IEEE Std 693-1997
(Revision of IEEE Std 693-1984)

IEEE Recommended Practice for Seismic Design of Substations

Sponsor
**Substation Design Criteria Committee
of the
IEEE Power Engineering Society**

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Abstract: Recommendations for seismic design of substations, including qualification of each equipment type, 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, damping, dynamic analysis, loads, required response spectrum, seismic performance levels, shake table, sine-beat, static coefficient analysis, support structures, suspended equipment, time history

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Introduction

(This introduction is not part of IEEE Std 693-1997, IEEE Recommended Practice for Seismic Design of Substations.)

This revision of IEEE Std 693 was developed as a recommended practice for the seismic design of substations. This recommended practice emphasizes the qualification of electrical equipment. Nuclear Class 1E equipment is not covered by this recommended practice, but is covered by IEEE Std 344-1987 .

This recommended practice presents one method only of qualification for each type of equipment. This one method should not be construed as the only acceptable method of qualification. The equipment may be qualified by other methods that meet the intent of this recommended practice.

This recommended practice is intended to establish standard methods of providing and validating seismic withstand of electrical substation equipment. It provides detailed test and analysis methods for each type of major equipment or component found in electrical substations.

This recommended practice is intended to assist the substation owner 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. 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 demonstrating and documenting the seismic withstand of their product in a form that can be universally accepted.

While 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.

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

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CLAUSE PAGE

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IEEE Recommended Practice for Seismic Design of Substations

1. Overview

1.1 Scope

This recommended practice is for the seismic design of substations, excluding Class 1E equipment for nuclear power generation stations. Seismic qualification of electrical equipment and their supports is emphasized.

The most important goal of this recommended practice 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 documentation. This will reduce costs, because the manufacturers can qualify their equipment once for each qualification level and eliminate specialized testing.

Three qualification levels are recommended. They are low, moderate, and high. The user should determine the desired qualification level when purchasing the equipment.

This recommended practice is divided into nine clauses (1 through 9) and 20 annexes (A through T). Clauses contain general seismic design requirements. Annexes 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 Annexes C through O, the seismic design requirements of Annex B may be used, if applicable.

Annexes are titled normative or informative. Normative annexes are official parts of this recommended practice. Informative annexes are for 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 anchorage:[1]

- *Buildings:* Uniform Building CodeTM (UBC), Southern Building Code, Mexican Code (MDOC/CFE), National Building Code (BOCA), or National Building Code of Canada (NBCC).
- *Anchorage design:* American Society of Civil Engineers (ASCE) Substation Structure Design Guide (draft).

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

[1]Information on these and additional references can be found in Clause 2..

- *Foundation design:* UBC MDOC/CFE, Southern Building Code, American Concrete Institute (ACI), ASCE Substation Structure Design Guide (draft), or NBCC.
- *Structures:* Strain bus structures, A-Frames, racks, box structures, rigid bus supports, and all other such substation structures. ASCE Substation Structure Design Guide (draft).
- *Rigid bus:* ASCE Substation Structure Design Guide (draft).

The ASCE "Guide for Improved Earthquake Performance of Power Systems," (draft) is in preparation. It will illustrate many methods of installing substation equipment and discuss their advantages. It will also provide useful information for evaluating existing installation details for good earthquake performance.

1.2 How to use this recommended practice

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

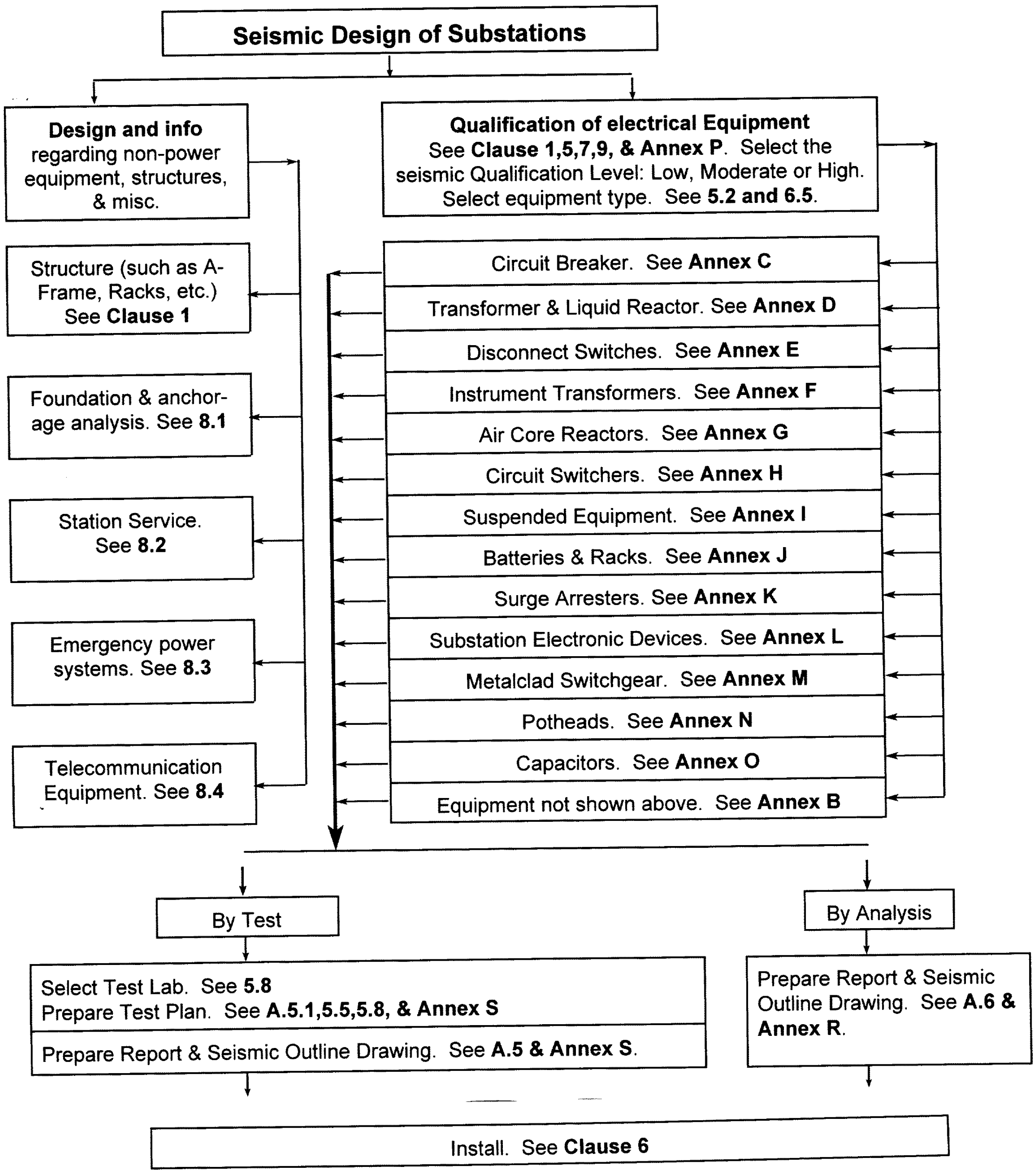

Figure 1— Using the recommended practice

1.3 Acceptance of previously qualified electrical equipment

Existing qualifications may be acceptable and need not be repeated, provided that the specialist who signs the report and the user agree in writing that the existing qualification adequately meets the requirements of this recommended practice. However, the existing qualification shall be augmented with the documentation requirements of this recommended practice.

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

1.4 Earthquakes and substations

Earthquakes are caused by the sudden rupture of a geologic fault. Shock waves radiate from the fault fracture zone and arrive at the earth's surface as a complex multifrequency vibratory ground motion, having both horizontal and vertical components.

The response of buildings and structures to earthquake ground motion depends on their strength of construction, ductility, and dynamic properties. Lightly damped structures that have one or more natural modes of oscillation within the frequency band of ground excitation can experience considerable amplification of both the forces and deflections.

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

If two or more structures or equipment are rigidly linked together they will interact with one another producing a modified response. If they are flexibly linked then, in an ideal situation, no forces are transferred between the structures or equipment. However, the linkage must be flexible enough to accommodate the relative displacements.

Many items of substation equipment, for electrical reasons, are highly interconnected and often contain brittle, relatively low-strength (as compared to steels, for example), low-damping materials (e.g., porcelain). The conductors are often installed with very little slack. In these cases, after only a little relative motion occurs, 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.

1.5 Design and construction

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 any planned modification or expansion of the substation is subject to proper review to verify that the intentions of this recommended practice are preserved.

1.6 The equipment at risk

The satisfactory operation of a substation during and immediately after an earthquake depends on the survival, without malfunction, of many diverse types of equipment. Not only must individual equipment be properly engineered, but their anchorage, services, and interconnections must be well designed. For critical areas, it may be prudent to have backup facilities and protected spares in the event of earthquake-causing ground motion.

1.7 Mechanical loads

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

Pre-existing 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 effects (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, normal operating current, or short-circuit current
h) Operating mechanism forces and reactions to open and close contracts

All of the above listed loading types, except item b), are discussed in Clause 6.. Of course, it is unreasonable to expect all of the above loads to occur simultaneously.

2. References

This recommended practice shall be used in conjunction with the following standards. When the following standards are superseded by an approved revision, the revision shall apply.

AISC M016-1989, Manual of Steel Construction, ASD—9th Edition.[2]

AISI SG-673 Part I, Specification for the Design of Cold-Formed Steel Structural Members, August 19, 1986, Edition with December 11, 1989 Addendum Cold-Formed Steel Design Manual-Part 1, 1986.[3]

ANSI C37.06-1987 (Reaff 1994), American National Standard for Switchgear—AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities.[4]

ANSI C37.32-1996, American National Standard for High-Voltage Air Disconnect Switches Interrupter Switches, Fault Initiating Switches, Grounding Switches, Bus Supports and Accessories Control Voltage Ranges—Schedule of Preferred Ratings, Construction Guidelines and Specifications.

ANSI C84.1-1995, American National Standard for Electric Power Systems and Equipment—Voltage Ratings (60 Hertz).

ANSI C93.1-1990, American National Standard for Power Line Carrier Coupling Capacitors and Coupling Capacitor Voltage Transformers (CCVT)—Requirements.

ASCE (draft 4.0), Substation Structure Design Guide.[5]

ASTM A36/A36M-96, Standard Specification for Carbon Structural Steel.[6]

ASTM A307-94, Standard Specification for Carbon Steel Bolts and Studs, 60,000 PSI Tensile Strength.

IEC60129 (1984-01) Alternating Current Disconnectors and Earthing Switches.[7]

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[2]AISC publications are available from the American Institute of Steel Construction, One East Wacker Drive, Chicago, IL 60601-2001.
[3]AISI publications are available from the Publication Orders, P. O. Box 4327, Chestertown, MD 21690.
[4]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.
[5]ASCE publications are available from the American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA 20191-4400.
[6]ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

IEEE Std 48-1996, IEEE Standard Test Procedures and Requirements for Alternating-Current Cable Terminations 2.5 kV through 765 kV.[8]

IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronics Terms.

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

IEEE Std 824-1994, IEEE Standard for Series Capacitors in Power Systems.

IEEE Std 1036-1992, IEEE Guide for Application of Shunt Power Capacitors.

IEEE Std C37.09-1979 (Reaff 1988), IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis (DoD).

IEEE Std C37.20.2-1993, IEEE Standard for Metal-Clad and Station-Type Cubicle Switchgear.

IEEE Std C37.20.3-1987 (Reaff 1992), IEEE Standard for Metal-Enclosed Interrupter Switchgear.

IEEE Std C37.90.1-1989 (Reaff 1994), IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems.

IEEE Std C37.90.2-1995, IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

IEEE Std C57.12.00-1993, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

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

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

IEEE Std C57.19.00-1991 (Reaff 1997), IEEE Standard General Requirements and Test Procedures for Outdoor Power Apparatus Bushings.

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

IEEE Std C62.11-1993, IEEE Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits.

MDOC/CFE Manual de Diseño de Obras Civiles, de la Comisión Federal de Electricidad. Instituto de Investigaciones Eléctricas, México, 1993.[9]

National Building Code of Canada, (NBCC) 1995 Edition (eleventh).[10]

[7]IEC publications are available from IEC Sales Department, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[8]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

[9]MDOC/CFE publications are available from the Civil Engineering Department, P.O. Box 1-475, 62001, Cuernavaca, Mor, Mexico.

[10]The National Building Code of Canada is available from the National Research Council of Canada, Institute for Research in Construction, Ottawa, Ontario, Canada.

NEHRP-1997 (National Earthquake Hazards Reduction Program), Recommended Provisions for Seismic Regulations for New Buildings, [Federal Emergency Management Agency (FEMA), 1997.][11]

PSM Peligro Sísmico en México, II-UNAM, CENAPRED, CFE, IIE, México, 1996.[12]

3. Definitions

The definitions in this clause establish the meanings of words in the context of their use in this recommended practice. See IEEE Std 100-1996 for further definitions.

3.1 biaxial testing: Simultaneously testing in one horizontal and the vertical direction.

3.2 brittle metal component: A metallic component that fails at an elongation of less than 10% in 5 cm (2 in).

3.3 critical damping: The least amount of viscous damping that causes a single-degree-of-freedom system to return to its original position without oscillation after initial disturbance.

3.4 cutoff frequency: The frequency in the response spectrum where the zero period acceleration asymptote begins. This is the frequency beyond which the single-degree-of-freedom oscillators exhibit no amplification of input motion and which indicates the upper limit of the frequency content of the waveform being analyzed.

3.5 damping: An energy dissipation mechanism that reduces the response amplification and broadens the vibratory response over frequency in the region of resonance. Damping is usually expressed as a percentage of critical damping. *See also:* **critical damping.**

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

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

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

3.9 maximum mechanical load: The largest service load allowed on a composite insulator or bushing. The maximum mechanical load (MML) is within the reversible elastic range and is supplied by the manufacturer. It is defined in IEC TC 36 WG07 Project 1462 Ed 1: 1996 (draft). (See Q.1.2.4.)

3.10 natural frequency: A frequency at which a body or system vibrates due to its own physical characteristics (mass and stiffness) when the body or system is distorted and then released.

3.11 normal operating load: Any equipment operation that can reasonably be expected to occur during an earthquake, except short-circuit loads, that produces a force, stress, or load.

3.12 oil leakage load: The load applied to the top of the bushings at which oil leakage begins.

3.13 overtesting: Testing beyond requirements.

3.14 performance factor: The ratio PL/RRS where PL, the performance level, is the level of ground shaking and RRS, the required response spectrum is the test or analysis level. As used in this recommended practice the performance factor is 2.

3.15 performance level (PL): A specified level of earthquake ground shaking that is used to define standardized seismic qualification levels (high, moderate, and low) for substation equipment.

[11]This NEHRP publication is available from the Building Seismic Safety Council, 1201 L St., N.W., Suite 400, Washington, D.C. 20005.
[12]PSM publications are available from the Instituto De Ingenieria, CD Universitaria, Coyoacan, 04510, Mexico, D.S.

3.16 required response spectrum (RRS): The response spectrum issued by the user or the user's agent as part of the specifications for qualification. The RRS constitutes a requirement to be met. IEEE Std 693-1997 's required response spectra are shown in Figures A.1 and A.2. See also 5.3.

3.17 resonant frequency: A frequency at which a response peak occurs in a system subjected to forced vibration. This frequency is accompanied by a phase shift of response relative to the excitation.

3.18 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.

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

3.20 seismic outline drawing: A 280 × 432 mm (11 × 17 in) or 216 × 280 mm (8 1/2 × 11 in) drawing that shows 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 of the equipment, the center of gravity of the equipment, and other key information about the equipment. (See A.5.3 and A.6.2.)

3.21 sine beats: A continuous sinusoid of one frequency, the amplitude of which is modulated by a sinusoid of a lower frequency.

3.22 specified mechanical load (SML): The bending moment load at which irreversible visible damage may be evident. SML is supplied from the manufacturer. It is defined in IEC TC 36 WG07 Project 1462 Ed 1: 1996 (draft). (See Q.1.2.4.)

3.23 test response spectrum (TRS): The calculated response spectrum that is developed from the actual time history of the motion of the shake table (not any point on the equipment or equipment structure) for a particular damping value.

3.24 time history: A record of motion, usually in terms of acceleration, as a function of time.

3.25 triaxial: Testing or analysis in the two horizontal orthogonal directions and the vertical direction simultaneously.

3.26 zero period acceleration (ZPA): The acceleration level of the high-frequency, nonamplified portion of the response spectrum (e.g. above the cut-off frequency). This acceleration corresponds to the maximum (peak) acceleration of the time history used to derive the spectrum. For use in this recommened practice, the ZPA is assumed to be the acceleration response at 33 Hz or greater.

4. Abbreviations and acronyms

ACI American Concrete Institute
AISC American Institute of Steel Construction
ASCE American Society of Civil Engineers
AWS American Welding Society
BIL basic impulse insulation level
CG center of gravity
CVT capacitor voltage transformer
DFR digital fault recorders
EPDM ethylene propylene diene copolymer
EPM ethylene propylene copolymer
FRP fiberglass reinforced polymer
IED intelligent electronic devices
IT instrument transformer
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

PL performance level
PSD power spectral density (g^2/Hz vs. frequency)
RRS required response spectra
RTU remote terminal unit
SED substation electronic devices
SER sequence of events recorders
SML specified mechanical load
SRSS square root of the sum of the squares
SSI soil-structure interaction
TRS test response spectra
UBC Uniform Building Code
VT voltage transformer
ZPA zero period acceleration

5. Instructions

5.1 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.

5.2 Specifying this recommended practice in user's specifications

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

a) The type of equipment should be stated and the name must match one of the types of equipment described in Annexes C through O, such as circuit breaker, disconnect switch, suspended wave trap, etc., or Annex B must be referenced.

NOTE — The electrical section of the user's specifications should define the detailed electrical requirements, including voltage, BIL, creep lengths, etc.

b) 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).
d) Equipment's in-service configuration. The user or user's agent should:
    1) Specify that the equipment be supplied with or without a support.
    2) If the equipment is intended to be elevated on a support but the support is not being supplied by the equipment manufacturer, then the user needs to supply the equipment manufacturer with either:
        — The details for the support. The manufacturer shall include the support in the analysis or provide a support for the test(s), except as allowed in 6.5, or
        — A response spectrum that reflects the effects of the ground motion at the top of the support, in which case the manufacturer will not include a support in the qualification.

    For economic and time saving purposes, the equipment should be supplied with the manufacturer's support. However, site conditions or economy may dictate other supports. Therefore, the other in-service configurations discussed in 5.2 items d) 1) and d) 2) or discussed in 6.5 may be used.
e) State whether frequency modifying devices (base isolation) are allowed. See 6.6 and A.7.
f) The user or user's agent should provide any necessary information, such as allowables for wood, plastics, or other material not provided for in this recommended practice. For example, the user's specifications may read as follows:

"The surge arresters and support structure shall be qualified according to the requirements of IEEE Std 693-1997 . The surge arresters and support shall meet the requirements of the high seismic qualification level. Frequency modifying devices shall not be allowed." (This example is for Annexes C through O.) Structure height and information discussed in 5.2 item d) must be included if support structure is required.

or

"The voltage divider shall be qualified according to the requirements of IEEE Std 693-1997 . 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. The RRS shown in Figure A.2 shall be used. No functional tests are required. Frequency modifying devices may be used."

Note that additional information is required, since this example is for Annex B. Structure height and information discussed in 5.2 item d), must be included if support structure is required.

5.3 Standardization of criteria

It is recommended that the user not include additional or different seismic requirements in their specifications for equipment. The reason being, this recommendation provides for a uniform and consistent seismic qualification procedure. This will allow multiple users to take advantage of prequalified 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. However, this recommended practice does not preclude a user from including requirements unique to their facilities. Nor does it preclude a user from requiring tests, reports, templates, or other topics defined in, but not required by, this recommended practice.

5.4 Selection of qualification level

This recommended practice provides three levels of qualification that 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 a number of reasons for this. The most important reason is interchangeability. Should equipment malfunction or, in the event of an earthquake, be lost and need to be replaced quickly, equipment from other substations can be moved and installed in the substation that experienced the loss. Another reason to keep the same criteria for all like equipment is simply to make it easier to keep track of equipment and its qualification level.

Following this practice makes economical sense. There are savings to be had by specifying fewer levels for the same equipment; the manufacturer 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.

5.5 Witnessing of shake-table testing

One to three potential users should witness the shake-table testing. (The users generally provide their own accommodations and transportation to the test site.) If the equipment is being qualified for a specific purchaser, it is suggested that additional potential users also be invited, with the approval of the purchaser. The names of the witnesses should be included in the report, with the approval of the witnesses.

5.6 Optional qualification methods

5.6.1 General

When a qualification technique is specified in an equipment annex, the manufacturer is permitted to use an alternative technique if the originally specified method has an optional qualification method listed in 5.6.2 through 5.6.7. 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 technique. Qualification techniques with recognized options are limited to those listed in 5.6.2 through 5.6.7.

5.6.2 Option to static analysis

When static analysis is specified, the manufacturer has the option of substituting dynamic analysis, time history testing, or sine beat testing according to the requirements of A.1 and the acceptance requirements of A.2 or A.3 as appropriate, provided all other requirements are met. Figure A.1 shall be used for the high level and Figure A.2 shall be used for the moderate level.

5.6.3 Option to dynamic analysis (static coefficient analysis)

When dynamic analysis is specified, the manufacturer has the option of substituting the static coefficient analysis method as defined in A.1.7, provided all other requirements are met. This method allows a simpler technique in return for added conservatism. Under this alternate 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.

5.6.4 Option to static coefficient analysis (dynamic analysis)

When the static coefficient analysis is specified, the manufacturer has the option of substituting dynamic analysis as an alternate method of analysis, provided all other requirements are met. Dynamic analysis shall be done according to the requirements of A.1.5.

5.6.5 Option to dynamic analysis (testing)

When dynamic analysis is specified, the manufacturer has the option of substituting the time history test or sine beat test and its associated acceptance criteria for 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 done according to A.2.

5.6.6 Option of using a greater acceleration

The manufacturer may use an acceleration greater than that specified or a response spectrum that envelopes the user’s spectrum as discussed in A.1.2, provided all the other requirements are met.

5.6.7 Option of testing at the performance level

When testing is specified, the manufacturer has the option of testing at the performance level, instead of the required response spectrum (RRS), provided all other requirements are met, except the following:

a) In lieu of the acceptance requirement of A.2, the following may be used:
    1) Insulating components, including porcelain and their end fittings or composite polymers and their end fittings, shall not crack or fail.
    2) Metal parts shall not fail. However, metal parts and composite parts may elongate or bend slightly provided the damage does not affect the function of the equipment.
    3) The functional test requirements of A.2.5 shall remain unchanged.
b) Monitoring requirements, as specified in Annexes B through O may be modified as follows: Monitoring of stresses may be omitted. Monitoring requirements for accelerations and displacements shall remain unchanged.
c) In lieu of the requirement of A.4.2, which states “Allowable stresses for anchor bolts or welds shall be as specified in AISC Manual of Steel Construction, ASD with no increase allowed for earthquake loads, unless qualification is by sine beat in which case a 1/3 increase is allowable,” the following may be used: “Stresses in anchor bolts or welds shall not exceed yield.”

When dynamic analysis is specified, the manufacturer has the option of substituting the time history test at the performance level 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, except as given in 5.6.7 item a). Monitoring requirements and anchorage requirements may be according to 5.6.7 items b) and c).

5.7 Qualifying equipment by group

Equipment that differs structurally or dynamically, including different voltage class, BIL, equipment type, etc., shall require a separate qualification, except as allowed herein.

Often, equipment of the same type, but of varying voltage, BIL, etc., are very similar physically and structurally, such as bushings, surge arresters, or instrument transformers. Equipment such as these may be combined into groups for qualification purposes, with the most seismically vulnerable piece of equipment of each group being analyzed or tested. That qualification would then apply to all equipment in that group. It shall be demonstrated analytically or by test that the equipment in the group are structurally similar and that the most seismically vulnerable equipment was tested or analyzed. The user or the user's agent must agree with the grouping and the demonstration method in writing or this method cannot be used. Should the user or the user's agent not agree with the grouping or the analytical demonstration, then the equipment shall be qualified separately and grouping shall not be used.

Note that additional equipment may be added to a grouping at any time. For example, surge arrester "Existg" has been qualified and some time later surge arrester "New" is required. If surge arrester "New" can be shown to be less vulnerable than surge arrester "Existg", then surge arrester "New" can be grouped with the qualification of surge arrester "Existg", provided the user or user's agent agree as discussed above.

5.8 Shake-table facilities

All shake-table facilities have limitations in what can be tested and to what degree it can be tested. Tables have limitations in size and weight of what can be tested, and in displacement, velocity, and acceleration of the table.

Equipment identified in this recommended practice as requiring shake-table testing can be fully tested by most commercial tables according to the requirements of this recommended practice, with the possible exception of equipment with long period resonant frequencies. Such equipment may include tall, slender cantilever type equipment, such as live tank circuit breakers or current transformers, or base isolated equipment. Equipment with natural frequencies below 1 Hz may be difficult to test.

The shake table facilities chosen for shake-table testing shall at least be capable of achieving all the requirements of this recommended practice, including the resonant frequency search from frequencies between 1 Hz and 33 Hz and all other testing requirements between the equipment's first fundamental frequency and 33 Hz. If it is apparent or reasonably possible that resonant frequencies exist below 1 Hz, testing below 1 Hz shall be done.

If the limitations of the test laboratories equipment require deviations from this recommended practice, the deviation shall be approved by the user or user's agent. (It is suggested that the deviations be discussed with the potential user witnesses discussed in 5.5.)

All safety requirements, as determined by the testing laboratory, shall be followed. A safety line should be attached to the equipment during testing and appropriate precautions should be followed for testing pressurized equipment.

5.9 Report templates

The manufacturer should use the report templates given in Annexes R and S. The template in Annex R is for analysis and the template in Annex S is for testing. Annexes R and S provide checklists for the manufacturer to follow to help ensure that no information or requirement is inadvertently omitted. They also provide the user with standard formats for the many reports the user will need to review and maintain.

6. Installation considerations

6.1 General

This clause discusses the effect that the parameters of installation may have on the equipment qualification. Installation parameters can have a significant effect on the way equipment will respond and perform during an earthquake. Some equipment installation parameters can affect the motion that the equipment will experience during an earthquake. This is true of both equipment that is installed and operating and spare components in storage. Installation parameters can either accentuate or attenuate the equipment response to an earthquake. The important installation parameters are equipment assembly, site response characteristics, soil-structure interaction, support structures, anchorage, and adjacent equipment interaction.

6.2 Equipment assembly

The proper assembly of equipment and its components in accordance with manufacturer's guidelines (e.g., tightening bolts to required torque levels, minimizing the conductor loading on insulators, ensuring that components are properly aligned, following anchorage recommendations, etc.) is critical to achieve the intended seismic performance of the equipment. It is the responsibility of the user to ensure that the equipment is properly installed except in the case when the manufacturer undertakes the responsibilities of erection. It is also crucial that all future field alterations be approved by an engineer familiar with the seismic design and criteria of the equipment. A statement reflecting this should be included on the manufacturer's installation drawings.

6.3 Site response characteristics

Site effects are dependent on the dynamic properties of the geologic formations at and around the site. The impact of site effects on the motion from an earthquake are usually considered in detailed hazard assessments. Site effects can result in dynamic amplification or deamplification between the bedrock and the soil immediately surrounding the foundation of the equipment of interest. Generally speaking, due to the usual frequency content of earthquakes, hard rock sites tend to have less severe motion of engineering significance than do the softer sites of alluvium or saturated clays or silts. It is the responsibility of the user to ensure that site response characteristics are reflected in the RRS.

6.4 Soil-structure interaction

Soil-structure interaction (SSI) occurs when the soil deforms due to the loading to the soil from the equipment-foundation system responding to an earthquake. The soil-foundation system may become a significant component in the dynamic properties of the equipment-foundations-soil system which may increase or decrease the motion the equipment experiences during an earthquake. SSI occurs with certain combinations of equipment mass and size, foundation type and configuration, and soil properties. Transformers are especially susceptible to SSI. SSI is generally not considered in the design of substation equipment, unless specifically requested by the user. SSI increases where there are high accelerations, heavy equipment, or soft sites. It is the responsibility of the user to ensure that the possible effects of SSI are accounted for in the RRS.

6.5 Support structures

Support structures can have a very significant effect on the motion that the supported equipment will experience during an earthquake. The acceleration that the equipment experiences on a structure can be several times more severe than the ground acceleration. During qualification, it is generally desirable to have the equipment mounted or modeled in a manner identical to what it would be in its in-service configuration. However, the following are typical reasons for not qualifying the equipment in its in-service configuration:

- The equipment will be used on a variety of supports.
- Adequate supports already exist that are different than those used in the equipment qualification. That is, the qualification for the equipment already exists, but the supports in the qualification are different from those to be used by the user.
- The exact location of the equipment or exact height of the pedestals are not known at the time the equipment is purchased.
- Testing or analyzing will be done or has been done on a support that transmits more severe accelerations than the equivalent support or the support on which equipment is to be mounted.

When equipment is installed on supports that are different than those used in qualification, the supports should be dynamically equivalent. Dynamically equivalent includes the following:

- Testing or analyzing on equivalent support: The equipment may be mounted or modeled on an equivalent (dynamically) structure.
- Testing or analyzing without support: Conservatively estimate the acceleration that the equipment would experience on the support structure during the required earthquake shaking and then qualify the equipment to the estimated or more severe motion.
- Testing or analyzing on a support that transmits more severe accelerations than equivalent support.

6.6 Base isolation

The support structure dynamics can figure heavily in the qualification strategy of equipment. Base isolation is an earthquake damage mitigation strategy that relies on a support structure to lessen the severity of earthquake-induced accelerations. Base isolators have been successfully used in many equipment applications. Under certain types of motion and base-isolation configurations, very large displacement, in certain cases, even over 1/3 m, may result. This should be accounted for in the equipment installation to ensure that proper electrical clearances are maintained. With displacements of the order of 1/3 m, there may be the potential for large impact loads at the limits of the displacement. Base isolation is particularly useful for equipment that is too fragile to be qualified to the required motion.

Historically, there have been significant problems with existing base-isolation designs that use conical shaped disked springs (washers). The design of this type of base-isolating device should be very carefully considered before using for the following reasons:

a) The springs (washers) have been known to change characteristics, usually due to environmental effects, such as corrosion, dust, or other material collecting between the washers. (This type of device should be sealed from the environment.)
b) The springs have been known to change characteristics due to fatigue or over tensioning.
c) In order to remove the equipment from its stand, this type of spring assembly usually must be entirely disassembled.
d) The expected response of the springs may not be achieved if improperly pretensioned.

6.7 Suspended equipment

Equipment that is suspended often takes on the dynamic characteristics of base-isolated equipment. As a consequence, it may not be subjected to the peak levels of the horizontal ground motion acceleration. On the other hand, just as with base-isolated equipment, it may experience significant vertical acceleration and horizontal displacements, and may be subject to large loads associated with snubbing action of restraints. In the case of suspended equipment, instances of displacements over a meter have been observed during a significant earthquake. The large motions may cause significant nonlinear effects due to interaction with conductor connections with inadequate slack. The dynamics of the upper support point may also influence the response and loads on support and restraint points. (It is expected that most suspension mounting structures are non-rigid in at least one direction.) These interactions can cause large connection point loads. Suspended equipment has included wave traps, current voltage transformers, capacitors, and thyristor valves. Requirements for suspended equipment other than thyristor valves are given in Annex I. Suspended thyristor valves should be qualified on a case-by-case basis.

There are four basic components to a suspended mounting configuration. They are as follows:

— The equipment
— A suspension system
— A restraint system
— Electrical connections

To achieve the intended seismic performance of the suspended equipment, the user must adequately design the suspension system, restraint system, and the electrical connections.

Figure 2 is provided to assist the user in understanding the terms used in conjunction with suspended equipment. It does not represent the only configuration. For example, the restraint system need not be below the equipment, and both the suspension and restraint systems may consist of more than one line.

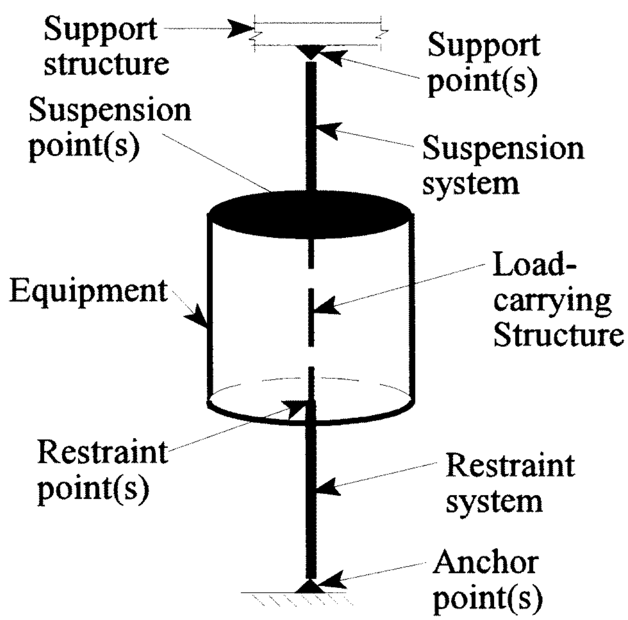


Figure 2— Definitions

There are numerous possible configurations for the mounting of suspended equipment, but seismically proven designs generally adhere to the following concepts:

a) *Equipment*. The requirements of suspended equipment are provided in Annex I.
b) *Suspension system*. The suspension system consists of all the hardware used to support the weight of the suspended equipment and is bounded by the upper support point(s) and the equipment’s suspension point(s) (see I.1.4.1). The suspension system must be constructed such that it allows the suspended equipment to oscillate about the upper support point(s).
To allow the necessary freedom of motion and yet control the attitude of the suspended equipment, the upper connection of the suspension system to the upper support point(s) and the lower connection of the suspension system to the equipment suspension point(s) must each have rotational freedom about any horizontal axis.
A suspension system can have coincident restraint functions. However, such configurations must not allow the suspension system to go slack.

c) *Restraint system.* All seismically qualified equipment that is suspension mounted shall have a restraint system. The purpose of the restraint system is to control oscillation (i.e., maintain electrical clearances of the suspended equipment), without unduly increasing the equipment acceleration and to maintain a continuous downward force upon the suspension system. The restraint system encompasses all of the hardware from the suspended equipment's restraint point(s) (see I.1.4.2) to the anchorage point(s), which are normally below the equipment.

   The restraint system must be constructed so that it continuously maintains electrical clearances of the suspended equipment. It is prohibited to have slack in the suspension system, neither initially nor as the system moves in an earthquake. Therefore the restraint system must not go slack. Past field experience has proven that designs with initial slack or lines that go slack in an earthquake have experienced impact damage. For reasons identical to those given for the suspension system, the connection of the restraint system to the equipment restraint point(s) must allow rotation freedom about, and translational freedom in, any horizontal axis. The connection of the restraint system to the anchorage point(s) must allow rotational freedom about any horizontal axis.

   The restraint system is usually attached to anchors located below the equipment, but the restraint system need not be below the equipment. However, restraint systems must be capable of maintaining a continuous downward load upon the suspension system throughout a seismic event (so as to avoid any slack in the suspension system). For restraint systems that are not below the equipment, maintaining a continuous downward load typically entails the incorporation of axial stiffness into the suspension system to prevent vertical displacements. Without axial stiffness, the insulators may go slack, resulting in the equipment bouncing and causing impact loads.

   A recommended, but not compulsory, feature of a spring type restrained system is to incorporate a damping mechanism. Care should be exercised not to over-damp the restraint system, thereby increasing the acceleration of the equipment.

   The ideal situation is to design the support system to also function as the restraint system. This is done by providing full rotational attachments at the support point(s) and the suspension point(s), providing rigid insulator(s), and providing adequate flexibility of movement of the conductor to allow free movement of the equipment. Because of the large deflections, attention to detail, such as the impact of insulator sheds on support structure members, is important.

d) *Electrical connections.* To allow the necessary freedom of motion of the suspended equipment, the equipment's electrical connections must be made with suitably flexible conductors that do not impede the free oscillations of the equipment. Also, the displacements of the entire suspended configuration should be accounted for when designing clearances with neighboring equipment or structures.

   Typically electrical conductors do not serve as part of the suspension or restraint systems. However, for certain equipment types [e.g., capacitor voltage transformers (CVTs)] the electrical conductor may provide the structural support. This is acceptable provided there are independent connectors at either end of the conductor that are capable of transferring the mechanical loads and the conductor can accommodate the structural loads.

The combination of unique requirements for a suspension mounted system (e.g., suitable structures from which to suspend the equipment, restraint anchorage points, physical clearances, and conductor terminals) may dictate the design of the suspended equipment. If this is the case, the user should provide the following information in their specification:

— The number and locations of the suspension and restraint points on the equipment.
— The direction and magnitude of the normal operating restraint load(s) at the restraint point(s).

6.8 Anchorage

Anchorage is often the most cost-effective measure that can be implemented to improve the earthquake performance of inadequately anchored equipment. It is important, as in the case of a support structure, that the anchorage used in the qualification closely simulate the in-service anchorage. Using a welded anchorage normally allows for simpler and stiffer anchorage configurations and can be stronger than bolted anchorages.

It is the responsibility of the manufacturer to supply a product with the capability of being secured by a fastening method condoned by the user (either welded or bolted). The manufacturer shall state the anticipated seismic loads (shear, tension, compression, bending, if applicable) in combination with normal loads at the footprint(s) of the equipment. It is the responsibility of the user to ensure that the connection between the manufacturer's equipment and the immediate support (either a foundation support structure or other piece of equipment) is made so that it will properly transfer the anticipated load combinations.

The recommended equipment anchorage is made by welding the base to structural steel members embedded in, or firmly anchored to, a concrete foundation. The manufacturer designs the welds, including the size, location, and type, and shows them on the manufacturer's installation drawing and on the seismic outline drawing. All welds and welders should conform to applicable American Welding Society (AWS) specifications. (Refer to A.4.2 for further information.)

If bolts are to be used, their size, strength, location, and materials should be shown on the manufacturer's installation drawings and on the seismic outline drawing. The size and strength of the anchor systems should be determined using critical material allowable stresses. However, the one-third increase in bolt allowable stresses, due to earthquake loads, should not be permitted, except for sine-beat tested equipment (see A.4.2). It is recommended that mild ductile steel, such as ASTM A36, be used, and that the design philosophy such as that stated in "Design of Headed Anchor Bolts" [B19][13] be followed. The depth of embedment and the type of bonding to that portion of the anchor system within the foundation should be determined by the user and should produce a strength greater than the strength of the anchor bolts. The intention here is to ensure that the bolt is weaker than the concrete so that the beginning of failure, should it occur, will be ductile. Consideration should be given by the user to any unequal distribution of dynamic earthquake loading on the anchor bolts.

All anchor systems must withstand the forces resulting from the design earthquake. Ultimate strength design of anchorage is acceptable as long as the anchorage capacity is equivalent to that required by the allowable strength design.

When designing equipment foundation anchoring systems, it is recommended that the anchor system be reviewed for adequacy to withstand the cyclic nature of the seismic forces. The anchor must withstand the shear, uplift, and compressive forces resulting from the design earthquake. Any anchoring system (e.g., expansion type, adhesive type, etc.) must be certified by the manufacturer as being acceptable for use in seismic applications. The manufacturer's recommendations for safety factors, embedment lengths, pullout design, and edge-shear design should be reviewed, modified, and applied as required by the designer. In the past it has been considered good engineering practice not to use mechanical fasteners that rely on friction or wedging action to anchor equipment against earthquake loading. Although certain types of mechanical fasteners perform acceptably for tension and shear vibrating loads, historical experience suggests that these types of anchors should not generally be used for tension and shear vibrating loads. In all cases, use caution and investigate qualification testing and in-situ experience for these types of anchors.

6.9 Conductor induced loading

6.9.1 Interconnection with adjacent equipment

All equipment, whether installed and operating or stored as spares, can be adversely affected by impacting an adjacent moving or stationary component. Therefore, care must also be given to the placement of important components so that failure or movement of adjacent components does not cause damage that would lessen the ability of a facility to operate.

Equipment that are connected by conductors must have some provision in their installation (e.g., sufficient flexible line slack) that will allow for any relative deflection between the equipment, which will occur during an earthquake. Likewise, in rigid bus installation, it is necessary to incorporate adequate flexibility to permit axial or longitudinal

[13]The numbers in brackets correspond to those of the bibliography in Annex T.

movement of individual major equipment assemblies while avoiding the transfer of excessive forces between the individual components.

6.9.2 Observed component displacements

Based on analysis, tests, and forensic engineering after earthquakes, it has been determined that individual items of major equipment and bus supports move by varying degrees depending on their mass, mounting height, type and size of support structure, etc. This movement results in the need for specific flexible bus configurations.

Typical ranges of observed axial or longitudinal movements at the conductor attachment point of various classes of 138 kV, 230 kV, and 500 kV equipment for 0.3 g peak ground acceleration are indicated in Table 1.

The classes of equipment have been chosen to arbitrarily identify three levels of expected displacement: high, medium, and low.

a) *High-frequency equipment (8 Hz and greater, small displacements)*. Transformers, tank reactors, dead-tank circuit breakers.
b) *Medium-frequency equipment (2.5–8 Hz, medium displacements)*. Disconnect switches, live tank circuit breaker, capacitor banks.
c) *Low-frequency equipment (less than 2.5 Hz, large displacements)*. Capacitor voltage transformer, current transformer, wave trap, suspended components.

The observed displacement for three categories of equipment are shown in Table 1.

Table 1— Typical equipment displacements in millimeters (where 25 mm~1 in)

Frequency	138 kV	230 kV	500 kV
High	25–50 mm (1–2 in)	25–75 mm (1–3 in)	100–300 mm (4–12 in)
Medium	50–150 mm (2–6 in)	70–200 mm (3–8 in)	200–600 mm (8–24 in)
Low	150–500 mm (6–20 in)	200–1000 mm (8–39 in)	300–1500 mm (12–59 in)

6.9.3 Conductor length determination

The typical movements (displacements) are given for informational purposes only and should not be used in design. The displacement found in the qualification should be used in the design. Wherever possible the design should provide additional slack or movement between equipment over that found in the qualification. A recommended method for calculating minimum required conductor length between components is:

a) Equipment #1 maximum displacement during earthquake plus;
b) Equipment #2 maximum displacement during earthquake;
c) Total sum of #1 and #2 multiplied by a factor of 1.5 plus;
d) Straight line distance between connection points plus;
e) Minimum required slack for conductor configuration under consideration.

For the installation of an adjacent disconnect switch and circuit breaker, for example, the movement for the disconnect switch is 50 mm and for the circuit breaker is 75 mm which, when combined, equal a differential movement of 125 mm for the completely out-of-phase scenario. To this a 50% margin, or 63 mm is added. Only the longitudinal motion (along the conductor length) is important for a flexible conductor. For a rigid conductor, both longitudinal and transverse motion can be important.

6.9.4 Installation

The stranded-bare conductor, although considered to be flexible, will not provide sufficient flexibility when installed unless adequate length is included. The minimum distance between termination points for which a stranded-bare conductor may be used is determined by the minimum bending radius of the conductor. The distance between termination points will determine the configuration of the conductor.

In addition to establishing the required amounts of differential movement, it is necessary to choose a practical conductor configuration that will provide the necessary limited flexibility. The flexible connection shall be configured so as to avoid compromising voltage gradients across bus and equipment insulators and maintaining the established phase-to-phase and phase-to-ground air insulation clearances.

As the result of analysis and tests aimed at establishing the flexibility characteristics of standard all-aluminum conductors, three basic configurations (see Figure 3) and adaptations of each were found to be most suitable. Also, it was found by analysis and confirmed by tests that the forces required to "stretch" or "compress" these configurations are at least an order of magnitude less than the peak dynamic forces generated by the equipment movements. The configurations are intended to provide the necessary conductor stretch and compression without applying excessive force to the bus and equipment terminations. The dimensions of configurations adequate for an application are determined according to voltage (clearances), conductor size (bending radius), equipment differential movement, and vertical and horizontal separation of the termination points (V and H). Adding conductor length normally decreases dynamic load, but can result in violation of required electrical clearances.

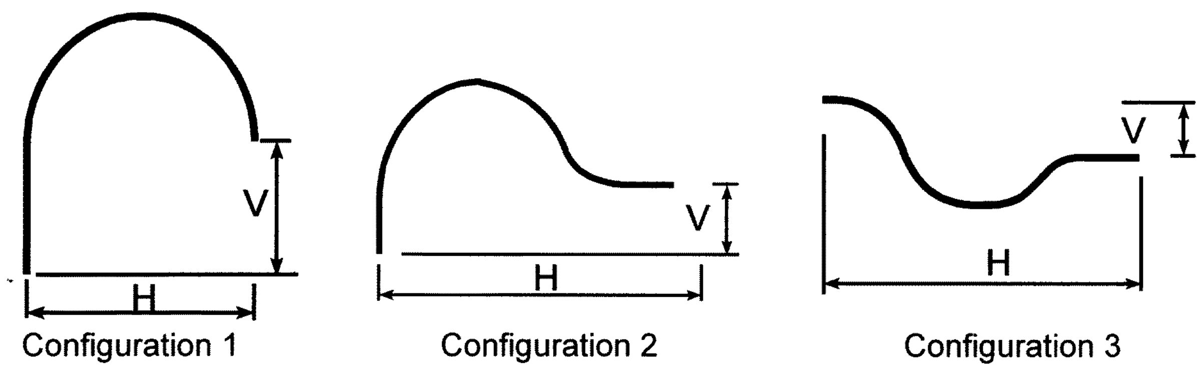


Figure 3— Basic slack configurations

For the configurations shown in Figure 3, the conductor length should be established with the recommended method presented in 6.9.3.

6.9.5 Short circuit

Short-circuit loads do not appear to have been a significant cause of failure during past earthquakes.

Short-circuit conditions typically produce a high fault current, which in turn produces electromagnetic forces between conductors carrying the current. Depending on the spacing of the conductors, the generated forces can be significant. The greater the current and the smaller the conductor spacing, the greater the force generated.

The oscillating force exists as long as the current flows and ceases as the current flow ceases. The faster the system recognizes that there is a fault and opens the circuit via circuit breaker operation, the less the system will respond and be stressed.

Sometimes, by the time the earthquake shaking reaches a substation, the substation is de-energized due to damage in other substations, circuit breaker operation in adjoining substations, or faulting along the lines leading into the substation causing the substation circuit breakers to open.

If the substation is still energized, there is some likelihood that the earthquake and the short circuit will affect the equipment at the same time.

Normally, equipment should not be designed for concurrent earthquake and short-circuit loading. If the user feels that additional margin is needed, the user may use equipment in a higher performance classification, increase phase spacing, or add specified short-circuit loads in the user's seismic requirements (refer to 5.3).

6.9.6 Weight of conductor (static) and conductor dynamic loads

The weight of the conductor (static) and conductor dynamic loads do not appear to have been a significant cause of failure during past earthquakes when a conductor was installed according to the recommendations of 6.9.2 through 6.9.4.

When a conductor is strung from another component, the conductor weight may exert a longitudinal force due to catenary action. Depending on the amount of sag, this force can be significant. During an earthquake, the conductor responds dynamically. This dynamic response can be significant.

Normally, equipment should not be designed for concurrent earthquake and the weight of the conductor (static) and conductor dynamic loads. If the user feels that additional margin is needed, the user may use equipment in a higher performance classification, evaluate factor of safety margins for equipment with existing qualification reports, or add specified weight of conductor or conductor dynamic loads in the user's seismic requirements (refer to 5.3).

6.9.7 Wind and ice loads

Wind and ice loads do not appear to have been a significant cause of failure during past earthquakes.

Wind and ice loads can be significant on electrical equipment, especially if they are due to the loading on conductors.

Normally, equipment should not be designed for concurrent earthquake and wind and ice loads. If the user feels that additional margin is needed, the user may use equipment in a higher performance classification, or add specified wind and ice loads in the user's seismic requirements (refer to 5.3).

7. Qualification methods: An overview

Static analysis, static coefficient analysis, dynamic response spectrum analysis, time history testing, sine-beat testing, and static pull testing are methods used in this recommended practice to qualify electrical equipment. This clause explains these methods. This clause does not provide qualification requirements. The requirements for the qualification methods are given in Annexes A through O. However, this clause discusses time history dynamic analysis, which the user may use as discussed within.

7.1 General

In order to qualify equipment to withstand earthquakes, the following dynamics problems should be considered:

a) *The expected magnitude of the excitation*. The geographical region, local site, soil conditions, historical seismic data, and degree of conservatism should all be considered when establishing the expected magnitude of excitation.

b) *The configuration of the equipment.* In general, taller, heavier high-voltage equipment having lower frequencies are more susceptible to seismic excitations. The result is higher stresses and motions than are found in shorter, lighter low-voltage, higher-frequency equipment. Thus, lower voltage equipment is more amenable to simpler calculation methods.
c) *The functional aspects of the equipment during and after a seismic event.* This is influenced by the importance of the equipment and level of acceptable risk. For important equipment it may be advisable to demonstrate by tests one or more of the following: equipment mechanisms, relays, contacts, etc., operate without malfunctioning before, during, and after a design earthquake. Refer to 5.4 and Clause 9 for more detailed information. Review of previous seismic performance or testing of similar equipment is recommended.

The use of seismic response spectra as a means for qualifying equipment, either by calculation or by test, has become the most widely accepted and powerful method. Figures A.1 and A.2 give the RRS for high and moderate levels, respectively.

The maximum acceleration response of equipment with modes in the range of 1.1 Hz to 8 Hz is as indicated by these spectra. The response levels are also a function of damping (the less damping the higher the response). Equipment modes above 33 Hz are considered rigid and respond at the constant zero period acceleration level (ZPA) of the required spectrum.

7.2 Calculation methods

7.2.1 Static analysis

For higher-frequency equipment, with modal frequencies above 33 Hz, apply a multiple of the ZPA at the center of gravity in each of the principal axis directions and calculate the combined resulting stresses and anchorage loads. See A.1.6 for further requirements.

7.2.2 Static coefficient analysis

This type of analysis usually applies to equipment having a few important modes in the seismic range. A factor of 1.5 times the peak g value from the RRS applied according to the mass distribution in each of the principal axis directions is required, unless otherwise specified in the annexes. Calculate loads and combine stresses. The 1.5 factor accounts for multimode effects. Refer to 5.6.3 and A.1.7 for more details.

7.2.3 Modal dynamic analysis

For complex structures with many modes in the seismic range, a detailed finite element model is needed. The RRS method is used with damping as verified by item a) of A.1.8 (simple-bump test) and other tests as specified in A.1.8, or a conservatively low value (e.g., 1% or 2%) is used. The lower frequencies of the mathematical model should, if possible, also be verified by the simple-bump or other specified test methods. The loads and modal stresses are combined using the square root or the sum of squares (SRSS) method, or closely-spaced modes (within 10% of lower modes) are added directly and then the remaining modes are added using the SRSS method. An alternate method for combining modes is the complete quadratic combination technique. (For requirements see A.1.5.) Residual mass effects at the center of gravity (CG) should be included.

7.2.4 Time history dynamic analysis

This method is a powerful tool when evaluating multiple, interconnected equipment or when studying equipment too large to test. Note that this method is intended as a qualification method for electrical equipment only if the user specifically requires it, because it requires proper definition of the time history and is more expensive.

Linear analysis, a time history representing a seismic event, can be applied to a linear finite element model, then calculate the instantaneous stresses and loads. Modal reduction techniques can be used to reduce models to important lower modes and degrees of freedom, then calculations can be made more readily.

A time history as above can be applied to a finite element model having nonlinear elements representing important nonlinearities in equipment. It is more time-consuming and costly, and also requires direct time integration of all degrees of freedom. Modal or modal reduction methods do not apply in general unless nonlinearities are treated as pseudo-forces. This is an approximate method requiring considerable engineering judgment.

7.3 Testing methods

Historically, testing has been done using a variety of the following test methods:

a) Single sine frequency
b) Continuous-sine
c) Sine-beat
d) Decaying sine
e) Multiple-frequency
f) Time history
g) Random motion
h) Random motion with sine beats
i) Combination of multiple sinusoids
j) Combination of multiple sine beats
k) Combination of decaying sinusoids, and others plus combinations of any of the above

The most important consideration, regarding methods that envelope the RRS, is that the calculated test response spectrum (TRS) of the table motion at the test facility envelopes the RRS in a manner similar to that of an actual earthquake. That is, it envelopes the RRS with amplitudes, frequencies, and energy levels that occur in a similar simultaneous manner.

Note that the method of attaching equipment to the test table should be the same or equivalent to that used on the actual foundation or supporting structure. Strain gauge hold-down bolts are recommended to measure anchorage loads.

Direction categories for testing include multiaxis, single-axis, biaxial, and triaxial. Primarily for device testing, it is important to introduce cross-effects due to the earthquake disturbance. Hence, multiple tests are required in different directions (orientations) of each system when biaxial testing is performed. Because the triaxial method requires only one test position, the consequent stress fatigue effects will be at a minimum in the equipment tested in this manner.

A biaxial machine with 100% horizontal and 80% vertical motion can be used in lieu of a triaxial table by mounting the equipment at 45° to the table motion with the table motion increased by 40% to meet the RRS in both directions simultaneously, which will simultaneously excite the two orthogonal principal directions. This reduces the number of tests, but the magnitude of motion to equipment in direction of table motion may be too severe. The severity is dependent on the geometry and type of equipment.

Instrumentation to measure accelerations at the overall CG is recommended, but not mandatory. If the CG is outside the equipment, the closest practical location on the equipment should be used. The results can be used to calculate and verify foundation loads and the equipment on other supports.

7.4 Special cases

Generic testing beyond specified requirements (overtesting) may be accomplished by broadening the specification to include a wide variety of applications. However, it can produce a very severe test motion and care must be taken to avoid costly damage. Generic or overtesting, if done carefully, can lead to improved seismic designs at reasonable costs.

Fragility testing can be used to determine the ultimate capability of equipment. Such information would serve to prove adequacy for more drastic earthquake disturbances and conclusively shows the weak link, which may result in improved seismic capability.

On-site testing can be accomplished by portable shaking devices, where the equipment was not tested before installation. It has the advantage of including the effects of attachments or modifications made to the equipment and limited foundation and soil effects, but is not typical earthquake random type motion. These results can be used to update and improve calculations (models).

7.5 Qualification method for specific equipment

The table of contents of this recommended practice lists annexes for equipment types found in substations. Depending upon the complexity of its structure, a specification has been provided for either calculations or tests necessary to qualify each piece of equipment to withstand an earthquake environment. The annexes contain a recommended qualification outline for the listed equipment.

7.6 Functionality of equipment

The functional aspects of specific equipment are defined in the “Operational requirements” and the “Acceptance criteria” of the annexes. The ultimate requirement for particular equipment is to be capable of functioning before, during, and after a seismic event. This can only be verified by testing to a level equivalent to the particular seismic event and performing the required functions before, during, and after the test. Switches, linkages, mechanisms, relays, etc. must remain functional, or must change state as required to perform their function. This includes both mechanical and electrical integrity requirements.

Functional requirements are only verified to the actual level of the test. On the other hand, structural requirements can be satisfied by lower levels of testing and extrapolating results to higher levels by comparison of actual stress measurements to the allowables.

7.7 Qualification by seismic experience data

Procedures for qualifying certain types of equipment through the use of actual earthquake experience have been developed in the nuclear power industry. The use of earthquake experience data as a qualification method is addressed in IEEE Std 344-1987 [B15], and in subsequent revisions of that standard under development at the time of this writing.

Earthquake experience data typically applies to categories of equipment rather than to specific items. The documented performance record of the equipment category must demonstrate that there is no tendency for significant structural seismic damage over the range of ground shaking experienced in actual earthquakes.

This documented performance record consists of an inventory of equipment (within the particular category) that has experienced substantial earthquake ground motion, for which the post-earthquake condition of the equipment can be verified. This inventory of earthquake-affected equipment comprises a database for the equipment category.

The use of experience data may be considered as an alternative to testing and analysis only when the following have been met:

a) The particular type of equipment can be shown to have no tendency for significant structural damage or performance degradation for the specified level of ground motion.
b) The specified ground motion is less than or comparable to the range of ground motions experienced by sites reviewed in compiling the database.

c) Items of equipment qualified by experience data must be shown to be generally represented by the equipment category for which an adequate database has been compiled. Representation means that a specific equipment item must fit within the database range of size, mass, and capacity; must be similar in operation and construction (including its support); and must contain no significant design differences compared to database equipment that might be sources of weakness under seismic loading. The equipment item need not be represented within the database by the specific manufacturer and model.
d) An adequate database inventory for a particular category of equipment should include about 50 examples (i.e., about 50 items of similar equipment) that have experienced earthquake ground motion comparable to or greater than the predicted level for the substation site. This database inventory should include multiple sites and multiple earthquakes.
e) The earthquake performance record for the category of equipment must demonstrate that there is no tendency for seismic damage in past earthquakes, or that sources of seismic damage are precluded by design or installation provisions for the particular item to be qualified.
f) Experience data may be used only when approved by the purchaser of the substation equipment.

Experience data can only be used to demonstrate the ability of equipment to survive the earthquake and remain operable afterward. It cannot be used to ensure that equipment, such as circuit breakers, relays, or contacts will maintain the correct operational state during shaking.

Procedures for qualification by experience data have been developed by the nuclear power industry for certain categories of equipment powered at voltages up to about 15 kV. These procedures are supported by an existing database of adequate size and detail, and a standard set of restrictions and requirements for reviewing specific equipment items. These procedures are discussed in Annex P and in the referenced standard “Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment” [B10]. Qualification by experience data requires appreciable expertise; it is suggested that the standards developed by the nuclear industry be utilized whenever possible.

8. Design considerations

8.1 Foundation analysis

This subclause applies to the design of foundations and the analysis of the soil. It does not apply to anchorage. See ASCE Substation Structure Design Guide (draft) and A.4.2 for anchorage.

8.1.1 Pad-type foundations supporting flexible equipment

Pad-type foundations supporting flexible equipment may be designed using lower loads than required by the qualification of the equipment and support. Experience has shown that these types of foundations can be analyzed to the requirements of Equation (1),

$$F_p = ZIC_pW_p \quad (1)$$

which comes from Section 1630.2, vol. 2 of the 1994 edition of the Uniform Building Code (UBC), where $C_p = 0.75$. This load should be applied horizontally at the CG of the equipment. As always, the dead weight of the equipment and foundation should be considered as vertical load. Normal operating loads, if applicable, should be included. F_p can be used for overturning and determining the loads on the soil. However, it is advisable to use working allowables for the soils instead of ultimate values.

8.1.2 Pad-type foundations supporting heavy or rigid equipment

Pad-type foundations supporting heavy or rigid equipment, such as transformers, may be designed to the same criteria as flexible equipment. However, special care should be exercised when designing the foundation and evaluating the soils. Poor or marginal soils may require that engineered fill or piles be placed under the foundation. Settlement of foundations and cracked or damaged foundations are typical problems found after earthquakes. Also, rocking of the foundation has been identified as a potential problem.

8.1.3 Pier and pile type foundations

Pier- and pile-type foundations supporting equipment should be designed to the loads found in the qualification process for the equipment and support. However, the soil may be analyzed to the same criteria and loads as the pad-type foundations, except Equation (1) should be multiplied by 1.67 for tall pedestal-type equipment and support.

If the electrical support structure is designed to act as an integral unit at the high and moderate performance levels and is located on multiple foundations, then consideration should be given to connecting the foundation with grade beams to minimize differential foundation displacement, due to an earthquake.

8.2 Station service

Station service is one of the key elements necessary to bring earthquake damaged stations back on-line. The station service is normally comprised of lower-voltage equipment (except the transformer high voltage side), and experience has shown that such equipment is generally inherently rugged. However, station service has been lost in earthquakes. Often this can be traced to inadequate attention to detail. The following checklist can be used when designing the station service:

a) Verify that all the equipment and the supports are adequately anchored to the foundations.
b) Verify that all of the equipment is decoupled and that there is adequate slack or jumper loops in the conductors and interconnections with rigid bus.
c) Verify that equipment meets the requirements of Annexes B through O.
d) Verify that the support structures are rugged and rigid.
e) Verify that there are no weak hinge points in the structures.
f) Verify that the bushings and their mounting fittings to the equipment are adequately designed.
g) Verify that there are no objects, such as trees or branches, outside of the station service area that can fall into the station service area.
h) It is desirable, if practicable, to place the station service equipment on one solid foundation. If liquefaction or soil settlement occurs, damage can be minimized using this technique. Also, differential movement between equipment is minimized.
i) All items, including “noncritical” items, such as light poles, that are within or near the station service area that have the potential of falling on station equipment or energized bus, should be considered as critical and designed not to fail, since their failure could cause the station service to fail.
j) Verify that no damage will result from the swinging of any suspended or hung equipment or article.

8.3 Emergency power systems

8.3.1 Station batteries

Station batteries are an integral part of the control and communication systems (ac station service supplies power to dc system) in electrical substations. When ac system power is lost, these batteries provide the critical emergency power for control, communications, and monitoring when off-site power is lost or if station power is disrupted. The operational life of batteries, that is, the number of hours the batteries can meet demand when station service is disrupted, typically ranges from 2 h to 6 h. For critical sites without engine-generators, battery operational life should be determined by the time it would take to supply emergency power with a mobile generator. To meet the vital needs supplied by the batteries for disruptions longer than the operational life of the batteries, emergency engine-generators can be used to recharge the batteries and provide other essential ac loads for an extended period. For sites with emergency generators that can support the load on the station batteries, batteries only need to be able to start the engine-generator.

It is vital that batteries be supported by seismically qualified battery racks, as described in Annex J. In addition to a seismically qualified battery rack, the cells should be restrained to the rack and provided with rigid foam separators between cells and between side and end restraints of the battery rack to prevent impact loads and damage to cell cases. Electrical connections should be provided with adequate slack to accommodate movement of the rack and conductor anchor points. Normal shipping loads for industrial grade batteries should be adequate to qualify the cells to 1 g motion at the base of the battery rack.

8.3.2 Engine-generators

The performance of engine-generators after earthquakes has not been good for a number of reasons. These include inadequate anchorage of the engine-generator or fuel supply system, overturning or malfunction of the engine-generator control system, or overloading of the system. Detailed discussion of issues related to the selection, installation, operation, maintenance, and testing of emergency generators is contained in the ASCE (draft), “Guide to Reliable Emergency Power” [B4].

The most common problems with emergency generators are easily avoided, as described in the following:

a) *Generator anchorage*. Engine generators are often mounted on vibration-isolation systems to keep vibrations of the engine-generator from getting into the engine support structure. In most cases, these isolation systems are not necessary. If they are used, it is vital that the system that is supported be restrained so that its motion is limited and it cannot fall off of its support system. Some isolation systems have self-contained restraints, but they are often made of cast iron and fail under earthquake induced loads. When isolation systems are used, it is also important to provide all utility connections, such as the fuel line, control lines, power lines, and cooling water lines with adequate slack and flexibility.
b) *Securing engine-generator starting batteries*. Frequently, in otherwise well-engineered emergency power facilities, batteries that are used to start the engine-generator are unanchored. In an earthquake, unanchored batteries can be damaged and hence, unavailable to start the emergency engine. Batteries should be secured so that they cannot fall or slide and impact against each other or their support structure.
c) *Day tank anchorage.* Modern day tanks, small tanks, and pump controls used to get fuel from the main storage tank to a small tank near the engine-generator, typically consist of a closed fuel tank sitting in a second open tank. While the overall system is typically anchored to the floor, the closed tank may not be anchored to the open tank in which it sits. In this case, fuel lines provide the restraint to secure the tank. The load path for all system components should be evaluated for adequate strength and limited flexibility.
d) *Fouled and contaminated fuel*. If diesel fuel is used, it should be treated with additives to prevent growth of micro-organisms and changed periodically, about every five years. Fouled fuel will clog injectors and filters. Under some conditions, partially filled tanks will allow water to condense and contaminate the fuel.
e) *Posted manual operating instructions*. Several conditions can prevent an engine from starting. For example, relays used to control and protect the engine may malfunction due to earthquake-induced vibrations. It is important that detailed instruction be posted near the engine for starting the units. These instructions should indicate the proper position for all switches and valves and sequence of actions needed to start the engine.
f) *Annually compare engine-generation capacity to its load*. Annually review electrical load on the engine-generator to ensure that it is below its capacity.

8.4 Telecommunication equipment

Three features common to telecommunication equipment can cause poor performance in earthquakes. They are as follows:

a) *Flexible anchorage details of communication equipment racks*. Telecommunication equipment racks are typically anchored to the floor by four bolts through large aluminum angles in front and back. While this anchoring method may have adequate strength, it is very flexible. These racks can experience earthquake-induced motions of many centimeters at the top of the rack. It is important that cable connections be provided with adequate slack to accommodate these motions. These motions can be greatly reduced by providing an upper brace to the rack by attaching the top of the rack to an overhead cable tray. The design should also prevent pinching of cables between cable trays. These motions can be greatly reduced by providing an upper brace to the rack or attaching the top of the rack to an overhead cable tray.
b) *Communication cable trays*. Cable trays commonly used by the communication industry are constructed so that sections are connected with friction clips. If these trays are used to brace equipment racks, positive connections should be used in their assembly.
c) *Communication equipment circuit board or pack restraints*. Communication equipment often contains circuit boards, or circuit packs, that plug into a mother board mounted in the equipment chassis. These boards should have positive restraints to prevent them from vibrating loose. The restraints can be provided by circuit board retractors with locks or with other means to restrain the boards.

9. Seismic performance criteria for electrical substation equipment

9.1 Introduction

This clause describes the following:

a) Three seismic qualification levels (high, moderate, and low)
b) The substation equipment performance that can be expected for each of the qualification levels
c) Guidelines to equipment purchasers on how to select the appropriate qualification level
d) The performance level
e) The required response spectrum
f) How the performance level is related to the required response spectrum

9.2 Objective

The objective of this recommended practice is to secure equipment that performs acceptably under reasonably anticipated strong ground motion. Acceptable performance means that following (and during, if so required) the earthquake shaking, there is no significant structural damage and most equipment continues to function. However, some minor damage may occur and a small portion of equipment may not fully function. (See 7.6 for a discussion of electrical function.)

Because the anticipated loading due to earthquakes differs greatly from region to region, and in some cases there is an associated cost for meeting significantly higher seismic qualification levels, three seismic qualification levels (high, moderate, and low) have been established.

9.3 Seismic performance levels

The PL of earthquake motion is represented by response spectra that reasonably envelop response spectra from anticipated ground strong motions. See 9.4 and 9.5 for more discussion.

The shape of the PL is a broad-band response spectrum that envelopes effects of earthquakes in different areas considering site conditions ranging from rock to soft soil as described in NEHRP-1997. Different damping percentages are specified, as shown in Figures 4 and 5.

The PL and RRS shapes bracket the vast majority of substation site conditions, and in particular provide longer period coverage for soft sites. However, very soft sites and hill sites may not be adequately covered by these spectral shapes.

9.3.1 High seismic performance level

Equipment that is shown by this practice to perform acceptably in ground shaking up to the high seismic performance level is said to be seismically qualified to the high level.

The high seismic performance level is shown in Figure 4.

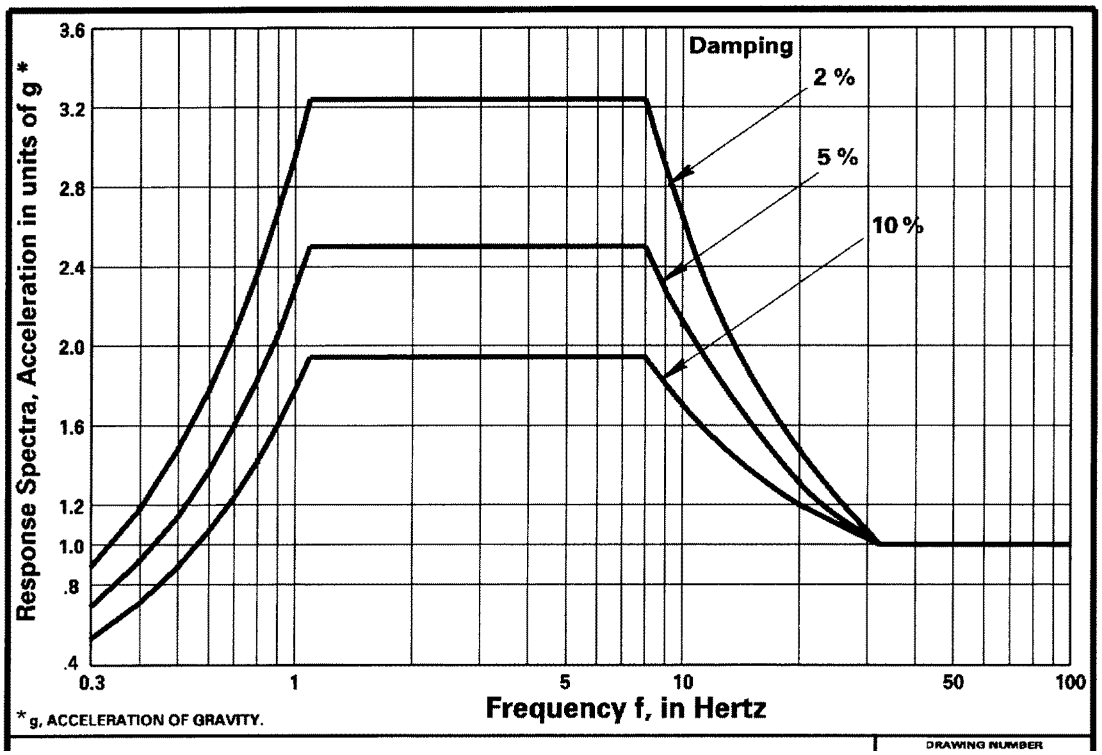


Figure 4— High seismic performance level

9.3.2 Moderate seismic performance level

Equipment that is shown by this practice to perform acceptably in ground shaking up to the moderate seismic performance level is said to be seismically qualified to the moderate level.

The moderate seismic performance level is shown in Figure 5.

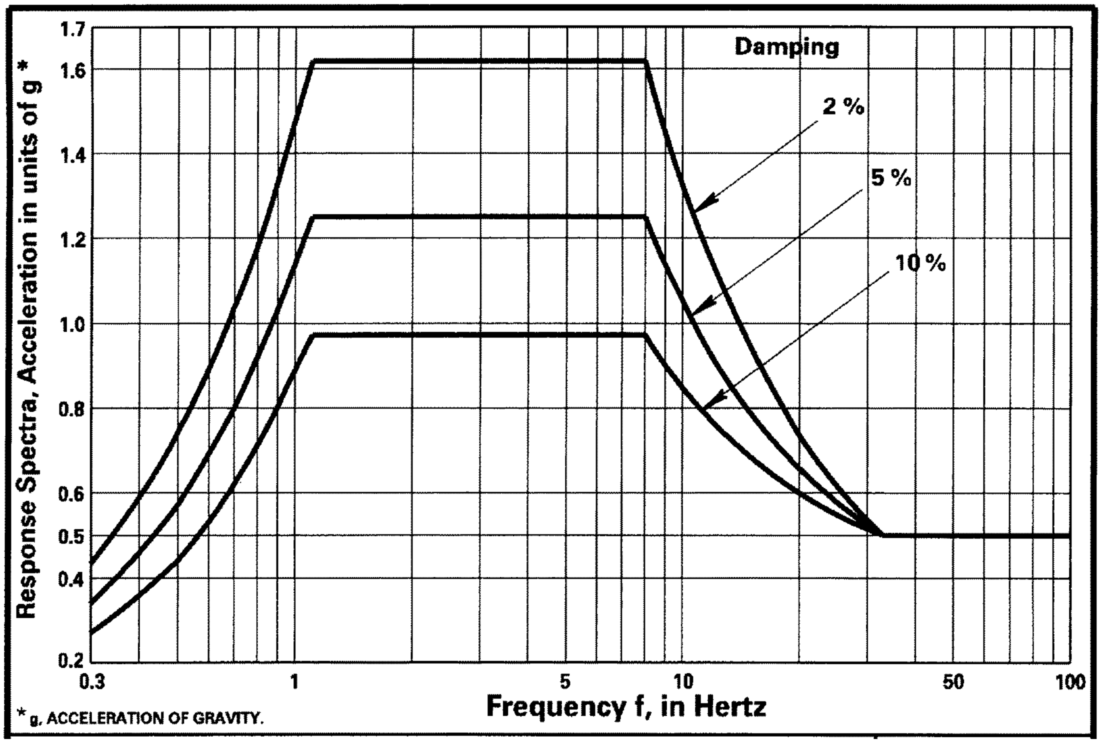


Figure 5— Moderate seismic performance level

9.3.3 Low seismic performance level

Equipment that is shown by this practice to perform acceptably in ground shaking up to the low seismic performance level is said to be seismically qualified to the low level.

The low seismic performance level represents the performance that can be expected when good construction practices are used and no special consideration is given to seismic performance. In general, it is expected that the majority of equipment will have acceptable performance at 0.1 g and less. However, live tank circuit breakers in voltage classifications of 500 kV and higher that have not been designed for earthquake loading and then qualified by shake-table testing or analysis may be damaged at these low acceleration levels.

9.4 Performance factor

It is often impractical or not cost effective to test to the high or moderate PL because of the following:

a) Test laboratories may not be able to attain these acceleration levels, especially at low frequencies; more importantly,
b) Since yielding of ductile materials is considered acceptable at the PL, some structural components may be damaged if tested to the PL and hence would be a financial loss.

For these reasons, the equipment may be tested at 50% of the PL. For consistency, analysis will also be performed at 50% of the PL. This reduced level is called the RRS. For the high level, compare Figure 4 to Figure A.1 and for the moderate level, compare Figure 5 to Figure A.2.

The ratio of PL to RRS in this practice is 2.0. This factor is called the performance factor. (That is, the performance factor is PL/RRS or two.) The performance factor does not apply to the low seismic level.

However, equipment tested or analyzed to the RRS is expected to have acceptable performance at the PL. This is achieved by measuring the stresses obtained from the test or found from the analysis at the RRS and by the following:

a) Comparing the stresses to 50% of the ultimate strength of the porcelain or cast aluminum component. The 50% is the inverse of the performance factor.
b) Using a lower factor of safety against yield combined with an allowance for ductility for steel and other ductile materials.
c) Considering that for most materials, the hysteresis damping capability increases at the higher levels of stress normally associated with higher levels of shaking.

Theoretically, because of the reasons stated above, components qualified using the moderate or high RRS should be able to withstand ground shaking at the respective PL. It is cautioned that this approach is dependent upon identifying the highest stressed locations within the equipment and then monitoring during testing or analyzing the stresses at these locations. Should the preparer of the qualification not identify the critical locations within the equipment, premature failure may occur in an earthquake. Also, the response of the equipment to the dynamic loading may change between the RRS and the PL. If this is not anticipated, premature failures may occur.

9.5 Seismic qualification

The discussion of 9.4 pertains to the structural performance of the equipment. Qualification by analysis provides no assurance of electrical function. Shake-table testing provides assurance for only those electrical functions verified by electrical testing and only to the RRS level, not to the PL.

Shake-table testing may be required for equipment that in previous years were qualified by dynamic analysis, but performed poorly during past earthquakes. However, static or static coefficient analysis may still be specified when past seismic performance of equipment qualified by such methods has led to acceptable performance.

9.5.1 High and moderate seismic performance level qualifications

The high and moderate RRS are shown in Figures A.1 and A.2, respectively. The RRS spectral shape is the same spectral shape as used in the PL, except at 50% of the PL. The equations for the spectra are listed in Figures A.1 and A.2.

9.5.2 Low seismic performance level qualification

A rigorous seismic qualification, such as is required to meet the high and moderate performance levels, is not required for equipment qualified to the low performance level. That is, no required response spectrum nor seismic report is required. However, the following should be met:

a) *Anchorage.* Anchorage for the low seismic performance level shall be capable of withstanding at least 0.2 times the equipment weight applied in one horizontal direction combined with 0.16 times the weight applied in the vertical direction at the CG of the equipment and support. The resultant load shall be combined with the maximum normal operating load and dead load to develop the greatest stress on the anchorage. The anchorage should be designed using the requirements of A.4.2.
b) *Defined load path.* The equipment and its support structure shall have a well defined load path. Documentation of the load path is not required. However, the manufacturer shall design the equipment so that it adheres to the characteristics described herein. The determination of the load path shall be established so that it describes the transfer of loads generated by, or transmitted to, the equipment from the point of origin of the load to the anchorage of the supplied equipment. Among the forces that shall be considered are seismic (simultaneous triaxial loading—two horizontal and one vertical), gravitational, and normal operating loads. The load path shall not include the following:
    1) Sacrificial collapse members
    2) Materials that will undergo non-elastic deformations, unrestrained translation, or rotational degrees of freedom

3) Solely friction dependent restraint (control energy dissipating devices excepted)

9.6 Selecting performance level for seismic qualification

A degree of judgment and advanced planning is likely to be involved in selecting the performance level for seismic qualification. The site hazard should not be expected to fall directly on the high, moderate, or low seismic performance level, and a decision to take more risk or less risk will need to be made. It is recommended that large blocks of service area be dedicated to a single level as discussed in 5.4. There are also many operational factors that will need to be considered when selecting equipment to go into the active inventory of an operating utility. Therefore, it is recommended that the user evaluate all sites in the entire service territory and establish a master plan, evaluating which sites are high, moderate, or low (see 5.4). Likewise, after a site for new electrical equipment has been identified, the user or user’s agent must determine the appropriate seismic performance level for selecting the seismic qualification.

Should the user determine that the spectra given in Figures 4, 5, A.1, or A.2 are unsuitable, then other spectra should be developed and used. (See 5.3.)

9.6.1 Earthquake hazard method

The procedure to select the appropriate seismic qualification level for a site consists of the following steps:

a) Establish the probabilistic earthquake hazard exposure of the site where the equipment will be placed. Use the site-specific peak ground acceleration developed in a study of the site’s seismic hazard, selected at a 2% probability of exceedance in 50 years, modified for site soil conditions.
b) The resulting site-specific peak acceleration value and spectral acceleration values should then be compared with the three seismic performance levels in order to select the level (high, moderate, or low) that best accommodates the ground motions expected. If the peak ground acceleration is equal or less than 0.1 g, the site is classified as low. If the peak ground acceleration is greater than 0.1 g, but equal or less than 0.5 g, the site is classified as moderate. If the peak ground acceleration is greater than 0.5 g, the site is classified as high. This level then specifies the seismic qualification level used for procurement.
   In selecting the qualification level based on the performance levels, it should be remembered that performance levels represent levels of ruggedness based on testing at lower levels combined with factors of safety for material, or analysis combined with experience from previous earthquakes. Therefore, these performance levels have a degree of uncertainty. For better assurance of structural performance during an earthquake, a user may require that the qualification spectra be higher to more closely fit the level that the user desires the equipment to be protected against. The user should carefully weigh the benefits of deviating from criteria specified herein against the added costs.

The earthquake hazard method is the preferred approach and can be used at any site.

9.6.2 Seismic exposure map method

These methods are alternate methods to the earthquake hazard method.

9.6.2.1 United States

The NEHRP-1997 seismic exposure maps can be used. The NEHRP-1997 maps provide spectral acceleration levels at several response spectra periods of ground-motion vibration for several probability levels.

To select the appropriate seismic qualification level, follow the steps outlined below.

a) Determine the soil classification of the site (NEHRP-1997 soil type A, B, C, D, or E).
b) Locate the site on the NEHRP-1997 seismic hazard map showing peak acceleration (%g) with 2% probability of exceedance in 50 years on soft-rock site.

c) Estimate the site peak soft-rock acceleration from the 2% map.
d) Multiply that value by the Fa value for the site soil conditions as a function of peak soft-rock acceleration.
e) From the resulting value, which is the site peak ground acceleration, select the PL. If the peak ground acceleration is ≤ 0.1 g, the site is classified as low. If the peak ground acceleration is > 0.1 g, but ≤ 0.5 g, the site is classified as moderate. If the peak ground acceleration is > than 0.5 g, the site is classified as high.

9.6.2.2 Canada

Seismic zoning maps, located in the 11th edition of the 1995 NBCC, can be used. The 1995 NBCC maps provide contours of peak horizontal firm ground acceleration and velocities for a probability of exceedance of 10% in 50 years (i.e., 475 year return period).

To select the appropriate seismic qualification level, follow the steps outlined as follows:

a) Determine the foundation category (1 to 4) at the site as defined in Table 2.
b) Locate the site on the 1995 NBCC peak acceleration zoning map.
c) Determine the site peak firm ground acceleration from the map (or the tabulated values provided in the 1995 NBCC for some sites).
d) Multiply the firm ground acceleration by 1.5.[14]
e) Multiply that value by the appropriate foundation factor from Table 2 to obtain the site peak ground acceleration.
f) Select the appropriate PL. If the site peak ground acceleration is < 0.1g, the site is classified as low. If the site peak ground acceleration is > 0.1g, but ≤ 0.5g, the site is classified as moderate. If the site peak ground acceleration is > 0.5g, the site is classified as high.

Table 2— Foundation factors (F)*

Category	Type and depth of rock and soil measured from the foundation or pile cap level	F
1	Rock, dense and very dense coarse-grained soils, very stiff and hard fine-grained soils; compact coarse-grained soils and firm and stiff fine-grained soils from 0 to 15 m deep.	1.0
2	Compact coarse-grained soils, firm and stiff fine-grained soils with a depth greater than 15 m; very loose and loose coarse-grained soils and very soft and soft fine-grained soils from 0 to 15 m deep.	1.3
3	Very loose and loose coarse-grained soils with depth greater than 15 m.	1.5
4	Very soft and soft fine-grained soils with depth greater than 15 m.	2.0

*Source—National Research Council of Canada, Institute for Research in Construction.

9.6.2.3 Mexico

To select the appropriate seismic qualification level, follow the steps outlined below.

[14]This factor is applied because the NBCC seismic zoning maps show accelerations that do not have the same probability of exceedance as the performance level accelerations defined in this recommended practice. Experience at various Canadian sites has shown that the computed peak firm ground acceleration has a probability of exceedance of 10% in 50 years. For critical sites, it is recommended that users consider the use of a factor larger than 1.5; in such cases it is advisable to consult an engineering seismologist familiar with the area.

a) Locate the area on the seismic zoning map of Manual de Diseño de Obras Civiles de la Comisión Federal de Electricidad (MDOC/CFE, 1993). Seismic zones from A to D reflect, from low to high, the peak acceleration level expected on stiff soil.

b) Establish the soil classification of the substation site as follows:

1) *Soil type I.* A soil formation with rock of any characteristic that has shear wave velocity greater than or equal to 700 m/s.

2) *Soil type II.* A soil formation whose effective shear wave velocity and dominant period are such that

$$\beta_o \le \beta_s < 700 \text{m/s}$$

or

$$\beta_o < \beta_s \text{ and } T_s \ge T_o(1 - \beta_s / \beta_o)$$

3) *Soil type III.* A soil formation whose effective shear wave velocity and dominant period are such that

$$\beta_s < \beta_o \text{and } T_s < T_o(1 - \beta_s / \beta_o)$$

where

Ts is dominant site period in shear waves
βs is effective shear wave velocity of the site
To is characteristic period depending on the seismic zone given in Table 3
βo is characteristic velocity depending on the seismic zone given in Table 3

Table 3— Values of T_o and β_o

Seismic zone	T_o (s)	β_o (m/s)
A	5.3	400
B	5.3	400
C	4.7	500
D	2.5	500

The site parameters β_s and T_s can be obtained as

$$\beta_s = H_s \sum (h_m / \beta_m)$$

$$T_s = 4H_s / \beta_s$$

where

H_s is depth of the soil layers overlying the rock
h_m is thickness of the mth soil layer
β_m is shear wave velocity of the mth soil layer

c) Determine the site coefficient S from Table 4 to account for the effects of the local soil conditions

Table 4— Value of the site coefficient *S*

Seismic zone	Soil type		
	I (stiff soil)	II (intermediate soil)	III (soft soil)
A	1	2	2.5
B	1	2	2.5
C	1	1.8	1.8
D	1	1.7	1.7

d) Estimate the peak rock acceleration *A*r from the seismic hazard maps of PSM, 1996, by locating the substation site on the map indicating the appropriate return period selected for seismic qualification. Interpolation or the higher adjacent value may be used. Return periods from 100–200 years are recommended for the west coast of Mexico due to its high seismicity; the former is typical of Mexico building codes.

e) Obtain the peak ground acceleration *A*g for the site as:

$$A\mathrm{g} = S\,A\mathrm{r}$$

Select the seismic qualification level as follows:

— If $A\mathrm{g} \leq 0.1$ g, the area is classified as low
— If $0.1 < A\mathrm{g} \leq 0.5$ g, the area is classified as moderate
— If $A\mathrm{g} > 0.5$ g, the area is classified as high

The following is provided as an example, using Manzanillo, Colima as the represented area. Longitude 104.28 and Latitude 19.05. Local soil conditions are stable deposit of sands with effective shear wave velocity $\beta\mathrm{s} = 590$ m/s. Recurrence interval for large earthquakes is for a 10% probability of exceedance in 20 years of exposure period, which is about 200 years return period.

— By using the MDOC/CFE, 1993 seismic zoning map, the area belongs to seismic zone D.
— From Table 3, $\beta\mathrm{o} = 500$ m/s for seismic zone D. Since $\beta\mathrm{o} \leq \beta\mathrm{s} < 700$ m/s, the soil is classified as type II.
— For seismic zone D and soil type II, the site coefficient is S = 1.7 according to Table 4.
— Beginning with the PSM seismic hazard maps, the peak rock acceleration for 200 year return period is about 60% of gravity, that is $A\mathrm{r} = 0.6$ g.
— The peak ground acceleration for the site results in $A\mathrm{g} = 1.7 \times 0.6 = 1.0$ g.
— Since Ag > 0.5 g, the high seismic performance level should be selected.

9.6.2.4 General

Users in countries other than those listed above may develop a seismic exposure map procedure. It is recommended that the map procedure be developed using a method similar to that described in 9.6.2. The method should yield results similar to or more conservative than 9.6.1.

Annex A Standard clauses

(Normative)

NOTE — Annexes B through O provide the qualification requirements for electrical equipment, such as circuit breakers, transformers, etc. Some of the qualification requirements are generic to all equipment. So, as not to repeat these requirements in each annex, those requirements are given once in Annex A, with Annexes B through O referring back to Annex A.

A.1 Qualification procedures

A.1.1 General

The equipment shall be tested or analyzed in its equivalent in-service configuration,[15] including pedestal or other support structure. The effects of the electrical connections, conduit, sensing lines, and any other interfaces supplied by the manufacturer shall be considered and included in the analysis or test, unless otherwise justified.

Porcelain, glass, and ceramic components that have been shake-table tested shall not be provided to the user unless the user is notified in writing and has provided written acceptance of the tested component.

Any equipment or equipment component that does not comply with the acceptance criteria or the functional requirements shall not be provided to the user.

The equipment shall be analyzed for the combination of dead, normal operating, if any, and seismic loads.

A.1.1.1 Triaxial analysis and testing

Analysis and time history testing shall be triaxial. The specified acceleration or RRS shall be applied in the two horizontal axes of the equipment together with the vertical axis whose specified acceleration or spectral value shall be taken as at least 80% of a horizontal value.

Analysis shall use the square root of the sum of the squares (SRSS) method to account for orthogonal acceleration effects. The SRSS method, as used in this recommended practice, combines seismic stresses at a particular location, or combines local seismic forces acting on a particular element of a structure system. With this method, the stresses or local forces associated with each maximum required orthogonal seismic response are determined separately and then combined by squaring each value, adding them algebraically, then taking the square root of that sum. The result of this calculation is the maximum seismic stress or force at the location or element in question, which shall then be applied in the direction that produces the most severe equipment stresses.

A.1.1.2 Biaxial testing

Biaxial time history testing (one horizontal and the vertical) may be used if it can be shown that no significant coupling exists in the equipment between the two horizontal axes to give additive responses in the unexcited axis or if the input acceleration is increased to account for any additive response. If biaxial testing is used, two separate tests shall be made—one for each principal horizontal axis. If both horizontal axes are symmetrical and have the same structural shape, only one horizontal axis test needs to be performed.

[15]See 6.5 for explanation of in-service configuration.

In lieu of showing that no significant coupling exists and performing two separate tests, one biaxial test may be conducted for both the time history test and the sine beat test, provided the equipment is rotated 45° to its principal horizontal axis and the horizontal acceleration is increased by a factor of 1.4. For the sine beat test, the resonant frequencies shall be in the rotated axis.

A.1.2 Time history shake-table test

The equipment and supporting structure shall be subjected to at least one time history test with a TRS that envelopes the RRS. The motion should be random. Alternately, when all the resonances of the equipment have been definitely established by actual tests, it will be sufficient for the TRS to envelop the RRS at and above the first mode frequency.

The TRS shall be computed with a damping value equal to or greater than the RRS. A TRS damping value equal to the RRS is preferred. A damping value of 2% is recommended.

The input duration of the time history tests shall be at least 20 s of strong motion. Ring down time or acceleration ramp-up time shall not be included in the 20 s of strong motion. The duration of strong motion shall be defined as the time range between when the plot of the time history first reaches 25% of the maximum value to the time when it falls for the last time to 25% of the maximum value.

A.1.3 Resonant frequency search test

A sine sweep frequency search shall be conducted at a rate not greater than one octave per minute in the range for which the equipment has resonant frequencies, but at least from 1 Hz, in the two horizontal axes and the vertical axis to determine the resonant frequencies and the damping. Damping may be found using the half-power bandwidth method. See A.1.8 item b). A frequency search above 33 Hz is not required. No resonant frequency search in the vertical axis is required if it can be shown that no resonant frequencies exist below 33 Hz in the vertical direction.

White noise may be used in lieu of the sine sweep, provided damping is found and the amplitude of the white noise input is not less than 0.25 g.

A.1.4 Sine beat test

The test shall be conducted in two stages:

a) *Stage 1, resonant frequency search.* A resonant frequency search shall be conducted as specified in A.1.3 and predominant frequencies determined.
b) *Stage 2, sine beat test.* A sinusoidal beat motion consisting of a sinusoid of the equipment resonant frequencies modulated by a lower frequency sinusoid that provides at least 10 cycles of resonant frequency per beat shall be applied to the equipment and supports. There shall be a minimum of five such beats of resonant frequency within a period ranging from 60 s to about 150 s, and the pause between bursts shall be long enough so that there will be no significant superposition of motion. The 10 cycle sine beat test shall be performed at the predominant resonant frequencies found in stage 1, once in each of the three orthogonal axes. Sine beat testing shall be run at the specified value in the horizontal axes, each simultaneously and in phase with 80% of the specified value in the vertical axis at the predominant frequencies found in the horizontal directions. Sine beat testing shall also be run at 80% of the specified value in the vertical axis at the predominant frequencies found in the vertical axis. If no predominant frequencies are found in the vertical axis below 34 Hz, then no test will be required for the vertical direction.

   The following are guidelines only for selecting the predominant frequencies. Unless the equipment is complex, it is usually sufficient to test no more than 3 or 4 of the most predominant frequencies in any one direction. The amplification at a predominant frequency is usually 2 or greater.
   If no resonant frequency is found in a horizontal axis, a test at 33 Hz shall be performed in that axis.

A.1.5 Dynamic analysis

Using dynamic analysis, the equipment and any support structure shall first be modeled as an assemblage of discrete structural elements interconnected at a finite number of points called nodes. The number, location, and properties of elements and nodes shall be such that an adequate representation of the modeled item(s) is obtained in the context of a seismic analysis. The resulting system is called a finite element model.

The finite element model shall be dynamically analyzed using a "modal spectrum analysis", as described, for example, by Chopra, Anil K., "Dynamics of Structures—A Primer," Earthquake Engineering Research Institute [B7], and "Response Spectrum Method in Seismic Analysis and Design of Structures," CRC Press, 1992 [B8]. The modal responses of the finite element model to the dynamic analysis shall have three translational and three rotational components in and about the defined orthogonal axes system. The total response of all the modes in any one direction shall be determined by combining all the modal response components acting in that direction using the SRSS technique, except if the mode frequencies differ by less than 10% of the next lower mode, then their combined modal response shall be determined by using the absolute sum technique. Alternatively, the total response in any one direction may be determined by applying the complete quadratic combination technique to all the modal response components acting in that direction.

Sufficient modes shall be included to ensure an adequate representation of the equipment's dynamic response. The acceptance criteria for establishing sufficiency in a particular direction shall be that the cumulative participating mass of the modes considered shall be at least 90% of the sum of effective masses of all modes. The acceptance criteria shall be applicable to the directions of orthogonal excitation and those response directions deemed significant, as determined by the specialist and the user, for the particular type of equipment being analyzed.

Should the finite element model have a number of resonant frequencies above 33 Hz such that the attainment of the acceptance criteria in an orthogonal excitation direction is impractical (as may be the case with vertical ground acceleration of vertically stiff equipment), then the effects of the orthogonal inputs can be simulated as follows:

a) Determine the remaining effective mass in a given direction.
b) For each component, apply a static force equal to the mass of the component times the percentage of mass missing times the ZPA.
c) Calculate stresses, reactions, etc., using these forces.
d) For each direction, combine stresses, reactions, etc., from the dynamic analysis with those from the analysis above using the SRSS.

A damping value of 2% shall be used for dynamic analysis, unless a higher damping value is justified by one of the tests specified in A.1.8.

Testing may be done to provide data for the analysis.

Discrete parts of the equipment may be tested independently of the overall equipment. If testing is done to qualify parts of the equipment, the input acceleration, at the mounting point of the part, shall be increased to account for the amplification of the intermediate parts between the base acceleration and the mounting point. The increase in acceleration may be determined by analysis or testing.

A.1.6 Static analysis

The forces on each component of the equipment shall be obtained by multiplying the values of the component's mass by the acceleration specified in the appropriate annex in the principal directions. The resulting force shall be applied at the component's CG. A part may be subdivided into smaller components in order to better represent the part's mass distribution.

The vertical seismic forces shall act simultaneously with both horizontal seismic forces. The three forces at each component's CG shall be applied using the SRSS method in the direction that produces the most severe equipment stresses, and then combined with dead load stresses and any normal operating stresses.

A.1.7 Static coefficient method

The acceleration response of the equipment shall be determined using the maximum peak of the RRS at a damping value of 2%, unless a higher value for damping is justified by a test specified in A.1.8. The seismic forces on each component of the equipment are obtained by multiplying the values of the mass, by the maximum peak of the RRS, by the static coefficient. A static coefficient of 1.5 shall be used, unless otherwise noted herein. The resulting force shall be distributed over the components in a manner proportional to its mass distribution. The stress at any point in the equipment shall be determined by combining the three orthogonal directional stresses (at that particular point) by the SRSS method, and combining all dead and normal operating stresses in such a manner to obtain the greatest stress at the point. The points of maximum stress shall be found.

A.1.8 Damping

Damping may be determined by any one of the following methods:

a) *Measuring the decay rate.* The equivalent viscous damping can be calculated by recording the decay rate of the particular vibration mode. This procedure is often referred to as the logarithmic decrement method.
b) *Measuring the half-power bandwidth.* The equipment should be excited with a slowly swept sinusoidal vibration. The response of any desired location in the equipment is measured and plotted as a function of frequency. From these response plots, the damping associated with each mode can be calculated by measurements of the width of the respective resonance peak at the half-power point.
c) *Curve fitting methods.* The equipment is excited by swept sine, random, or transient excitation, and a response transfer function is developed. The modal damping is obtained by fitting a mathematical model to the actual frequency response data (transfer function). This curve fitting will smooth out any noise or small experimental errors.

A.2 Acceptance criteria for testing

The seismic test will be acceptable if the criteria in A.2.1 through A.2.5 are met.

A.2.1 General criteria

No cracking, buckling, or other types of failure or distress are found on the equipment and equipment supports.

A.2.2 Time history test(s)

The time history will be acceptable if the following criteria are met:

a) For porcelain components, the total stresses (including seismic, pressure, dead, and normal operating load) shall not exceed 50% of the porcelain's ultimate strength. Where applicable, the resulting seismic loads shall not exceed 50% of the oil leakage load.
b) The total stresses in the steel components shall not exceed the allowable stresses specified in the latest revision of AISC Manual of Steel Construction, ASD.
c) The total stresses in ductile aluminum components shall not exceed the allowable stresses specified in the Aluminum Design Manual: Specifications and Guidelines for Aluminum Structures by the Aluminum Association [B2].
d) For cast aluminum or other brittle components, the seismic stresses shall not exceed 50% of the ultimate strength.
e) Composite components shall not be damaged. The requirements of A.2.4 for composite material shall be met.

f) There shall be no leaks or observable offset of the porcelain on its base, movement of the porcelain relative to the gaskets, nor movements of the gaskets.

A.2.3 Sine beat test(s)

The sine beat test will be acceptable if the following criteria are met:

a) The total stresses in the porcelain components shall not exceed 90% of the ultimate mechanical strength.
b) The total stresses in the steel and ductile aluminum components shall not exceed their yield stress.
c) For cast aluminum and other brittle components, the total stresses shall not exceed 90% of the ultimate mechanical strength.
d) Composite components shall not be damaged. The requirement of A.2.4 for composite material shall be met.
e) There shall be no leaks or observable offset of the porcelain on its base, movement of the porcelain relative to the gaskets, nor movements of the gaskets.

A.2.4 Composite polymer

Composites that require testing do not require strain gauges or stress measurements, except at the points of maximum stress on the metal end fitting.

Composites that require testing shall be verified as follows in A.2.4.1 through A.2.4.3.

A.2.4.1 Composite polymer load test

At least three static load tests shall be performed before shake-table testing.

Prior to the shake-table tests, a horizontal static load of 50% of the specified mechanical load (SML) for the insulator or bushing shall be applied at the top of the insulator or bushing in the direction of the shake-table test(s), perpendicular to the insulator or bushing. The resulting deflections shall be measured. The load shall be removed and the above procedure repeated at least two more times. If there is excessive scatter in the deflection data, additional tests should be performed. The deflections shall be averaged. However, if more than three static load tests are performed, the largest and smallest deflection may be discarded and the remaining deflections averaged.

During shake-table testing, deflections shall either be directly measured or calculated from measured accelerations. Either way, the maximum deflection(s) shall be found.

The deflections shall be measured between the top of the composite and the base of the composite, excluding the rotation at the base.

A.2.4.2 Composite polymer load test acceptance criteria

The composite load test will be acceptable if the following criteria are met as applicable:

a) The sine beat test will be acceptable if the maximum deflection(s) measured during the shake-table testing do not exceed the average of the static load test deflections times 1.8.
b) The time history test will be acceptable if the maximum deflection(s) measured during the shake-table testing do not exceed the average of the static load test deflections times 1.0.
c) After each static load is released, the composite shall return to its pre-deflected position within ± 5% of its measured deflection.

A.2.4.3 Composite polymer shed seal test

A shed seal test shall be performed on composite polymer insulators and bushings. This is a test of the ability of the sheath-shed to prevent entrance of water. Only one test needs to be performed for each design that uses the tested sealing method. This one test applies to all equipment using the tested sealing method. That is, the test need not be repeated for different equipment types or voltage class, when the same sealing method is used.

After completion of shake-table testing, the equipment shall be immersed in ambient temperature water for 7 calendar days or boiling water for 42 h. The shank of bushings need not be immersed in water, but the flange and the bushing exposed to the environment shall be immersed. It is recommended and preferable that the testing be to the high RRS level, but the moderate RRS level is acceptable.

The specified functional test shall be performed and compared to the tests done prior to shake-table testing.

The sealing method will be considered acceptable if the post functional tests are within acceptable limits specified for these functions and have not changed appreciably, and there is no indication of water migration past the outside surface of the sheds. Special attention shall be paid to the seal between the end of the sheds and the metal end fitting. A signed copy of the test results shall be included with the seismic report. The following information shall be provided: the equipment type tested, the voltage class, the results of the functional tests done before and after, and a sketch of the equipment (such as provided in the seismic outline drawing) if requested by the user.

A.2.5 Functional test

The specified functions of the equipment shall be checked before and after the shake- table testing. The test will be acceptable if, after the test, the equipment continues to perform its intended functions as defined in the applicable annex or by the user. If demonstration of correct functions during the shake-table test has been specified, then the test will be considered acceptable if the equipment has performed the functions successfully within the accepted limits set down for these functions.

A.3 Acceptance criteria for dynamic, static coefficient, and static analysis

A.3.1 Equipment (excluding insulators and bushings) and support component stresses

The calculated internal stresses in steel or aluminum components shall not exceed the allowable stresses given in AISC Manual of Steel Construction, ASD and the Aluminum Design Manual [B2] respectively with a 1/3 increase for seismic load cases where allowed in the code. For brittle components, such as cast aluminum, the total stresses shall not exceed 50% of the material’s ultimate strength.

A.3.2 Insulator and bushing stresses

The total stresses, including seismic, pressure, dead, and normal operating stresses, shall not exceed 50% of the ultimate strength of the porcelain. If applicable, the resulting stresses shall not exceed 50% of the oil leakage load.

The total stresses in fiberglass shall not exceed the calculated stress derived from 50% of the component’s SML.

A.3.3 Structural connections (welded or bolted)

The calculated stresses in steel or aluminum connections shall not exceed the allowable stresses given in the AISC Manual of Steel Construction, ASD and the Aluminum Design Manual [B2] respectively for welded or bolted connections in equipment or supports. No increase in allowable stresses for earthquake loads shall be permitted.

A.4 Design requirements

The equipment, supports, and anchorage shall be designed and constructed according to the following requirements in A.4.1 through A.4.3.

A.4.1 Support frames

A.4.1.1 General

The support frames shall be fabricated from steel, aluminum, or other materials allowed by the user or the user's agent. The design, materials, workmanship, fabrication, and detailing of support frames shall be in accordance with the following, as applicable:

a) The AISC Manual of Steel Construction, ASD
b) The AISI Specification for the Design of Cold-formed Steel Structural Members
c) The Aluminum Association's Aluminum Design Manual

If supports are required, erection drawings and shop drawings for support frame components that show member sizes, materials used, dimensions, connection details, and welding details shall be furnished, and shall include bills of material. The drawings shall be prepared using standard AWS and AISC symbols.

Support drawings and all copies shall be retained by the user only and not by the user's agent.

A.4.1.2 Deflection criteria

The support frame shall be designed to minimize deflections. The support frame shall be designed so that the top of the frame does not deflect more than as allowed by the ASCE Substation Structure Design Guide (draft). The deflection criteria may be exceeded for suspended equipment and when base isolation is used.

A.4.2 Anchorage to concrete

All anchorage to concrete assemblies, including welds and anchor bolts, shall be designed for loads resulting from the analysis or from the test. (The user will supply and install the anchorage materials, such as anchor bolts, embeds, and welds, unless otherwise specified by the user or the user's agent.) If more than one qualification method is used, the one that produces the largest bolt or weld shall be used. Anchor bolts shall comply with the requirements of ASTM A36/A36M-96 or ASTM A307-94. Anchor bolts shall not be less than 19 mm (0.75 in) in diameter, unless it can be shown that the allowable stresses exceed the applied stresses by not less than a factor of two. Allowable stresses for anchor bolts or welds shall be as specified in AISC Manual of Steel Construction, ASD with no increase allowed for earthquake loads, unless qualification is by sine beat test in which case a 1/3 increase is allowable.

A.4.3 Structural bolted connections

Structural bolts, including equipment and support bolts, with an ultimate tensile (minimum) strength of 965 MPa (140 000 lbf/in^2) or greater shall not be used.

A.5 Test report

A seismic report, including corrected (as tested) test plan, shall be prepared and supplied to the user. The report should be as described in Annex S. The report, test(s), test plan, and all test results, calculations, seismic outline drawing, charts, and records that show compliance with the seismic requirements of this recommended practice shall be approved prior to issuance to the user by a qualified specialist competent in seismic testing and qualification of electrical equipment. The specialist shall sign the report, test plan, and seismic outline drawing. The specialist shall meet the following requirements:

a) Understand and comply with all of the requirements of this recommended practice.
b) Provide an acceptable report to the user. An acceptable report provides the data and results required herein, in sufficient detail that is easily understood, and has labeled sketches and charts, well organized (preferably as described in Annex S), with calculations that meet industry standards.

c) Have appropriate and adequate education in seismic testing. (The education may be on-the-job training.)
d) Have appropriate and adequate experience in preparing electrical equipment seismic testing-qualification reports.

If any of the above points are not met, the person will not be considered qualified to sign the above documents.

The documentation demonstrating compliance with the above points shall be provided to the user or the user's agent upon request.

The following points will be considered, but are not mandatory:

- Holds a valid Civil, Structural or Mechanical Professional Engineering license.
- Has teaching experience or has written papers concerning seismic testing.
- Has directed and signed seismic testing-qualification reports.

The report shall be supplied to the user or the user's agent in the language of the user. Should the initial report need corrections, or if omissions are discovered, the corrections and omissions may be provided to the user on a case-by-case basis. However, once the user approves the corrections and the omissions have been included, then the entire final report shall be resubmitted to the user with the corrections and omissions included.

The equipment parameters and variables that may increase the equipment's vulnerability shall be defined in the qualification report. Of particular concern are equipment parameters or variables that influence the failure modes. Items such as operating voltages, current rating, BIL, creep length, and rated strengths of porcelain members shall be documented.

A.5.1 Test plan

A test plan shall be prepared and approved by the specialist prior to the test. At minimum, this plan shall contain the following:

a) *Monitoring requirements.* An outline drawing of the equipment showing the proposed locations of monitoring devices, such as accelerometers and strain gauges. The monitoring devices shall be placed at critical points on the equipment and the equipment support. (It is suggested that sufficient calculation should be done to determine whether the equipment can be expected to pass the qualification requirement and to find points of critical stress.) The use of "strain bolts" is recommended so that the reactions can be determined directly. If composite insulators are to be tested, the SML shall be provided in the test plan.
b) *Equipment calibration.* An equipment calibration list that lists the equipment to be used during the test and the last calibration date.
c) *Test method.* Testing to be triaxial or justification of biaxial testing. See A.1.1.
d) *Functional test.* Description of functional tests and where test will be performed.
e) *Performance level.* The plan shall state the performance level.
f) *Listing of testing.* The plan shall include a sequence listing of all tests to be performed at the test facility.

The test plan should be reviewed by the witnesses, if any, prior to the test. See 5.5.

A.5.2 Data (shake-table test)

The report shall include the following:

a) Tabulated summary of maximum controlling stresses, allowable capacities, and their factors of safety for the support structure and equipment (See the "Example of Shake-Table Test—Summary of maximum stresses, loads, etc" table in Annex S).
b) Location and date of test.
c) Test engineer's name and title.

d) Description of testing equipment, test method(s) and instrumentation.
e) Photographs showing the test setup and instrumentation location.
f) Sketch showing location of strain gages and accelerometers.
g) Anchorage of the equipment.
h) Serial number of the equipment and equipment components being tested.
i) Resonant frequencies and damping, including resonant frequency search records.
j) Comparison of the RRS and the TRS.
k) Tabulated list of all tests, including resonant frequency search, showing maximum accelerations, stresses, and displacements at measurement points (See the “Example of Data Measurement Points” in Annex S).
l) Reactions at support points.
m) Apparent physical damage during and after the testing.
n) Modifications required to pass the test.
o) List of utility (user) representative(s), if any, who witnessed the testing and which part(s) of the testing was witnessed.
p) Static load deflections (for composites).
q) Tabulated list of acceptance criteria allowables and performance values.
r) A picture or graphical reproduction of the identification tag. (See A.8.)

A video tape of the tests shall be provided with the test report.

A Supplemental Work and Options section shall be provided at the front of the report. It shall include a listing of supplemental work and options, such as the following:

a) The use of structural plastics, which are not provided for in this recommended practice, but are approved by the original user. Note that the use of plastic must be approved by all subsequent users.
b) The original user requires the specialist to also be a licensed civil engineer.
c) The manufacturer chooses to do the sine beat in addition to the time history, e.g., for a 230 kV surge arrester.
d) The manufacturer chooses to qualify by time history instead of dynamic analysis, e.g., for a 138 kV disconnect switch.
e) The section shall state that there were no supplemental work or options performed.

A.5.3 Seismic outline drawing (shake-table test)

The supplier shall also supply one 280 432 mm (11 17 in) or 216 280 mm (8 1/2 11 in) seismic outline drawing of the equipment and any support. The seismic outline drawing should be as shown in the “Example of Seismic Test—Seismic Outline Drawing” in Annex S. All of the following shall be shown on one drawing:

a) Total weight
b) Dimensions and weights of major components
c) Location of the center of gravity of the equipment and major components
d) Anchoring details showing bolt or weld sizes or both and their corresponding locations
e) Resonant frequencies and damping ratio of the equipment
f) The test(s) used to qualify the equipment, including the acceleration levels used
g) Maximum deflections at conductor attachment point(s)
h) Controlling reactions at the base of the supporting structure for seismic loads and for seismic plus normal operating loads
i) Seismic level for which the equipment is qualified
j) Date of test
k) Statement that the qualification is by this recommended practice to the high or moderate seismic qualification level

A.6 Analysis report

A seismic report shall be prepared and supplied to the user. The report should be as described in Annex R. The report, calculations, seismic outline drawing, charts, and records that show compliance with the seismic requirements of this recommended practice shall be approved and signed prior to issuance to the user by a qualified specialist competent in seismic analysis and qualification of electrical equipment. Test reports and plans used to justify any part of the analysis shall also be approved and signed prior to issuance to the user by the specialist.

The specialist shall meet the following requirements:

a) Understand and comply with all of the requirements of this recommended practice.
b) Provide an acceptable report to the user. An acceptable report provides the data and results required herein, in sufficient detail that is easily understood, and has labeled sketches and charts that are well organized (preferably as described in Annex R), with calculations that meet industry standards.
c) Use assumptions generally acceptable to experienced specialists.
d) Have appropriate and adequate education in seismic analysis.
e) Have appropriate and adequate experience in preparing electrical equipment seismic analysis-qualification reports.

If any of the above points are not met, the person will not be considered qualified to sign the above documents.

The documentation demonstrating compliance with the above points shall be provided to the user or the user's agent upon request.

The following points will be considered, but are not mandatory:

— Holds a valid Professional Civil, Structural or Mechanical Engineering license
— Has teaching experience or has written papers concerning seismic analysis
— Has directed and signed seismic analysis-qualification reports

The report shall be supplied to the user or the user's agent in the language of the user. If the initial reports needs corrections, or if omissions have been discovered, the entire final report shall be resubmitted to the user with the corrections and omissions included, once agreement of corrections and omissions has been reached.

The equipment parameters and variables that may increase the equipment's vulnerability shall be defined in the qualification report. Of particular concern are equipment parameters or variables that influence the failure modes. Items such as operating voltages, current rating, BIL, creep length, and rated strengths of porcelain members shall be documented.

A.6.1 Data (analysis)

The report shall include the following:

a) Tabulated summary of maximum controlling stresses, allowable capacities, and their factors of safety for the support structure and equipment. (See "Example: Dynamic Analysis—Summary of maximum stresses, loads, etc" in Annex R.)
b) Dimensions and weights, both overall and of major components.
c) Resonant frequencies and damping ratio, if by dynamic analysis. (If damping ratio of other than 2% is used, provide test data.)
d) Center of gravity of equipment and its major components.
e) Tabulated list of all load cases showing maximum accelerations, stresses, and displacements at critical points, if by dynamic analysis.
f) Equipment and structure reactions at support points, including magnitude and direction, at each reaction point.

g) Anchorage details, including size, location, and material strength for structural members, bolt, and plates.
h) Maximum input (ground) accelerations.
i) Modifications required to pass the analysis.
j) Method of analysis and computer program name, if computer program used.
k) Assumptions made in modeling the equipment and supporting structure.
l) Material types and strengths.
m) Final computer listing (input and output) of qualification run(s), if computer program was used.
n) Model[16] with labeled nodes, members, and dimensions, if by dynamic analysis.
o) Member properties.
p) Plot of all modes considered, if by dynamic analysis.
q) Tabulated list of acceptance criteria allowables and performance values.
r) A picture or graphical reproduction of the identification tag. (See A.8.)

A Supplemental Work and Options section shall be provided at the front of the report. It shall include a listing of supplemental work and options, such as

— The use of structural plastics, which are not provided for in this recommended practice, but are approved by the original user. Note that the use of plastic must be approved by all subsequent users.
— The original user requires the specialist to also be a licensed civil engineer.
— The manufacturer chooses to do the sine beat in addition to the time history, e.g., for a 230 kV surge arrester.
— The manufacturer chooses to qualify by time history instead of dynamic analysis, e.g., for a 138 kV disconnect switch.
— The section shall state that there were no supplemental work or options performed.

A.6.2 Seismic outline drawing (analysis)

The supplier shall also supply one 280 × 432 mm (11 × 17 in) or 216 × 280 mm (8 1/2 × 11 in) seismic outline drawing of the equipment and support, if any support. The seismic outline drawing should be as shown in the “Example of Seismic Analysis—Seismic Outline Drawing” in Annex R. All of the following shall be shown on one drawing:

a) Total weight
b) Dimensions and weights of major components
c) Location of the center of gravity of the equipment and its major components
d) Anchoring details showing bolt or weld sizes or both and their corresponding locations
e) Resonant frequencies and damping ratio of the equipment, if by dynamic analysis
f) The analysis method and acceleration level used
g) Any tests used to qualify the equipment, including the acceleration levels used
h) Maximum deflections
i) Controlling reactions at the base of the supporting structure for seismic loads and for seismic plus normal operating loads
j) Seismic level for which the equipment is qualified
k) Date prepared
l) Statement that the qualification is by this recommended practice to the high or moderate seismic qualification level

A.7 Frequency or damping modifying devices or attachments (Base isolation)

For systems that change the frequency or the damping characteristics of the equipment or the equipment support assembly for the purpose of seismic qualification, evidence and proof shall be provided in the report as follows:

a) The damping and the frequency characteristics of the devices or attachments will not change.

[16]If the model is very complex, with many nodes and members, the model may be simplified provided all the critical nodes and members are shown.

b) The devices or attachments will not require maintenance.
c) The devices or attachments do not and will not require field adjustments or field pre-load or other installation requirements, unless otherwise approved by the user in writing.
d) The system will not adversely affect the operation or maintenance of the equipment over the life of the equipment.

The life of the equipment will be assumed to be 30 years. (See 6.6.)

A.8 Seismic qualification identification tag

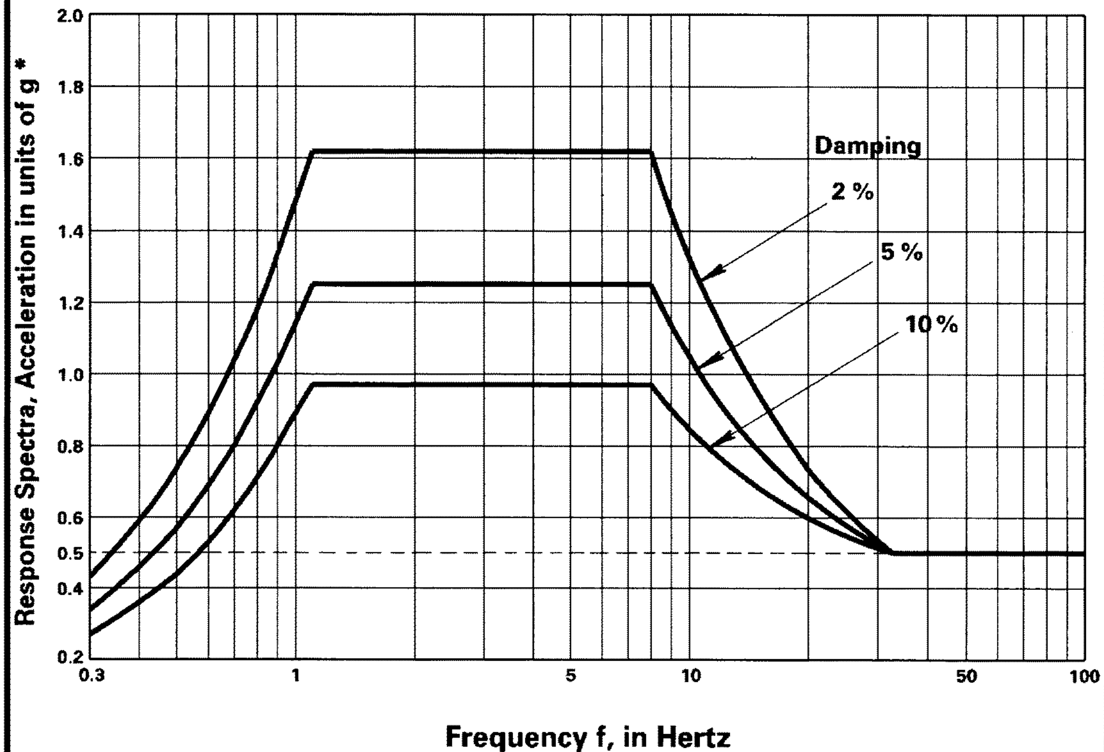
The seismic qualification identification tag shall be designed and attached to the equipment to last its service life. The tag shall use the following designation:

Seismic Qualification Tag: XYZ Company IEEE Std 693-1997 - [DATE REPORT SIGNED] - QUALIFICATION LEVEL - [REPORT NUMBER] - OPTIONAL INFORMATION

An example tag for a 121 kV power circuit breaker is shown as follows:

Seismic Qualification Tag: XYZ Company IEEE Std 693-1997 - [12/97] - Moderate - [56877-FL] - Time History Shake-Table Test

— IEEE Std 693-1997 = This recommended practice.
— [12/1997] = Date (Month/Year) testing or analysis report signed.
— Moderate = Seismic qualification level; high or moderate.
— [56877-FL] = Seismic qualification report number.
— Time History Shake-Table Test = Optional information: This qualification tag area can be used to specify optional qualification methods as specified in 5.6. The above example demonstrates a 121 kV power circuit breaker that was qualified using shake-table testing in lieu of the IEEE Std 693-1997 -specified dynamic analysis. Other seismic qualification information as specified by the manufacturer or purchaser can be placed in this area.



THE ABOVE REQUIRED RESPONSE SPECTRA ARE DERIVED FROM THE FOLLOWING:

f is in Hertz

$$\beta = \left[3.21 - 0.68 \ln (D)\right] / 2.1156$$

D = Percent of Critical Damping Expressed as 1, 2, 5, 10, etc

$$0 - 1.1\text{Hz} = 1.144\beta f$$

$$1.1 - 8\text{Hz} = 1.25\beta$$

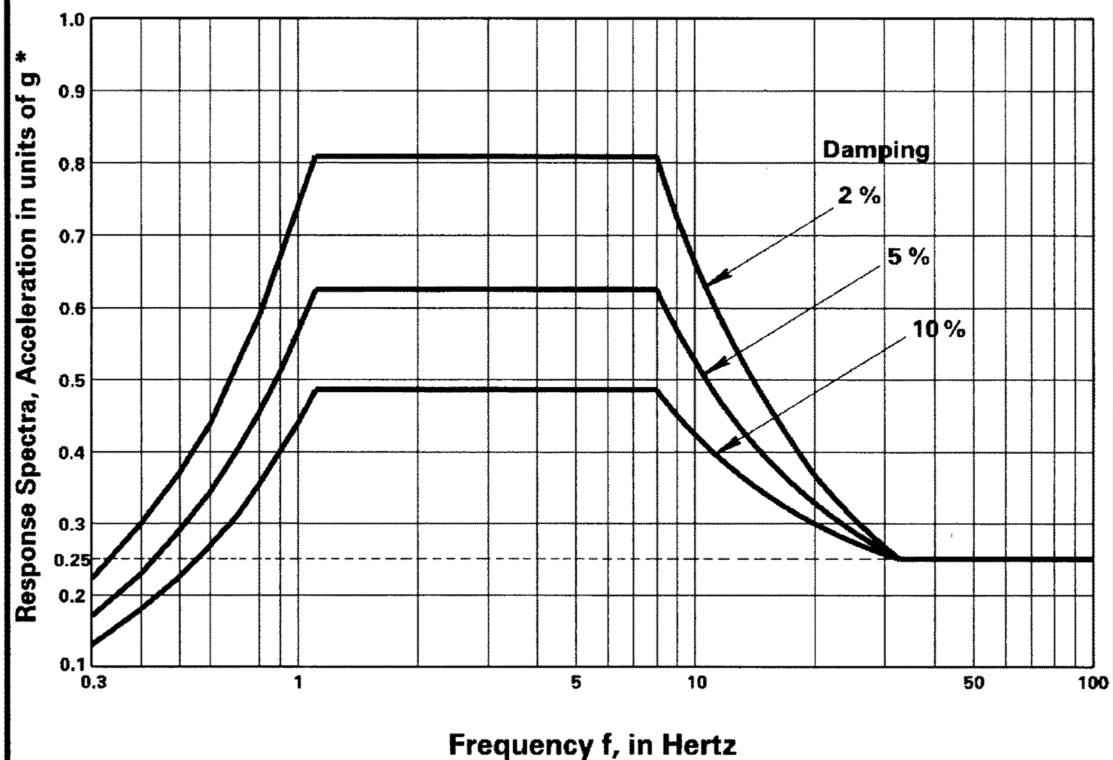
$$8 - 33\text{Hz} = (13.2\beta - 5.28)\frac{1}{f} - 0.4\beta + 0.66$$

$$33\text{Hz and over} = 0.5g$$

0.5g

* g, ACCELERATION OF GRAVITY.

Figure A.1—High required response spectrum



THE ABOVE REQUIRED RESPONSE SPECTRA ARE DERIVED FROM THE FOLLOWING:

f is in Hertz

$\beta = [3.21 - 0.68 \ln(D)] / 2.1156$

D = Percent of Critical Damping Expressed as 1, 2, 5, 10, etc

0 - 1.1Hz = $0.572\beta f$

1.1 - 8Hz = 0.625β

8 - 33Hz = $(6.6\beta - 2.64)\frac{1}{f} - 0.2\beta + 0.33$

33Hz and over = 0.25g

0.25g

*g, ACCELERATION OF GRAVITY.

DRAWING NUMBER

Figure A.2—Moderate required response spectrum

Annex B Equipment, general

(Normative)

NOTE — Qualification requirements for specific types of equipment (e.g., circuit breakers, transformers, etc.) are given in Annexes C through O. This annex may be used, if applicable, to qualify equipment that is not specifically provided for in Annexes C through O.

B.1 General

The requirements of this annex are applicable to equipment (except for equipment that is specifically addressed in Annex C through O) in high and moderate seismic qualification level areas. This annex contains four qualification methodologies: time history shake-table testing, sine beat shake-table testing, static coefficient analysis, and qualification by analysis. The user or the user's agent will supply the following information to the manufacturer as a part of the specification for that equipment:

a) Which qualification method to use (time history shake-table testing, sine beat shake-table testing, static coefficient analysis, qualification by analysis, or a combination of methods).
b) For the sine beat test—the acceleration level and the resonant frequency search acceleration level.
c) For static coefficient analysis, qualification by analysis, or time history shake-table test—a required response spectra. (Figure A.1 or A.2 should be specified by the user.)
d) Whether the equipment is to be supplied with or without a support.
e) Functional requirements, if any. (See B.5.2.)
f) Monitoring requirements, if testing is required.

Functional requirements are generally associated with shake-table testing. These are electrical and mechanical production test(s) that should be performed before and after the shake-table test to ensure that the equipment continues to perform its intended operations and maintains correct operational state after the testing.

The user or the user's agent may, if applicable, supply to the manufacturer the following:

— Materials, other than those already provided for in this recommended practice, that the user will allow for use as equipment supports.
— An amplification value to be used in conjunction with the ZPA of the RRS, should static analysis be acceptable as specified in B.4.4.

B.2 Operational requirements

The equipment and supporting structure shall be designed so that there will be neither damage nor loss of function during and after the seismic event. In addition, equipment shall maintain correct operational state during the seismic event.

B.3 Seismic qualification method

Seismic withstand capability shall be demonstrated as directed by the user or the user's agent (i.e., time history shake-table testing, sine beat shake-table testing, static coefficient analysis, or analysis).

B.4 Qualification procedure

The qualification procedure shall be according to the requirements of A.1.1.

B.4.1 Qualification procedure for time history shake-table testing

The equipment and structure, if required, shall be tested according to the requirements of A.1.2. The spectrum supplied by the user or the user's agent shall be used.

A resonant frequency search shall be performed according to the requirements of A.1.3 at an input level of 0.05 g to 0.1 g.

B.4.2 Qualification procedure for sine beat shake-table testing

The equipment and structure shall be tested according to the requirements of A.1.4.

The amplitude of the input acceleration shall be as specified by the user or the user's agent.

B.4.3 Monitoring requirements for resonant frequency search, time history shake-table testing, and sine beat shake-table testing

Critical locations on the equipment and supporting structure shall be monitored for maximum displacement, maximum accelerations, and maximum stresses. As a minimum, the following shall be monitored:

- *Maximum displacement.*[17] Conductor attachment points of insulators and bushings.
- *Maximum accelerations (vertical and horizontal).* Top of insulators and bushings.
- *Maximum stresses.* Base of porcelain insulators and porcelain bushings.[18]
  Base of supporting structure's leg(s).

B.4.4 Qualification procedure for analysis

The qualification procedure shall be according to the requirements of A.1.5. The response spectrum supplied by the user or the user's agent shall be used in the analysis.

The preparer of the analysis shall first determine the resonant frequency or frequencies of the equipment and its support by tests or dynamic analysis. The maximum horizontal modal response shall then be determined using the input ground motion that is described by the response spectra supplied by the user or the user's agent, as a minimum.

If all the natural frequencies exceed 33 Hz, the static analysis method of A.1.6 may be used. If static analysis is used, the analysis shall use the acceleration at the ZPA of the response spectrum (supplied by the user or the user's agent) multiplied by the user's magnification factor, if any.

B.4.5 Qualification procedure for static coefficient analysis

The qualification procedure shall be according to the requirements of A.1.7. The response spectrum supplied by the user or the user's agent shall be used in the analysis.

B.5 Acceptance criteria

The qualification will be considered acceptable if the requirements given in B.5.1 and B.5.2 are met.

[17] Displacements may be found by double integration of accelerometer data.
[18] Stress measurements are not required for composites. See A.2.4.

B.5.1 General

The general requirements are as follows:

a) The general criteria specified in A.2.1.
b) If the time history test is required, the requirements of A.2.2.
c) If the sine beat test is required, the requirements of A.2.3.
d) If analysis is required, the requirements of A.3.
e) If static coefficient analysis is required, the requirements of A.3.

B.5.2 Functional requirements for shake-table tested equipment

If the shake-table test is required, the functional requirements of the user or user's agent and those given in A.2.5 shall be met.

B.6 Design requirements

The equipment, support, and anchorage shall be designed according to A.4.

B.7 Report(s)

A report shall be prepared and supplied.

B.7.1 Report for shake-table test

The report shall be in accordance with the requirements of A.5.

B.7.2 Report for dynamic, static coefficient analysis, or static analysis

The report shall be in accordance with A.6.

B.8 Frequency or damping modifying devices or attachments

The requirements of A.7 shall be met.

B.9 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.8.

Annex C Circuit breakers

(Normative)

C.1 General

The voltage in kilovolts (kV), as used in this annex, is the rated maximum voltage as defined in ANSI 37.06 , 1987.

Seismic qualification levels are as given in C.1.1 through C.1.3.

C.1.1 High seismic qualification level

The requirements of this annex, with the exception of C.1.2 and C.1.3, are applicable to all circuit breakers in high seismic level areas.

C.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of C.1.1 and C.1.3, are applicable to all circuit breakers in moderate seismic level areas, with the following exceptions:

a) Figure A.2 may be used instead of Figure A.1.
b) The sine beat test, as specified in C.4.1, item d), is not required.

C.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to circuit breakers in low seismic qualification level areas. The user should refer to Clauses 1. through 9. for information.

C.2 Operational requirements

The circuit breaker and supporting structure shall be designed so that there will be neither damage nor loss of function during and after the seismic event. In addition, equipment shall maintain correct operational state during the seismic event.

C.3 Seismic qualification method

Seismic withstand capability shall be demonstrated as follows:

a) *169 kV and above by time history and sine beat shake-table testing.* For circuit breakers that have dynamically independent poles, only one pole need be tested. The tested equipment shall include the control cabinet, including stored energy sources, and associated current transformer.
b) *121 kV to less than 169 kV by dynamic analysis.* The analyzed equipment shall include the control cabinet, including stored energy sources, and associated current transformer.
c) *Less than 121 kV by the static coefficient method.* The analyzed equipment shall include the control cabinet, including stored energy sources, and associated current transformer.

C.4 Qualification procedure

The qualification procedure shall be according to the requirements of A.1.1.

C.4.1 Qualification procedure for 169 kV and above

The qualification procedure shall be in four stages. They are as follows:

a) *Stage 1—Resonant frequency search.* A resonant frequency search shall be conducted to determine resonant frequencies according to the requirements of A.1.3. The amplitude of the input acceleration of the sine sweep shall be 0.1 g. For circuit breakers below 169 kV, which do not require testing, but are tested, the input acceleration of the sine sweep can be reduced to below 0.1 g to a minimum acceleration of 0.05 g. However, the input acceleration should be high enough so that the resonant frequencies can be readily determined.
b) *Stage 2—Time history test.* The equipment and support structure shall be tested according to the requirements of A.1.2. The spectrum shown in Figure A.1 shall be used.
c) Stage 3—*Time history operational test.* The circuit breaker and support structure shall be subjected to the same test described above in stage 2 with the addition of a breaker open-close-open (O-C-O) operation, during the strong motion. During this test, the breaker shall be filled with gas at the rated operating pressure.
d) *Stage 4—Sine beat test.* The equipment and support structure shall be tested according to the requirements of A.1.4. The amplitude of the input acceleration (i.e., the specified value) shall be 0.5 g.

To prevent injury or damage from possible failure of pressurized components, test with protective barriers and other appropriate precautions, as needed. As a minimum, all precautions shall be in accordance with any laboratory and legal requirements.

C.4.1.1 Monitoring requirements

Critical locations on the circuit breaker and supporting structure shall be monitored during all stages required above and for each test run for maximum displacement, maximum accelerations, and maximum stresses. As a minimum, the following shall be monitored:

a) *Maximum displacement*. Top of bushing.
b) *Maximum accelerations (vertical and horizontal).* Top of bushing.
c) *Maximum stresses.* Base of porcelain bushing.
   Base of supporting structures leg.

To detect relay bounce and to verify that false operation will not occur, the following components shall be energized and monitored during stage 2 and stage 3 tests:

— The trip, close circuits, and mechanism motor shall be energized.
— The X and Y relay contacts, and SF_6 density switch contacts shall be monitored.

The timing characteristics of the circuit breaker and the measurement of the resistance of the current carrying parts shall be recorded before the testing begins, and as a minimum after completion of the last shake-table test. Pressure readings and sniff tests shall be made directly after each pressurized time history test to detect possible leaks.

The equipment and supports shall be inspected for cracking, buckling, or other types of failure or distress. Gaskets associated with support columns and bushings shall be inspected for evidence of slippage.

C.4.1.2 Production tests following shake-table testing

The circuit breaker shall undergo standard production tests after the completion of the shake-table tests.

C.4.2 Qualification procedure for 121 kV to less than 169 kV

The qualification procedure shall be according to the requirements of A.1.5. The response spectrum shown in Figure A.1 shall be used in the analysis.

C.4.3 Qualification procedure for less than 121 kV

The qualification procedure shall be according to the requirements of A.1.7. The static coefficient may be taken as 1.0. The response spectra shown in Figure A.1 shall be used.

C.5 Acceptance criteria

The qualification will be considered acceptable if the requirements given in C.5.1 and C.5.2 are met.

C.5.1 General

The general requirements are as follows:

a) The general criteria of A.2.1. Also, there shall be no evidence of support column or bushing gasket slippage.
b) For the time history test, the requirements of A.2.2.
c) For the sine beat test, the requirements of A.2.3.
d) For the dynamic and static coefficient analysis, the requirements of A.3.

C.5.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.5.

The circuit breaker shall maintain correct operational state, its trip coils shall perform their desired function, and contact bounce of circuits shall not occur to the extent that malfunction or misoperation will occur during the seismic event.

No leaks are found using a portable leak detector.

There shall not be a significant change in resistance readings between the terminals of each pole of the circuit breaker when measured in accordance with manufacturer’s procedures. If changes in readings do occur, they shall be within the tolerances in the manufacturer’s specifications.

Changes in the opening and closing timing parameters [which shall include, as a minimum, open (contact part) time and opening velocity, and close (contact make) time and closing velocity] shall not exceed normal operation-to-operation variations, which are typically within milliseconds.

Passage of the 60 Hz, one minute high voltage withstand tests as specified by IEEE Std C37.09-1979 paragraph 5.15 is required. These tests will have to be performed in a high voltage laboratory. The tests should be performed in accordance with the manufacturer’s production test procedures.

C.6 Design requirements

The equipment and support shall be designed according to A.4.

C.7 Report(s)

A report shall be prepared and supplied.

C.7.1 Report for shake-table test

The report shall be in accordance with A.5.

C.7.1.1 Timing and resistance

The circuit breaker's pre-test and post-test opening and closing-timing characteristics, and resistance measurements of its current carrying parts shall be included in the report. Pre-test characteristics and measurements shall be provided prior to the beginning of shake-table tests.

C.7.1.2 Circuits monitoring

A list of circuits that were monitored along with any indication of a change in status during the tests shall be included in the report.

C.7.2 Report for dynamic or static analysis

The report shall be in accordance with A.6.

C.8 Frequency or damping modifying devices or attachments

The requirements of A.7 shall be met.

C.9 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.8.

Annex D Transformers and liquid-filled reactors

(Normative)

D.1 General

The voltage (kV), as used in this annex, is the nominal system voltage as defined in IEEE Std C57.12.00-1993 .

The seismic qualification levels are given in D.1.1 through D.1.3.

D.1.1 High seismic qualification level

The requirements of this annex, with the exception of D.1.2 and D.1.3, are applicable to transformers and liquid filled reactors in high seismic qualification level areas.

D.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of D.1.1 and D.1.3, are applicable to all transformers and liquid filled reactors in moderate seismic qualification level areas, with the following exceptions:

a) Figure A.2 may be used instead of Figure A.1.
b) An acceleration of 0.25 g may be used in lieu of 0.5 g, and 0.2 g may be used in lieu of 0.4 g in D.4.1.1 and D.4.2.
c) An acceleration of 0.5 g may be used in lieu of 1.0 g, and 0.4 g may be used in lieu of 0.8 g in D.4.1.2.

D.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to transformers and liquid-filled reactors in low seismic qualification level areas. The user should refer to Clauses 1 through 9 for information.

D.2 Operational requirements

Transformers and liquid-filled reactors shall be designed so there will be neither structural damage nor loss of function after an earthquake when subjected to design seismic loads occurring simultaneously with dead and normal operation loads.

D.3 Seismic qualification method

Seismic withstand capability shall be demonstrated as follows:

a) Except for bushings and surge arresters, transformers and liquid-filled reactors that have a high side of ≥ 115 kV shall be qualified by static analysis.
b) Static analysis load path calculations are required for transformers and liquid-filled reactors that have a high side < 115 kV.
c) Bushings ≥ 161 kV shall be qualified by time history shake-table tests.
d) Bushings < 161 kV shall be qualified by static pull test.
e) Surge arresters shall be qualified by the methods given in Annex K.

D.4 Qualification procedure

The qualification procedure shall be according to the requirements of A.1.1.

D.4.1 Qualification of transformers and liquid-filled reactors, except bushings and surge arresters, 115 kV and above

D.4.1.1 Qualification of tank components (excluding appendages)

The transformer tank, core, coils, anchorage, and other components other than appendages, bushings, and surge arresters shall be qualified using static analysis according to the requirements of A.1.6. The static analysis shall use 0.5 g in the two horizontal directions and 0.4 g in the vertical direction.

The static analysis calculations shall include verification of the load path from the core, coils, tank, and base to the anchorage for all three orthogonal axes. All components of the load path shall have sufficient rigidity to restrain the core and coil from shifting. Sketches shall be provided with the analysis that clearly show complete load path(s) to the anchorage. Load path parts and members shall be clearly labeled and dimensioned. Section properties, calculated stresses, and allowables of all load path parts and members shall be provided.

D.4.1.2 Qualification of appendages, such as radiators, conservators, and control cabinets

Appendages, such as radiators, conservators, and control cabinets, shall be qualified by static analysis according to the requirements of A.1.6. The static analysis shall use 1.0 g in the two horizontal directions and 0.8 g in the vertical direction.

D.4.2 Qualification of transformers and liquid-filled reactors, except bushings and surge arresters, less than 115 kV

D.4.2.1 Qualification of tank components (excluding appendages)

The static analysis calculations shall include verification of the load path from the core, coils, tank, and base to the anchorage for all three orthogonal axes. All components of the load path shall have sufficient rigidity to restrain the core and coil from shifting. Sketches shall be provided with the analysis that clearly show complete load path(s) to the anchorage. Load path parts and members shall be clearly labeled and dimensioned. Section properties, calculated stresses, and allowables of all load path parts and members shall be provided. Static analysis shall use 0.5 g in the two horizontal directions and 0.4 g simultaneously in the vertical direction with the two horizontal directions.

D.4.2.2 Qualification of appendages, such as radiators, conservators, and control cabinets

Seismic calculations that meet the requirements of D.4.1.2 shall be provided only if requested after review of shop drawings.

D.4.3 Qualification of bushings of 161 kV and above

Bushings ≥ 161 kV shall be qualified using a time history test according to the requirements of A.1.2. Because it is impractical to shake-table test the bushing(s) on the transformer or liquid-filled reactor, the bushing(s) shall be mounted on a rigid stand during the test. The stresses the bushing actually experience from the ground acceleration are amplified due to the influence of the transformer body and the local flexibility of the area around the bushing. Therefore, the bushing shall be tested at an input motion of twice the response spectra shown in Figure A.1, to account for this amplification.

Each bushing shall be tested at no less than its in-service slope (the slope angle measured from vertical). It is recommended that the bushing be tested at 20° measured from vertical. Hence, the bushing qualification will be acceptable for use on all transformers with angles from vertical to 20°. All bushings at angles greater than 20° shall be tested at its in-service angle.

A resonant frequency search shall be performed according to the requirements of A.1.3 at an input level of .05 g to 0.1 g.

D.4.3.1 Monitoring requirements for porcelain bushings

During the shake-table tests, porcelain bushings shall be monitored for the following:

a) Maximum vertical and horizontal accelerations at the top of the bushing, at the end of the shank, at the bushing flange, and at the top of the shake-table.
b) Maximum relative displacement of the top of the bushing to the flange shall be measured during the test or calculated from the acceleration time histories.
c) Maximum porcelain stresses at the base of the bushing (near the flange).
d) Maximum stresses at the flange metal end fitting and maximum stresses in the flange attachment bolts. The maximum stresses in the bolts may be found by calculations. However, the use of strain bolts is recommended.

D.4.3.2 Monitoring requirements for composite polymer bushings

During the shake-table tests, composite polymer bushings shall be monitored for the following:

a) Maximum vertical and horizontal accelerations at the top of the bushing, at the end of the shank, at the bushing flange, and at the top of the shake-table.
b) Maximum relative displacement of the top of the bushing to the flange shall be measured during the test or calculated from the acceleration time histories.
c) Maximum stresses at the flange metal end fitting and maximum stresses in the flange attachment bolts. The maximum stresses in the bolts may be found by calculations. However, the use of strain bolts is recommended.

D.4.4 Qualification of bushings less than 161 kV

Bushings < 161 kV shall be qualified by a static pull test. A static pull of 2.0 times the weight of the bushing shall be applied horizontal to the bushing and at the top of the bushing and held for at least 2 s.

D.4.5 Qualification of surge arresters

Surge arresters shall be qualified according to the requirements of Annex K, except the effects of the transformer body shall be found and the input acceleration shall be increased accordingly for transformer mounted surge arresters. In lieu of determining the amplification effects of the transformer body, twice the input accelerations specified in Annex K may be used.

D.4.6 Review of shop drawings

Review and approval of shop drawings is an integral part of the seismic qualification of all transformers and liquid-filled reactors. Shop drawings shall be submitted and approved prior to fabrication. Approval of shop drawings includes approval of any calculations requested.

D.5 Acceptance criteria

The qualification will be considered acceptable, if the following requirements given in D.5.1 and D.5.2.

D.5.1 General

The general requirements are as follows:

a) *General criteria.* For components that are shake-table tested or static pull tested, there shall be no evidence of damage, such as broken, shifted or dislodged insulators, visible leakage of oil, or broken support flanges.
b) *Allowable stresses.* The stresses in parts, members, and components, including flange attachment bolts, meets the requirements of A.2.2 and A.3. The 1/3 increase shall not be used in parts, members, and components in the core, coil, base, anchorage, load path, and for bushing flange attachment bolts.
c) *Composite polymer bushings.* These bushing should meet the requirements in A.2.4.
d) *Leakage criteria for bushings.* In addition, bushings qualified by shake-table testing shall have a minimum safety factor of two against gasket leaks for loads imposed during application of the test response spectrum (TRS). An acceptable method to demonstrate this factor of safety is to have no leaks after the application of twice the Figure A.1 spectra that has been adjusted to incorporate the influence of the transformer or liquid-filled reactor body and local flexibility of the transformer or liquid-filled reactor near the bushing mounting.
e) *Requirements for radiators.* For radiators of transformers and liquid-filled reactors having a high side of ≥ 115 kV, horizontal and vertical seismic bracing for the radiator shall be connected directly to the body of the transformer. Bending, shear, and axial loads across the gasket connection of the radiators or radiator manifolds to the main body of the transformer shall be limited by assuring that stiffness of the radiator bracing system is much larger than that of the gasket connection. Alternatively, the radiator can be supported independently of the transformer and connected to the transformer by flexible connections. Support of the radiator by both the transformer and an independent support to the foundation is not permitted.

D.5.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.5.

After the bushings have been shake-table tested, they shall be subjected to and pass all routine tests as specified in the latest revision of IEEE Std C57.19.00-1991 .

Surge arresters shall pass the functional tests described in Annex K.

D.6 Design requirements

D.6.1 Design and construction

The transformer or liquid-filled reactor tank shall be fabricated from steel. The transformer or liquid-filled reactor and supports for appendages shall be designed according to A.4.

D.6.2 Anchorage welds

All transformers and liquid filled reactors shall be designed to be field welded to embedded plates or beams. The vendor shall indicate, on the equipment outline drawing, locations where field welding to the transformer or liquid-filled reactor is preferred, load or stress limits at these locations, and if applicable, locations where welding is not allowed.

D.7 Report(s)

Portions of the transformer or liquid-filled reactor will be qualified by testing (bushing and surge arresters), while other portions will be qualified by analysis. For components qualified by testing, a test report shall be prepared and supplied in accordance with A.5. For portions qualified by analysis, an analysis report shall be prepared and supplied in accordance with A.6.

D.8 Frequency or damping modifying devices or attachments

The requirements in A.7 are applicable to these components.

D.9 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.8.

Annex E Disconnect and grounding switches

(Normative)

E.1 General

The voltage (kV), as used in this annex, is the rated maximum voltage as defined in ANSI C37.32-1996 .

Seismic qualification levels are given in E.1.1 through E.1.3.

E.1.1 High seismic qualification level

The requirements of this annex, with the exception of E.1.2 and E.1.3, are applicable to all voltage classes of disconnect switches and grounding switches, including the support structure, operating mechanism, and other associated equipment as required for field installation in high seismic qualification level areas.

E.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of E.1.1 and E.1.3, are applicable to all voltage classes of disconnect switches and grounding switches, including the support structure, operating mechanism, and other associated equipment as required for field installation in moderate seismic qualification level areas, except Figure A.2 may be used instead of Figure A.1.

E.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to disconnect switches in low seismic qualification level areas. The user should refer to Clauses 1 through 9 for information.

E.2 Operational requirements

The disconnect switches, grounding switches, and support structures shall be designed so there will be neither damage nor loss of function during and after the seismic event. The operational state shall remain correct during the seismic event.

E.3 Seismic qualification methods

Seismic withstand capability shall be demonstrated as follows:

a) *169 kV and above.* By time history shake-table testing.
b) *121 kV to less than 169 kV.* By dynamic analysis.
c) *Less than 121 kV.* By static coefficient analysis.

E.4 Qualification procedures

The qualification procedures shall be according to the requirements of A.1.1.

E.4.1 Qualification procedures for 169 kV and above

The switch, structure, operating mechanism, and other associated equipment shall be set up (on the shake-table) and adjusted. Correct operating (full opening and full closing) is to be verified prior to any testing. The tests shall be performed with the disconnect switch open and closed. If a ground switch is included, the tests shall be performed with the disconnect switch open and the ground switch closed, with the disconnect switch open and the ground switch open, and with the disconnect switch closed and the ground switch open. After the equipment is set up and adjusted, the testing is to proceed as follows:

a) The equipment and structure shall be tested according to the requirements of A.1.2. The spectrum shown in Figure A.1 shall be used.
b) A resonant frequency search shall be performed according to the requirements of A.1.3 at an input level of 0.05 g to 0.1 g.

E.4.1.1 Monitoring requirements

Critical locations on the disconnect switch, grounding switch, and supporting structure shall be monitored for maximum displacement, maximum acceleration, and maximum stresses. As a minimum, the following shall be monitored:

a) Maximum displacement at the top of the insulator and the end of the blade.
b) Maximum accelerations, vertically and horizontally, at the top of the insulator, the end of the blade, and the top of the shake table.
c) Maximum stresses at the base of the porcelain insulator, at the base of the switch arm hinge, and the base of the two opposite diagonal legs of the supporting structure.
d) Any electrical equipment, such as a motor operator, shall be energized during testing and monitored to detect relay bounce and the potential for misoperation.

All data shall be time dependent, so values can be compared.

E.4.2 Qualification procedure for 121 kV to less than 169 kV

The qualification procedure shall be according to the requirements of A.1.5. The response spectra shown in Figure A.1 shall be used in the dynamic analysis.

E.4.3 Qualification procedure for less than 121 kV

The qualification procedure shall be according to the requirements of A.1.7. The RRS of Figure A.1 shall be used. A static coefficient of 1.0 may be used.

E.5 Acceptance criteria

The qualification will be considered acceptable, if the requirements given in E.5.1 and E.5.2 are met.

E.5.1 General

The general requirements are as follows:

a) The general criteria of A.2.1.
b) During the testing, the disconnect switch and grounding shall maintain correct operational state. When tested in the closed position, it shall stay closed throughout the duration of testing. When tested in the open position, it shall stay open throughout the duration of testing.

c) For the shake-table test, the measured deflections shall be within the design limitations of the disconnect switch or grounding switch.
d) For the time history test, the requirements of A.2.2.
e) For the dynamic and static coefficient analysis, the requirements of A.3.

E.5.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.5.

The shake-table tested switch shall pass the following tests to ensure its functionality:

a) *Millivolt drop test.* Circuit resistance shall be tested before and after the shake-table test as specified in IEC 60129 (1984-01).
b) *Continuity.* Electrical continuity shall be monitored across the main disconnect switch or ground circuit when the switch or ground is closed during shake-table testing.
c) *Mechanical operating test.* The disconnect switch and the ground switch, if applicable, shall be operated (closed to open and opened to closed).
Correct operation, full opening, and full closing shall be verified. The correct operation and function of all associated equipment shall be verified. Insulator support plates, shafts, and mechanical linkage should be evaluated or monitored for deformation or failure.

The post shake-table millivolt (mV) drop test and the mechanical operating test shall be performed while the disconnect switch is still on the shake table.

E.6 Design requirements

The equipment and support shall be designed according to A.4.

E.7 Report(s)

A report shall be prepared and supplied.

E.7.1 Report for shake-table test

The report shall be in accordance with A.5.

E.7.2 Report for dynamic or static coefficient analysis

The report shall be in accordance with A.6.

E.8 Frequency or damping modifying devices or attachments

The requirements of A.7 shall be met.

E.9 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.8.

Annex F Instrument transformers

(Normative)

F.1 General

The requirements of this annex are applicable to all instrument transformers (IT), including:

a) Capacitor voltage transformers (CVTs)
b) Coupling capacitor voltage transformers (CCVT)
c) Voltage transformers (VTs)
d) Current transformers (CTs)

The voltage (kV), as used in this annex, is the nominal system voltage per IEEE Std C57.13-1993 for the CT and VT and per ANSI C93.1-1990 for the CVT and CCVT.

Seismic qualification levels are as given in F.1.1 through F.1.3.

F.1.1 High seismic qualification level

The requirements of this annex, with the exception of F.1.2 and F.1.3 are applicable to all instrument transformers in high seismic qualification level areas.

F.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of F.1.1 and F.1.3, are applicable to all instrument transformers in moderate seismic qualification level areas, except Figure A.2 may be used instead of Figure A.1.

F.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to instrument transformers in low seismic qualification level areas. The user should refer to Clauses 1 through 9 for information.

F.2 Operational requirements

The equipment and supporting structure shall be designed so that there will be neither damage nor loss of function during and after the seismic event. In addition, equipment shall maintain correct operational state during the seismic event.

F.3 Seismic qualification method

Seismic withstand capability of the equipment shall be demonstrated by the following:

a) Time history shake-table testing for equipment having a nominal system voltage ≥ 230 kV or having a total equipment height ≥ 6.1 m (20 f) including the support structure.
b) Dynamic analysis for equipment having a nominal system voltage from 69 kV to < 230 kV.
c) Static coefficient analysis for equipment having a nominal system voltage < 69 kV.

F.4 Qualification procedure

The qualification procedure shall be according to the requirements of A.1.1.

F.4.1 Qualification procedure for shake-table testing

The equipment to be shake-table tested shall be tested according to the requirements of A.1.2. The spectrum shown in Figure A.1 shall be used. Devices that are pressurized should be shake-table tested in a pressurized condition.

A resonant frequency search shall be performed according to the requirements of A.1.3 at an input level of 0.05 g to 0.1 g.

F.4.1.1 Monitoring requirements

Critical locations on the equipment and supporting structure shall be monitored for maximum displacement, maximum accelerations, and maximum stresses. As a minimum, the following shall be monitored:

a) *Maximum displacement.* Top of equipment.
b) *Maximum accelerations (vertical and horizontal).* Top of equipment.
c) *Maximum stresses.* Base of porcelain insulator, and base of supporting structure.

F.4.1.2 Post shake-table testing

The equipment shall undergo routine production electrical and mechanical tests after the completion of the shake-table tests. In addition, devices that are pressurized or sealed against atmospheric contamination shall be tested to ensure seal integrity. Oil-filled units shall be checked for leaks.

F.4.2 Qualification procedure for dynamic analysis

The equipment to be dynamically analyzed shall be analyzed according to the requirements of A.1.5. The spectrum shown in Figure A.1 shall be used.

F.4.3 Qualification procedure for static coefficient analysis

The equipment shall be analyzed according to the requirements of A.1.7. The spectrum shown in Figure A.1 shall be used. The static coefficient may be taken as 1.0.

F.5 Acceptance criteria

The qualification will be considered acceptable, if the requirements given in F.5.1 and F.5.2 are met.

F.5.1 General

The general requirements are as follows:

a) The general criteria of A.2.1.
b) For the time history shake-table test, the requirements of A.2.2.
c) For dynamic and static coefficient analysis, the acceptance requirements of A.3.

F.5.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.5.

Functional requirements for post shake-table testing include, passage of routine production electrical and mechanical tests. In addition, devices that are pressurized and sealed against atmospheric contamination shall be tested to ensure seal integrity. Oil filled units shall not leak.

F.6 Design requirements

The equipment and support shall be designed according to A.4.

F.7 Report(s)

A report shall be prepared and supplied.

F.7.1 Report for shake-table test

The report shall be in accordance with A.5.

F.7.2 Report for dynamic or static coefficient analysis

The report shall be in accordance with A.6.

F.8 Frequency or damping modifying devices or attachments

The requirements of A.7 shall be met.

F.9 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.8.

Annex G Air core reactors

(Normative)

G.1 General

Liquid-filled reactors shall meet the requirements specified in Annex D.

The voltage (kV), as used in this annex, is the nominal system voltage as defined in IEEE Std C57.16-1996 and IEEE Std C57.21-1990 .

The seismic qualification procedure for suspended air core reactors shall be according to Annex I.

Devices used to provide air core reactors with the necessary clearance to the foundation for convection cooling, voltage clearance, and magnetic field effects are deemed to be an inherent component of an air core reactor.

Seismic qualification levels are given in G.1.1 through G.1.3.

G.1.1 High seismic qualification level

The requirements of this annex, with the exception of G.1.2 and G.1.3, are applicable to all air core reactors in high seismic qualification level areas.

G.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of G.1.1 and G.1.3, are applicable to all air core reactors in moderate seismic qualification level areas, with the exception that Figure A.2 may be used instead of Figure A.1.

G.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to air core reactors in low seismic qualification level areas. The user should refer to Clauses 1 through 9 for information.

G.2 Operational requirements

Reactors shall be designed so that there will be neither structural damage nor loss of function when design seismic loads occur simultaneously with dead and normal operating loads.

G.3 Seismic qualification method

Seismic withstand capability shall be demonstrated as follows:

a) *By dynamic analysis for ³ 115 kV.* Shake-table testing or a combination of shake-table testing and analysis may be used in lieu of dynamic analysis.
b) *By static coefficient analysis for < 115 kV.* In lieu of static coefficient analysis, the requirements for reactors 115 kV and above may be used.

G.4 Qualification procedure

The qualification procedure shall be according to the requirements of A.1.1.

G.4.1 Qualification procedure for 115 kV and above

The qualification procedure shall be according to the requirements of A.1.5. The response spectrum shown in Figure A.1 shall be used in the dynamic analysis.

G.4.2 Qualification procedure for reactors less than 115 kV

The qualification procedure shall be according to the requirements of A.1.7. The response spectra shown in Figure A.1 shall be used. The static coefficient shall be taken as 1.5 for stacked reactors. For single reactors, a static coefficient of 1.0 may be used.

G.5 Acceptance criteria

The qualification will be considered acceptable, if the following requirements are met:

a) For dynamic and static coefficient analysis, stresses shall meet the requirements of A.3, item b) below, and item c) below.
b) Allowable loads in cast aluminum connections and fiberglass connections are 50% of ultimate. The ultimate loads for cast aluminum connectors, as well as fiberglass connections that are essential to carry seismic loads shall be verified using static or dynamic tests.
c) Allowable stresses in stainless steel components are 50% of the yield stress as defined by AISI SG-673-1986, Part I.

G.6 Design requirements

The equipment and supports shall be designed according to the following requirements:

a) The support frames shall meet the requirements of A.4.1.
b) Anchorage shall meet the requirements of A.4.2.
c) Welded and bolted connections shall meet the requirements of A.4.3.

G.7 Report(s)

A report shall be prepared and supplied in accordance with A.6.

G.8 Frequency or damping modifying devices or attachments

The requirements in A.7 shall be met.

G.9 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.8.

Annex H Circuit switchers

(Normative)

H.1 General

The voltage (kV), as used in this annex, is the rated maximum voltage, the highest root-mean-square voltage, above nominal system voltage, for which the circuit switcher is designed.

Seismic qualification levels are given in H.1.1 through H.1.3.

H.1.1 High seismic qualification level

The requirements of this annex, with the exception of H.1.2 and H.1.3, are applicable to all circuit switchers in high seismic qualification level areas.

H.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of H.1.1 and H.1.3, are applicable to all circuit switchers in moderate seismic qualification level areas, except Figure A.2 may be used instead of Figure A.1.

H.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to circuit switchers in low seismic qualification level areas. The user should refer to Clauses 1 through 9 for information.

H.2 Operational requirements

The circuit switcher consisting of interrupter, optional disconnecting switch, operating mechanism, control cabinet, and supporting structure shall be designed so that there will be neither structural damage nor loss of function during and after a seismic event. The circuit switcher shall not misoperate during the seismic event.

H.3 Seismic qualification method

Seismic withstand capability shall be demonstrated as follows:

a) *169 kV and above.* By time history shake-table testing.
b) *121 kV to less than 169 kV.* By dynamic analysis.
c) *Less than 121 kV.* By static coefficient analysis.

H.4 Qualification procedure

The qualification procedure shall be according to the requirements of A.1.1.

H.4.1 Qualification procedure for 169 kV and above

The qualification procedure shall be in three stages. They are as follows:

a) *Stage 1—Resonant frequency search.* A sine wave frequency search shall be conducted according to the requirements of A.1.3. The amplitude of the input acceleration shall be 0.1 g.
b) *Stage 2—Time history shake-table test.* The circuit switcher and structure shall be tested according to the requirements of A.1.2. The spectrum shown in Figure A.1 shall be used. The circuit switcher shall be tested in both closed and open positions.
c) *Stage 3—Time history shake-table operational test.* The circuit switcher shall be tested again according to the requirements of A.1.2. The spectrum shown in Figure A.1 shall be used. This time, however, the circuit switcher shall be operated open from a closed position during the strong motion period. During this test the circuit switcher shall be filled with gas at rated operating pressure.
(NOTE-- Test with protective barriers to prevent injury or damage from failure of pressurized components.)

H.4.1.1 Monitoring requirements

Critical locations on the circuit switcher and supporting structure shall be monitored to determine the maximum displacements, maximum accelerations, and maximum stresses. As a minimum, the following shall be monitored:

a) Horizontal displacements of circuit switcher terminals.
b) Accelerations, vertical and horizontal, of the top ends of vertical insulating components.
c) Stresses at the bases of vertical porcelain insulating components.
d) Stresses at the ends of horizontal porcelain insulating components.
e) Stresses at the base of the supporting structures.

The main power contact circuits and auxiliary contact stack shall be monitored to verify that the circuit switcher does not misoperate during the seismic event.

Timing and resistance measurements shall be taken before the testing begins and after the shake-table tests are completed.

The circuit switcher shall be monitored for leaks before and after each time history test. Pressure readings shall be made after each pressurized time history test for comparison with pretest readings to detect leaks.

H.4.1.2 Production tests following shake-table testing

The circuit switcher shall undergo standard production tests after the completion of the shake-table tests.

H.4.2 Qualification procedure for 121 kV to less than 169 kV

The dynamic analysis procedure shall be according to the requirements of A.1.5. The response spectrum shown in Figure A.1 shall be used.

H.4.3 Qualification procedure for less than 121 kV

The qualification procedure shall be according to the requirements of A.1.7. The static coefficient may be taken as 1.0. The response spectra shown in Figure A.1 shall be used.

H.5 Acceptance criteria

The qualification will be considered acceptable, if the criteria given in H.5.1 and H.5.2 are met.

H.5.1 General

The general requirements are as follows:

a) The general criteria of A.2.1;
b) For the time history test, the requirements of A.2.2;
c) For the dynamic and static coefficient analysis, the requirements of A.3.

H.5.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.5.

The circuit switcher shall maintain correct operational state during the time history test. The circuit switcher shall properly open during the time history operational test. Control logic components, trip and close coils, and mechanical systems shall operate properly. Pressurized modules shall not leak. Resistance readings between the terminals shall be within manufacturing limits for a new device after shake-table testing. Disconnect blades shall operate without binding or requiring physical adjustment.

The circuit switch shall pass all standard production tests after completion of the shake-table tests.

H.6 Design requirements

The circuit switcher and support shall be designed according to A.4.

H.7 Report(s)

A report shall be prepared and supplied.

H.7.1 Report for shake-table test

The report shall be in accordance with A.5.

Pretest circuit switcher open and close timing characteristics and resistance readings shall be included. A list of circuits that were monitored during the tests shall also be included.

H.7.2 Report for dynamic or static coefficient analysis

The report shall be in accordance with A.6.

H.8 Frequency or damping modifying devices or attachments

The circuit switcher shall comply with A.7.

H.9 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.8.

Annex I Suspended equipment

(Normative)

I.1 General

Equipment shall only be considered suspended if:

a) It is provided with suspension points and restraint points.
b) There are provisions to control the movement of the equipment horizontally and vertically.
c) The system complies with 6.7.

Suspending thyrister valves is a recommended method of support. However, thyristor valves are out of the scope of this annex.

Seismic qualification levels are given in I.1.1 through I.1.3.

I.1.1 High seismic qualification level

The requirements of this annex, with the exception of I.1.2 and I.1.3, are applicable to all suspended equipment in high seismic qualification level areas.

I.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of I.1.1 and I.1.3, are applicable to all suspended equipment in moderate seismic qualification level areas, except 0.25 times the weight of the equipment (Wt) horizontal may be used in lieu of 0.5 Wt horizontal, 3.5 Wt may be used in lieu of 5 Wt vertical, and 2.5 Wt may be used in lieu of 4 Wt vertical.

I.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to suspended equipment in low seismic qualification level areas. The user should refer to Clauses 1. through 9. for information.

I.1.4 Load carrying components

I.1.4.1 through I.1.4.3 define the load-carrying components of the equipment.

I.1.4.1 Suspension point(s)

Suspension point(s) are attachment part(s) from which the equipment is suspended. There may be more than one suspension point. Suspension point(s) shall be supplied by the equipment manufacturer. Suspension systems beyond the suspension point(s) will be supplied by the user.

I.1.4.2 Restraint point(s)

Restraint point(s) are attachment point(s) from which lateral restraint is provided. An external component, such as a cable, will limit the deflection of the equipment under the action of lateral loads, such as winds or earthquakes, and will be attached to the restraint point(s). There shall be at least one restraint point. A restraint point may be coincident with a suspension point. Restraint point(s) shall be supplied by the manufacturer. Restraint systems beyond the restraint point(s) will be supplied by the user.

I.1.4.3 Load-carrying structure

The load-carrying structure is the equipment's component or components through which the suspension point and restraint point loads are transmitted. The load-carrying structure may include the components that provide the function of the equipment, (e.g., the insulator units or electrical component housings) or may be structural components (e.g., rods or other members) whose only function is to transmit these loads.

I.2 Operational requirements

The equipment, including the suspension point(s), load-carrying structure, and restraint point(s) shall be designed so that there will be neither damage nor loss of function during and after a seismic event. In addition, equipment shall maintain correct operational status during the seismic event.

I.3 Seismic qualification method

The seismic withstand capability shall be demonstrated by static analysis in accordance with the method described hereinafter.

I.4 Qualification procedure—static analysis

The equipment will be installed in a suspended configuration. The entire weight will be carried from one or more suspension points of the equipment. The equipment will be restrained laterally at one or more restraint points on the equipment.

Suspension point(s), restraint point(s), and the load-carrying structure shall be capable of supporting the loads described in I.4.1 through I.4.3.

I.4.1 Suspension point(s)

Each suspension point shall be capable of supporting and transmitting the following combined vertical and horizontal loads from where the suspension point attaches to the load-carrying structure to where the suspension point attaches to the cable or other external supporting component:

a) Vertical positive (upward) load equal to 5 times the weight of the equipment appropriately distributed to the suspension points (if more than one point) plus any positive vertical normal operating load carried by the suspension point.
b) Horizontal load equal to 0.5 times the weight of the equipment appropriately distributed to the suspension points (if more than one point) applied in both principal horizontal axes, plus any horizontal normal operating load carried by the suspension point.

I.4.2 Restraint point(s)

Restraint point(s) shall be positioned so that they can restrain horizontal movement. Restraint point(s) may induce additional vertical and horizontal load. Restraint point(s) shall not induce torsion or other unbalanced loads, [i.e., the restraint point(s) shall be "balanced" with the suspension point(s)]. Each restraint point shall be capable of resisting and transmitting the following combined vertical and horizontal loads from where the restraint point attaches to the load-carrying structure to where the restraint point attaches to the cable or other external restraining component:

a) Vertical negative (downward) load equal to 4.0 times the weight of the equipment distributed according to the laws of statics to the restraint point(s), plus any vertical normal operating load carried by the restraint point(s). (The vertical load includes dynamic loads and preloads.)
b) Horizontal load equal to 0.5 times the weight of the equipment applied in both principal horizontal axes and distributed according to the laws of statics to the restraint point(s), plus any horizontal normal operating load carried by the restraint point(s).

The manufacturer shall notify the user of any restrictions in preload.

I.4.3 Load-carrying structure

The load-carrying structure, which can be an equipment structure or an independent structure, shall be capable of transmitting the combined vertical and horizontal loads from the suspension point(s) to the restraint point(s).

For the analysis, the load-carrying structure shall be treated as a free-body with the boundary suspension point(s) and the boundary restraint point(s) assumed to be supported and the loads required by I.4.1 and I.4.2 applied horizontally and vertically through the load-carrying structure.

The load-carrying structure shall be analyzed using 1.0 times the equipment's weight distributed according to its actual weight distribution, applied simultaneously in both principal horizontal axes, simultaneously with the vertical loads required in I.4.1 and I.4.2. (See Figure I.1)

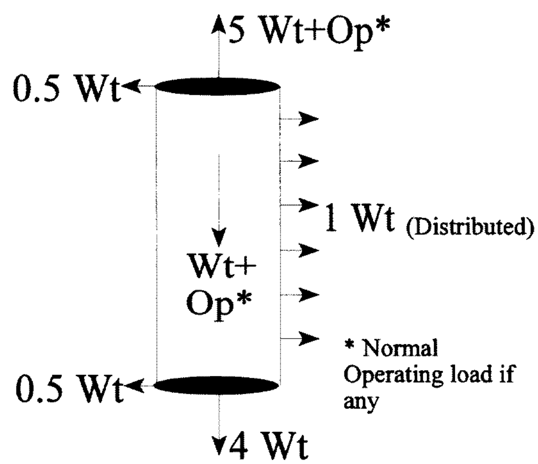


Figure I.1—Example of load-carrying structure (High seismic qualification level)

I.5 Acceptance criteria

The qualification will be considered acceptable if the following requirements are met:

a) *Allowable equipment stresses.* The calculated internal stresses in a steel or aluminum component shall not exceed the allowable stresses given in ASIC Manual of Steel Construction, ASD and the Aluminum Association's Aluminum Design Manual [B2]. The vertical loads shall be considered long term or "dead" loads and a 1/3 increase in allowables shall not be used. The horizontal loads may be considered as short term and a 1/3 increase in allowables, where allowed by code, may be used. For brittle components, the seismic stresses shall not exceed 50% of the ultimate strength.

b) *Connections.* Allowable stresses for connection bolts or welds and connection hardware shall be as specified in AISC Manual of Steel Construction, ASD and the Aluminum Association's Aluminum Design Manual [B2]. A 1/3 increase is not allowed.
c) *Allowable insulator stresses.* The resulting internal stresses shall not exceed 50% of that component's maximum mechanical strength for porcelain and fiberglass components.

I.6 Design requirements

I.7 The connections shall be designed according to A.3.3 and A.4.3

I.7.1 Report(s)

A report shall be prepared and supplied in accordance with A.6, except that the seismic outline drawing requirements given below shall be used in lieu of the requirements of A.6.2.

a) The supplier shall supply one 28 × 43.2 cm (11 × 17 in) or 21.6 × 28 cm (8 1/2 × 11 in) seismic outline drawing of the equipment.
b) An outline drawing of the equipment, including overall dimension, weights, and location of the CG of the equipment.
c) Connection details showing bolt and weld sizes, if applicable, and their corresponding locations.
d) Suspension and restraint point locations.
e) The method used to qualify the equipment, including the acceleration levels used (e.g., 0.5 g).

I.8 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.8.

Annex J Station batteries and battery racks

(Normative)

J.1 General

Battery racks, as used in this annex, refers to the load carrying structure.

Seismic qualification levels are given in J.1.1 through J.1.3.

J.1.1 High seismic qualification level

The requirements of this annex, with the exception of J.1.2 and J.1.3, are applicable to all station batteries and battery racks, specified for use in high seismic qualification level areas.

J.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of J.1.1 and J.1.3, are applicable to all station batteries and battery racks, specified for use in moderate seismic qualification level areas, with the following exceptions:

a) Figure A.2 may be used instead of Figure A.1.
b) An acceleration of 0.5 g may be used for static analysis instead of 1.0 g, as specified in J.4, item b).

J.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to station batteries and battery racks specified for use in low seismic qualification level areas. The user should refer to Clauses 1 through 9 for information.

J.2 Operational requirements

The station batteries and battery racks shall be designed so that there will be neither damage nor loss of function during and after the seismic event.

J.3 Seismic qualification method

Station batteries may be qualified by normal shipping loads.

Seismic withstand capability of modular racks shall be demonstrated by time history shake-table testing and seismic withstand capability of lead-acid battery racks shall be demonstrated by static analysis.

J.4 Qualification procedure

The qualification procedures shall be conducted according to the following:

a) The qualification procedure for modular racks shall be according to the requirements of A.1.1 and shall be time history tested according to the requirements of A.1.2. The spectrum shown in Figure A.1 shall be used.

A resonant frequency search shall be performed according to the requirements of A.1.3 at an input level of 0.05 g to 0.1 g.

b) The qualification procedure for lead-acid racks shall be according to the requirements of A.1.1, and shall be statically analyzed according to the requirements of A.1.6 at 1.0 g.

J.4.1 Monitoring requirements

Critical locations on the battery rack shall be monitored for maximum displacement, maximum accelerations, and maximum stresses. As a minimum, the following shall be monitored:

a) *Maximum displacement.* Top of rack and connection points.
b) *Maximum accelerations (vertical and horizontal).* Top of rack.
c) *Maximum stresses.* Base of rack.

J.5 Acceptance criteria

The qualification will be considered acceptable if the criteria given in J.5.1 and J.5.2 are met.

J.5.1 General

The general requirements are as follows:

a) The general criteria of A.2.1.
b) For the modular battery racks, the time history test requirements of A.2.2.
c) For lead-acid battery racks, the static analysis requirements of A.3.

J.5.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.5.

Modular battery racks that do not lose power during the testing meet the functional requirements.

J.6 Design requirements

The equipment and support shall be designed according to A.4. In addition, rigid foam separators shall be provided in all spaces around the battery to ensure a snug fit between cells, between restraints and cells, and between cells and the rack ends. In case of an installation on a raised access floor, the rack shall be anchored with steel rods directly to the concrete sub-floor and the access floor shall be seismically qualified for the appropriate seismic zones.

J.7 Report(s)

A report shall be prepared and supplied in accordance with the following:

a) For modular battery racks, the requirements of A.5.
b) For lead-acid battery racks, the requirements of A.6.

J.8 Frequency or damping modifying devices or attachment

The requirements of A.7 shall be met.

J.9 Seismic identification plate

A seismic identification plate shall be attached to each rack supplied. The plate shall be as specified in A.8.

Annex K Surge arresters

(Normative)

K.1 General

The voltage (kV), as used in this annex, is the duty cycle voltage rating as defined in IEEE Std C62.11-1993 .

These requirements are applicable to all free standing surge arresters.

Seismic qualification levels are given in K.1.1 through K.1.3.

K.1.1 High seismic qualification level

The requirements of this annex, with the exception of K.1.2 and K.1.3 are applicable to all surge arresters in high seismic qualification level areas.

K.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of K.1.1 and K.1.3 are applicable to all surge arresters in moderate seismic qualification level areas, except Figure A.2 may be used instead of Figure A.1.

K.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to surge arresters in low seismic qualification level areas. The user should refer to Clauses 1 through 9 for information.

K.2 Operational requirements

The equipment and supporting structure shall be designed so that there will be neither damage nor loss of function during and after the seismic event. Additionally, equipment shall maintain correct operational states during the seismic event.

K.3 Seismic qualification methods

The seismic withstand capability, where the kV rating is a measure of the duty cycle voltage rating, shall be demonstrated by

a) *90 kV and above.* By time history shake-table testing.
b) *54 kV to less than 90 kV.* By dynamic analysis.
c) *Less than 54 kV.* By static coefficient analysis.

K.4 Qualification procedures

The qualification procedures shall be in accordance with the requirements of A.1.1.

K.4.1 Qualification procedure for shake-table testing

Surge arresters to be shake-table tested shall be tested according to the requirements of A.1.2. The spectrum shown in Figure A.1 shall be used.

A resonant frequency search shall be performed according to the requirements of A.1.3 at an input level of 0.05 g to 0.1 g.

K.4.1.1 Monitoring requirements

Critical locations on the surge arresters and the supporting structure shall be monitored for maximum displacement, maximum accelerations, and maximum stresses. As a minimum, the following shall be monitored:

a) *Maximum displacement.* Top of equipment.
b) *Maximum accelerations.* Top of equipment (vertical and horizontal).
c) *Maximum stresses.* Bottom end of porcelain surge arrester, bottom metal end fitting, and base of supporting structure.

K.4.1.2 Post shake-table testing

The equipment shall undergo standard electrical production tests as defined by IEEE Std C62.11-1993 after the completion of the shake-table tests. In addition, devices that are pressurized or sealed against atmospheric contamination shall be tested to ensure seal integrity.

K.4.2 Qualification procedure for dynamic analysis

The surge arresters to be dynamically analyzed shall be analyzed according to the requirements of A.1.5. The spectrum shown in Figure A.1 shall be used.

K.4.3 Qualification procedure for static coefficient analysis

The qualification procedure shall be according to the requirements of A.1.7. The static coefficient may be taken as 1.0. The response spectra shown in Figure A.1 shall be used.

K.5 Acceptance criteria

The qualification will be considered acceptable if the requirements given in K.5.1 and K.5.2 are met.

K.5.1 General

The general requirements are as follows:

a) The general criteria of A.2.1.
b) For the shake-table test, the time history test requirements of A.2.2.
c) For the dynamic analysis, the requirements of A.3.
d) For static coefficient analysis, the requirements of A.3.

K.5.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.5.

For shake-table tested surge arresters, the equipment shall maintain correct operational state during the seismic event. Confirmation of this requirement shall entail passage of standard production electrical tests and mechanical tests as defined by IEEE Std C62.11-1993 after completion of any shake-table tests.

K.6 Design requirements

The equipment and supports shall be designed according to A.4.

K.7 Report(s)

A report shall be prepared and supplied in accordance with A.5 or A.6, as appropriate.

K.8 Frequency or damping modifying devices or attachments

The requirements of A.7 shall be met when applicable.

K.9 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.8.

Annex L Substation electronic devices, distribution panels and switchboards, and solid-state rectifiers
(Normative)

L.1 General

These following requirements are applicable to the following substation electronic devices (SEDs):

a) Remote terminal units (RTUs)
b) Digital fault recorders (DFRs)
c) Sequence of events recorders (SERs)
d) Intelligent electronic devices (IEDs)

These requirements are also applicable to distribution panels and switchboards for ac and dc power, and solid-state rectifiers for battery charging.

Seismic qualification levels are given in L.1.1 through L.1.3.

L.1.1 High seismic qualification level

The requirements of this annex, with the exception of L.1.2 and L.1.3, are applicable to all equipment listed in L.1 in high seismic qualification level areas.

L.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of L.1.1 and L.1.3, are applicable to all equipment listed in L.1 in moderate seismic qualification level areas, with the following exceptions:

a) Figure A.2 may be used instead of Figure A.1.
b) An acceleration of 0.75 g may be used for static analysis, as specified in L.4.2, instead of 1.5 g.

L.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to all equipment listed in L.1 in low seismic qualification level areas. The user should refer to Clauses 1 through 9 for information.

L.2 Operational requirements

The equipment and supporting structure shall be designed so that there will be neither damage nor loss of function during and after a seismic event.

L.3 Seismic qualification method

The seismic withstand capability shall be demonstrated by time history shake-table testing for the RTUs and IEDs. The seismic withstand capability of all other equipment listed in L.1 shall be demonstrated as follows:

a) The internal components may be qualified by experience based qualification.
b) The panels or cubicles and their hold down fittings shall be qualified by static analysis.

L.4 Qualification procedure

The qualification procedure shall be according to the requirements of A.1.1.

L.4.1 RTU and IED qualification procedure

The RTUs and IEDs shall be tested according to the requirements of A.1.2. The spectrum shown in Figure A.1 shall be used.

A resonant frequency search shall be performed according to the requirements of A.1.3 at an input level of 0.05 g to 0.1 g.

L.4.2 Equipment listed in L.1 (except RTUs and IEDs) qualification procedure

All equipment listed in L.1, except RTUs and IEDs, shall be analyzed according to the requirements of A.1.6 at 1.5 g.

L.5 Acceptance criteria

The qualification will be considered acceptable, if the criteria given in L.5.1 and L.5.2 are met.

L.5.1 General

The general requirements are as follows:

a) The general criteria of A.2.1.
b) For the RTUs and IEDs, the requirement of A.2.2.
c) For all equipment listed in L.1, except RTUs and IEDs, the requirements of A.3.

L.5.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.5.

The following shall be carried out in sequence:

a) Before the shake-table tests, the RTU or IED shall be tested by simulating all its functions. Appropriate signals shall be injected to inputs, and all outputs shall be monitored for correct operation. Also, noise testing shall be conducted with the latest revisions to the applicable standard as follows:
    1) Surge withstand capability and fast transient tests in accordance with IEEE Std C37.90.1-1989 .
    2) Radiated radio frequency wave test in accordance with IEEE Std C37.90.2-1995 .
    3) Radiated transient voltage tests in accordance with 5.3.1 of IEEE Std 518-1982 .
b) Only monitoring of critical circuits for relay bounce shall be carried out during the shake-table tests. Any failures shall be noted.
c) After the shake-table tests, the functional and noise tests in item a) above shall be repeated. Also, all components shall be inspected to ensure that no components have shaken loose or broken off, and that they are securely in their sockets. The integrity of the wiring shall also be checked. Any failures shall be noted.

Inspection per item c) above may also be carried out before the testing per item a) above, but only to ensure the correct state of components within the device. However, attempts to press down components within their sockets shall not be made.

L.6 Design requirements

All equipment listed in L.1 shall be designed according to A.4.

L.7 Report(s)

The following reports shall be prepared and supplied:

a) For RTU and IED, a report in accordance with A.5.
b) For all equipment listed in L.1, except RTUs and IEDs, a report in accordance with A.6.

L.8 Frequency or damping modifying devices or attachments

The requirements of A.7 shall apply.

L.9 Seismic identification plate

A seismic identification plate shall be attached to each piece of equipment supplied. The plate shall be as specified in A.8.

Annex M Metalclad switchgear

(Normative)

M.1 General

The voltage (kV), as used in this annex, is the rated maximum voltage, as defined in ANSI C37.06-1987 .

Seismic qualification levels are as given in M.1.1 through M.1.3.

M.1.1 High seismic qualification level

The requirements of this annex, with the exception of M.1.2 and M.1.3, are applicable to all voltage levels of indoor and outdoor metalclad switchgear in high seismic qualification level areas.

M.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of M.1.1 and M.1.3, are applicable to all voltage levels of indoor and outdoor metalclad switchgear in moderate seismic qualification level areas, except Figure A.2 may be used instead of Figure A.1 and 0.25 g may be used in lieu of 0.5 g.

M.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to all voltage levels of indoor and outdoor metalclad switchgear in low seismic qualification level areas. The user should refer to Clauses 1 through 9 for information.

M.2 Operational requirements

The completely assembled and installed equipment shall be designed so that there will be neither damage nor loss of function during and after a seismic event. In addition, metalclad switchgear and equipment installed in the switchgear shall maintain correct operational state during a seismic event.

M.3 Seismic qualification method

Metalclad switchgear installations designs shall be verified by the following:

a) Seismic Qualification Utility Group (SQUG) rules or static analysis for < 15 kV for qualification. (Refer to Annex P and 7.7 for SQUG rules).
b) Dynamic analysis for ≥ 15 kV. Figure A.1 shall be used.

M.4 Qualification procedure

The qualification procedures shall be in accordance with the requirements of A.1.1.

M.4.1 Qualification procedure for static analysis

Static analysis shall be according to the requirements of A.1.6. An acceleration of 0.5 g shall be used in the analysis.

M.4.2 Qualification procedure for dynamic analysis

Dynamic analysis shall be in accordance with the requirements A.1.5. The spectrum shown in Figure A.1 shall be used.

M.5 Acceptance criteria

The qualification will be considered acceptable, if the requirements given in M.5.1 and M.5.2 are met.

M.5.1 General

The general requirements are as follows:

a) The general criteria requirements of A.2.1.
b) For the dynamic and static analysis, the requirements of A.3.

M.5.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.5.

The equipment shall function adequately from a structural viewpoint. The removable circuit breaker and instrumentation units shall operate normally, and the tolerances and other critical dimensions in the equipment shall not change unacceptably. In order to avoid unwanted tripping of circuit breakers or false alarms there shall be no malfunctioning protection and control devices or circuits.

Further, the equipment shall meet all the electrical functional and operational requirements before and after tests as defined in applicable clauses of IEEE Std C37.20.2-1993 and IEEE Std C37.20.3-1987 .

M.6 Design requirements

The complete components installation shall be designed in accordance with A.4. Other clauses of this recommended practice may apply to individual devices or equipment of this installation.

M.7 Report(s)

An analysis report shall be prepared and supplied in accordance with A.6. The analysis report should include both subparagraphs pertaining to data and the seismic outline drawing.

M.8 Frequency or damping modifying devices or attachments

The requirements of A.7 shall be met.

M.9 Seismic identification tag

A seismic identification tag shall be attached to each piece of equipment supplied. The tag shall be as specified in A.8.

Annex N Cable terminators (potheads)

(Normative)

N.1 General

The voltage (kV), as used in this annex, is the rated maximum voltage, as defined in ANSI C37.06-1987 .

Seismic qualification levels are as given in N.1.1 through N.1.3.

N.1.1 High seismic qualification level

The requirements of this annex, with the exception of N.1.2 and N.1.3, are applicable to all cable terminators (potheads) in high seismic qualification level areas.

N.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of N.1.1 and N.1.3, are applicable to all cable terminators (potheads) in moderate seismic qualification level areas, except Figure A.2 may be used instead of Figure A.1.

N.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to cable terminators (potheads) in low seismic qualification level areas. The user should refer to Clauses 1 through 9 for information.

N.2 Operational requirements

The cable terminators (potheads) and supporting structures shall be designed so that there will be neither damage nor loss of function during and after the seismic event. Cable terminations shall include any cantilever loads acting on pothead porcelains due to seismic disturbance.

N.3 Seismic qualification method

Seismic withstand capability shall be demonstrated as follows:

a) Seismic withstand capability of the potheads in voltage classifications of ≥ 242 kV shall be demonstrated by time history shake-table testing.
b) Pull tests or time history shake-table tests shall be used to demonstrate the seismic withstand capability of potheads in voltage classifications < 242 kV.

N.4 Qualification procedure

The qualification procedure shall be according to the requirements of A.1.1.

N.4.1 Qualification of pothead in voltage classifications of 242 kV and above

Pothead in voltage classification ≥ 242 kV shall be time history tested according to the requirements of A.1.2. The spectrum shown in Figure A.1 shall be used.

A resonant frequency search shall be performed according to the requirements of A.1.3 at an input level of 0.05 g to 0.1 g.

N.4.2 Qualification of potheads in voltage classifications less than 242 kV

Potheads in voltage classifications < 242 kV can be qualified by static pull tests. The static pull test shall consist of pulling perpendicular to the top of the potheads with a load that is twice the operating weight of potheads. This load shall be applied for a minimum of 2 s. In lieu of the above described test, the time history shake-table test as specified in A.1.2 may be used as an alternative.

N.4.3 Monitoring requirements

Critical locations on the potheads and supporting structure shall be monitored for maximum displacement, maximum accelerations, and maximum stresses. As a minimum, the following shall be monitored.

a) *Maximum displacement.* Top of the potheads.
b) *Maximum accelerations (vertical and horizontal).* Top of the potheads. (If qualified by shake-table test.)
c) *Maximum stresses.* Bottom end of porcelain pothead and base of the supporting structure.

N.4.4 Post shake-table testing

The potheads shall undergo standard electrical production tests after the completion of the shake-table tests. In addition, potheads that are sealed against atmospheric contamination shall not leak during or after the shake-table tests.

N.5 Acceptance criteria

The qualification will be considered acceptable, if the requirements given in N.5.1 and N.5.2 are met.

N.5.1 General

The general requirements are as follows:

a) The general requirements of A.2.1.
b) For the time history test, requirements of A.2.2.
c) For the pull test, requirements of A.3 and there shall be no damage or cracks in any part, including the porcelain, and no oil leakage before and after the static pull test.

N.5.2 Functional requirements for shake-table tested equipment

The equipment shall meet the requirements of A.2.5.

The shake-table tested potheads (cable terminators) shall pass the following electrical requirements as defined in IEEE Std 48-1996 :

a) Visual inspection. There shall be no damage or cracks in any part, including the porcelain and no oil leakage before or after the shake-table test.
b) Mechanical efficiency of seal temperature rise.
c) Power frequency withstand voltage.

d) Power frequency flash over.
e) Impulse withstand voltage.
f) Capacitance measurements.
g) Ionization measurements.
h) Radio influence.
i) Pressure (leak).

N.6 Design requirements

The potheads and support shall be designed to the specifications given in A.4.

N.7 Report(s)

A report shall be prepared and supplied in accordance with A.5.

N.8 Frequency or damping modifying devices or attachments

The requirements of A.7 shall be met.

N.9 Seismic identification tag

A seismic identification tag shall be attached to each pothead by supplier. The tag shall be as specified in A.8.

Annex O Capacitors, series, and shunt compensation

(Normative)

O.1 General

The voltage (kV), as used for shunt compensation banks and for series compensation banks in this annex, is the system nominal voltage as defined in IEEE Std 1036-1992 and IEEE Std 824-1994 , respectively.

Seismic qualification levels are given in O.1.1 through O.1.3.

O.1.1 High seismic qualification level

The requirements of this annex, with the exception of O.1.2 and O.1.3, are applicable to all series and shunt bank assemblies in high seismic qualification level areas.

O.1.2 Moderate seismic qualification level

The requirements of this annex, with the exception of O.1.1 and O.1.3, are applicable to all series and shunt bank assemblies in moderate seismic qualification level areas, with the following exceptions:

a) Figure A.2 may be used in lieu of Figure A.1.
b) An acceleration of 0.25 g may be used in lieu of 0.5 g in O.4.

O.1.3 Low seismic qualification level

Only the requirements of 9.5.2 are applicable to series and shunt banks in low seismic qualification level areas. The user should refer to Clauses 1. through 9. for information.

O.2 Operational requirements

Series and shunt compensation installations > 38 kV shall be designed so that there will be no permanently disabling functional damage as a result of the seismic event.

O.3 Seismic qualification method

Seismic withstand capability shall be demonstrated as follows:

a) Series and shunt compensation banks for use on systems voltages > 230 kV shall be verified by dynamic analysis.
b) Series and shunt banks > 38 kV but ≤ 230 kV system voltages shall be verified by static coefficient analysis.
c) A seismic report is not required for series and shunt compensation banks ≤ 38 kV.

O.4 Qualification procedure

The qualification procedure shall be according to the requirements of A.1.1.

O.4.1 Qualification procedure for dynamic analysis

Series and shunt compensation banks to be dynamically analyzed shall be analyzed in accordance with the requirements of A.1.5. The spectrum shown in Figure A.1 shall be used.

O.4.2 Qualification procedure for static coefficient analysis

The qualification procedure shall be in accordance with A.1.7. The static coefficient may be taken as 1.0. The response spectra shown in Figure A.1 shall be used.

O.5 Acceptance criteria

The qualification will be considered acceptable if the requirements of A.3 are met.

O.6 Design requirements

The complete compensation installation shall be designed in accordance with A.4.

O.7 Report(s)

A report shall be prepared in accordance with A.6.

O.8 Frequency or damping modifying devices or attachments

The requirements of A.7 shall be met.

O.9 Seismic identification plate

A seismic identification plate shall be attached to each bank supplied. The plate shall be as specified in A.8.

Annex P Experience-based qualification procedures for low-voltage substation equipment

(Normative)

P.1 General

Low-voltage ac and dc control, instrumentation, and power supply equipment are housed in or adjacent to substation control buildings. This type of equipment includes the following general categories:

a) Control, instrumentation, and relay panels and cabinets
b) Distribution panels and switchboards for ac and dc power
c) Solid-state rectifiers for battery charging
d) Solid-state inverters for uninterruptible power supply
e) Racks of station batteries for dc power supply
f) Metal-clad ac switchgear assemblies (< 15 kV)
g) Station service transformers (primary voltage < 15 kV)

The earthquake performance records of these categories of equipment have been studied in detail by the nuclear power industry through programs conducted by the Electric Power Research Institute (EPRI), and the Seismic Qualification Utility Group (SQUG). An extensive sample of these types of equipment has been compiled from some 24 strong motion earthquakes and more than 100 earthquake-affected sites. For most of the equipment categories listed above, more than 100 examples have been compiled of equipment items that experienced ground motion ranging from about 0.20 g to more than 0.50 g. This database of earthquake experience is described in EPRI TR-102641, 1993 [B9]. The database demonstrates that certain types of standard commercial grade equipment can withstand at least moderate amplitude earthquake motion without damage as long as good practice is used in equipment installation.

Good practice generally includes adequate anchorage to floors or walls, positive attachment of all internal components to the enclosing cabinet or framing, and sufficient slack in attachments such as cable or conduit to accommodate anticipated sway under earthquake conditions. A review procedure for installed equipment was developed for the nuclear industry by EPRI and SQUG to identify and eliminate credible sources of earthquake damage. This review procedure for the specific categories of equipment listed above is described in the SQUG's, "Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment" [B10]. Although the review procedure is intended for installed equipment, it also may function as a design and installation guide for new equipment.

The EPRI/SQUG review procedure for the eight categories of equipment listed above, may be adopted as an alternative to the rigorous seismic qualification methods of analysis or testing. In effect, use of this procedure waives rigorous seismic qualification where extensive experience in actual earthquakes indicates no tendency for damage in standard commercial grade equipment.

Use of seismic experience data as an alternative method for equipment qualification should be subject to the following restrictions:

a) A database of actual earthquake experience of sufficient size and diversity should be available to demonstrate that the particular type of equipment has no tendency for seismic damage, at least up to certain bounds of ground shaking intensity.

b) As part of the procedure, the user should ensure that the substation equipment under review is in fact generally represented by the equipment included in the database.
c) As part of the procedure, the user should ensure that the predicted ground motion for the substation site falls within the range of ground motion experienced by sites surveyed in compiling the database.

Adoption of a review procedure based on earthquake experience ensures that seismic design of low voltage control, instrumentation, and power supply equipment for substations does not require more rigorous and expensive procedures than nuclear power plant safety systems.

Annex Q Composites and porcelain insulators

(Informative)

Q.1 Composite insulators

Composite insulators, as used in this recommended practice are composed of fiber reinforced core, elastomer sheath-sheds, and metal end fittings.

Q.1.1 Definitions

Terms to know when using this annex are as follows:

Elastomer: A synthetic rubber.

Hydrophobicity: Lacking affinity for water. Water repellant. Causing water to bead.

Mandrel: Tube or rod device onto which the fiber and resin is placed to form a hollow fiberglass tube.

Pultrusion: Continuous fiber, which have been soaked in resin are formed into either a solid rod or a hollow tube by pulling the fibers through a die. The finished shape is then oven cured. The fibers run axially.

Vulcanization: The cross-linking of long molecular chains of the polymer materials resulting in keeping elastic properties and removing the plasticity of the original rubber.

Q.1.2 Core

The core usually consists of glass fibers in a resin matrix. The core provides the load bearing nonconductive structure for the insulator.

Q.1.2.1 Core types

Cores can be categorized into two general types—solid core (rod) and hollow tube core. It is important to recognize that the method of manufacture, the mechanical behavior, and the application is often different. Two different core types are as follows:

a) *Solid core rod.* The glass fibers are pultruded axially. Solid core rods are used in all tension load applications. Because presently solid core rods are only made to a maximum of 1.18 cm to 1.38 cm (3 in to 3-1/2 in) in diameter, they are generally used in bending only when service loads are low to moderate. Applications include transmission line insulators, dead-end insulators, and line post and station post insulators. (For high bending load applications, hollow core composite insulators are generally used due to their greater rigidity and depending upon the design, their greater strength.)
b) *Hollow tube core.* The glass fibers can be axial (pultruded) or a crisscrossing weave (mandrel wrapped). Hollow tube crisscrossing weave-type fiberglass cores are the recommended type for seismic applications. In the weave core type, the glass fibers are wound onto a mandrel at a specific angle, crisscrossing in both directions. Hollow core composite insulators are generally used for apparatus such as bushings, current and voltage transformers, surge arresters, and other equipment and parts where bending and pressure are major considerations.

Q.1.2.2 Materials of core

The fiberglass structure is generally made of epoxy resin or polyester resin reinforced by glass fiber, or a fiberglass reinforced polymer (FRP). The fiberglass core generally contains more than 50% by weight of glass type fiber.

Q.1.2.3 Core properties

The strength properties of fiber-reinforced hollow and solid core vary depending on many factors, such as the winding pitch of the fiber, the choice of reinforcing material and resin, the volume of the fiber, the number of fiber layers, and the method of winding. FRP strength and property values can vary greatly. Therefore, the values given in Tables Q.1 and Q.2 should not be used for design. Rather, Tables Q.1 and Q.2 offer a general comparison of FRPs to other materials such as porcelain, steel, aluminum, etc.

Table Q.1 shows typical FRP properties.

Table Q.1—Typical FRP Properties

Properties	Data	
Ultimate stress (rod)	550–750 MPa	80–109 ksi
Damage limit (rod)	450–550 MPa	65–80 ksi
Poisson's ratio	0.25–0.28	

Table Q.2 compares typical values for steel, porcelain, and FRP.

Table Q.2—Typical values for steel, porcelain and FRP

Material	Young's modulus		Fracture toughness
Steel	210 GPa	30 000 ksi	100 MPa/m$^{1/2}$
FRP (E glass)	8–48 GPa	1160–7000 ksi	20–60 MPa/m$^{1/2}$
Porcelain	70 GPa	10 200 ksi	0.1–10 Mpa/m$^{1/2}$

Q.1.2.4 Defining core strength

Identifying an allowable or design strength is difficult. The allowable or design strength is the value against which the calculated or tested stresses are compared. In order to use FRP allowables or design strength values, the reader should understand the mechanical behavior of composites.

The composites have four modes or levels of mechanical behavior. They are as follows:

a) *Elastic behavior.* The fiberglass core deforms elastically under initial load. The duration of the load does not affect strength as long as the stresses remain in the elastic domain. When the load is removed, the core returns to its original position and there is no reduction of strength.
b) *Damage limit behavior.* The transition zone between elastic behavior and plastic behavior is the damage limit zone. Below this limit, no fibers break. As one might expect, the actual damage limit is not well defined. Therefore, it is generally considered to be a range rather than a single point.
c) *Plastic behavior.* When the damage limit is exceeded, fibers begin to break and the load is transferred from the broken fiber to the epoxy resin. The resin creeps under the additional load, transferring the load to surrounding undamaged fibers. Assuming the new surrounding fibers are overstressed, more fibers will break passing more load to the resin. This process may repeat itself until the core fails. It should be noted that this does not happen suddenly, because this process involves creep. The time required to reach failure depends on the magnitude of the overload.
   For failure to occur, three events must occur:
   1) The load must be above the elastic limit.
   2) The load must be large enough that the fiberglass structure will not stabilize.
   3) The load must be held long enough for the process to go to completion.

However, if the load is not an overload and it is removed early enough during this process, the total strength capacity of the core generally will not dramatically change. This characteristic is important for seismic applications, since the dynamic loads due to earthquakes are short and the creep discussed above does not have sufficient time to progress. Thus the structural load carrying capability of the insulator is not dramatically changed.

d) *Instantaneous failure*. As can be seen, failure is possible in the plastic range, but it is time dependent. A significant amount of load above the damage limit must be applied to achieve instantaneous failure.

The insulator manufacturers provide two ratings. They are as follows:

— *Specified mechanical load (SML)*. The manufacturer specifies that the insulator will withstand this load without visual damage. This value is above the damage limit zone. This value is useful for short duration loads, such as short-circuit and seismic loads. The SML normally applies to bending loads.
— *Maximum mechanical load (MML)*. If the core is required to hold a sustained load, that load must be kept below the SML. It is recommended that for sustained service loads, the MML be specified. The MML is usually 50% or less of the SML.

Q.1.3 Sheath-sheds

Elastomers, such as ethylene propylene copolymer (EPM), ethylene propylene diene copolymer (EPDM), and silicone rubber (SR), are the main materials used for sheath-sheds of composite insulators. Some typical properties of SR and EPDM are given in Table Q.3.

Table Q.3—EPDM and SR

Material	EPDM	SR
Specific gravity	1.25-1.55	1.25-1.60
Hardness (shore A)	75	25–75
Tensile strength	8.3–13.8 MPa (1200–2000 lbf/in^2)	5.5–6.9 MPa (800–1000 lbf/in^2)
Modulus of elasticity	4.8 MPa (700 lbf/in^2)	1.4–2.8 MPa (200–400 lbf/in^2)
Tear strength	350–613 N/cm (200–350 lbf/in)	88–175 N/cm (50–100 lbf/in)

There are three general methods of applying sheath-sheds to the core. They are as follows:

a) The sheath-sheds are placed over the fiberglass core, either one by one or by multiple continuous sections. A thin layer of silicone grease is placed between the fiberglass and the sheath-sheds to eliminate air gaps and to maintain dielectric integrity. The sheath-sheds are also compressed axially on the core to prevent the core from being exposed to the environment during large deflections.
b) A thin polymer sheath is extruded onto the core and partially cured. Sheds are placed along the sheath and the entire assembly is completely cured. A chemical bond exists between the fiberglass and the sheath-shed material.
c) The entire sheath-shed housing is formed, vulcanized, and bonded to the core and the metal end fittings.
d) The sheath-sheds are extruded and helically wound on the core.

Q.1.4 Metal fittings

The end fittings are of extreme importance. The metal end fittings or their attachment to the core may be the weakest link in the structure. The end fittings perform the following functions:

a) Transfer the load from the fiberglass core to the attachment point
b) Seal liquid or gas under pressure in hollow core insulators or bushings
c) Seal the ends of the fiberglass from the environment

The metal end fittings are generally made from cast, forged, or machined aluminum; malleable iron; forged steel; or aluminum alloy.

There are various methods of attaching the metal end fittings to the core. The two most used methods are as follows:

- *Swaging or crimping (radial pressing).* The metal end fitting is crimped onto the fiberglass core. This method is most often used for suspension insulators.
- *Shrink fitting.* This method transfers load by creating an extremely tight fit between the fiberglass and the metal end fitting achieved by various proprietary methods. Most manufacturers use some type of adhesive between the fiberglass and metal end fitting, such as epoxy, to increase the load transfer. This method is used with hollow tube cores.

A third method no longer in common usage is potting. The metal end fitting is shaped like a cup, except the bottom of the cup is larger in diameter than the rim of the cup. The fiberglass core is inserted into the metal end fitting and epoxy is injected into the void between the fiberglass and the metal fitting to form a wedge. The epoxy bonds to the fiberglass and is wedged in the metal fitting.

Q.1.5 Seismic comparison of composite with porcelain

Composite insulators have the following advantages over porcelain insulators with regard to their ability to survive seismic events:

a) Composite insulators have the ability to absorb a greater degree of the vibrational energy due to their greater elasticity.
b) Composite insulators are lighter for a given voltage and mechanical strength rating.
c) Composite insulators are less prone to failure due to impact from falling objects.
d) If the conductor that connects equipment is suddenly drawn tight or experiences resonance during earthquake shaking, then the equipment’s insulators may be subjected to shock loading. This phenomenon is a common cause of failure in earthquakes. Composite insulators, by virtue of their greater fracture toughness, are better able to withstand the shock loads imparted by seismic conductor interaction. (Refer to 6.9.1 and Q.1.2.3.)

Q.1.6 Safety considerations

Safety considerations for composites are as follows:

a) If a composite under pressure is punctured (such as vandals shooting at insulators), it would just lose pressure. Porcelain can explode.
b) Composite bushings, which can become overpressurized due to an internal arc, will simply delaminate or develop a local puncture.
c) Hollow porcelain can “post-explode” due to an external flash over. The composite insulator just flashes over.
d) Porcelains fail suddenly and without warning in seismic shaking. There are no known failures of composites due to earthquakes. However, static pull tests show that composites split or crack, rather than break brittlely, like porcelains.

Q.1.7 Topics of special concern

As with all technologies, composite have characteristics that should be understood by the user. Q.1.7.1 through Q.1.7.6 address some of those characteristics.

Q.1.7.1 Environmental factors

Damage of the sheath-sheds due to environmental factors (e.g., ultraviolet light, dry-band discharges, temperature, and humidity) have long been of concern. All materials degrade due to environmental conditions. However, the rate of degradation differs. Unlike porcelain, which is made of inert materials and degrades very slowly, polymer sheath-sheds may degrade more quickly due to environmental conditions. Therefore, the question that must be asked is whether the material will remain fully functional over its required life.

Not all elastomer sheath-sheds resist aging at the same rate. The user must evaluate the materials to determine which are appropriate for their application. Therefore, it is recommended that the user require the manufacturer pass aging tests. IEEE Std 1133-1988 [B16], IEC 60587 (1984-01) [B12], IEC 61109 (1992-03) [B14], and ASTM D2303-95 [B5] are but a few of the standards defining requirements for aging. The user should adopt an aging testing program appropriate to the specific service conditions.

The sheath-sheds provide not only the necessary electrical clearances, but they also protect the fiberglass core from the environment. Careful attention should be given to the interface of the sheath-shed and the metal end fitting. Due to the differences in thermal expansion of the various materials, this area is the most likely avenue for the ingress of moisture.

Composite insulators were developed and used in outdoor transmission lines in the 1970s. Various technical improvements have been made and large numbers have since been used in transmission lines. The use of composite insulators in substations began in the 1980s.

Q.1.7.2 Deflection

Composites deflect more than porcelain of comparable diameter and size. This characteristic should be considered when providing adequate bus slack, maintaining electrical clearances, and designing for short-circuit interactions.

Q.1.7.3 Creep

Fiberglass creeps with time under sustained loads. If the load is maintained, the deflection will increase over time. This is generally not a problem in seismic events, because earthquake bending loads are transient. However, creep should be considered in the design if long term loads are present, such as insulators mounted horizontally carrying significant vertical loads. If the loads are kept under the elastic limit, the insulator will return to its original position, after the load has been removed for a time.

Q.1.7.4 Liners

When sulfur hexafluoride (SF_6) is used, there is a potential for fluoric acids to be present. A protective coating of the inside wall of the hollow core should be required. This coating should be acid resistant and maintain high surface resistance. It is also recommended that a long term pressure test, such as given in NEMA SG 4 [B17], be required.

For oil-filled bushings or insulators, a protective inner liner or coating should be required to facilitate cleaning.

Q.1.7.5 Fiberglass

The fiberglass core provides a lightweight, strong structure that is lighter than porcelain and therefore easier to handle. The ductile characteristics of fiberglass reduce the chance of damage during shipping, handling and mounting. Of course, the insulators should be handled with care, especially the sheath-sheds, which are more susceptible to damage.

Q.1.7.6 End fittings

The metal end fitting's capacity to transfer the load to the core is very important to the structural capacity of the insulator or bushing, especially for solid core insulators, where the metal end fitting may be the weakest link.

Q.1.8 Related documents

For further information, refer to Australian Standard DR 95425-1996 (Draft) [B6], IEC 61109 (1992-03) [B14], IEEE Std 1133-1988 [B16], and IEC Project 1462, Composite Insulators (Draft) [B11].

Q.2 Porcelain insulators

Over the past century, porcelain insulators have proven themselves to be strong, reliable, and durable when proper design practices are applied. As a ceramic, porcelain is a brittle material and, therefore, attention must be paid to how mechanical loads are transferred to it.

The main components that make up porcelain insulators and bushings are porcelain body and metal end fittings. The mechanical strength of porcelain insulators and bushings depends upon the following:

a) The microstructure of the porcelain body and end fittings.
b) Whether the porcelain is glazed or unglazed.
c) The cross-sectional geometry of the porcelain body and end fittings.
d) The load transfer mechanism employed between the porcelain body and end fittings.

Q.2.1 Porcelain material

The composition and microstructure of each manufacturer's porcelain will differ and therefore, the strength will be different. However, porcelain material can generally be divided into two classifications: normal and high strength.

IEC 60672-3 (1997-01) [B10] defines the two classifications that are commonly used in high voltage insulators. These classifications are shown in Table Q.4.

Table Q.4—Insulator strength

IEC group	Approximate flexural strength (min)	
	Unglazed	**Glazed**
C110 (normal strength)	50 N/mm^2 (7250 psi)	60 N/mm^2 (8700 psi)
C120 (high strength)	90 N/mm^2 (13 100 psi)	110 N/mm^2 (16 000 psi)

Q.2.2 Metal end fittings

The mechanical strength of insulators and bushings is greatly affected by the type of end fittings and how uniformly the load is transferred to the porcelain body. An improperly designed end fitting can actually decrease the strength of the insulator by concentrating stress in a narrow band or point. Porcelain is many times stronger in compression than in tension. Therefore, good end fitting design must make use of this fact.

There are three types of end fittings—center clamped, mechanically clamped, and cemented. It is important that the user understand the design considerations inherent with each type. They are discussed in Table Q.5 and illustrated in Figures Q.1, Q.2, and Q.3.

Table Q.5—Metal end fittings

Type	Equipment	Advantages	Disadvantages
Center clamped (bending capacity determined by prestress of center tension rod.)	—Transformer bushing —Dead-tank breaker bushings	—Economical design —Compact design	—Potential of oil leak (i.e. as bushing rocks off center, an opening between porcelain and the end fitting can occur.) —Potential of cracking or breakage (i.e. concentration of stress at one point as the bushing rocks off- center.)
Mechanically clamped	—Measuring devices (current transformer, Potential device, etc.) —Bushing	—Economical design —Compact design	—Potential for breakage at a lower value than cemented type, due to a concentration of stresses at clamp.
Cemented	All	—Minimizes potential for oil leakage. —Minimizes potential for breakage due to concentration of stresses.	—The overall length of the insulator or bushing must include the height of the metal end fittings at both ends. This means the insulator or bushing must be slightly longer than the center clamped type.

Q.2.2.1 Center clamped fittings

Center clamped bushings (see Figure Q.1) and insulators have a pretensioned rod (normally the conductor) that runs down the center of the bushing. The rod is connected to each end fitting. The pre-tension in the center rod provides the moment resistance of the bushing. There are no chemical or mechanical bonds. By tensioning the rod, the end fittings are pressed onto the ends of the porcelain body. Lateral loads, such as earthquake loads, must overcome the precompression in the interface between the metal end fitting and the porcelain before uplift of the bushing from the end fitting can occur. The end fittings are generally plates with non-metal gaskets to cushion the interface between the metal end fitting and the porcelain. When this type of bushing fails in an earthquake, it is generally due to one of the following two reasons:

a) Oil leakage due to rocking or lifting of the bushing off the end fitting.
b) Cracking at one edge of the porcelain caused by rocking or tilting of the porcelain.

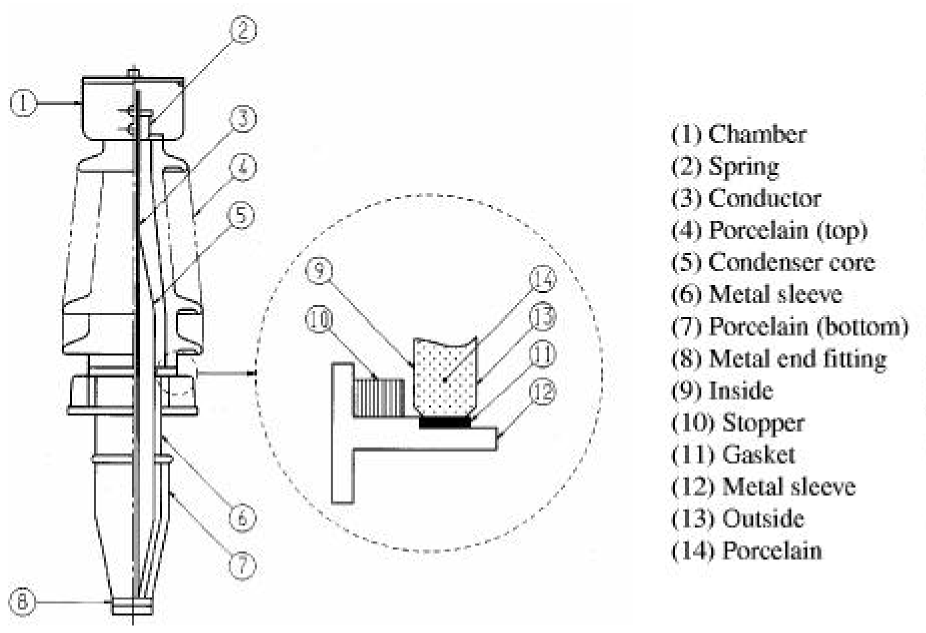


Figure Q.1—Center clamped type

Q.2.2.2 Mechanically clamped fittings

The metal end fitting of the clamped type is attached to the porcelain by means of a mechanical clamping device (see Figure Q.2). The main disadvantage of this method is that the full strength of the porcelain may not be achieved due to concentration of stresses in the porcelain at the clamp. The following special considerations must be given when designing the area labeled as “A” in Figure Q.2:

a) The clamping device should be designed to evenly and properly bear on the porcelain surface. If this cannot be done, the porcelain must be ground to achieve a proper bearing surface. No sharp corners should be allowed. Sharp corners are stress risers that invite cracking. All corners should have as large a radius as possible.

b) The bearing area of the clamp on the porcelain must be adequate.

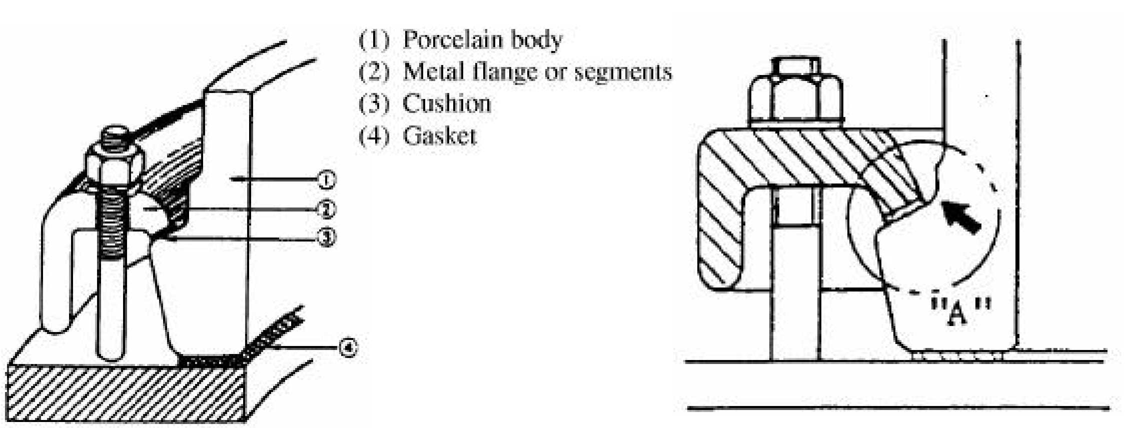


Figure Q.2—Mechanically clamped type

Q.2.2.3 Cemented fittings

The third type of metal end fitting is the cemented metal socket or fitting (see Figure Q.3). Here, the inside of the metal end fitting is contoured to translate tensile loads into compressive loads on the porcelain body.

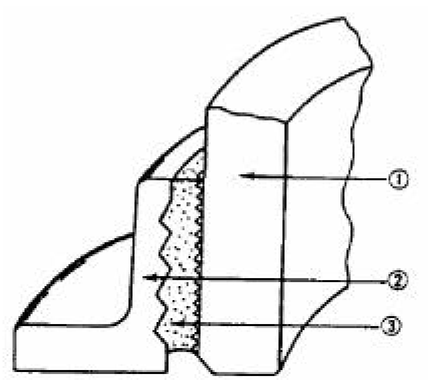
A grout material is employed between the end fitting and the porcelain body. This material must be rigid enough to transfer the compressive loads and yet be pliable enough to prevent load concentrations on the porcelain. The most common material used for this purpose is portland cement. Other materials used include alumina cement, sulfur cement, lead, and epoxy.

The strength of porcelain with a cemented fitting is markedly influenced by the ratio of depth of engagement to the diameter of the porcelain (H/D). Should the H/D be too shallow, the load cannot be properly transferred from the metal end fitting, causing a concentration of stresses in the porcelain. This results in failure at a lower value than the inherent strength of porcelain. To attain the inherent strength of the porcelain, it is recommended that the H/D be at least 0.45 for normal strength porcelain. This ratio must be increased for high- strength porcelain proportionally to any increase in porcelain strength.

There are four materials generally used for cemented fittings: gray iron, ductile iron, aluminum alloy, and bronze. Aluminum and bronze are non-magnetic materials suitable for bushings and insulators under heavy current.

The inside of cemented metal end fittings are generally one of two shapes—saw-tooth shape and rectangular-groove shape. The appropriate shape is dependent on the application of the insulators or the bushings. The saw-tooth design is applicable when the metal end fitting material has a low thermal expansion, such as gray iron and ductile iron. The saw-tooth design provides a uniform stress distribution.

Rectangular-groove shape is applicable where a material with a comparatively large thermal expansion is needed, such as aluminum alloy and bronze. This type provides for a small amount of sliding within the fitting for thermal expansion at elevated temperature.



(1) Porcelain body
(2) Metal flange
(3) Cement material—Portland cement

Figure Q.3—Cemented type

Q.2.3 Tests

Three tests are suggested, as routine tests, in addition to the requirements specified in the relevant sections of the IEC and ANSI standards, as routine tests, as a means to more precisely assure the mechanical performance of the porcelain insulators and bushings. The tests are as follows:

a) *Station post insulators.* Before assembly of end fittings.
   — 8-direction uniform bending moment test at 70% rating
   — Ultra-sonic flaw detection test

b) *Bushings.* Before assembly of fittings.
   — Inner pressure withstand test
   NOTE — Inner pressure withstand tests are applied for pressurized insulators only.
c) *Bushings.* After assembly of fittings.
   — 4-direction bending moment test
   — Inner pressure withstand test

Q.2.4 Performance of porcelain compared with composites

When properly designed, equipment employing porcelain insulators can be made to withstand seismic forces. The industry has over one hundred years of experience using porcelain and that experience has generally been very good.

Porcelain has the following advantages over composites:

a) Slow aging and degradation of insulating material.
b) No material degradation reason to protect the inner-core from the environment. (Of course, the electrical components may need to be protected from the environment.)
c) It is highly rigid. Therefore, interconnections and tolerance of mating parts are not as critical.
d) Less chance of damage during high-pressure washing.
e) Wide variation of configuration.

Q.2.5 Measures for improving porcelains performance in earthquakes

a) *De-tune porcelain support.* As noted in 6.5, the equipment support has a significant affect on the motion of the equipment. If the support can be designed such that its natural frequencies are away from the frequencies of higher acceleration, then the equipment will not need to withstand the higher dynamic loads.
b) *Pre-stress the insulators and bushings in compression.* Since the compressive strength of porcelain is very high, its apparent bending strength can be increased by imposing a compressive load (pre-stress).
c) *Uprating porcelain strength.* Increase the strength of the porcelain body by improving the composition and microstructure. Increases in strength can be obtained without an appreciable increase in mass.
d) *Limit the number of mechanical joints.* Since the joints in the insulator or bushing are the weakest link, limiting their usage would improve performance.

Annex R Analysis report template

(Informative)

Report No.____________

Seismic Analysis-Qualification Report

Qualified to Level______________________; ____g ZPA of the RRS

High or Moderate

____

Equipment Designation

____

kV or equipment rating

Report Prepared by:_____________________________

Date Signed or Revised:_______________

Address of Preparer:

____

____

____

Equipment Manufactured by:

____

This is to certify that the above-named equipment and support, if support is required, meets or exceeds all of the requirements according to IEEE Std 693-1997.

Signed:_____________________________

Table of Contents

Appendices

1.0 General

a) Supplemental work and options.
b) Load cases considered, including operating, dead, live, seismic, etc.
c) Equipment configurations considered, such as switch open or switch closed, with or without associated cabinet, etc.
d) General or global assumptions used (detailed assumptions should be embedded in the report).
e) Testing, if any (such as testing for damping, or testing of a component).
f) Modifications required, if any, to pass the analysis.
g) Replica of identification tag.
h) Other topics, as required.

2.0 Equipment data

a) Overall dimensions and weights.
b) Resonance frequencies, if by dynamic analysis.
c) Damping ratio, if by dynamic analysis or by Annex B.
d) Center of gravity of equipment and its components.
e) Maximum accelerations and displacements at critical points, if by dynamic analysis.
f) Equipment and structure reactions at support points, including magnitude and direction, at each reaction point.
g) Anchorage details, including size, location, and material strength for structural members, bolts, welds, and plates.
h) Maximum input (ground) accelerations.
i) Materials types and strengths.
j) Other topics, as required.

3.0 Method of analysis

a) Method of analysis.
b) Name of computer program used, if any.
c) Assumptions made in modeling the equipment and supporting structure.
d) Other topics, as required.

Summary of maximum stresses, loads, etc.[a]

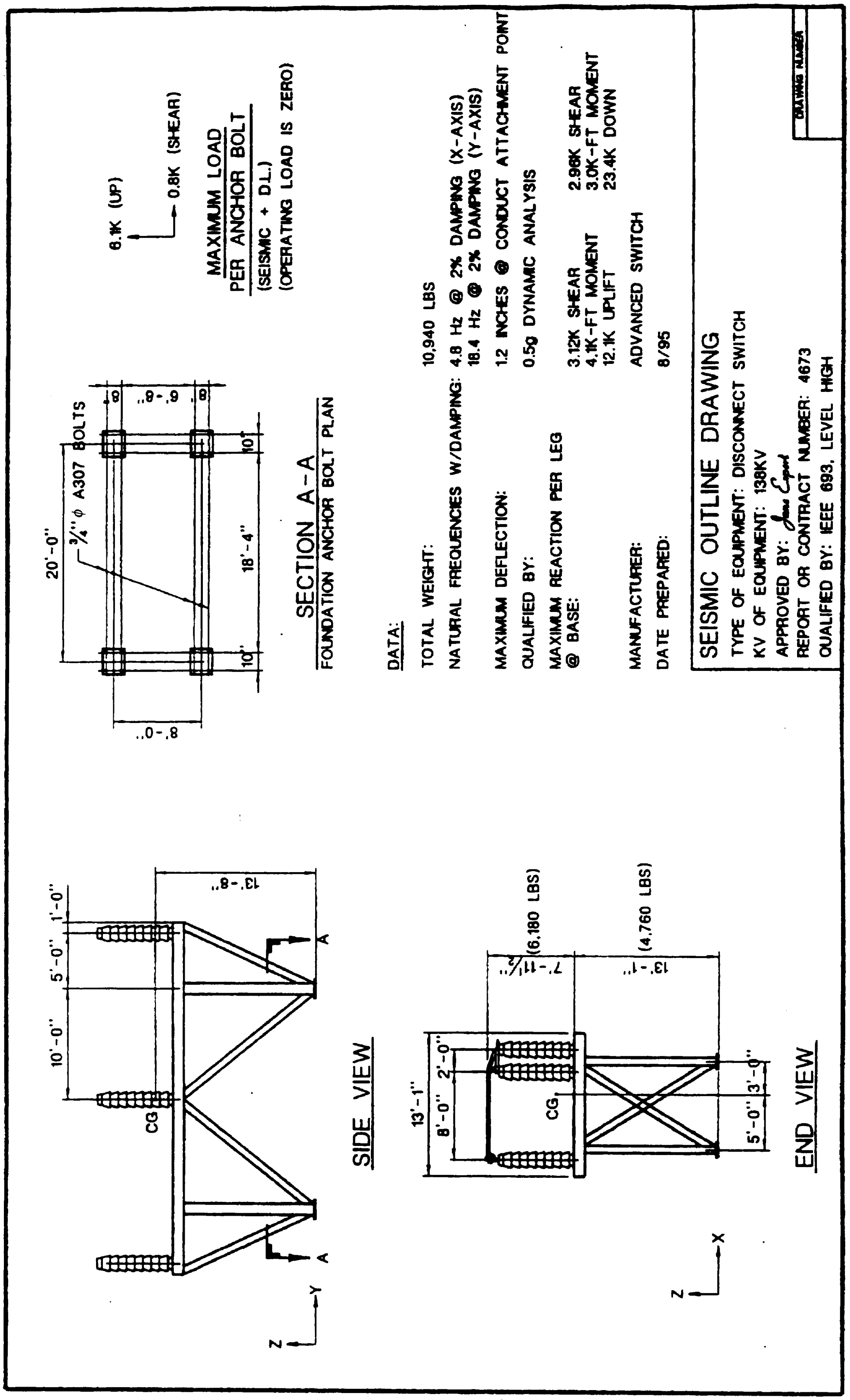
Component	Page #	Location of component in equipment, location of stress in component, or both	Moment, shear, torsion, tension, combination, etc.	Calculated value (f)	Allowable value (F)	F/f

[a]Lists the eleven smallest [F/f] factors

Example: Dynamic analysis—Summary of maximum stresses, loads, etc.[a]

Component	Page #	Location of component in equipment, location of stress in component, or both.	Moment, shear, torsion, tension, combination, etc.	Calculated value (f)	Allowable value (F)	F/f
Porcelain insulator	27	Base of porcelain insulator #2	Moment	43 in-k	43 in-k	1.00
Steel support leg	30	Base of corner columns	Moment compression	28 ksi	28 ksi	1.00
Connection weld	19	Connecting brace frame bracket to vertical leg.	Shear and bending	20 ksi	21 ksi	1.05
Porcelain insulator	27	Base of porcelain insulator #3	Moment	37 in-k	40 in-k[b]	1.08
Connection bolts	21	Connecting insulators to base	Tension and shear	17.4 ksi	19 ksi	1.09
Porcelain insulator	25	Base of porcelain insulator #4	Torsion	36 in-k	40 in-k[b]	1.11
Porcelain insulator	24	Base of porcelain insulator #1	Moment	44 in-k	50 in-k	1.14
Aluminum bracket bolt	31	Interface between insulator and tank.	Shear	10.8 ksi	27 ksi	2.50
Steel frame	46	All symmetrical corners.	Bending	12 ksi	31.9 ksi	2.66
Anchor bolts	88	All anchor bolts	Shear and tension	5 ksi	20 ksi	4.00
Steel beam	7	Cross member between legs	Bending	6.1 ksi	29 ksi	4.75

[a] Include the eleven smallest [F/f]s.
[b] Note that the porcelain's ultimate strength is 80 in-k. The allowable is 40 in-k or 0.5 × 80. (Manufacturer's insulator data is in Appendix D.)



EXAMPLE OF "SEISMIC ANALYSIS—SEISMIC OUTLINE DRAWING"

Annex S Test report template

(Informative)

Report No.____________

Seismic Test-Qualification Report

Qualified to Level________________; ____g ZPA of the RRS
High or Moderate

____
Equipment Designation

____
kV or equipment rating

Report Prepared by:__________________________

Date Signed or Revised:______________

Address of Preparer:

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Equipment Manufactured by:

____

This is to certify that the above-named equipment and support, if support is required, meets or exceeds all of the requirements according to IEEE Std 693-1997.

Signed:__________________________

Table of Contents

Appendices

1.0 General

a) Supplemental work and options
b) Equipment configurations considered, such as switch open and/or switch closed, with or without associated cabinet, etc.
c) The g level at which the resonant frequency search was conducted.
d) List the test(s) and the witness(es), if any, and the company(ies) the witness(es) represented.
e) Test plan.
f) Modifications required, if any, to pass the test.
g) Pretest calculations as described in A.5.1a, if any.
h) Replica of identification tag
i) Other topics, as required.

2.0 Equipment data

a) Resonance frequencies, if resonant frequency search required.
b) Damping ratio.
c) Table of displacements at measured points.
d) Equipment and structure reactions at support points, including magnitude and direction, at required locations.
e) Anchorage details, including size, location, and material strength for structural members, bolts, welds, and plates.
f) Maximum input (ground) accelerations.
g) Table of measured accelerations.
h) Table of measured stresses.
i) Materials types and strengths.
j) Other topics, as required

3.0 Method of testing

a) Testing case(s) conducted (i.e., time history, time history operation, sine beat).
b) Location and date of test.
c) Test engineer's name and title.
d) Description of testing equipment.
e) Serial numbers of the equipment and equipment components being tested.
f) Physical damage from testing, if any.
g) Other topics, as required.

4.0 Functional requirements

a) List of functional test performed and all other required non-shake-table testing or monitoring, such as timing, resistance, or any production test.

5.0 Video

Summary of maximum stresses, loads, etc.[a]

Component	Page #	Location of component in equipment, Discussion of value	Type of test	Measured value (f)	Allowable values (F)	F/f

[a]Maximum measured.

Example: Shake-Table Test—Summary of maximum stresses, loads, etc.[a]

Component	Page #	Location of component in equipment, Discussion of value	Type of test	Measured values (f)	Allowable values (F)	F/f
Porcelain insulator	24	Base of porcelain insulator #1	Time history	32 in-k	32 in-k[a]	1.00
Porcelain insulator	25	Base of porcelain insulator #1	Time history	32.6 in-k	32 in-k[a]	1.02
Porcelain insulator	27	Base of porcelain insulator #2	Sine beat	62.2 in-k	57.6 in-k[b]	1.08
Porcelain insulator	27	Base of porcelain insulator #3	Time history	35.5 in-k	32 in-k[a]	1.11
Steel support leg	30	Base of corner columns	Time history	25.4 ksi	29 ksi	1.14
Steel plate	21	Interface between base container and shaft.	Sine beat	24 ksi	36 ksi	1.50
Composite insulator	36	Insulator #6. Measured deflection during test. Allowable values found from static load test done before time history test.	Time history	2.1 in	3.2 in	1.52
Composite insulator	37	Insulator #6. Measured deflection during test. Allowable values found from static load test done before sine beat test.	Sine beat	3.3 in	5.76 in[c]	1.75

[a]The porcelain's ultimate strength is 64 in-k. Time History allowable is 32 in-k = 0.5×64.
[b]Porcelain's Sine Beat allowable is 0.9×64 or 57.6 in-k.
[c]Composite's 1/2 SML is 3.2 in. The composite's allowable for Sine Beat is 3.2×1.8 or 5.76 in.

NOTE—Safety factors need not be shown for the sine beat tests.

Example of data measurement points[a]
Example of a transformer bushing
(Tested triaxially)

Test # or Page #	Test Description/ Configuration	Axis	Maximum data from Instrumentation								
			Acceleration in Units of g, acceleration of gravity						Stress in ksi		Composite
			Table 1	Flange 2	C.G. 3	End fitting 4	Top 5	Shank 6	Base 7	End fitting 8	Max. deflection inches
1	Static load	X	0	0	0	0	0	0	6.07	3.47	6.20[b]
24	Sine sweep X 0.1 g	X	0.09	0.13	0.37	0.13	0.71	0.40	0.81	0.47	1.22
		Y	0.01	—	—	0.01	0.10	0.11	0.18	0.11	—
		Z	0.01	0.08	—	0.01	0.09	0.07	—	—	—
35	Sine beat X–Z 1.0 g @ 5.3 Hz	X	1.19	1.31	2.21	1.29	6.11	3.11	6.07	3.19	4.46
		Y	0.18	—	—	0.48	3.47	1.97	0.28	0.26	—
		Z	1.01	1.06	—	1.19	1.94	1.23	—	—	—
46	Time history X, Y, and Z 1.0 ZPA RRS	X	1.02	1.10	1.45	1.09	2.97	2.28	2.54	1.60	2.44
		Y	1.21	—	—	1.11	2.99	2.31	2.53	1.69	—
		Z	0.81	0.95	—	0.92	2.14	2.01	—	—	—

[a]See A.5.2 k.
[b]Maximum permanent set after a static load test was 0.15 in. Maximum allowable is 0.31 in.

Example of Minimum Information for Test Plan

1. Description of equipment.

2. Test facility name, location, and test dates.

3. Equipment (and support) set-up. Provide description and sketches or pictures.

   a) Set-up in in-service configuration. (See 9.5)
   b) Anchorage of equipment base to shake-table (or to an adapter plate attached to shake-table) to be same as in-service configuration. (If adapter plate between equipment and table, then provide attachment details of adapter plate to table.)
   c) Discussion of: Equipment to be pressurized, filled with oil, gas, etc. and other conditional requirements, as applicable.
   d) Test equipment description (see 5.8) and calibration.
   e) Test method. Triaxial or biaxial (See A.1.1)

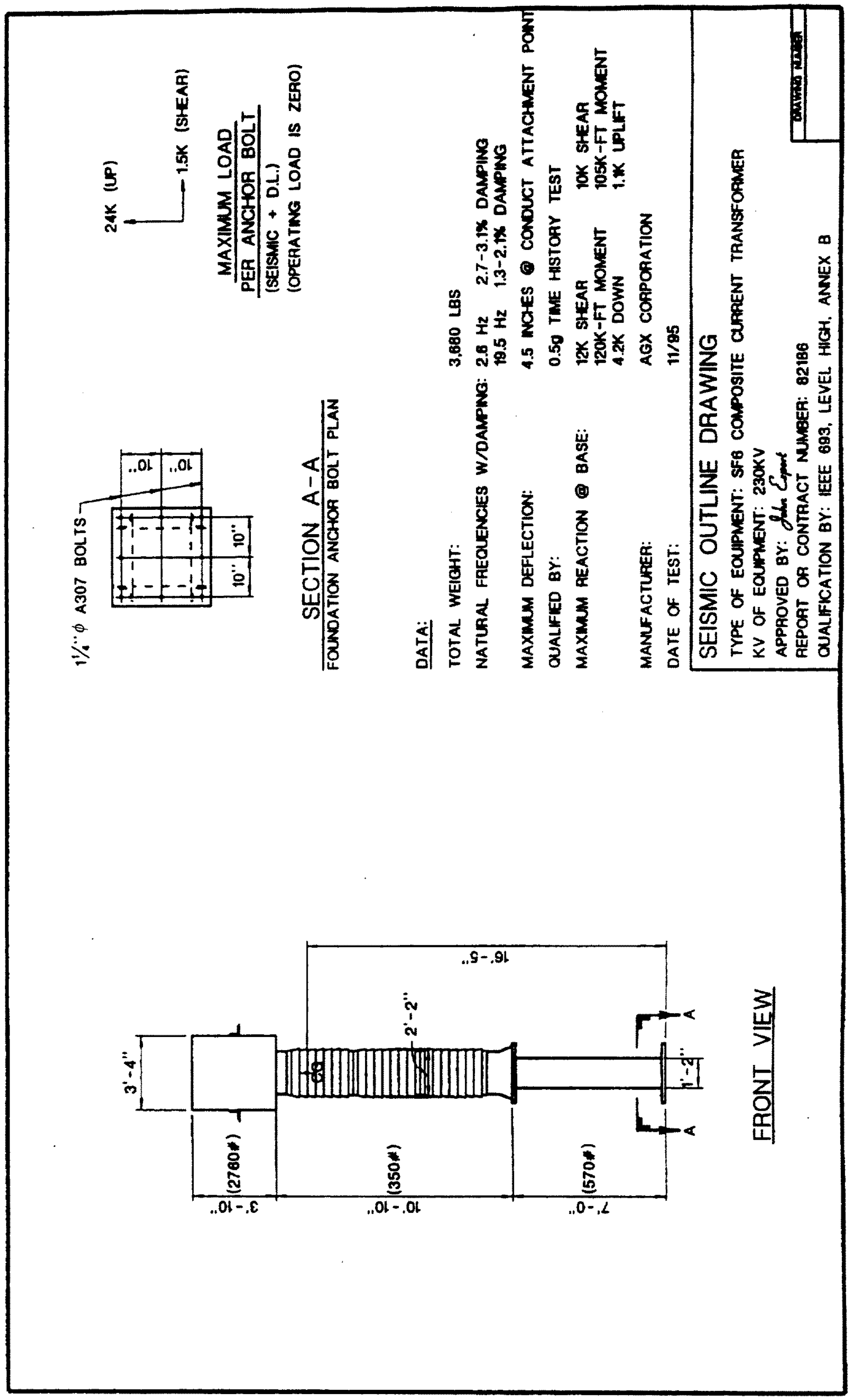
4. Functional test—Description of functional tests, including electrical hoop-ups, if any, and where test will be performed.

5. Performance level is high (or moderate).

6. Monitoring—Provide sketch(es) that show location of strain gages, accelerometers, and displacement gages, if any.

7. Provide testing program sequence—Example: Assuming biaxial testing of sloped composite bushing, i.e., non-symmetrical in x and y axes, as set up. High performance level. After each test, equipment to be inspected and results logged.

   a) Set-up equipment, install monitoring, and develop TRS. (See A.1.2).
   b) Static pull tests at 1/2 SML in x axis. (See A.2.4).
   c) Sine sweep in x axis at 0.1 g and one octave per minute. (See A.1.3).
   d) Determine resonant frequencies in x axis and damping.
   e) Sine beat in x axis at 1.0 g and 0.8 g in z axis, both measured at the flange (See A.1.4).
   f) Time history in x axis at 2 times spectra shown in RRS and 80% of the horizontal in the z axis, both measured at the flange (See A.1.2)
   g) Rotate equipment 90°.
   h) Static pull tests at 1/2 SML in y axis.
   i) Sine sweep in y axis at 0.1 g and one octave per minute.
   j) Determine resonant frequencies in y axis and damping.
   k) Sine beat in y axis at 1.0 g and 0.8g in z axis, both measured at the flange.
   l) Time history in y axis at 2 times spectra shown in figures and 80% of the horizontal in the z axis, both measured at the flange.
   m) Sine sweep in z axis (vertical) at 0.1 g and one octave per minute.
   n) Determine resonant frequencies in z axis and damping.
   o) Sine beat in z axis, if necessary, at 0.8 g measured at the flange.



EXAMPLE OF "SEISMIC TEST—SEISMIC OUTLINE DRAWING"

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[B14] IEC 61109 (1992-03), Composite Insulators for a.c. Overhead Lines with a Nominal Voltage Greater Than 100 V—Definitions, Test methods and Acceptance Criteria.

[B15] IEEE Std 344-1987 (Reaff 1993), IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations.

[B16] IEEE Std 1133-1988, IEEE Application Guide for Evaluating Non-ceramic Materials for High-Voltage Outdoor Applications.[21]

[19]This document is available from the American Concrete Institute, Farmington Hills, MI, USA.
[20]This document is available from the American Welding Society, Miami Fla, USA.

[B17] *National Building Code, 1996 Edition*, Building Officials and Code Administrators International Inc., (BOCA), County Club Hills, Ill., 1996.

[B18] NEMA SG 4, Alternating Current High Voltage Circuit Breakers.

[B19] Shipp, J. G., and Haninger, E. R., "Design of Headed Anchor Bolts," *Engineering Journal*, American Institute of Steel Construction (AISC), 1983.

[B20] *Southern Building Code,* Southern Building Code Congress International Inc., SBCCI, 1994 Ed. (with 1996 Revisions), Birmingham, Ala.

[B21] *Uniform Building Code 1994 Edition,* Structural Engineering Design Provisions, vol. 2, International Conference of Building Officials (ICBO), Whittier, Calif., 1994.

[21]IEEE 1133-1988 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181