EBU SI-S02 Wind, Ice, and Seismic Withstand

1. Scope

This material specification states the requirements for the wind, ice, and seismic withstand capability of substation equipment to be purchased by the company.

2. Applicable Documents

The following publications shall be used in conjunction with this material specification, and form a part of this material specification to the extent specified herein. When a referenced publication is superseded by an approved revision, the revision shall apply.

2.1. Industry Publications

Referenced industry publications are:

IEEE Std 693-2005, *Recommended Practice for Seismic Design of Substations*

ASCE 7-10, *Minimum Design Loads for Buildings and Other Structures*

ASCE Manual of Practice 113, *Substation Structure Design Guide*

ANSI/AISC 360, *Steel Construction Manual*

AISI S100, *American Iron and Steel Institute*

ACI 318-2011, *Building Code Requirements for Structural Concrete*

AWS D1.1, *Structual Welding Code – Steel*

IBC-2012, *International Building Code*

ICC-ES, *International Code Council Evaluation Services, Inc.*

OSHA, Occupational Safety and Health Administration

3. General

3.1. Application Information

This material specification states the general requirements for the wind, ice, and seismic withstand capability of substation equipment. The equipment-specific requirements that vary depending on the particular equipment and application shall be stated in the purchase order. This material specification is a supplement to the company material specification for specific substation equipment identified in the purchase order.

4. General Wind, Ice, and Seismic Withstand Requirements

4.1. Codes and Standards

Except as required otherwise by this material specification, the general wind, ice, and seismic withstand requirements shall be in accordance with the latest applicable industry codes/standards, ANSI, AWS, IBC, ASTM, IEEE, ASCE, AISC, AISI, ACI, NEMA, OSHA, and company construction standards and material specifications in effect on the date of invitation to bid.

4.2. Wind and Ice Performance Criteria

Substation power equipment and manufacturer-provided supporting structures shall be designed to the applicable provisions for wind and ice loadings and corresponding load combinations in ASCE 7.

4.2.1. Wind

The following parameters based on ASCE 7-10, Chapter 26 and 29 shall be assumed for the design:

Basic wind speed	=	120 mph (3 second gust speed at 33 feet above the ground in Exposure category C)
Exposure category	=	C
Wind directionality factor K_d	=	0.95
Topographic factor K_{zt}	=	1.0
Gust effect factor G	=	0.85

4.2.2. Ice Concurrent with Wind

The following parameters based on ASCE 7-10, Chapter 10 shall be assumed for the design:

Radial ice thickness	=	one (1) inch
Concurrent wind speed	=	40 mph

4.3. Seismic Performance Criteria

Substation power equipment and manufacturer-provided supporting structures shall meet the requirements of IEEE Std 693 seismic qualification level as checked (✔) below:

Low seismic qualification level

Moderate seismic qualification level —

High seismic qualification level

The seismic qualification and design of the equipment, with the exception of standby generators, shall be in accordance with the applicable provisions in IEEE Std 693 and the supplementary requirements per Section 4.3.1. Seismic loads computed per IEEE 693 shall be combined with other loads in accordance with IEEE 693 A.2.1. For equipment meeting the moderate or high seismic qualification, the nameplate shall indicate the seismic qualification level to which the equipment was designed and built. Standby generators identified to be qualified to the moderate or high seismic qualification level shall be qualified in accordance with the IBC, ASCE 7, and ICC-ES AC 156 as outlined in Appendix D.

Equipment Specifier Note: When selecting the seismic performance criteria for spare equipment, the following items shall be considered:

- The peak ground acceleration at potential locations of equipment installation
- The current stock of spare equipment and corresponding seismic qualification levels
- Justification for selecting a higher seismic qualification level equipment based on the cost difference of equipment qualified to different seismic qualification levels (equipment qualified to the high or moderate seismic qualification levels from some manufacturers may cost the same)
- The need for robust performance of mobile units may justify a higher seismic qualification level

4.3.1. Supplementary Seismic Qualification and Design Requirements

Supplementary seismic qualification and design requirements applicable to certain equipment identified to be qualified to the high or moderate qualification level are included in appendices as listed below:

- Appendix A – Special Anchorage Requirements
- Appendix B – Control House Equipment Panels and Racks
- Appendix C – Series Capacitor Bank Support Structures
- Appendix D – Standby Generators

4.4. Foundation Design

The equipment foundation will be designed by the company. However, the equipment manufacturer will be responsible for providing the equipment foundation design forces and anchor forces for all load cases (dead, wind, seismic, etc.) and load combinations required to design the foundations. The equipment manufacturer shall also be responsible for designing the equipment anchor (anchor rod size and material grade, fillet weld size, length, spacing and electrode type). Unless noted otherwise, the company will provide the anchor materials.

4.5. Required Documentation

- Documentation for seismic qualification shall be prepared per IEEE Std 693 Annex S and Annex T for analysis and test reports

- Documentation shall also include seismic qualifications for bushings, arresters and other appurtenances supported by the equipment. Surge arresters supported by transformers shall comply with IEEE Std 693, D.4.6.
- If the qualification is by analysis, the report shall be submitted on a mutually-agreed-upon date after the award of contract
- If the qualification is by testing, the test plan and test report shall be submitted on a mutually-agreed-upon date
- Documentation for the wind and ice calculations shall be submitted on the same date as the final seismic report
- Calculations for anchor design shall be included
- Drawings shall indicate the maximum forces at each anchor location (tension, shear, compression)
- Drawings shall indicate forces to be used for designing foundations (shear, overturning moments, axial forces)
- It shall be the responsibility of the equipment manufacturer to ensure that the calculations and other documents required to qualify equipment to EBU SI-S02, *Wind, Ice, and Seismic Withstand* are prepared in strict accordance with the applicable standards, are complete, accurate, checked, stamped, and signed before submitting to the company for review
- For moderate and high seismic level qualifications, required per Section 4.3, all calculations, test results, and drawings shall be checked, stamped, and signed by a professional engineer licensed in the United States. Test reports for qualifications by the static pull test per IEEE Std 693 A.1.2.4 are exempted from this requirement.
- Allow a minimum of four (4) weeks in the schedule for company review of the calculations and other documents submitted. The manufacturer shall assume all responsibility for any additional calculation and document review time that may result from errors and omissions in the submittals
- The company has in the past accepted equipment qualification calculations and other documents prepared by several consultants. The familiarity of these consultants with the company requirements for qualifying substation equipment could potentially result in shorter document preparation time for manufacturers and review times for the company. The company can provide this list of consultants to manufacturers who request this information. There is no requirement that a manufacturer use one of these consultants

4.6. Copies of Wind, Ice, and Seismic Analyses

The manufacturer shall furnish one set of electronic copies (in PDF format) of the analyses for wind and ice loading, and seismic effects, including all calculations, drawings and reports duly certified as required. Another set of electronic copies shall be provided as an electric copy. Copies shall be sent with equipment approval drawings. Email and postal mail shall be sent to the addresses provided in the corresponding equipment specification.

4.7. New Equipment Qualifying Requirements

IEEE Std 693 requires some equipment to be seismically-qualified by time history shake-table testing. If equipment tested accordingly is currently not available, the company will not require the manufacturer to conduct shake-table testing. In such cases the equipment to be installed at the substation will be determined by the company project team. This determination will be based on available equipment options, the site specific ground accelerations, criticality of this substation, system redundancy, availability of spares, replacement/repair durations, and associated risks.

5. Issuing Department

The engineering publications department of PacifiCorp published this material specification. Questions regarding editing, revision history and document output may be directed to the lead editor at eampub@pacificorp.com. Technical questions and comments may be submitted by email to: TDManufacturerSubmittal@pacificorp.com.

This material specification shall be used and duplicated only in support of company projects.

Appendix A—Special Anchorage Requirements

A.1. General

These provisions are applicable only to the following equipment identified as being qualified to the high or moderate seismic qualification level per Section 4.3:

- Transformers
- Oil-filled reactors
- Three-phase voltage regulators
- Phase shifters
- Power circuit breakers
- Shunt capacitor banks

The type of anchorage on company-supplied flat concrete slabs shall be in accordance with the voltage classifications in the sections below.

A.1.1. Transformers / Reactors / Voltage Regulators / Phase Shifters Larger Than 138 kV (Nominal High-Side Voltage)

Equipment bases shall be designed to be anchored by welding to steel embedments in the concrete foundation, unless indicated otherwise by the anchorage box checked below:

In lieu of welded anchorage use cast-in-place bolted anchorage

In lieu of welded anchorage use post-installed bolted anchorage

In addition to welded anchorage provide option for alternate installation of post-installed bolted anchorage

Requirements for welded, cast-in-place bolted, and post-installed bolted anchorages are provided in Sections A2.1, A2.2, and A2.3 respectively.

A.1.2. Transformers / Reactors / Voltage Regulators / Phase Shifters 138 kV (Nominal High-Side Voltage) or Smaller

Equipment bases shall include tabs with holes ("anchor tabs") for anchoring the equipment to a concrete foundation using post-installed steel rods, bolts, special anchors, or welds.

Anchor tabs shall be designed such that they can be either bolted or welded to a foundation, depending on the particulars of an installation. If bolting anchorage is most suitable, the company will drill the foundation and install anchors through the holes provided in the equipment base. If welding is most suitable, the company will weld the anchor tabs directly to the steel embedments in the foundation. Locations of anchor tabs shall be coordinated with the embedded steel locations indicated in Figure A1. The company will choose the method of attachment after the transformer is delivered to the site.

Requirements for welded and post-installed bolted anchorages are provided in Sections A2.1 and A2.3 respectively.

A.1.3. Power Circuit Breakers of All Voltage Classes

Manufactured equipment bases for power circuit breakers of all voltage classes shall include holes for anchoring the equipment to a concrete foundation using steel rods, bolts, or special anchors. Unless indicated otherwise by the anchorage box checked below, post-installed anchors per A2.3 shall be assumed for circuit breakers in voltage classes 345 kV and below, and cast-in-place anchors per A2.2 for circuit breaker voltages greater than 345 kV.

In lieu of the above requirement design anchorage per A2.2 for cast-in-place anchors

In lieu of the above requirement design anchorage per A2.3 for post-installed anchors

A.1.4. Shunt Capacitor Banks of All Voltage Classes

Equipment bases for shunt capacitors of all voltage classes shall include holes for anchoring the equipment to a concrete foundation using post-installed steel rods, bolts, or special anchors per Section A2.3, unless indicated below.

In lieu of the above requirement design anchorage per A2.2 for cast-in-place anchors

A.2. Anchorages

Equipment anchorage design forces shall be determined using the LRFD load combinations specified in IEEE Std 693 for seismic loading, and ASCE 7 for all other applicable load combinations. Anchors resisting seismic forces may be considered to be ductile if they meet the provisions in ACI 318 D.3.3.4.3(a) and D.1 for ductile steel elements. Non-ductile anchors resisting seismic forces shall be designed for IEEE Std 693 LRFD seismic loads ($1.4E_{RSS}$) multiplied by an overstrength factor, $\Omega_0 = 1.5$.

Anchors resisting seismic forces shall be assumed to be ductile

Anchors resisting seismic forces shall be assumed to be non-ductile

A.2.1. Welded Anchorage

All welding shall be performed according to AWS D1.1 by a certified welder and inspected by a certified welding inspector (CWI).

Selection of the size and length of prequalified field welds shall be included in the engineering analysis and calculations for qualification of the equipment. Where feasible field welds shall be designed as 5/16″ single-pass fillet welds. The welds shall be made at locations that are selected and designed to transfer forces. The heat caused by welding shall be considered. Welding to an embedment shall be completed in a manner not to produce sufficient heat to compromise the concrete substrate. When required, extended base plate tabs (may be the same plate as for the bolted options) shall be provided.

An example of steel embedments in the concrete foundation is described below and indicated in Figure A1. The steel embedments are a minimum of ½″ thick X 8″ wide (plates with welded studs or wide flanges) with the top of steel flush with the top of concrete slab. For this example the length of the embedments match the width of the foundation and are spaced 2′-6″ on center along the length of the foundation. Field welds are to be provided where the equipment base crosses the embedments. It should be noted that the embedments provided (or available on existing foundations) for a specific project may be similar to the above or be variations thereof. <u>Therefore, it is important for the manufacturer to coordinate the project-specific embedment configuration with the company during the design phase and design the equipment anchorages accordingly.</u>

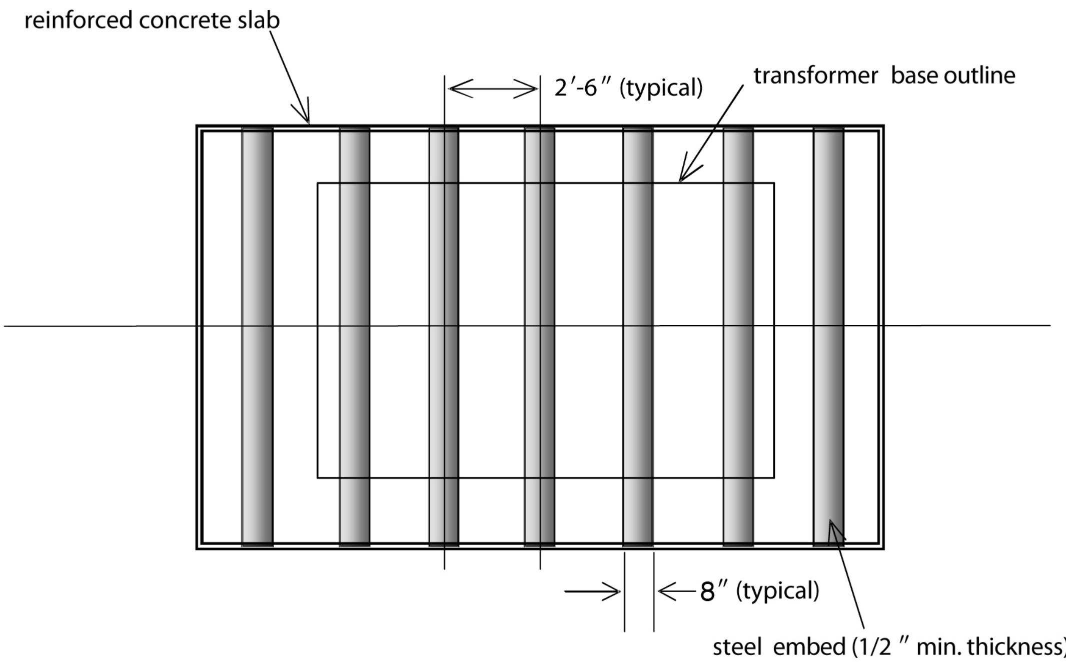

Figure A1—Example of Foundation Plan with Embedded Steel

A.2.2. Cast-in-Place Bolted Anchorages

The selection of the number, positions, and diameters of cast-in-place anchors shall be included in the engineering analysis and calculations for qualification of the equipment. Anchor rod material shall be assumed to be ASTM F1554 Grade 36 with a diameter not less than ¾ inch nor greater than 1 ½″. Anchor rods shall be sized using the LRFD design provisions for tension, shear and interaction of tension-shear capacities in AISC, with the exception that the interaction ratio of 1.3 (AISC equation J3-3a) shall be limited to 1.1. Connection stiffness and its effect on the increase in anchor rod tension due to prying action shall be considered. Stand-off anchors supporting equipment on levelling nuts shall be designed to the provisions in ASCE 113 except that the effects of anchor rod bending due to shear shall be considered for all base plate bottom to top of concrete distances.

The minimum center-to-center spacing shall be 6D for anchors cast in concrete, where D is the nominal diameter of the anchor rod.

For all cast-in-place bolted anchorages, a physical template of the anchor rod placement plan shall be provided. This template shall be fabricated from a material not sensitive to dimensional variations due to moisture content changes. Proposed template materials and required delivery time shall be coordinated with the company.

Anchor rod/bolt hole size in the equipment base shall be at least 3/8″ in diameter larger than the diameter of the rod/bolt to facilitate installation.

Plate washers appropriately sized (but not less than 1/2″ thick) with holes no more than 1/16″ greater than the bolt diameter shall be provided with each bolt. These plate washers will be field-welded to the equipment base. Calculations and drawings shall indicate the washer and field weld details.

Any deviations from the above requirements shall be approved by the company during the design phase.

A.2.3. Post-Installed Bolted Anchorage

The selection of the number, positions, and diameters of post-installed anchors shall be included in the engineering analysis and calculations for the qualification of equipment. The design shall facilitate the installation of post-installed anchors, i.e. adhesive, expansion, or undercut anchors installed after placing equipment on the foundation. The minimum clearance space required to install this type of anchor in concrete is 9″ between the equipment face and the anchor, 15″ to either side of the anchor, and 84″ above the anchor (see Figure A2 below). Anchor rod material shall be assumed to be ASTM F1554 Grade 36 with a diameter not less than 3/4″ nor greater than 1 1/4″. Anchor rods shall be sized using the LRFD design provisions for tension, shear, and interaction of tension-shear capacities in AISC, with the exception that the interaction ratio of 1.3 (AISC equation J3-3a) shall be limited to 1.1. Connection stiffness and its effect on the increase in anchor rod tension due to prying action shall be considered. Ensure that the selected post-installed anchor has been qualified in accordance with the requirements of the International Code Council with a valid ICC-ES ESR report.

The minimum center-to-center spacing of post-installed anchors shall be 6D, where D is the nominal diameter of the anchor rod.

Holes larger in diameter than the proposed anchors (by 1/4″ or more) are considered oversized. Oversized holes may result in shear forces distributed unevenly amongst the anchors. Oversized holes are permitted if plate washers are used, with holes no more than 1/16″ greater than the bolt diameter, field-welded to the equipment base.

Any deviations from the above requirements shall be approved by the company during the design phase.

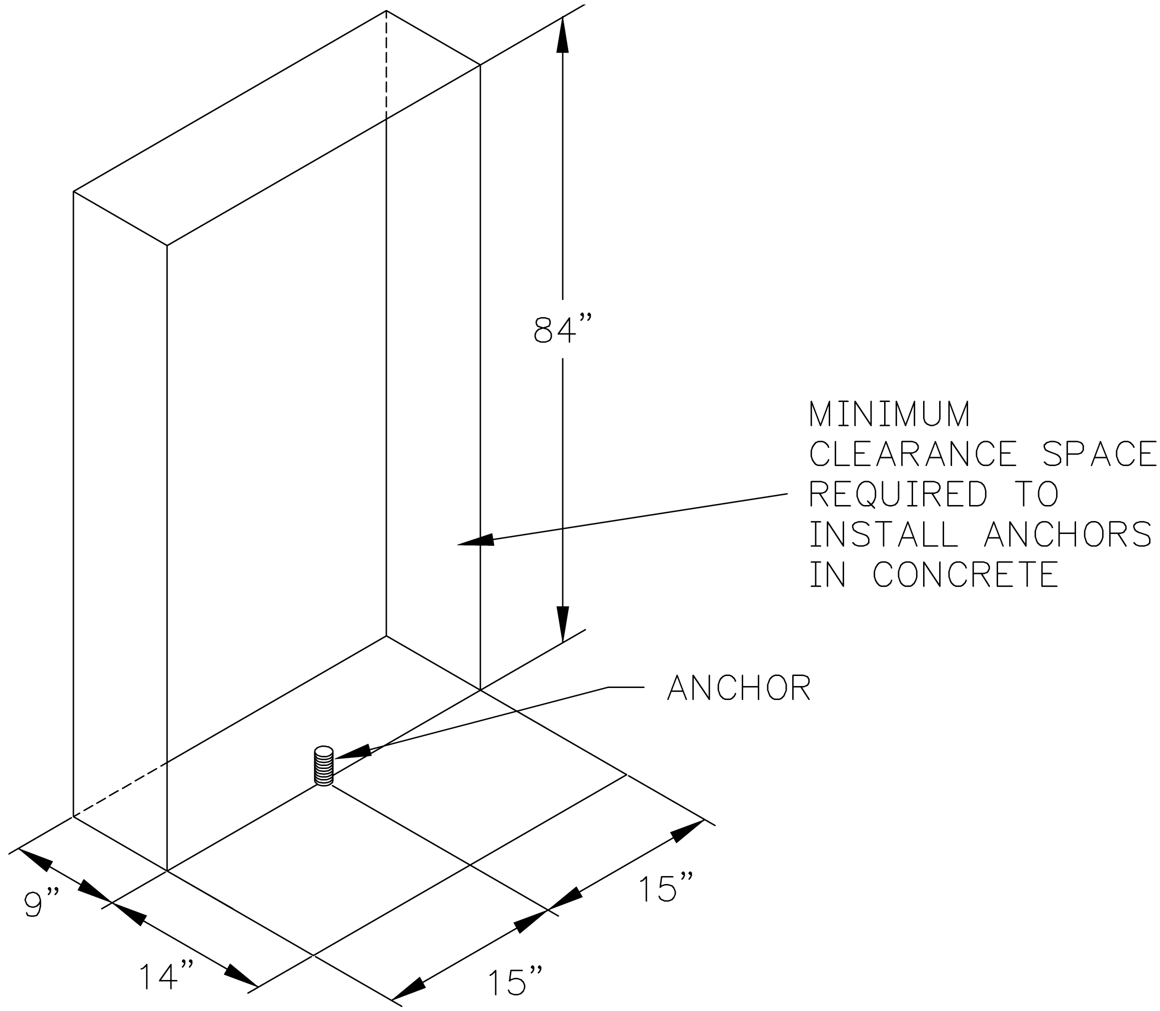

Figure A2—Anchor Clearance Zone for Post-Installed Anchors

Appendix B—Control House Equipment Panels and Racks

B.1. General

These provisions are applicable only to the seismic evaluation of control house equipment panels and racks identified as qualified to the high or moderate seismic qualification level per Section 4.3.

B.2. Seismic Qualification and Design

IEEE Std 693 requires certain panels and racks to be seismically qualified by shake-table testing. As an alternate to this testing requirement, the company will accept seismic qualification calculations and design performed to the high seismic qualification level loading per IEEE Std 693, Annex L.4.2 (Static analysis per A.1.3.1 at 1.5g in each horizontal direction and 1.2g in the vertical direction). Forces shall be combined by the SRSS method or 100/40/40 combination. Finite element models (FEMs) of the panels and racks should be utilized for the analysis and design. The software for this FEM shall be commercially available software commonly used by structural engineers. Electronic files of the FEMs that include information of model geometry, loading, etc., that can be imported into other commonly used software shall be provided (ex. CIS/2 format). This requirement shall be coordinated with the company prior to commencing any structural modeling of the panels and racks.

Allowable stresses, which account for local buckling effects of the sheet metal panels, racks and components, shall be evaluated per AISI S100. Typically, panels and racks are fabricated with ASTM A1011 Grade SS (structural steel grade). However, ASTM A1011 Grade CS (commercial grade) steel will be acceptable provided coupon tests are performed to prove that the minimum yield strength is 30 ksi (kips per square inch). A plate bending radius of 1xt (thickness) may be assumed for 90 degree bends for shapes. Design shall include reinforcements required at panel cutouts for instruments, and anchorage of the panels.

Appendix C—Series Capacitor Bank Support Structures

C.1. General

These provisions are applicable only to the seismic evaluation of series capacitor bank support structures identified as qualified to the high or moderate seismic qualification level per Section 4.3.

C.2. Seismic Qualification and Design

The fixed series capacitor bank platform and support structure shall be qualified in accordance with IEEE Std 693, Annex O, and the provisions contained herein. All capacitor bank platform structures shall utilize columns and diagonal bracing systems built with insulators between the platform and foundation for lateral force resistance. Bracing systems can utilize either tension-only or tension-compression members. The tops and bottoms of porcelain insulator columns shall be designed and detailed to inhibit any moment transfer when lateral braces and columns are designed to resist all the lateral loads as axial forces.

For structures with tension-only diagonal bracing systems, structural analysis shall be performed utilizing either site-specific developed time response histories, or IEEE Std 693 developed time response history record. The seismic response history procedures in the latest version of ASCE 7 shall be used. Time histories shall be scaled to envelope the IEEE Std 693 performance level response spectrum for 2% damping. For tension-only bracing systems, the loss of pre-tensioning during response history analysis shall be explicitly modeled. All connections and components of the bracing system shall be modeled. The software used for the analysis and design shall be commercially available software that is commonly used by structural engineers. This requirement shall be coordinated with the Company prior to commencing any structural modeling of the capacitor bank support structure.

For diagonal bracing elements consisting of materials other than structural steel, structural capacity shall be established by means of testing and shall include all connection components that comprise the bracing assembly (i.e. shackles, pins, clevises, etc.). Testing shall include the development of load-deflection curves (loading and unloading) required for the structural analysis model. Results of test data shall be included in the final seismic qualification report. All bracing member capacities shall have a tested minimum factor of safety of 1.2 at the IEEE Std 693 performance level demands. Further, for tension-only bracing, the minimum factor of safety shall be 1.5. Shackles, pins, clevises and other hardware shall be provided with a minimum 2.0 factor of safety at the IEEE Std 693 performance level demands.

The use of supplemental damping or response modification devices shall be acceptable provided the demonstrated system response meets the IEEE Std 693 performance level requirements. All nonlinear components of the lateral force resisting system shall be explicitly modeled to capture behavior and effect on the support structure system. The performance characteristics of all supplemental damping or response modification devices, both linear and nonlinear, shall be established by component testing and shall demonstrate adequacy for entire range of expected forces and displacements. The performance characteristics shall be explicitly used in the computer model.

The top of the capacitor bank platform shall not deflect in any horizontal or vertical direction more than H/50 when subject to IEEE Std 693 performance level demands, where “H” is equal to the height of the capacitor bank/support structure platform interface as measured from the top of the foundation.

The company recommends the support structure columns and diagonal braces be connected to and supported by steel pedestals embedded in the concrete foundation, rather than directly connected to concrete pedestals. The use of cast-in-place anchor rods or post-installed anchors is discouraged due to difficulty in satisfying requirements of ACI 318, Appendix D provisions. However, if either cast-in-place or post-installed anchors are provided, the ACI 318, Appendix D provisions shall be used and all concrete shall be assumed to be cracked for purpose of analysis.

Calculations shall be submitted to demonstrate the performance of the capacitor bank system as specified above. The submittal shall include a Seismic Qualification Report prepared in accordance with IEEE Std 693, Annex S. The Report shall contain a comprehensive narrative that clearly explains all analysis & design assumptions along with final conclusions and recommendations. In addition, electronic file copies of input and output used for the structural analyses shall be provided electronically such that the company can review the computer files. Input data of model geometry, loading, etc., in electronic format that can be imported into other commonly used software programs (ex. CIS/2 format) must also be provided. Computer files will be used as part of technical review and validation of proper modeling methodology and analysis results.

Appendix D—Standby Generators

D.1. General

These provisions are applicable only to the seismic evaluation of standby generators identified as qualified to the high or moderate seismic qualification level per Section 4.3.

Generator configuration shall meet the project specific requirements which may include one of the following:

- Generator mounted directly on a concrete foundation with a separate fuel tank
- Generator mounted on a sub-base fuel tank that is supported by a concrete foundation, where the top of the fuel tank is used as a working/walking platform
- Generator mounted on a sub-base fuel tank that is supported by a concrete foundation, with a separate grated platform used as a working/walking platform

Seismic qualification of the generator, sub-base fuel tanks and platforms shall be in accordance with the applicable provisions in IBC, ASCE 7, ICC-ES AC 156 and Section D.2.

All working/walking platform surfaces and approach steps shall be OSHA compliant, free of slip/trip hazards and be equipped with fall protection when applicable. Platforms and approach steps shall be designed for a minimum snow load of 30 pounds per square foot (psf), uniform live load of 50 psf and concentrated live load of 500 pounds.

Steel design shall be in accordance with the applicable provisions in AISC and AISI, with due consideration to effects of buckling and pryout at bolted connections.

Post-installed anchors (adhesive or mechanical anchors) shall be used to anchor the generator, fuel tank, and platform support steel to concrete foundations. Adequate clearance shall be provided to enable the installation of the anchors after the equipment is set in place on the concrete foundation.

D.2. Seismic Qualification Methods

1. The generator set should be qualified by shake-table testing that meet or exceed the parameters below:
   a. Building code/referenced standards, IBC 2012/ASCE 7-10
   b. Test criteria, ICC-ES AC 156
   c. S_{DS} (g) = 1.67
   d. z/h = 1.0
   e. A_{FLX-H} (g) = 2.67; A_{RIG-H} (g) = 2.00
   f. A_{FLX-V} (g) = 1.12; A_{RIG-V} (g) = 0.45
   An I_p = 1.5 shall be assumed for evaluating functional requirements after testing (Ref ICC –ES AC156 Section 6.8.2).

For generators supported on top of sub base fuel tanks additional calculations shall be provided to verify that the support system is dynamically better (will transmit lower accelerations to the generator) than the support used for the shake-table test.

2. The enclosure, fuel tank, other components, connections and anchorages that are not shake table tested must be analyzed and designed to the following ultimate (LRFD) seismic forces:
   a. F_{p-hori} = 3.76 W_p
   b. F_{p-vert} = 1.12 W_p

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