

IEEE Recommended Practice for Seismic Design of Substations

IEEE Power and Energy Society

Sponsored by the
Substation Design Criteria Committee



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(Revision of
IEEE Std 693-2005)

IEEE Recommended Practice for Seismic Design of Substations

Sponsor

Substation Design Criteria Committee
of the
IEEE Power and Energy Society

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Abstract: Seismic design recommendations for substations, including qualification of different equipment types are discussed. Design recommendations consist of seismic criteria, qualification methods and levels, structural capacities, performance requirements for equipment operation, installation methods, and documentation.

Keywords: anchorage, conductor, electrical equipment, damping, dynamic analysis, IEEE 693™, loads, projected performance, required response spectrum, seismic protective devices, seismic qualification, shake table, static coefficient analysis, support structure, suspended equipment, time history

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Introduction

This introduction is not part of IEEE Std 693-2018, IEEE Recommended Practice for Seismic Design of Substations.

This revision of IEEE Std 693-2005 was developed as a recommended practice for the seismic design of substations. This recommended practice emphasizes the seismic qualification of electrical equipment. Nuclear Class 1E equipment is not covered by this recommended practice, but it is covered by IEEE Std 344™.

This recommended practice is intended to establish standard methods of providing and validating seismic withstand capability of electrical substation equipment. It provides detailed test and analysis methods for selected common equipment types of major equipment or components found in electrical substations.

This recommended practice is intended to assist the substation user or operator in providing substation equipment that will have a high probability of withstanding seismic events to predefined ground acceleration levels. It establishes standard methods of verifying seismic withstand capability. This gives the substation designer the ability to select equipment from various manufacturers, knowing that the seismic withstand rating of each manufacturer's equipment is an equivalent measure.

This recommended practice is also intended to guide the manufacturers of power equipment in the seismic design and in demonstrating and documenting the seismic withstand capability of their product in a form that can be universally accepted.

Although most damaging seismic activity occurs in limited areas, many additional areas could experience an earthquake with forces capable of causing great damage. This recommended practice should be used in all areas that may experience earthquakes.

This revision of the recommended practice incorporates a number of substantive as well as editorial changes from the previous version. The most significant of these changes include the following:

- Shake-table test requirements for qualification of bushings have been modified;
- Conductor seismic loading effects are explicitly included as part of the qualification of certain equipment;
- Time history shake-table testing at the Performance Level is required for most equipment that are required to be qualified by the time history test method;
- Seismic loads for the design of anchorages of inherently acceptable equipment have been increased.

It is the hope of those who worked on the development of this recommended practice that these standard methods of verifying seismic withstand capability will lead to better earthquake performance and to lower qualification costs.

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IEEE Recommended Practice for Seismic Design of Substations

1. Overview

1.1 Scope

The recommended practice contains recommendations for the seismic design of substation buildings, and structures, and the seismic design and qualification of substation equipment.

1.2 Purpose

This recommended practice is for new substations and planned additions or improvements to existing substations. It is not intended that existing substations must be retrofitted to these recommended practices.

~~For instruction~~ Instructions on how to include this recommended practice in specifications, ~~refer to 5.2 are provided.~~ IEEE Std 693TM is designed as an integrated set of requirements for the seismic qualification of electrical power equipment. Users should use IEEE Std 693 ~~as a whole. Do not modify~~ without modification or ~~remove~~ removal of any requirement, except as allowed herein.

~~If any part of this recommended practice is removed, not met, or reduced, then neither the user nor the manufacturer may claim the equipment is in compliance with IEEE Std 693 and should not attach the seismic identification plate to the equipment. The user is strongly urged not to modify any of the requirements herein, including increasing or adding to the requirements.~~

1.3 General

This recommended practice provides minimum requirements for the seismic design of substations, ~~excluding Class 1E and seismic qualification of equipment for nuclear power generation stations.~~ Emphasis is on seismic qualification of electrical equipment and its ~~support is emphasized~~ anchorage. Instructions on the use of this recommended practice is provided in Clause 4.

~~The most~~ There are several important ~~goal~~ goals of this recommended practice; one is to provide a single standard set of design recommendations for seismic qualification of each equipment type. Design recommendations consist of seismic criteria, qualification methods and levels, structural capacities, performance requirements for equipment operation, installation methods, and qualification documentation. The intent of a uniform and consistent seismic qualification procedure is to enable manufacturers to incorporate seismic criteria into their design process and reduce the cost for qualification of substation equipment. ~~, because the~~ Manufacturers can qualify their equipment once for ~~each~~ a given qualification level and ~~eliminate~~ reduce the need for specialized testing. It should also improve earthquake performance by establishing clear performance criteria that take into account the dynamic characteristics of substation equipment.

Another goal of this recommended practice is to allow the user, or user's agent, to secure substation equipment that will have no significant structural damage and maintain electrical functionality at nominal operating conditions during and after a seismic event as specified herein.

This recommended practice establishes three qualification levels ~~are defined for earthquake performance~~. They are low, moderate, and high qualification levels. The user ~~should~~ is required to determine the ~~desired~~ qualification level when purchasing the equipment. ~~See Clause 8.~~

~~Annexes are titled normative or informative. Normative annexes are official parts of this recommended practice. Informative annexes include information only and are not an official part of this recommended practice.~~

~~The following references are recommended for seismic design of substation structures, foundations, and anchorage¹:~~

- ~~— Buildings: International Building Code (IBC), Mexican Code (MDOC/CFE), Uniform Building Code (UBC), or National Building Code of Canada (NBCC).~~
- ~~— Anchorage design: American Society of Civil Engineers (ASCE) Substation Structure Design Guide.~~

¹~~Information on references can be found in Clause 2.~~

~~NOTE—Anchorage design requirements are found in the ASCE Substation Structure Design Guide. Anchorage requirements for equipment qualification are provided in this recommended practice.²~~

- ~~— *Foundation Design:* International Building Code (IBC), Uniform Building Code (UBC), Mexican Code MDOC/CFE, NBCC, or Canadian Foundation Engineering Manual [B6].³~~
- ~~— *Structures:* Strain Bus Structures, A Frames, racks, box structures, rigid bus supports, and all other such substation structures. ASCE Substation Structure Design Guide.~~

~~The ASCE “Guide to Improved Earthquake Performance of Electric Power Systems,” ASCE Manual 96, is a guide that illustrates many methods of installing substation equipment and discusses their advantages. This guide will provide useful information for evaluating existing installation details for good earthquake performance.~~

~~The ASCE “Guide to Reliable Emergency Power for Lifelines and Critical Applications,” ASCE Manual, is a guide that discusses methods of selecting, installing, maintaining, and testing emergency power systems. It illustrates many methods of installation of emergency power equipment and discusses their advantages. This guide provides useful information for evaluating existing installation details for good earthquake performance.~~

1.4 Associated design references

1.4.1 Electrical connections between equipment

The design and implementation of electrical connections between equipment should be in accordance with the recommendations of this recommended practice and IEEE Std 1527TM.

1.4.2 Electrical equipment

Electrical equipment and their associated anchorage should be designed in accordance with the requirements given within this recommended practice and ASCE 113.

³~~The numbers in brackets correspond to those of the bibliography in Annex V.~~

1.4.3 Dedicated support structures

Dedicated support structures, which are qualified together with the equipment, shall be designed in accordance with the requirements of this recommended practice as prescribed by the methodology used to qualify the supported equipment. All other support structures may be designed in accordance with this recommended practice or the requirements given in ASCE 113. Connection of the equipment to any support structure shall be designed in accordance with the requirements of this recommended practice.

1.4.4 Primary substation structures

The seismic design of primary substation structures, (e.g., strain bus structures, A frames, rigid bus structures, etc.) is beyond the scope of this recommended practice and should be designed in accordance with the requirements given in ASCE 113. The anchorage of substation structures should be designed in accordance with ASCE 113.

1.4.5 Foundations

Foundations are designed to have an adequate load capacity with limited settlement and lateral displacement by a civil or geotechnical engineer and the footing itself may be designed structurally by a civil or structural engineer. The primary design concerns are settlement and bearing capacity. When considering settlement, total settlement and differential settlement are normally considered. Foundation loads from the equipment may be designed in accordance with 6.6 or to the requirements of the relevant code in the jurisdiction of the utility and/or substation.

1.4.6 Buildings

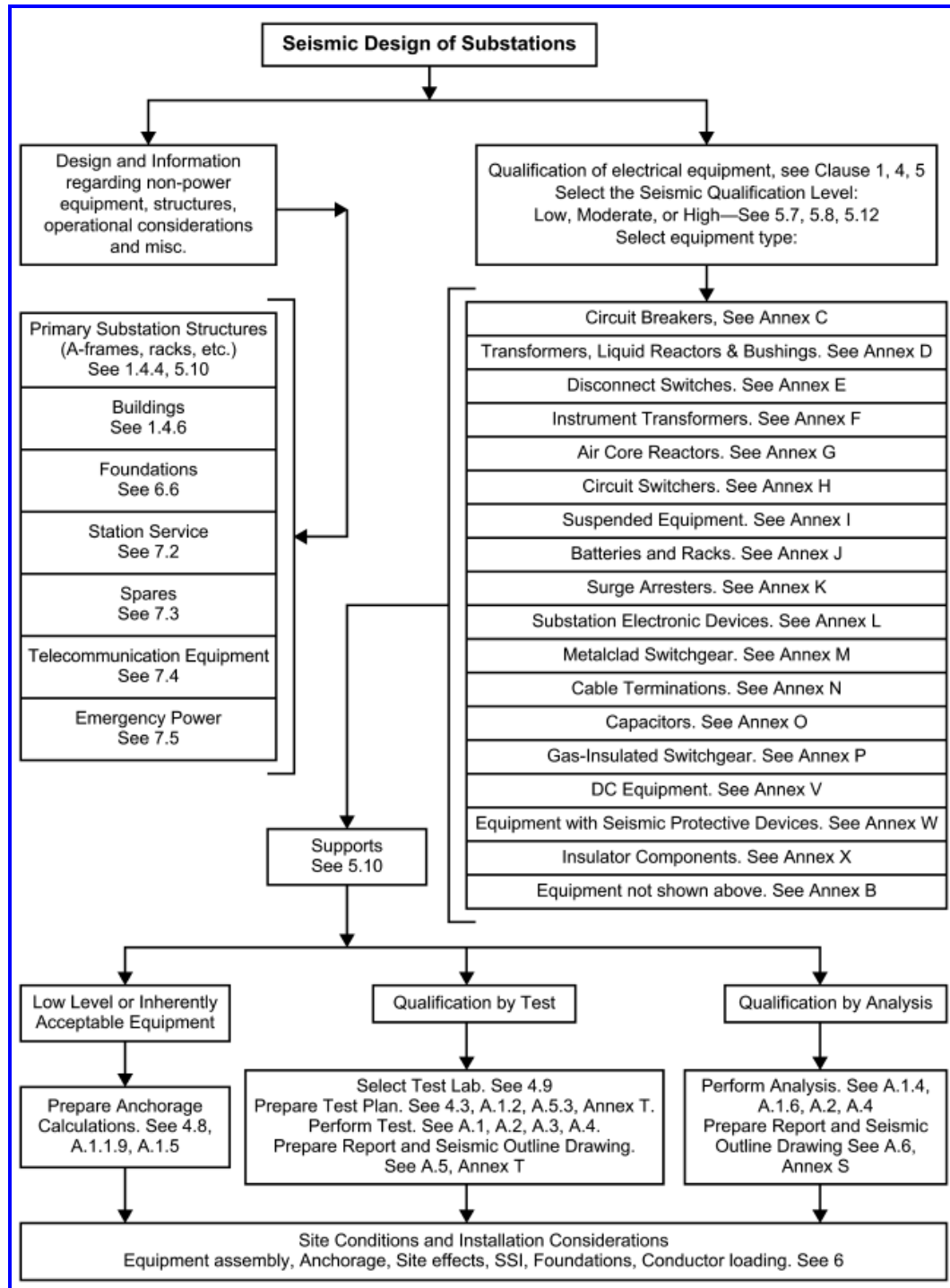
Buildings should be designed in accordance with the requirements of the relevant code in the jurisdiction of the substation.

1.5 Substation seismic design flow chart

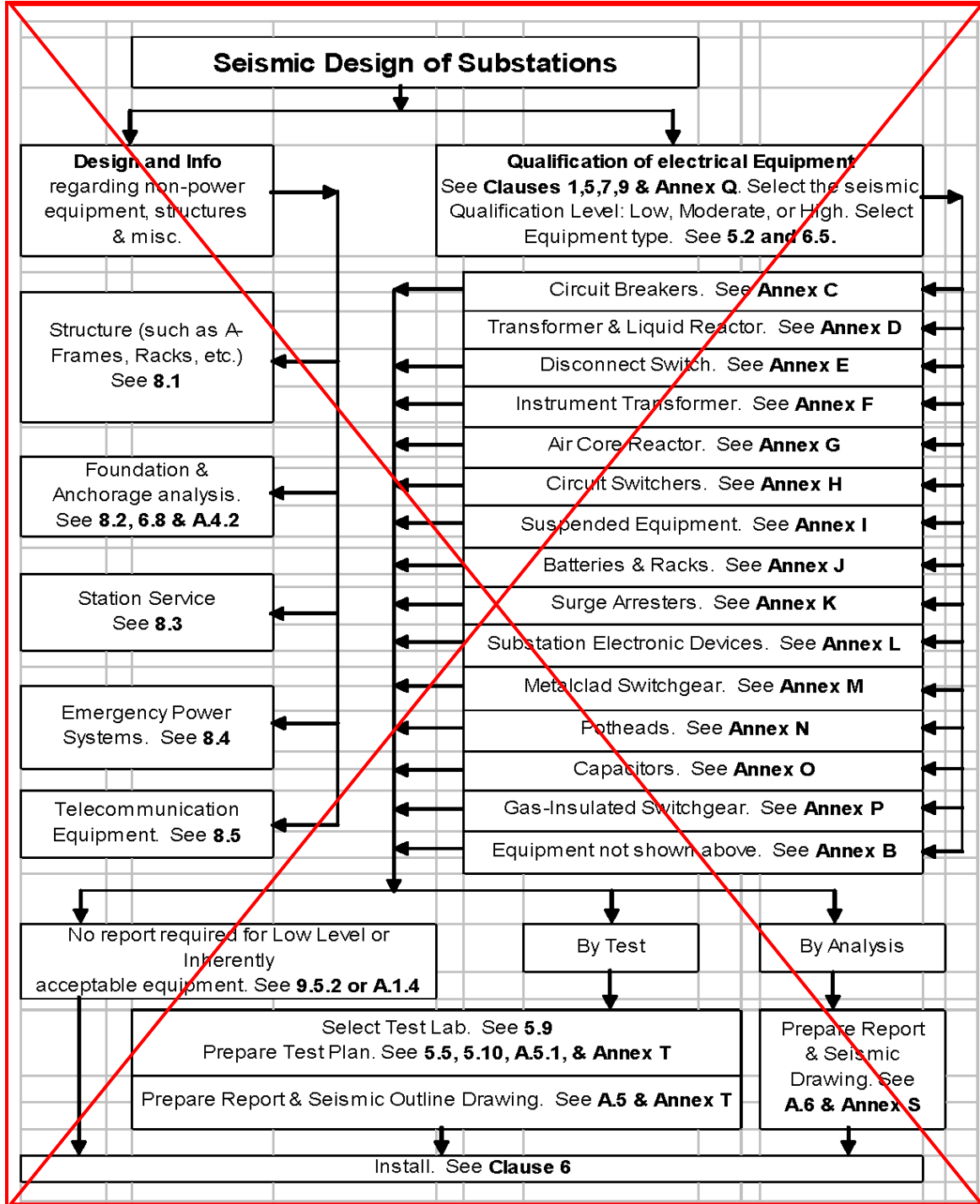
A flow chart (Figure 1) has been provided to help the user determine what clauses or annexes should be used for the seismic design of the substation.

1.4 How to use this recommended practice

Follow the flow chart Figure 1, and read the clauses and annexes noted.



(New)



(Deleted)

Figure 1 – Using this recommended practice

1.6 Earthquakes and substations

~~Earthquakes are caused by~~ An earthquake is the sudden release of energy from rupture of geological faults in the earth's crust in which elastic strain has been accumulating; a ~~geologic fault. Shock~~ sudden lateral or vertical movement of rock along a rupture (break) surface. The seismic waves that radiate from the ~~fault fracture zone and~~ rupture arrive at the earth's surface as a complex multi-frequency vibratory ground motion, having both horizontal and vertical components.

It is this ground shaking, surface faulting, and earthquake induced soil failure that can damage substation equipment.

The poor seismic performance of substations during previous earthquakes, coupled with society's demand for electrical service in a post-earthquake environment, lead to an increased focus on the earthquake survivability of substations.

The initial approach of providing earthquake engineering to substations was based on the approaches used in conventional building structures. However, the realization emerged that the seismic engineering of substations presented unique challenges that differed from buildings. Among these challenges are the need to maintain functionality, the unique materials (e.g., porcelain and composites), relatively low damping and high frequency dynamic characteristics (in comparison to building structures), and the effects of the interconnection of the equipment via electrical conductors.

~~The response of buildings and structures to earthquake ground motion depends on factors, including their configuration, strength of construction, ductility, and their dynamic properties. Lightly damped structures having one or more natural modes of oscillation within the frequency band of ground excitation can experience considerable amplification of the forces, component stresses, and deflections.~~

~~Mechanisms that absorb energy in a structure, in response to its deformation, provide damping.~~

~~If two or more structures or equipment are linked together, such as through a conductor, they may interact with one another producing a modified response and interaction loads. Even when the link is sufficiently flexible to accommodate the relative displacement, forces may be transferred between the structures or equipment including dynamic effects. Therefore, particular care should be given to that design aspect so that the level of forces is minimized. However, provisions should also be taken in equipment design to take such forces into account. (See 5.9 and IEEE Std 1527-2006 [B23].) In particular, many items of substation equipment, for electrical reasons, are highly interconnected and often contain brittle, relatively low strength (compared with, e.g., steels), and/or low damping materials (e.g., porcelain). The conductors are often installed with very small slack. In these cases, after only a little relative motion occurs, damaging nonlinear interaction, including impacting between connected equipment will begin. Thus, items of substation equipment whose natural frequencies lie in the normal frequency range of earthquake ground motion are particularly vulnerable to damage by seismic events.~~

1.7 Design ~~and~~ /construction and quality assurance processes

It is recognized that a substation may not always be designed and constructed solely by a utility using its in-house expertise. A substation may be designed as a “turnkey contract.” In between these two extremes lie many hybrid possibilities, including the involvement of consultants or architect-engineers as third parties.

After the substation is complete, the user should have procedures that ensure that the installed configuration and any subsequent modification or expansion of the substation is subject to proper review of plans and inspection of as-installed facilities to verify that the intentions of this recommended practice are preserved.

~~1.9 Mechanical loads~~

~~Seismic loads (horizontal and vertical, acting simultaneously) are superimposed on other preexisting loads or other loads that may occur due to the earthquake.~~

~~Preexisting loads and loads other than seismic loads include the following:~~

- ~~a) Dead weight (gravitational load)~~
- ~~b) Assembly loads, either deliberate (i.e., by design) or accidental (arising from manufacturing tolerances and assembly misalignment)~~
- ~~c) Line pull (and other interconnections)~~
- ~~d) Wind, snow, and ice loads~~
- ~~e) Internal pressure (or vacuum)~~
- ~~f) Thermal affects (stresses due to thermal expansion, plus influence on strength properties of materials over the full temperature range from minimum ambient to maximum ambient plus temperature rise due to load heating effects)~~
- ~~g) Electromagnetic forces due to normal current and short circuit current~~
- ~~h) Operating mechanism forces and reactions to open and closed contacts~~ Of course, it is not reasonable to expect all of these loads to occur simultaneously.

2. Normative references

The following referenced documents are indispensable for the application of ~~this document~~ [IEEE Std 693](#). The referenced documents must be understood and used in conjunction with this document. Therefore each referenced document is cited in text and its relationship to this document is explained. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

[ACI 318, Building Code Requirements for Structural Concrete and Commentary.](#)¹

¹ [ACI publications are available from the American Concrete Institute, 38800 Country Club Drive, Farmington Hills, MI 48331, USA \(https://www.concrete.org\).](#)

ADM 1-516166, Aluminum Association, Aluminum Design Manual, Specification and Guidelines for Aluminum Structures, ~~2000 Edition~~.^{4 2}

AISC Manual of Steel Construction, ~~Load Resistance Factor Design (LRFD) Third Edition, 2003~~.^{5 3}

[ANSI/NEMA C29.9, Wet Process Porcelain Insulators – Apparatus, Post Type.](#)⁴

~~AISC M016-1989, Manual of Steel Construction, ASD – 9th Edition, Including updates, which exclude the 1/3 increase of allowable stresses.~~

~~ANSI C37.32-2002, High Voltage Switches, Bus Supports, and Accessories – Schedules of Preferred Ratings, Construction Guidelines, and Specifications.~~

ANSI C93.1-~~1999~~, Power-Line Carrier Coupling Capacitor and Coupling Capacitor Voltage Transformers (CCVT) – Requirements.

[ASCE 4, Seismic Analysis of Safety-Related Nuclear Structures.](#)⁵

[ASCE 7, Minimum Design Loads for Buildings and other Structures.](#)

ASCE [113](#), Substation Structure Design Guide.⁷

~~ASTM A36/A36M-04, Standard Specification for Carbon Structural Steel.~~⁸

^{4 2} ADM publications are available from the Aluminum Association, 1525 Wilson Boulevard, Suite 600, Arlington, VA 22209, USA (<http://www.aluminum.org>).

^{5 3} AISC Publications are available from the American Institute of Steel Construction, ~~One 130 East Wacker Drive~~ [Suite 2000](#), Chicago, IL ~~60601-2001~~ [60601](#), USA (<http://www.aisc.org>).

^{6 4} ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

^{7 5} ASCE publications are available from the American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA 20191-4400.

~~ASTM A307-04, Standard Specification for Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength.~~

ASTM F1554-04 Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength.⁶

IBC-2003, International Building Code.⁹⁷

[IEC 60099-4, Surge arresters—Part 4: Metal-oxide surge arresters without gaps for ac systems.](#)⁸

[IEC 61462, Composite hollow insulators—Pressurized and unpressurized insulators for use in electrical equipment with rated voltage greater than 1000 V—Definitions, test methods, acceptance criteria and design recommendations.](#)

[IEC 62155, Hollow pressurized and unpressurized ceramic and glass insulators for use in electrical equipment with rated voltages greater than 1000 V.](#)

[IEC 62231, Composite station post insulators for substations with ac voltages greater than 1000 V up to 245 kV—Definitions, test methods and acceptance criteria.](#)

[IEC 62231-1, Composite station post insulators for substations with ac voltages greater than 1000 V up to 245 kV—Part 1: Dimensional, mechanical, and electrical characteristics.](#)

[IEC 62271-102, High voltage switchgear and controlgear—Part 102: Alternating current disconnectors and earthing switches.](#)

⁶ ⁶ ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

⁹ ⁷ IBC publications are available from International Code Council, 900 Montclair Road, Birmingham, AL 35213-1206, USA.

⁸ ⁸ IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3 Rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

IEEE Std 48TM-~~1996 (Reaff 2003)~~, IEEE Standard Test Procedures and Requirements for Alternating-Current Cable Terminations 2.5 kV through 765 kV. ~~9, 10, 11~~

IEEE Std 518TM-~~1982 (Reaff 1996) (Withdrawn)~~, IEEE Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources.

IEEE Std 824TM-~~1994~~, IEEE Standard for Series Capacitors in Power Systems. IEEE Std 1036TM -~~1992~~, IEEE Guide for Application of Shunt Power Capacitors.

IEEE Std 1527-~~2006~~TM, IEEE Recommended Practice for the Design of ~~Flexible~~ Buswork Located in Seismically Active Areas.

[IEEE Std C37.016TM, IEEE Standard for AC High-Voltage Circuit Switcher Rated 15.5 kV through 245 kV.](#)

~~ANSI~~ [IEEE Std C37.06-~~2000~~TM](#), Switchgear—AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities.⁶

IEEE Std C37.09TM -~~1999~~, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

[IEEE Std C37.20.1TM, IEEE Standard for Metal-Enclosed Low-Voltage \(1000 Vac and below, 3200 Vdc and below\) Power Circuit Breaker Switchgear.](#)

IEEE Std C37.20.2TM-~~1999~~, IEEE Standard for Metal-Clad Switchgear.

[IEEE Std C37.30.1TM, IEEE Standard for High-Voltage Air Switches for Alternating Current, Rated Above 1000 Volts.](#)

~~10~~⁹ IEEE publications are available from The Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

~~11~~ ¹⁰ The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.

IEEE Std C37.90.1TM-~~2002~~, IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems Associated With Electric Power Apparatus.

IEEE Std C37.90.2TM-~~2004~~, IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

[IEEE Std C37.100.1TM, IEEE Standard for Common requirements for switchgear rated above 1000 Volts.](#)

IEEE Std C37.122TM-~~1993~~, IEEE Standard for Gas-Insulated Substations.

IEEE [Std C57.12.00TM](#)-~~2000~~, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.13TM-~~1993~~, IEEE Standard Requirements for Instrument Transformers.

IEEE Std C57.16TM-~~1996~~, IEEE Standard Requirements, Terminology, and Test Code for Dry-Type Air-Core Series-Connected Reactors.

IEEE Std C57.19.00TM-~~2004~~, IEEE Standard General Requirements and Test Procedure for Outdoor Power Apparatus Bushings.

IEEE Std C57.21TM ~~1990 (Reaff 1995)~~, IEEE Standard Requirements, Terminology, and Test Code for Shunt Reactors Over 500 kVA.

IEEE Std C62.11TM ~~1999~~, IEEE Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits.

MDOC/~~CFE~~-[CDS](#). Manual de Diseño de Obras Civiles, de la Comisión Federal de Electricidad, Instituto de Investigaciones Eléctricas, México, ~~1993~~.^{12 11}

^{12 11}[MDOC/CFE](#) publications are available from the Civil Engineering Department, P.O. Box 1-475, 62001, Cuernavaca, Mor, Mexico.

National Building Code of Canada (NBCC), ~~Eleventh Edition, 1995.~~¹³ [12](#)

~~NEHRP-2000 (National Earthquake Hazards Reduction Program), Recommended Provisions for Seismic Regulations for New Buildings [Federal Emergency Management Agency (FEMA), 2000].~~¹⁴

~~PSM Peligro Sísmico en México, II UNAM, CENAPRED, CFE, IIE, México, 1996.~~¹⁵ ~~Uniform Building Code, 1997.~~¹⁶

~~Wilson, E. L., Der Kiureghian, A., and Bayo, E. R., "A replacement for the SRSS method in seismic analysis," *Earthquake Engineering and Structural Dynamics*, vol. 9, pp. 187-192, 1981.~~¹⁷

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply.

The ~~Authoritative~~ [IEEE Standards Dictionary](#) ~~of IEEE Standards Terms [B16]~~ [Online](#) should be ~~referenced~~ [consulted](#) for terms not defined in this clause.¹³

¹³¹² The National Building Code of Canada is available from the National Research Council of Canada, Institute for Research in Construction, Ottawa, Canada.

¹³ [IEEE Standards Dictionary Online](http://dictionary.ieee.org) is available at: <http://dictionary.ieee.org>.

¹⁴ ~~The NEHRP publication is available from the Building Seismic Safety Council, 1201 L St., N.W., Suite 400, Washington, D.C. 20005, USA.~~

¹⁵ ~~PSM publications are available from the Instituto De Ingenieria, CD Universtaria, Coyoacan, 04510, Mexico, D.S.~~

¹⁶ ~~UBC publications are available from International Code Council, 4051 W. Flossmoor Rd, Country Club Hills, IL 60478-5795, USA.~~

¹⁷ ~~The *Earthquake Engineering and Structural Dynamics* publication available online from John Wiley and Sons, Inc. at <http://cajun.es.nott.ac.uk/engineering/civeng.html>.~~

3.1.1 arias intensity: A ground motion parameter that is a measure of the total energy associated with a ground motion record. The Arias Intensity is proportional to the integral over time of the acceleration (m/s^2) squared, and thus, it considers the full range of frequencies recorded over the duration of the given record.

$$\text{Arias Intensity } A(t) = (\pi/2g) \int_0^t a(\tau)^2 d\tau$$

$$\text{Normalized Arias Intensity } I(t) = A(t) / A(\infty)$$

where

$a(\tau)$ is the acceleration time history function

~~**3.1.2 basketing of conductors (bird caging):** The unraveling or untwisting of outer and inner strands. Basketing can be caused by the following:~~

- ~~— Minimum bending radius being violated.~~
- ~~— Ends being twisted opposite to direction of twist.~~

~~**3.1.3 biaxial testing:** Testing simultaneously in two directions, i.e., one horizontal and one vertical direction.~~

3.1.4 brittle material components: A material that experiences limited or no plastic deformation before fracture. Limited deformation shall be taken as less than 10% in 5 cm (2 in) at failure in tension.

bushing shake-table rated moment: The measured moment observed at the insulator-flange interface corresponding to the prescribed shake table test. The maximum moment that the bushing can survive without damage, i.e., the moment capacity, will be equal to or greater than the shake-table rated moment.

~~**3.1.5 complete quadratic combination (CCC CQC method):** A modal combination method, especially useful for systems with closely spaced frequencies.~~

composite insulator: An insulator composed of a fiber-reinforced core, with metal end fittings, and elastomer sheath and sheds.

critical variables: Strain, stress, and deflection determined at locations that indicate the seismic or structural capacity of a component.

dedicated support: A dedicated support is a structure designed exclusively to support only a single piece of substation equipment. Dedicated supports may be seismically qualified in conjunction with a specific piece of equipment by the prescribed methodology in this recommended practice for the supported equipment. Examples include a pedestal supporting a CVT or the entire structure supporting a disconnect switch.

Design level: The level of shaking or seismic event that is half the performance level. At this level of shaking or seismic event, qualified equipment should be fully functional and completely undamaged.

~~NOTE—See 5.9.3.~~

~~**3.1.6 composite:** Materials that refer to polymer impregnated fiber components used as insulators or bushings.~~

~~**3.1.7 ductile material:** Material that experiences considerable plastic deformation before fracture. Considerable plastic deformation is defined as 10% or greater in 5 cm (2 in) at failure in tension.~~

~~NOTE—See 3.1.4.~~

~~**3.1.8 dynamically equivalent or better support structure(s):** A functionally similar support structure that transmits results in seismic motions, such as translation and rotation, at demand of the equipment interface that is less than or equal to (equivalent) or less (better) than a structure to which a comparison is being made. Accelerations should include all possible axes of freedom that occurring when mounting the equipment on a support with which the equipment has been seismically qualified.~~

equivalent terminal force (ETF) method: Method of accounting for the effects of conductor interaction by applying a force to the terminal of equipment. These responses due to ETF are then added to the seismic responses of the unconnected equipment item. See A.1.6.3.

~~3.1.9 first support:~~ The primary aboveground support of a piece of equipment. For stand-alone equipment, the first support is the entire structure, such as a CVT pedestal or the entire frame for a disconnect switch. For racks or A-frames that support other equipment or carry pull-off loads, the first support is the member(s) upon which the equipment is attached and its connections.

~~NOTE—The rest of the structure is designed according to the ASCE Substation Structure Design Guide.¹⁸~~

~~3.1.10 flexible equipment:~~ Equipment, structures, and components whose lowest resonant frequency is less than ~~the cutoff frequency, 33 Hz, on the response spectrum.~~

~~3.1.11 fragility testing:~~ Vibration testing of substation equipment to the minimum level of shaking at which the equipment will ~~no longer operate as intended~~ experience structural failure.

~~3.1.12 g:~~ Acceleration due to gravity that is 9.81 m/s^2 (32.2 ft/s^2).

~~3.1.13 ground acceleration:~~ The acceleration of the ground resulting from the motion of a given earthquake. ~~The maximum or See: peak ground acceleration is the zero period acceleration (ZPA) of the ground response spectrum.~~

high (0.5 g) design level required response spectrum: A response spectrum used to qualify equipment using the design level seismic qualification approach. The spectrum is defined by halving the acceleration values shown in Figure A.1 for the high performance level required response spectrum.

high (1.0 g) performance level required response spectrum: A response spectrum that directly reflects the accelerations associated with the seismic qualification objective (refer to 5.2) at the high level. The spectrum is defined by the plots and equations detailed in Figure A.1.

¹⁸~~Information on references can be found in Clause 2.~~

intermediate support: The structural member or sub-assembly in between the equipment and primary substation structure. Intermediate supports may also act as the support for other pieces of equipment, or conductor pull off loads.

3.1.14 load path: The route the loads follow through the equipment and support. It describes the transfer of loads generated by, or transmitted through, the equipment from the point of origin of the load to the anchorage.

3.1.15 maximum mechanical load (MML): The largest service load allowed on a composite hollow insulator or bushing. The MML is within the reversible elastic range and is ~~supplied~~ specified by the manufacturer. See IEC 61462 (Ed. 1.0) and R.1.2.4.

moderate (0.25 g) design level required response spectrum: A response spectrum used to qualify equipment using the design level seismic qualification approach. The spectrum is defined by halving the acceleration values shown in Figure A.2 for the moderate performance level required response spectrum.

moderate (0.5 g) performance level required response spectrum: A response spectrum that directly reflects the accelerations associated with the seismic qualification objective (refer to 5.2) at the moderate level. The spectrum is defined by the plots and equations detailed in Figure A.2.

modified performance level required response spectrum: These spectra are used for shake-table testing transformer bushings and are defined in D.5.2.1.d).

moment amplification factor (MAF) method: Method of accounting for the effects of conductor interaction by applying a factor to the seismic responses of a standalone unconnected equipment item. See A.1.6.2.

~~NOTE—It is defined in IEC TC 36 WG07 Project 1462 Ed 1 (draft). See R.1.2.4.~~

3.1.16 normal operating load: Any force, stress, or load resulting from equipment operation that can reasonably be expected to occur during an earthquake, except ~~short-circuit~~ the loads given in 6.10 through 6.12.

peak ground acceleration: The peak ground acceleration is the maximum ground acceleration of any component of the time history.

performance level: The level of shaking or seismic event at which qualified equipment is anticipated to perform acceptably with little or no significant structural damage.

performance level response spectrum: A response spectrum that directly reflects the accelerations associated with the seismic qualification objective (refer to 5.2).

polymer-housed surge arrester: Arrester using polymeric and composite materials for housing.

primary substation structure: In the context of the support of substation electrical equipment, a primary substation structure shall be considered to be any other structure not deemed a dedicated support. Primary substation structures may also support rigid bus work or conductors.

required response spectrum (RRS): Response spectrum that defines the required level of input motion for a given level of qualification.

~~**3.1.17 oil leakage load:** The cantilever load applied to the top of any oil-filled component at which oil leakage begins.~~

~~**3.1.18 projected performance:** The estimated performance based on the value of critical variables (strain, stress, and deflection) determined from shake-table tests or analyses at the required response spectrum using acceptance criteria that assure the critical variables are equal to or less than their acceptance allowables.~~

~~NOTE—See A.2.~~

~~**3.1.19 resonant frequency:** Frequencies coinciding with the natural frequency of a system (at which the response amplitude is a relative maximum) are known as resonance frequencies. At these frequencies, even small periodic driving forces can produce large amplitude oscillations. A frequency at which a response peak occurs in a system subjected to sinusoidal forced vibration. This frequency is accompanied by a 90° phase shift of response relative to the excitation.~~

3.1.20 response spectrum: A plot of the maximum response of an array of single-degree-of-freedom (SDOF) identically damped oscillators with different frequencies, all subjected to the same base excitation.

3.1.21 rigid equipment: Equipment, structures, and components whose lowest resonant frequency is greater than ~~the cutoff frequency, 33 Hz,~~ on the response spectrum.

seismic identification plate: A physical plate to be placed on the equipment identifying it as having satisfied the requirements of this recommended practice. See A.7 for details on the data to be placed on the plate.

3.1.22 seismic outline drawing: A ~~280 mm × 432 mm (11 in × 17 in), A3, 216 mm × 280 mm (8½ in × 11 in), or A4~~ drawing that shows ~~dedicated to the depiction of key information concerning the seismic qualification of the equipment. It shows information such as the resonant frequencies of the equipment, important loads, an outline drawing~~ parameters of the equipment, ~~the center of gravity of the equipment, and other key information about the equipment and meeting the requirements of~~ either A.5.5 or A.6.4. See also Annex S and Annex T.

seismic protective device: A device such as a base isolator or damper that reduces seismic response by lowering the frequency and/or increasing the damping to a system.

seismic qualification approach: The solution path for seismic qualification. The two seismic qualification approaches used in this recommended practice are the design level approach and the performance level approach.

seismic qualification level: There are three levels of qualification, high, moderate, and low. The level at which equipment must be qualified is dependent upon the seismicity of the region where it will be in service.

seismic specialist: An individual who, through education, training, and experience, is capable of planning, performing, and documenting a seismic qualification as described in this recommended practice (A.5.2, A.6.2).

specified cantilever load: As defined in IEC 62231, the cantilever load that a solid core station post composite insulator can withstand for a short term.

specified long-term load (SLL): As defined in IEC 60099-4, the force perpendicular to the longitudinal axis of an arrester, allowed to be continuously applied during service without causing any mechanical damage to the arrester.

~~NOTE—See A.5.3 and A.6.2.~~

~~**3.1.23 specified mechanical load (SML):** The bending moment load of A composite, which is $\geq$ rated load a composite insulating product (insulator or housing) can withstand for 1 min. It is predominantly associated with cantilever loads. The SML is equal to or greater than 2.5 times the maximum mechanical load. After application of the SML load, the residual strain may be $\pm 5\%$ of the maximum strain (irreversible plastic phase), but no visible damage may occur. The SML is a load rating used for composite insulators. [adapted from IEC TC 36 WG07 Project 1462 Ed 1 (draft)]~~
(MML) for a composite hollow insulator.

specified short-term load (SSL): As defined in IEC 60099-4, the greatest force perpendicular to the longitudinal axis of an arrester, allowed to be applied during service for short periods and for relatively rare events without causing any mechanical damage to the arrester.

standalone configuration: The configuration of an equipment item that is not connected by conductors to equipment. The seismic qualification of the equipment is usually performed in the standalone or unconnected configuration. See 6.9.

test response spectrum (TRS): The response spectrum that is calculated from the time history motion recorded at the base of equipment in a time history (shake table) test.

~~NOTE—In the context of this recommended practice, the term will be used in reference to bending loads, but users should be aware that the terminology is also applicable to other loading directions. See R.1.2.4.~~

~~**3.1.24 triaxial:** Testing~~ Test or analysis in procedure in which the effects of vertical and two horizontal orthogonal ~~directions and the vertical direction~~ components of earthquake are applied simultaneously.

~~3.1.25~~ **zero period acceleration (ZPA):** The acceleration level of the high-frequency, non-amplified portion of the response spectrum ~~(e.g., above the cutoff frequency, 33 Hz)~~. This acceleration corresponds to the maximum (peak) acceleration of the time history used to derive the spectrum.

~~NOTE~~—For use in this recommended practice, the ZPA is assumed to be the acceleration ~~response~~ at 33 Hz or greater.

3.2 Abbreviations and acronyms

ACI	American Concrete Institute
ADM	Aluminum Design Manual
AISC	American Institute of Steel Construction
ASCE	American Society of Civil Engineers
ASD	allowable stress design/ allowable strength design
AWS	American Welding Society
BIL	basic impulse insulation level
CG	center of gravity
CQC	complete quadratic combination
CT	current transformer
CVT	capacitor voltage transformer
D	dead load
DCV	duty cycle voltage (rating)
DFR	digital fault recorders
E	earthquake loads or seismic loads; modulus of elasticity

EPDM	ethylene propylene diene copolymer
EPM	ethylene propylene copolymer
ETF	equivalent terminal force
FACTS	flexible alternating current transmission systems
FRP	fiberglass reinforced polymer
GIS	gas insulated switchgear
HVDC	high voltage direct current
IEC	International Electrotechnical Commission
IED	intelligent electronic devices
IBC	International Building Code
IT	instrument transformer
LTR	laboratory test report
LRFD	load and resistance factor design
MAF	moment amplification factor
MDOC/CFE	Manual de Diseño de Obras Civiles de la Comisión Federal de Electricidad
MML	maximum mechanical load
NBCC	National Building Code of Canada
~~NEHRP~~	~~National Earthquake Hazards Reduction Program~~
PGA	peak ground acceleration

PSD power spectral density (g^2/Hz vs. frequency)

RRS required response spectrum

RTU remote terminal unit

[SCL](#) [specified cantilever load](#)

SDOF single degree of freedom

SED substation electronic devices

SER sequence of events recorders

[SLL](#) [specified long-term load](#)

SML specified mechanical load

SR silicone rubber

SRSS square root of the sum of the squares

SSI soil-structure interaction

[SSL](#) [specified short-term load](#)

TRS test response spectrum

~~UBC~~ ~~Uniform Building Code~~

VT voltage transformer

W wind loads

ZPA zero period acceleration

4. Instructions

4.1 Format of this recommended practice

This recommended practice is divided into ~~8~~ seven clauses (Clause 1 through Clause ~~8~~ 7) and ~~22~~ 25 annexes (Annex A through Annex ~~V~~ Y). Clauses contain general seismic ~~design~~ requirements. Annex C through Annex P and Annex V contain equipment-specific seismic design requirements and are located after the clauses. If the type of equipment to be qualified is not specifically addressed in Annex C through Annex P and Annex V, the seismic ~~design~~ requirements of Annex B may be used, if applicable.

Sections of the document that are deemed “normative” establish requirements of the recommended practice. Whereas sections of the document deemed “informative” are included for information purposes only.

All the clauses of the document (Clause 1 through Clause 7) are to be considered as being normative. Annexes can be either normative or informative. For any particular annex, the designation of it being either normative or informative will be in parenthesis immediately before the annex title.

4.2 Standardization of criteria

IEEE Std 693 is designed as an integrated set of requirements for the seismic qualification of electrical substation equipment. Users should use IEEE Std 693 as a whole. Do not modify or remove any requirement, except as allowed herein (refer to 5.8.3).

If any part of this recommended practice is changed, removed or not met, then neither the user nor the manufacturer may claim the equipment is in compliance with this recommended practice and should not attach the seismic identification plate to the equipment.

~~The user should not include additional or different seismic requirements in their specifications for equipment. This recommendation provides for a uniform and consistent seismic qualification procedure and allows multiple users to take advantage of pre-qualified equipment with the goal of distributing the cost among the users. This also allows the manufacturer to design the equipment to a standard set of requirements.~~

4.1 General

~~This recommended practice provides qualification requirements for substation equipment and supports manufactured from steel, aluminum, porcelain, and composites. Should other material, such as timber, structural plastics, concrete, or glass, be specified, the user or the user's agent should provide the acceptance criteria. Any acceptance criteria proposed by the manufacturer shall first be accepted by the user or user's agent, before it can be used by the manufacturer in the qualification.~~

4.3 Specifying this recommended practice in user's specifications

~~For equipment to be qualified to this recommended practice, this recommended practice must be used in its entirety. The user or user's agent must not add additional requirements to their specifications, nor remove requirements given herein from their specifications. Nor should the user or user's agent attempt to cut and paste sections from this recommended practice to create a specification.~~

The user or the user's agent should supply the following information in their equipment specifications to the manufacturer:

- a) The type of equipment shall be stated, and the name must match one of the types of equipment described in Annex C through Annex P and Annex V, such as circuit breaker, disconnect switch, or suspended wave trap, ~~and so on, or~~ otherwise Annex B must be referenced.

NOTE—The electrical section of the user's specifications should define the detailed electrical requirements, including (e.g., voltage, BIL, creep lengths, ~~and so on).~~ ¹⁴

- b) A statement that the equipment shall be qualified according to the requirements of this recommended practice.
- c) The seismic qualification level required (i.e., high, moderate, or low). To determine the qualification level, ~~;~~ refer to 4.4, 5.7, 5.8-6, and 5.12.

² ¹⁴ Notes ~~in to~~ text, tables, and figures are ~~given~~ for information only and do not contain requirements needed to implement the ~~recommended practice~~ standard.

- d) Equipment's in-service configuration. The user or user's agent should specify:
- 1) ~~Specify that~~ Whether the equipment be supplied with or without a support.
 - 2) The configuration, height of the support, and any other specific detailing requirement, if furnished with a dedicated or intermediate support.
 - 3) The details of the support structure including anchorage points, if the manufacturer is responsible for qualifying the equipment on any other support, including primary substation structures.
- 2) ~~If without a support, the requirements of 5.5 shall be followed.~~
- e) ~~The user or user's agent should provide any necessary information, such as allowables or acceptable codes for wood, plastics, or other material not provided for in this recommended practice.~~
- e) The user should include a schedule of due dates for completion of the test plan, testing (if needed), and the report.

The templates given in Annex U may be used in preparing seismic qualification specifications for Annex B through Annex P, Annex V, and Annex W.

The specification templates are given in English. ~~It~~ They may be translated into other languages.

~~For example, filling in the template in Annex U, the user's specifications for Annex C through Annex P may read as follows:~~

~~The surge arresters and support structure shall be qualified according to the requirements of IEEE Std 693-2005. The surge arresters and support shall meet the requirements of the high seismic qualification level. (Structure height and information discussed in item d) of 4.2 must be included if the support structure is required.) The test plan shall be submitted within 35 calendar days of award of contract, and the test shall be completed within 75 calendar days of award of contract. The report shall be submitted within 21 calendar days after testing is complete.~~

~~For example, filling in the template in Annex U, the user's specifications for Annex B may read as follows: The voltage divider and support shall be qualified according to the requirements of IEEE Std 693-2005. The voltage divider and support shall meet the requirements of the moderate seismic qualification level and shall be qualified according to Annex B. Qualification shall be by time history testing. No functional tests are required. The test plan shall be submitted within 35 calendar days of award of contract, and the test shall be completed within 75 calendar days of award of contract. The report shall be submitted within 21 calendar days after testing is complete.~~

~~Note that additional information is required, because this latter example is for Annex B.~~

~~Structure height and information discussed in item d) of 4.2 must be included if a support structure is required.~~ The test plan schedule requirements should be omitted from the Annex B template, if the qualification is by analysis.

4.4 Selection of qualification level [for a region](#)

This recommended practice provides three levels of qualification that should encompass the needs of most users. Experience has shown that it is good practice to specify the same criteria for all like equipment in all substations within a reasonably large geographical area, ~~even if some of the substations within the area have moderately higher or slightly lower expected levels of ground shaking. There are several reasons for this. The most important reason is interchangeability. Should~~ [In the event of](#) equipment malfunction ~~or in the event of~~ [following](#) an earthquake, ~~be lost and need to be replaced quickly,~~ equipment from other substations [or standard spares](#) can be moved and installed in the substation that experienced the loss. ~~Also, keeping the same criteria for all like Equipment will simply make it easier to keep track of equipment and its~~ [inventory management may be simplified by employing the fewest number of different](#) qualification ~~level~~ [levels](#).

[When selecting or standardizing a seismic qualification level for a region, the qualification level should be based on the highest seismicity within the region being considered. Refer to 5.7 and 5.12.](#)

~~Following this practice makes economical sense. There are savings to be had by specifying fewer levels for the same equipment. The manufacturer only needs to design and manufacture fewer modifications of the same equipment. Also, the equipment supplied to slightly different areas is generally the same equipment with possible minor modifications.~~

4.5 Acceptance of previously qualified electrical equipment

4.5.1 Acceptance of previous qualifications from other standards

~~Existing qualifications, including qualifications~~ Equipment that is in conformance with other standards, may be acceptable and need not be ~~repeated, provided the~~ requalified. However, a supplemental report shall be prepared by a seismic specialist who signs the. The supplemental report must provide detailed explanation and the user agree in writing documentation that shows that the existing previous qualification adequately meets or exceeds the requirements of this recommended practice. ~~However, "Adequately" means that the existing previous~~ qualification report shall be augmented with a detailed explanation of the adequacy of the equipment can be used to meet or exceed the requirements of ~~this~~ the current recommended practice. ~~Changes to the report will be identified, in the opinion of the user and the seismic specialist.~~

~~"Adequately" means that if the qualification was repeated using the requirements of this current recommended practice, in the opinion of the user and the specialist and based on the data in the existing qualification report, the equipment would meet or exceed the acceptance criteria of this current recommended practice.~~

~~Part of an existing qualification may be acceptable and need not be repeated provided the requirements stated here are met.~~

4.5.2 Acceptance of previous versions of IEEE Std 693

Equipment qualified to IEEE Std 693-1997 or later versions will be deemed to be in conformance with the current version of IEEE Std 693, and the qualification need not be repeated, unless a previous qualification test or analysis method is ~~explicitly excluded by the current version. The qualification will be acceptable once the explicitly excluded part is done according to the current recommended practice and found acceptable according to A.5 or A.6. Additional documentation will be required if the current version requires additional documentation~~ specifically excluded by the current version.

The equipment that is excluded by the current version are the following:

- Bushings that are required to be qualified by time history testing (by D.5.5)
- Equipment utilizing composite insulators that have not passed the shed seal test (by A.4.6)
- Equipment 110 kV and above with conductor load effects, and qualified by means other than the static pull test (by A.1.6)
- Surge arresters 90 kV DCV and above with conductor load effects (by A.1.6.)
- Inherently acceptable equipment—anchorage calculations (by A.1.5)

For ~~a manufacturer to use a qualification from a previous edition of this recommended practice~~ equipment that is excluded by the current version as listed above, a supplemental report shall be prepared by the seismic specialist to be able to qualify the equipment to the current version of ~~this~~ the recommended practice, ~~a supplemental report must. The qualification will be appended acceptable provided the issues that cause the exclusion can be shown to be satisfied in the old~~ previous qualification or additional analysis or tests that are performed. The supplemental report explaining how sections excluded in the new version of the recommended practice will meet the adequacy criteria given in 1.5. The identification tag for the equipment supplied to that user can state that the equipment has been qualified to the current IEEE Std 693 shall clearly identify the report applicable to the previously qualified equipment. The manufacturer shall furnish to the user, the supplemental report, and the seismic report for the previously qualified equipment.

4.5.3 Seismic identification plate

When previously qualified equipment has satisfied the requirements of 4.5, the manufacturer shall furnish a seismic identification plate in accordance with A.7.2. The manufacturer of such equipment shall provide to the user a supplemental report/letter that includes depiction of the seismic identification plate.

4.6 Optional qualification methods

4.6.1 General

The manufacturer may replace an annex-specified qualification method with an optional qualification method listed in 4.6.2 through 4.6.710. The intent of the optional qualification methods is to return either a more conservative or a more precise determination of the seismic loads than the ~~original required~~ annex specified technique. Qualification techniques with recognized options are limited to those listed in 4.6.2 through 4.6.710.

It should be noted that these are manufacturers' options only. The user is not to exercise these options. The qualification shall be done according to the requirements of A.1, and the acceptance requirements shall be according to the requirements of A.2 or A.4 as applicable.

4.6.2 Option to static analysis

When static analysis is specified, the manufacturer has the option of substituting it by dynamic analysis, time history analysis, or time history testing, ~~or sine beat testing according to the requirements of A.1 and the acceptance requirements of A.2 as appropriate~~ (design or performance level), provided all other requirements are met.

4.6.3 Option to dynamic analysis (static coefficient analysis)

When dynamic analysis is specified, the manufacturer has the option of substituting it by the static coefficient analysis method as defined in A.1.3-24.6, provided a static coefficient of 1.5 is used and all other requirements are met. ~~This method allows a simpler technique in return for added conservatism. Under this alternative method, a determination of natural frequencies and damping is not required. Where natural frequencies are normally shown or provided in the report and seismic outline drawing, the note "Optional analysis" should be shown.~~

4.6.4 Option to dynamic analysis (time history analysis or testing)

When dynamic analysis is specified, the manufacturer has the option of substituting it by the time history analysis or time history test ~~or sine beat test~~ (design or performance level) and its associated acceptance criteria in lieu of the analytical method, provided all other requirements are met. ~~The testing shall be done according to the requirements of A.1, and the acceptance requirements shall be according to A.2.~~

4.6.5 Option to static coefficient analysis

When the static coefficient analysis is specified, the manufacturer has the option of substituting dynamic analysis, time history analysis, or ~~sine beat testing~~ time history test (design or performance level) as an alternative method of analysis, provided all other requirements are met. ~~The qualification shall be done according to the requirements of A.1, and the acceptance requirements shall be according to A.2.~~

4.6.6 Option to time history analysis

When the time history analysis is specified, the manufacturer has the option of time history test (design or performance level) as an alternative method of analysis, provided all other requirements are met.

4.6.7 Option to use a greater acceleration

The manufacturer may use an acceleration greater than that specified or a response spectrum that envelops the required response spectrum ~~as discussed in~~ [\(refer to Figure A.1 of Figure A.2.2\)](#), provided all other requirements are met.

4.6.8 Option to ~~test at the performance~~ [design level test](#)

When [design level](#) testing [\(refer to 5.4.2\)](#) is specified, the manufacturer has the option of testing ~~at the performance level, which is twice the RRS level. For sine beats, the acceleration level is increased by a factor of 1.2; that is, for the moderate seismic level, the peak acceleration is 0.3g, and for the high seismic level, it is 0.6g. All other requirements shall be met, except as allowed in A.2.6~~ [using performance level testing \(refer to 5.4.1\)](#).

~~When an analysis or pull test is specified, the manufacturer has the option of testing at twice the RRS level specified, provided all other requirements are met. The testing shall be done according to the requirements of A.1, and the acceptance requirements shall be according to A.2.6.~~

~~Equipment tested at twice the RRS level shall not be provided to the user, unless the user accepts in writing the tested equipment.~~

4.6.9 Option to pull test

When a pull test is specified, the manufacturer has the option of substituting the time history test ~~or sine beat test~~ and its associated acceptance criteria in lieu of the pull test, provided all other requirements are met. ~~The testing shall be done according to the requirements of A.1, and the acceptance requirements shall be according to A.2.~~