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IEEE Guide for Seismic Qualification of Class 1E Metal-Enclosed Power Switchgear Assemblies

Sponsor

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of the
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Abstract: IEEE C37.81-1989, *IEEE Guide for Seismic Qualification of Class 1E Metal-Enclosed Power Switchgear Assemblies*, provides specific requirements and guidance for seismic qualification of metal enclosed power switchgear assemblies. This guide may also be used in other applications in which seismic response of metal-enclosed power switchgear assemblies is a consideration.
Keywords: Class 1E metal-enclosed power switchgear assemblies, generic response spectrum (GRS), performance requirements, seismic criteria

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Foreword

(This Foreword is not a part of IEEE C37.81-1989, IEEE Guide for Seismic Qualification of Class 1E Metal-Enclosed Power Switchgear Assemblies.)

This guide complements ANSI/IEEE Std 344-1987, Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations [10][1] by providing specific requirements and guidance for seismic qualification of metal-enclosed power switchgear assemblies.

Metal-enclosed power switchgear assemblies fall into the category of complex devices as described in ANSI/IEEE Std 344-1987 [10]; therefore, basic seismic qualification is dependent on test data. Analysis may be used in data reduction, reconciling response spectra, and evaluating changes. A method of combined test and analysis may also be used in justifying seismic qualification of similar equipment to the tested samples.

It should be noted that while the primary purpose of this guide is for the application of metal-enclosed power switchgear assemblies in nuclear power generating stations, it is not restricted to this application. This guide may also be used as a guide in other applications in which the seismic response of metal-enclosed power switchgear assemblies is a consideration.

At the time this guide was published, it was under consideration for approval as an American National Standard. The Accredited Standards Committee on Power Switchgear, C37, had the following members at the time this guide was sent to letter ballot:

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[1]The numbers in brackets correspond to the references listed in 1.2 of this guide.
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IEEE Guide for Seismic Qualification of Class 1E Metal-Enclosed Power Switchgear Assemblies

1. Scope and References

This guide provides requirements and guidance for the seismic qualification of metal-enclosed power switchgear assemblies including switching, interrupting, control, instrumentation, metering, and protective and regulating devices mounted therein.

1.1 Scope

This guide may be used by equipment manufacturers to establish procedures that will yield data to substantiate performance claims or by equipment users to evaluate and verify performance of representative devices and assemblies as part of an overall qualification effort.

As used in this guide, the word *switchgear* shall mean *metal-enclosed power switchgear assemblies* with the requirements as defined in ANSI/IEEE C37.20.1-1987, Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear [4], ANSI/IEEE C37.20.2-1987, Standard for Metal-Clad and Station-Type Cubicle Switchgear [5], and ANSI/IEEE C37.20.3-1987, Standard for Metal-Enclosed Interrupter Switchgear [6]. By definition, metal-enclosed power switchgear assemblies include metal-clad switchgear, station-type cubicle switchgear, metal-enclosed interrupter switchgear, and low-voltage power circuit breaker switchgear. This guide does not cover metal-enclosed bus or control switchboards.

Metal-enclosed power switchgear assemblies fall into the category of complex devices as described in ANSI/IEEE Std 344-1987 [10]. Therefore, basic seismic qualification is dependent on test data. Switchgear assemblies have many different types and arrangements of devices and components. It is neither practical nor necessary to test each unique configuration of devices and components, nor is it necessary to test a given configuration for every possible seismic environment. However, it is essential that each switchgear assembly used in Class 1E applications be seismically qualified for its environment, and this qualification must be based on data obtained by test. Analysis may be used in data reduction, reconciling response spectra, and evaluation of changes.

A method of combined test and analysis may also be used in justifying seismic qualification of equipment similar to the tested sample.

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Devices, such as relays, instruments, circuit breakers, and control switches, are qualified for use on a switchgear assembly by demonstrating that their seismic withstand capabilities as determined by seismic tests equal or exceed the seismic environment of the location on the switchgear assembly where they will be mounted.

Three standard Generic Response Spectra (GRS) have been developed that cover the seismic requirements for most locations. The GRS have been developed as a composite of a number of Required Response Spectra (RRS) proposed for nuclear generating stations throughout the US, and cover approximately 75% of the locations sampled. The GRS establish standard seismic ratings, and any switchgear assembly that has been demonstrated by test to have met a rating will therefore be seismically qualified for any user application where the RRS is enveloped by the GRS.

If the standard GRS do not apply to a particular application, specific seismic information must be furnished by the user and used as the basis for qualification.

1.2 References

The following references should be used in conjunction with this guide:

[1] ANSI/IEEE C37.09-1979, Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

[2] ANSI/IEEE C37.13-1981, Low-Voltage AC Power Circuit Breakers Used in Enclosures.

[3] ANSI/IEEE C37.14-1979, Low-Voltage DC Power Circuit Breakers Used in Enclosures.

[4] ANSI/IEEE C37.20.1-1987, Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

[5] ANSI/IEEE C37.20.2-1987, Standard for Metal-Clad and Station-Type Cubicle Switchgear.

[6] ANSI/IEEE C37.20.3-1987, Standard for Metal-Enclosed Interrupter Switchgear.

[7] ANSI/IEEE C37.98-1987, Standard for Seismic Testing of Relays.

[8] ANSI/IEEE C37.100-1981, Definitions for Power Switchgear.

[9] ANSI/IEEE Std 323-1983, Qualifying Class 1E Equipment for Nuclear Power Generating Stations.

[10] ANSI/IEEE Std 344-1987, Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations.

2. Definitions

The definitions in this section establish the meanings of terms in the context of their use in this guide. See ANSI/IEEE C37.100-1981 [8] for further definitions.

Biaxial Test: Specimen under test is subjected to acceleration in the principal horizontal axis and in the vertical axis simultaneously.

Class 1E: The safety classification of the electric equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or are otherwise essential in preventing significant release of radioactive material to the environment. (See ANSI/IEEE Std 344-1987 [10].)

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Damping: The generic term ascribed to the numerous complex energy dissipating mechanisms in a system. As an identifying parameter of a specific seismic response spectrum, the percent of critical damping is assumed to be constant.

Fragility Level: The highest level of input excitation, expressed as a function of input frequency, that an equipment can withstand and still perform the required Class 1E functions. (See ANSI/IEEE C37.98-1987 [7] and ANSI/IEEE Std 344-1987 [10].)

Fragility Response Spectrum (FRS): A Test Response Spectrum (TRS) obtained from tests to determine the fragility level of equipment. (See ANSI/IEEE C37.98-1987 [7] and ANSI/IEEE Std 344-1987 [10].)

Generic Response Spectra (GRS): The response spectra that define the seismic ratings of metal-enclosed power switchgear.

Ground Acceleration: The acceleration of the ground resulting from the motion of a given earthquake. The maximum ground acceleration can be obtained from the ground response spectrum as the acceleration at high frequencies (in excess of 33 Hz). (See ANSI/IEEE Std 344-1987 [10].)

Malfunction: The loss of capability of Class 1E equipment to initiate or sustain a required function, or the initiation of an undesired spurious action that can result in consequences adverse to safety. (See Reference [10].)

Metal-Enclosed Power Switchgear: A switchgear assembly completely enclosed on all sides and top with sheet metal (except for ventilating openings and inspection windows) containing primary power circuit switching or interrupting devices, or both, with buses and connections and may include control and auxiliary devices. Access to the interior of the enclosure is provided by doors or removable covers. (See ANSI/IEEE C37.100-1981 [8].)

NOTE — Metal-clad switchgear, station-type cubicle switchgear, metal-enclosed interrupter switchgear, and low-voltage power circuit breaker switchgear are specific types of metal-enclosed power switchgear.

Modal Participation Factor: The magnitude of each structural mode (natural frequency) that participates to compose the final dynamic response of the system. Each participation factor is a function of the system mass distribution and the generalized mode shape at each natural frequency.

Multifrequency Test: A broad band test motion, simulating a typical seismic motion, that can produce a simultaneous response from all applicable modes of a multidegree-of-freedom system.

Natural Frequency: The frequency or frequencies at which a body vibrates due to its own physical characteristics (mass, shape, boundary condition, and elastic restoring forces brought into play) when the body is distorted in a specific direction and then released. (See ANSI/IEEE Std 344-1987 [10].)

Octave: The interval between two frequencies that have a frequency ratio of 2 (e.g., 1 to 2 Hz, 2 to 4 Hz, 4 to 8 Hz, etc.). (See ANSI/IEEE C37.98-1987 [7].)

Operating Basis Earthquake (OBE): An earthquake that could reasonably be expected to occur at the plant site during the operating life of the plant; it is that earthquake which produces the vibratory ground motion for which those features of the nuclear power plant, necessary for continued operation without undue risk to the health and safety of the public, are designed to remain functional. (See ANSI/IEEE C37.98-1987 [7] and ANSI/IEEE Std 344-1987 [10].)

Production Test (for Switchgear): Tests made to check the quality and uniformity of the workmanship and materials used in the manufacture of switchgear. (See ANSI/IEEE C37.100-1981 [8].

Proof Testing: Tests that are used to qualify equipment for a particular application or to a particular requirement.

Required Response Spectrum (RRS): The response spectrum issued by the user or his agent as part of his specifications for qualification, or artificially created to cover future applications. The RRS constitutes a requirement to be met. (See ANSI/IEEE C37.98-1987 [7] and ANSI/IEEE Std 344-1987 [10].)

Response Spectrum: A plot of the maximum response of single-degree-of-freedom bodies of different natural frequencies, at a damping value expressed as a percent of critical damping, when these bodies are rigidly mounted on the surface of interest (that is, on the ground for the ground response spectrum or on the floor of a building for the floor's response spectrum) when that surface is subjected to a given earthquake's motion as modified by any intervening structures. (See ANSI/IEEE Std 344-1987 [10].)

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Safe Shutdown Earthquake (SSE): The earthquake that produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to remain functional. These structures, systems, and components are those necessary to assure: (1) the integrity of the reactor coolant pressure boundary, (2) the capability to shut down the reactor and maintain it in a safe shutdown condition, and (3) the capability to prevent or mitigate the consequences of accidents that could result in potential off-site exposures comparable to the guideline exposures of the Code of Federal Regulations, Title 10, Part 100 (December 5, 1973). (See ANSI/IEEE Std 344-1987 [10].)

Sine Sweep Test: A sinusoidal input with continuously varying frequency covering the range of interest.

Test Response Spectrum (TRS): The response spectrum that is developed from the actual time history of the actual motion of the shake table. (See ANSI/IEEE Std 344-1987 [10].)

Transmissibility: Ratio of the response at any one point in the equipment to the input of the equipment at a single frequency.

Zero Period Acceleration (ZPA): The peak acceleration of the motion time history that corresponds to the high-frequency asymptote on the response spectrum. (See ANSI/IEEE C37.98-1987 [7].)

3. Seismic Criteria

3.1 Generic Response Spectrum

Three GRS's, (GRS I, GRS II, and GRS III) have been defined for the seismic qualification of switchgear as shown in Fig 1. These spectra were developed to provide a selection of standard switchgear seismic ratings that meet the requirements of most seismic applications. Experience has shown that most RRS peaks lie between 3 and 12 Hz. For the purposes of defining practical values for analysis of test data, the 1/3 octave frequencies 3.2 Hz and 12.8 Hz are used. This broad range has been divided into three narrower parts to more accurately represent typical response spectra, to be used individually or in various combinations.

1) GRS I was chosen to meet RRS peaking between 3.2 Hz and 5 Hz.
2) GRS II was chosen to meet RRS peaking between 5 Hz and 8 Hz.
3) GRS III was chosen to meet RRS peaking between 8 Hz and 12.8 Hz.

In the event that an equipment's seismic capability cannot be accurately represented by the three GRS's, then scaling factors G1, G2, and G3 can be used to adjust GRS I, GRS II, and GRS III up or down across the entire frequency range. For example, ratings of G1 = 0.5, G2 = 1.0, and G3 = 1.0, respectively, would mean that the equipment is qualified for the full GRS II and GRS III levels shown in Fig 1, but through either test machine or equipment capability limitations, data exists to establish qualification to only 0.5 of the GRS I level.

One or more of the GRS's (I, II, or III) shall envelop both the horizontal and vertical RRS. If the GRS does not envelop both the vertical and horizontal RRS, then a special qualification test must be developed.

If none of the GRS apply for a particular application, the user must provide the specific seismic requirements.

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FREQUENCY (Hz)	GRS AMPLITUDE (g's) I	II	III	FREQUENCY (Hz)	GRS AMPLITUDE (g's) I	II	III
1.0	0.5	0.5	0.5	8.0	2.3	3.8	3.8
1.3	0.7	0.7	0.7	10.0	1.9	3.3	3.8
1.6	0.9	0.9	0.9	12.8	1.9	2.3	3.8
2.0	1.5	1.5	1.5	16.0	1.9	1.9	3.3
2.5	2.3	1.7	1.7	20.0	1.8	1.8	2.3
3.2	3.8	1.9	1.9	25.6	1.6	1.6	1.8
4.0	3.8	2.3	1.9	32.0	1.3	1.3	1.3
5.0	3.8	3.8	1.9	ZPA	1.0	1.0	1.0
6.4	3.3	3.8	2.3				

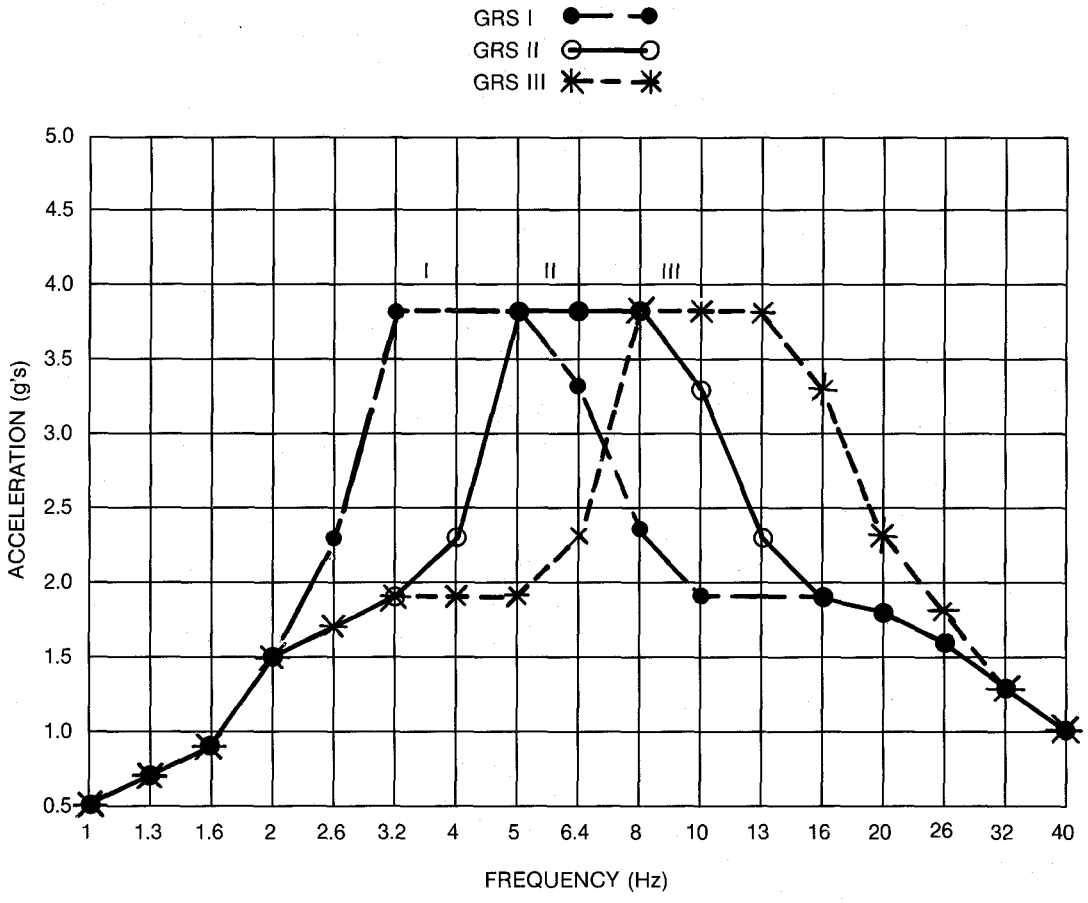

Figure 1— 5% Generic Response Spectra for Switchgear Seismic Testing (All Values Are for SSE.)

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3.2 Information Furnished by the User

The information furnished by the user must describe the seismic environment for the equipment. Any condition that may be of consequence during the seismic event must be described. The information to be furnished by the user is shown below:

1) If one or more GRS applies, the user shall specify the applicable GRS for the SSE. He shall also specify the OBE in relationship to the SSE.
2) If the GRS does not apply, the user shall provide adequate information to describe the seismic environment for both the SSE and the OBE. If response spectra are provided, the same damping shall be used for the front-to-back, side-to-side, and vertical directions for the switchgear orientation. The preferred damping to be provided by the user is 5%.
3) Identify Class 1E power circuits and functions. For example, the failure of a circuit breaker to trip or failure to remain open may be critical; whereas, for other applications, failure to close or false tripping may be acceptable fail-safe modes.
4) Identify Class 1E control circuits and functions. For example, a certain relay may be used for alarm only and malfunction is acceptable; whereas, other relays or controls in safety related circuits must not malfunction.
5) Identify interface and boundary requirements
    a) Electrical connections—Purchaser is to provide interface information so that the possible seismic effects of interfaces, such as incoming buses, cable, or conduits, can be evaluated. As an example, incoming power cables entering the equipment from above may add mass to the switchgear and change its seismic responses; or conduit connections may be too stiff to allow for relative motion between the switchgear and the conduit support.
    b) Physical clearances—Due to expected relative motion between the switchgear and walls, columns, and adjacent equipment, the clearances around the switchgear shall be specified.
    c) Mounting—The mounting methods or requirements shall be specified to the user by the manufacturer or qualifier based on the qualification test mounting configuration.
6) Any special requirements or interlocks to prevent the interchange of non-Class1E and Class 1E circuit breakers or other components shall be specified.

4. Performance Requirements

4.1 General

This section defines the criteria of adequacy that the switchgear must satisfy. Adequacy means the capability of each component to perform its function during and after the SSE postulated for the specific equipment location.

When the switchgear is seismically tested to qualify for application in a specified seismic environment, the possible failure modes may be structural or functional or both. Structural damage is a permanent alteration of a critical part of the switchgear structure or of accessory devices or components. Functional failure during or after a seismic event is any seismically induced momentary or sustained change of state of a multistate device, which causes the device to operate outside the limits of its specified operating characteristics. Such functional failures are usually caused by chatter or changes of state of contacts in control devices rather than by structural damage. Acceptance criteria for device operating characteristics must be specified.

4.2 Functional Performance Criteria

4.2.1 Circuit Breakers and Primary Switching Devices

Class 1E circuit breakers or primary switching devices shall change state only when called upon to do so.

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4.2.2 Accessories and Controls

Accessories and control components shall not malfunction in a manner that would jeopardize their Class 1E function or the Class 1E function of the switchgear.[1] Where the qualification method is by proof testing, the Class 1E functions must be specified by the user. For a generic seismic qualification program, the manufacturer may have to conduct this review based on his experience with specific Class 1E switchgear applications, such as incoming lines, motor protection, diesel generator protection, etc.

In addition, the following shall apply:

1) All the Class 1E control and instrument transformers shall continue to operate properly with no malfunctions, such as interruptions or short circuits.
2) All Class 1E control devices shall have a sustained change of state only when called upon to do so.
3) Components that are not Class 1E may malfunction but such malfunction shall not jeopardize the intended Class 1E functions of any other components.

4.3 Electrical Performance Criteria

4.3.1 Switching Capability

The seismic event shall not impair the switching capability of any Class 1E circuit breaker included in the assembly. (See 6.8.)

4.3.2 Current Carrying Capability

The seismic event shall not impair the continuous current or short-time current capability of the circuit breaker(s) disconnecting switch(es), bus(es), and other current carrying path(s) as demonstrated in 6.8.

4.3.3 Dielectric Strength

The seismic event shall not degrade the dielectric strength of the insulation systems so as to result in dielectric breakdown of the equipment. (See 6.8 for more information.)

4.4 Structural Performance Criteria

Structural damage, such as local yielding, is acceptable if it does not jeopardize the intended Class 1E function of the circuit breaker(s) and associated auxiliary systems. Also, that loss of structural integrity or failure of component mounting and becoming missiles are not acceptable.

4.5 Demonstration of Adequacy

The capability of the switchgear to meet its seismic requirements shall be demonstrated by test or combined test and analysis in accordance with Sections 6 and 7 of this guide.

[1]Prior to the final design of the associated electrical system, it may be difficult to determine which of the switchgear control and auxiliary functions will be used in Class 1E circuits. It is possible that indicating lights, indicating meters, and visual alarms may not be used for crtitical functions. Therefore, prior to any seismic qualification program, all Class 1E circuits, devices, and contacts and their function must be reviewed and identified.

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5. Qualification Methods

5.1 Analysis

Switchgear falls into the category of complex devices as described in ANSI/IEEE Std 344-1987 [10]. Seismic qualification is dependent on test data, and analysis alone cannot be justified.

However, analysis may be used in data reduction, reconciling response spectra, and evaluating changes.

5.2 Testing

The testing method for seismic qualification is described in Section 6 of this guide.

5.3 Combined Test and Analysis

Some Class 1E switchgear cannot be qualified by testing alone, because of the size of the equipment, or the large number of possible configurations. Therefore, another method of qualification, which is to calculate the expected seismic motions of the equipment based on analysis of the performance of typical units during a test, may be used. This method is described in Section 7.

5.4 Experience

There are many types of equipment that are similar in function and physical characteristics to equipment that has been previously qualified by testing, analysis, or a combination of testing and analysis. In addition, other equipment types are similar to equipment that has been in service for various periods of time and has been exposed to in-plant vibration and natural seismic disturbances.

Qualification of the aforementioned equipment types may be accomplished by justifying their similarity with the previously qualified equipment or with equipment that has been exposed to other more severe environments. Similarity of the equipment characteristics and of the excitation environment must be established by techniques that can be technically justified.

Due consideration to differences in design and manufacturing techniques must be considered as part of the technical justification supporting similarity.

When using performance experience of switchgear during past natural seismic disturbance, it is required to document that the switchgear equipment has been adequately cycled to end-of-design life conditions, then mechanically aged to the equivalent of five OBE events, and then performed its intended Class 1E function during and after the specified earthquake event.

6. Testing and Results

6.1 Introduction

The seismic testing of Class 1E switchgear should demonstrate its ability to perform its required functions during and after it is subjected to the forces resulting from one SSE. Prior to the SSE, the switchgear must withstand the effects of OBE testing. (See 6.5.)

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For the Class 1E function, the GRS or the RRS define the SSE level. Therefore, the objective of the seismic tests is to produce TRS's that envelop the SSE.

The seismic responses of the assembly at the device location become the seismic requirements for the various Class 1E devices located throughout the switchgear assembly. Devices, such as instruments, relays, switches, instrument transformers, panel meters, fuses, terminal blocks, and indicating lights, are qualified either during tests on the switchgear assembly or else separately and individually based upon comparison of the seismic capability of the device and the seismic response at the device location.

There are different ways in which this can be accomplished, such as:

1) Devices are in place on the switchgear and functionally operative when the assembly is being tested.
2) Devices mounted on other equipment and having undergone seismic tests can be qualified, if it can be shown by test data that the seismic environment at the device mounting locations on the tested specimen exceeds that on the switchgear under consideration.
   Devices must have been functionally operated during the SSE of the seismic test.
3) The seismic environments of the device mounting locations are recorded during the seismic test of the assembly to define the seismic environments for separate testing of the devices.
4) Other methods combining test and analysis. (See Section 7.)

6.2 Selection and Test Setup

The test assembly shall be representative of the switchgear to be qualified. Variations in size or component configuration from the tested sample of switchgear may be seismically qualified by justifiable interpretation and extrapolation of test results.

The switchgear to be tested shall be attached to the test table in a manner that simulates the intended service mounting specified by the manufacturer, or to that agreed to by the user and the manufacturer.

Interface and boundary requirements, such as incoming buses, cables, or conduits, shall be considered. Equipment shall be connected in a manner that simulates its expected installation when in actual use unless an analysis can be performed and justified to show that the equipment's performance would not be altered by the expected means of connection.

The switchgear shall be completely assembled and wired, with circuit breakers and/or switches connected to the bus and energized. Application of rated voltage and current on the primary circuits is not required during the seismic test. The control circuits for the primary switching device and all control, protective, and auxiliary devices being qualified shall be energized at rated voltage.

6.3 Resonance Search Procedure

A resonance search may be performed to aid in the analysis of seismic performance of the switchgear. A low-level sine sweep of approximately 0.2 g may be performed in the front-to-back plus vertical and side-to-side plus vertical orientations. The frequency of the sine sweep should cover the range between 1 Hz and 50 Hz at a sweep rate of not more than 1 octave/min.

6.4 Seismic Test Input

The seismic test input requirements are described in ANSI/IEEE Std 344-1987 [10]. The narrow band characteristic of the GRS may make it beneficial to utilize the "random motion with sine beats" motion suggested in ANSI/IEEE Std 344-1987 [10] as a method of enveloping a narrow peak and keeping the ZPA at a reasonable level. The motion may be either biaxial or triaxial with the method of achieving an acceptable test shown later on in this section. The

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horizontal and vertical shake table input components for the test shall be designed such that the horizontal and vertical TRS's envelop the applicable GRS as specified in 6.3.1.5 of ANSI/IEEE Std 323-1983 [9]. The horizontal and vertical shake table input components do not have to be equal.

For tests using the user's specified RRS, the TRS must envelop the applicable RRS within the guidelines of ANSI/IEEE Std 344-1987 [10]. The margins specified in ANSI/IEEE Std 323-1983 [9] and ANSI/IEEE Std 344-1987 [10] apply.

6.4.1 Multiaxis Testing

1) For phase-independent biaxial inputs, the switchgear shall be tested in two orientations: front-to-back plus vertical and side-to-side plus vertical.
2) For biaxial inputs that are not phase independent, the switchgear shall be tested in four orientations:
   a) With horizontal and vertical inputs in phase (front-to-back and up-to-down)
   b) With the horizontal inputs 180° out of phase with the vertical inputs (back-to-front and up-to-down)
   c) With switchgear orientation rotated 90° about the vertical axis and the horizontal inputs 180° in phase with the vertical inputs (left-to-right and up-to-down)
   d) With the switchgear orientation rotated 90° about the vertical axis and the horizontal inputs 180° out of phase with the vertical inputs (right-to-left and up-to-down)

   When a single inclined input force is used, the 180°, out-of-phase input may be achieved by rotating the switchgear 180° about the vertical axis for above orientations (b) and (d).
3) For triaxial tests, only one orientation is required for phase independent input motions.

6.5 Number and Duration of Tests

The duration of each test designed to reproduce the OBE and SSE shall be at least equal to the original time history used to obtain the RRS, with a minimum of 15 seconds. The 15 second minimum duration requirement also applies when using a GRS for the RRS if the time history data is not known. The number of OBE tests shall be justified for each site or shall produce the equivalent effect of five OBE's. OBE level tests shall precede the SSE test in each pair of equipment axes (front-to-back plus vertical and side-to-side plus vertical). (See 6.1.4 in ANSI/IEEE Std 344-1987 [10].)

6.6 Tests and Measurements Before Seismic Tests

Prior to making the seismic tests, the switchgear shall be subjected to the standard production tests specified in ANSI/IEEE C37.09-1979 [1], ANSI/IEEE C37.14-1979 [3], ANSI/IEEE C37.20.1-1987 [4], ANSI/IEEE C37.20.2-1987 [5], ANSI/IEEE C37.20.3-1987 [6], and ANSI/IEEE C37.13-1981 [2] as applicable to the equipment being tested. These tests are made for the purposes of establishing benchmarks and criteria for use as reference values.

6.7 Tests and Measurements During Seismic Tests

Various measurements, recordings, and operational tests are made during the seismic tests as shown below:

6.7.1 Accelerometers

Accelerometers shall be used to monitor the horizontal and vertical table motion. The TRS for one OBE and one SSE test in each orientation shall be documented. If an adjustment in the OBE level is made to optimize the input curve shape, the test at the lowest level OBE can be documented in lieu of documenting all tests. The preferred value of damping for the generation of the TRS's is 5%, which corresponds to the value of damping used for the input GRS.

Consideration should be given to the placement of additional accelerometers on fixed panels, hinged panels, and other areas where critical components, devices, and accessories can be located.

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After testing has been completed, data from these accelerometers can be useful to allow requalification, in the event that changes are made to parts of the equipment which would make requalification of those areas necessary, possibly without the need for retesting.

6.7.2 Electrical Measurements

Electrical monitoring circuits shall be used to record simulated Class 1E functions during the SSE tests.

The monitoring shall cover at least the following:

1) The change of state of the power circuit breaker or other primary switching device. Remotely operate the primary switching device during the test and monitor for proper operation. At least one opening and one closing operation shall be made.
2) Continuity of voltage and current transformer windings
3) Continuity of primary and secondary disconnect contacts
4) Performance of auxiliary devices, in order to determine if a malfunction has occurred in the behavior of relay, auxiliary switch, or control switch contacts

For proof testing, the preferred method is to simulate the Class 1E function and evaluate functional performance directly before, during, and after the seismic test of the switchgear assembly by having all control circuits, devices, relays (set at user's expected most sensitive setting), and instruments energized and fully operative. The pass/fail criterion in this case is that all control devices must maintain their position, or state, to operate as required by the Class 1E function. In the case where a contact provides a signal to a control device located elsewhere, functional performance may be evaluated directly by having the downstream device in operation. If the downstream device is not available, use the second method listed below. For generic testing, the following methods can be applied:

1) Class 1E function is established based on the review as described above, and testing to evaluate functional performance directly as for proof testing; or,
2) Monitor the contacts for a maximum of two milliseconds change of state for electromechanical device malfunction as described in ANSI/IEEE C37.98-1987 [7]. Either an electronic chatter detector, which is described in 5.2.4.1 of ANSI/IEEE C37.98-1987 [7], or a recording device may be used.

6.7.3 Other Information Obtained During Tests

Information shall be obtained to measure the displacement at the locations where the switchgear may interface with other equipment or structures.

6.8 Tests and Measurements After Seismic Tests

Tests and measurements after the seismic test program shall be the same as those performed prior to the seismic test (see 6.6) except the dielectric tests shall be at the standard field test levels. The purpose of these tests is to verify that the equipment can still perform in an acceptable manner.

The switchgear shall be inspected visually to determine which parts, if any, may have sustained damage. Any findings shall be suitably documented. For high-voltage circuit breakers, the operation of the circuit breaker is verified by repeating the mechanical operation and timing test portions of the production tests. For ac low-voltage circuit breakers, operation is verified by repeating the no-load operation test portion of the production tests. Any damage, or significant changes in operating times or speeds over the preseismic test values, shall be justified by the manufacturer.

All current carrying components shall be inspected visually to determine where damage, if any, has occurred. Any findings shall be suitably documented. For ac high-voltage circuit breakers, the capability to carry continuous and short-time currents is verified by repeating the electrical resistance of current path test portion of the production tests.

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The dc resistance shall not exceed the predetermined limits set by the manufacturer. Any damage, or significant changes in resistance over the preseismic values, shall be justified by the manufacturer.

All insulation systems shall be inspected visually to identify any parts which may have sustained damage. Any findings shall be suitably documented. The integrity of the insulation systems is verified by repeating the dielectric test portions of the production tests. However, the dielectric tests shall be made at the field dielectric test level, which is 0.75 times the production test level.

6.9 Refurbishment Maintenance and Repairs During Testing

6.9.1 Refurbishment

Any refurbishment performed on equipment during a test program may be classified as maintenance or repair according to its degree. Examples of maintenance activities include calibration of relays and retorquing of hardware. Examples of repairs include welding or rewelding of portions of equipment; replacing damaged components, such as sheared bolts; and retightening loose electrical terminals.

6.9.2 Maintenance

When maintenance is required, the severity of the problem shall be determined and documented in detail in the test report. Maintenance may be performed, and testing continued. When maintenance is performed during OBE testing, it becomes part of the post-earthquake field maintenance checks and procedures for the equipment.

6.9.3 Repairs

When repairs are necessary during the OBE test, retest is required unless justified otherwise. When repairs are necessary during or after the SSE test, the general requirement is to retest unless justified otherwise. When the condition requiring repair during the SSE tests does not interfere with the performance of the safety function, during or after the test, then the SSE can be shown to be not cumulative due to testing in other axes, and does not unacceptably affect equipment performance in subsequent qualification tests, such as LOCA, then continuation without retest may be justifiable. When repairs constitute a design change, the equipment must be retested, unless justified otherwise. When repairs are made, the details shall be included in the test report.

7. Combined Analysis and Testing

7.1 Introduction

As discussed in Section 5. of ANSI/IEEE Std 344-1987 [10], the qualification of complex equipment by analysis alone is not recommended because of the difficulty in developing an accurate model of the equipment and in obtaining data numbers describing the physical parameters of the model. However, an accurate mathematical model can be constructed and validated by using data acquired from a seismic test performed on a representative switchgear assembly.

Because a switchgear is complex equipment, it is necessary to have detailed information about the switchgear structure in order to identify significant mass points and structural elements, and in order to provide adequate descriptions of these items so that the responses at all points of interest can be calculated.

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7.2 Analysis

7.2.1 Developing the Model

Switchgear assemblies are comprised of various basic structural modules arranged together in a cooperative manner to form a vertical section. A complete assembly may consist of a single self-standing vertical section or of two or more vertical sections located side by side on a common floor or base structure and having adjacent sections joined and bussed together.

Basic structural modules typically include power circuit breakers, circuit breaker compartments, main bus compartments, line compartments, front and rear housing extensions, superstructures mounted atop other compartments, and similar items. Circuit breakers, bus assemblies, voltage transformers, current transformers, and similar items having different ratings may vary in size and weight, thus generating groups of similar but slightly different modules, each of which has its own unique response characteristics.

The objective of modeling is to provide mathematical descriptions for each module, which will define the response of the module for seismic input conditions. The inputs are derived from the specified response spectra. The results of the analysis include parameters such as basic structural natural frequencies, mode shapes, and maximum equipment responses (in terms of peak accelerations, peak-to-peak displacements, and “in-structure” response spectra).

7.2.2 Validating the Model

After a modeling technique has been developed, then a specific combination of basic modules is selected for validation. The same combination of modules is physically assembled and subjected to seismic testing.

Comparisons are made between the responses of the mathematical model and those obtained from the test, given the same input conditions. Modifications of the modeling technique may be required in order to obtain the same responses as those observed in the test. When the condition is reached where model responses and test responses coincide within the envelope, then the model technique is considered to have been validated.

In the validation testing procedure, it is important to include as many different basic modules as practical in order to validate a broad cross section of the types of modules that may be expected to be utilized. When the condition is reached in which model responses and test responses are in agreement, then the modeling technique is considered to have been validated. Documentation of validation is required. (See 9.3.)

7.3 Test Procedure

1) A static test may be performed to determine the structural stiffness of equipment and its mounting.
   a) In situ low-level dynamic testing may be used to determine the dynamic properties of switchgear equipment.
2) Dynamic tests shall be made as follows:
   a) To establish seismic qualification of a circuit breaker and other related devices that can change state, a multifrequency seismic test program, as described in Section 6., shall be conducted on a representative assembly. See 6.7 for qualifition data to be taken during the test.
   b) In addition to the qualification data above, additional data shall be taken and recorded to determine natural frequencies, damping factors, and structural responses at selected points in the assembly. A multi-frequency test alone is not adequate for this purpose, since it does not provide the parameters required for the mathematical model. Single-frequency tests shall be used to provide this information in addition to any multifrequency tests. The following parameters are necessary to validate the computer model:
      i) Equipment resonances in terms of natural frequency, damping factor, and modal shape. Only base-excitable modes due to input frequencies in the 1 Hz to 33 Hz range need be considered.

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ii) Measurements of the important nonlinear effects, such as softening or hardening systems, or increasing damping with increasing seismic input levels.
iii) Characteristic modal participation parameters that relate response motions at the points of interest in the assembly to the multifrequency biaxial or triaxial test input motions.

7.4 Qualifying the Complete Assembly

A mathematical model of the complete assembly can be synthesized by combining the models for its basic modules that have been generated using the validated modeling techniques. This model is then mathematically subjected to the seismic input derived from the applicable response spectra.

The seismic responses computed at each device in the assembly define the seismic requirement for those devices.

Qualification shall consist of demonstrating that:

1) The structural and functional capability of each device is not less than the required displacement at the location of the device in the equipment in terms of the following criteria:
   a) FRS, GRS, or other TRS's shall be used for active Class 1E devices (those which are subject to malfunction, such as relays).
   b) The ZPA level shall be used for rigid passive Class 1E devices (those which are not subject to malfunction, such as terminal blocks).
   c) The ZPA level shall be used for non-Class 1E devices.
2) The seismic responses of the switchgear assembly, as determined by the analysis, are no greater than responses observed during validation testing in terms of both maximum displacements and of mounting reaction forces. When larger responses are determined, they shall be justified.

8. Extrapolation for Similar Equipment

It has been noted in 7.2 that switchgear assemblies may consist of one or more vertical sections arranged in a single assembly. While all vertical sections produced by the same manufacturer are usually similar in construction, each may contain a different complement of devices. Additionally, since adjacent vertical sections are joined and bussed together, the responses to a given input response spectra may vary from one assembly to another depending upon the number of vertical sections in the assembly. It is necessary to consider the possible effects of all differences when comparing the responses of similarly modeled assemblies.

As an example, one characteristic of large multisectional assemblies may involve the appearance of low-frequency torsional modes that are somewhat different from the characteristics of single vertical sections or small multisectional assemblies. The degree of importance of these torsional modes may depend upon factors such as length-to-depth ratio of the assembly, characteristics of the required response spectra, modal participation factors, and damping factors as they combine to affect the assembly response. This assembly response shall be considered when qualifying devices mounted on the switchgear assembly, when qualifying attachments and connections to the assembly, and when qualifying clearances to objects adjacent to the assembly.

Extrapolations from one switchgear assembly to another shall be justified.

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9. Documentation

9.1 General

The documentation shall verify that the switchgear meets its performance requirements when subjected to specific seismic accelerations. The information to be furnished for the various qualification methods is shown below:

9.2 Test Qualification Report

1) Dates of testing
2) Test specimen description and identification, including the bill of materials and a list of all auxiliary devices and their locations in the switchgear assembly
3) User seismic specification reference
4) Test facility name and location
5) Test facility report reference
6) The general test description, including photographs, response spectra, assembly anchoring details, interfaces with outside systems, instrumentation lists, and drawings shall be provided that demonstrate that the requirements of Section 6 have been met. If the test data is not supplied, references to the identification and location of the complete test data shall be provided.
7) Test data in the form of TRS. Show enveloping of RRS or justify any points not enveloping
8) Records of any malfunctions, failures, repairs, and maintenance that occurred or was required during the test, including justification and retesting performed
9) Results, conclusions, and qualification statement
10) Signatures (as required) and date

9.3 Combined Analysis and Test Qualification Report

1) Identification and description of equipment qualified
2) Summary of user requirements
3) Switchgear seismic test references and documentation (See 9.2.)
4) Seismic analysis documentation
    a) Computer program used and validation references
    b) Comparison of the computed description with actual weight, dimensions, arrangements, and other physical characteristics of the equipment being qualified
    c) List of critical frequency modes in the 1 Hz to 33 Hz range
    d) Model validity and justification statement
    e) Equipment response for RRS specified
        i) Mounting-Reaction forces
        ii) Connections, attachments, and clearances-Deflections
        iii) RRS generated for active Class 1E devices
        iv) ZPA levels generated for passive Class 1E devices and non-Class 1E devices
    f) Seismic capability for each device, component, and accessory in terms of:
        i) FRS, GRS, or other TRS for the active Class 1E devices
        ii) ZPA levels for the passive Class 1E devices and for all the non-Class 1E devices
5) Results, conclusions, and qualification statement
6) Signatures (as required) and date

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9.4 Documentation for Qualification by Extrapolation

If qualification is established by extrapolation from similar tested equipment, the documentation shall contain as a minimum:

1) Description of both equipments
2) Qualification of original equipment as applicable (See 9.2 and 9.3.)
3) A detailed description of the differences between the two equipments
4) Justification that the differences do not degrade the seismic performance below the acceptable limits (may require additional analysis or testing) including any supporting data
5) Signatures (as required) and date

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