cooler, water pump, dairy water heater, milk house heater, gutter cleaner (8 hp), hay drier, or utility motor (7 hp)</td>
<td>125</td>
</tr>
<tr>
<td>Same, above 2,500 sq-ft</td>
<td>Same as above, but two 7 1/2-hp motors</td>
<td>195</td>
</tr>
<tr>
<td>Milking barn or “milking parlor”—includes milk room—(cows not housed)</td>
<td>Normal amount of lighting, milker, milk cooler, dairy water heater, milk house heater, ventilation</td>
<td>55</td>
</tr>
<tr>
<td>Milk house (when separate from barn)</td>
<td>Normal amount of lighting, milk cooler, dairy water heater, milk house heater</td>
<td>55</td>
</tr>
<tr>
<td>Horse, beef-cattle, sheep, and hog barn up to 2,500 sq-ft</td>
<td>Normal amount of lighting, ventilation, pig or lamb brooders, water pump, antifreezing protection on plumbing, utility motor (5 hp)</td>
<td>70</td>
</tr>
<tr>
<td>Same, above 2,500 sq-ft</td>
<td>Normal amount of lighting, ventilation, pig or lamb brooders, water pump, antifreezing protection on plumbing, utility motor (7 1/2 hp)</td>
<td>100</td>
</tr>
<tr>
<td>Poultry laying house (including feed room) up to 4,000 sq-ft pen floor area</td>
<td>Normal amount of lighting, ventilation, water warmers, antifreezing protection on plumbing, automatic feeders, feed grinder (up to 1 hp)</td>
<td>55</td>
</tr>
<tr>
<td>Same, above 4,000 sq-ft pen floor area</td>
<td>Normal amount of lighting, ventilation, water warmers, antifreezing protection on plumbing, automatic feeders, feed grinder (up to 2 hp)</td>
<td>70</td>
</tr>
<tr>
<td>Poultry brooder house, portable type</td>
<td>Light and outlet for single brooder and water warmer (2-wire, 115-V)</td>
<td>20</td>
</tr>
<tr>
<td>Poultry brooder house, permanent type, up to six pens</td>
<td>Normal amount of lighting, ventilation, brooders, water warmers, antifreezing protection on plumbing</td>
<td>55</td>
</tr>
<tr>
<td>Poultry brooder house, permanent type, above six pens</td>
<td>Normal amount of lighting, ventilation, brooders, water warmers, antifreezing protection on plumbing</td>
<td>70 minimum; estimate 2,000 W per pen</td>
</tr>
<tr>
<td>Poultry-cleaning and -dressing house</td>
<td>Normal amount of lighting, poultry scalder, waxer, wax reclaimer, picker, and refrigeration</td>
<td>55</td>
</tr>
<tr>
<td>Farm shop</td>
<td>Normal amount of lighting, bend tools (tool grinder, drill, soldering iron, etc.), farm welder, air compressor, saw, and battery charger</td>
<td>70</td>
</tr>
</tbody>
</table>
547. **Service-Entrance Requirements** *(Continued)*

<table>
<thead>
<tr>
<th>Type of building</th>
<th>Installation</th>
<th>Service-entrance conductors, A (All services are 9-wire, 115/230-V, unless otherwise specified)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General farm buildings</td>
<td>Minimum capacity where lighting, motors, and miscellaneous 116- and 230-V equipment will be used</td>
<td>50</td>
</tr>
<tr>
<td>Storage sheds, stock shelters</td>
<td>Lighting and small portable equipment—not over two 2-wire (2-wire, 115-V) bench circuits</td>
<td>40*</td>
</tr>
</tbody>
</table>

*Ordinarily such buildings are supplied by a feeder or circuit from another building. In such cases, this is not a service as defined by the National Electrical Code. If a brooder house or similar structure is supplied directly from the power source, the minimum permissible size of service-entrance conductors would be No. 8 for two 2-wire branch circuits. If the building is served by a feeder from another building the minimum size of service-entrance conductors would be No. 10 for two 2-wire branch circuits. For a single branch-circuit source, the minimum permissible size of service-entrance conductors would be No. 8 for two 2-wire branch circuits.

**SOLAR PHOTOVOLTAIC SYSTEMS**

548. **Solar photovoltaic systems** *(Secs. 548 to 554; adapted from Practical Electrical Wiring, 20th ed., © Park Publishing, 2008, all rights reserved)* are becoming increasingly common, given favorable tax incentives and increasing energy costs. These systems are covered in NEC Article 690. They are very complex, and this handbook section will only cover the most common application in which a limited array provides power that offsets some of the power that would otherwise have come from the utility. It is important to keep in mind that the power produced by these systems is direct current (dc), frequently at voltages approaching 600 V. Special considerations must be made in order to harness this power safely. PV systems have another significant difference from conventional systems in that the amount of current is inherently limited by the capacity of the array.

549. **The array** captures the solar energy. Solar cells are grouped into modules that comprise the basic unit of solar generating hardware. The panels are then field connected to make a functioning array that provides dc power for the owner’s use. A new change in the 2008 NEC requires that each array framework or supporting structure be connected to a grounding electrode located as near as practicable to the array. The power system electrode can be substituted if its location is within 6 ft of where the array electrode would normally be provided. If a separate electrode is used, whether or not it must be bonded to the power system electrodes depends on whether the inspector views them as “auxiliary” electrodes as covered in 250.54. The proposal for this change clearly intended that they be so classified; the panel removed the reference, but failed to substantiate its actions. Ask the inspector, but be prepared to make the bonding connection.

The NEC requires modules to be listed, and they will be marked by their manufacturer with the information specified in NEC 690.51. This information (short-circuit current, maximum power, operating current and voltage, open circuit voltage, and maximum system...
voltage) forms the basis for calculations that are essential to system layout and conductor selection. These values will be in terms of standardized test conditions, and it is known that actual conditions can result in substantially exceeding the ratings. For example, extreme cold can result in voltage levels as much as 125 percent of rated output voltage [see NEC 690.7(A)]. In addition, some solar installations substantially exceed the standardized irradiance levels in the time period around solar noon, resulting in current production as much as 125 percent of the rated amount. In addition, the current produced by PV systems is, almost by definition, continuous. This generally adds another 25 percent to sizing overcurrent devices (refer to the extensive coverage of this topic in Div. 3, Sec. 94).

550. Special wiring rules apply at the modules. Effective with the 2008 NEC, unless conventional multicore wiring methods are used, module and panel interconnections must use either single-conductor Type USE-2 cable or the new Type PV (photovoltaic) single conductor wire; the previous allowance for Types UF, SE, and USE is discontinued. Do not use welding cable. Note that USE-2 wire must not be used inside a building unless it is dual rated as building wire, as shown by an additional marking of XHHW-2 or RHW-2 or comparable. These wires have 90°C temperature ratings and tolerate sunlight and wet-location exposure, and they can be connected to the positive and negative leads coming from the modules. However, if the array is readily accessible to passersby, the conductors must usually run within a raceway. Single-conductor entries into a pull box must have strain relief provided, such as through listed gland-type connectors that maintain the wet-location integrity of the box. Leave enough slack in the module leads so the module can be removed for servicing or replacement. When selecting wires, try to avoid wire stranded more finely than Class C concentric (19 strands up to 2 AWG, then 37 strands on larger wires). Wire more finely stranded than this must have both its stranding class and the numbers of strands marked on the connector, and such lugs are very difficult to find. Note also that the new Type PV conductors have a thicker than usual insulation, and as such require special raceway fill calculations if pulled into conduit or tubing.

Generally each string of modules connected in series should have a fuse in its ungrounded (usually the positive) lead based on 125 percent of 125 percent (net = 156 percent) of the rated short-circuit current of each of the series-connected modules. Remember that voltages add in series circuits, but current is everywhere the same. For example, the short-circuit current rating of four modules, each rated at 5.4 A short-circuit current and connected in series, is 5.4 A, but the voltage produced by this string will be four times the voltage of any single module. To size the fuse, multiply the current by 1.25 to get 6.75 A, and then multiply that by 1.25 for continuous loading for a result of 8.4 A, and choose the next higher standard size fuse. Choose a 9-A fuse, because the NEC specifies that PV source circuit overcurrent devices be in increments of a single ampere for all ratings below or equal to 15 A.

Figure 9.334 shows an array of six parallel strings of modules, four in each. The combiner box to the left provides terminals for the paralleled strings, and facilitates connections to the home run conductors. Wiring leaving the array can be multicore cable such as Type UF if it is identified as sunlight resistant and suitable for the temperature, or it can be a raceway-type wiring method suitable for the location. All wiring terminating on or running with a PV array should be assumed to be operating in a 70°C ambient or higher due to solar heating. This means that the wiring (and any nonmetallic raceway if used) must have a minimum temperature rating of 90°C as a practical matter, and that the effects of temperature on final conductor ampacity will be pronounced. For example, 12 AWG THWN-2, a 90°C conductor with a Table 310.16 ampacity of 30 A would end up with (using a 0.58 derating factor) a final ampacity of 17.4 A or even 12.3 A if a higher temperature were assumed.
FIGURE 9.334  The major elements of a utility-interactive PV supply.
551. **DC feeder wiring** connects the array with the inverter. The wiring between the PV source and the inverter is a feeder for a separately derived system and follows normal rules for sizing, although, depending on how it is routed, temperature may have an important impact. As we have seen, each of the six strings generates 6.75 A, resulting in a total array load of 41 A. Since these wires will be connected to an overcurrent device and switch terminals, and transmit continuous loads, we need to add 25 percent of this number to determine conductor sizes. The minimum ampacity of the feeder conductors would be 125 percent of 41 or 51 A. This corresponds to 6 AWG copper conductors, evaluated under the 75°C column of Table 310.16. If these feeder conductors were routed along the array the evaluation would change, because ambient temperature would become a major factor. In such a case (assuming 70°C conditions) the derating factor to be applied to THWN-2 conductors is 0.58. 41 A/0.58 = 71 A. Since this is less than the ampacity (in the 90°C column) of these conductors, the 6 AWG conductors can still be used, but the result is far closer to the table limits. Refer to Div. 3, Secs. 89 to 111 for a comprehensive explanation of these considerations.

552. **Equipment grounding** must not be forgotten. Although equipment grounding conductors are normally sized per Table 250.122 based on the rating of the line-side overcurrent device, in cases like this the NEC requires that the short-circuit current be used to enter that table, or in this case, 51 A. A 10 AWG conductor would be the correct size. Take care in terminating these conductors at an array. Listed modules will provide for grounding connections and they must be used. Other modules, typically aluminum bodied, will require field terminations. Look for a copper-bodied lug that has a tin coating and is listed for direct burial. These lugs are compatible with an aluminum surface and their stainless steel hardware will survive outdoor conditions. To attach these to the module, drill a small pilot hole, then seat the lug with a 10-32 thread-forming sheet metal screw treated with an antioxidant compound rated for aluminum connections. This is not a “teck” screw with sheet-metal threads; it is an actual machine screw, and the compound will assure that no oxygen reaches the raw aluminum surface during the thread-making process. This prevents the formation of aluminum oxide and assures a low-impedance, long-lasting connection.

553. **Disconnects must be located upon entry** unless a metal raceway is used. When the wiring enters the building, there must be a disconnect provided unless the wiring runs in a metal raceway. The metal raceway may be difficult to install, but the owner may prefer it to the appearance of wiring running down the outside of the building. On new construction the metal raceway can be preinstalled easily and avoids a disconnect at an inconvenient location. Note that NEC 690.15 requires the inverter (and comparable equipment) that could be energized from two sources to have a disconnecting means from each source, and also requires those disconnects to be grouped and identified. It follows that the PV disconnect shown in Fig. 9.334 would be required whether or not a disconnect were provided in the attic.

554. **Disconnects must be applied** within their ratings. A typical open-circuit voltage for the array in Fig. 9.334 might be 64 V (open circuit); with four modules in series the voltage would be 256 V, and after applying the 125 percent multiplier as noted the required rating becomes 320 V. As a practical matter, look for 600 V dc rated equipment when you are considering these components. The NEC also requires a label to be placed as shown in Fig. 9.334 showing system parameters. If the system includes storage batteries (the one shown does not) the maximum output current of the charge controller must be shown on the same label.
because a short-circuited battery bank adds many thousands of amperes of available fault current to the dc side of the system and the components need to be rated accordingly.

555. Inverters provide the interface with the ac side. The next step is to convert the dc output to ac, which is the principal function of the inverter. Inverters are selected based on the generally expected power capability of the system. This is far from the worst-case voltage (expected on the coldest morning) times the worst case current (expected at solar noon during the warm season), or about 10 kW in this example. Consult the manufacturers’ recommendations; in this case a 5-kW inverter would be a typical size. Note that the inverter output conductors are sized to the continuous output current rating of the inverter, even if the capacity of the modules on the roof is smaller than what the controller can deliver. Most inverters listed for this application include a mechanism to interrupt the ground-fault current path, as required by NEC 690.5 for all dwellings, and all other locations using a grounded PV system unless the equipment grounding conductor is double the size of the circuit conductors after upsizing for conduit fill and ambient temperature. Both the ac and the dc sides of the inverter have grounding electrode requirements, and therefore both sides require a grounding electrode conductor to be in place. The ac side is already taken care of by the normal grounding connections in the building, but the dc side has to be added, sized in accordance with NEC 250.166. This means equal in size to the ungrounded conductor unless the electrode is a ground rod, or ring or concrete-encased electrode. Just as for ac system conductors, those conductors need not exceed 6 AWG, or the size of the ring conductor, or 4 AWG, respectively. Since this electrode must be bonded to the normal power system electrode, and can actually be the same electrode, many inverters include a ground bus common to both sides that facilitates this connection.

It should also be noted that there must be one, and never more than one, connection between the grounded dc circuit conductors and the grounding electrode. Since the interruption of the ground-fault current path is a required feature of a NEC 690.5 device, having this connection in the inverter allows for the proper application of these requirements. In addition, the PV disconnect must not open the grounded conductor; the switch in Fig. 9.334 will only have one of its poles (if more than one are present) in use.

556. Connection point to the normal power system are restricted. Most panelboards have busbars with ratings equal to the rating of the main overcurrent protective device ahead of them in the panel. Figure 9.334 shows a common 200-A panelboard. The NEC now requires that the input breaker from the inverter be at the opposite end of the bus from the normal main. In this way, no configuration of branch circuit or feeder loads could draw more than the current the busbars were designed to carry. In addition, the panel must be marked with a warning label advising against repositioning this breaker. There is, however, still a 20 percent limitation on the size of the interconnecting breaker. This is because, although the busbars could not be overloaded, the panel would still be delivering more power than the conditions under which it was tested. The 20 percent is a reasonable limit until more testing is carried out.

Note that the interconnecting breaker must be suitable for backfeeding. Most breakers are tested in both directions. The ones that are not are marked “line” and “load” and if so marked they can only be used in the direction indicated. In this example, a 5-kW inverter operating on a continuous basis on a 240-V system would calculate as a \((5000 \text{ kW}/240 \text{ V}) \times 1.25 = 26\text{-A load for termination purposes, and a 30-A circuit breaker would be used. Note that this would be OK for a 150-A or larger panel, but too large for a smaller panel.}