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Experience-Based Seismic Equipment Qualification

Experience Based Seismic Equipment Qualification

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REPORT SUMMARY

This report provides guidelines that can be used to perform an experience-based seismic equipment qualification for verification of seismic adequacy of active electrical and mechanical equipment consistent with requirements of American Society of Civil Engineers (ASCE)-7. The report summarizes what requirements are sufficient to ensure that an item of equipment can perform its intended safety function after a design earthquake. The report also provides additional guidance on ensuring that an item of equipment can perform its intended safety function during an earthquake as well as following an earthquake.

Background
The Seismic Qualification Utility Group (SQUG) developed guidelines for verifying seismic adequacy of safety-related equipment in nuclear power plants. This report adapts those guidelines to provide a procedure using earthquake experience data for the seismic qualification of equipment in non-nuclear facilities, consistent with the requirements of ASCE-7.

Objectives
- To provide an efficient means of verifying that critical equipment will function after a design earthquake.
- To verify "function-during" performance, if necessary, with a relay chatter evaluation.

Approach
The project team determined the applicable requirements of the SQUG *Generic Implementation Procedure* for anchorage adequacy, seismic interaction, seismic capacity, and design difference evaluation for verification of the seismic capability of equipment and distribution systems in commercial facilities that are subject to ASCE-7 requirements.

Results
This report provides a procedure that can be used to perform seismic verification of equipment and distribution systems in accordance with ASCE-7. Seismic qualification is required for important equipment that must function after a design earthquake. The seismic review procedure is sufficient to ensure that an item of equipment will be able to perform its intended safety function following a design earthquake. The relay functionality guidelines provided enable verification of the ability to function during a design earthquake as well as following a design earthquake.

EPRI Perspective

EPRI provided oversight for the collection and reporting of earthquake experience data in 20 classes of active electrical and mechanical equipment and developed the online electronic earthquake experience database, eSQUG. Earthquakes investigated by SQUG ranged in Richter magnitude from 5.4 to 8.1, motion duration from 5 seconds to more than 40 seconds, and soil conditions from deep alluvium to rock. The building structures housing the equipment had a wide range in size and construction. As a result, the database covers a wide diversity of seismic input to equipment in terms of seismic motion amplitude, duration, and frequency content. This database provided the basis for the SQUG Generic Implementation Procedure for verification of seismic adequacy of equipment in nuclear power plants. This report modifies the procedure for application at non-nuclear facilities.

Keywords

Seismic qualification
Anchorage adequacy
Seismic interaction
Seismic capacity
Design difference evaluation
Inclusion rules
Caveats

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INTRODUCTION

Seismic qualification is required for important equipment that must function after a design earthquake. Section 13.2.2 (Special Certification Requirements for Designated Seismic Systems) of ASCE-7 [1] states that:

> Active mechanical and electrical equipment that must remain operable following the design earthquake shall be certified by the supplier as operable based on approved shake table testing in accordance with Section 13.2.5 or experience data in accordance with Section 13.2.6. Evidence demonstrating compliance of this requirement shall be submitted to the authority having jurisdiction after review and approval by the registered design professional.

ASCE-7 Section 13.2.5 (Testing Alternative for Seismic Capacity Determination) recognizes AC156 (Reference 8), as a nationally recognized procedure for seismic qualification of equipment, by shake table testing. However, as required by Section 13.2.6 (Experience Data Alternative for Seismic Capacity Determination), there is no current nationally recognized procedure for seismic qualification by experience data.

The nuclear power industry has been using earthquake experience data as the basis for verification of seismic adequacy of active electrical and mechanical equipment for about 20 years. The development and maintenance of the experience-based method was by the Seismic Qualification Utility Group (SQUG). Attachment A of this report provides a summary description of SQUG and the development of experience-based methods for seismic qualification of equipment. SQUG is the nationally-recognized authority in the application of earthquake experience data for seismic qualification of equipment. SQUG has developed this report to provide an interim procedure to enable use of earthquake experience data for seismic qualification of equipment, consistent with the requirements of ASCE-7.

In Chapter 2 of this report all elements important to the seismic qualification of equipment are addressed. These include:

- <u>Anchorage Adequacy</u>. The presence of properly engineered anchorage is perhaps the single most important item which affects the seismic performance of equipment. Earthquakes have repeatedly demonstrated that equipment will slide, overturn or move excessively when lacking positive anchorage or when it does not have proper engineered anchorage. Engineered anchorage means having sufficient strength and stiffness to withstand an earthquake.

- Seismic Interaction. Seismic interaction issues such as differential settlement or building movement, inadequate flexibility of attached lines, failure and falling of adjacent items, and seismic induced water spray or flooding can render equipment inoperable following an earthquake.
- Seismic Capacity vs. Demand Comparison. When properly anchored and with certain restrictions (inclusion rules and caveats), equipment has an inherent seismic ruggedness and a demonstrated capability to withstand substantial seismic motion up to certain seismic motion bounds. The seismic motion bounds are defined by a seismic capacity response spectrum.
- Inclusion Rules and Caveats. Caveats are used to provide assurance that known equipment vulnerabilities, as demonstrated by past earthquakes and shake table tests, are not present in the equipment. Inclusion rules are used as a demonstration that the candidate equipment falls within the defined bounds of the applicable reference equipment class (*i.e.*, is represented in the experience data). The seismic experience database inclusion rules and caveats for twenty (20) classes of equipment are provided in Chapter 3.
- Design Difference Evaluation. Newly-designed and newly-manufactured equipment can be qualified by similarity provided that a design difference evaluation confirms to representation by the experience database equipment class. The database does not indicate that there is a tendency for newer vintage equipment to have lower seismic capacity than older vintage equipment.

The above requirements are sufficient to ensure that an item of equipment will be able to perform its intended safety function following a design earthquake. The SQUG program also addressed a higher performance goal, that is, verification of equipment function both during and after the design earthquake. The primary additional requirement for seismic verification of the "function-during" performance goal is a relay chatter evaluation. This is described in Attachment B of this report.

In addition to experience-based equipment seismic qualification requirements, SQUG also developed experience-based seismic design requirements for distribution systems including cable trays, conduit, HVAC ducting, and supports. This provides an alternative to the lateral force (F_p) design method as described in ASCE-7 [1]. The SQUG method only applies to cases when the distribution systems are suspended on supports that are designed and detailed to enable ductile behavior at the overhead attachment points. The seismic design methodology is described in Chapter 4.

2 EXPERIENCE BASED SEISMIC QUALIFICATION REQUIREMENTS

2.1 Anchorage Adequacy

Seismic qualification of equipment requires that the equipment is anchored and that the anchorage has adequate strength and stiffness. Minimum design requirements for equipment anchorage are described in detail in Section 13.3.1 of ASCE-7.

The presence of properly engineered anchorage is perhaps the single most important item which affects the seismic performance of equipment. Earthquakes have repeatedly demonstrated that equipment slides, overturns, or moves excessively when it lacks positive anchorage or when it does not have proper engineered anchorage. Equipment anchorage failures in the earthquake experience database include pull-out of expansion bolts with very shallow embedment, slipping and bending failure of friction clips (steel plates anchored to the concrete base which extend over the flange or base of the equipment without a positive connection), and failure of base anchorage details with significant eccentricities which allow the equipment base to bend or tear or which generate large prying forces. Adequate stiffness is as important as adequate strength.

SQUG recommends that anchorage design forces be separately determined for each of the three directions of motion (front-to-back, side-to-side, and vertical) and then combined using the square root of the sum of the squares (SRSS) method. Dead load can be used to offset uplift forces due to overturning. The 3-direction of motion SRSS method provides more transparent description of the seismic forces than the ASCE-7 “worst direction” method, and in general results in more robust anchorage designs.

The anchorage design should address key internal attachment points for larger items of equipment that have one or multiple heavy internal subassemblies. The various subassemblies can have different response and amplification factors, and these individual factors should be properly considered and carried through in the design calculations. Other load path issues are addressed by inclusion rules and caveats on an equipment class-by-class basis in Section 2.4.

Base isolation systems are used on many items of mechanical equipment to isolate vibrations within the equipment from their supporting structures. The earthquake experience database has numerous examples of failed vibration isolators which allowed excessive movement of equipment and loss of function. Careful seismic design attention is warranted. Specialty products designed to resist earthquake forces are now available from a host of manufacturers. Impact factors should be addressed as necessary as described in ASCE-7.

2.2 Seismic Interaction

Seismic qualification of equipment requires that the equipment is free of potential spatial seismic interaction concerns. Design requirements are described in the following sections. The kinds of seismic interactions that have to be addressed are listed as follows:

- Failure and falling
- Proximity impact
- Spray and flooding.
- Differential displacement
- Flexibility of attached cable and lines

Seismic interaction issues can be difficult to address during the equipment procurement, seismic design, and seismic qualification process, because the concerns extend beyond the candidate item of equipment. Final walk-through verification by trained engineers is a very good method to ensure that the final installation is free of seismic interaction concerns. This is highly recommended, based on the implementation experience of SQUG member utilities.

The seismic walkdown should in particular identify any cases of poor “seismic housekeeping.” Unlatched door panels, unsecured equipment drawers containing important devices, unsecured emergency lighting, unsecured gas bottles, unanchored temporary equipment stored above or near safety equipment, and heavy unsecured items on shelves are examples of poor seismic housekeeping which should be noted and brought to management's attention. The purpose of identifying poor seismic housekeeping issues is to instill an attitude of "thinking seismic" among operations and maintenance personnel.

2.2.1 Failure and Falling

In general, structural failure and falling (of overhead and adjacent commodities) seismic interactions are not a concern for candidate items of equipment being seismically qualified because ASCE-7 requires that all items of the building are adequately designed for at least life safety considerations. However, Section 13.1.4 of ASCE-7 contains certain exceptions for lateral load design requirements -- such as items weighing less than 400 lbs located less than 4 ft. above a floor level, and items weighing less than 20 lbs. These exceptions cannot be used near the candidate equipment that is being seismically qualified, because this can lead to seismic interaction hazards.

Besides the item of equipment itself, special consideration should be given to the distribution lines for utilities serving the item of equipment such as for air, power, fuel, and cooling. These can be fragile and prone to failure and falling interaction concerns, and loss of a key utility line can render an item of equipment as inoperable following an earthquake.

2.2.2 Proximity Impact

Seismic proximity interaction is the impact between adjacent equipment or structures and the candidate equipment due to their relative motion during seismic excitation. This relative motion can be the result of the vibration and movement of the candidate item of equipment itself, or any adjacent equipment or structures. The design engineer should develop realistic estimates of seismic deflection amplitudes for the items of interest and use these to establish commodity clearance installation requirements for the project. Determination of relative seismic displacement is described in Section 13.3.2 of ASCE-7.

Even if there is impact between adjacent equipment and structures, there may not be any impairment of the safety function of the equipment. In such cases, this seismic interaction should not be considered as a reason for concern, provided the equipment can still accomplish its intended post-earthquake function. The motion of piping, conduit, cable trays, and other distribution lines may result in impact interactions with the item of equipment being seismically qualified if adequate clearance is not provided. In general, impacts between distribution systems (piping, conduit, ducts, and raceways) and equipment of comparable size are not a cause for concern; the potential for large relative motions between dissimilar size systems should be carefully evaluated to assure that a large system cannot impact against a smaller one.

Facility operating conditions should be considered when specifying or reviewing commodity clearance requirements. Where potential interactions involve systems with significant thermal movements during operating conditions, the thermal displacements should be evaluated along with those resulting from seismic deflections.

2.2.3 Spray and Flooding

Seismic induced spray or flooding can lead to loss of function of an item of equipment following an earthquake. Examples include flooding resulting from seismic failure of a nearby tank, or spray or flooding resulting from failure or malfunction of fire suppression systems. Fire protection sprinkler heads can be damaged due to impact, and sprinkler system failures can quickly release large amounts of water. It is not only the area directly exposed to the discharge that is vulnerable, but water might spread over large areas and affect equipment at lower elevations in the building structure.

To address spray and flooding seismic interaction concerns, sources such as piping in the vicinity of equipment being seismically qualified should be assigned an importance factor $I_p = 1.5$. This higher importance factor per ASCE-7 provides additional strength and requires more attention to detail for the potential spray and flooding sources, thereby helping to preclude seismic-induced spray and flooding interaction concerns for the candidate item of equipment being seismically qualified.

2.2.4 Differential Displacement

Cables and lines connected to the candidate equipment being seismically qualified should have adequate slack and flexibility so that seismic deflections can be safely accommodated. Distribution lines, such as small bore piping, tubing, conduit, or cable (inside conduit) can potentially fail if there is insufficient flexibility to accommodate relative motion between the equipment and the first support point of the distribution line. Straight, in-line connections in particular are prone to failure.

The scope of review for flexibility of these lines extends from the item of equipment being qualified to their first rigid support point on the building or nearby structure. Determination of seismic relative displacements is described in Section 13.3.2 of ASCE-7. Include inter-story drift where appropriate. Include consideration of equipment mounted on vibration isolators as appropriate.

2.3 Seismic Capacity versus Demand Comparison

Seismic qualification of equipment requires that the seismic capacity of the equipment exceeds the seismic demand at the attachment point of the equipment to the building structure. The response accelerations representing the seismic capacity of the equipment must exceed the seismic demand response accelerations on the equipment at and above the natural frequency of the item of equipment being qualified.

Simplified Method

For experience-based seismic equipment qualification, seismic capacity exceeds seismic demand when the normalized seismic equipment demand (S_{ED}) is less than the experience data threshold value

$$S_{ED} \leq 1.2$$

Where:

$$S_{ED} = [\ 1 + 2\ (z/h)\ ] \times S_{DS} \geq 1.5 \text{ x } S_{DS}.$$

The basis for the above simplified and normalized seismic capacity versus seismic demand comparison equation is provided below. The seismic capacity of the equipment is defined by the SQUG Bounding Spectrum and Reference Spectrum [2]. The seismic demand on the equipment is defined by the ASCE-7 lateral force requirements [1].

Detailed Method

For experience-based seismic equipment qualification, seismic capacity exceeds seismic demand when the design earthquake in-structure 5% damped spectral acceleration, at the attachment point of the item of equipment to the building structure, corresponding to the natural frequency of the item of equipment is less than or equal to the spectral acceleration of the SQUG Reference Spectrum for that frequency. The SQUG Reference Spectrum is shown in Figure 2-1 and is discussed below. The natural frequency of the item of equipment should be estimated using conservative methods.

2.3.1 Seismic Capacity

Seismic capacity is based on the SQUG earthquake experience database. Earthquake experience-based seismic capacity is defined by the SQUG Bounding Spectrum and 1.5 × Bounding Spectrum (Reference Spectrum) as shown in Figure 2-1. The SQUG Reference Spectrum represents an upper-bound average of horizontal ground motion experienced by sites in the earthquake experience database. Additional discussion is provided in the SSRAP Report (Reference 5).

As background information, there are two (2) SQUG methods (Method A or Method B) in Reference 2 for comparing experience-based seismic capacity to demand:

- Method A can be used when the equipment is mounted less than 40 feet above grade, in a stiff building structure (e.g., reinforced concrete frame and shear wall structures, and heavily braced steel frame structures). In Method A, the ground motion response spectrum for the design earthquake is compared with the SQUG Bounding Spectrum. Method A cannot be applied for equipment that has a natural frequency less than 8 Hz (natural period greater than 0.125 sec). The 8 Hz. limitation does not apply to equipment that is line mounted on a piping system (such as valves and temperature sensors).
- Method B applies to equipment located at any elevation in any type of building structure. In Method B, the realistic median-centered in-structure response spectrum calculated for the design earthquake is compared with the SQUG Reference Spectrum.

The 5% damped peak spectral acceleration is 0.8g for the SQUG Bounding Spectrum and 1.2g for the SQUG Reference Spectrum. The broad band peak of the Reference Spectrum ranges from a frequency of 2.5 Hz to 7.5 Hz (natural period of 0.133 sec to 0.40 sec). Comparing Method A using the SQUG Bounding Spectrum with Method B using the Reference Spectrum implies that stiff structures have an in-structure amplification factor of 1.5 or less at elevations within 40 feet above grade for frequencies greater than 8 Hz.

The 8 Hz limitation on equipment frequency for the Method A comparison is intended to avoid situations where (1) both the equipment and supporting structure have frequencies close to each other, and (2) where equipment frequencies are within the frequency range of the significant power of the earthquake shaking. For typical earthquake design spectra, much of the power comes from frequencies below about 7 Hz. The 8 Hz limitation (0.133 sec) is intended to avoid the frequency range below 7 Hz (above 0.143 sec), which contains most of the power of the earthquake motion. If the equipment natural frequency is less than 8 Hz (natural period more than 0.133 sec), then Method B, comparing the in-structure spectrum with the Reference Spectrum, should be used.

2.3.2 Seismic Demand

Seismic demand is based on ASCE-7 methods. In ASCE-7, equipment seismic demand is defined in terms of the following lateral force equation:

$$F_p = 0.4\ a_p\ S_{DS}\ [\ 1\ /\ (R_p/I_p)\ ] \times [\ 1 + 2\ (z/h)\ ]\ \ W_p$$

Where, F_p has the following bounds:

$$0.3\ S_{DS}\ I_p\ W_p \leq\ F_p\ \leq 1.6\ S_{DS}\ I_p\ W_p$$

and

W_p = weight of the equipment.

The effective seismic demand acceleration response for ASCE-7 equipment can be defined as:

$$(F_p/W_p) = 0.4\ a_p\ S_{DS}\ [\ 1\ /\ (R_p/I_p)\ ] \times [\ 1 + 2\ (z/h)\ ]$$

Where:

S_{DS} = design spectral response acceleration (5% damped) at short periods. S_{DS} is derived from the maximum considered earthquake spectral acceleration response at short periods, S_{MS}, as follows:

$$S_{DS} = S_{MS}\ /\ 1.5$$

S_{MS} is developed based on mapped values and site soil classifications. In general, the value of 1.5 in the above equation accounts for the factors of safety used in the strength design for the building.

I_p = component importance factor. I_p ranges from 1.0 for normal facility installations up to 1.5 for important facility installations. I_p = 1.5 for equipment that is required to function after an earthquake. I_p = 1.5 means that the equipment anchorage is designed with additional strength, and seismic qualification is required. Seismic qualification is not required when I_p = 1.0.

a_p = component amplification factor: 1.0 for rigid equipment or 2.5 for flexible equipment. Flexible equipment is defined as having a natural frequency less than 16.7 Hz. The spectral acceleration seismic response of flexible equipment is considered to be 2.5 times greater than that of rigid equipment. Note that $2.5 \times 0.4\ S_{DS} = S_{DS}$

R_p = component response modification factor. The component response modification factor accounts for decreases in response due to various nonlinear seismic response attributes such as ductility. R_p ranges from 1.5 for low deformability features, to 2.5 for most types of equipment, and up to 5.0 for distribution systems.

[1 + 2 (z/h)] = in-structure amplification factor, where z is the in-structure height of the component attachment point, ranging from 0 to h (roof height of the building above grade). The in-structure amplification factor ranges from 1.0 at grade level up to 3.0 for the roof level of a building.

The simplified ASCE-7 lateral force equations do not address calculation of seismic in-structure acceleration response spectra. Rather, the building structure design short period acceleration, S_{DS}, is scaled and used for the equipment evaluation.

2.3.3 Building Seismic Design

The seismic design of the building is based on an ASCE-7 ground motion response spectrum. The building design ground motion response spectrum is shown in Figure 2-2. The design response spectrum shape is defined by the control points S_{D1}, S_{DS} (described above), f_0, and f_s as follows:

S_{D1} = design spectral response acceleration (5% damped) at 1 second period.

$$S_{D1} = S_{M1} / 1.5$$

S_{M1} is developed based on mapped values for 1 second period and site soil classifications.

$$1 / f_0 = T_0 = 0.2\ S_{D1} / S_{DS}$$

$$1 / f_s = T_S = S_{D1} / S_{DS}$$

The natural period of the building structure, T is generally based on dynamic analysis, and has limitations as follows:

$$T \leq C_u\ T_a$$

Where:

C_u = coefficient for upper limit on calculated period. The values for C_u range from 1.4 for $S_{D1} \geq 0.4g$ to 1.7 for $S_{D1} \leq 0.05g$.

T_a = approximate natural period. There are various methods for calculating T_a. The simplest form is for buildings less than 12 stories in height (N = number of stories), with a story height of at least 10 feet, and construction of concrete or steel moment-resisting frames. In this case:

$$T_a = 0.1\ N$$

2.3.4 Shake Table Test Criteria

AC156 (by ICC-ES, Reference 8) provides acceptance criteria for equipment seismic qualification by shake table testing methods. The AC156 seismic demand methods should be used when the SQUG GERS (Reference 6) are used for seismic capacity. The SQUG GERS capacity levels are shake table motion levels, so in-structure response spectra should be used for seismic demand. The seismic demand definitions in AC156 represent in-structure floor response spectra, and are intended to be consistent with ASCE-7. The shake table test motion response spectrum is shown in Figure 2-3.

The AC156 shake table input motion frequency control points conservatively define a broad-band spectrum that generally envelopes the expected frequency range for site design ground motion as described above (that is, for $f_S > 1.3$ Hz, and $f_0 < 8.3$ Hz.).

The response acceleration values A_{FLX} and A_{RIG} are defined as follows:

$$A_{FLX} = S_{DS}\ [\ 1 + 2\ (z\ /\ h)\ ]$$

$$A_{RIG} = 0.4\ S_{DS}\ [\ 1 + 2\ (z\ /\ h)\ ]$$

$A_{FLX} / A_{RIG} = 2.5$, accounting for the in component amplification factor a_p (1.0 for rigid equipment or 2.5 for flexible equipment). Also, the derivation for the above response spectrum control acceleration values considers that $R_p / I_p = 1.0$ as follows:

- $R_p = 1.0$ is used. During seismic simulation testing, the test specimen equipment that is subject to the testing will respond to the shaking, and the inelastic behavior and component response reductions will occur naturally. The table motion should not be reduced.
- $I_p = 1.0$ is used. The importance factor does not increase the seismic test input motion. As described above, $I_p = 1.5$ triggers seismic qualification, and requires that the equipment be checked for functionality after the seismic simulation testing. That is, $I_p = 1.5$ does not increase the seismic demand levels.

2.3.5 Discussion of Basis for Experience-Based Capacity vs Demand Approach for Equipment Seismic Qualification

Component Response Modifiers

In the experience-based seismic equipment qualification method, equipment class definitions, inclusion rules, caveats, and design difference evaluations are used to ensure that the candidate equipment is represented within the seismic experience database equipment class. If the equipment making up the basis for a particular class in the seismic experience database was flexible and highly deformable, then the candidate equipment should also be flexible and deformable. Similarly, if the database equipment for a different class were rigid, and with low deformation capability, then the candidate equipment should also be rigid and with low deformability.

That is, candidate items of equipment have the same a_p and R_p values as the equipment forming the basis for their respective experience database equipment classes. Because the a_p and R_p values are the same on both the capacity and demand sides of the equation within every equipment class, then a_p and R_p can be removed from the capacity versus demand check.

Furthermore, the a_p and R_p values cannot be assigned to the earthquake experience database ground motion definition. As described above for the AC156 shake table test method, the amplifications due to flexibility and response modifications due to nonlinear behavior were inherent in the equipment subjected to the actual earthquake shaking. The amplifications and response modifications occurred naturally during the earthquake. The amplifications and response modifications did not affect the measurement of the ground motion.

For these reasons, the a_p and R_p values are removed from both the demand and capacity side of the equation. Equipment a_p and R_p values do not need to be considered when assessing capacity versus demand for experience-based seismic equipment qualification. The equipment a_p and R_p values are only used for determining the lateral loads for anchorage design.

Importance Factor

As described above for the AC156 shake table test method, $I_p = 1.0$ is used. The importance factor does not increase the seismic demand; $I_p = 1.5$ only triggers the equipment seismic qualification requirement and provides a higher factor of safety for the strength of the anchorage.

Response Amplitude

For equipment located low in the building structure, the final capacity versus demand equation checks if the ground motion S_{MS} value is less than the spectral peak of the SQUG Reference Spectrum (1.2g). Another way of looking at this is as follows. The $1.5 \times S_{DS}$ lower bound limit for S_{ED} in the capacity versus demand equation checks that the ground motion S_{DS} value is less than the spectral peak of the SQUG Bounding Spectrum (1.2 / 1.5 = 0.80g). This is consistent with SQUG Method A. The SQUG 8 Hz. rule for Method A need not apply in this case. This provides an added conservatism.

For equipment located higher in the building structure, the final capacity versus demand equation checks if the in-structure amplified S_{DS} value is less than the spectral peak of the SQUG Reference Spectrum (that is, 1.2g). This is consistent with SQUG Method B.

Response Spectrum Shape

The developed capacity versus demand check only considers the peak of the SQUG Reference Spectrum. This implies that the capacity versus demand check is only in the frequency range from 2.5Hz to 7.5 Hz (period range of 0.133 sec to 0.40 sec). This is sufficient as follows:

- High Frequency Response for Ground Mounted Equipment

  ASCE-7 ground motion in the high frequency range does not trend down to the peak ground acceleration at reasonable frequencies. The existing equations may be suitable for building design purposes, but are not realistic for equipment design purposes. In general, a frequency of 33 Hz defines rigid response. In the ASCE-7 ground motion response spectrum development methodology, as illustrated in Figure 2-2, the response at 33 Hz is as follows (using f_0 = 7.5 Hz for this illustration):

  $$S_{33} = S_{DS} \times [0.4 + 0.6\ (\ 7.5\ /\ 33)] = 0.536\ S_{DS}$$

  $$S_{33}\ /\ 0.4\ S_{DS} = 1.34$$

  An amplification of 1.34 is not considered to be a realistic amplification at 33 Hz (0.303 sec). At 50 Hz (0.020 sec), the formula derives an amplification of 1.23 (also not realistic). The SQUG Reference Spectrum should in general envelope any ASCE-7 response spectrum whose 0.6 S_{DS} value is below 1.2g.

- High Frequency Response for Building Mounted Equipment

  It would be possible for the SQUG Reference Spectrum to be exceeded by an in-structure seismic demand spectrum, even if $S_{ED} \leq 1.2g$, if a building structure has considerable high frequency response. This is illustrated in Figure 2-4.

  In this case, such building amplification would require that the building have a natural frequency greater than 7.5 Hz., or a natural period of

  $$T \leq 1\ /\ 7.5 = 0.133 \text{ seconds.}$$

  In order for a building to have a natural period less than 1.33 seconds, using 16 ft as an upper bound story height, the building would have to have a height less than

$$h \leq (T / C_U) (16 / 0.1) = 15 \text{ ft.}$$

Clearly, it is only possible to have significant in-structure amplification above a frequency of about 7.5 Hz if the height of the building is less than 40 ft. and if the building is stiff. However, stiff buildings less than 40 ft. tall would be adequately covered by SQUG Method A and SQUG Method B need not apply. Therefore, high frequency response is not a concern.

- Low Frequency Response

The control point for the SQUG Reference Spectrum at a lower bound frequency of 2.5 Hz (upper bound period of 0.40 sec) is based on very conservative estimates of the ground motion for the key seismic experience database sites. As shown in Figure 2-5, individual seismic experience database ground motion response spectra have amplitudes exceeding 1.2g down to a frequency of about 1Hz.

Seismic demand exceeding the SQUG Reference Spectrum would only be a concern for equipment with natural frequencies of less than about 2.5 Hz. With the exception of equipment mounted on spring-type vibration isolators, all of the base mounted and wall-mounted equipment in the seismic experience database have natural frequencies greater than 2.5 Hz. Equipment on spring-type vibration isolators have been seen to be a problem in past earthquakes, and all applicable equipment classes have a caveat specifically addressing vibration isolators. Therefore, equipment with frequencies below 2.5 Hz get special treatment, and this need not be addressed in seismic capacity versus demand comparison.

Line-mounted equipment can have response frequencies below 2.5 Hz due to the frequency of the piping system. In general, equipment such as valves and dampers are not considered to be vulnerable to low frequency accelerations. This is evidenced by the a_p / R_p ratio for high deformability piping systems in ASCE-7:

$$a_p / R_p = 1.0 / 3.5 = 0.286$$

This is a significant response reduction and offsets any potential concerns for low frequency response seismic demand exceeding the SQUG Reference Spectrum (when $S_{ED} \leq 1.2g$). However, low frequency line-mounted equipment may be vulnerable to the relative large displacements associated with low frequency response. Seismic interaction addresses seismic displacement issues for line-mounted equipment.

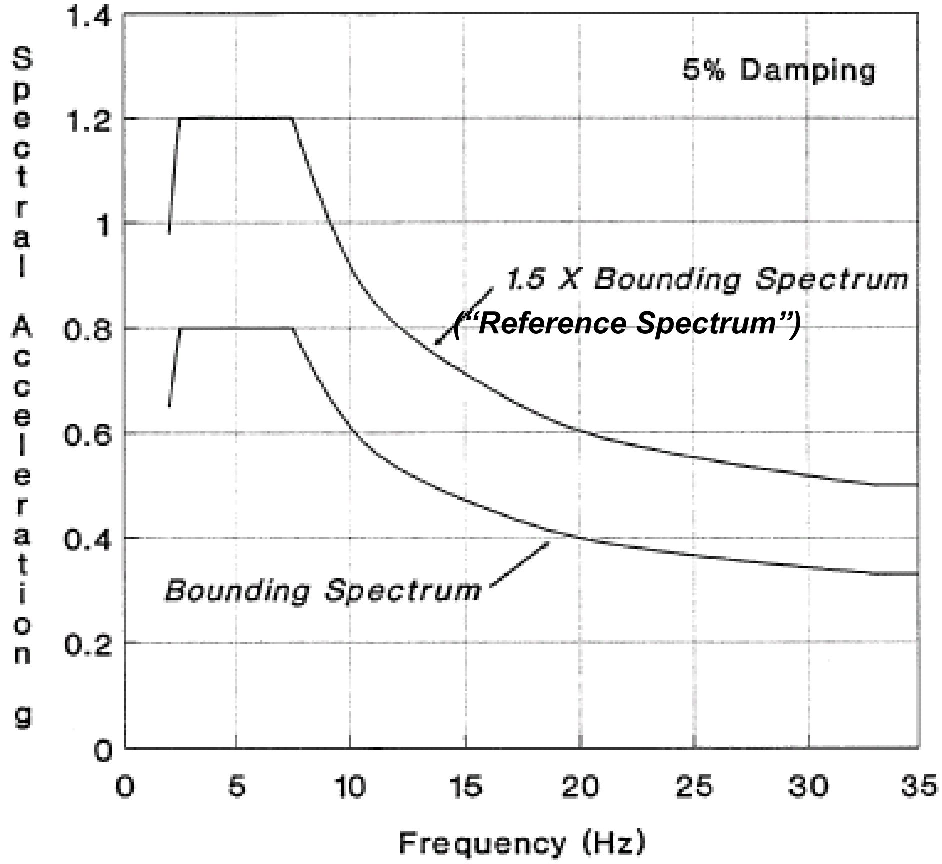
2.3.6 Conclusion and Recommendation

Based on the above, it is suitable in experience-based seismic equipment qualification to use the following rule for comparing seismic capacity to seismic demand:

$$S_{ED} \leq 1.2$$

Where:

$$S_{ED} = 0.4 \times [\ 1 + (2\ z\ /\ h)\ ] \times S_{DS} \geq 0.6 \text{ x } S_{DS}$$



Frequency (Hz)	2.0	2.5	7.5	8.0	10	12	16	20	28	33
1.5 X Bounding Spectrum (g)	.98	1.2	1.2	1.13	.90	.80	.68	.59	.53	.50
Bounding Spectrum (g)	.65	.80	.80	.75	.60	.53	.45	.39	.35	.33

Figure 2-1
SQUG Bounding Spectrum and Reference Spectrum

Source: Reference 2

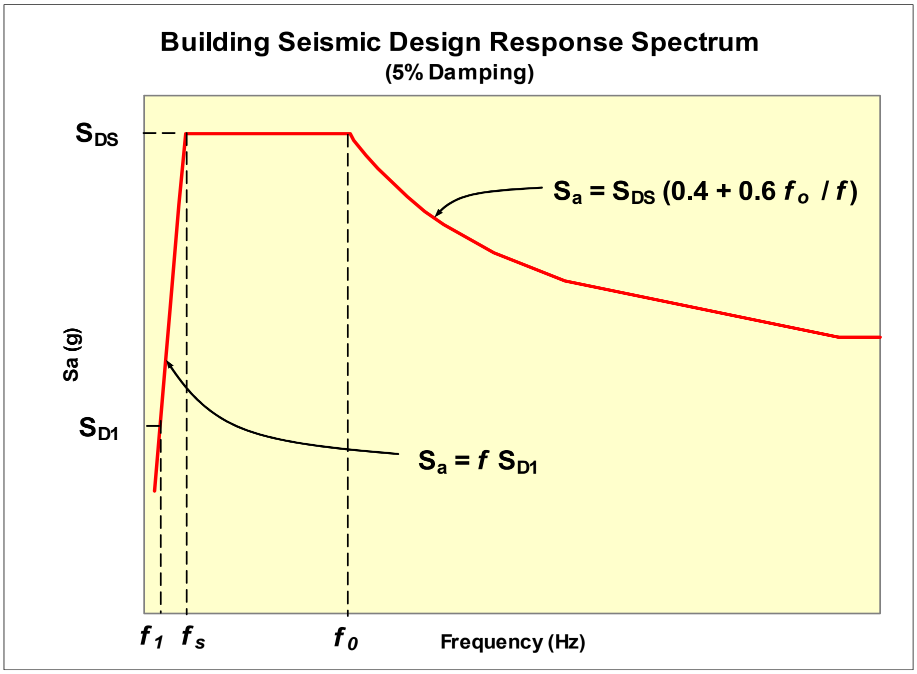


Figure 2-2
Building Design Response Spectrum

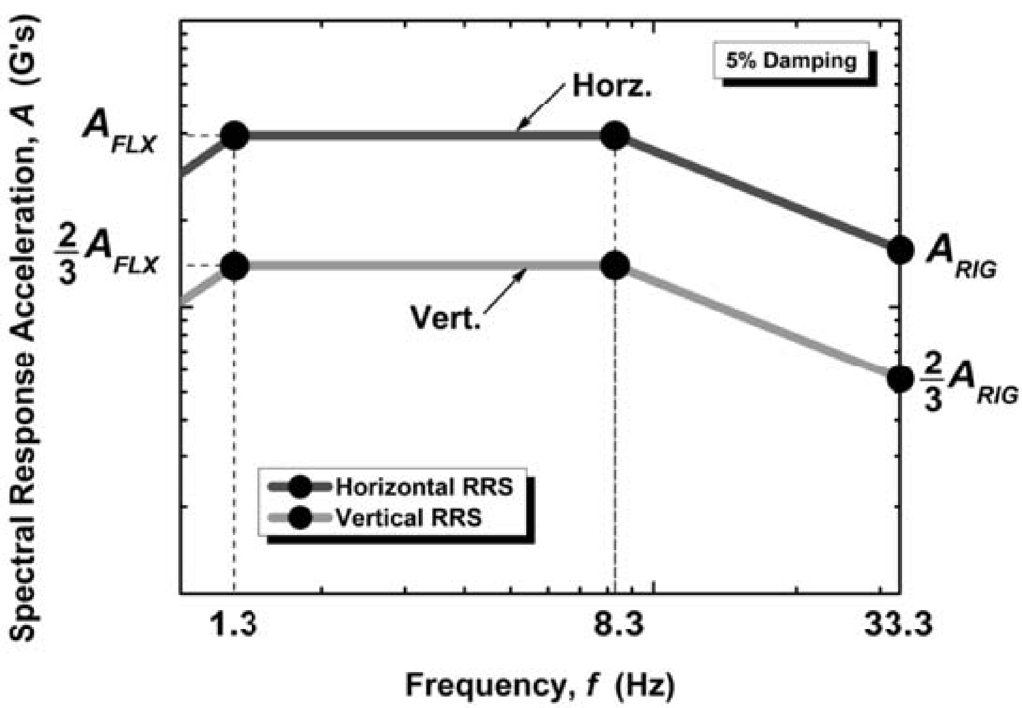


Figure 2-3
AC156 Normalized Test Response Spectrum

Source: Reference 8

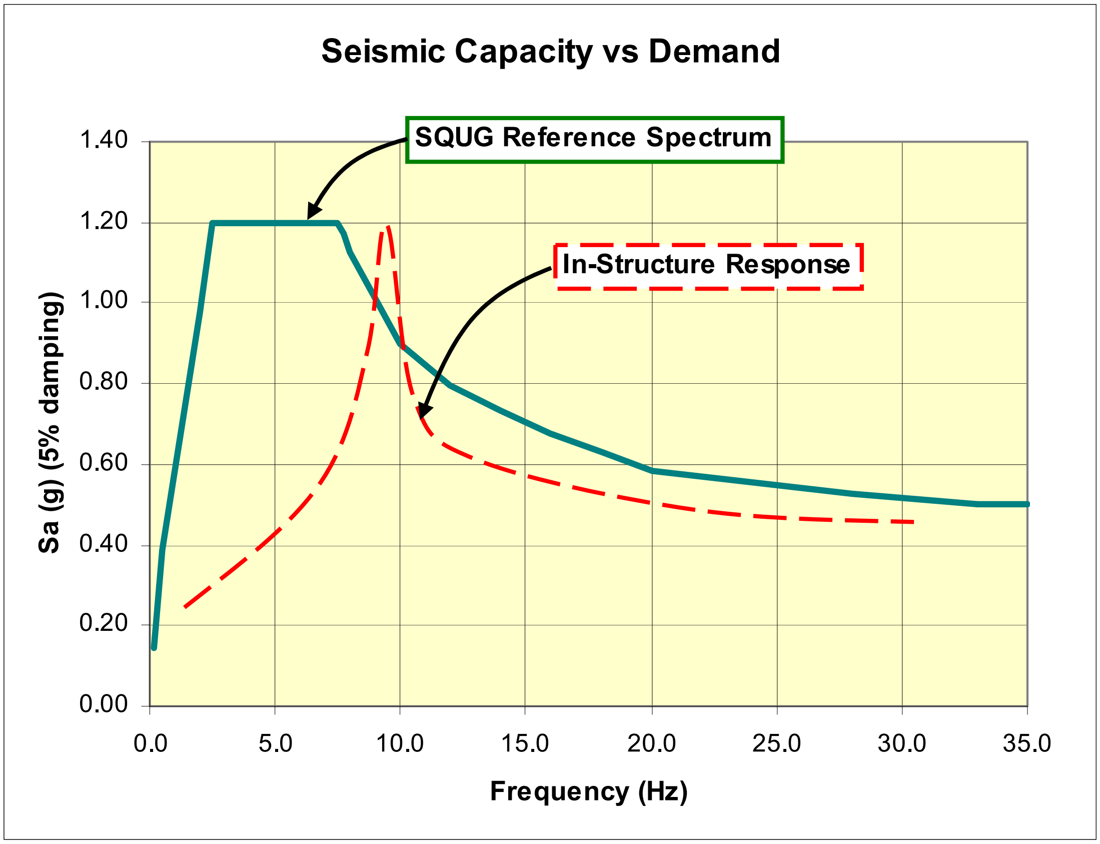


Figure 2-4
Example of High Frequency Building Response

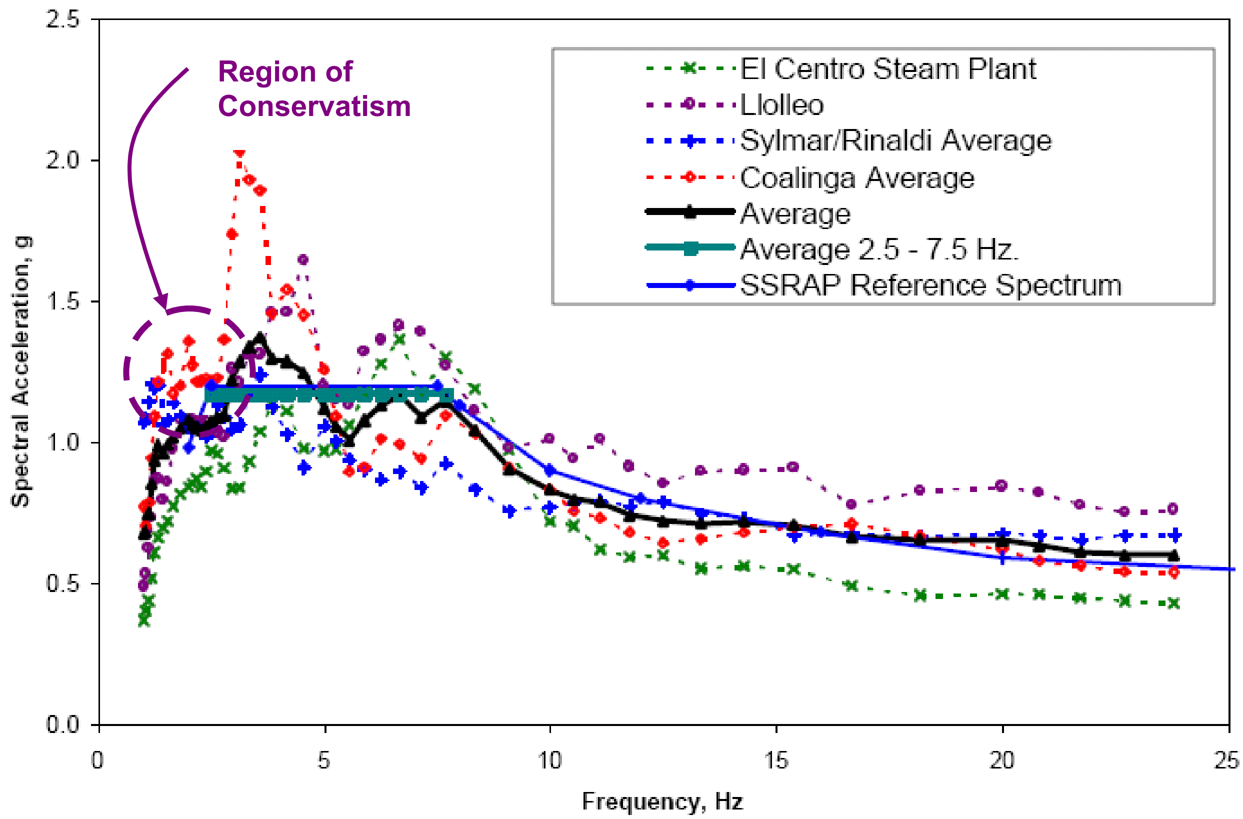


Figure 2-5
SQUG Reference Spectrum and Seismic Experience Database Ground Motion Response Spectra

2.4 Inclusion Rules and Caveats

Equipment-class-specific inclusion rules and caveats are used to define the experience-based equipment classes for seismic qualification. If a candidate item of equipment meets all of the inclusion rules and caveats for its experience-based equipment class, then that item of equipment has a seismic capacity as least as great as that defined by the Reference Spectrum (1.2g, as described in Section 2.3). The equipment class-by-class inclusion rules and caveats are defined in Chapter 3.

The caveats are established based on observed failures or instances of damage in the earthquake experience or testing databases. New candidate items of equipment being qualified by the experience data method are not allowed to have attributes that have led to past failures in earthquakes or shake table tests. If the equipment component does not pass all of the caveats, then the experience data method cannot be used for the qualification. Additional testing or analysis is required.

The inclusion rules are established to define the physical or operational limits of equipment that is represented by the earthquake experience equipment class. If a candidate item of equipment is outside of the bounds established by the equipment class inclusion rules, then the experience data method cannot be used for the qualification. Additional testing or analysis is required.

While it is not required for users to understand which rules are caveats and which rules are inclusion rules and class definitions, the following example for the fluid-operated valve (FOV) equipment class helps to clarify the basis for seismic qualification based on earthquake experience. It also helps to illustrate the substantial amount of conservatisms in the experience-based seismic qualification methodology. The rules for fluid-operated valves and the background for each rule are as follows:

- FOV Rule 1 - Earthquake Experience Equipment Class. The valve should be similar to and bounded by the FOV class of equipment. The list of attributes defines the limits of the class. They are inclusion rules:
  - Hydraulic Piston-Operated Valves Excluded. The earthquake experience database does not include enough examples of this type of valve.
  - Pipe Size 1-inch or Larger. The valve should be mounted on a pipe line of at least l-inch diameter. This is the lower bound of pipe sizes supporting large FOVs in the earthquake experience equipment class. The concern is that valves with heavy operators on small lines may cause an overstressed condition in the adjacent piping.
  - Valve Operator Cantilever Length for Air-Operated Diaphragm Valves, Spring-Operated Pressure Relief Valves, and Light Weight Piston-Operated Valves. The distance from the centerline of the pipe to the top of the operator or cylinder should not exceed the distance given in the earthquake experience equipment class, Figure 3-1, corresponding to the diameter of the pipe. This figure bounds the pipe diameter and operator length combinations included in the earthquake experience equipment class.
  - Valve Operator Cantilever Length for Substantial Piston-Operated Valves. For piston-operated valves which are of substantial weight, the distance from the centerline of the pipe to the top of the operator or cylinder and the weight of the operator should not exceed the values given in the earthquake experience equipment class, Figure 3-2, corresponding to the diameter of the pipe. This figure represents the pipe diameter and operator weight/length combinations included in the earthquake experience equipment class.
- FOV Rule 2 - Valve Body Not of Cast Iron. The valve body should not be made of cast iron. The intent of this caveat is to avoid the brittle failure mode of cast iron as evidenced by the poor performance of some cast iron components in past earthquakes. This is a caveat.
- FOV Rule 3 - Valve Yoke Not of Cast Iron for Piston-Operated Valves and Spring-Operated Pressure Relief Valves. The yoke of piston-operated valves and spring-operated pressure relief valves should not be made of cast iron. The intent of this caveat is to avoid the brittle failure mode of cast iron as evidenced by the poor performance of some cast iron components in past earthquakes. This is a caveat.

- FOV Rule 4 - Actuator and Yoke Not Independently Braced. The valve actuator and yoke should not be independently braced to the structure or supported by the structure unless the pipe is also braced to the same structure immediately adjacent to the valve. The concern is that if the operator is independently supported from the valve and attached piping, then the operator may act as a pipe support during seismic motion and attract considerable load through the yoke and possibly fail the yoke or bind the shaft. In addition, if both the operator and the valve/pipe are restrained, and if they are both not tied back to the same structure, then differential motion of support points may lead to high seismic loads and possible binding of the shaft. If either of these concerns is noted, then a special evaluation should be conducted to demonstrate low stress and small deflections. This is a caveat.
- FOV Rule 5 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., air) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support. Sufficient slack and flexibility of lines is a seismic interaction concern.

2.5 Design Difference Evaluation

The design difference evaluation is intended to address the potential that newly designed equipment may not be as rugged as the “older” vintage equipment represented in the seismic experience database equipment classes. Equipment is considered seismically qualified so long as it meets all of the requirements as described in Sections 2.1 through 2.4, including the meeting the inclusion rules for the equipment classes. The inclusion rules were determined by reviewing the experience databases, which are primarily made up of older vintage equipment. Newly designed or newly manufactured equipment may contain design changes not are adequately represented within the earthquake experience databases. For example, vendors may make design improvements for functional reasons (e.g., use of plastic in place of steel) which could adversely impact seismic ruggedness compared to older vintage equipment.

2.5.1 Identification of Design Differences

Design differences are identified by comparing design attributes of the new equipment item with the design attributes typical of the vintage of equipment in the seismic experience database. Contacting vendor representatives and reviewing vendor literature are good sources for obtaining design and design change information for equipment for identification of the design differences. The design comparison focuses only on design attributes that may affect seismic performance. Design attributes that shall be considered are as follows:

- Specific seismic experience-based inclusion rules and caveats for the applicable equipment class.
- Mass of the item relative to its attachment or anchorage.
- Structural stiffness of the item and its load path / anchorage.
- Item strength as affected by materials, section properties, and construction details.

- Item anchorage method (footprint, support locations, etc.).
- Strength of the anchorage and the load path to the major internal components.
- Attachments (tubing, cables, electrical leads, etc.) to the item.
- Natural frequencies, if they affect seismic capacity/design comparison.
- Moveable subassemblies in certain equipment classes (e.g., breakers in switchgear and doors on cabinets).

It is the intent that the evaluation of these attributes be based primarily on judgment by experienced engineers. If design differences of potential significance to seismic adequacy are identified, then an evaluation of the adequacy of the relevant design changes is performed.

2.5.2 Evaluation of Effect of Design Differences on Seismic Capacity of Candidate

If potentially significant design differences are identified, then the effect of the differences on the seismic adequacy of the candidate must be evaluated. The design difference must be either accepted by engineering judgment or identified for seismic qualification by other methods such as testing or analysis. In particular, each potentially significant design difference is evaluated to determine if the difference adversely affects seismic adequacy, violates any experience-based equipment-specific caveats or inclusion rules, changes the equipment fundamental frequency so that capacity versus demand comparisons are invalidated, or introduces new features not included in the experience database.

When performing the design difference evaluation, it is important to consider foremost the required post-earthquake function of the candidate item of equipment. As an example, suppose that only the fans in an air handler are required to function after an earthquake. In this case, there may be no requirement for the cooling system to function after the earthquake. Thus, any identified design differences in the cooling system may be irrelevant if they cannot impact the capability of the fans to operate.

The design difference evaluation should focus on the seismic experience database. Have the newly designed equipment features caused instances of damage in the experience database equipment? Does the experience database contain a significant number of newer vintage equipment items that performed adequately and are representative of the new design feature? Is the newly designed equipment equally or more rugged than the experience database equipment using judgment based on comparison of key design attributes?

The identified design difference(s) for the equipment item under consideration may be evaluated using engineering judgment, analysis, testing, or combinations thereof to ensure the seismic capacity of the subject equipment is equal to or greater than the experience database generic capacity.

Note that the intent of the design difference evaluation is to identify differences between items represented in the experience databases and newly designed models. The evaluation is not intended to identify and document each and every detailed design variation. Rather, it is intended to assure that design changes arising out new technology that could have a significant effect on equipment ruggedness are evaluated. The objective is to utilize experienced engineering judgment in combination with available sources of information to identify credible seismic vulnerabilities not considered in the experience-based equipment class inclusion rules and caveats.

3 EQUIPMENT CLASS INCLUSION RULES AND CAVEATS

The purpose of this section is to summarize the descriptions of the equipment classes and the inclusion rules and caveats, which apply to the classes of equipment determined to be seismically rugged based on earthquake experience data and generic seismic testing data. The equipment class descriptions summarize the general characteristics of equipment in the class. The inclusion rules contain the limits of equipment physical characteristics that are represented for the class within the experience databases. The caveats identify characteristics with the potential to reduce seismic capacity.

The class descriptions, inclusion rules and caveats summarized in this section are based on the information contained in References 2 and 5. The list of rules for each class in Reference 2 has been reordered for clarity within the scope of this report; the inclusion rules are grouped together under Rule 1 rather than listed separately within the class description or with the caveats as in Reference 5.2. More details and photographs are given in References 3 and 4.

3.1 Motor Control Centers

The equipment class of motor control centers (MCCs) includes control and electrical fault protection systems for motors powered at 600 volts or less (typically 480 volts). Motor controllers are mounted in sheet metal cubicles with controller cubicles typically assembled into stacks which are lined up side-by-side and bolted together to form a motor control center. This equipment class also includes motor controllers mounted in individual cubicles on racks or walls as well as freestanding, single stack MCCs.

Individual motor controllers are mounted in a sheet metal box (bucket) that can be removed from its cubicle in the motor control center. The individual sub-components of the motor controller are attached to the sides and rear face of the box. The MCC equipment class includes the following types of standard sub-components: molded case circuit breakers (or disconnect switches), magnetic contactors, control transformers, fuses, push buttons, and pilot lights.

The motor controller cubicles are arranged in vertical stacks within an MCC assembly. Each stack is a separate sheet metal enclosure, reinforced at its corners by overlapped sheet metal or steel angle framework. Stacks are bolted together through adjacent sheet metal side walls or steel framework.

The equipment class includes both single- and double-sided MCCs. Double-sided MCCs have controller cubicles on both the front and rear face of the cabinet, with vertical bus bars routed through a center compartment between the front and rear stacks of controller cubicles. Single-sided MCCs typically route electrical connections through vertical raceways along the sides of each stack section.

The equipment class includes both freestanding units and units forming part of a more complex assembly. In many cases, MCCs are included in an assembly with switchgear, distribution panels, and/or transformers. The class also includes wall- or rack-mounted motor control cubicles. Within these cubicles, motor control components are bolted to the inner faces of the wall in the same manner as in a small control or instrument cabinet. Access to the cubicle is usually through a swinging door that forms the front face of the cubicle.

Motor control center assemblies represented in the equipment class contain motor starters (contactors), disconnect switches, and over-current relays. They also contain distribution panels, automatic transfer switches, and relay/instrumentation compartments, and include attachments such as junction boxes, conduit and cables. Motor controllers are represented in a variety of mounting configurations ranging from individual mounted controllers to MCC assemblies in outdoor enclosures.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Motor Control Center (MCC) if the MCC meets the intent of the following inclusion rules and caveats.

- MCC Rule 1 - Earthquake Experience Equipment Class. The MCC should be similar to and bounded by the MCC class of equipment described above.
  - Height less than 90 inches excluding mounting channel
  - Depth greater than 12 inches
  - Individual stacks 20 to 24 inches wide
  - Stacks bolted together side to side (and front to back if double-sided)
  - Voltage rating 600V or less
  - Constructed to meet NEMA or similar standard
  - Weight of each stack less than 650 lb
- MCC Rule 2 - Externally Attached Items Rigidly Anchored. Externally attached items should be rigidly attached to the cabinet. The concern is that these items could impact other components of the MCC as a seismic interaction hazard. As an example, some electrical cabinets have small, externally attached panels mounted on hinges to the main cabinet frame. During seismic motion the externally attached panel may swing and cause significant impact loading to the electrical panel.
- MCC Rule 3 - No Large Cutouts. Cutouts in the lower half of the cabinet sheathing should be less than 6 inches wide and 12 inches high. The concern is that the shear load from the earthquake will not be able to be transferred through the shear walls to the anchorage. MCCs

may exceed this caveat if the area around the cutout is reinforced with additional plate or steel members alleviating the concern of shear transfer.

- MCC Rule 4 - Doors/Buckets Secured. All doors and draw-out buckets should be secured by a latch or fastener. The concern is that the doors and draw-out buckets could open during an earthquake and repeatedly impact the housing, causing internal components to malfunction.

3.2 Low Voltage Switchgear

The equipment class of low voltage switchgear (LVS) assemblies consists of one or more circuit breakers and associated control relays, instrumentation, disconnect switches, and distribution buses mounted in a sheet metal enclosure. The term “low voltage switchgear” is associated with circuits of 600 volts or less, typically 440 to 480 volts in common applications.

The class includes switchgear assemblies composed of vertical sections which contain stacks of two to four circuit breaker cubicles. The vertical section is a sheet metal enclosure welded to a framework of steel angles or channels. Each section includes a circuit breaker or other control devices in a forward compartment and bus connections for the primary circuits in the rear compartment.

Included low voltage circuit breakers are the draw-out type. They are mounted on a roller/rail support system that allows them to be disconnected from their primary contacts at the rear, and drawn forward out of their sheet metal enclosure for maintenance. While in operation, the circuit breaker clamps to bus bars in the rear of the switchgear assembly. Additional positive attachment of the breaker to its enclosure is made by a mechanical jack or racking mechanism which slides the breaker in or out of its operating position.

The class includes the following types of sub-components: spring-actuated electric contacts, a closing solenoid, various types of tripping devices (overcurrent, shunt, under voltage), fuses, and auxiliary switches.

Low voltage breakers may be combined in assemblies with transformers, distribution panels, medium voltage breakers, and motor controllers. Circuit breakers, relays, instrumentation, the switchgear assembly enclosure, internal transformers, attachments such as junction boxes, and attached conduit and cables are included in the Low Voltage Switchgear equipment class.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Low Voltage Switchgear (LVS) if the switchgear meets the intent of the following inclusion rules and caveats.

- LVS Rule 1 - Earthquake Experience Equipment Class. The low voltage switchgear should be similar to and bounded by the LVS class of equipment described above.
  - Voltage rating 600V or less
  - Height about 90 inches
  - Depth about 60 inches
  - Individual sections 20 to 36 inches wide
  - Individual section weight does not exceed 2000 lb
  - Individual sections bolted together
  - Constructed to ANSI C37.20 or similar standard
- LVS Rule 2 - Side-to-Side Restraint of Breaker. The support structure for circuit breakers of the draw-out type should have side-to-side restraint to limit relative motion with respect to the cabinet. The concern is to prevent damage or disconnection of secondary contacts. Restraint may be provided by the breaker support structure or by a special lateral restraint device.
- LVS Rule 3 - Externally Attached Items Rigidly Anchored. Externally attached items should be rigidly attached to the cabinet. The concern addressed is that these items could impact other components of the switchgear as a seismic interaction hazard. As an example, some electrical cabinets have small, externally attached panels mounted on hinges to the main cabinet frame. During seismic motion the externally attached panel may swing and cause significant impact loading to the electrical panel.
- LVS Rule 4 - No Large Cutouts. Cutouts in the lower half of cabinet sheathing should be less than 30% of the width of the side panel, and the height of the cutout should be less then 60% of the width of the side panel. This rule also applies to side panels between multi-bay cabinets. Cutout restrictions do not apply to the bus transfer compartment if the remaining part of the enclosure conforms to the cutout limitation. The concern is that the shear load from the earthquake will not be able to be transferred through the shear walls to the anchorage. Reinforcement around the cutout with additional plate or steel members may alleviate the concern of shear transfer.
- LVS Rule 5 - Doors Secured. All doors should be secured by a latch or fastener. The concern addressed by this rule is that loose doors could repeatedly impact the housing and damage internal components.

3.3 Medium Voltage Switchgear

The equipment class of medium voltage switchgear (MVS) consists of one or more circuit breakers and associated control relays and instrumentation mounted in a sheet metal enclosure. The equipment class includes electrical switching and fault protection circuit breakers for systems powered between 2400 and 4160 volts. Medium voltage circuit breakers are mounted in sheet metal cabinets which are bolted together, side-by-side, to form a switchgear assembly.

Medium voltage circuit breakers or load interrupter switches are often integrated into unit substations that may include a transformer (typically 4160/480 volt), a set of low voltage switchgear, or a distribution switchboard. The switchgear assembly also may include internal transformers, junction boxes, and attached conduit and cables. The basic component of a medium voltage switchgear assembly is a metal-clad enclosure, typically containing a circuit breaker compartment in a lower section and a metering compartment in an upper section. The rear of the enclosure is a separate compartment for primary electrical connections. The enclosure consists of sheet metal panels welded to a supporting frame of steel angles or channels. Individual enclosures are typically 90 inches in height and approximately 90 inches in depth. The width of an enclosure typically varies from 24 to 36 inches, depending on the size of the circuit breaker within. The weight of a metal-clad enclosure ranges from 2000 to 3000 pounds, with the circuit breaker itself weighing from 600 to 1200 pounds.

Electro-mechanical relays are mounted either to the swinging doors at the front of the enclosure, or to the interior of the metering compartment. Relays are typically inserted through cutouts in the door and secured by screws through a mounting flange into the sheet metal. The metering compartment may also contain components such as ammeters, voltmeters, hand switches, and small transformers.

Commonly used medium voltage circuit breakers include the drawout-type air-magnetic circuit breakers, and stationary load interrupter switches. Each type is discussed in this section.

Draw-out, air-magnetic circuit breakers are mounted on rollers to allow them to be wheeled in and out of their individual sheet metal enclosures. There are two general types of draw-out circuit breakers: the horizontally racked model and the vertically racked model.

The horizontally racked model has clamping bus connections at its rear. It is racked into operating position by a mechanical jack that rolls the circuit breaker into contact with the bus connections at the rear of its enclosure and secures it in place. The weight of the circuit breaker rests on the floor.

Vertically racked circuit breakers roll into position within their enclosure and are then engaged by a jack built into the walls of the enclosure. The jack lifts the circuit breaker several inches above the floor, until the clamping connections atop the circuit breaker contact the bus connections at the top of the enclosure. The weight of the circuit breaker is then supported on the framework of the sheet metal enclosure. Lateral restraint of the circuit breaker should be provided by the cabinet framing and not solely by the jack lifts.

Air-magnetic circuit breakers typically include the following types of components: spring-actuated contacts, tripping devices, auxiliary switches, and fuses. Typical capacities for medium voltage circuit breakers range from 1200 to 3000 amperes.

Load interrupter switches perform the load connecting and interrupting function of circuit breakers, but do not include the same capabilities of electrical fault protection. Interrupter switches are bolted into sheet metal enclosures and are therefore designated as stationary devices. Like air-magnetic circuit breakers, interrupter switches usually operate with spring-actuated contacts to ensure quick opening of the primary circuit.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Medium Voltage Switchgear (MVS) if the switchgear meets the intent of the following inclusion rules and caveats.

- MVS Rule1 - Earthquake Experience Equipment Class. The switchgear should be similar to and bounded by the MVS class of equipment described above.
  - Voltage between 2400V and 4160V
  - Height about 90 inches
  - Depth about 90 inches
  - Individual enclosures 24 to 36 inches wide
  - Individual enclosures weigh 2000 to 3000 lb
  - Individual sections bolted together
  - Breakers either drawout-type air-magnetic or stationary load interrupter
  - Constructed to ANSI C37.20 or similar standard
- MVS Rule 2 - Transformers Restrained from Relative Motion. Potential transformers and/or control power transformers mounted on the switchgear should have restraints that limit relative motion of the transformers to prevent damage or disconnection of contacts. In particular, trunnion-mounted transformers should have positive vertical restraint to keep the trunnion pin in its cradle. Positive vertical restraint of the trunnion pin is not required if the seismic demand at the base of the switchgear cabinet is less than or equal to about l/2 of 1.5 x Bounding Spectrum, i.e., less than 0.75 x Bounding Spectrum.
- MVS Rule 3 - Externally Attached Items Rigidly Anchored. Externally attached items should be rigidly attached to the cabinet. The concern is that these items could impact other components of the switchgear as a seismic interaction hazard. As an example, some electrical cabinets have small, externally attached panels mounted on hinges to the main cabinet frame. During seismic motion the externally attached panel may swing and cause significant impact loading to the electrical panel.
- MVS Rule 4 - No Large Cutouts. Cutouts in the lower half of cabinet sheathing should be less than 30% of the width of the side panel, and the height of the cutout should be less than 60% of the width of the side panel. This rule also applies to side panels between multi-bay cabinets. Cutout restrictions do not apply to the bus transfer compartment if the remaining part of the enclosure conforms to the cutout limitations. The concern is that the shear load from the earthquake will not be able to be transferred through the shear walls to the anchorage. Reinforcement around the cutout with additional plate or steel members may alleviate the concern of shear transfer.

- MVS Rule 5 - Doors Secured. All doors should be secured by a latch or fastener. The concern addressed by this rule is that the doors could open during an earthquake, and the loose door could impact the housing and internal components.

3.4 Transformers

The equipment class of transformers (TRN) includes the unit substation type, typically 4160/480 volts, and the distribution type, typically 480/120 volts. Small transformers that are components of electrical equipment, such as motor control centers or control panels, are not included in this equipment class but are addressed as components of other classes of electrical equipment.

Unit substation transformers step power down from the medium voltage levels (4160 volts for use in large mechanical equipment) to lower voltage levels (480 volts) for use in smaller equipment. Distribution transformers step power from the 480 volt level to the 120 to 240 volt level to operate small mechanical equipment, battery chargers, or lighting systems.

Unit substation transformers included in the equipment class can be freestanding or attached to motor control centers or switchgear assemblies. This transformer type may be either liquid- or air-cooled. Liquid-cooled units consist of a rectangular steel tank filled with oil or a similar insulating fluid. The transformer coils are submerged in a liquid bath which provides cooling and insulation within the steel tank casing. Liquid-filled transformers have one or more radiator coils attached to the side of the transformer.

Air-cooled or dry-type unit substation transformers are similar in size and construction to liquid-cooled units, except the transformer coils are mounted in a ventilated steel enclosure, rather than a liquid bath. Larger air-cooled unit substation transformers have small fans mounted to their enclosures for forced air-cooling.

Distribution transformers are air-cooled. The construction of distribution transformers is essentially the same as that of unit substation transformers, except for a difference in size. The sizes of typical distribution transformers range from small wall-mounted or cabinet-mounted units that have overall dimensions of about 10 inches in height, width, and depth, and weights of 50 to 100 pounds; to larger floor-mounted units with dimensions ranging up to the size of unit substation transformers and weights ranging up to 5000 pounds.

The transformer equipment class includes the enclosure along with the internals and attached cable and conduit.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Transformer (TRN) if the transformer meets the intent of the following inclusion rules and caveats.

- <u>TRN Rule 1 - Earthquake Experience Equipment Class</u>. The transformer should be similar to and bounded by the TRN class of equipment described above.
  - Unit substation transformers
    - Primary voltage 2400 to 4160V, secondary 480V
    - 60 to 80 inches height
    - 40 to 100 inches depth
    - 40 to 100 inches width
    - 2000 to 15,000 lb weight
    - Individual sections bolted together
  - Distribution transformers
    - Primary voltage 480V, secondary 120 to 240V
    - Wall or cabinet mounted
    - Height up to 80 inches
    - Weight up to 5000 lb
    - Individual sections bolted together
- <u>TRN Rule 2 - Transformer Coils Positively Restrained Within Cabinet</u>. For floor-mounted dry- and oil-type units, the transformer coils should be positively restrained within their cabinet so that relative sliding and rocking motions between the transformer coil and their cabinet is kept to an acceptable level. The concern is that excessive relative motions may damage the wiring yoke, or that the coils may come in contact with their cabinet which may result in a short circuit or damage to the electrical insulation. This rule especially applies to transformers whose installation procedure recommends that bolts used to anchor the coils during shipping be removed.
- <u>TRN Rule 3 - Coils Top-Braced or Analyzed for Large Transformers</u>. Large transformers of 750 kVA or larger should also have the top of the coils braced by a structural frame or should be analyzed for adequate restraint.
- <u>TRN Rule 4 - Clearance Between Energized Component and Cabinet</u>. For 750 kVA transformers and larger, there should be at least a 2-inch gap between the energized component and the upper portion of the transformer cabinet. If the gap is less than 2 inches, it should be verified by analysis that there is sufficient gap and/or there should be provisions for relative lateral displacement to preclude contact between the energized component and the cabinet. The concern is that without adequate clearance, transformers could be shorted out during the earthquake and thereby rendered inoperable.

- TRN Rule 5 - Adequate Slack in High Voltage Leads. For 750 kVA transformers and larger, the connection between the high voltage leads and the first anchor point should accommodate at least a 3-inch relative displacement, or should be analyzed for adequate slack for relative displacement.
- TRN Rule 6 - Wall-Mounted Units Anchored Close to Enclosure Support. The transformer coil contained in wall-mounted units should have engineered anchorage and be anchored to its enclosure near the enclosure support surface. The concern is that a well-engineered load path should exist for earthquake loadings from the transformer coil (which is relatively massive), through the enclosure, and to the enclosure support.
- TRN Rule 7 - Doors Secured. All doors should be secured by a latch or fastener. The concern addressed by this rule is that the doors could open during an earthquake, and the loose door could repeatedly impact the housing and damage internal components.

3.5 Horizontal Pumps

The equipment class of Horizontal Pumps (HP) includes all pumps which have their axes aligned horizontally. The class includes pumps driven by electric motors, reciprocating piston engines, and steam turbines. The common peripheral components such as conduit, instrumentation, and suction and discharge lines up to their first support on the building or nearby structure are included in this equipment class.

The class includes single- and multi-stage kinetic (rotary impeller) and positive displacement pumps. Kinetic pumps move fluid using the kinetic energy of a rotating impeller. Positive displacement pumps move fluid by volumetric displacement.

Most kinetic pumps in the database are powered by electric motors with the pump and motor sharing the same shaft through a close-coupled connection. Larger multi-stage pumps couple the motor and pump through a gearbox, which allows the pump and motor to turn at different speeds. Some smaller, single-stage pumps have the motor and impeller within the same casing. Larger pumps, both single- and multi-stage, have the motor and pump in separate casings, with both casings anchored to the same steel skid or concrete pedestal. Some kinetic pumps are powered by engines or steam turbines.

Reciprocating-piston positive displacement pumps are similar in design to reciprocating-piston air compressors. They include an electric motor that powers a set of piston impellers through a shaft or belt connection. The piston impellers are mounted within a cast block that also contains the piston crank shaft and valve mechanism.

Rotary-screw positive displacement pumps are somewhat similar to multi-stage kinetic pumps, except that the screw impeller moves fluid axially through volume displacement rather than through a transfer of kinetic energy from the impeller to the fluid. The screw impeller is powered by an electric motor through a close-coupled shaft.

Kinetic and positive displacement horizontal pumps driven by electric motors, engines, and turbines are represented in the range from 5 to 2300 HP and 45 to 36,000 gpm. Submersible pumps are not included in this equipment class.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Horizontal Pump (HP) if the pump meets the intent of the following inclusion rules and caveats.

- HP Rule 1 - Earthquake Experience Equipment Class. The horizontal pump should be similar to and bounded by the HP class of equipment described above.
  - Driven by electric motor, engine or steam turbine
  - Drive motor not over 2300 HP
  - Flow rate not over 36,000 gpm
  - Not a submersible pump
- HP Rule 2 - Driver and Pump on Rigid Skid. The driver and pump should be connected by a rigid base or common skid. The concern is that differential displacement between the pump and driver may cause shaft misalignment. If they are not mounted on a rigid skid, the potential for differential displacement between the driver and pump should be specially evaluated.
- HP Rule 3 - Thrust Bearings in Both Axial Directions. Thrust restraint of the shaft in both axial directions should exist. The concern arose from shake table testing on pumps without thrust bearings that performed poorly. In general, pumps from U.S. manufacturers have such axial thrust restraint so that explicit verification is not necessary; however, any indication to the contrary should be investigated.
- HP Rule 4 - Check of Long Unsupported Piping. Consideration should be given to identify situations where the horizontal pump may be affected by gross pipe motion, differential displacement, and excessive nozzle loads. The concern is that excessive force on pump nozzles could potentially break the pump nozzle or cause sufficient pump case distortion to cause binding, or fail the anchorage. These excessive forces are uncommon and need only be considered if there is a long section of unsupported pipe or a heavy valve attached to the pipe near the pump.
- HP Rule 5 – Base Vibration Isolation System Checked. Several types of horizontal pumps, including pumps that are sub-assemblies of other equipment, can be mounted on vibration isolation systems. If the unit is mounted on vibration isolators, the adequacy of the vibration isolators for seismic loads should be evaluated in accordance with Section 2.1.
- HP Rule 6 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., cooling, air, and electrical) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.

3.6 Vertical Pumps

The equipment class of Vertical Pumps (VP) includes pumps with the impeller drive shaft mounted in a vertical (as opposed to horizontal) direction. Vertical pumps in the database are powered by an electric drive motor, vertically aligned, and mounted atop a steel or cast-iron support frame that is anchored to a concrete base pad.

The two general types of vertical pumps represented in the earthquake experience equipment class are deep-well pumps and centrifugal pumps. Motor sizes range from 5 to 7000 hp and flow rates range from 95 to 16,000 gpm.

Deep-well turbine type pumps have the pump impeller attached to the bottom of a long vertical drive shaft extending beneath the pump base plate. The pump drive shaft is enclosed in a steel or cast iron casing which extends below the pump base plate. The pump impeller is mounted in a contoured housing or bowl at the base of the casing. The casing or suction pipe is immersed in a well and opened at the bottom for fluid inlet.

A variation of the deep-well turbine pump is the can-type pump. The casing that encloses the impeller drive shaft is, in turn, enclosed by an outer casing or can. Fluid feed to the pump flows through an inlet line, usually mounted in the support frame above the pump base plate. The can forms an annular reservoir of fluid that is drawn into the impeller at the base of the inner casing.

Deep-well pumps range in size from fractional horsepower units to pumps of several thousand horsepower. The casings, cantilevered below the base plate, have typical lengths of 10 to 20 feet. The most massive component of the pump is normally the drive motor, which may weigh several tons.

Single-stage centrifugal pumps are configured with the impeller mounted above the base plate, directly beneath the drive motor. The impeller is housed in a casing that is usually part of the support frame for the drive motor. Instead of drawing fluid from a well or can beneath the pump base plate, the fluid inlet is a piping attachment aligned with a centerline of the impeller drive shaft. The discharge line is tangential to the periphery of the centrifugal impeller casing. Smaller centrifugal pumps are sometimes mounted directly on the piping system they serve.

The pump, drive motor, associated instrumentation and controls attached to the pump, and attached piping and conduit up to their first support on the building or nearby structure are included in the vertical pump equipment class. The equipment class does not include submersible pumps.

The Bounding Spectrum Pump (BS) represents the seismic capacity of a Vertical (VP) if the pump meets the intent of the following inclusion rules and caveats.

- <u>VP Rule 1 – Earthquake Experience Equipment Class</u>. The vertical pump should be similar to and bounded by the VP class of equipment described above.
  - Powered by electric motor

  - HP not over 7000
  - Flow rate not over 16,000 gpm
  - Cantilever impeller shaft on deep well pump has radial bearing at the impeller
  - Unsupported cantilever impeller shaft less than 20 feet long

- VP Rule 2 - Check of Long Unsupported Piping. Consideration should be given to identify situations where the vertical pump may be affected by gross pipe motion, differential displacement, and excessive nozzle loads. The concern is that excessive force on pump nozzles could potentially break the pump nozzle or cause sufficient pump case distortion to cause binding, or fail the anchorage. These excessive forces are uncommon and need only be considered if there is a long section of unsupported pipe or a heavy valve attached to the pipe near the pump.
- VP Rule 3 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., cooling, air, and electrical) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.

3.7 Fluid-Operated Valves

The equipment class of Fluid-Operated Valves (FOV) includes diaphragm-operated, piston-operated, and pressure relief valves. The most common type of fluid-operated valve found in power plant applications is a spring-opposed, diaphragm-operated pneumatic valve. The bell housing contains a diaphragm (usually a thin, steel membrane) which forms a pressure barrier between the top and bottom sections of the housing. The position of the actuated rod (or valve stem) is controlled by a return spring and the differential pressure across the diaphragm. The actuated rod position, in turn, controls the position of the valve. A yoke supports the bell housing and connects it to the valve body. A solenoid valve or, on larger valves, a pneumatic relay controls the air pressure difference across the diaphragm. This solenoid valve or pneumatic relay is often mounted directly to the operator yoke.

Piston-operated valves are similar to diaphragm-operated valves, with a piston replacing the diaphragm as the valve actuator. The piston typically acts in opposition to a spring to control the position of the valve. Liquid-operated (i.e., hydraulic) piston valves are not included in the FOV class of equipment

Pressure relief valves are also included in this equipment class. Pressure relief valves balance confined fluid pressure against the force of a spring. The actuating force in a pressure relief valve is supplied by the fluid that is confined by the valve. Fluid-operators are typically cantilevered either above or to the side of the valves they serve. The valve and actuator can form a continuous body, or the actuator can be attached to the valve through a flanged, threaded, or ring clamp connection.

The valve, the operator, the inlet and outlet lines up to their first support on the building or nearby structure, and peripheral attachments (air lines, pneumatic relays, control solenoids, and conduit) are included in the Fluid-Operated Valve equipment class. The valve may be of any type, size, or orientation.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Fluid-Operated Valve (FOV) if the valve meets the intent of the following inclusion rules and caveats.

- <u>FOV Rule 1 - Earthquake Experience Equipment Class</u>. The valve should be similar to and bounded by the FOV class of equipment described above.
  - Hydraulic piston-operated valves excluded
  - Pipe size 1-inch or larger
  - Distance from centerline of pipe to top of operator or cylinder does not exceed distance given in Figure 3-1
  - For heavy piston-operated valves, distance from centerline of pipe to top of operator or cylinder and weight of the operator do not exceed the values given in Figure 3-2
- <u>FOV Rule 2 - Valve Body Not of Cast Iron</u>. The valve body should not be made of cast iron. The intent of this rule is to avoid the brittle failure mode of cast iron as evidenced by the poor performance of some cast iron components in past earthquakes.
- <u>FOV Rule 3 - Valve Yoke Not of Cast Iron for Piston-Operated Valves and Spring-Operated Pressure Relief Valves</u>. The yoke of piston-operated valves and spring-operated pressure relief valves should not be made of cast iron. The intent of this rule is to avoid the brittle failure mode of cast iron as evidenced by the poor performance of some cast iron components in past earthquakes.
- <u>FOV Rule 4 - Actuator and Yoke Not Independently Braced</u>. The valve actuator and yoke should not be braced to the building structure unless the pipe is also braced to the same structure immediately adjacent to the valve.
- <u>FOV Rule 5 - Sufficient Slack and Flexibility of Attached Lines</u>. Sufficient slack and flexibility should be present in attached lines (e.g., air) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.

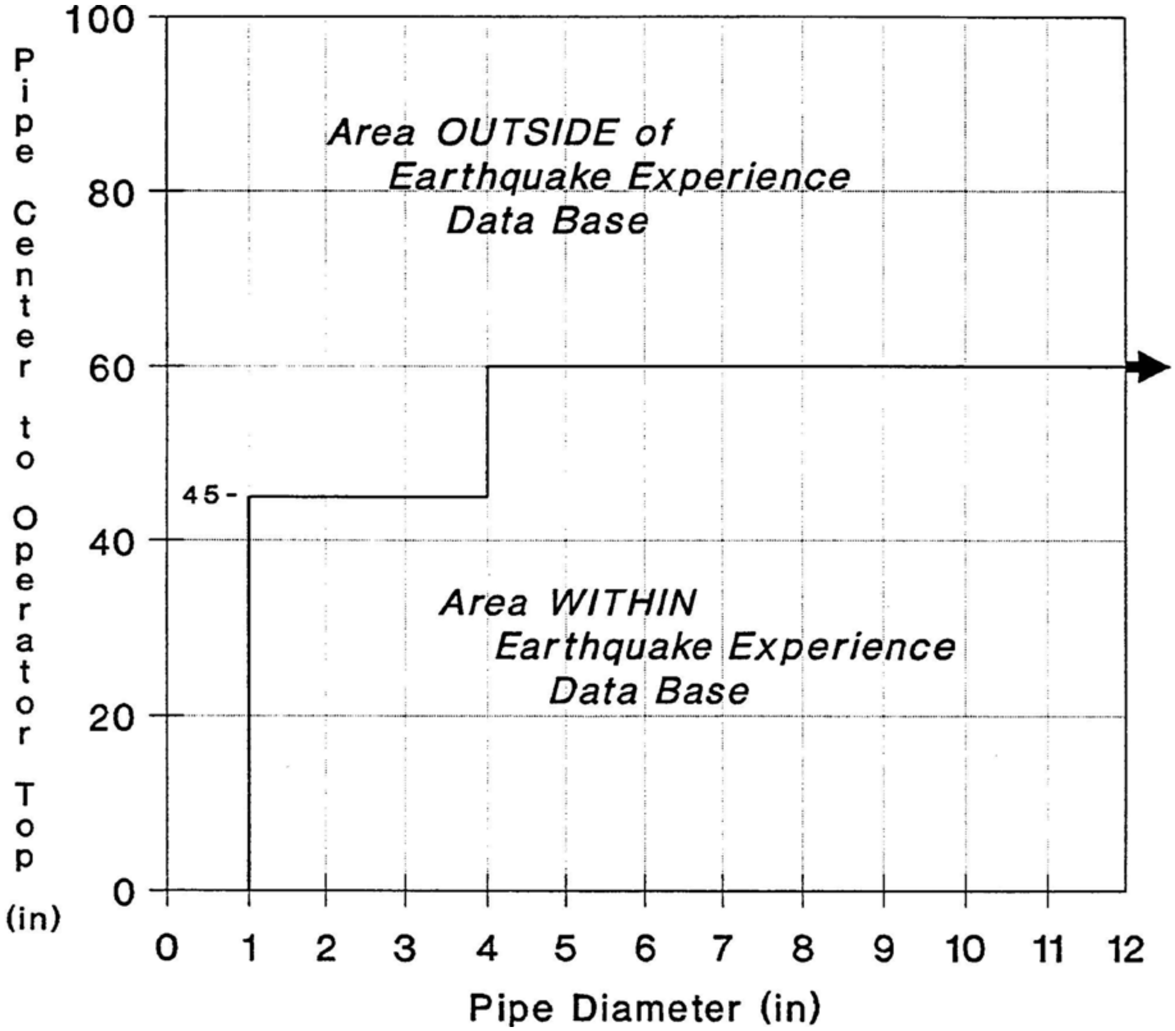
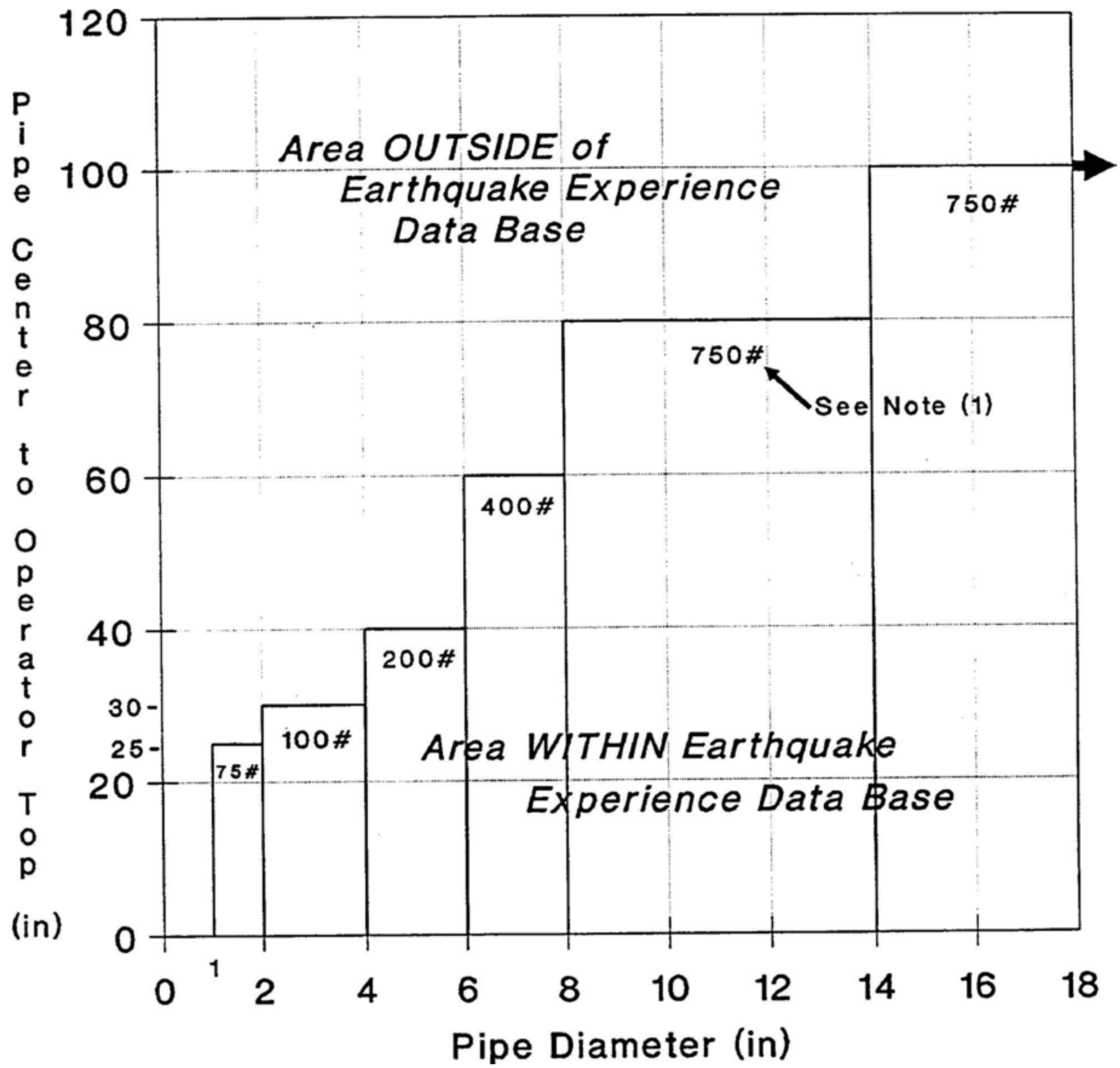


Figure 3-1
Valve Operator Cantilever Length Limits for Air-Operated Diaphragm Valves, Spring-Operated Pressure Relief Valves and Light Piston-Operated Valves

Source: Reference 2



(1) Approximate Maximum Operator Weights Given for Various Ranges of Pipe Diameter

Figure 3-2
Valve Operator Cantilever Length Limits for Heavy Piston-Operated Valves

Source: Reference 2

3.8 Motor Operated and Solenoid Operated Valves

3.8.1 Motor-Operated Valves

The equipment class of Motor-Operated Valves (MOV) includes a wide diversity of sizes, types, and applications.

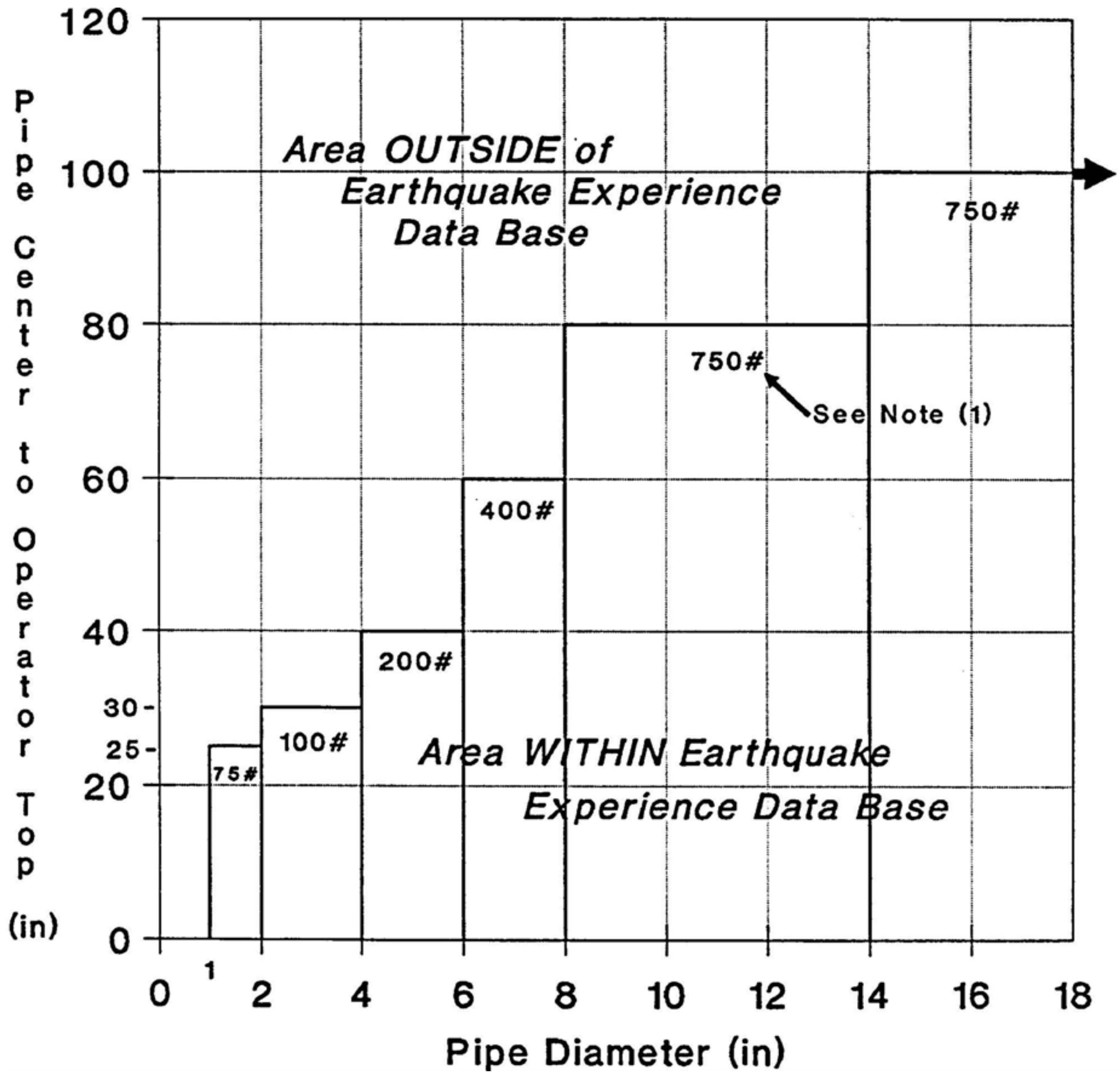
Components of a motor-operated valve include a motor operator with a control box, gearbox, and drive motor. The gearbox includes the gears which link the valve actuation to the drive motor shaft. Local controls typically include a relay for actuating the primary circuit to the motor, and torque and limit switches for coordinating the drive motor and the valve position. Valve operators may have a local motor controller built into the operator housing. The valve actuator shaft typically passes through the steel support frame or yoke. The valve which is actuated by a motor operator may be of any type, size, or orientation.

Motor operators may be mounted in any position (e.g., cantilevered vertically above, below, or to the side of the valve). The yoke, which connects the operator to the valve body, may take the form of a steel pipe enclosing the actuator shaft or a frame of welded beams. The attachments of the motor-gearbox to the yoke and the yoke to the valve are typically bolted flange connections, threaded connections, or ring clamps. In some applications, motor operators are mounted at a remote location above the valve.

The equipment class of motor-operated valves includes all valves actuated by an electric motor. The valve, the operator, and the inlet and outlet lines and attached conduit up to their first support on the building or nearby structure are included in the Motor-Operated Valve equipment class.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Motor-Operated Valve (MOV) if the valve meets the intent of the following inclusion rules and caveats.

- MOV Rule 1 - Earthquake Experience Equipment Class. The valve should be similar to and bounded by the MOV class of equipment described above.
  - Pipe size 1-inch or larger
  - Distance from centerline of pipe to top of operator and weight of operator do not exceed values given in Figure 3-3
- MOV Rule 2 - Valve Body Not of Cast Iron. The valve body should not be made of cast iron. The intent of this rule is to avoid the brittle failure mode of cast iron as evidenced by the poor performance of some cast iron components in past earthquakes.
- MOV Rule 3 - Valve Yoke Not of Cast Iron. The yoke of the motor-operated valve should not be made of cast iron. The intent of this rule is to avoid the brittle failure mode of cast iron as evidenced by the poor performance of some cast iron components in past earthquakes.
- MOV Rule 4 - Actuator and Yoke Not Independently Braced. The valve actuator and yoke should not be braced to the building structure unless the pipe is also braced to the structure close to the valve. The concern is that if the operator is independently supported from the valve body and attached piping, then the operator may act as a pipe support during seismic motion and attract considerable load through the yoke and possibly fail the yoke or bind the shaft.
- MOV Rule 5 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., electrical) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.



(1) Approximate Maximum Operator Weights Given for Various Ranges of Pipe Diameter

Figure 3-3
Valve Operator Cantilever Length Limits for Motor-Operated Valves

Source: Reference 2

3.8.2 Solenoid-Operated Valves

The equipment class of Solenoid-Operated Valves (SOV) includes a wide diversity of sizes, types, and applications.

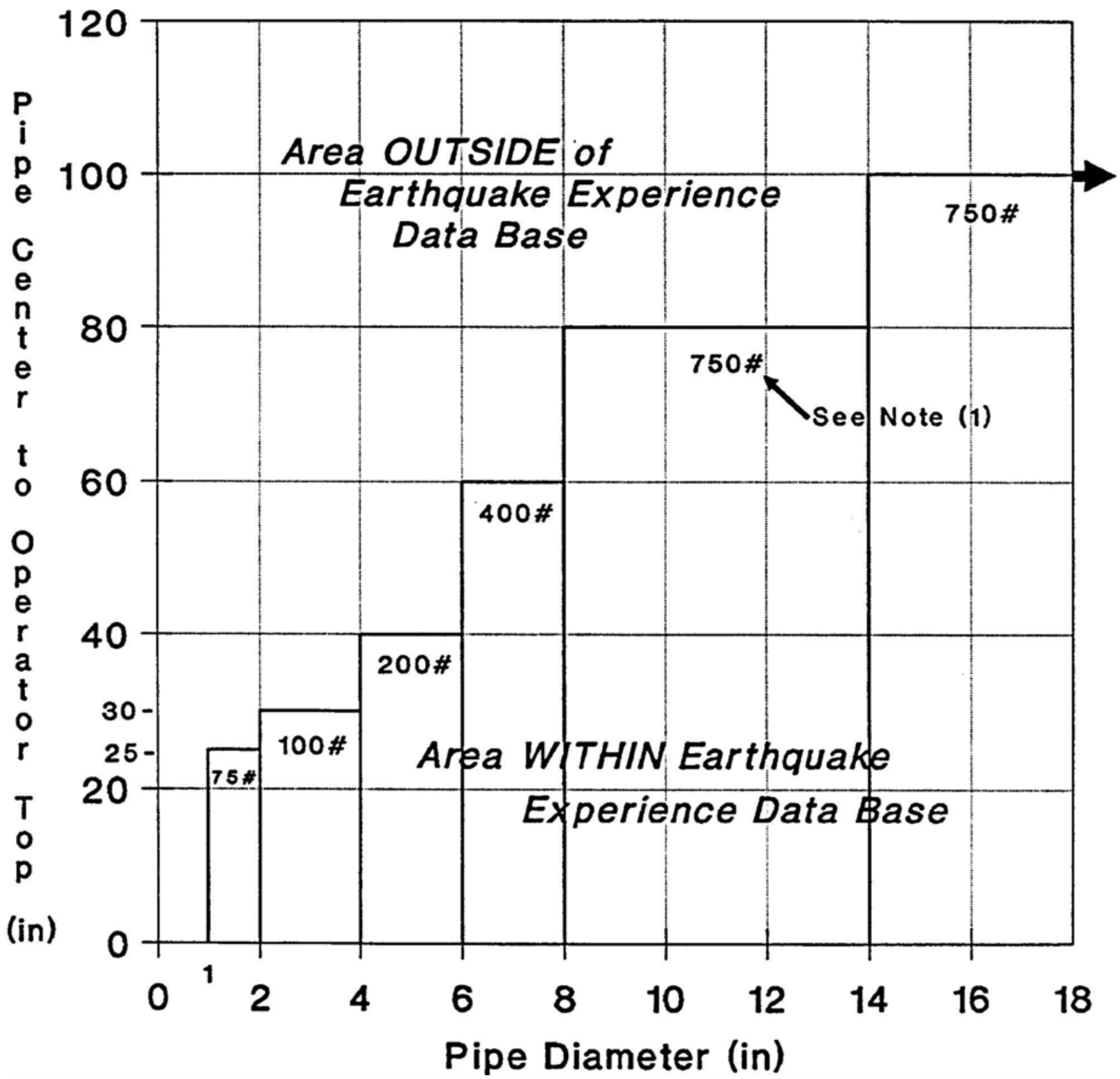
Solenoid operators are smaller and lighter than motor operators. Solenoid-operated valves are actuated by passing an electrical current through a coil, thereby creating a magnetic field which opens or closes the valve. Solenoid operators are generally more compact than motor operators with less of a cantilevered mass supported from the valve body. In addition, solenoid-operated valves are typically mounted on smaller diameter lines than MOVs.

The equipment class of solenoid-operated valves includes all valves actuated by a solenoid. The valve, the operator, and the inlet and outlet lines and attached conduit up to their first support on the building or nearby structure are included in the Solenoid-Operated Valve equipment class.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Solenoid-Operated Valve (SOV) if the valve meets the intent of the following inclusion rules and caveats.

- SOV Rule 1 - Earthquake Experience Equipment Class. The valve should be similar to and bounded by the SOV class of equipment described above.
  - Distance from centerline of pipe to top of operator and weight of operator do not exceed values given in Figure 3-4
- SOV Rule 2 - Valve Body Not of Cast Iron. The valve body should not be made of cast iron. The intent of this rule is to avoid the brittle failure mode of cast iron as evidenced by the poor performance of some cast iron components in past earthquakes.
- SOV Rule 3 - Valve Yoke Not of Cast Iron. The yoke of the solenoid-operated valve should not be made of cast iron. The intent of this rule is to avoid the brittle failure mode of cast iron as evidenced by the poor performance of some cast iron components in past earthquakes.
- SOV Rule 4 - Actuator and Yoke Not Independently Braced. The valve actuator and yoke should not be braced to the structure unless the pipe is also braced to the structure close to the valve.
- SOV Rule 5 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., electrical) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.

Heavy Valve Operator
Cantilever Limits



(1) Approximate Maximum Operator Weights Given for Various Ranges of Pipe Diameter

Figure 3-4
Valve Operator Cantilever Length Limits for Solenoid-Operated Valves

Source: Reference 2

3.9 Fans

The equipment class of Fans (FAN) includes both freestanding and duct-mounted fans. Fans that are components of other classes of equipment such as air handlers are included in those equipment. Blowers and exhausters are included in this equipment class. The two types of fans in this equipment class are axial fans and centrifugal fans.

Differential pressures for fans in the class range up to 12 inches of water. Air flow rates range from less than 1000 cubic feet per minute (cfm) to flows on the order of 50,000 cfm. Corresponding fan drive motors range from 1 hp to 200 hp. Weights of fan units range from 100 to 1000 pounds.

Axial fans are used in relatively low pressure applications such as building HVAC systems or cooling towers. Propeller fans and vane-axial fans are the two major types of axial fans. Propeller axial fans consist of two or more blades assembled on a central shaft and revolving within a narrow mounting-ring. Propeller fans are often mounted to a wall or ceiling. Vane-axial fans have an impeller wheel, typically with four to eight blades, mounted to a central shaft within a cylindrical casing. Vane-axial fans are generally used in higher pressure, higher flow applications than propeller fans. Vane-axial fans include a set of guide vanes mounted either before or after the impeller that streamline the air flow for greater efficiency. A variation of vane-axial design is the tube-axial fan, which includes the higher pressure impeller wheel mounted within a cylindrical casing, but without the provision of vanes.

Certain axial fan designs include multiple impellers for increased pressure boost. Axial-flow fans are normally mounted inside cylindrical ducting, supported by radial struts running from the duct wall to the duct centerline. Electric drive motors are usually mounted along the duct centerline immediately upstream of the impeller. The impeller and drive shaft are normally cantilevered from the motor. Alternate designs mount the motor on the outside of the duct with a belt connection between the motor and the impeller drive shaft.

Centrifugal fans are divided into three major categories depending upon the position of their blades. The three blade positions are forward-curved, radial, and backward-inclined. Forward-curved centrifugals have blades inclined toward the direction of rotation at the tip. These fans produce high flow volumes at low static pressures. Radial-blade centrifugals have their blades positioned on the radii extending from their axis of rotation. Backward-inclined fans are a type of centrifugal fan and have their blades inclined opposite to the direction of rotation at the tip.

Centrifugal fans have a cylindrical intake duct centered on the fan shaft and a square discharge duct directed tangentially from the periphery of the fan. A variation of the centrifugal fan is the tubular centrifugal fan which redirects the discharged air in the axial direction. As with axial-flow fans, centrifugal fans can have the electrical drive motor mounted either directly on the fan shaft, or outside of the fan casing with a belt drive to the fan. The impeller and drive shaft may have either a single-point, where they are cantilevered from the motor, or a two-point support, where the shaft is supported both at the motor and at an end bearing.

The fan impeller and its enclosure, drive motor, attached ducting, mounted louvers, and attached conduit and instrumentation lines are included in the Fan equipment class.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Fan (FAN) if the fan meets the intent of the following inclusion rules and caveats.

- FAN Rule 1 - Earthquake Experience Equipment Class. The fan should be similar to and bounded by the FAN class of equipment described above.
  - Vane axial or centrifugal fan
  - Differential pressure not over 12 inches water
  - Air flow not over 50,000 cfm
  - Drive motor not over 200 HP
  - Fan weight not over 1000 lb
  - Motor and fan anchored to common base
- FAN Rule 2 - Drive Motor and Fan Mounted on Common Base. The driver and fan should be connected by a common base or attached in a way to limit differential displacement. The concern is that differential displacement between the driver motor and fan may cause shaft misalignment. If the driver motor and fan are not mounted on a common base, then the potential for differential displacement should be specially evaluated.
- FAN Rule 3 - Long Shafts Should be Supported at Fan and at Motor. Axial fans with long shafts between the motor and fan should have the shaft supported at the fan and at the motor. The concern is shaft misalignment. If the shaft is not supported in both locations, then a special evaluation should be conducted. The potential earthquake displacement of the shaft should be determined and compared to the operability displacement limits of the fan.
- FAN Rule 4 - No Possibility of Excessive Duct Distortion Causing Binding or Misalignment of Fan. The possibility of excessive duct distortion during an earthquake should be considered for its effect on binding or misalignment of the fan. This need only be considered in cases of long unsupported ducts near the fan or relatively stiff ducts subjected to significant relative support motion.
- FAN Rule 5 - Base Vibration Isolation System Checked. Several types of fans, including fans that are sub-assemblies of other equipment, can be mounted on vibration isolation systems. If the unit is mounted on vibration isolators, the adequacy of the vibration isolators for seismic loads should be evaluated in accordance with Section 2.1.
- FAN Rule 6 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., electrical) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.

3.10 Air Handlers

The equipment class of Air Handlers (AH) includes sheet metal enclosures containing (as a minimum) a fan and a heat exchanger. Air handlers are used for heating, dehumidifying or chilling, and distributing air.

The basic components of an air handler include a fan and a coil section. Small capacity, simple air handlers are often referred to as fan-coil units. Additional components such as filters, air-mixing boxes, and dampers are included in more elaborate air handlers. Fans (normally centrifugal) produce air flow across the coil for heat transfer. Coils act as heat exchangers in an air handler. Cooling coils are typically rectangular arrays of tubing with fins attached. Filters are typically mounted in steel frames which are bolted together as part of a modular system. Mixing boxes are used as a plenum for combining two airstreams before channeling the resulting blend into the air handler unit. Dampers are rotating flaps provided in the inlet or outlet sides of the air handler to control the flow of air into or out of the fan.

Air handlers are typically classified as being either a draw-through or a blow-through type. Draw-through air handlers have the heat exchanger (coil) upstream of the fan, whereas the blow-through design locates the coil downstream. Air handler enclosures normally consist of sheet metal welded to a framework of steel angles or channels. Typical enclosures range in size from two feet to over ten feet on a side, with weights ranging from a few hundred pounds to several thousand pounds. Large components, such as fans and coils, are typically bolted to internal frames which are welded to the enclosure framing. Fans may be located in a variety of orientations with respect to the coil unit.

Air handlers typically include a system of attached ducts which provide for the intake and discharge of air. Additional attachments to air handlers include piping and cooling water or refrigerant, electrical conduit, and instrumentation lines. Self-contained air conditioning units are a variation of air handlers, in which the sheet metal enclosure includes a small refrigeration unit. Note that large centralized chillers are addressed as a separate equipment class (3.10).

Air handler configurations range from large floor-mounted units to smaller units suspended on rod hangers from ceilings. The sheet metal enclosure, fans and motors, heat exchanger coils, air filters, mixing boxes, dampers, attached ducts, instrument lines, and conduit are included in the Air Handler equipment class.

The SQUG Reference Spectrum (RS) represents the seismic capacity of an Air Handler (AH) if the air handler meets the intent of the following inclusion rules and caveats.

- AH Rule 1 - Earthquake Experience Equipment Class. The air handler should be similar to and bounded by the AH class of equipment described above.
  - Large components, such as fans and coils, are bolted to internal frames which are welded to the enclosure framing

- AH Rule 2 - Anchorage of Internal Component. In addition to reviewing the adequacy of the unit's base anchorage, the attachment of heavy internal equipment in the air handler must be assessed.
- AH Rule 3 - Doors Secured. All doors should be secured by a latch or fastener. The concern addressed by this rule is that the door may act as an integral structural member and may need to be latched to provide both stiffness and strength to the unit.
- AH Rule 4 - No Possibility of Excessive Duct Distortion Causing Binding or Misalignment of Internal Fan. If the air handling unit contains a fan, then the possibility of excessive duct distortion during an earthquake should be considered for its effect on binding or misalignment of the fan. This need only be considered in cases of long unsupported ducts near the air handling unit or relatively stiff ducts subjected to significant relative motion.
- AH Rule 5 - Base Vibration Isolation System Checked. Several types of air handlers, including sub-assemblies air handlers, can be mounted on vibration isolation systems. If the unit or portions of it are mounted on vibration isolators, the adequacy of the vibration isolators for seismic loads should be evaluated in accordance with Section 2.1.
- AH Rule 6 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., cooling, air, and electrical) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.

3.11 Chillers

The equipment class of Chillers (CHL) includes skid-mounted units comprised of components such as a compressor, a condenser, an evaporator, and a control and instrumentation panel. Chillers condense refrigerant or chill water for indoor climate-control systems which supply conditioned air for equipment operating environments and for personnel comfort.

Compressors draw vaporized refrigerant from the evaporator and force it into the condenser. The compressor of a chiller unit may be either the centrifugal or the reciprocating piston type. Condensers are heat exchangers which reduce the refrigerant from a vapor to a liquid state. Chiller condensers are usually shell- and tube-type heat exchangers, with refrigerant on the shell side. Evaporators are tube bundles over which refrigerant is sprayed and evaporated, the inverse function of the condenser. Evaporator tubes can have either finned or plain surfaces. Control panels provide local chiller system monitoring and control functions. Typical components include: oil level switches/gauges, temperature switches/gauges, pressure switches/gauges, undervoltage and phase protection relays, and compressor motor circuit breakers.

Chiller components may be arranged in a variety of configurations. Typically the evaporator and condenser are mounted in a stacked configuration, one above the other, with the compressor and the control panel mounted on the side. Variations of this arrangement include the side-by-side configuration, with the compressor usually mounted above the condenser and evaporator, or a configuration with all components mounted side by side on the skid. Components are usually bolted to a supporting steel skid, which is, in turn, bolted to a concrete pad. Attachments to chillers include piping for routing cooling water or refrigerant to the unit, electrical conduit, and instrumentation and control lines. Chiller weights range up to about 40,000 lbs.

The compressor, condenser, evaporator, local control panel, support framing, and attached piping, instrument lines, and conduit which are attached to the same skid are included in the Chiller equipment class.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Chiller (CHL) if the chiller meets the intent of the following inclusion rules and caveats.

- CHL Rule 1 - Earthquake Experience Equipment Class. The chiller should be similar to and bounded by the CHL class of equipment described above.
- CHL Rule 2 - No Reliance on Weak-Way Bending of Steel Plate or Structural Steel Shapes. The evaporator and condenser tanks should be reasonably braced between themselves for lateral forces parallel to the axis of the tanks without relying on weak-way bending of steel plate or webs of structural steel shapes. The concern is that in weak-way bending the structure will not be capable of transferring the lateral earthquake loads. If weak-way steel plate bending must be relied on to brace the upper tank, then the adequacy of the steel components should be specially evaluated for adequate strength and stiffness.
- CHL Rule 3 - Check Vibration Isolation Systems. Some chiller units are mounted on base vibration isolation systems and/or are equipped with vibration isolators in the mountings of the compressors and/or motors to the evaporators or condensers. The adequacy of these vibration isolators for seismic loads should be evaluated in accordance with Section 2.1.

3.12 Air Compressors

The equipment class of Air Compressor (AC) includes freestanding air compressors together with attached components such as air intakes, air receiver tanks, local control panels, conduit, and discharge lines. Air compressors can be generally categorized as reciprocating piston or rotary screw. The equipment class of air compressors encompasses a wide range of sizes, configurations, and applications. Air compressors typically include as components: electric drive motor, piston- or impeller-driven compressor, air receiver tank, air intake filter, air aftercooler, moisture separator, lubrication system, and the control and instrument panel. Large compressors typically include water jackets to cool the compressor casing and the air aftercoolers, while smaller units are typically cooled by natural or fan-assisted convection to the surrounding air.

Air compressors supply operating pressure to pneumatic instrumentation and control systems, in particular to diaphragm-operated valves. Air compressors also charge pressurized air receiver tanks that serve the pneumatic starting systems for emergency engine-generators.

Compressor configurations in the equipment class include air receiver tank-mounted reciprocating piston or rotary screw compressors, skid-mounted reciprocating piston or rotary screw compressors, and freestanding reciprocating piston compressors.

Reciprocating piston compressors are constructed much like an automobile engine, with pistons encased in cast steel cylinders compressing the gas, and a system of timed valves controlling the inlet and discharge. Drive motor sizes typically range from fractional horsepower to over 100 horsepower. Piston air compressors generally have one or two cylinders but may include more. Cylinders are normally supported on a cast iron crankcase, which encloses the rotating crankshaft, linked either directly to the electric motor through a drive shaft, or indirectly through a belt linkage. Smaller reciprocating piston compressors are commonly mounted atop an air receiver tank.

Rotary screw compressors replace the reciprocating piston with a set of helical screws, typically encased in a cast iron block. The components and attachments of the air compressor are similar to reciprocating piston units except that the system of timed intake and discharge valves are not required. The most common configuration has the air compressor mounted on top of its air receiver tank. The units are usually not large, ranging in capacity from about 1 to 100 cfm (cubic feet per minute of discharge air), with drive motors typically ranging from fractional horsepower up to 30 HP. Tank-mounted rotary screw compressors typically range in weight from about 200 to 2500 pounds.

Reciprocating piston and rotary screw compressors may also be mounted on a steel skid. The skid may be either open or enclosed in a sheet metal housing. The skid is normally constructed of a welded steel frame with the compressor, drive motor, receiver tank, control panel, and other components bolted to the frame in some convenient configuration. Skid-mounted compressors typically range in capacity up to about 2000 cfm, with drive motors of up to about 300 HP. Skid-mounted compressors typically range in weight from about 2000 to 8000 pounds.

Freestanding compressors are usually the reciprocating piston type with one or two cylinders normally cantilevered from a crankcase. The crankcase may form the primary support for all components, or it may be mounted on a steel or cast iron pedestal. Freestanding compressors include the largest units typically found in power plant applications, ranging in capacity up to about 4000 cfm, with drive motors up to about 1000 HP. Freestanding compressors range in weight from small units on the order of about 500 pounds to units as large as 10 tons.

The Air Compressor equipment class includes the piston- or impeller-driven compressor, drive motor, air receiver tank, and attached cooling coils and air intakes, attached air discharge lines, instrument lines, and attached conduit (up to the first support away from the unit).

The SQUG Reference Spectrum (RS) represents the seismic capacity of an Air Compressor (AC) if the compressor meets the intent of the following inclusion rules and caveats.

- <u>AC Rule 1 - Earthquake Experience Equipment Class</u>. The air compressor should be similar to and bounded by the AC class of equipment described above.

- AC Rule 2 - Check Vibration Isolation Systems. Some compressor units are mounted on base vibration isolation systems and/or are equipped with vibration isolators in the compressor or drive motor mountings (e.g., if the compressor is mounted atop an air receiver tank). The adequacy of these vibration isolators for seismic loads should be evaluated in accordance with Section 2.1.
- AC Rule 3 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., cooling, air, and electrical) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.

3.13 Motor-Generators

The equipment class of Motor-Generators (MG) includes motors and generators that are coupled into a motor-generator set (M-G set). Motor-generator sets are structurally similar to horizontal pumps, which consist of an electric motor connected to a pump through a shaft. Motor-generators are basically two motors connected through a common shaft. M-G sets normally include either an AC or DC motor attached through a direct drive shaft to an AC or DC generator. A large flywheel is often mounted at one end of the shaft for storage of rotational inertia, to prevent transient fluctuations in generator output. Usually, both the motor and generator in an M-G set are mounted to a common drive shaft and bolted to a steel skid. Smaller sets sometimes house the motor and generator within the same casing. Motor-generator sets typically range in weight from about 50 to 5000 pounds.

The motor, generator, flywheel, and attached conduit are included in the Motor-Generator equipment class.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Motor- Generator (MG) if the motor-generator meets the intent of the following inclusion rules and caveats.

- MG Rule 1 - Earthquake Experience Equipment Class. The motor- generator should be similar to and bounded by the MG class of equipment described above.
- MG Rule 2 - Driver and Driven Component on Rigid Skid. The main driver and the driven component should be connected by a rigid base or common skid. The concern is that differential displacement between the driver and the driven component may bind the shaft or lead to excessive bearing wear. If they are not mounted on a rigid skid, the potential for differential displacement between the main driver and the driven component should be specially evaluated.
- MG Rule 3 - Base Vibration Isolation System Checked. Some types of motor generators can be mounted on vibration isolators. If the unit is mounted on vibration isolators, the adequacy of the vibration isolators for seismic loads should be evaluated in accordance with Section 2.1.

- MG Rule 4 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., electrical) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.

3.14 Distribution Panels

The equipment class of Distribution Panels (DP) consists of circuit breakers or fusible disconnect switches mounted in vertical stacks within sheet metal cabinets. The function of distribution panels is to distribute low voltage AC or DC power from a main circuit to branch circuits, and to provide overcurrent protection. Distribution panels typically serve AC power systems ranging up to 600 volts and DC power systems ranging up to 250 volts.

Two types of distribution panels are found in power plant electrical systems: switchboards and panelboards. Although switchboards and panelboards perform the same function, they differ in construction and application. Switchboards are typically floor-mounted assemblies, while panelboards are usually wall-mounted. Switchboards usually distribute larger quantities of power than panelboards.

Distribution switchboards are freestanding cabinets containing stacks of circuit breakers or fusible switches. They have assemblies of circuit breakers or switches mounted into shelf-like cubicles. Electrical connections are normally routed through enclosed cable compartments in the rear of the cabinet. A switchboard will sometimes include a main circuit breaker and a power metering section mounted in separate compartments within the cabinet. Switchboards are often incorporated into substation assemblies that include motor control centers, transformers, and switchgear. In typical power plant applications, the completely enclosed (safety) switchboard is almost exclusively used. These switchboards are completely enclosed in a sheet metal casing. Switchboard dimensions are standardized with individual sections ranging from 20 to 40 inches in depth and width. The height is generally 90 inches. Switchboard sections can weigh up to 500 pounds.

Distribution panelboards are defined by the National Electric Code (NEC) as panels which include buses, switches, and automatic protective devices designed for the control or distribution of power circuits. Panelboards are placed in a cabinet or cutout box which is mounted in or against a wall and accessible only from the front. The assembly of circuit breakers contained in a panelboard is normally bolted to a steel frame, which is in turn mounted to the rear or sides of the panelboard enclosure. Individual circuit breakers are either bolted or plugged into the steel chassis. A cable gutter typically runs along the side of the circuit breaker chassis. Panelboards have a wide range of cabinet sizes. Typical dimensions for wall-mounted units are 20 to 40 inches in height and width, and 6 to 12 inches in depth. Weights for wall-mounted panelboards typically range from 30 to 200 pounds.

Industry standards developed by the National Electrical Manufacturers Association and the Underwriters Laboratories (e.g., NEMA ICS-6, UL-SOS) are maintained for the construction of distribution panel enclosures. These standards determine the minimum structural framing and sheet metal thickness for distribution panel enclosures as a function of sheet metal area between supports or reinforcing.

The Distribution Panel equipment class includes the circuit breakers, fusible switches, metering compartments, switchboard/panelboard enclosure and internals, and attached conduit.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Distribution Panel (DP) if the panel meets the intent of the following inclusion rules and caveats.

- DP Rule 1 - Earthquake Experience Equipment Class. The distribution panel should be similar to and bounded by the DP class of equipment described above.
  - Up to 600V AC or 250V DC
  - Switchboard or panelboard
  - Switchboard
    - Sections 20 to 40 inches depth and width
    - Height about 90 inches
    - Weight up to 500 lb
  - Panelboard
    - Height and width 20 to 40 inches
    - Depth 6 to 12 inches
    - Weight up to 200 lb
  - Contains only circuit breakers and switches
  - Individual sections bolted together
  - Constructed to NEMA or similar standard
- DP Rule 2 - Doors Secured. All doors, latches or screwdriver-operated door fasteners should be secured. The concern addressed by this rule is that the doors could open during an earthquake and the loose door could repeatedly impact the housing and be damaged or cause internal components to malfunction or chatter.

3.15 Batteries On Racks

The equipment class of Batteries on Racks (BAT) includes both storage batteries and their supporting structures. Most battery systems consist of lead-acid storage batteries mounted in series on steel-frame racks or wooden racks.

A battery is a group of electro-chemical cells interconnected to supply a specified voltage of DC power. Individual battery weights typically range from about 50 to 450 pounds. Batteries are used to supply a steady source of DC power for circuits in control and instrumentation systems, to power DC starter motors for emergency engine-generators, and to provide DC power to inverters for uninterruptible power systems.

Lead-acid storage batteries are the most prevalent type of battery and are the subject of this equipment class. The basic components of a lead-acid battery cell are the electrode element, cell cover, cell jar, electrolyte, and flame arrestor. The electrode elements are the key components of the battery system.

There are four basic types of lead-acid storage batteries which are distinguished by the construction of their positive plates. These four types are: calcium flat plate, Planté or Manchex, antimony flat plate, and tubular. Since there are no examples of antimony flat plate and tubular batteries in experience data, they are excluded from the equipment class. The Planté or Manchex battery is one of the older designs of batteries but still has limited use in the power industry. It is constructed of heavy lead plate with either a series of horizontal cross-ribs attached to the plate (Planté plate design), or a matrix of spiral buttons inserted into the plate (Manchex design).

Battery racks are normally frames of steel channels, angles, and struts that support the batteries above the floor. Racks can be multi-rowed, multi-tiered, or multi-stepped. Multi-rowed racks are adjacent rows of batteries all at the same level. Multi-tiered racks are vertical rows of batteries mounted directly above each other. Multi-stepped racks have each succeeding row of batteries located above and to the rear of the previous row.

The shelf that supports the batteries typically consists of steel channels running longitudinally that are, in turn, supported by transverse rectangular frames of steel angles. The racks are usually braced by diagonal struts along either the front or rear face for longitudinal support. The rack members are connected by a combination of welds and bolts.

Well-designed battery racks include a restraining rail running longitudinally along the front and the rear of the row of batteries and wrapping around the ends of the row. The rails are located at about mid-height of the battery, and can prevent accidental overturning of the batteries, or overturning from earthquake loadings.

The battery (including the cell jar and enclosed plates, the supporting rack, electrical connections between batteries (bus bar), and attached electrical cable) are included in the Batteries on Racks equipment class.

The SQUG Reference Spectrum (RS) represents the seismic capacity of Batteries on Racks (BAT) if the batteries and racks meet the intent of the following inclusion rules and caveats.

- <u>BAT Rule 1 - Earthquake Experience Equipment Class</u>. The batteries and racks should be similar to and bounded by the BAT class of equipment described above.
  - Lead-calcium flat plate, Planté or Manchex design
  - Individual batteries weigh less than 450 lb

- Batteries are restrained by side and end rails
- Battery rack constructed of steel

- BAT Rule 2 - Close-Fitting, Crush-Resistant Spacers Between Cells. There should be close-fitting, crush-resistant spacers between the cells, which fill about two-thirds of the vertical space between the cells. The concern is that the batteries without spacers can rock and collide during the earthquake causing malfunction and damage.
- BAT Rule 3 - Battery Racks Have Longitudinal Cross Bracing. The racks should have longitudinal cross bracing unless engineering judgment or analysis shows that such bracing is not needed. The concern is that racks without cross bracing may not be able to transfer the lateral seismic loads to the base support.
- BAT Rule 4 - Batteries Greater Than 10 Years Old To Be Evaluated. Batteries that are more than 10 years old should be evaluated for aging. The concern with the aging of batteries is that some models have been shown by shake table testing to be susceptible to structural and or metallurgical changes with time that result in either structural failure or reduced capacity after vibration.

3.16 Battery Chargers and Inverters

Chargers and Inverters are grouped into a single equipment class since they perform similar (although electrically inverse) functions, contain similar components, and are packaged in similar cabinets. Solid-state battery chargers are assemblies of electronic components whose function is to convert AC input into DC output. Inverters are assemblies whose function is to convert DC input into AC output. Battery chargers and inverters are normally housed in floor-or wall-mounted cabinets.

The most common applications for both battery chargers and inverters are as components of an uninterruptible power supply (UPS). A typical UPS consists of a solid-state inverter, a battery charger, a set of lead-acid storage batteries, and an automatic transfer switch. Chargers serve the station batteries which provide a DC power source to controls, instrumentation, and switchgear. A portion of the DC power from the batteries is routed through inverters which provide a source of AC power to critical equipment.

The primary electrical function of a battery charger is accomplished using a rectifier. Most battery chargers are based on solid-state rectifiers consisting of semiconductors. This equipment class is limited to solid-state battery chargers and inverters.

The primary components of battery chargers include solid-state diodes, transformer coils, capacitors, electronic filters, and resistors. In addition, the primary components are usually protected from electrical faults by molded case circuit breakers and fuses. The internal components are normally bolted either to the rear panel or walls of a cabinet, or to interior panels or steel frames mounted within a cabinet. The front panel of the cabinet typically contains instrumentation and controls, including ammeters, voltmeters, switches, alarms, and control relays. Inverters contain primary components similar to those found in battery chargers. Virtually all inverters use solid state components.

Battery chargers and inverters are typically mounted in separate cabinets, but they are sometimes supplied as an assembly of two adjoining cabinets. The smallest units are wall-mounted or rack-mounted with typical dimensions of 10 to 20 inches in height, width, and depth, and typical weights of 50 to 200 pounds. Typical cabinet dimensions for larger floor-mounted units are 20 to 40 inches in width and depth, and 60 to 80 inches in height. The weights of the floor-mounted chargers and inverters range from several hundred to several thousand pounds. Typical AC voltages to battery chargers and from inverters range from 120 to 480 volts. Voltages in DC power typically range from 24 to 240 volts.

Industry standards are maintained for the construction of cabinets by the National Electrical Manufacturers Association and Underwriters Laboratories. These standards determine the minimum structural framing and sheet metal thickness for charger and inverter cabinetry as a function of size.

Solid-state inverters and battery chargers are included in the equipment class in freestanding, rack-mounted, and wall-mounted configurations. The Battery Charger and Inverter equipment class includes the sheet metal enclosure, all internal components, junction boxes, and attached cable or conduit.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Battery Charger or Inverter (BCI) if the equipment meets the intent of the following inclusion rules and caveats.

- BCI Rule 1 - Earthquake Experience Equipment Class. The battery charger or inverter should be similar to and bounded by the BCI class of equipment described above.
  - All solid state components
  - Up to 40 inches depth and width
  - Up to 80 inches height
  - Voltages up to 480V AC and 240V DC
  - Cabinet constructed to NEMA or similar standard
- BCI Rule 2 - Transformer Mounted Near Base of Floor-Mounted Units. For floor-mounted units, the transformer, which is the heaviest component of this equipment, should be positively anchored and mounted near the base of the cabinet. If not mounted near the base, then the load path should be specially evaluated. The concern is that the lateral earthquake loads on the transformer will not be properly transferred to the equipment base.
- BCI Rule 3 - No Reliance on Weak-Way Bending of Steel Plate or Structural Steel Shapes. The base assembly of floor-mounted units should be properly braced or stiffened such that lateral forces in any direction do not rely on weak-way bending of sheet metal or thin webs of structural steel shapes. If such un-braced or unstiffened steel webs exist, they should be investigated and verified for adequacy.

- BCI Rule 4 - Load Path Check for Wall-Mounted Units. If the battery charger or inverter is a wall-mounted unit, the transformer supports and bracing should be reviewed for a proper load path to the rear cabinet wall. Lateral earthquake loads on the heavy transformer need to be properly transferred to the anchorage.
- BCI Rule 5 - Doors Secured. All doors should be secured by a latch or fastener. The concern addressed by this rule is that the doors could open during an earthquake and the loose door could impact the housing and be damaged or cause internal components to malfunction.

3.17 Engine-Generators

The equipment class of Engine-Generators (EG) includes a wide range of sizes and types of generators driven by piston engines. Turbine driven generators are not included in this equipment class.

In common applications, generators range from 200 kVA to 5000 kVA; electrical output is normally at 480, 2400, or 4160 volts. Generators are typically the brushless rotating-field type with either a rotating rectifier exciter or a solid-state exciter and voltage regulator. Reciprocating-piston engines are normally diesel-fueled, although engines may operate on natural gas or oil. In typical applications piston engines range from tractor-size to locomotive-size, with corresponding horsepower ratings ranging from about 400 to 4000 horsepower.

Engine-generators normally include the piston engine and generator in a direct shaft connection, bolted to a common steel skid. The skid or the engine block also supports peripheral attachments such as conduit, piping, and a local control and instrumentation panel.

The engine-generator system also includes peripheral components for cooling, heating, starting, and monitoring operation, as well as supplying fuel, lubrication, and air. The peripheral components may or may not be mounted on or attached directly to the engine-generator skid. If they are not mounted on the skid, they should be evaluated separately.

The SQUG Reference Spectrum (RS) represents the seismic capacity of an Engine-Generator (EG) if the generator meets the intent of the following inclusion rules and caveats.

- EG Rule 1 - Earthquake Experience Equipment Class. The engine-generator should be similar to and bounded by the EG class of equipment described above.
  - Driven by piston engine
  - Up to 5000kVA
  - Up to 4160V
  - Up to 4000 HP
  - Engine and generator on common skid

- EG Rule 2 - Base Vibration Isolation System Checked. Some types of engine generators, or sub components of engine generators, can be mounted on vibration isolators. If the unit or parts of it are mounted on vibration isolators, the adequacy of the vibration isolators for seismic loads should be evaluated in accordance with Section 2.1.
- EG Rule 3 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., cooling, air, and electrical) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.

3.18 Instruments On Racks

The equipment class of Instruments on Racks (IR) consists of steel frames that provide mounting for local controls and instrumentation, such as signal transmitters to remote control panels. Instrument racks typically consolidate transducer or control signals from several equipment items in their immediate vicinity.

Instrument racks usually consist of steel members (typically steel angle, pipe, channel, or Unistrut) bolted or welded together into a frame. Components are attached either directly to the rack members or to metal panels that are welded or bolted to the rack. Floor-mounted instrument racks typically range from 4 to 8 feet in height, with widths varying from 3 to 10 feet, depending on the number of components supported on the rack. A simpler configuration of an instrument rack is a single floor-mounted post supporting one or two components. Wall-mounted and structural column-mounted racks are often used for supporting only a few components.

Control system components mounted on instrument racks may include electronic systems used for functions such as temperature monitoring, starting, stopping, and throttling electric motors, and monitoring electric power. Pneumatic system components mounted on instrument racks may be used for monitoring fluid pressure, liquid level, fluid flow, and for adjusting pneumatically-actuated control valves. Electronic control and instrumentation system components mounted on instrument racks include transmitters that convert a pneumatic signal from the transducer to an electric signal for transmission to the main control panel.

Typical components supported on instrument racks include pressure switches, transmitters, gauges, recorders, hand switches, manifold valves, and solenoid valves. Attachments to instrument racks include steel or plastic tubing, conduit, and junction boxes. Freestanding, wall-mounted, and structural column-mounted instrument racks of bolted and welded steel construction are included in the equipment class along with the components mounted on them. Both pneumatic and electronic components, as well as associated tubing, wiring, and junction boxes, are included in the Instruments on Racks equipment class.

The SQUG Reference Spectrum (RS) represents the seismic capacity of Instruments on Racks (IR) if the instruments and racks meet the intent of the following inclusion rules and caveats.

- IR Rule 1 - Earthquake Experience Equipment Class. The instruments and racks should be similar to and bounded by the IR class of equipment described above.
  - Up to 8 feet high
  - Up to 10 feet wide
  - Computers and programmable controllers not included
  - Adjacent racks which are close enough to impact each other and sections of multi-bay assemblies are bolted together
- IR Rule 2 - Structure Adequate. The steel frame and sheet metal structure should be evaluated for adequacy. An adequate load path is required to transfer the lateral earthquake loads to the foundation.
- IR Rule 3 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., air or electrical) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.

3.19 Temperature Sensors

The equipment class of Temperature Sensors (TS) includes thermocouples and resistance temperature detectors (RTDs) that measure fluid temperature and typically are mounted within or on piping or tanks. Thermocouples are probes consisting of two dissimilar metal wires routed through a protective sleeve that produce a voltage output proportional to the difference in temperature between the hot junction and the lead wires (cold junction). RTDs are similar in construction to thermocouples, but their operation is based on variation in electrical resistance with temperature. RTDs and thermocouples are connected to pressure vessel boundaries (piping, tanks, heat exchangers, etc.) using threaded joints. The sensor's sheath will often be inserted into a thermowell or outer protective tube that is permanently mounted in the pipe or tank. A thermowell allows the thermocouple or RTD to be removed without breaking the pressure boundary of the pipe or tank.

Sensors are typically linked to transmitters mounted on nearby instrument racks, which amplify the electronic signal generated in the sensors, and transmit the signal to a remote instrument readout.

The Temperature Sensors equipment class includes the connection head, threaded fitting, sheath or protective tube, thermowell, and attached wires.

The SQUG Reference Spectrum (RS) represents the seismic capacity of a Temperature Sensor (TS) if the sensor meets the intent of the following inclusion rules and caveats.

- TS Rule 1 - Earthquake Experience Equipment Class. The temperature sensor should be similar to and bounded by the TS class of equipment described above.
  - Thermocouple or resistance temperature detector
  - Solid state electronics
- TS Rule 2 - No Possibility of Detrimental Differential Displacement. Detrimental differential displacement between the mounting of the connection head and the mounting of the temperature sensor should not occur. The concern is that the differential displacement may cause the wiring to be pulled out of the sensor.
- TS Rule 3 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., electrical) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.

3.20 Instrumentation and Control Panels and Cabinets

The equipment class of Instrumentation and Control Panels and Cabinets (I&C) includes all types of electrical panels that support instrumentation and controls. This equipment class includes both the sheet metal enclosure and typical control and instrumentation components mounted on or inside the enclosure. Instrumentation and control panels and cabinets create a centralized location for the control and monitoring of electrical and mechanical systems. In addition to main control panels, local instrumentation and control panels are sometimes distributed throughout the facilities, close to the systems they serve.

Instrumentation and control panels and cabinets have a wide diversity of sizes, types, functions, and components. Panel and cabinet structures generally consist of a steel frame supporting sheet metal panels to which instrumentation and control components are bolted or clamped. Cabinet structures range from a single panel, braced against or built into a wall, to a freestanding cabinet enclosure. These enclosures are generally categorized as either switchboards or benchboards as described below.

A vertical switchboard is a single reinforced sheet metal instrument panel, which is either braced against an adjacent wall or built into it. An enclosed switchboard is a freestanding enclosed sheet metal cabinet with components mounted on the front face, and possibly on the interior walls. The front or rear panel is usually hinged as a single or double swinging door to allow access to the interior. A dual switchboard consists of two vertical panels braced against each other to form a freestanding structure, with components mounted to both front and rear panels. The sides are usually open, and the two panels are joined by cross members spanning between their tops. A duplex switchboard is similar to a dual switchboard, except that it consists of a panel fully enclosed by sheet metal on all sides, with access through doors in the two side panels.

A benchboard consists of a control desk with an attached vertical panel. A control desk has components mounted on the desk top, and interior access through swinging doors in the rear. The single panel is similar to a vertical switchboard and is normally braced against or built into a wall. A dual benchboard is similar to a dual switchboard, but the lower half of the front panel is a desk console. A duplex benchboard is similar to a duplex switchboard, a totally enclosed panel, but with a desk console in the lower half of the front panel.

Panel and cabinet enclosures normally consist of steel angles, channels, or square tubes welded together, with sheet metal siding attached by spot welds. Large panels are typically made of individual sections bolted together through adjoining framing. The cabinet may or may not include a sheet metal floor or ceiling.

Electronic or pneumatic instrumentation or control devices attached to sheet metal panels or within sheet metal cabinets are included in the equipment class. The Instrumentation and Control Panels and Cabinets equipment class includes the sheet metal enclosure, switches, push buttons, panel lights, indicators, annunciators, gauges, meters, recorders, relays (provided they meet relay requirements), controllers, solid-state circuit boards, power supplies, tubing, wiring, and terminal blocks.

The SQUG Reference Spectrum (RS) represents the seismic capacity of Instrumentation and Control Panels and Cabinets (I&C) if the panel or cabinet meets the intent of the following inclusion rules and caveats.

- <u>I&C Rule 1 - Earthquake Experience Equipment Class</u>. The panel or cabinet should be similar to and bounded by the I&C class of equipment described above.
  - Switchboard or benchboard
  - Constructed to NEMA or similar standard
  - Computers and programmable controllers not included in class
  - Adjacent panels and cabinets which are close enough to impact each other and sections of multi-bay assemblies are bolted together
- <u>I&C Rule 3 - Evaluate Strip Chart Recorders Separately</u>. Strip chart recorders should be evaluated separately. The concern is that long, narrow recorders which are cantilevered off the panel may not have adequate structural support. Strip chart recorders are commonly supported on compression-type mounting brackets supplied by the manufacturer. These types of support brackets are inherently rugged and generally adequate for transfer of seismic loads.
- <u>I&C Rule 4 - Structural Adequacy</u>. The steel frame and sheet metal should be evaluated for adequacy. An adequate load path is required to transfer the lateral earthquake loads to the foundation.
- <u>I&C Rule 6 - Drawers or Equipment on Slides Restrained</u>. Drawers or equipment on slides should be restrained to prevent them from falling out during seismic motion. The concern is that the components in the drawer could slide and become damaged, or slide out and fall onto

some other fragile essential component in the vicinity. A latch or fastener should secure these sliding components.

- I&C Rule 7 - Doors Secured. All doors should be secured by a latch or fastener. The concern addressed by this rule is that loose doors could repeatedly impact the housing and be damaged or cause internal components to malfunction.
- I&C Rule 8 - Sufficient Slack and Flexibility of Attached Lines. Sufficient slack and flexibility should be present in attached lines (e.g., air or electrical) to preclude a line breach due to differential seismic displacement of the equipment and the line's nearest support.

4
SEISMIC DESIGN OF DISTRIBUTION SYSTEMS

4.1 Cable Tray, Conduit, and HVAC duct System Seismic Design Requirements

As an alternate to the lateral force (F_p) design method as described in ASCE-7 [1], cable tray, conduit, and HVAC duct systems and their supports can be designed using the experience-based ductile design method as described in this Section. This only applies to systems that are suspended on supports that are designed and detailed to enable ductile behavior at the overhead attachment points as described in Section 4.2. The following design requirements are sufficient for important (i.e., I_p = 1.5) systems.

4.1.1 Design Requirements for Supports

Design requirements for supports are as follows:

- All support members and connections shall be designed for deadweight.
- Overhead support attachment connection details (such as anchor bolts, bolts, and welds) shall be designed for a vertical force of a_V x DL (vertical load carrying capability). Eccentricities in the load path can be neglected. Use working stress level allowable capacities.

  a_V = 3.0 for cable tray and conduit supports
  a_V = 5.0 for HVAC duct supports

- Check that overhead support attachment connection details have shear capacity sufficient to withstand a lateral force of 0.7 × FP. Use working stress level allowable capacities.
- When fixed-end connections are used at the ceiling, the overhead support attachment connection details (such as welds and base plates with anchor bolts) shall have bending strength greater than the yield capacity of the vertical member.

4.1.2 Electrical Raceway Design Requirements

Cable trays and conduit shall be positively attached to the support member by means of standard components such as tray hold down clips for cable trays, and C-clamps or finger clamps for conduit. This requirement is intended ensure position retention during a seismic event.

Maximum span lengths for cable trays (between supports) shall be established in accordance with NEMA Standard Publication VE 1. Maximum span lengths for conduit shall be established in accordance with the National Electric Code.

Adequate flexibility shall be provided for cable tray or conduit systems that are routed between different building structures, or that interface with flexible equipment items. See Section 4.1.4.

4.1.3 HVAC Duct Seismic Design Requirements

HVAC ducts shall be positively attached to the support member by means of standard components such as pipe clamps or U-bolts for smaller diameter ducts using pipe sections, straps for round ducts, and clip angles for rectangular ducts. This requirement is intended ensure position retention during a seismic event.

All HVAC ductwork shall be fabricated and installed in accordance with the SMACNA duct construction standards. HVAC duct stresses shall be calculated to establish the maximum allowable duct spans between supports (L_{duct}). The following simplified equivalent static method for calculating duct bending stress shall be utilized. As an alternative method, duct stress may be evaluated using finite-element analysis so long as the methodology is consistent with the equations provided below. Stresses shall include the following load cases and shall be calculated as follows:

$$f_b = (M_{DL} + M_E + M_{ED}) / Z \leq F_b$$

Where,

Z = duct section modulus

M_{DL} = duct bending moment due to deadweight (DL)

= $\omega \times L_{duct}^2 / 10$

ω = weight per unit length of duct including contents and insulation as applicable

M_E = duct bending moment due to lateral seismic load F_P applied in the transverse direction

= $0.7 \times F_P \times \omega \times L_{duct}^2 / 10$

M_{ED} = $0.7 \times$ duct bending moment due to differential displacements (see Section 4.3)

For round ducts, section modulus based on the full section is calculated as follows:

$$Z = \pi D^2 t / 4$$

Where,

D	=	outer diameter of the round duct (in)
t	=	duct thickness (in)

The lower bound allowable bending stress limits for various material types under consideration, as specified by SMACNA, are provided below:

$F_b = 10.7$ ksi	for $D/t < 294$	(hot rolled carbon steel)
$F_b = 3140/(D/t)$ ksi	for $D/t \geq 294$	(hot rolled carbon steel)
$F_b = 11.0$ ksi	for $D/t < 285$	(cold formed steel, galvanized sheet)
$F_b = 3140/(D/t)$ ksi	for $D/t \geq 285$	(cold formed steel, galvanized sheet)
$F_b = 8.8$ ksi	for $D/t < 113$	(stainless steel)
$F_b = 993/(D/t)$ ksi	for $D/t \geq 113$	(stainless steel)

For rectangular ducts, the effective area of sheet metal for calculation of the duct section modulus is limited to a 2-inch by 2-inch region at the four corners of the duct. Calculate the section modulus by assuming only these corners are effective in resisting bending. Effective section moduli for rectangular duct are calculated as follows:

$$Z_{1\text{-}1} = 16t \left[D^2/4 + (D/2 - 1)^2 \right] / D$$

$$Z_{2\text{-}2} = 16t \left[W^2/4 + (W/2 - 1)^2 \right] / W$$

Where,

D	=	depth of duct cross-section (in)
W	=	width of duct cross-section (in)
T	=	duct thickness (in)

The lower bound allowable bending stress, F_b, for rectangular ducts of carbon steel, galvanized steel, and stainless steel materials is 8 ksi.

Adequate flexibility shall be provided for HVAC duct systems that are routed between different building structures, or that interface with flexible equipment items. See Section 4.1.4.

4.1.4 Differential Displacement and Commodity Clearance

Important distribution systems shall be designed to accommodate the seismic effects known as differential displacement of support points, or seismic anchor movement as follows:

1. Distribution systems routed between different building structures must have sufficient flexibility to accommodate the differential displacement of the two building structures.
2. Distribution systems attached to flexible equipment must have sufficient flexibility to accommodate the displacement of flexible equipment. The use of flexible conduit, free-air cables, or HVAC bellows connections is preferable.
3. Distribution systems spanning from floor to ceiling must have sufficient flexibility to accommodate the differential displacement of the two floor levels.

The differential displacement for two separate buildings shall be determined as the absolute sum of the maximum seismic displacement of each building at the floor level of interest (termed δ_X). In accordance with ASCE-7, the deflection of each building structure shall be determined as follows:

$$\delta_X = C_D \times \delta_{XE}$$

Where,

δ_{XE} = the floor defection determined by an elastic analysis of the seismic-force-resisting system

C_D = the deflection amplification factor as defined in ASCE-7(ranges from 1.25 to 6.5 depending on the type of the building structure)

When determining the seismic deflection of flexible equipment systems (δ_{EQ}), the initial component elastic stiffness (K_E) shall be determined. Seismic deflection is then determined as follows:

$$\delta_{EQ} = R_P \times F_P / K_E$$

The differential displacement that the distribution system must be designed for is the absolute sum of δ_{EQ} and the displacement of the distribution system (δ_{DS}). δ_{DS} shall be determined as the seismic deflection of the support, plus the seismic deflection of the distribution system spanning between supports (as applicable) due to a lateral force equal to $F_P \times R_P$.

When the distribution system is routed in proximity to sensitive systems or components, sufficient clearance shall be used to preclude any damaging impacts. The deflection of the distribution system shall be taken as δ_{DS} as described above. If it is flexible (natural period > 0.06 sec.), the deflection of the sensitive system or component shall be determined in a similar manner (i.e., using elastic analysis, and eliminating any force reduction factors such as R_P if used in the design). The clearance shall be at least as great as the absolute sum of δ_{DS} and the deflection of the other system or component.

4.2 Ductile Design Methodology

In general, the seismic design objective for cable trays and HVAC ducting is to achieve rugged, ductile supports that will not fall down during or after the design earthquake. The seismic design approach used to achieve this objective is to have a support system that is suspended from the overhead with a high factor of safety against falling down, with ductile details to ensure that the vertical load carrying capability of the supports is not compromised when the systems respond and sway to lateral seismic shaking.

When a support responds to lateral seismic shaking, the desired limit state is ductile bending of the vertical steel support members. The anchorage and connections for the support must have sufficient strength and stiffness such that a plastic hinge will form in the support members before anchorage failure can occur. Yielding associated with ductile bending of vertical support elements or attachment clip angles is not a failure mode but is desirable seismic performance. Failure of welded connections or anchorage is unacceptable behavior.

In a conventional lateral force approach, members and anchors are designed to resist the lateral force F_P that is applied at the center of mass of the system. When the center of mass is located far below the ceiling, there is a large calculated moment caused by the lateral force F_P (see Figure 4-1). This is not an overturning moment for supports suspended from the overhead. It is a counter-pendulum moment (M_{C-P}). When faced with this large moment, when using conventional methods the designer has to either select relatively large members for the vertical support post, or adopt a support system that has lateral diagonal bracing or rigid framing. The support anchorage is then sized for the reactions due to F_P and M_{C-P}.

If an earthquake is larger than the design earthquake, then the loads transmitted to the anchorage become larger than their design capacity. As lateral loading increases, loss of anchorage is the failure mode. If the anchorage fails, the distribution system loses it position integrity. This is undesirable performance. The preferred performance is ductile yielding and bending of vertical support elements, which have the ability to behave in a stable and dampened swaying mode when subject to increased lateral loading.

The lateral force approach is required when non-ductile behavior is possible. Examples of non-ductile configurations requiring the F_P minimal lateral force approach include:

- Base mounted supports that are cantilevered up from the floor. For base mounted supports, ductile behavior (as discussed above for supports suspended from the overhead) can lead to instability. If a plastic hinge forms at the base of a support cantilevered up from the floor, the inverted pendulum can collapse. Base mounted supports require sufficient strength and stiffness, and have to be designed using the lateral force F_P approach.

- Supports with diagonal bracing. A diagonal brace in a support suspended from the overhead attracts lateral forces and generates high reaction loads to the primary support anchorage (see Figure 4-2). When lateral sway bracing is used, such as to limit deflections, then the support and its anchorage have to be designed using the lateral force F_P approach.
- Supports that are constructed as rigid welded frames. Rigid welded frame supports suspended from the overhead can generate large reaction forces to primary anchorage during lateral seismic loading (see Figure 4-3). Rigid welded frame supports have to be designed using the lateral force F_P approach.
- Supports with non-ductile anchorage details have to be designed using the lateral force F_P approach. When non-ductile anchorage details are used, F_P must be determined using R_P=1.0.

Example ductile support configurations and connection details are as follows:

- Rod hangers
- Steel strap hangers
- Light gage strut with 90 degree fittings (clip angles)
- Open rolled sections with all-around fillet weld connections to overhead steel

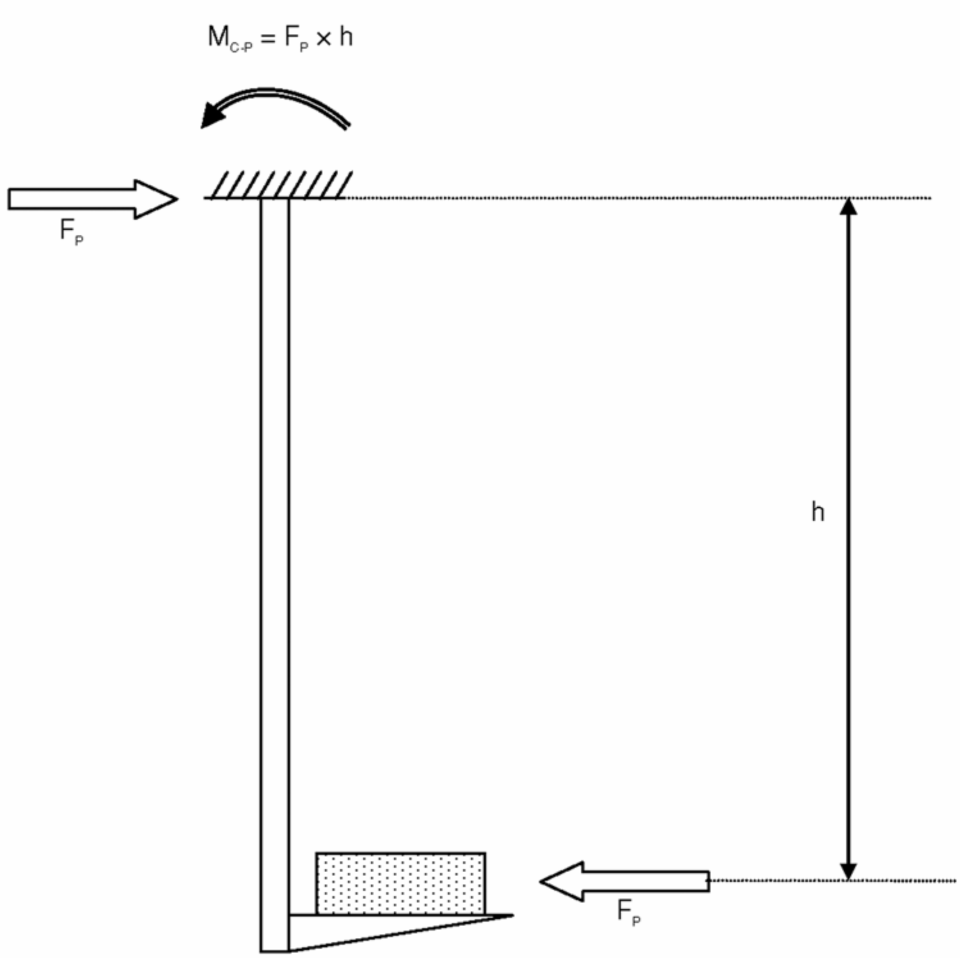


Figure 4-1
Conventional Lateral Force Approach

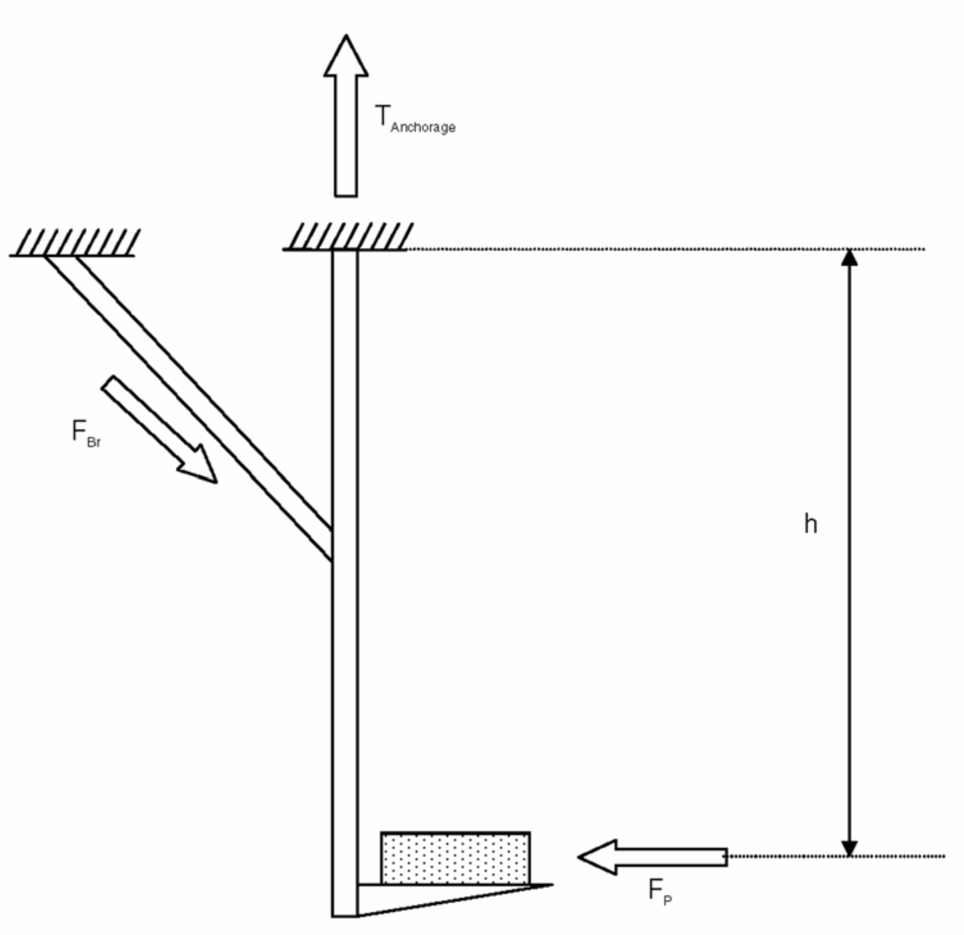


Figure 4-2
High Tension In Anchorage Caused By Diagonal Brace Action In Support

5 REFERENCES

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A

EARTHQUAKE EXPERIENCE DATA AND THE SEISMIC QUALIFICATION UTILITY GROUP (SQUG)

A.1 Earthquake Experience Data

The Seismic Qualification Utility Group (SQUG – see Section A.2) collected and evaluated earthquake performance information for equipment over a ten-year period in the 1980s and early 1990s. The equipment earthquake experience data were used to develop criteria and procedures for verifying the seismic adequacy of equipment in older operating nuclear power plants. This work involved participation and review by the U.S. Nuclear Regulatory Commission (NRC) and an independent panel of experts, the Senior Seismic Review and Advisory Panel (SSRAP). More information on SQUG and SSRAP is provided in Section A.2. The Electric Power Research Institute (EPRI) provided oversight for the collection and reporting of earthquake experience data, and compiled the electronic earthquake experience database, termed eSQUG.

The SQUG investigation of the earthquake performance of equipment was in general limited to 20 classes of active electrical and mechanical equipment. The 20 classes of equipment are listed in Table A-1. The selection of these 20 classes of equipment was based on the scope of the SQUG needs at that time. In addition to the 20 classes of active electrical and mechanical equipment, SQUG studied flat bottom cylindrical vertical storage tanks and horizontal heat exchangers supported on saddles. SQUG also investigated distribution systems including conduit, cable trays, HVAC ducting, and piping systems as well as their supports.

SQUG collected past earthquake performance data for the above classes of equipment at power and industrial facilities that were subject to major worldwide earthquakes. The SQUG seismic experience database is founded on studies of 172 facilities located in the strong-motion areas of 29 earthquakes that have occurred within the Pacific basin since 1971. This information was compiled through surveys of power generating plants and substations, industrial facilities and data processing centers, water processing and pumping plants, hospitals, and telecommunications centers.

In general, data collection efforts focused on facilities located in the areas of strongest ground motion for each earthquake investigated. Facilities were sought that contained substantial inventories of mechanical or electrical equipment, or control and instrumentation systems. Because of the number of earthquake-affected areas and types of facilities investigated, there is a wide diversity in the types of installations included in the database. For the classes of equipment of focus, this includes a wide diversity in age, size, configuration, application, operating conditions, manufacturer, type of building, location within building, local soil conditions, quality of maintenance, and quality of construction.

Usually there were several different sites investigated in each earthquake-affected area. Table A-2 provides a list in chronological order of the earthquakes and the specific sites from which the database was compiled. The earthquakes investigated by SQUG range in Richter magnitude from 5.4 to 8.1. Measured or estimated peak ground accelerations for database sites range from 0.10g to 0.85g. Strong motion duration (bracketed ~ 0.10g or greater) ranges from about 5 seconds to more than 40 seconds. Local soil conditions range from deep alluvium to rock. The building structures housing the equipment of interest have a wide range in size, and type of construction. As a result, the database covers a wide diversity of seismic input to equipment, in terms of seismic motion amplitude, duration, and frequency content.

Information on each database facility, its performance during the earthquake, and any damage or adverse effects caused by the earthquake were collected through the following general kinds of sources:

- Interviews with the facility management and operating personnel usually provide the most reliable and detailed information for earthquake effects. At most facilities several individuals were consulted to confirm or enhance details. In most cases the interviews are recorded on audio tape.
- Facility operating logs are a written record of the conditions of the operating systems before and after the earthquake. Operating logs list problems in system operation associated with the earthquake and usually tabulate earthquake damage to the facility. Operating logs are useful in determining the amount of time the facility may have been out of operation following the earthquake and any problems encountered in restarting the facility.
- The facility management often produces a report summarizing the effects of the earthquake following detailed inspections. These reports normally describe causes of any system malfunctions or damage, and typically include any incipient or long-term effects of the earthquake.
- If the facility can be surveyed immediately following the earthquake, as has been the case in 19 of the 28 earthquakes included in the database, earthquake damage can often be inspected prior to repairs.

Standard procedures used in surveying database facilities (formalized by EPRI) focus on collecting all information on damage or adverse effects of any kind caused by the earthquake. Except for sites that experienced very high seismic motion (in excess of 0.50g peak ground acceleration), seismic damage to well-engineered facilities is generally limited to only a few items.

In addition to the above database, limited literature reviews (searching for reported failures of equipment) were conducted by SQUG and SSRAP for several earthquakes including the 1964 Alaska (magnitude 8.4); 1952 Kern County (magnitude 7.4); 1978 Miyagi-ken-oki, Japan (magnitude 7.4); 1976 Friuli, Italy (magnitude 6.5); and 1972 Managua, Nicaragua (magnitude 6.2) earthquakes.

The earthquakes and sites investigated prior to about 1992 formed the primary basis for the SQUG seismic verification methodology. Since that time, SQUG and EPRI, in cooperation with the Earthquake Engineering Research Institute (EERI), have continued to investigate the performance of equipment in earthquakes in detail, up to present time. These additional investigations are performed so that SQUG can continuously validate the earthquake experience database methodology, as well as expand and enhance the earthquake experience data. In particular, the additional investigations enable collection of more detailed data, especially for current vintage equipment.

A.1.1 Primary Observations from Earthquake Experience Database

The detailed and careful review of the seismic experience data by SQUG and SSRAP included observations from shake table and in-situ testing, analysis, shipping, and operational experience. The primary observations from this investigation of the earthquake performance of the 20 classes of equipment are as follows:

- The presence of properly engineered anchorage is perhaps the most important single item which affects the seismic performance of equipment. Earthquakes have repeatedly demonstrated that equipment will slide, overturn or move excessively when it lacks positive anchorage or when it does not have proper engineered anchorage. Engineered anchorage means sufficient strength and stiffness.
- Seismic interaction issues such as differential settlement or building movement, inadequate flexibility of attached lines, failure and falling of adjacent items, and seismic induced water spray or flooding can render equipment inoperable following an earthquake.
- When properly anchored and with certain restrictions (inclusion rules and caveats), the equipment has an inherent seismic ruggedness and a demonstrated capability to withstand substantial seismic motion without significant structural damage.
- Up to the earthquake shaking levels considered, functionality after the strong shaking has ended has been demonstrated for this equipment, but the absence of relay (electro-mechanical switch devices) chatter during strong shaking has not been demonstrated. Other than for the exception of relay chatter, functionality during strong shaking has also been demonstrated.
- Provided that equipment is properly anchored and free of seismic interaction concerns, and meets the class-specific inclusion rules and caveats, for excitation levels below the established seismic motion bounds, it is unnecessary to perform explicit seismic qualification of existing equipment in these classes.
- Newly-designed and newly manufactured equipment can be similarly qualified provided that a design difference evaluation confirms representation by the experience database equipment

class. The database does not indicate that there is a tendency for newer vintage equipment to have lower seismic capacity

SQUG and EPRI developed seismic experience based criteria and procedures for seismic qualification of equipment. The main elements of the criteria and procedures are as follows:

- Verification that equipment anchorage and associated load paths are adequate.
- Verification of no potential for adverse seismic spatial interaction with nearby equipment and structures.
- Demonstration that the candidate equipment falls within the defined inclusion rules for the applicable equipment class (*i.e.*, is represented in the experience data).
- Assurance that known equipment vulnerabilities are not present in the equipment.
- Verification that the experience-based seismic capacity of the equipment class exceeds the plant-specific seismic demand.
- Review of potential design differences that could affect seismic performance of the equipment.
- Review and concurrence by qualified and trained engineers.
- Documentation of the entire process, including required supplemental analyses and inspections.

A.1.2 Generic Equipment Ruggedness Spectra

An important limitation in the use of earthquake experience data is the seismic motion bounds experienced by the equipment. In order to enable seismic qualification for levels of shaking in excess of that associated with the earthquake experience data, EPRI and SQUG established a second database, of equipment seismically qualified by shake table tests. This work included development of equipment classes with associated inclusion rules and caveats, with class-specific seismic capacities defined by Generic Equipment Ruggedness Spectra (GERS). In general, the inclusion rules and caveats are more restrictive extensions of those developed based on the earthquake experience data. These GERS are intended to represent the highest input levels for which one has high confidence of successful equipment performance for each of the defined classes of equipment. The equipment classes for which GERS are available are highlighted in Table A-1.

A.2 Seismic Qualification Utility Group (GIP, NARE)

Seismic design criteria and methods for the seismic qualification of mechanical and electrical equipment in commercial nuclear power plants underwent significant changes during the early development of the commercial nuclear power program in the United States in the early 1960's through the 1970's. Rigorous and well-defined requirements for qualification of active equipment in nuclear power plants were in general not introduced until the mid 1970's and were eventually defined in the U.S. Nuclear Regulatory Commission (NRC), Regulatory Guide 1.100, "Seismic Qualification of Electric Equipment for Nuclear Power Plants." This regulatory guide, with some exceptions, basically endorses IEEE Standard 344-1975, "IEEE Recommended Practices for Seismic Qualification of Class IE Equipment for Nuclear Power Generating Stations." Revision 2 to the NRC Standard Review Plan included Section 3.10, "Seismic and Dynamic Qualification of Mechanical and Electrical Equipment."

The need for a reassessment of the seismic capability of equipment in older operating plants that did not undergo “current” requirements was identified as Unresolved Safety Issue (USI) A-46, “Seismic Qualification of Equipment in Operating Plants.” by the NRC in December 1980. The objective of US1 A-46 was to develop alternative seismic qualification methods and acceptance criteria that could be used to assess the capability of mechanical and electrical equipment in operating nuclear power plants to perform the intended safety functions. This objective was based on the recognition by the NRC that it was not practical to qualify equipment in operating plants using current seismic criteria. Equipment could not be removed from the nuclear plants, qualified by shake table testing, and re-installed in the plants without great difficulties and expense.

A group of affected nuclear power utilities formed the Seismic Qualification Utility Group (SQUG) in 1982. SQUG’s purpose was to work with the NRC in developing a program methodology to enable resolution of the USI A-46 issue. SQUG gathered the extensive earthquake experience database (described in Section 1.1) and demonstrated the seismic ruggedness of many items of non-seismically qualified industrial grade equipment installed in fossil fuel power plants and heavy industrial facilities. SQUG also demonstrated that the database equipment was very similar to the equipment installed in the older operating nuclear power plants.

This database was extensively reviewed by the NRC and by a five-member Senior Seismic Review and Advisory Panel (SSRAP). SSRAP, whose members were jointly selected by SQUG and the NRC, was retained in June 1983 to make an independent assessment of whether certain classes of equipment in operating nuclear power plants in the U.S. have demonstrated sufficient seismic ruggedness in past earthquakes so as to render an explicit seismic qualification unnecessary. SSRAP operated as an independent review body with all of its findings submitted concurrently to both SQUG and the NRC. The conclusions from the SSRAP reviews were documented in the SSRAP report, "Use of Past Earthquake Experience Data to Show Seismic Ruggedness of Certain Classes of Equipment in Nuclear Power Plants."

A.2.1 Generic Implementation Procedure (GIP)

SQUG’s efforts together with the reviews by SSRAP and NRC culminated in the “Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment” in the early 1990’s. The GIP was used by all SQUG-member utilities to evaluate and strengthen, as required, the important safety-related equipment in each plant in order to resolve USI A-46. A very important element of the SQUG GIP was the seismic verification walkdown. This required a team of *Seismic Capability Engineers* who were required to attend a SQUG walkdown training course. The SQUG training course involved one week of document review and one week of lectures and exercises. The SQUG training course included an in-plant walkdown exercise.

The SQUG GIP was successfully implemented at a total of about 70 operating nuclear power reactor units. The scope and content of the SQUG GIP are summarized as follows:

The GIP describes the nuclear licensing requirements as well as the technical criteria and procedures that the utilities used to resolve USI A-46. The main technical elements of the GIP include the following:

- Selection of safe shutdown path(s) and equipment for resolution of A-46
- Seismic capacity vs. demand assessments
- Anchorage inspection, analysis and acceptance criteria
- Seismic spatial interaction assessment
- Analysis methods and criteria for tanks and heat exchangers
- Relay evaluation criteria
- Cable and conduit raceway evaluation criteria
- Documentation requirements
- Personnel qualification and training
- Methods for resolving items that do not meet the GIP screening criteria.

Based on the success of the GIP implementation process and the resolution of USI A-46, SQUG expanded use of earthquake experience data from the USI A-46 seismic verification program and the GIP to New and Replacement Equipment (NARE). SQUG and EPRI also used the experience data to develop seismic verification criteria for piping, tubing, and supports; and HVAC ducting and supports.

A.2.2 New and Replacement Equipment Evaluation

The GIP was developed by SQUG primarily as a practical method for demonstrating the seismic adequacy of installed equipment in older, operating nuclear plants so as to resolve USI A-46. Seismic experience data can be used for seismic qualification of new and replacement equipment and parts (NARE) using the rules of the Generic Implementation Procedure (GIP). Additional provisions are necessary to address new and replacement equipment evaluations as follows:

- Installed equipment - New equipment items may not yet be installed or procured. Accordingly, provisions are made to assure that GIP requirements are met by means of procurement and installation specifications, with required verifications. The NARE Guidelines are intended to be used as an aid to engineering and procurement personnel in the preparation of plant-specific procedures and implementation of the GIP methodology.

- Equipment design changes - New and replacement equipment items may include design changes. Where this is the case, an assessment of design differences is required to assure that these differences do not reduce the equipment seismic capacity compared to that in the GIP equipment classes.
- Parts vs. equipment classes - The addition or replacement of a part is addressed by performing a GIP evaluation on the host item of equipment in which the part is mounted. The applicable inclusion rules and caveats, and the load path evaluations, are performed on the replaced or added part in its installed location. In addition, the required safety function of the part and the structural and seismic adequacy of the part is also specifically addressed.

A.3 Other Experience-Based Seismic Equipment Qualification Methods

A.3.1 Seismic Evaluation Procedure for Equipment in U.S. Department of Energy Facilities

U.S. Department of Energy (DOE) Report No. DOE/EH-0545 provides criteria and procedures for the verification of the seismic adequacy of equipment at DOE facilities. This report in general includes all of the main contents of the SQUG GIP, and also has additional experience and test based provisions for other type of equipment components including the following:

- Piping systems
- Underground piping systems
- HEPA Filters
- Glove Boxes
- Miscellaneous Machinery
- Underground Tanks
- Canisters and Gas Cylinders
- HVAC Duct Systems
- Unreinforced Masonry (URM) Walls
- Raised Floors
- Storage Racks

This DOE guideline is available online at the following URL location:

http://www.llnl.gov/tid/lof/documents/toc/231931_toc.html.

A.3.2 IEEE Standard 344-2004

IEEE Standard No. 344-2004 is the "*Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations*." Qualification based on earthquake experience data involves the following five steps:

- Characterization of the earthquake experience reference equipment class
- Characterization of earthquake motions experienced by the reference equipment
- Establishment of the earthquake experience-based seismic capacity for the reference equipment class
- Comparison of the candidate equipment to the earthquake experience reference equipment class
- Documentation of the qualification process

Detailed requirements are provided for each of the above steps. In general, the standard was intended to describe and codify the basic steps followed by SQUG and SSRAP in the development of the GIP. Similar to the SQUG GIP, the use of earthquake experience reference data for seismic qualification of a given candidate equipment class under the IEEE 344-2004 guidelines includes, in part, meeting the following basic requirements:

- Seismic capacity of a reference equipment class must exceed the seismic demand of the candidate equipment;
- All inclusion rules and caveats of the equipment class of interest must be satisfied.

Meeting the above requirements will ensure that the candidate equipment is representative of and bounded by the earthquake experience reference data equipment class that experienced strong motion in past earthquakes, which is used as the seismic qualification basis. In addition, the subject equipment will be free of any characteristics and attributes that have been shown by past earthquakes to be potential vulnerabilities.

Table A-1
Twenty (20) Classes of Equipment

1*	Motor Control Centers
2*	Low Voltage Switchgear
3*	Medium Voltage Switchgear
4*	Transformers
5	Horizontal Pumps
6	Vertical Pumps
7*	Fluid Operated Valves
8*	Motor Operated and Solenoid Operated Valves
9	Fans
10	Air Handlers
11	Chillers
12	Air Compressors
13	Motor Generators
14*	Distribution Panels
15*	Batteries on Racks
16*	Battery Chargers and Inverters
17	Engine Generators
18*	Instruments on Racks
19	Temperature Sensors
20	Instrument and Control Panels and Cabinets

* Indicates that GERS are also available for the equipment class.

Table A-2
SQUG Earthquake Experience Database Earthquakes & Sites

Earthquake	Site	Original PGA Estimate (g)	Updated PGA Estimate (g)
San Fernando, CA Earthquake 1971 (M6.5)	Sylmar Converter Station	0.50	0.69
	Rinaldi Receiving Station	0.50	0.66
	Valley Steam Plant	0.40	0.29
	Burbank Power Plant	0.30	0.24
	Glendale Power Plant	0.30	0.24
	Pasadena Power Plant	0.20	
Point Mugu, CA Earthquake 1973 (M5.7)	Ormond Beach Power Plant	0.20	0.10
Ferndale, CA Earthquake 1975 (M5.5)	Humboldt Bay Power Plant	0.30*	0.375
Imperial Valley, CA Earthquake 1979 (M6.6)	El Centro Steam Plant	0.42*	0.43
	Drop IV Hydro. Plant	0.30	
Humboldt, CA Earthquake 1980 (M7.0)	Humboldt Bay Power Plant	0.25	
Coalinga, CA Earthquake 1983 (M6.7)	Getty Oil Pumping Plant	0.60	0.51
	Union Oil Butane Plant	0.60	0.62
	Shell Water Treatment Plant	0.60	0.60
	Coalinga Water Treatment Plant	0.60	0.53;
	Shell Tank Farm No. 29	0.60	
	Pleasant Valley Pumping Plant	0.56*	0.35
	San Luis Canal Pump Stations	0.35	
	Gates Substation	0.25	
	Kettleman Compressor Station	0.20	
Morgan Hill, CA Earthquake 1984 (M6.2)	IBM/Santa Teresa Facility	0.37*	0.28
	San Martin Winery	0.35	
	Metcalf Substation	0.40	
	Mirassou Winery	0.20	
	Eastridge Mall	No records	
	Wiltron	No records	
Chile Earthquake 1985 (M7.8)	Bata Shoe Factory	0.64	
	Llolleo Water Pumping Plant	0.55	0.75
	Rapel Hydroelectric Plant	0.23*	
	Concon Petroleum Refinery	0.30	
	Oxiquim Chemical Plant	0.30	
	Concon Water Pumping Station	0.30	
	Renca Power Plant	0.30	
	Laguna Verde Power Plant	0.25	

Table A-2 (continued)
SQUG Earthquake Experience Database Earthquakes & Sites

Earthquake	Site	Original PGA Estimate (g)	Updated PGA Estimate (g)
Chile Earthquake Continued	Las Ventanas Copper Refinery	0.25	
	Las Ventanas Power Plant	0.25*	0.22
Mexico Earthquake 1985 (M8.1)	Infiernillo Dam	0.15	
	La Villita Power Plant	0.14	
	SICARTSA Steel Mill	0.25	
	Fertimex Fertilizer Plant	0.25	
Adak, Alaska Earthquake 1986 (M7.5)	Adak Naval Base	0.23*	
North Palm Springs, CA Earthquake 1986 (M6.0)	Devers Substation	0.85*	0.81
	Whitewater Hydro Plant	0.50	0.74
	Whitewater Trout Farm	0.55*	
Chalfant Valley, CA Earthquake 1986 (M6.0)	Control Gorge Hydro Plant	0.25	
	Hi-Head Hydro Plant	0.25	
San Salvador Earthquake 1986 (M5.4)	Soyapango Substation	0.50	
	San Antonio Substation	0.30	
Bay of Plenty, New Zealand Earthquake 1987 (M6.25)	Edgecumbe Substation	0.50	
	New Zealand Distillery	0.50	
	Bay Milk Products	0.50	
	Caxton Paper Mill	0.40	
	Kawerau Substation	0.40	
	Whakatane Board Mill	0.25	
	Matahina Dam	0.26*	
Whittier, CA Earthquake 1987 (M5.9)	Olinda Substation	0.62*	
	SCE Dispatch Headquarters	0.56*	
	SCE Headquarters	0.42*	
	California Federal Bank Facility	0.40	
	Ticor Facility	0.40	
	Mesa Substation	0.35	
	Sanwa Bank Facility	0.40	
	Alhambra Pacific Bell Station	0.30	
	Rosemead Pacific Bell Station	0.30	
	Pacific Bell Central Station	0.15	
	Wells Fargo Bank Facility	0.35	
	Center Substation	0.35	
	Del Amo Substation	0.20	
	Lighthype Substation	0.26*	

Table A-2 (continued)
SQUG Earthquake Experience Database Earthquakes & Sites

Earthquake	Site	Original PGA Estimate (g)	Updated PGA Estimate (g)
Whittier, CA Earthquake, Continued	Commerce Refuse-to-Energy Plant	0.30	0.39
	Puente Hills Power Plant	0.25	
	Glendale Power Plant	0.20	
Superstition Hills (El Centro), CA Earthquake 1987 (M6.3)	Mesquite Lake Power Plant	0.20	
	El Centro Steam Plant	0.25*	
Loma Prieta, CA Earthquake 1989 (M7.1)	Moss Landing Power Plant	0.30	0.3
	Gilroy Energy Cogen Plant	0.32*	0.39
	Cardinal Cogen Plant	0.20	
	Hunter's Point Plant	0.15	
	Portrero Plant	0.15	
	Metcalf Substation	0.30	
	San Mateo Substation	0.20	
	National Refractory	0.30	
	Green Giant Foods	0.33	
	Watsonville Wastewater Plant	0.40	
	Watsonville Pac-Bell Station	0.33*	
	Seagate Watsonville	0.40	
	Santa Cruz Water Treatment	0.40	0.43
	Soquel Creek Water	0.50	
	Lipton Foods	0.30	
	Lone Star Cement	0.25	
	Watkins-Johnson Instruments	0.30	0.48
	Rinconada Water Treatment Plant	0.40	
	Cabrillo Community College	0.50	
	West Valley Community College	0.40	
	IBM/Santa Teresa Facility	0.20.	0.28
	EPRI Headquarters	0.25	
	Mt. Umunhum Control Center	0.50	
	UC Santa Cruz Central Campus		0.43
	UC Santa Cruz Cogen Plant		0.43
Philippine Earthquake 1990 (M7.7)	Cabanatuan Substation	No records	
	San Manuel Substation	No records	
	La Trinidad Substation	No records	
	Moog Electronics Plant	No records	
	Texas Instrument, Baguio	No records	

Table A-2 (continued)
SQUG Earthquake Experience Database Earthquakes & Sites

Earthquake	Site	Original PGA Estimate (g)	Updated PGA Estimate (g)
Costa Rica Earthquake 1991 (M7.4)	Moin Power Plant	No records	
	Changuinola Power Plant	No records	
	Limon Telephone Station	No records	
	Bomba Water Plant	No records	
	RECOPE Refinery	No records	
	Port of Limon	No records	
	Port of Moin	No records	
	Cachi Dam	0.12	
Sierra Madre Earthquake 1991 (M5.8)	Pasadena Power Plant	0.20	
	Goodrich Substation	0.30	
Cape Mendocino Earthquakes 1992 (M7.0)	Pacific Lumber Mill	0.47	0.46
	Centerville Navy Base	0.40*	
	Humboldt Bay Power Plant	0.24*	
	Humboldt Substation	0.10	
Landers & Big Bear Earthquakes 1992 (M7.4)	Cool Water Power Plant	0.35*	0.37
	Solar Electric Plants	0.35	
	Newberry Gas Compressor Plant	0.25	
	Mitsubishi Cement Plant	0.30	
Guam Earthquake 1993 (M8.0)	Cabras Power Plant	0.25	0.25
	Piti Power Plant	0.25	
	Tanguisan Power Plant	0.25	
	Yigo Gas Turbine Plant	0.25	
	Dededo Gas Turbine Plant	0.25	
	Guam Caterpillar Diesel Plants	0.25	
	Orote Point Diesel Plant	0.25	
	Uguam Water Plant	0.25	
	Navy Water & Sewage System	0.25	
Northridge Earthquake 1994 (M6.7)	Sylmar Converter Station	0.85*	0.75
	Rinaldi Substation	0.66*	0.66
	Olive View Cogen Plant	0.72*	
	Olive View Hospital	0.89*	
	Great Western Data Center	0.75	0.4
	Placerita Cogen Plant	0.50	0.59
	Pitchess Cogen Plant	0.50	
	Pardee Substation	0.45*	
	Castaic Hydro Plant	0.35*	

Table A-2 (continued)
SQUG Earthquake Experience Database Earthquakes & Sites

Earthquake	Site	Original PGA Estimate (g)	Updated PGA Estimate (g)
Northridge Earthquake, Continued	Vincent Substation	0.15*	
	Valley Steam Plant	0.40	
	Burbank Power Plant	0.30	
	Glendale Power Plant	0.30	
	Pasadena Power Plant	0.15	
Manzanillo Earthquake 1995 (M7.6)	Manzanillo Power Plant	0.40*	0.42
Turkey Earthquake 1999 (M7.4)	Ambarli Fuel Oil Power Plant	0.25	0.22
	Ambarli Combined Cycle Power Plant	0.25	0.22
	Pakmaya Cogen Facility	0.37	0.36
	Nuh Cimento Cogen Facility	0.20	0.24
	Adapazari 380 kV Substation	0.41	0.43
	Yarimca Substation	0.30	0.31
	Kosekoy Substation	0.20	0.28
	Sultanmurat Substation	0.15	0.12
Taiwan Earthquake 1999 (M7.6)	Kukuan Dam	0.40	
	Kukuan Hydro Plant	0.40	0.63
	Wanta Hydro Plant	0.40	0.71
	Tienlun Hydro Plant	0.40	0.26
	Techi Hydro Plant	0.30	0.64
	Mingtan Hydro Plant	0.50	0.3
	Takuan Hydro Plant	0.50	
	Chungliao 345-kV Switching Station	0.50	0.47

* Ground acceleration measured by an instrument at the site

B

VERIFICATION OF FUNCTION DURING EARTHQUAKE SHAKING—RELAY REVIEW REQUIREMENTS

B.1 Introduction

Studies by SQUG and SSRAP identified that chatter of electro-mechanical switches and relays during earthquake shaking can lead to loss of function of equipment during the earthquake. In general, relays and switches are rugged devices that can be reset after an earthquake, so the effects of relay chatter are not a concern for seismic qualification of equipment per ASCE-7. That is, the purpose of ASCE-7 seismic qualification is to verify that equipment will be able to perform its intended function after an earthquake (not during the earthquake).

This Appendix B provides an overview of the relay chatter evaluation methodology. These guidelines can be used for the higher performance objective of equipment function during earthquake shaking Conformance with these guidelines is optional and is beyond the requirements of ASCE-7.

Relay types that should be addressed include those devices which are provided to cause contact operation in electric control circuits. In general, they fall into three categories:

- The largest category is designated as auxiliary relays. This category typically includes electromechanical, pneumatic timing, and solid state relays used for general purpose control, blocking, closing, lockout, seal-in, and other logic or control functions.
- A second category includes protective electromechanical and solid state relays whose function is to protect equipment from system faults and other abnormal or dangerous conditions by automatically initiating appropriate control circuit action. Protective relays include over-current and under-voltage relays.
- The third general category of relays is contactors. A contactor is a heavy-duty relay which may carry significant amounts of current. It is distinguished from a circuit breaker (such as is used in switchgear) in that its contacts are moved by a small solenoid-type mechanism rather than by compressed springs or other actuating mechanisms.

Other devices which have contacts, such as control switches which are used in relay logic control circuits, should also be addressed in the relay evaluation, even though they are not considered relays.

Mechanically actuated switches are considered seismically rugged and need not be evaluated for relay chatter.

B.2 Identification of Circuits, Relays, Consequences of Relay Malfunction

Drawings of the electrical control circuit(s) for each important item of equipment should be identified. The electrical circuits used to operate and control the equipment should then be reviewed. The relays identified in this review should then be evaluated.

Once the list of system equipment, circuits, and relays needed for intended equipment (or system) function is narrowed to only those required to function (i.e., change state or maintain a state) during and immediately after the earthquake, an evaluation should be made to assess the consequences of relay malfunction in those systems and circuits. Relay malfunction includes chatter of the contacts in the relay itself and any other spurious signals from other devices which control the operation of the relay. The other devices could include other relays which chatter or instruments which send spurious signals due to the earthquake vibration (e.g., water sloshing in a tank could trigger a low water level signal from the level instrument).

The evaluation of the consequences of relay malfunction is comparable to a failure modes and effects analysis and is intended to identify those specific relays whose malfunction is important and those whose malfunction is inconsequential -- that is, those relays whose malfunction will not prevent the essential function from occurring, either because of the specific circuit design or the failure logic employed. For example, a control or power circuit may be designed such that component malfunction (including relay malfunction) results in the system failing in a safe or desired manner. Relays whose malfunction is inconsequential from an earthquake resistance standpoint can be eliminated from further review.

Also, if relay malfunction may lead to inadvertent equipment or system operation which is acceptable, then these relays can be excluded from further review. For example, spurious operation of some pumps and valves may not prevent the intended post-earthquake safety function and can be considered acceptable. In addition, some relay-controlled devices respond slowly enough that relay chatter may cause either no operation or only a temporary but acceptable spurious operation of the controlled device (e.g., relay chatter leading to partial valve opening and then re-closing, or momentary energizing of pumps which do not affect the intended function of the system). Further, operator actions can be relied upon in certain situations to correct the effects of relay malfunction by resetting the affected relays.

The functional screening process described above will result in the minimum set of “essential” electrical relays whose seismic capacity should be verified to ensure that the system or item of equipment can perform its intended function. It will also identify those cabinets, panels, racks, and other enclosures which support or house the subject relays. These cabinets and panels will have to be seismically qualified if they have not already been addressed.

B.3 Seismic Capacity Versus Demand Evaluation for Essential Relays

In general, the seismic capacity of relays must be based on the available relay GERS, or determined by shake table testing of the specific relay (same make and model number) or by using available documentation about pervious shake table testing for that specific relay. Relay seismic capacity (to resist chatter) is highly sensitive to very minor changes in relay construction and operational state. Similarity arguments should not be used to estimate relay capacity for one relay model based on the capacity of a similar appearing but different model of another relay.

The seismic demand level for relays is determined by using the in-structure floor response spectrum ("IRS") times an amplification factor ("AF") for the cabinet that the relay is housed in. The seismic capacity response spectrum for the relay ("CAP") must exceed this seismic demand:

$$\text{CAP} \geq \text{IRS} \times \text{AF}$$

A relay is considered seismically adequate if the seismic demand spectrum is bounded by the relay capacity spectrum in the frequency range from 4 - 16 Hz and from 33 Hz and above, i.e., the zero period acceleration (ZPA).

The methods described in AC156 (see Section 2.3.4) should be used for determination of the in-structure floor response spectrum, except that the seismic motion should be reduced by the ($1/R_p$) factor. Only the relay is tested, so response modification due to seismic response of the panel has to be accounted for in the seismic demand determination for the relay itself.

In-cabinet seismic amplification factors ("AF") vary with the type of cabinet. In general, the stiffer the panel that the relay is mounted to, the lower the amplification factor. The following amplification factor guidelines shall be used:

- MCC-like cabinet (narrow doors). AF = 3.0
- Conventional control panel or benchboard. AF = 4.5. These kinds of cabinets in general have a natural frequency greater than 11 Hz.
- Switchgear-like cabinet, with wide un-stiffened door panels. AF = 7.0

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