UL 467

STANDARD FOR SAFETY

Grounding and Bonding Equipment

UL Standard for Safety for Grounding and Bonding Equipment, UL 467

Eleventh Edition, Dated April 29, 2022

Summary of Topics

This is the new Eleventh Edition of ANSI/UL 467, Standard for Grounding and Bonding Equipment, dated April 29, 2022.

As noted in the Commitment for Amendments statement located on the back side of the title page, UL, CSA, and ANCE are committed to updating this harmonized standard jointly.

The new requirements are substantially in accordance with Proposal(s) on this subject dated July 23, 2021 and January 14, 2022.

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Association of Standardization and Certification
NMX-J-590-ANCE
Second Edition

CSA Group
CSA C22.2 No. 41:22
Seventh Edition

Underwriters Laboratories Inc.
UL 467
Eleventh Edition

Grounding and Bonding Equipment

April 29, 2022

Approved American National Standard

ANSI/UL 467-2022

Commitment for Amendments

This standard is issued jointly by the Association of Standardization and Certification (ANCE), the Canadian Standards Association (operating as “CSA Group”), and Underwriters Laboratories Inc. (UL). Comments or proposals for revisions on any part of the standard may be submitted to ANCE, CSA Group, or UL at anytime. Revisions to this standard will be made only after processing according to the standards development procedures of ANCE, CSA Group, and UL. CSA Group and UL will issue revisions to this standard by means of a new edition or revised or additional pages bearing their date of issue. ANCE will incorporate the same revisions into a new edition of the standard bearing the same date of issue as the CSA Group and UL pages.

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This Standard is subject to review within five years from the date of publication, and suggestions for its improvement will be referred to the appropriate committee. To submit a proposal for change, please send the following information to inquiries@csagroup.org and include "Proposal for change" in the subject line: Standard designation (number); relevant clause, table, and/or figure number; wording of the proposed change; and rationale for the change.

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This ANSI/UL Standard for Safety consists of the Eleventh edition. The most recent designation of ANSI/UL 467 as an American National Standard (ANSI) occurred on April 29, 2022. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page (front and back), or the Preface.

The Department of Defense (DoD) has adopted UL 467 on June 12, 1987. The publication of revised pages or a new edition of this Standard will not invalidate the DoD adoption.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at https://csds.ul.com.

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CONTENTS

PERFORMANCE

No Text on This Page

Preface

This is the harmonized ANCE, CSA Group, and UL standard for grounding and bonding equipment. It is the second edition of NMX-J-590-ANCE, the seventh edition of CSA C22.2 No. 41, and the eleventh edition of UL 467. This edition of CSA C22.2 No. 41 supersedes the previous edition published in 2013. This edition of UL 467 supersedes the previous edition published in 2013.

This harmonized standard was prepared by the Association of Standardization and Certification (ANCE), the CSA Group, and Underwriters Laboratories Inc. (UL). The efforts and support of the Technical Harmonization Committee for Connectors, of the Council on the Harmonization of Electrotechnical Standards of the Nations of the Americas (CANENA), are gratefully acknowledged.

This Standard is considered suitable for use for conformity assessment within the stated scope of the Standard.

The present Mexican standard was developed by the CT Conductors from the Comite de Normalizacion de la Asociacion de Normalizacion y Certificacion, A.C., CONANCE, with the collaboration of the connectors manufacturers and users.

This standard was reviewed by the CSA Integrated Committee on Electrical Connectors, under the jurisdiction of the CSA Technical Committee on Wiring Products and the CSA Strategic Steering Committee on Requirements for Electrical Safety, and has been formally approved by the CSA Technical Committee. This Standard has been developed in compliance with Standards Council of Canada requirements for National Standards of Canada. It has been published as a National Standard of Canada by CSA Group.

Application of Standard

Where reference is made to a specific number of samples to be tested, the specified number is to be considered a minimum quantity

Note: Although the intended primary application of this standard is stated in its scope, it is important to note that it remains the responsibility of the users of the standard to judge its suitability for their particular purpose.

Level of harmonization

This standard uses the IEC format but is not based on, nor is it considered equivalent to, an IEC standard.

This standard is published as an equivalent standard for ANCE, CSA Group and UL.

An equivalent standard is a standard that is substantially the same in technical content, except as follows: Technical national differences are allowed for codes and governmental regulations as well as those recognized as being in accordance with NAFTA Article 905, for example, because of fundamental climatic, geographical, technological, or infrastructural factors, scientific justification, or the level of protection that the country considers appropriate. Presentation is word for word except for editorial changes.

Reasons for differences from IEC

The Technical Harmonization Committee identified one IEC standard, IEC 60364-5-54, that addresses grounding and bonding equipment included in the scope of this Standard, Electrical installations of buildings – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements, protective conductors and protective bonding conductors. This standard addresses the earthing arrangements, protective conductors, and protective bonding conductors in order to satisfy the safety requirements of the electrical installation. It has the status of a basic safety publication in accordance with IEC Guide 104.

The IEC standards for grounding and bonding equipment are recognized as being generally system specific. The THC determined that the safe use of grounding and bonding equipment is dependent on the design and performance of the grounding and bonding equipment in relation to the North American electrical codes with which they are intended to be installed.

Interpretations

The interpretation by the standards development organization of an identical or equivalent standard is based on the literal text to determine compliance with the standard in accordance with the procedural rules of the standards development organization. If more than one interpretation of the literal text has been identified, a revision is to be proposed as soon as possible to each of the standards development organizations to more accurately reflect the intent.

1 Scope

1.1 This Standard applies to grounding and bonding equipment for use in accordance with CSA C22.1, Canadian Electrical Code, Part I in Canada, the National Electrical Code, NFPA 70, in the United States, or the Standard for Electrical Installations, NOM-001-SEDE, in Mexico.

1.2 This Standard applies to the following grounding and bonding equipment:

a) ground clamps, bonding devices, grounding bushings, water-meter shunts, grounding electrodes, and the like used in a grounding system;

b) equipment for making electrical connections between

i) the grounding conductors used in electrical power systems, non-current-carrying metal parts of electrical equipment, armored grounding wires, metal raceways, and the like; and

ii) grounding electrodes;

c) equipment for making electrical connections between

i) the grounding conductors used in telecommunications systems such as telephone, radio, CATV, network power broadband, and the like; and

ii) grounding electrodes;

d) hospital grounding jacks and mating grounding cord assemblies (for Mexico and the United States, see Annex A);

e) bonding devices for making electrical connections between

i) the hex head of a brass fitting used in a piping system in accordance with 250.104 of NFPA 70; and

ii) the grounding electrodes; and

f) intersystem bonding terminations for connecting intersystem bonding and grounding conductors for other systems in accordance with NFPA 70.

Notes:

1) In Canada, “hospital grounding jacks” are not defined in CSA C22.1, Canadian Electrical Code, Part I.

2) In Canada, ″mating ground cord assemblies″ are covered in CSA C22.2 No. 21 and CSA C22.2 No. 42.

2 Reference publications

For undated references to Standards, such reference shall be considered to refer to the latest edition and all revisions to that edition up to the time when this Standard was approved. For dated references to Standards, such reference shall be considered to refer to the dated edition and all revisions published to that edition up to the time the Standard was approved.

ANCE (Association of Standardization and Certification)

NOM-001-SEDE
Standard for Electrical Installations

NMX-J-010-ANCE
Thermoplastic-Insulated Wires and Cables

NMX-J-017-ANCE
Conduit, Tubing and Cable Fittings – Specifications and Test Methods

NMX-J-451-ANCE
Wires and Cables – Thermoset-Insulated Wires and Cables – Specifications

NMX-J-543-ANCE
Connectors – Wire Connectors – Specifications and Test Methods

NMX-J-548-ANCE
Connectors – Splicing Wire Connectors – Specifications and Test Methods

CSA Group

C22.1:21
Canadian Electrical Code, Part I

CAN/CSA-C22.2 No. 0:20
General requirements – Canadian Electrical Code, Part II

C22.2 No. 0.4-17
Bonding and grounding of electrical equipment

C22.2 No. 18.3-12 (R2017)
Conduit, tubing, and cable fittings

C22.2 No. 21-18
Cord sets and power supply cords

C22.2 No. 42-10 (R2020)
General use receptacles, attachment plugs, and similar wiring devices

C22.2 No. 51:20
Armoured cables

C22.2 No. 65-18
Wire connectors

C22.2 No. 188-18
Splicing wire connectors

UL (Underwriters Laboratories Inc.)

UL 4
Armored Cable

UL 44
Thermoset-Insulated Wires and Cables

UL 83
Thermoplastic-Insulated Wires and Cables

UL 486A-486B
Wire Connectors

UL 486C
Splicing Wire Connectors

UL 514B
Conduit, Tubing, and Cable Fittings

ASTM (American Society for Testing and Materials)

ASTM A 90/A 90M
Standard Test Method for Weight [Mass] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

ASTM A 653/A 653M
Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by Hot-Dip Process

IEEE (Institute of Electrical and Electronics Engineers)

IEEE 837
Standard for Qualifying Permanent Connections Used in Substation Grounding

NFPA (National Fire Protection Association)

NFPA 70
National Electrical Code (NEC)

3 Definitions

The following definitions apply in this Standard:

Bonding bushing – a bushing having one or more screws intended to provide the bonding function between the bushing and the enclosure (see Figure 1(c)).

Ground clamp – a device used for connection of a grounding conductor to a grounding electrode (see Figure 1(a)).

Grounding bushing – a bushing having provision for the connection of a bonding or grounding conductor (see Figure 1(b)).

Note 1: A grounding bushing may also be provided with one or more screws intended to supplement the bonding function between the bushing and the enclosure.

Note 2: A grounding bushing is commonly referred to as a bonding bushing.

Ground mesh – a copper wire mesh that is intended to be installed in ground or embedded in concrete and bonded to a grounding electrode system for the purpose of improving ground planes.

Intersystem bonding termination – a device that provides a means for connecting bonding conductor(s) for communications systems to the grounding electrode system.

Plate electrode – a metal plate, having a defined surface area, with a means for attachment to the system-grounding conductor.

Protective-type clamp – a ground clamp designed so that the grounding conductor and its connection will be effectively protected against mechanical damage.

Separable wire connector – a wire connector that is removable from the bushing with which it is used.

Strap-type clamp – a clamp constructed of perforated or expanded flexible metal suitable for assembly on pipe.

4 General requirements

4.1 The values given in SI (metric) units shall be normative, except for AWG/kcmil conductor sizes and other trade sizes. Any other values given shall be for information only.

4.2 For products intended for use in Canada, general requirements are given in CAN/CSA-C22.2 No. 0 and grounding and bonding requirements are given in C22.2 No. 0.4.

5 Components

A component shall comply with the ANCE, CSA Group or UL standards as appropriate for the country where the product is to be used.

6 Construction

6.1 General

6.1.1 A grounding or bonding device shall be constructed of metals or metal alloys that provide sufficient strength and rigidity to permit installation and use in the intended manner without either:

a) adversely affecting the function of the device; or

b) damaging the grounding or bonding conductor, the grounding electrode, or equipment to which the device is attached.

6.1.2 A grounding or bonding device marked for direct burial shall be provided with all screws necessary for assembly or connection of the device, and all components shall be constructed of:

a) copper or a copper alloy containing not less than 80 % copper;

b) stainless steel; or

c) materials other than aluminum and aluminum alloys, if investigated and found to be acceptable for the application.

Note: Among the factors to be taken into consideration when judging the acceptability of such materials are the

a) change of resistance across the bonding-grounding joint; and

b) amount and degree of corrosion.

6.1.3 Connectors provided as part of a grounding or bonding device shall comply with the construction requirements of

a) NMX-J-543-ANCE, CSA C22.2 No. 65 or UL 486A-486B; or

b) NMX-J-548-ANCE, CSA C22.2 No. 188 or UL 486C and may be made of iron or steel with a steel terminal screw.

6.1.4 Means for the attachment of a grounding or bonding conductor shall be so designed that the conductor is securely and reliably held without depending on solder.

6.1.5 For connectors not covered in Clause 6.1.3, and where the conductor is attached by means of a single screw, the size of the screw shall not be smaller than as specified in Table 1.

6.1.6 A wire-binding screw shall be provided with upturned lugs or the equivalent capable of holding a wire under the head of the screw.

6.1.7 A cast iron part, other than malleable iron, shall be not less than 3.2 mm (1/8 in) thick. A malleable iron part, a nonferrous cast-metal part, and a die-cast or extruded part shall be not less than 2.4 mm (3/32 in) thick, except that a die-cast part may be not less than 1.6 mm (1/16 in) thick if it is ribbed or otherwise reinforced and not marked for direct burial.

6.1.8 A fitting, such as a hub, a bushing, or a locknut to be used for grounding and intended to provide a rain-tight or liquid-tight connection between threaded metal conduit and a sheet metal enclosure shall comply with the requirements in this Standard and with the requirements for such a fitting in NMX-J-017-ANCE, CSA C22.2 No. 18.3, or UL 514B. See Clause 10.4.

6.1.9 A device intended for the connection of metal conduit, electrical metallic tubing, or flexible armor shall be provided with an end stop or the equivalent, and if intended for the connection of metal conduit, it shall be provided with not less than three full threads in the metal.

6.2 Protective-type ground clamps

6.2.1 A clamp intended to be threaded onto or otherwise rigidly attached to any form of metal raceway or flexible armor enclosing a grounding conductor shall be of the protective type. The clamp shall be such that the grounding conductor and its connection will be effectively protected against mechanical damage, except that a grounding conductor connection having inherent protection against mechanical damage, because of its size, shape, and the like, is not required to be otherwise protected.

6.2.2 A ground clamp in which the grounding conductor and its connection to the clamp is recessed between protective side walls shall be acceptable, provided that such protective walls are not formed by removable parts that are not essential for the assembly of the device.

6.2.3 A protective-type clamp shall provide an electrical and mechanical connection between the grounding electrode and a grounding conductor protected by armor or metal raceway. The mechanical connection shall be rigid if the clamp is designed for use with metal conduit.

6.2.4 A protective-type clamp of the strap type shall have a rigid metal base to be seated on the grounding electrode, and if the clamp is designed for use with metal conduit, it shall be provided with not less than the applicable number of straps specified in Table 2, depending upon the trade size of metal conduit with which it is intended to be used.

6.3 Strap-type clamps

6.3.1 A strap-type clamp shall not be less than 12.7 mm (1/2 in) wide and 0.64 mm (0.025 in) thick.

6.3.2 A communications strap-type clamp shall not be less than 12.7 mm (1/2 in) in width and not be less than 0.64 mm (0.025 in) in thickness. Strap-type clamps intended for outdoor use shall satisfy the temperature conditioning test described in Clause 9.9.

6.3.3 Communication ground clamps may be in the form of straps of copper or other suitable metal.

6.3.4 Communication ground straps shall be fitted either with brass or galvanized steel screws.

6.4 Protection against corrosion

6.4.1 A grounding or bonding device shall be protected by a zinc coating at least 0.025 mm (0.001 in) thick, except as follows:

a) if the metal is inherently resistant to corrosion such as nonferrous or stainless steel;

b) a device that is used in conjunction with an electrical metallic raceway or metallic cable system and complies with the corrosion protection requirements for fittings in CSA C22.2 No.18.3 or UL 514B;

c) the thickness of the coating shall be at least 0.013 mm (0.0005 in) if the device provides for a direct pressure connection between the grounding or bonding conductor and the surface of an outlet box; or

d) the thickness of the coating shall be at least 0.0038 mm (0.00015 in) if the device is intended for use completely inside an outlet box.

Also see Clause 6.4.6.

6.4.2 In regards to Clause 6.4.1, corrosion protection on small parts of the grounding and bonding device, such as screws, is not specified. Evidence of corrosion protection shall be verified by visual inspection.

6.4.3 Unless a grounding or bonding device is made of a material specified in Clause 6.1.2, a plating or a coating provided on the device shall not be of a material or color that would tend to indicate that the device is of a material other than that of which it is actually made.

6.4.4 Except as specified in Clause 6.4.3, colored chromate shall be permitted.

6.4.5 Die-cast zinc or another metal shall be one or more of the following:

a) a grade or alloy known to be resistant to atmospheric corrosion;

b) subjected to appropriate tests; or

c) additionally protected against corrosion.

6.4.6 In accordance with Clause 6.4.1, a device constructed of ferrous metal shall be protected against corrosion by one of the following means or by other metallic coatings that have been found to give equivalent protection, as described in Clause 6.4.7:

a) hot-dipped, mill-galvanized sheet steel conforming with the coating designation G90 in Table I of ASTM A 653/A 653M, with not less than 40 % of the zinc on any side, based on the minimum single-spot-test requirement in ASTM A 653/A 653M. The weight of zinc coating may be determined by any acceptable method; however, in case of question, the weight of coating shall be established in accordance with ASTM A 90/A 90M; and

b) a zinc coating, other than that provided on hot-dipped mill-galvanized sheet steel, uniformly applied to a thickness of not less than 0.025 mm (0.001 in) on each surface. The thickness of the coating shall be established by the thickness of protective coating test described in Clause 9.6.

6.4.7 With reference to Clause 6.4.6, other finishes, including special metallic finishes, may be used when comparative tests with galvanized sheet steel having no annealing, wiping, or other surface treatment that conform to Clause 6.4.6, Item (a), indicate they provide equivalent protection.

Note: Among the factors that are taken into consideration when judging the acceptability of such coating systems are exposure to salt spray, moist carbon dioxide-sulphur dioxide-air mixtures, moist hydrogen sulphide-air mixtures, ultraviolet light, and water.

6.5 Ground clamps

6.5.1 Clamps and electrode connections shall be any one of the following:

a) rigid bolted clamps of cast, formed, or extruded metal;

b) plug-type grounding fittings (pipe fittings, plugs, or other approved forms for threading into pipes or pipe fittings); or

c) exothermically welded connections.

6.5.2 A clamp for use in damp or dry locations shall be made of copper alloy, malleable iron, aluminum, or die-cast zinc.

6.5.3 In Canada, a clamp used for a wet location shall be of copper, bronze, or brass, and the bolts shall be of similar material or of stainless steel.

In Mexico and the United States, a clamp used for a wet location shall be of copper, bronze, brass, zinc alloys, or aluminum, and the bolts shall be of similar material or of stainless steel.

6.6 Bushings

6.6.1 Bushings shall meet the requirements of CSA C22.2 No. 18.3, UL 514B, or NMX-J-017-ANCE. For an insulated metal bushing, all surfaces of the throat that can be contacted by a conductor shall be lined with the insulating material.

6.6.2 Bonding bushings shall be provided with a means (usually one or more set screws) for reliably bonding the bushing (and the conduit or fittings on which it is attached) to the metal equipment enclosure or box. A means for connecting a grounding or bonding conductor shall not be provided.

Note: If there is need for a grounding or bonding conductor, a grounding bushing should be used.

6.6.3 A bonding screw intended to bond a bushing to an enclosure shall be adjustable to extend not less than 3.2 mm (1/8 in) beyond the surface of the bushing, except that if two or more such screws or the equivalent are evenly spaced around the bushing, this adjustment may be less than 3.2 mm (1/8 in), but not less than 1.6 mm (1/16 in). When adjusted in any position, a bonding screw shall engage not less than two threads in the bushing.

6.6.4 Grounding bushings shall have provision for the connection of the minimum size bonding or grounding conductor in accordance with Table 3 or have provisions for mounting a separable wire connector accepting the minimum size conductor in accordance with Table 3. A grounding bushing shall also have means (usually one or more set screws) for reliably bonding the bushing to the metal equipment enclosure or box in the same manner that is accomplished by a bonding bushing, see Clauses 6.6.2 and 6.6.3.

Note: Grounding bushings may be used with or without a bonding or grounding conductor as determined by the bonding or grounding function that is intended to be accomplished.

6.6.5 With reference to the requirement in Clause 6.6.4, an integral wire connector is considered to be nonremovable from the grounding bushing. A separable wire connector may be either factory assembled to the grounding bushing or be separately available from the manufacturer.

6.7 Fittings

A grounding fitting or bonding fitting shall meet the requirements of Clauses 6.2, 6.4, 6.5, and 6.6, as applicable.

6.8 Water-meter shunts

A water-meter shunt shall consist of two clamps connected by means of a 4 AWG (21.2 mm^2) or larger solid copper wire. The clamps shall comply with the requirements for clamps given in this Standard.

6.9 Armored grounding wire

6.9.1 General

Armored grounding wire shall consist of a single corrosion-resistant copper, aluminum, or copper-clad aluminum conductor, within a flexible, helically formed steel armor similar in general design to that employed in armored cable.

6.9.2 Conductor

The conductor shall be sized in accordance with Table 4 and shall comply with the short-time current requirement in Clause 9.5. The conductor is not required to be tinned.

6.9.3 Armor

6.9.3.1 Splices made in the steel strip forming the armor shall not increase the thickness or diameter of the armor or lessen its mechanical strength.

6.9.3.2 The strip used in the armor shall not be less than 0.64 mm (0.025 in) thick.

6.9.3.3 In an armored grounding wire employing an uninsulated (bare) conductor, the weight of single-strip steel armor shall not be less than specified in Table 4.

6.9.3.4 The steel armor of an armored grounding wire shall comply with the requirements for zinc coating, be able to support a tension of 667 N (150 lbf), and have the flexibility applicable to armored cable.

Note: The steel armor of an armored grounding wire conforming to CSA C22.2 No. 51 or UL 4 is considered to be in compliance with Clauses 6.9.3.1 to 6.9.3.4.

6.10 Grounding electrodes

6.10.1 General

Grounding electrodes shall be one of the types described in Clauses 6.10.2 to 6.10.4.

6.10.2 Rod electrodes

6.10.2.1 In Canada and Mexico, a rod electrode shall not be less than 3 m (10 ft) long.

In the United States, a rod electrode shall be not less than 2.44 m (8 ft) long.

6.10.2.2 In Mexico, a solid rod electrode of iron or steel shall have a diameter not less than 16 mm (5/8 in).

In Canada, a solid rod electrode of iron or steel shall have a diameter not less than 15.8 mm (5/8 in).

In the United States, a solid rod electrode of iron or steel shall have a diameter not less than 15.87 mm (5/8 in).

6.10.2.3 In Mexico, an uncoated solid rod electrode of stainless steel, copper, or suitable nonferrous metal shall have a diameter of not less than 14.8 mm (0.583 in).

In Canada and the United States, a solid rod electrode of stainless steel, copper, or suitable nonferrous metal shall have a diameter not less than 12.7 mm (1/2 in).

6.10.2.4 A coated solid rod electrode of iron or steel shall have a zinc, stainless steel, copper, or suitable nonferrous metal coating and shall have a diameter of not less than 12.7 mm (1/2 in).

6.10.2.5 The stainless steel coating shall not be less than 0.38 mm (0.015 in) thick at any point.

6.10.2.6 The copper coating shall not be less than 0.25 mm (0.010 in) thick at any point and shall comply with the adherence requirement in Clause 7.7.1 and the bending requirement in Clause 7.7.2.

6.10.2.7 A zinc coating shall not be less than 0.099 mm (0.0039 in) thick at any point and shall comply with the adherence requirements in Clause 7.7.1 and the bending requirements in Clause 7.7.2.

6.10.2.8 The stainless steel coating or a stainless steel rod shall be formed of an austenitic stainless steel of the 18 % chromium, 8 % nickel type.

6.10.3 Chemically charged rod electrodes

6.10.3.1 A hollow-tube, chemically-charged-rod electrode shall

a) be constructed of copper or an equivalent material resistant to the corrosive effects of moist soil;

b) have an internal diameter not less than 49.3 mm (1.94 in) and a wall thickness not less than 1.93 mm (0.076 in);

c) comply with the minimum length in Clause 6.10.2.1; and

d) be accompanied by adequate installation and maintenance instructions.

6.10.3.2 The chemical charge within the rod electrode shall be a substance that does not cause the electrode to corrode at a faster rate than an electrode constructed of trade size 3/4 (21) ferrous metal conduit.

6.10.3.3 A chemical charge of 60 % sodium chloride and 40 % calcium chloride having a total weight of less than 5 kg (11 lb) may be used without further evaluation.

6.10.4 Plate electrodes

6.10.4.1 A plate electrode shall

a) be not less than 6.4 mm (1/4 in) in thickness if of iron or steel, or 1.5 mm (0.06 in) if of nonferrous metal, other than aluminum;

b) have a total surface area of not less than 0.186 m^2 (2 ft^2);

c) if provided with a means of connection to the system grounding conductor, have connections that comply with the requirements of Clauses 6.1.3, 7.1, and 7.5; and

d) shall be marked in accordance with Clause 10.10.

6.10.4.2 In Canada, a plate electrode for concrete encasement shall

a) be not less than 6 mm (0.24 in) in thickness if of iron or steel or 1.5 mm (0.06 in) if of nonferrous metal, other than aluminum;

b) have a total surface area of not less than 0.4 m^2 (4.3 ft^2);

c) have a means of connection to the system-grounding conductor that shall be accessible. Solderless connections used for attachment to the system grounding conductor shall comply with the requirements of Clauses 6.1.3, 7.1, and 7.5; and

d) comply with the requirements of Clauses 6.4 and 10.11.

In the United States, the requirements of Clause 6.10.4.1 apply to all plate electrodes.

6.11 Ground mesh

6.11.1 Ground mesh shall consist of 8 AWG minimum copper or copper alloy wire, stainless steel wire, or other material found to meet the requirement of this Standard.

6.11.2 The wire shall be fashioned into a grid. The grid pattern shall not have any dimension less than 102 mm (4 in) or greater than 610 mm (24 in). The intersections of the wires of the grid shall be welded or brazed.

6.12 Miscellaneous devices

Grounding or bonding devices not specifically covered in the preceding requirements, such as bonding locknuts, gaskets, grounding wedge lugs, signal reference grids, exothermic welding connection systems (see Annex D), twist-on connecting devices, and adapters, shall be judged under the intent of these requirements. Special attention shall be given to the reliability of the bonding afforded, the protection of iron and steel parts against corrosion, and the provision of means for the connection of suitable grounding or bonding conductors where the use of such conductors is involved. Unusual features and those not contemplated by these requirements shall be investigated to determine if they are suitable for the purpose.

7 Test requirements

7.1 Wire connectors

7.1.1 Except as stated in Clause 7.1.2, wire connectors provided as part of a grounding or bonding device shall comply with the static heating sequence and the mechanical sequence test requirements of NMX-J-543-ANCE, CSA C22.2 No. 65 or UL 486A-486B, or NMX-J-548-ANCE, CSA C22.2 No. 188, or UL 486C, as appropriate. The static heating test of the static heating sequence is not required.

7.1.2 A binding-screw-type connector employed in a grounding device shall not be required to be subjected to these tests.

7.2 Tightening force for ground clamps

7.2.1 A ground clamp shall withstand, without damage, a tightening force applied to each clamping bolt or screw when assembled on each size of grounding electrode with which it is intended to be used.

7.2.2 With regards to Clause 7.2.1, an acorn style clamp that has been subjected to the requirements in Clause 7.1 need not be subjected to this test.

7.3 Pull – protective-type ground clamp

A protective-type ground clamp having provision for the connection of cable armor or an armored grounding conductor shall withstand for 5 min a pull of 667 N (150 lb) applied between the device and the armor of an armored grounding conductor of the proper size.

7.4 Grounding and bonding devices with throat liners

7.4.1 Grounding and bonding devices with throat liners shall comply with the performance requirements for Bushings, Insulating bushings, and Fittings with throat liners of CSA C22.2 No.18.3, NMX-J-017-ANCE, or UL 514B.

7.5 Short-time current

7.5.1 A grounding or bonding device shall not crack, break, or melt when subjected to the current and time specified in Table 5.

Note 1: Arcing, burning, and melting of a throat insulator is acceptable.

Note 2: Burning, cracking, and melting of the insulation or gripping surface of a grounding and/or bonding connector is acceptable.

7.5.2 After having carried the current specified in Clause 7.5.1, continuity shall be maintained on the test sample assembly.

7.6 Thickness of protective coating

7.6.1 The measured thickness of any protective coating shall comply with the requirements in Clause 6 for that particular device.

7.6.2 The coating on the head of a bolt or screw may be considered to be representative of the shank and thread.

7.6.3 A cut, stencilled, or threaded surface of a device not intended for burial in earth or embedment in concrete need not be tested.

7.7 Rod electrodes

7.7.1 Adherence of coating

There shall be no separation of the coating from the steel core when subjected to the test described in Clause 9.7.1. Peeling of the coating by the steel plates or the jaws of the vise shall be allowed.

7.7.2 Bending

There shall be no cracking of the coating when subjected to the test described in Clause 9.7.2.

7.8 Coating integrity

The coating of a strap-type ground clamp shall neither flake off nor crack when the strap is subjected to the test described in Clause 9.8.

7.9 Temperature conditioning (communications strap-type clamp)

Prior to performing the short-time current test, a communications strap-type clamp for outdoor use shall be conditioned.

7.10 Grounding and bonding devices for the termination of armor

Grounding and bonding devices for the termination of the armor on armored grounding wire shall comply with the performance requirements for Fittings for armored cable in CSA C22.2 No.18.3, NMX-J-017-ANCE, or UL 514B.

8 Sampling requirements

8.1 Wire connectors

The minimum number of samples shall comply with

a) NMX-J-543-ANCE, CSA C22.2 No. 65, or UL 486A-486B; or

b) NMX-J-548-ANCE, CSA C22.2 No. 188, or UL 486C.

8.2 Tightening force for ground clamps

8.2.1 To determine if a ground clamp complies with the requirement in Clause 7.2, two samples of a representative size of each design shall be subjected to the test described in Clause 9.2.

8.2.2 If the ground clamp is designed for use with a range of electrode sizes, two samples shall be tested for both the largest and smallest sizes specified. If a reversible part is employed, two samples shall be tested in both the normal and reversed positions.

8.3 Pull – protective-type ground clamp

To determine if a protective-type ground clamp complies with the requirement in Clause 7.3, two samples shall be subjected to the test described in Clause 9.3.

8.4 Grounding and bonding devices with throat liners

8.4.1 The minimum number of samples shall comply with CSA C22.2 No. 18.3, NMX-J-017-ANCE, or UL 514B.

8.4.2 For a line of a particular design, not less than three samples of each trade size shall be tested.

8.5 Short-time current

To determine if a grounding or bonding device complies with the requirement in Clause 7.5, three samples shall be subjected to the test described in Clause 9.5.

8.6 Thickness of protective coating

To determine if a grounding or bonding device complies with the requirement in Clause 7.6, three samples shall be subjected to the test described in Clause 9.6.

8.7 Rod electrodes

8.7.1 Adherence of coating

To determine if a grounding or bonding device complies with the requirement in Clause 7.7.1, three samples shall be subjected to the test described in Clause 9.7.1.

8.7.2 Bending

To determine if a grounding or bonding device complies with the requirement in Clause 7.7.2, three samples shall be subjected to the test described in Clause 9.7.2.

8.8 Coating integrity

To determine if a grounding or bonding device complies with the requirement in Clause 7.8, three samples shall be subjected to the test described in Clause 9.8.

8.9 Temperature conditioning (communications strap-type clamp)

To determine if a grounding or bonding device complies with the requirement in Clause 7.9, three samples shall be subjected to the test described in Clause 9.9.

8.10 Grounding and bonding devices for the termination of armor

The minimum number of samples shall comply with CSA C22.2 No. 18.3, NMX-J-017-ANCE, or UL 514B.

9 Test methods

9.1 Wire connectors

Test methods shall be in accordance with

a) NMX-J-543-ANCE, CSA C22.2 No. 65, or UL 486A-486B; or

b) NMX-J-548-ANCE, CSA C22.2 No. 188, or UL 486C.

9.2 Tightening force for ground clamps

A tightening torque of 16.9 N·m (150 lbf-in) shall be applied to each clamping bolt or screw. For a clamping screw intended to be tightened only by a screwdriver, a torque of 5.6 N·m (50 lbf-in) shall be applied.

9.3 Pull – protective-type ground clamp

The armor (of the armored cable) shall be assembled to the protective-type ground clamp in the intended manner. The conductor (of the armored cable) shall not be connected. Bolts and screws shall be tightened with the torque specified in Clause 9.2. The protective-type ground clamp shall be fixed. The specified tensile pull shall then be applied to the armor.

9.4 Grounding and bonding devices with throat liners

9.4.1 The throat of a bushing made of an insulating material shall have a thickness not less than the thickness used to determine the vertical burning rate.

9.4.2 Test methods shall be in accordance with CSA C22.2 No. 18.3, NMX-J-017-ANCE, or UL 514B.

9.4.3 The throat insulator shall be assigned one of the temperature ratings specified in Table 6, and it shall be marked where visible after installation with its temperature rating.

9.5 Short-time current

9.5.1 If the grounding or bonding devices are provided with specific instructions for assembling the connector to the conductor, such instructions shall be followed in the preparation of the test specimen.

Note: In Clauses 9.5.2 to 9.5.10, grounding or bonding devices are referred to as devices.

9.5.2 A device intended for use with a grounding conductor shall be mounted on a length of maximum size ground rod, rebar, conduit, galvanized pipe, or brass fitting for which it is intended to be used; or on an enclosure or outlet box in the intended manner.

9.5.3 A device intended to bond conduit to an enclosure shall be tested by assembling the device, with the maximum intended size conduit, to a typical enclosure, such as a 102 mm (4 in) square outlet box.

9.5.4 A device, such as a twist-on wire connector, not intended for attachment to a ground rod, rebar, conduit, pipe, outlet box, etc., shall be assembled in the intended manner using its largest rated conductors.

9.5.5 A grounding conductor of the maximum intended size, not less than 610 mm (2 ft) long, shall be installed. A wire connector employed to hold the conductor(s) shall be tightened using a torque specified in NMX-J-543-ANCE, CSA C22.2 No. 65, or UL 486A-486B, or NMX-J-548-ANCE, CSA C22.2 No. 188, or UL 486C.

9.5.6 The specified torque shall be applied by

a) tightening the fastening until the specified value of torque is attained; and

b) maintaining this value, with a static torque reading, for 5 s.

9.5.7 If the device is designed to be assembled to a conductor by means of more than one type of specific tool, the device shall meet the performance requirements when any intended type of specific tool is employed in the assembly operations.

Note: In some cases, an additional series of tests will have to be carried out in order to assess the performance of the device when assembled using each intended type of specific tool.

9.5.8 The test current shown in Table 5 shall pass through the assemblies specified in Clauses 9.5.2 to 9.5.4. The current shall be applied for the time specified in Table 5.

For AC testing, the test current specified in Table 5 shall be treated as the root mean square (RMS) over a waveform's entire test duration.

The test current shall be based on either the conduit size involved, rebar size, or the largest size of wire for which the device is marked, whichever is less.

For a plate electrode intended for concrete encasement, the test shall be conducted between the plate and the means of attachment. The test current in Table 5 shall be determined by the means of attachment.

When the conductor cannot maintain minimum current as defined in Table 5, the current may be reduced to a lesser value, but not less than 5000 A, provided the test time is increased to a higher value, not to exceed 1 min. The values for test current and time are calculated using the formula in Table 5.

9.5.9 After having carried the current specified in Clause 9.5.8, the test assembly shall have continuity, when measured between a point on the ground rod, rebar, wire, conduit, pipe, enclosure, brass fitting, or outlet box 6.4 mm (1/4 in) from the connection of a grounding or bonding device and a similar point on the conductor (see Figure 1). For a test assembly in accordance with Clause 9.5.4, continuity shall be maintained between the conductors as measured at a connection point 6.4 mm (1/4 in) from the device.

If the grounding conductor opens and fails to carry the required current for the time specified in Clause 9.5.8, the test is inconclusive. The test may be repeated using an alternate grounding conductor capable of carrying the required current for the time specified. An example would be substituting copper for an aluminum conductor.

9.5.10 Any indicating means, such as an ohmmeter, battery-and-buzzer combination, or the like, may be used to determine whether continuity exists.

9.6 Thickness of protective coating

9.6.1 The thickness of a protective coating shall be determined by a reliable electronic or magnetic method, or by an electrochemical method; see Clauses 9.6.2 to 9.6.10.

9.6.2 To calculate the thickness of a protective coating being tested, the thickness factor appropriate for the temperature at which the test was conducted shall be selected from Table 7, multiplied by 0.00025 mm (0.00001 in), and multiplied by the time in seconds required to expose base metal as described in Clause 9.6.9.

9.6.3 The method of determining the thickness of zinc coatings by the electrochemical method is described in Clauses 9.6.4 to 9.6.10.

9.6.4 The solution to be used for the electrochemical method shall contain distilled water, 200 g per litre of reagent grade chromic acid (CrO_3), and 50 g per litre of reagent-grade concentrated sulphuric acid (H_2SO_4).

Note: The latter is equivalent to 27 mL per litre of reagent-grade concentrated sulphuric acid, specific gravity 1.84, containing 96 % of H_2SO_4.

9.6.5 The test solution shall be contained in a glass vessel such as a separatory funnel with the outlet equipped with a stopcock and a capillary tube having an inside bore of 0.64 mm (0.025 in) and a length of 140 mm (5.5 in). The lower end of the capillary tube shall be tapered to form a tip, the drops from which are about 0.05 mL each. To preserve an effectively constant level, a small glass tube shall be inserted in the top of the funnel through a rubber stopper, and its position shall be adjusted so that, when the stopcock is opened, the drop rate shall be 100 ±5 drops per minute.

Note: An additional stopcock may be used in place of the glass tube to control the drop rate.

9.6.6 The test shall be conducted at a room temperature of 21 °C to 32 °C (70 °F to 90 °F). The sample and the test solution shall be kept in the test room long enough to acquire the temperature of the room, which shall be noted and recorded.

9.6.7 Each sample shall be thoroughly cleaned before testing. All grease, lacquer, paint, and other nonmetallic coatings shall be removed completely by means of solvents. Samples shall then be thoroughly rinsed in water and dried with clean cheesecloth. Care shall be exercised to avoid contact of the cleaned surface with the hands or any foreign material.

9.6.8 The sample to be tested shall be supported from 18 mm to 25 mm (0.7 in to 1 in) below the orifice, so that the drops of solution strike the point to be tested and run off quickly. The surface to be tested shall be inclined to 45° ±5° from horizontal.

9.6.9 After cleaning, the sample to be tested shall be put in place under the orifice. The stopcock shall be opened and the time in seconds shall be measured with a stop watch until the dropping solution dissolves the protective metal coating exposing the base metal. The end of the test is the first appearance of the base metal recognizable by a change in color at that point.

9.6.10 Each sample of a test lot shall be subjected to the test at three or more points on the inside surface and at an equal number of points on the outside surface, at places where the metal coating may be expected to be the thinnest.

Note: On grounding and bonding equipment made from precoated sheets, the external corners that are subjected to the greatest deformation are likely to have thin coatings.

9.7 Rod electrodes

9.7.1 Adherence of coating

A 457 mm (18 in) length of the rod with one end cut to a 45° point shall be driven between two steel clamping plates or the jaws of a vise set 1.02 mm (0.04 in) less than the diameter of the rod, so as to shear off sufficient metal to expose the bond between the coating and rod.

9.7.2 Bending

A length of the rod shall be rigidly held in a clamp or vise. A force shall be applied normal to the free end of the rod at a distance from the clamping device equal to 40 times the rod diameter. The application of force shall be such that the rod is permanently bent through a 30° angle (see Figure 2).

9.8 Coating integrity

The steel strap of a strap-type ground clamp shall be tightly wrapped at least half-way around a 12.7 mm (1/2 in) diameter mandrel.

9.9 Temperature conditioning (communications strap-type clamp)

Prior to performing the short-time current test, a communications strap-type clamp for outdoor use shall be conditioned for 20 cycles, each cycle consisting of exposure to a temperature of 0 °C (32 °F) for 8 h followed by 60 °C (140 °F) for 16 h.

9.10 Grounding and bonding devices for the termination of armor

Test methods shall be in accordance with CSA C22.2 No. 18.3, NMX-J-017-ANCE, or UL 514B.

10 Marking, labeling, and packaging

Note: In Canada, there are two official languages, English and French. Annex B provides French translations of the markings specified in this Standard. All markings required by this Standard may be in other languages to conform with the language requirements of the country where the product is to be used.

10.1 A ground clamp shall be permanently marked where readily visible as follows:

a) A clamp shall be marked with

i) the manufacturer's name, trade name, or both, or any other acceptable marking whereby the organization responsible for the product can be readily identified; and

ii) the size of electrode, pipe, tubing, or rebar and the size of the grounding conductor with which the clamp is intended to be used.

Note: Electrode, pipe, and tubing trade sizes are usually stated in fractions such as 1/2, 5/8, etc., whereas rebar sizes can be specified by fractions or a number such as 3, 4, 5, etc. (This number represents the numerator of the fraction when stated in eighth inch increments, i.e., 4 = 4/8ths).

b) A protective clamp shall be marked with the size of metal conduit or armor, unless the size is obvious.

c) A clamp larger than the 53 (2) trade size shall be marked with a distinctive catalog number or equivalent identification.

d) For a 53 (2) trade size or smaller clamp, the catalog number or an equivalent identification shall be marked on at least one of the following:

i) clamp;

ii) smallest unit, carton, or package;

iii) clamp and the package; or

iv) durable tag with an eyelet or other means found to be acceptable.

e) A ground clamp rated for direct burial in earth and embedment in concrete shall be marked "Direct Burial", "DB", or an equivalent marking.

f) A clamp that is suitable for use with aluminum wire only shall be marked "AL".

g) A clamp that is suitable for use with both aluminum and copper wire shall be marked "AL-CU".

h) A clamp that is suitable for use with copper water tubing shall be marked as specified in Item (a)(ii) and either preceded or followed by the words "Copper Water Tubing" or the equivalent.

i) A clamp that is suitable for use with a brass fitting shall be marked "Brass Fitting – X", or "BF – X", where "X" is a numeric number or fraction representing the fitting size. See Clause 10.12.

Note: UPC labels do not meet the intent of readily identifying the organization responsible for the product.

10.2 A grounding or bonding bushing shall be permanently marked where readily visible as follows:

a) A bushing shall be marked with the manufacturer's name, trade name, or both, or any other distinctive marking whereby the organization responsible for the product can be readily identified.

b) A bushing larger than the 53 (2) trade size shall be marked with a distinctive catalog number or equivalent identification.

c) For a 53 (2) trade size or smaller bushing, the catalog number or equivalent identification shall be marked on at least one of the following:

i) bushing;

ii) smallest unit, carton, or package;

iii) bushing and the package; or

iv) durable tag with an eyelet or other means found to be acceptable.

d) A bushing that does not have a mounting for a separable wire connector shall be marked with the size of the grounding conductor with which the bushing is intended to be used.

e) For a bushing provided with a separable wire connector, the connector shall be marked with the size of the grounding conductor with which the connector is intended to be used.

f) For a bushing having a mounting for a separate wire connector, but supplied without a wire connector as permitted by Clause 6.6.5, the size of conductor accommodated by each connector shall be marked on the connector, and the identity of the connector intended for use with the bushing shall be marked on at least one of the following:

i) bushing;

ii) smallest unit, carton, or package; or

iii) bushing and the package.

Note: UPC labels do not meet the intent of readily identifying the organization responsible for the product.

10.3 A grounding or bonding locknut shall be permanently marked where readily visible as follows:

a) A locknut shall be marked with the manufacturer's name, trade name, or both, or any other distinctive marking whereby the organization responsible for the product can be readily identified.

b) A locknut larger than the 53 (2) trade size shall be marked with a distinctive catalog number or equivalent identification.

c) For a 53 (2) trade size or smaller locknut, the catalog number or equivalent identification shall be marked on at least one of the following:

i) locknut;

ii) smallest unit, carton, or package; or

iii) locknut and the package.

Note: UPC labels do not meet the intent of readily identifying the organization responsible for the product.

10.4 A fitting with the environmental ratings specified in Clause 6.1.8 shall be marked in accordance with CSA C22.2 No. 18.3, NMX-J-017-ANCE, or UL 514B.

10.5 In a series or complete line of products that consists of devices assembled from interchangeable parts, each part shall have a marking that, taken together with the markings on all of the other parts assembled as intended to form a complete device, results in a distinctive catalog number, type designation, or the like that identifies the assembled device.

Note: As an example of compliance of devices with the requirement in Clause 10.5, threaded parts for the connection of metal conduit might be designated and marked A for trade size 1/2 (16), B for trade size 3/4 (21), C for trade size 1 (27), D for trade size 1-1/4 (35), and the like. Clamp parts for water-pipe or rod electrodes might be designated and marked 2 for trade size 1/2 (16), 3 for trade size 3/4 (21), 4 for trade size 1 (27), 5 for trade size 1-1/4 (35), and the like. Then the complete assemblies constituting the series would be designated and identifiable as A-2, B-3, B-4, C-3, C-4, D-5, and the like.

10.6 The temperature rating of an insulating bushing shall be marked or color-coded in accordance with CSA C22.2 No. 18.3, NMX-J-017-ANCE, or UL 514B.

10.7 The marking of a ground rod shall be located within 305 mm (12 in) of the top of the rod and shall include the following:

a) the manufacturer's name, trade name, or both, or any other distinctive marking whereby the organization responsible for the product can readily be identified;

b) a distinctive catalog number or an equivalent identification; and

c) the length of the rod.

Note: UPC labels do not meet the intent of readily identifying the organization responsible for the product.

10.8 The following information shall be plainly marked on a tag that is to be tied to every shipping length of finished armored grounding wire. If the wire is wound on a reel or coiled in a carton, the tag may be glued, tied, stapled, or otherwise attached to the reel or carton, or the information may be printed or stencilled on the reel or carton. Other information may be included if it is not confusing or misleading. The marking shall be as follows:

a) the words "armored grounding wire";

b) the manufacturer's name, trade name, or both, or any other distinctive marking whereby the organization responsible for the product can readily be identified; and

c) the wire size of the grounding conductor.

Note: UPC labels do not meet the intent of readily identifying the organization responsible for the product.

10.9 An armored grounding conductor shall have a distinctive marking throughout its entire length by which it may be readily identified as the product of a particular factory. The marking shall consist of a letter or symbol legibly indented or embossed in the armor at intervals of not more than 305 mm (12 in).

10.10 A plate electrode conforming to Clause 6.10.4.1 shall be marked with the manufacturer's name, trade name, or both, or any other distinctive marking whereby the organization responsible for the product can readily be identified.

Note: UPC labels do not meet the intent of readily identifying the organization responsible for the product.

10.11 A plate electrode for concrete encasement conforming to Clause 6.10.4.2 shall be marked within 50 mm (2 in) of the top of the means for attachment of the system-grounding conductor with the information in Clause 10.10.

10.12 A clamp intended for use with brass fittings shall be provided with installation instructions that include the size(s) of the fitting nut for which it is intended to be used.

Table 1
Sizes of terminal screws

(See Clause 6.1.5.)

Size of conductor		Minimum size of screw*	
AWG	(mm^2)	in	(mm)
14 – 8	(2.1 – 8.4)*	No. 10	(4.8)
6	(13.3)	1/4	(6.4)
4	(21.2)	5/16	(7.9)
* The common form of wire-binding screw shall not be considered acceptable for securing a wire larger than 8 AWG (8.4 mm^2) solid or 10 AWG (5.3 mm^2) stranded.			

Table 2
Straps for protective-type clamps

(See Clause 6.2.4.)

Metal conduit		Minimum number of straps
Metric designator	Trade size	
16	1/2	1
21	3/4	2
27	1	3

Table 3
Sizes of connected conductors

(See Clause 6.6.4.)

Bushing		Minimum size of grounding or bonding conductor	
Metric designator	Trade size	AWG	(mm^2)
35 and smaller	1-1/4 and smaller	8	(8.4)
41	1-1/2	6	(13.3)
53	2	4	(21.2)
63	2-1/2	2	(33.6)
78	3	1/0	(53.5)
91, 103	3-1/2, 4	2/0	(67.4)
129, 155	5, 6	3/0	(85.0)

Table 4
Weights of single-strip armor

(See Clauses 6.9.2 and 6.9.3.3.)

Size of conductor		Minimum weight, kg/30.5 m (lb/100 ft)			
AWG	(mm^2)	Solid conductor		Stranded conductor	
8	(8.4)	3.2	(7.05)	3.6	(7.97)
6	(13.3)	3.9	(8.60)	4.3	(9.53)
4	(21.2)	4.7	(10.30)	5.2	(11.48)

Table 5
Short-time test currents

(See Clauses 7.5.1 and 9.5.8.)

Rebar		Conduit		Equipment grounding and bonding conductor size		Test current, A			
Metric designator	Trade size	Metric designator	Trade size	AWG or kcmil	(mm^2)	Time, s	Copper	Aluminum	Steel rebar
–	–	–	–	20 AWG	(0.52)	4	70	40	–
–	–	–	–	18	(0.82)	4	115	65	–
–	–	–	–	16	(1.3)	4	185	105	–
–	–	–	–	14	(2.1)	4	300	170	–
–	–	–	–	12	(3.3)	4	470	270	–
–	–	–	–	10	(5.3)	4	750	430	–
–	–	16	1/2	8	(8.4)	4	1180	680	–
–	–	21, 27	3/4, 1	6	(13.3)	6	1530	880	–
–	–	35, 41	1-1/4, 1-1/2	4	(21.2)	6	2450	1400	–
–	–	–	–	3	(26.7)	6	3100	1770	–
–	–	53	2	2	(33.6)	6	3900	2230	–
–	–	63	2-1/2	1	(42.4)	6	4900	2800	–
–	–	78, 91, 103	3, 3-1/2, 4	1/0	(53.5)	9	5050	2900	–
#10	#3 (3/8)	–	–	2/0	(67.4)	9	6400	3600	2900
–	–	129, 155	5, 6	3/0	(85.0)	9	8030	4600	–
–	–	–	–	4/0	(107)	9	10100	5800	–
#13	#4 (1/2)	–	–	250 kcmil	(127)	9	12000	6900	5300
–	–	–	–	300	(152)	9	14300	8200	–
–	–	–	–	350	(177)	9	16700	9600	–
#16	#5 (5/8)	–	–	400	(203)	9	19100	11000	8200
#19	#6 (3/4)	–	–	500	(253)	9	23900	13700	11700
–	–	–	–	600	(304)	9	28700	16500	–

Table 5 Continued on Next Page

Table 5 Continued

Rebar		Conduit		Equipment grounding and bonding conductor size		Test current, A			
Metric designator	Trade size	Metric designator	Trade size	AWG or kcmil	(mm^2)	Time, s	Copper	Aluminum	Steel rebar
–	–	–	–	700	(355)	9	33500	19250	–
#22	#7 (7/8)	–	–	750	(380)	9	35900	20600	16000
–	–	–	–	800	(405)	9	38300	22000	–
–	–	–	–	900	(456)	9	43100	24700	–
#25	#8 (1)	–	–	1000	(507)	9	47900	27500	21000

Note: Test current values are derived from the following formula and have been rounded. To derive test current values for electrode materials other than the ones listed above, see Annex C of IEEE 837-2002.

$$I = A\sqrt{\frac{ln\frac{K_o + T_m}{K_o + T_a}}{\beta * t}}$$

where

T_m = 1083 °C for melting point for copper and 657 °C for melting point for aluminum and 1510 °C for melting point for steel

T_a = 40 °C = ambient temperature

I = short time current (amperes) in kA

A = conductor cross section in mm^2

t = time (s)

K_o = reciprocal of thermal coefficient of resistivity at 0 °C = 234 for copper and 228 for aluminum and 605 for steel

β = material constant = 19.8 for copper and 45.1 for aluminum and 77.5 for steel

Table 6
Temperatures for conditioning bushings and parts

(See Clause 9.4.3.)

Temperature rating of device, °C	Oven temperature, °C
90	112
105	128
150	173

Table 7
Coating thickness factors

(See Clause 9.6.2.)

Temperature, °C	Thickness factors for zinc protective coatings
21.1	0.980
21.7	0.990
22.2	1.000

Table 7 Continued on Next Page

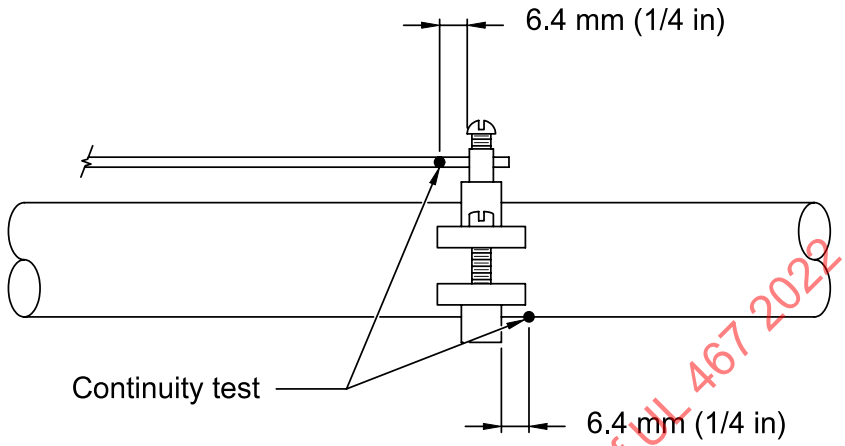
Table 7 Continued

Temperature, °C	Thickness factors for zinc protective coatings
22.8	1.010
23.3	1.015
23.9	1.025
24.4	1.033
25.0	1.042
25.6	1.050
26.1	1.060
26.7	1.070
27.2	1.080
27.8	1.085
28.3	1.095
28.9	1.100
29.4	1.110
30.0	1.120
30.6	1.130
31.1	1.141
31.7	1.150
32.2	1.160

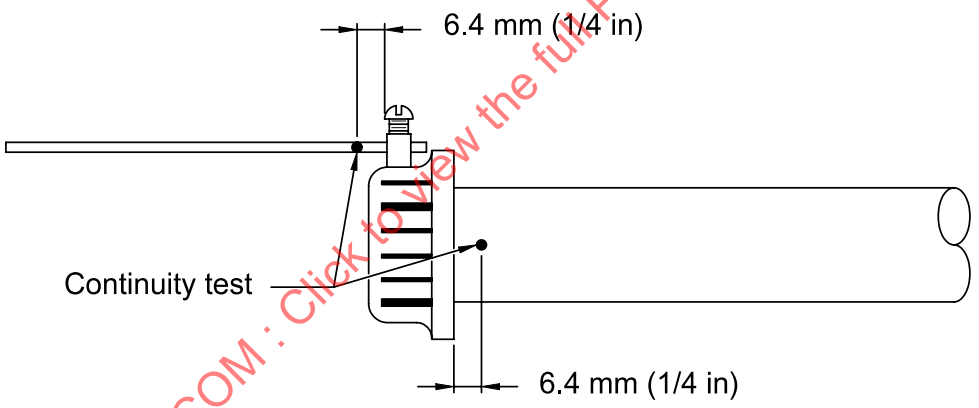
Figure 1

Continuity test points

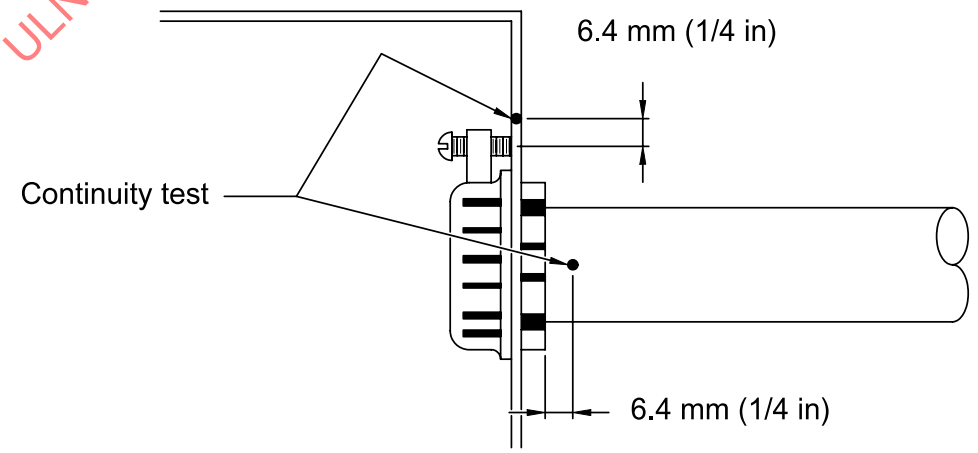
(See Clauses 3 and 9.5.9.)



(a) Typical ground clamp



(b) Typical grounding bushing



(c) Typical bonding bushing

S5420