Table 17.3 Continued

Maximum size of wire or cable, AWG or kcmil	(mm²)	Minimum width and depth of wiring space, Inches	(mm)	Minimum area in square inches (cm²) required for multiple wires based on factor of 2.5											
				Two wires		Three wires		Four wires		Five wires		Six wires		Seven wires	
750	(380)	2	(50.8)	7.04	(45.4)	10.56	(68.1)	14.08	(90.8)	17.60	(113.5)	21.12	(136.3)	24.64	(159.0)
800	(405)	2-1/8	(54.0)	7.39	(47.7)	11.09	(71.6)	14.78	(95.4)	18.48	(119.2)	22.18	(143.1)	25.87	(166.9)
900	(456)	2-1/4	(57.2)	8.09	(52.2)	12.13	(78.3)	16.18	(104.4)	20.22	(130.5)	24.26	(156.5)	28.31	(182.6)
1000	(507)	2-1/4	(57.2)	8.77	(56.6)	13.15	(84.8)	17.54	(113.2)	21.92	(141.4)	26.30	(169.7)	30.69	(198.0)
1250	(633)	2-1/2	(63.5)	11.03	(71.2)	16.55	(106.8)	22.06	(142.3)	27.58	(177.9)	33.10	(213.5)	38.61	(249.1)
1500	(760)	2-3/4	(69.8)	12.74	(82.2)	19.11	(123.3)	25.48	(164.4)	31.85	(205.5)	38.22	(246.6)	44.59	(287.7)
1750	(887)	2-7/8	(73.0)	14.45	(93.2)	21.67	(139.8)	28.90	(186.5)	36.12	(233.0)	43.34	(279.6)	50.57	(326.3)
2000	(1010)	3-1/8	(79.4)	16.04	(103.5)	24.06	(155.2)	32.08	(207.0)	40.10	(258.7)	48.12	(310.5)	56.14	(362.2)

17.2.3.6 In determining whether a wiring space complies with the requirements in 17.2.3.5, consideration is to be given to the actual size of wires that will be used in the space; but it is to be assumed that wires smaller than 12 AWG (3.3 mm^2) will not be used. In computing the area of a wiring space, consideration is to be given to all the available space that may be used for the more common multiple wire connections as specified in Table 17.1. The space occupied by a termination area and the space above such an area – see 17.1.1(a) – is not included when wiring space is determined, but space above or around an individual terminal or neutral located in a wiring gutter – see 17.2.2.2 – is considered to be available space.

17.2.3.7 No wiring system shall enter or exit the enclosure in a wiring space.

17.3 Wire deflection and bending space

17.3.1 Top and bottom bending space

17.3.1.1 Enclosed panelboards shall be provided with bending space at the top and bottom. Each space (distances T_1 and T_4 in Illustrations 1, 2, and 2a of Figure 17.2) shall be as specified in Table 17.1 for the largest conductor (conductors M and N) entering or exiting the enclosure.

Exception No. 1: For a panelboard having both top and bottom bending spaces, either of these spaces, but not both, shall be as specified in Table 17.2 for the largest conductor entering or leaving the enclosure when:

a) The panelboard is rated 225 amperes or less and has provisions for 42 over-current protective devices or less,

b) There are no conductors terminated in that space, or

c) At least one of the side bending spaces complies with Table 17.1 for the largest conductor to be terminated in any panelboard side bending space.

Exception No. 2: For a panelboard that is provided with both top and bottom bending spaces, both spaces shall be as specified in Table 17.2 for the largest conductor entering or leaving the enclosure when the panelboard is intended and constructed for wiring using only one single 90 degree bend for the main and main neutral conductors (the M and N conductors of Illustration 2a, Figure 17.2) and the panelboard is

marked in accordance with 34.2.1. However, the main neutral conductor (Conductor N of Illustration 2, Figure 17.2) is capable of being wired straight in or having more than one bend when the distance for this conductor is in accordance with Table 17.1.

Exception No. 3: Bending space is not required when the main supply connections are made using bus bars or using factory installed wire through openings into adjacent equipment which in combination with the panelboard has been investigated and found capable of being used in the application. The bending space at the opposite end of the line connection shall be in accordance with Table 17.2.

17.3.2 Side bending space

17.3.2.1 Other than as mentioned in 17.3.2.2, side wire bending space (distances T_2 and T_3 in Figure 17.2) shall be in accordance with Table 17.2 for the largest conductor to be terminated in that space.

17.3.2.2 With reference to the requirements in 17.3.2.1, if a hole, knockout, or other provision for connection of a wiring system for the main ungrounded conductors is provided in a sidewall opposite the main terminals, it will be assumed that the main conductors, ungrounded and grounded, will enter or exit the enclosure through that wall and the wire bending space for those conductors (distance T_5 in Illustration 3 of Figure 17.2) shall be as specified in Table 17.1.

Exception: The wire bending space (distance T_5 in Figure 17.2) may be in accordance with Table 17.2 if the provision for the wiring system in the enclosure wall opposite the terminal is located at the end of the gutter where it joins the adjacent gutter, and the adjacent gutter provides wiring space (distance G_1 in Figure 17.2) in accordance with Table 17.1 for that conductor. See Illustration 4 of Figure 17.2.

17.3.3 Individual connector bending space

17.3.3.1 The wire bending space from a connector to any barrier or other obstruction that is part of a panelboard shall be as specified in Table 17.2. The adjacent space shall be so arranged that normal routing of conductors (such as down a gutter) will not be restricted. See 17.4.7 and 17.4.8.

17.4 Determination of deflection and bending space distances

17.4.1 For the purpose of determining deflection and bending space distances, the size and material of conductors shall be determined as described in 17.1.3. For top and bottom spaces, conductor sizing shall be based on the maximum ampere rating of the mains. Conductor sizing for side bending spaces shall be based on the largest conductor to be terminated in that space. For individual connector spacings, conductor sizing shall be based on the maximum ampere rating of the connector application.

17.4.2 The wire terminal shall be turned so that the axis of the wire opening in the connector is as close to perpendicular to the wall of the enclosure as it can assume without defeating any means provided to prevent its turning, such as a boss, shoulder, walls of a recess, multiple bolts securing the connector, or the like. A barrier, shoulder, or the like is to be disregarded when the measurement is being made if it does not reduce the radius to which the wire must be bent. However, it is to be assumed that the connector is not oriented so that the wire will be directed into a corner of the box to such extent that the transverse wall would necessitate additional bending.

17.4.3 When measuring wire bending space for compliance with Table 17.1 or Table 17.2, the distance is to be measured in a straight line from the edge of the wire terminal closest to the wall in a direction perpendicular to the box wall or barrier. That is, no credit is to be given for angling of terminals as illustrated by distance D_1 in Figure 17.3; the correct method is to measure perpendicular to the box wall from the edge of the terminal, as illustrated by distance D_2 in Figure 17.3. If a terminal is provided with one or more connectors for the connection of conductors in multiple, the distance is to be measured from the wire opening closest to the wall of the enclosure. If the connectors for a circuit are fixed in position – for

example, by the walls of a recess– so that they are turned toward each other, the distance is to be measured at the wire opening nearest the wall in a direction perpendicular to the wall.

Exception: When measuring bending space for compliance with Table 17.2, the distance (distance D_3 in Figure 17.4) may be measured in a straight line from the center of the wire opening in the direction the wire leaves the terminal.

Figure 17.3

Measurement of wire bending space distances

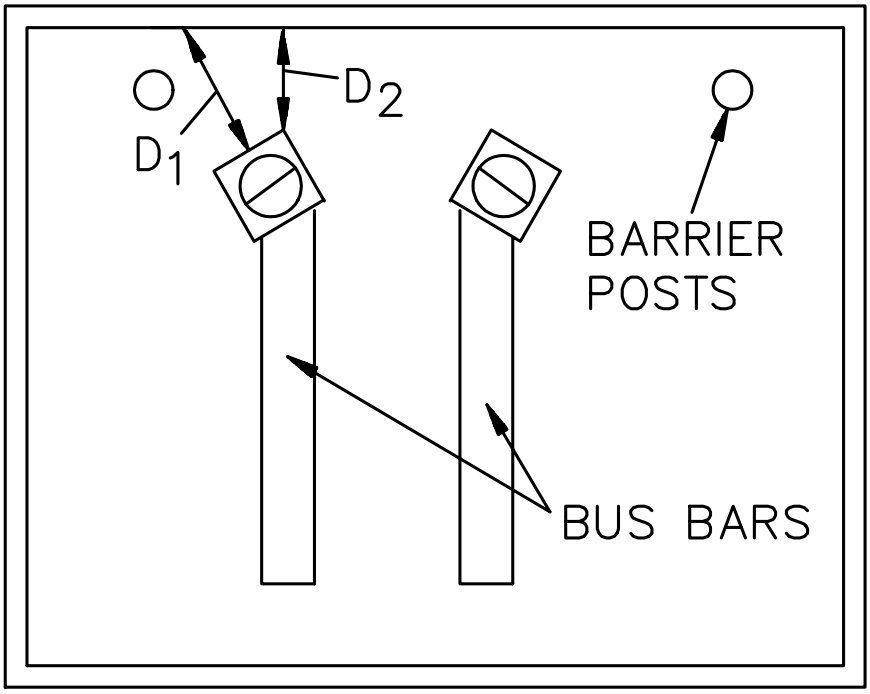
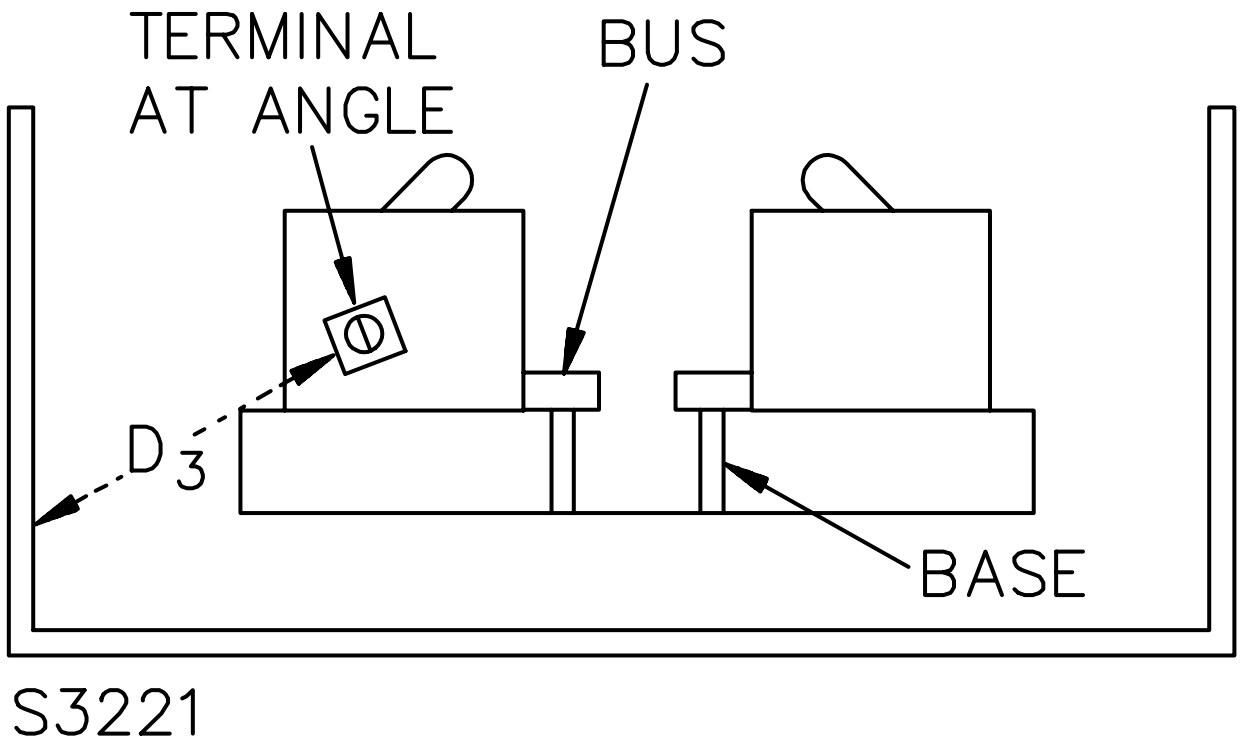


Figure 17.4

Optional measurement of wire bending space distance for compliance with Table 17.2

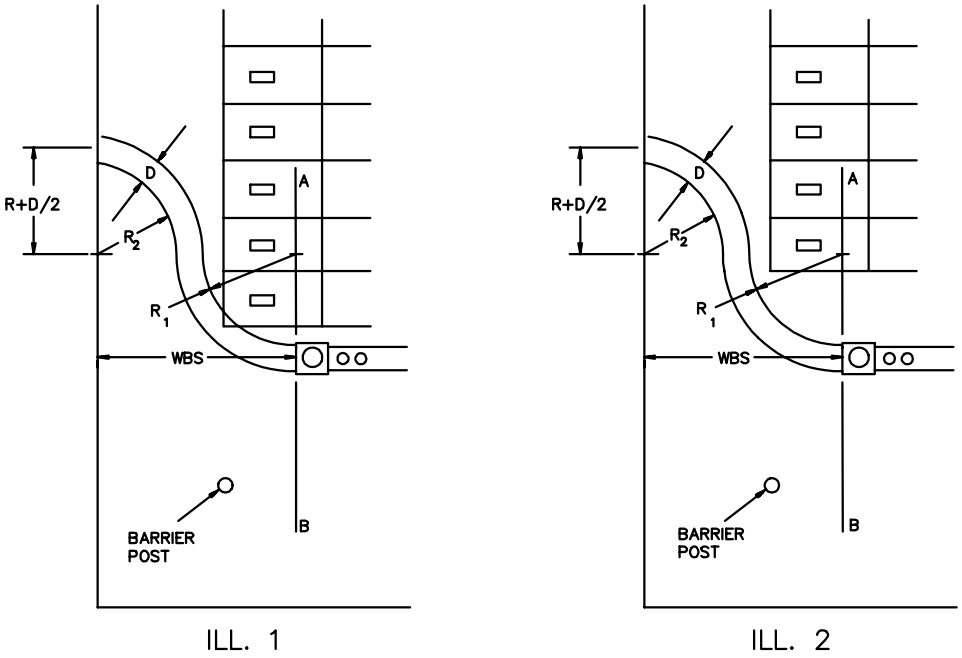


17.4.4 If a wire is restricted by barriers, branch circuit units, or other means from being bent in a 90 degree or S bend from the terminal to any usable location in the wall of the enclosure, the distance is to be measured from the end of the barrier or other obstruction.

17.4.5 With reference to 17.4.4, a barrier is considered to restrict wire bending if the barrier extends beyond an arc with radius R described in 17.4.6. For example, the barrier (branch circuit unit) in Illustration 1 of Figure 17.5 is considered to restrict wire bending; the barrier in Illustration 2 of Figure 17.5 is not considered to restrict wire bending.

Figure 17.5

Restriction of S bends[a,b]



S3222A

[a] The diameter of the wire, D, in the illustrations is as specified in the National Electrical Code, ANSI/NFPA 70, Chapter 9, Table 5 for the wire size being considered.

[b] WBS is the distance available for wire bending, but is not to be less than the value specified in Table 17.2 for the wire size being considered.

17.4.6 The arc mentioned in 17.4.5 is to be constructed as specified in (a) and (b):

a) For an S bend, see Figure 17.5, line AB is to be:

1) Perpendicular to the line measuring wire bending space (line WBS), and

2) Through the face of the wire connector for which the determination is being made.

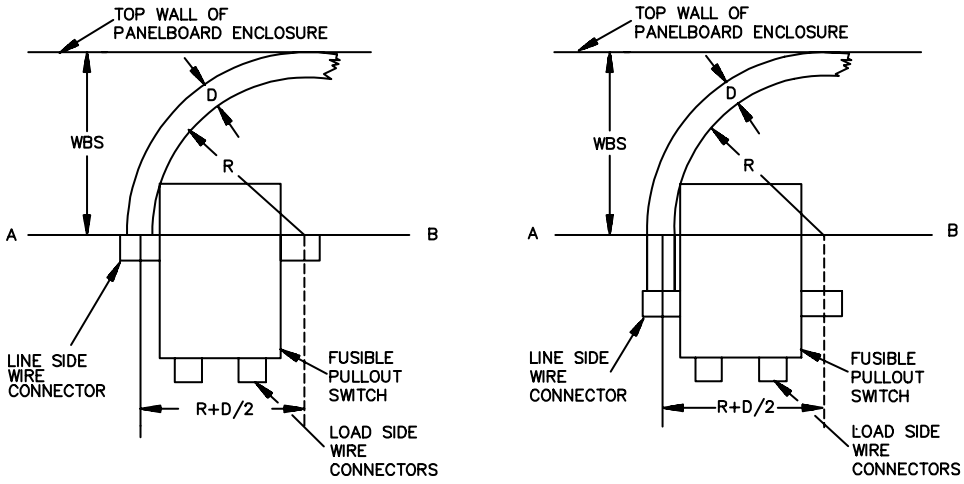
Arc R_1 has a center located on line AB at a distance equal to R+(D/2) from the center of the wire opening with a radius R equal to (WBS-D)/2 and is the inside radius of a wire exiting the wire connector. A second arc with the same center and a radius equal to R+D represents the outside radius of the wire exiting the wire connector. Arc R_2 has center at the intersection of a line perpendicular to line AB and through the center of the radius of arc R_1 and the enclosure wall. The inside and outside radius is the same as for arc R_1.

b) For a 90 degree bend, see Illustration 1 of Figure 17.6, line AB is to be perpendicular to the line measuring wire bending space (line WBS) and through the face of the wire connector for which the determination is being made. The arc has a center located on line AB at a distance equal to R +(D/2) from the center of the wire opening with a radius R equal to WBS-D and is the inside radius of a wire exiting the wire connector. A second arc with a radius equal to WBS represents the outside radius of the wire.

Exception: If the wiring space provided is greater than the value specified in Table 17.2, line AB may be located at the required distance and need not be through the face of the wire connector. See Illustration 2 of Figure 17.6 as an example.

Figure 17.6

Restriction of 90 degree bends[a,b]



S3223A

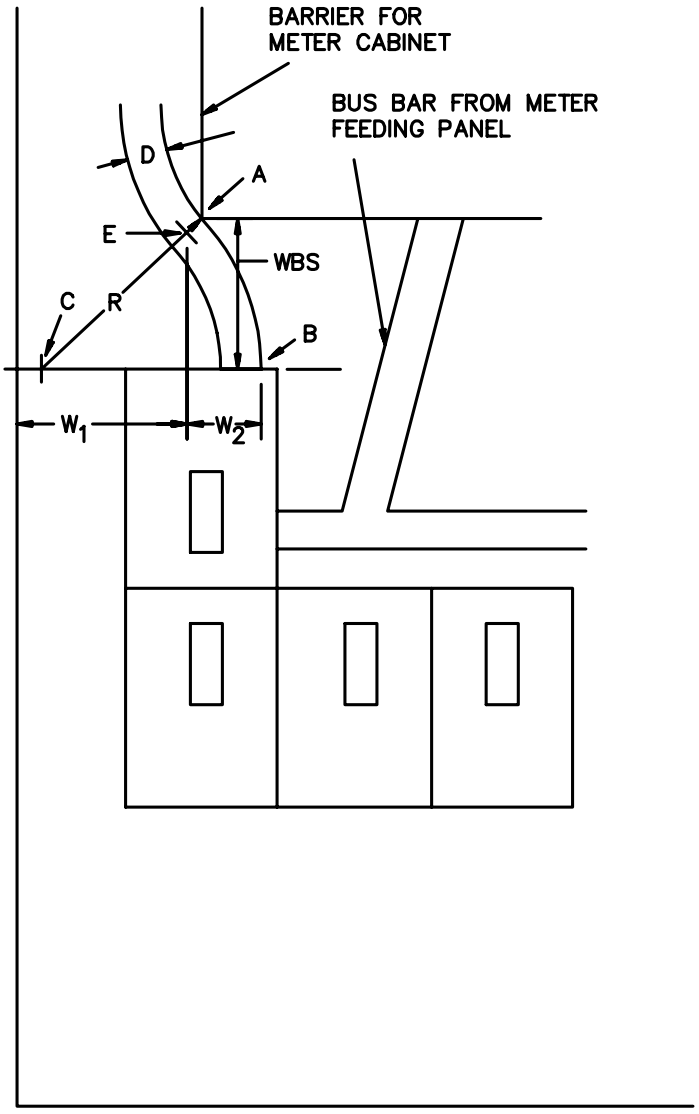
[a] The diameter of the wire, D, in the illustrations is as specified in the National Electrical Code, ANSI/NFPA 70, Chapter 9, Table 5 for the wire size being considered.

[b] WBS is the distance available for wire bending, but is not to be less than the value specified in Table 17.2 for the wire size being considered.

17.4.7 With reference to 17.3.3.1, the adjacent space is considered to restrict normal routing of conductors if the adjusted width W_1 of an adjacent space is less than the adjusted width W_2 required to route the conductor. See Figure 17.7 and 17.4.8.

Figure 17.7

Restriction of wire to be directed down a gutter



17.4.8 With reference to Figure 17.7, to determine the adjusted widths, W_1 and W_2, mentioned in 17.4.7, a line CB perpendicular to the line measuring wire bending space (line WBS) and through the face of the connector is found. An arc AB is located with center on line CB and a radius that:

a) Is the maximum radius that will just clear the barrier, and

b) Is not less than:

$$\frac{WBS + D}{2}$$

in which:

WBS is the distance specified in Table 17.2 for the applicable wire; and

D is the diameter of the wire for the size being considered in accordance with Chapter 9, Table 5 of the National Electrical Code, ANSI/NFPA 70.

A line AC through arc AB is found and a point E is located on line AC at a distance D/2 from point A. The distance W_1 is the distance between a line through point E and perpendicular to line CB and the enclosure wall or barrier. W_2 is the distance between the perpendicular line through line CB and point B. If an arc that complies with (a) and (b) cannot be constructed, then the spacing is unacceptable.

18 Grounding and Bonding

18.1 General

18.1.1 Other than as indicated in 18.1.2, there shall be provision for permanently and effectively grounding a metal plate that covers uninsulated live parts.

18.1.2 The provisions for grounding the plate mentioned in 18.1.1 need not be included if the plate is provided with a means for effectively insulating it from live parts or is located so that it is not likely to become energized.

18.1.3 A panelboard marked as being suitable for use as service equipment shall have provision for connection of the grounding electrode conductor to the grounded service conductor. The size of the grounding electrode conductor shall be assumed to be in accordance with Table 18.1. A soldering lug or other connection means that depends upon solder is not acceptable.

Table 18.1
Size of grounding electrode conductor and main bonding jumper

Ampere rating not exceeding	Size of main bonding jumper (minimum)[a,b,h]				Cross section of main bonding jumper in square inches (mm^2) minimum[b,c]				Size of grounding electrode[b] conductor (minimum)			
	Copper, AWG or kcmil (mm^2)		Aluminum, AWG or kcmil (mm^2)		Copper		Aluminum		Copper, AWG (mm^2)		Aluminum,AWG or kcmil (mm^2)	
90	8	(8.4)	6	(13.3)	0.013	(8.4)[c]	0.021	(13.6)[c]	8	(8.4)	6	(13.3)
100	6	(13.3)	4	(21.2)	0.021	(13.6)[c]	0.033	(21.3)[c]	6	(13.3)	4	(21.2)
125	6	(13.3)	4	(21.2)	0.021	(13.6)[c]	0.033	(21.3)[c]	6	(13.3)	4	(21.2)

Table 18.1 Continued on Next Page

Table 18.1 Continued

Ampere rating not exceeding	Size of main bonding jumper (minimum)[a,b,h]				Cross section of main bonding jumper in square inches (mm^2) minimum[b,c]				Size of grounding electrode[b] conductor (minimum)			
	Copper, AWG or kcmil (mm^2)		Aluminum, AWG or kcmil (mm^2)		Copper		Aluminum		Copper, AWG (mm^2)		Aluminum,AWG or kcmil (mm^2)	
150	6	(13.3)	4	(21.2)	0.021	(13.6)[d]	0.033	(21.3)[d]	6	(13.3)	4	(21.2)
200	4	(21.2)	2	(33.6)	0.033	(21.3)[d]	0.052	(33.6)[d]	4	(21.2)	2	(33.6)
225	2	(33.6)	1/0	(53.5)	0.052	(33.6)[e,f]	0.083	(53.5)[e,f]	2[e,f]	(33.6)	1/0	(53.5)
400	1/0[g]	(53.5)	3/0[g]	(85.0)	0.083	(53.5)[f,g]	0.132	(85.0)	1/0[g]	(53.5)	3/0[g]	(85.0)
500	1/0	(53.5)	3/0	(85.0)	0.083	(53.5)	0.132	(85.0)	1/0	(53.5)	3/0	(85.0)
600	2/0	(67.4)	4/0	(107.2)	0.105	(67.7)	0.167	(107.7)	2/0	(67.4)	4/0	(107.2)
800	2/0	(67.4)	4/0	(107.2)	0.105	(67.7)	0.167	(107.7)	2/0	(67.4)	4/0	(107.2)
1000	3/0	(85.0)	250	(127)	0.132	(85.2)	0.196	(127.0)	3/0	(85.0)	250	(127)
1200	250	(127)	250	(127)	0.196	(127.0)	0.196	(127.0)	3/0	(85.0)	250	(127)
1600	300	(152)	400	(203)	0.236	(152.0)	0.294	(189.7)	3/0	(85.0)	250	(127)
2000	400	(203)	500	(253)	0.314	(203.0)	0.393	(253.0)	3/0	(85.0)	250	(127)
2500	500	(253)	700	(355)	0.393	(253.0)	0.550	(355.0)	3/0	(85.0)	250	(127)
3000	600	(304)	750	(380)	0.412	(265.8)	0.589	(380.0)	3/0	(85.0)	250	(127)
4000	750	(380)	1000	(507)	0.589	(380.0)	0.785	(507.0)	3/0	(85.0)	250	(127)

[a] The cross section may be reduced to 12.5 percent of the total cross section of the largest main service conductor(s) of the same material (copper or aluminum) for any phase on a panelboard rated 1200 amperes and above. This applies when the cross section of the service conductors is limited by the wire terminal connectors provided.

[b] For a panelboard rated 1200 amperes or more and that has wiring terminals intended to connect service conductor wires sized larger than 600 kcmil copper or 750 kcmil aluminum, the cross section of the main bonding jumper shall be at least 12.5 percent of the total cross section of the largest main service conductor(s) of the same material (copper or aluminum) for any phase.

[c] A No. 8 or larger brass or No. 10 or larger steel screw may be used.

[d] A No. 10 or larger brass or steel screw may be used.

[e] A No. 10 or larger brass screw may be used.

[f] A 1/4-inch (6.4 mm) diameter or larger brass or steel screw may be used.

[g] When the ampere rating is 400 and the wire terminal connectors for the main service conductors are acceptable for two 3/0 AWG copper or two 250 kcmil aluminum conductor but will not accept a 600 kcmil conductor, these values may be reduced to 2 AWG (0.052 square-inch) copper or 1/0 AWG (0.083 square-inch) aluminum.

[h] These are also sizes for the grounded service conductor mentioned in 18.1.3.

18.1.4 The provision for connection of the grounding-electrode conductor specified in 18.1.3 shall be on the neutral.

Exception: The provision may be on the equipment-grounding terminal assembly, bus, or the like if the main bonding jumper is a bus bar or wire and is connected, or is intended to be field connected, directly from the neutral to the equipment-grounding-terminal assembly. See 34.2.2.

18.1.5 For a panelboard marked as being suitable for use as service equipment, when an insulated neutral is provided, a main bonding jumper consisting of a separate screw, strap, or other means shall be provided to bond:

a) The box or the interior pan, if a box is provided, or

b) The interior pan if no box is provided,

to the insulated grounded circuit conductor – the insulated neutral – of an alternating-current system. Except for steel or brass screws as noted in the notes to Table 18.1, the bonding means shall be of copper or aluminum and shall have a cross-sectional area as specified in Table 18.1. The means used to provide the removable bonding means described in 16.1.7 shall also comply with the foregoing requirement. When an insulated neutral is provided, the construction shall be such that when the bonding means is not used, at least the minimum acceptable spacings will exist. Unless the intended use and method of installation of the bonding means are obvious, instructions for its installation shall be provided. See 11.2.12 for thread engagement requirements.

18.1.6 For a panelboard marked as being suitable for use as service equipment, when the neutral is mounted directly on or is otherwise in permanent electrical connection with the enclosure (or mounting pan if no enclosure is provided), the connecting joint between the uninsulated neutral and the enclosure (or mounting pan) shall have a cross-sectional area as specified in Table 18.1. If threaded fasteners are used, see 11.2.12 for thread engagement requirements. Panelboards constructed as described in this paragraph shall be marked as specified in 34.9.1(a).

18.1.7 With respect to 18.1.5, if the main bonding jumper is a screw, the screw shall have a green colored head that is hexagonal, slotted, or both. The screw shall be visible without disassembly or removal of devices inside the panelboard.

18.1.8 If the main bonding jumper is a screw as permitted in 18.1.7 or includes a screw, either of which are field-installable and permitted to be located in the back plane of the enclosure's intended mounting position, the screw should not project past the back plane of the enclosure's intended mounting position by more than 0.063 inches (1.6 mm).

18.1.9 A panelboard that is marked for service equipment use shall be provided with a terminal for a grounded service conductor even though there may be no provision for a load conductor to be connected to the grounded service conductor. If there is no provision for such a load conductor, the grounded service conductor terminal shall:

a) Accommodate a conductor of the same size as the main bonding jumper specified in Table 18.1,

b) Be bonded to the enclosure, and

c) Be directly-connected to the grounding-electrode-conductor terminal.

Exception: The terminals may be omitted if the panelboard is marked in accordance with 34.12.7.

18.1.10 When installed as intended, the bonding connection described in 18.1.5, 18.1.6, and 18.1.9 shall:

a) Provide a reliable bond to the panelboard frame or enclosure; and

b) Be such that the resistance of the connection between an installed grounded service conductor and the frame or enclosure is not more than 0.005 ohm. See Bonding Resistance Test, Section 27.

18.1.11 In a panelboard incorporating ground-fault protection of the ground-return type as described in 15.7, the main bonding jumper as required by 18.1.5 shall be factory connected to the insulated grounded circuit conductor (neutral) and to the box or interior pan and the panelboard shall be marked to indicate that it is suitable only for use as service equipment.

18.2 Equipment-grounding terminals

18.2.1 A panelboard, or the enclosure in which it is intended to be installed, shall be provided with a means for terminating equipment-grounding conductors for both the main equipment grounding conductor and for the branch-circuit equipment-grounding conductors in accordance with Table 18.2.

Exception No. 1: A panelboard or enclosure marked in accordance with 34.13.4 or 34.13.5.

Exception No. 2: For a panelboard marked in accordance with 34.9.1(a), a terminal for connection of the grounding electrode conductor provided in accordance with 18.1.3 may be considered to be the main equipment-grounding-conductor means if it is acceptable for the wire size specified in Table 18.2.

Exception No. 3: For a panelboard marked in accordance with 34.9.1 (b) or (c), and employing the construction described in 18.1.9, a terminal for connection of the grounding-electrode conductor may be considered to be the main equipment-grounding-conductor means if it is acceptable for the wire size specified in Table 18.2.

Exception No. 4: For a panelboard marked in accordance with 34.9.1 (b) or (c) and employing pressure terminal connectors for the connection of the main bonding jumper, the terminal mounted on the panelboard frame or enclosure for the connection of the main bonding jumper may be considered to be the main equipment-grounding-conductor means if it is acceptable for the wire size specified in Table 18.2.

Table 18.2
Equipment-grounding conductor

Rating, amperes	Size, AWG or kcmil (mm^2)			
	Copper		Aluminum or copper-clad aluminum	
15	14	(2.1)	12	(3.3)
20	12	(3.3)	10	(5.3)
30	10	(5.3)	8	(8.4)
40	10	(5.3)	8	(8.4)
60	10	(5.3)	8	(8.4)
100	8	(8.4)	6	(13.3)
200	6	(13.3)	4	(21.2)
300	4	(21.2)	2	(33.6)
400	3	(26.7)	1	(42.4)
500	2	(33.6)	1/0	(53.5)
600	1	(42.4)	2/0	(67.4)
800	0	(53.5)	3/0	(85.0)
1000	2/0	(67.4)	4/0	(107)
1200	3/0	(85.0)	250	(127)
1600	4/0	(107)	350	(177)

18.2.2 An equipment-grounding terminal or terminal assembly and associated parts shall be of a metal or metals that are not likely to be adversely affected by electrolysis in service.

18.2.3 Metal employed for an equipment-grounding terminal shall be nonferrous, stainless steel, or other metal that is inherently resistant to corrosion, or it shall be protected by a coating of zinc or cadmium that complies with 18.2.4 or by an equivalent metallic-plated coating.