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Topical Report

Basis for Adoption of the Experience-Based Seismic Equipment Qualification (EBSEQ) Methodology by Non-A46 Nuclear Power Plants

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Executive Summary

This Topical Report provides technical and regulatory justification for an experience-based seismic equipment qualification (EBSEQ) method for adoption by operating nuclear power plants as an acceptable alternative to current licensing basis methods. The utility members of the SEQUAL Owners Group, who collectively own nuclear plants both within and outside of the scope of Unresolved Safety Issue (USI) A-46, plan to implement the EBSEQ method according to the process delineated in 10 C.F.R. § 50.59 for changes to the facility, referring to this Topical Report for the purpose of including the EBSEQ methodology in their current licensing basis for seismic qualification of mechanical and electrical equipment.

The proposed EBSEQ method is the process described in Appendix A to this report. Leading seismic experts in the U.S., including an independent peer review panel (the Senior Seismic Review and Advisory Panel -- SSRAP), with input from representatives of the U.S. Nuclear Regulatory Commission (NRC) and their consultants, developed the methodology over a ten-year period. The NRC Staff approved an experience-based methodology in a Supplemental Safety Evaluation Report (SSER) in 1992, and the method has since been successfully used by the majority of the operating plants in the U.S. for resolution of NRC Unresolved Safety Issue (USI) A46. Importantly, the methodology was approved not only for evaluation of existing, installed equipment, but also for seismic qualification of new and replacement equipment in these plants.

Subsequent to these activities, SEQUAL and SQUG representatives have held discussions with the NRC staff and provided specific ground rules on how the approved GIP methodology may be applied to demonstration of seismic adequacy of new and replacement equipment and electrical raceways (NARE) in A46 and non-A46 nuclear plants. SQUG submitted to the NRC Revision 1 of a report on how its members plan to use the GIP for NARE (References 9.5 and 9.6). The NRC reviewed this report and provided comments (Reference 9.7). The NRC comments and recommendations have since been fully incorporated into these guidelines (Reference 9.8) and in the EBSEQ procedure included as Appendix A to this Topical Report. Additional explanations undertaken by the SEQUAL Owners Group, and presented in Section 6 of this report, show that based on risk-informed, performance-based assessment principles, the addition of the EBSEQ process has no significant effect on the overall seismic risk contribution to a plant's core damage frequency (CDF).

The EBSEQ method is based on documented performance of equipment in dozens of strong motion earthquakes in hundreds of power plants and industrial facilities, and is supplemented by results of shake table tests and analyses. An important finding of the research, which is the basis for the EBSEQ methodology, is that the conventional electrical and mechanical equipment included in the scope of the EBSEQ is inherently rugged for earthquake levels significantly higher than the design basis earthquakes for eastern U.S. nuclear plants provided the criteria outlined in the EBSEQ procedure (Appendix A) are met. The guidelines given in Appendix A provide a systematic, controlled and well-documented performance-based method to evaluate (*i.e.*, screen out) those types of conventional equipment shown to be insensitive to earthquake motions expected in eastern U.S. plants and to focus on actual equipment and installation vulnerabilities identified in strong motion earthquakes and prior qualification tests. The EBSEQ process described in Appendix A makes use of this equipment performance data to define the procedure for seismic qualification of new and replacement equipment in operating nuclear plants. This process has been demonstrated to be cost-effective in identifying risk-significant seismic issues without reduction of seismic design margins. As a result, adoption of this methodology is considered to be a risk-informed and performance-based licensing action.

The report provides the technical and regulatory bases for NRC acceptance of the EBSEQ methodology as an alternative seismic equipment qualification method for those operating plants not included in the scope of USI A-46 (*i.e.,* non-A46 plants), some of which are committed to NRC regulatory requirements found in 10 C.F.R. Part 50, Appendix A, General Design Criterion (GDC) 2, and Appendix A of 10 C.F.R. Part 100. The key facts supporting the proposed licensing basis change are as follows.

- After years of review and participation by the NRC Staff in the development and trial use of an experience-based method, specifically the SQUG Generic Implementation Procedure (GIP), the NRC accepted the GIP in SSER No. 2 in May 1992 (Reference 9.3), for A46 plants. This acceptance included provisions for use of the method in the qualification of new equipment over the life of the plants. The procedure given in Appendix A is consistent with the EBSEQ process accepted by the NRC for A46 plants.

- The experience-based method has been used in more than half of U.S. operating plants for a period of almost 20 years. It has been found to be safe and effective. Results of numerous strong motion earthquakes worldwide since approval of the GIP have validated the adequacy of its criteria.

- Technical evaluations presented in Section 5 of this Topical Report show that the EBSEQ methodology, while different than current licensing basis seismic equipment qualification methods for non-A46 plants, nevertheless provides assurance of seismic adequacy of the more rugged conventional equipment in its scope, without any significant change in seismic design margins in the affected plants.

- The regulatory analysis included in Section 4 of this Topical Report confirms that the EBSEQ methodology satisfies the pertinent equipment seismic qualification requirements of GDC 2, and meets the purpose of the NRC regulations relevant to equipment seismic qualification, including 10 C.F.R. Part 100, Appendix A. The NRC reached this conclusion in SSER No. 2 for the GIP methodology on which the EBSEQ procedure of Appendix A is based (SSER No. 2 at 5). If a generic methodology meets the intent of the regulations, then its application is not limited to a specific plant or group of plants. For these reasons, the EBSEQ method clearly meets the fundamental intent of the NRC regulatory requirements to provide adequate assurance of protection of the health and safety of the public. This conclusion is consistent with conclusions reached in meetings among SEQUAL and NRC staff representatives (reported in References 9.9 and 9.10) and in the NRC letter to SEQUAL (Reference 9.11) which concludes: "NRC staff accepts, in concept, that the use of earthquake experiential data for seismic qualification is permissible in the context of Part 100."

- Results of probabilistic studies performed in accordance with <u>accepted industry practice</u> are presented in Section 6. These studies show that although individual elements of present licensing basis SEQ methods and the proposed EBSEQ process differ considerably, the net effect of these differences on the seismic contribution to risk is negligible for the full range of uniform hazard spectra for SEQUAL plants. The average decrease in risk using the EBSEQ method compared to using the IEEE 344 testing method is in the range of 1E-07 per year for the SEQUAL plants covered by this Topical Report. Regulatory Guide 1.174 permits a small increase in CDF (of up to 1E-06 per year). The highest increase in risk in using the EBSEQ method is on the order of 1E-10, which is significantly less than the Regulatory Guide limit. Sensitivity studies show this overall conclusion is not significantly changed by varying input assumptions.

Finally, in the current nuclear plant operating environment, it is essential that utilities seriously evaluate and implement operations and maintenance (O&M) practices that are cost-effective, while continuing to ensure adequate protection of public health and safety, thereby permitting the utilities to better focus their attention and resources on issues with greater safety and risk significance. The EBSEQ method is one such O&M practice. Utilities operating A46 plants have demonstrated cost savings ranging from several thousand dollars to several hundred thousand dollars per equipment item procured using the experience-based seismic qualification method. Equipment availability is also greatly enhanced, particularly as vendors increasingly decide to no longer supply IEEE 344 qualified equipment for nuclear applications. Precluding the use of an experience-based seismic qualification method for the non-A46 operating plants, some of which share the same site, procedures, and personnel as A46 plants, creates technical and economic inequities that are, based on years of operating experience and earthquake data, no longer justified. Additionally, requiring a dual standard for procurement of otherwise identical equipment promotes more complex and costly procurement and material control processes, and complicates facility modifications, without a commensurate increase in the overall safety and seismic adequacy of the plants.

In summary, sound technical, regulatory, risk-informed and economic reasons exist for adoption by licensees, and approval by the NRC, of the EBSEQ methodology proposed herein as an acceptable alternative seismic equipment qualification method for all operating nuclear power plants.

1.0 Introduction

1.1 Purpose

This Topical Report describes and justifies a proposed change in the current licensing bases of operating nuclear power plants. NRC approval would permit adoption of the experience-based seismic equipment qualification (EBSEQ) method, delineated in Appendix A, as an acceptable alternative seismic equipment qualification (SEQ) method meeting all applicable seismic regulations for plants not included in the scope of Unresolved Safety Issue (USI) A-46 (these plants are referred to hereinafter as "non-A46 plants"). The EBSEQ method is based on the approach developed by the Seismic Qualification Utility Group (SQUG) for demonstrating the seismic adequacy of new and replacement equipment in A46 plants.

Members of the Seismic Experience-based Qualification (SEQUAL) Owners Group (owners of non-A46 plants) plan to implement the EBSEQ methodology according to the provisions of 10 C.F.R. § 50.59, referring to this Topical Report and the NRC's associated Safety Evaluation as the technical and regulatory justification for implementing the proposed licensing basis change.[1] Current members of the SEQUAL Owners Group, who collectively own and operate both A46 and non-A46 operating nuclear plants, include:

Utilities	**Number of Affected Units**
Duke Energy	4
Progress Energy	4
First Energy	2
Entergy	3
TXU	2
Tennessee Valley Authority	2
Exelon	3
Wolf Creek Nuclear Operating Company	1

Implementation of the EBSEQ methodology by the above-listed utilities, and possibly by owners of other nuclear power plants, in accordance with the licensee's 10 C.F.R. § 50.59 Program, will cover the plant-specific bounds and limitations on the use of this method, including modifications to the affected sections of the plant's Safety Analysis Report (SAR), identification of the equipment classes to which the method can be applied, and identification of the buildings in which the equipment is located. Licensees will also describe how plant-specific

[1] Specifically, once the NRC has reviewed and approved the EBSEQ methodology, incorporation of the EBSEQ methodology, for its intended application, into a plant's licensing basis is allowed in accordance with the provisions of 10 C.F.R. § 50.59 for a change to the facility's Updated Final Safety Analysis Report. According to Section 50.59 and its associated guidance, if the NRC has approved a method of evaluation for the intended application, as demonstrated by a licensee in a Section 50.59 process, prior NRC approval of the change is not required.

licensing basis loading combinations and environmental requirements are to be addressed when the EBSEQ method is used for seismic qualification of new and replacement equipment.

The main sections of this report provide a general description of the proposed licensing basis change, the applicable regulatory framework and precedent licensing actions, the regulatory and technical justifications for the EBSEQ method described herein, and a summary of probabilistic studies which address the risk significance of the change relative to existing licensing basis SEQ methods. NRC Staff questions and comments contained in NRC's letter dated August 24, 2000, to SEQUAL (Reference 9.11) are also addressed.

1.2 Background

Over a ten-year period in the 1980s and early 1990s, the Seismic Qualification Utility Group (SQUG), with participation and review by the NRC and an expert panel, developed an experience-performance-based method for demonstrating seismic equipment adequacy. In 1992 it was approved by the NRC for use in resolving USI A-46 *as well as* for demonstrating the seismic adequacy of a specified scope of new and replacement equipment and raceways (NARE) in plants affected by USI A-46. The approved methodology, embodied in the SQUG Generic Implementation Procedure (GIP), has since been implemented in more than half of the operating U.S. nuclear plants[2] to verify the seismic adequacy of the plants and thereby resolve USI A-46.

Of more importance to the SEQUAL utility members, the EBSEQ method has also been used by many A46 plants to verify the seismic adequacy of new and replacement equipment (NARE) in these plants. This use of the EBSEQ method, following guidelines consistent with the NRC's acceptance of the GIP method for NARE, has demonstrated that the process is a practical, cost-effective method to assure the seismic adequacy of certain new equipment for plant modifications and replacements. Because of this, a number of non-A46 plant owners recognized the value of the EBSEQ method, and formed the SEQUAL Owner's Group in 1995 to pursue use of the EBSEQ method in non-A46 plants.

SEQUAL's evaluation of the EBSEQ method confirmed its applicability to non-A46 plants (*e.g.*, the application is the same for non-A46 plants as for A46 plants and regulatory analyses, summarized in Section 3 and 4 of this report, show that the method meets regulations applicable to plants subject to 10 C.F.R. 100, Appendix A). Accordingly, after preliminary discussions with NRC management and Office of General Counsel (OGC) representatives, SEQUAL and NRC representatives met to discuss use of the EBSEQ process in non-A46 plants in September 1999 and March 2000. These meetings are documented in References 9.9 and 9.10. Subsequently, the NRC forwarded a letter to SEQUAL (Reference 9.11) summarizing its comments and questions on the EBSEQ process as applied to non-A46 plants.

These meetings and the NRC's review documented in its letter to SEQUAL (Reference 9.11) resulted in the following agreements and conclusions:

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[2] It has also been adopted and used to various degrees, by the U.S. Department of Energy and nine international organizations and utilities.

- The SEQUAL and NRC staff representatives agreed that the GIP process implemented by A46 utilities for resolution of USI A46 improved the level of seismic safety in those plants and that the method, properly implemented, assures adequate protection of the health and safety of the public for use in the A46 plants.

- The NRC staff does not object to the concept of using an experience-based approach for seismic qualification of certain equipment in operating nuclear power plants. However, the staff noted that since the GIP was not written as a standard for qualification of new and replacement equipment, integrated guidelines are needed so that the method can be considered as an alternative to IEEE Standard 344. (Reference 9.12). SEQUAL representatives agreed. In response, SEQUAL and SQUG submitted to the NRC a summary of the NARE Guidelines (Reference 9.8), which provide the overall approach and additional implementation details necessary to apply the basic GIP methodology to newly procured equipment. As described in Section 3.2, these guidelines have since been accepted by the NRC and are in use by A46 plants. A revised version of these guidelines, which is specifically tailored for use by non-A46 plants, is included in Appendix A.

- In the September 1999 meeting with SEQUAL, the NRC expressed concerns whether the GIP method meets the regulations applicable to most non-A46 plants (GDC 2 and 10 C.F.R. 100, Appendix A). NRC and SEQUAL agreed this is the main question to be addressed in determining the acceptability of the process for non-A46 plants. This conclusion is documented in the NRC's report of this meeting (Reference 9.9).

- The NRC subsequently concluded in Reference 9.11 that the "NRC staff accepts, in concept, that the use of earthquake experiential data for seismic qualification is permissible in the context of Part 100…" The detailed regulatory analysis in Section 4 confirms this conclusion as applied to the proposed EBSEQ methodology.

- The NRC expressed several technical concerns regarding use of the EBSEQ method for non-A46 plants. One is related to the estimation of ground motion in past earthquakes at data base sites. Other concerns question whether the EBSEQ process adequately maintains seismic design margins in the non-A46 plants. These concerns are delineated in Reference 9.11 and are addressed in Section 5.3 of this report.

- Finally, the NRC suggests in Reference 9.11 that if SEQUAL members decide to pursue use of the EBSEQ method for their plants, they should consider using a quantitative, risk-informed approach to the extent practical, to evaluate seismic design margin. Qualitative and risk-informed quantitative evaluations are presented in Sections 5.2 and 6 of this report.

Based on the above and the results of the technical and regulatory analyses presented herein, and subsequent to NRC approval of the SEQUAL Topical Report, utilities may adopt the EBSEQ method as an alternative method in addition to existing licensing basis SEQ methods through a change to the Updated Final Safety Analysis Report in accordance with 10 C.F.R. § 50.59. Plants not specifically addressed within this Topical Report would be required to follow the described evaluation methods, including a plant-specific Risk Informed Evaluation.

1.3 Factors Motivating Non-A46 Plants to Adopt the EBSEQ Method

The nuclear power plants included in the scope of USI A46 (*i.e.,* A46 plants) comprise more than half of the operating nuclear units in the U.S. today. It is not atypical for a utility to operate both A46 and non-A46 nuclear units located on the same site and supported by the same engineering, procurement, and quality assurance organizations. As related to seismic adequacy, this situation presents a technical and economic inequity because theA46 unit may use an experience-based method for seismic qualification of equipment and as a very practical and cost-effective method to determine seismic adequacy, while a similar, non-A46 unit may not. Such a situation promotes more complex and costly procurement and material control processes for the licensee, and complicates facility modifications and configuration control because the licensee has to maintain and apply two different methods for seismic qualification, both of which the NRC has determined provide adequate protection of public health and safety.

Specific features and advantages of the EBSEQ methodology that motivate non-A46 utilities to adopt and use this approach for SEQ include the following:

- The method provides a practical and effective procedure for screening out seismically rugged conventional equipment, thereby allowing the utility staff to focus important resources on more sensitive or vulnerable items. This is the objective of the risk-informed processes.

- An experience-based method is an important element of commercial grade dedication, especially as the number of vendors supplying IEEE 344 qualified equipment continues to diminish. Application of an experience-based method has resulted in substantial improvements in equipment availability and delivery times for A46 plants, thereby saving millions of dollars in lost power generation at the affected plants. Even when IEEE 344 qualified equipment is available, the application of the EBSEQ method for seismic qualification of commercial grade, new and replacement equipment in A46 plants has demonstrated that it is very cost effective. Estimated savings in equipment procurement costs range from several thousand dollars for smaller parts and subassemblies, to several hundred thousand dollars for major equipment items.

- The EBSEQ method is an effective alternative method (to analysis and testing) for evaluating the seismic adequacy of installed equipment when plant conditions require an operability assessment.

In the current nuclear plant operating environment, it is essential that utilities seriously evaluate and implement operations and maintenance (O&M) practices that are cost-effective, while continuing to ensure adequate protection of the public health and safety. This permits utilities to better focus their attention and resources on safety and risk significant issues with no reduction of plant seismic safety. The EBSEQ method is such an O&M practice.

Perhaps the most important result of the joint industry and NRC research that led to the development and acceptance of an experience-based method (*i.e.,* the GIP) is the finding that the types of conventional electrical and mechanical equipment covered by the method are inherently rugged, provided that the criteria outlined in the GIP are satisfied.

NRC approval of the EBSEQ will allow non-A46 plants to realize efficiencies in engineering and procurement processes while maintaining an adequate level of safety, allow licensees to reduce the complexities of managing two separate seismic qualification programs, and allow licensees to better focus resources on more safety and risk significant issues.

2.0 Proposed Licensing Basis Change

SEQUAL proposes that the EBSEQ process which is described by this Topical Report, and attached as Appendix A, be added to the plants licensing bases as an alternative SEQ method that meets all NRC regulations pertinent to seismic adequacy to which the plants are presently committed in their licenses. Following NRC approval of the EBSEQ methodology, utilities can add the EBSEQ method to the acceptable methods discussed in the plant's licensing basis in accordance with 10 C.F.R. § 50.59. It is important to note that the proposed EBSEQ procedure does not change or supplant existing licensing basis SEQ methods and commitments related to these methods; rather, it would add another acceptable alternative method for SSC types specifically identified in its scope.

A general description of the proposed alternative EBSEQ method, together with its important features and specified limitations, are given below.

2.1 The EBSEQ Process

The EBSEQ process given in Appendix A makes use of applicable elements of the NRC-approved GIP process. However, as noted by the NRC in discussions and correspondence with SEQUAL representatives, the GIP is not a "stand-alone" seismic qualification standard. As discussed in "Background," above, and in more detail in Section 3.2, the NRC accepted the applicable sections of the GIP for verification of seismic adequacy of new and replacement equipment in the A46 plants, subject to imposition of additional conditions. Further, additional implementation details are necessary to define how the GIP requirements are to be applied in the procurement and qualification of new equipment. The necessary supplemental requirements to convert the GIP methodology into a seismic qualification[3] procedure meeting all NRC conditions, and containing appropriate implementation guidance, were developed by SQUG, working with the NRC staff, and are summarized in a "SQUG Report on the Use of GIP for New and Replacement Equipment and Parts, Revision 1," (References 9.5 and 9.6). Those guidelines, referred to as the "NARE Guidelines," were reviewed by the NRC and tested in a pilot application for the Oconee Station. NRC staff comments and recommended revisions to those NARE Guidelines were subsequently documented in an NRC letter to SQUG (Reference 9.7) and were all incorporated into the NARE Guidelines as described in Reference 9.8. The SEQUAL EBSEQ procedures in Appendix A to this Topical Report is consistent with the accepted NARE Guidelines currently being used by A46 plants for demonstrating the seismic adequacy of new equipment and raceways. A summary of the scope of the GIP and how it is supplemented by the EBSEQ procedure follows.

The scope of the GIP process approved and used for resolution of USI A-46 contains the following main elements:

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[3] It is noted that the NRC regulations pertinent to seismic adequacy do not define or distinguish between the words "verification" and "qualification;" the intent of both (and the regulations) is demonstration of equipment seismic adequacy.

- Selection of safe shutdown path(s) and equipment for resolution of A46.
- Seismic capacity versus 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.

The evaluation approach for resolution of USI A-46 made use of plant walkdown inspections, analyses, and prior data from earthquake experience and dynamic (*e.g.*, shake table) tests. The GIP approach is directed primarily at installed equipment (*i.e.*, equipment that is installed and accessible).

The EBSEQ procedure in Appendix A (and the NARE Guidelines) provide the roadmap for applying the GIP methodology to new equipment and the additional conditions imposed by the NRC in Reference 9.3 (SSER No. 2). Additional implementation guidelines, addressed in the EBSEQ procedure, include:

- The use of procurement and installation specifications to implement requirements for new equipment.
- Requirements for a design differences evaluation to address possible changes in newer vintage equipment.
- Ground rules for parts and subassemblies.
- Specific instructions as to which sections of the GIP are applicable and which are not; applicable sections include:
    - Basic ground rules approved in SSER No. 2 for use of the GIP process for seismic verification of new equipment (Part I, Section 2.3.4).
    - Personnel qualification and training (Part II, Sections 2.1.2, 2.4).
    - Capacity vs. demand evaluation (Part II, Section 4)

- Equipment class rules (inclusion rules and caveats) (Part II, Section 4 & Appendix B)

- Equipment anchorage (Part II, Section 4 & Appendix C)

- Seismic interaction (Part II, Section 4 & Appendix D)

- Relay capacity vs. demand (Part II, Section 6.5)

- Tank and heat exchanger evaluation (Part II, Section 7)

- Cable and conduit raceway evaluation (Part II, Section 8)

- Documentation requirements (Part II, Sections 4, 6, 7, 8 & Appendix G)

- Post-installation inspection requirements.

- Detailed implementation checklists.

2.2 Specific Limitations of the EBSEQ Method

The procedure for using the EBSEQ method in Appendix A includes several important limitations that have been discussed among NRC staff and SEQUAL representatives:

- The scope of equipment to which the method may be applied includes only non-NSSS, conventional electrical and mechanical equipment classes defined in the EBSEQ. All seismic category equipment in a plant is not covered by the methodology.

- Specific limitations on use of the EBSEQ method apply:

  - The EBSEQ method does not apply to non-normal concurrent loads (such as accident loads and BWR suppression pool loads). Such loads must be evaluated by supplemental tests or analyses, or other SEQ methods.

  - The EBSEQ method does not address the effect of harsh environments requiring pre-aging under current licensing basis requirements. Such applications require supplemental evaluations or use of other SEQ methods.

  - The EBSEQ method does not verify the function of chatter-sensitive devices (*e.g.*, relays) during an earthquake based on earthquake experience data; shake table test data must be used.

  - The EBSEQ method is not applicable to low-cycle, fatigue-sensitive items (*e.g.*, items shown to be affected by prior Operating Basis Earthquake cycles), as defined in the EBSEQ.

- The use of EBSEQ to estimate seismic demand for building elevations less than 40 feet is restricted to buildings that do not exhibit significant amplification of motion. The limitations are stated in Attachment A of the EBSEQ procedure.

- The EBSEQ method requires that personnel who make the seismic adequacy determinations possess specific seismic engineering experience, and complete the SQUG developed (and NRC approved) training for Seismic Capability Engineers.

In summary, the proposed EBSEQ method provides for an effective and well-documented evaluation (or screening) of equipment, which has been shown through earthquakes and tests to be inherently rugged (provided specific requirements and prohibitions are met). In addition, the EBSEQ focuses on actual equipment vulnerabilities identified in strong motion earthquakes and in prior qualification tests and analyses. As such, the EBSEQ method is a risk-informed, performance-based process.

3.0 Regulatory Framework

3.1 Governing SEQ Requirements

The following regulatory requirements are applicable to the seismic adequacy of nuclear power plant structures, systems, and components (SSCs).

- 10 C.F.R. Part 50, Appendix A, General Design Criterion 2, “Design Bases for Protection Against Natural Phenomena,” sets forth the requirements for design of nuclear plants to protect against natural phenomena, including earthquakes. This general design criterion requires reasonable assurance of seismic adequacy of necessary equipment. (The General Design Criterion applies to plants with construction permits issued after May 21, 1971.)

- 10 C.F.R. Part 100, Appendix A, “Seismic and Geologic Siting Criteria for Nuclear Power Plants,” sets forth the principal seismic and geologic considerations that guide the Commission in its evaluation of the suitability of proposed sites and of the plant design bases established in consideration of the seismic and geological characteristics of the proposed sites. (Appendix A became effective on December 13, 1973.)

Demonstration of compliance with these regulations satisfies all requirements pertinent to seismic qualification of SSCs.[4]

3.2 Regulatory and Industry Guidance and Plant Licensing Basis Commitments Related to Seismic Adequacy

To further explain the above listed regulatory requirements, the NRC established guidance for seismic qualification in Regulatory Guide 1.100. This guide endorses an industry standard (IEEE 344) and the experience-based method for ensuring seismic adequacy of equipment in nuclear power plants.

When the NRC issues a regulatory guide and endorses a method, licensees are not required to comply with that particular method. If, however, a licensee elects to use an alternative method, then specific NRC approval of the alternative method may be required[5]. The method that a licensee elects to use for complying with regulatory requirements is generally described in the plant's SAR, or other licensing basis document, and is considered a licensee commitment. Licensing basis documents, including commitments, may be changed pursuant to the provisions in 10 C.F.R. § 50.59, "Changes, Tests, and Experiments," or under the control of a licensee's Commitment Management System. Under certain conditions, specific NRC approval of licensing basis changes is required.

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[4] No regulation specifically requires seismic adequacy demonstration by “qualification tests” or compliance with IEEE 344-75.

[5] NRC approved methodologies may be applied according to 10 C.F.R. § 50.59 if certain conditions are met.

The framework of guidance and commitments for seismic qualification is as follows:

- Regulatory Guide ("RG") 1.100, "Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants," describes a method acceptable to the NRC Staff for complying with NRC's regulations with respect to seismic qualification of electric and mechanical equipment. (RG 1.100 provides guidance rather than regulatory requirements. A licensee may have committed to follow the guidance in RG 1.100 for seismic qualification of equipment.)

- IEEE-344, "Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations," includes principles, procedures, and methods of seismic qualification that, when satisfied, will confirm the adequacy of the equipment design for the performance of safety functions before, during, and after the time the safety-related equipment is subjected to high stresses resulting from design basis events (*i.e.*, operating basis earthquake and safe shutdown earthquake). (IEEE-344 is guidance rather than regulatory requirements. Licensees may have committed to use of IEEE-344 for seismic qualification of equipment.)

- SAR Commitments. As part of licensing a plant, the applicant utility generally made commitments in the plant's SAR that the NRC relied upon for approving the license application. Many of the commitments indicated how a licensee would implement a specific regulatory requirement, such as Appendix A of 10 C.F.R. Part 100. Accordingly, there may be a group of plants that would not have been required to meet the requirements of Appendix A to 10 C.F.R. Part 100, but that made specific commitments to meet the requirements. By adding the EBSEQ methodology to the SAR, it is not the objective that plant-specific commitments, related to existing licensing basis SEQ methods, would change since the proposed change is to add an alternative, acceptable SEQ method. If plant-specific SEQ commitments are changed, these changes will be addressed in the plant-specific 10 C.F.R. § 50.59 process or through other licensing actions, as appropriate.

3.3 Precedent Licensing Actions

The NRC has issued several significant conclusions and positions regarding the compliance of the EBSEQ method with the applicable regulations and the acceptability of the method for demonstrating the seismic adequacy of new equipment:

- Generic Letter 87-02 (February 1987) presents the NRC's conclusion that the EBSEQ process is acceptable (actually, the best available process) for resolution of USI A-46. This Generic Letter also recognizes the value and acceptability of this method for qualification of equipment procured for future plant modifications and replacements:

  > *"If a utility replaces components for any reason, each replacement (assembly, subassembly, device) must be verified for seismic adequacy either by using A46 criteria and methods or, as an option, qualifying by current licensing criteria. This provision also applies to future modification or replacements. "Component" in this context means equipment and assemblies (including anchorages and supports) "such*

as pumps and motor control centers" –and subassemblies and devices-such as motors and relays that are part of assemblies." (GL 87-02, Enclosure, at 5.)

- Generic Letter 87-02, Supplement 1, issued Supplemental Safety Evaluation Report (SSER) No. 2 following the development and review of GIP-2 in February 1992. This NRC SSER approved the EBSEQ process defined in GIP-2 for resolution of USI A-46. It also confirmed its acceptance of the EBSEQ method for new equipment by noting:

  "…the criteria and procedures described herein [referring to the GIP procedures] are determined to be an acceptable evaluation method for <u>verifying</u> the seismic adequacy of new equipment in USI A-46 plants." (SSER No. 2 at 9.)

- In SSER No. 2, the NRC provided the specific conditions under which the GIP methodology may be used as an acceptable SEQ method for NARE:

  "…with the provisions that the seismic evaluations are performed in a systematic and controlled manner so as to ensure that new or replacement items of equipment are properly represented in the earthquake experience or generic testing equipment classes, and that applicable caveats are met. In particular, each new or replacement item of equipment and parts must be evaluated for any design changes that could reduce its seismic capacity from that reflected by the earthquake experience or generic testing equipment classes, and these evaluations must be documented." (SSER No. 2 at 8.)

  EBSEQ process in Appendix A includes these provisions.

- Regarding compliance of the GIP methodology with the regulations, the NRC concluded in SSER No. 2 that implementation of the GIP approach:

  "…satisf[ies] the pertinent equipment seismic requirements of General Design Criterion 2 and the purpose of the NRC regulations relevant to equipment seismic adequacy including 10 CFR Part 100." (SSER No. 2 at 5.)

- This conclusion that the methodology meets the intent of the seismic regulations is clearly independent of the specific plants or groups of plants involved (*i.e.*, if the method meets the regulations, it meets the regulations for all plants).

In summary, the staff clearly has concluded that the GIP methodology is consistent with the applicable regulations and, by accepting the methodology to verify the seismic adequacy of equipment in the majority of the operating nuclear plants in the U.S., has acknowledged that it provides the required reasonable assurance of adequate protection of the public health and safety.

Finally, to ensure proper implementation of the GIP process in the determination of seismic adequacy of new and replacement equipment (NARE), SQUG developed guidelines for use of the applicable portions of the GIP for NARE. These guidelines (referred to as the "NARE Guidelines") have been discussed in several meetings in 1999 and 2000 among representatives of SQUG, SEQUAL and the NRC. A summary of these guidelines was submitted for NRC review in References 9.5 and 9.6. Following additional discussions and trial use of the process for new equipment procured for the Oconee Station, the NRC accepted the results of the trial application of the process and issued Reference 9.7, which contained the NRC's comments and recommendations on the summary NARE Guidelines. These comments and recommendations have been incorporated by SQUG without exception in the NARE Guidelines, a copy of which was transmitted to the NRC by Reference 9.8. The EBSEQ procedure in Appendix A is fully consistent with the guidelines accepted by the NRC and includes the necessary additional detailed implementation procedures, including checklists, for application of the process for new equipment and part procurements in non-A46 plants.

4.0 Regulatory Analysis

SEQUAL legal/licensing representatives have performed regulatory analyses to determine whether the proposed EBSEQ procedure (1) complies with seismic regulations applicable to most non-A46 plants – namely, GDC-2 and 10 C.F.R. 100, Appendix A, and (2) meets the acceptance criteria for NRC approval. The results and conclusions of these analyses are presented below.

4.1 Compliance with GDC-2, "Design Bases for Protection Against Natural Phenomena"

The General Design Criteria for nuclear power plants were effective May 21, 1971. These criteria were added to the NRC's regulations to establish the minimum design requirements for nuclear power plants. General Design Criterion (GDC) 2 requires that structures, systems, and components important to safety be designed to withstand the effects of natural phenomena, including earthquakes. As described in Section 5.0, the EBSEQ process is an engineering method that has been demonstrated to be effective for verifying the seismic adequacy of certain power plant equipment and raceways. The NRC confirmed this conclusion in SSER No. 2, in which it determined that implementation of the GIP approach satisfies "the pertinent equipment seismic requirements of General Design Criterion 2 and the purpose of the NRC regulations relevant to equipment seismic adequacy including 10 C.F.R. Part 100." (SSER-2 at 5.)

4.2 Compliance with 10 C.F.R. 100, Appendix A

The compliance of the EBSEQ process with the provisions of 10 C.F.R. 100, Appendix A, is evaluated based on (1) the intent of Appendix A, and (2) an interpretation of the key words of Appendix A pertinent to equipment seismic qualification. The results of these evaluations follow.

4.2.1 The EBSEQ Method Meets the Intent of the Purposely Flexible Guidance of Appendix A

The NRC's regulations addressing the seismic adequacy of equipment within safety-related structures, systems, and components are set out in the "Engineering Design" section of 10 C.F.R. Part 100, Appendix A. The regulatory scheme of Part 100 is intended to be flexible, and to permit the use of several engineering methods.

Part 100, Appendix A, contains specific provisions concerning engineering methods for demonstrating the seismic adequacy of equipment. For both the operating basis earthquake (OBE) and the safe shutdown earthquake (SSE), Appendix A expressly calls for an "engineering method . . . [which] shall involve the use of either a suitable dynamic analysis or a suitable qualification test to demonstrate that structures, systems, and components can withstand the seismic and concurrent loads, except where it can be demonstrated that the use of an equivalent static load method provides adequate conservatism." Neither the specific attributes -- "suitable dynamic analysis" and a "suitable qualification test" -- nor other characteristics of an acceptable engineering method are defined in the seismic adequacy regulation. Furthermore, these engineering attributes were "not intended as a definitive treatment of the engineering aspects of seismic design." (SECY-79-300, Enclosure B at 2 (April 27, 1979).)

Although acceptable engineering methods are not expressly defined by the regulations, the NRC Staff has acknowledged an acceptable engineering method in a number of guidance documents, including Regulatory Guide (Reg. Guide) 1.100 and Section 3.9.2 and 3.10 of the Standard Review Plan (SRP). The NRC's guidance documents endorse IEEE 344-1975 (and subsequently issued IEEE 344-1987) as providing an acceptable method for demonstrating seismic adequacy. (*See* RG 1.100, Rev. 2, at 2-3; SRP at 3.10-3.) Nothing in the NRC's guidance, however, indicates that the IEEE standards offer the only acceptable method for demonstrating seismic adequacy. Moreover, it is well established that licensees are free to offer alternatives to NRC guidance documents to demonstrate compliance with an underlying regulation.

Notwithstanding the NRC's endorsement of IEEE 344-1975, the IEEE standard specifically notes that other effective methods may be adequate to verify the ability of the equipment to meet the seismic adequacy requirements. (IEEE 344-1975 § 4; IEEE 344-1987 § 4.) In addition, RG 1.100 itself acknowledges that the use of experience-based "methods of qualification will be evaluated by the NRC Staff on a case-by-case basis." (RG 1.100 at 2.) Thus, both IEEE 344-1975 and NRC guidance reinforce the flexibility of the Appendix A criteria.

Beyond the flexibility inherent in the specific engineering design provisions and the NRC's guidance documents, the overall regulatory scheme contemplated by Part 100 offers flexibility for meeting its regulatory provisions. For example, the scoping section of 10 C.F.R. Part 100 explicitly states that the criteria in this part are "deliberately flexible" in order to accommodate uncertainty and to account for changing reactor designs. (10 C.F.R. § 100.2(b).)

Similarly, 10 C.F.R. Part 100, Appendix A, is phrased in inherently flexible terms. Appendix A states: "[I]t is the purpose of these criteria to set forth the principal seismic and geologic considerations which guide the Commission in its evaluation of proposed sites . . . and . . . plant design bases established in consideration of the seismic geologic [site characteristics]." (10 C.F.R. Part 100, Appendix A § I (emphasis added).)

It is clear that the Commission intended to apply 10 C.F.R. Part 100 broadly and did not intend to prescribe specific methods for satisfying the criteria set out in the regulations. This interpretation is supported by several NRC and federal cases. For example, the federal courts have upheld the Commission's view of the "inherent flexibility of 10 C.F.R. Part 100," as well as the "necessity of flexibility" in Appendix A. (North Anna Environmental Coalition v. Nuclear Regulatory Comm'n, 533 F.2d 655, 662, 667 (D.C. Cir. 1976); see also Carstens v. Nuclear Regulatory Comm'n, 742 F.2d 1546, 1550 (D.C.Cir. 1984) (acknowledging that Appendix A is crafted broadly and properly "leav[es] wide discretion to the Commission").) Similarly, the NRC Appeal Board concluded, "10 C.F.R. Part 100 makes clear that it is not intended to furnish the final word in all situations . . . [the regulation] contains repeated admonitions that is to be used flexibly." (Public Service Co. of New Hampshire (Seabrook Station, Units 1 and 2), ALAB-422, 6 NRC 33, 51 (1977).)

Therefore, in view of the flexibility contained in both the specific engineering design provisions and in 10 C.F.R. Part 100 generally, the Commission may not preclude licensees from offering engineering methods other than the IEEE 344-1975 standard to demonstrate compliance with the seismic adequacy requirements.

4.2.2 The EBSEQ Method is Consistent with the Specific Wording of Appendix A

In discussions with the NRC Technical Staff, staff concerns regarding compliance of the EBSEQ method with Appendix A have centered on how the methodology conforms to the statement that the "engineering method" used to assure seismic adequacy "shall <u>involve</u> the use of either a suitable dynamic analysis or a suitable qualification test to demonstrate that the structures, systems and components can withstand the seismic and other concurrent loads. . ." (emphasis added). The EBSEQ methodology, as embodied in applicable sections of the GIP, clearly <u>involves</u> the use of a number of dynamic (as well as static) analyses and qualification tests. Examples include the following:

4.2.2.1 Seismic Demand

The EBSEQ method requires that the seismic demand (*i.e.* seismic input) be developed for equipment whose seismic adequacy is to be verified. One acceptable method specified is development of in-structure response spectra. The set of in-structure response spectra is the seismic demand for equipment at certain elevations in buildings and structures at a nuclear site. The development of these spectra uses modeling and the engineering methods of "dynamic analysis." (Reference: GIP, Part II, Section 4.2.4.)

4.2.2.2 GERS (Generic Equipment Ruggedness Spectra)

The GERs represent a significant source of seismic capacity data used in the EBSEQ methodology, and supplement earthquake experience data. GERS were developed based on the results of shake table testing of various nuclear power plant equipment, including motor control centers, switchgear, transformers, batteries and valves. Lessons learned from previous shake table tests (*e.g.*, seismic vulnerabilities), were also evaluated and included in the equipment caveats for use of the GERS, as described in the GIP. (Reference: GIP, Part II, Sections 4.1.2 and 4.2.2, Appendix B (B.3-6, for example).)

4.2.2.3 Equipment Anchorage

The evaluation of the seismic adequacy of equipment anchorage is an integral step in the EBSEQ process. As stated in the SQUG Class of Twenty Report (Reference 9.18), and the SSRAP report (Reference 9.14) authored by seismic experts who reviewed the GIP methodology, the keys to preventing damage to, and assuring the proper function of equipment during an earthquake are adequate anchorage and avoidance of seismic spatial interactions. Evaluation of equipment anchorage according to the EBSEQ method utilizes either dynamic analysis or an equivalent static analysis. An equivalent static analysis is a simplified approach that applies a single static load (or demand) at the center of gravity of the equipment, from which the demand on the anchorage is relatively straightforward to calculate. The equivalent static analysis is an accepted engineering practice noted in 10

C.F.R. Part 100, Appendix A. (Reference: GIP, Part II Section 4.4, Appendix C; also EPRI NP-5228, "Seismic Verification of Nuclear Plant Equipment Anchorage," 1991.)

4.2.2.4 Relays

Relay evaluation in the EBSEQ methodology incorporates individual relay-specific shake-table testing, and GERS data derived from industry testing data on relays. The test results incorporated in the GIP include not only seismic capacity, but identified vulnerabilities and "bad actor" relays which have been shown to be susceptible to damage or "chatter" due to moderate shaking. (Reference: GIP Part II, Section 6.4.1; also EPRI NP-7148, "Procedure for Evaluating Nuclear Power Plant Relay Seismic Functionality," 1990.)

4.2.2.5 Tanks

The EBSEQ methodology for the seismic evaluation of storage tanks is based on dynamic analysis. While the EBSEQ method is essentially a "cookbook" approach, the equations used are based on those developed to explain the dynamic behavior of fluids (*e.g.*, sloshing) during excitation. (Reference: GIP Part II, Section 1.3.6 (also EPRI NP-5228, "Seismic Verification of Nuclear Plant Equipment Anchorage," Volume 4, "Guidelines for Tanks and Heat Exchangers," 1991.)

4.2.2.6 Seismic Spatial Interaction

The EBSEQ methodology uses analytical techniques for determining the "zone of influence" between a potential source of interaction (*e.g.*, nearby cabinets, piping, equipment) and the equipment covered by the GIP equipment classes. This includes the estimation of maximum displacement of equipment cabinets based in excitation, natural frequency, cabinet stiffness and other analytical factors. (Reference: GIP Part II, Section 4.5, Appendix D; SQUG Walkdown Screening and Seismic Evaluation Video Training Course Workbook, Section VI, 1993.)

4.2.2.7 Cable Trays and Conduit Raceways

The seismic capacity of electrical cable trays and conduit raceways was determined not only from earthquake experience data but also extensive shake table testing data. The EBSEQ evaluation process itself contains a limited analytical review, which includes an engineering analysis of the "worst case" sample of the cable trays and supports. Analytical methods including fatigue evaluations of rod supports are an integral part of the EBSEQ method for cable trays and conduit raceways. (Reference: GIP Part II Section 1.3.7.)

4.2.2.8 Estimation of Equipment Natural Frequency

The estimation of equipment natural frequency is an integral part of one of the EBSEQ approaches for determining seismic capacity, *i.e.*, "Method A." This method can be used only for equipment in the scope of the GIP that has a natural frequency of greater than about 8 Hz. Use of in-cabinet amplification factors for relay evaluations also involves estimation of the natural frequency of electrical cabinets. The estimation of equipment natural frequencies in the EBSEQ method can involve either analysis (classical modeling techniques) or testing (*e.g.*, impact hammer response). (Reference: GIP Part II Sections 4.1 and 4.4.1, Appendix C-1; also EPRI TR-102180, "Guidelines for the Estimation and Verification of Equipment Natural Frequency," 1993.)

Therefore, in view of the inherent flexibility of Appendix A and the inclusion of suitable analysis and testing in the EBSEQ method, it is concluded that the EBSEQ method meets both the intent and the specific wording of 10 C.F.R. Part 100, Appendix A.

4.3 The EBSEQ Methodology Provides Reasonable Assurance of Adequate Protection of the Public Health and Safety

The ultimate finding of compliance with the requirements of Appendix A, as with other Commission regulations, requires a demonstration that a facility will provide "adequate protection to the public health and safety." (North Anna Environmental Coalition, 533 F.2d at 659 (quoting the Atomic Energy Act of 1954, 42 U.S.C. § 2232(a)).) This standard is reflected in the "Scope" section of 10 C.F.R. Part 100, Appendix A. Therefore, in order to utilize an alternate engineering method, a licensee must demonstrate that the method provides reasonable assurance of adequate protection of the health and safety of the public.

In SSER No. 2, the NRC has already determined that implementation of the GIP approach "satisf[ies] the pertinent equipment seismic requirements of General Design Criterion 2 and the purpose of the NRC regulations relevant to equipment seismic adequacy including 10 C.F.R. Part 100." (SSER No. 2 at 5.) Moreover, the Staff already has concluded that the GIP methodology can be used for NARE. (SSER No. 2 at 8.) Therefore, the Staff clearly has concluded that the GIP methodology provides the required reasonable assurance of adequate protection of the public health and safety for more than half of the operating nuclear power plants in the U.S. It is this accepted methodology upon which the EBSEQ is based.

In addition, and as discussed above, an examination of the GIP methodology reveals a number of technical areas which involve dynamic analysis, static analysis, and shake table test results. Thus, if the GIP methodology demonstrates compliance with the seismic adequacy requirements for A46 plants for both existing and new and replacement equipment, and the IEEE 344 methodology likewise demonstrates compliance for non-A46 plants, then both A46 and non-A46 plants should be able to use either approach (*i.e.*, IEEE-344 or an experience-based method) to demonstrate compliance with 10 C.F.R. Part 100, Appendix A, and GDC-2.

4.4 Implementation of the EBSEQ Methodology is Acceptable

SEQUAL is requesting NRC review and approval of the EBSEQ methodology prior to implementation of the methodology by SEQUAL members. Subsequent to NRC approval, SEQUAL member may add the methodology to the plant's licensing basis in accordance with 10 C.F.R. § 50.59. Plant-specific considerations will be included in the individual plant evaluation and application by the member utilities during the implementation process.

4.5 Conclusions

The NRC's regulations addressing the seismic adequacy of equipment do not prescribe a single acceptable engineering method. Indeed, the plain language of the regulations contains a significant degree of flexibility and appears to invite licensees to offer alternate engineering methods to demonstrate compliance with the seismic adequacy provisions. The flexibility contained in the regulations has been reaffirmed in NRC case law and upheld by the federal courts. The proposed EBSEQ method also meets a literal interpretation of the words in 10 C.F.R. Part 100, Appendix A. Therefore, there is a sufficient regulatory basis for authorizing licensees to use an alternate engineering method, such as an experience-based SEQ method based on the principles of the GIP, to demonstrate seismic qualification of SSCs.

The NRC, in evaluating whether an alternate engineering method is acceptable, must be satisfied that the method in question satisfies the regulations and provides reasonable assurance of adequate protection of the health and safety of the public, not whether there is more or less conservatism than another acceptable method. The foregoing analysis of the experience-based methodology demonstrates that it satisfies the applicable regulatory provisions of 10 C.F.R. Part 100, Appendix A and GDC-2. The NRC also has determined that the experience-based methodology complies with these same provisions and has approved its use for A46 plants. Implicit in the NRC's determination and acceptance is the conclusion that the experience-based methodology provides the requisite reasonable assurance of adequate protection of public health and safety. Similarly, as discussed above, the addition of this methodology to those of analysis and testing is acceptable.

Therefore, because the experience-based methodology satisfies the reasonable assurance standard and complies with the seismic adequacy regulations, there is a sufficient regulatory and statutory basis upon which to permit non-A46 plants to use the EBSEQ methodology, which is based on the principles of the previously approved experience-based methodology (*i.e.*, GIP).

5.0 Engineering Analysis

5.1 Technical Bases

An experience-based method of assuring seismic adequacy, as defined by SQUG in the GIP and the NARE Guidelines, was developed over a period of ten years by a team of utility and contractor seismic engineers, was reviewed and contributed to by a panel of independent seismic experts selected by SQUG and the NRC staff (the Senior Seismic Review and Advisory Panel, or SSRAP)[6], and was reviewed by the NRC Staff and their consultants as part of an interactive process. The method was demonstrated to be feasible in a pilot project in the early 1980's and selected by the NRC in Reference 9.13 as an acceptable basis for resolution of USI A-46. It was further developed to include 20 classes of conventional electrical and mechanical equipment and raceways in the late 1980's and was demonstrated in trial applications at a PWR and a BWR pilot plant. NRC and SSRAP representatives participated in reviewing earthquake experience data collection in the field and in reviewing the trial plant equipment evaluations, both of which were assessed to be successful by SSRAP and the NRC staff. The GIP was accepted by the NRC in 1992 in SSER No. 2 (Reference 9.3) not only for resolution of USI A-46, but also for use on new and replacement equipment (NARE) in the A-46 plants. The GIP has since been used and demonstrated to be effective in assuring the seismic adequacy of a majority of the operating nuclear plants in the United States. Subsequently, SQUG prepared additional guidance for use in applying the GIP for NARE (Reference 9.8). *As such, this method has been demonstrated and accepted as an engineering method that assures adequate protection of the health and safety of the public*. The EBSEQ method, delineated in Appendix A, builds on the principles in the GIP and NARE Guidelines.

The method is based on (a) data collected through literature and field surveys on the performance of conventional power plant and industrial equipment in many strong motion earthquakes worldwide, and (b) data from shake table tests by utilities, equipment vendors, and test laboratories. From this information, equipment classes were defined by inclusion rules, and specific vulnerabilities/weaknesses (caveats) were identified and prohibited for each class. Equipment capacity was defined on the basis of ground motions at earthquake sites in the case of earthquake data (Reference Spectrum) or test response spectra in the case of test data (Generic Equipment Ruggedness Spectra or GERS).

The main conclusion of this research, as reported by the independent review panel SSRAP (Reference 9.14), is that equipment within the bounds of the equipment classes included in the scope of the EBSEQ, subject to the class-specific caveats, are inherently rugged, provided the equipment are properly anchored, adverse spatial interactions are avoided, and the possibility of chatter of electrical relays and contractors is evaluated separately.

The main elements of the EBSEQ procedures for applying earthquake and test experience are listed below:

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[6] Senior Seismic Review and Advisory Panel (SSRAP) consisting of: Robert P. Kennedy, RPK Structural Mechanics Consulting, Chairman; Walter von Riesmann, Sandia National Laboratories; Loring A. Wyllie Jr., H. J. Degenkolb Assoc., Engrs.; Anshel J. Schiff, Stanford University; Paul Ibanez, ANCO Engineers.

- 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.
- Verification that equipment anchorage and associated load paths are adequate.
- Verification of no potential for adverse seismic spatial interaction with nearby equipment and structures.
- Review of potential design differences that could affect seismic performance of the equipment.
- Review and concurrence in all results by two qualified and trained Seismic Capability Engineers.
- Documentation of the entire process, including required supplemental analyses and inspections.

In summary, the EBSEQ method is based on the principles of the GIP and NARE Guidelines. Leading seismic experts in this country, with input from NRC representatives, and an independent expert peer review panel, developed the GIP. The GIP has been thoroughly tested and implemented over a period of almost 20 years, thereby demonstrating its adequacy and cost-effectiveness, further evidencing that an experience-based method provides an adequate level of assurance of seismic safety. The application of the EBSEQ method to demonstrate seismic qualification of new equipment is performed under specific controls and limitations prescribed in Appendix A, of this Topical Report, which are consistent with the procedures approved by the NRC for application of NARE at A-46 plants. The A-46 plants procure the same equipment types and vintages as non-A46 plants and use of consistent seismic qualification criteria across the facilities would be beneficial to both. *Accordingly, it is concluded that for the equipment within its scope, the EBSEQ method is an engineering method that provides adequate protection of the health and safety of the public*.

5.2 Seismic Design Margin

The issue of whether use of the EBSEQ method reduces or improves seismic design margin compared to current IEEE 344-1975 and -1987 methods is one which has received considerable attention by SQUG, SEQUAL and the NRC Staff. It is understood that there are elements of the EBSEQ method that are less conservative than IEEE 344 test methods (in areas of demonstrated low seismic risk) and other areas where the EBSEQ method is more conservative by addressing demonstrated seismic sensitivities of the equipment classes in the scope of the EBSEQ. It is for these reasons that SQUG and SEQUAL have concluded that, on the whole, the use of the EBSEQ method as defined in the NARE Guidelines and in the EBSEQ Procedure in Appendix A does not result in a reduction of seismic design margin compared to the methods prescribed in the currently accepted standards, IEEE 344-1975 and -1987.

A factor in the assessment of whether implementation of the EBSEQ method can result in a change in design margin is the fact that IEEE-344 permits a variety of seismic qualification methods including shake table testing, analysis, similarity to previously qualified equipment, and “other methods.” A significant amount of equipment is qualified by methods other than testing. The EBSEQ method provides seismic qualification that has equivalent rigor and effectiveness to many of these currently accepted practices.

Additional considerations that support SEQUAL’s assessment that the EBSEQ method, taken as a whole, does not result in reduction of seismic design margin compared to IEEE 344-1975 and IEEE 344-1987 methods are as follows:

- The equipment capacities, class inclusion rules, and prohibited features defined in the GIP were based on earthquake and test experience documented up to approximately 1985. Since that time, SQUG and EPRI have continued to investigate facilities affected by strong motion earthquakes. No failures of equipment that meet GIP rules have been identified in these post-1985 earthquakes, thereby providing significant additional validation of the robustness of the GIP/NARE method, upon which the EBSEQ method is based.

- About 60 nuclear units have implemented the GIP method over the last five to seven years to resolve USI A-46. In those reviews, there were few instances identified of equipment with insufficient seismic capacity (*i.e.*, ruggedness), the attribute which is the focus of IEEE-344 shake table tests. Instead, the majority of weaknesses were in areas that have not been adequately addressed by IEEE-344 testing. These included inadequate anchorages or load paths from the equipment to its foundation, potential for adverse seismic spatial interaction, and the possibility of relay chatter due to impacting of adjacent cabinets or structures.

- The current SEQ standards accepted by the NRC staff under 10 C.F.R. 100, Appendix A (IEEE-344-1975 and -1987) have been used successfully for SEQ for many years. However, the EBSEQ method includes a number of provisions that provide more detailed guidance or more insightful criteria for seismic qualification of equipment. Some examples include:

    – The EBSEQ method provides more detailed guidance for performing qualification by similarity and evaluating equipment design differences than IEEE-344.

    – The EBSEQ method provides a better focus on specific vulnerabilities identified in earthquake and testing qualification experience.

    – The use of a diverse set of numerous equipment samples in the EBSEQ method provides a better statistical basis for the seismic qualification criteria.

    – The EBSEQ method provides greater emphasis on installation issues (*e.g.*, anchorage and interaction) which have been shown to be the biggest contributors to seismic damage in actual earthquakes.

Therefore, the perceptions that the current SEQ standard for non-A46 plants requires testing or dynamic analysis of all items, or that a single test of a single equipment item is superior to the requirements of the EBSEQ method, are not consistent with actual experience.

5.3 NRC Issues/Comments

The following concerns about the adequacy of the GIP as a method to use experiential data for seismic equipment qualification were enumerated in the attachment to the letter from Brian W. Sheron (NRC) to Gregory Ferguson (SEQUAL) dated August 24, 2000 (Reference 9.11). The following subsections include a statement for each of the seven NRC issues along with the SEQUAL response.

5.3.1 Treatment of Concurrent Loads

NRC Issue Statement:

Section VI of Part 100 requires that concurrent functional and accident-induced loads be accounted for in determining that safety-related structures, systems and components remain functional during and after design-basis seismic events. Concurrent functional and accident-induced loads are not considered when using the GIP-2 process. 10 C.F.R. 100 requires seismic loads to be combined with concurrent normal and accident loads. A-46 did not include accident loads. How will the EBSEQ be used to show pressure boundary components meet ASME Section III allowable stresses?

SEQUAL Response:

The SEQUAL "Procedure for Performing Experience-Based Seismic Equipment Qualification (EBSEQ)" included in Appendix A is intended to provide a procedure for performing seismic equipment qualification using seismic experience data to the extent that seismic experience is applicable. The procedure is based on the applicable requirements in the GIP-2 and GIP-3 (References 9.1 and 9.2) as accepted by the USNRC in SSER No. 2 and SSER No. 3 (Reference 9.3 and 9.4). It is not intended that seismic experience based criteria be used to qualify equipment or parts that are unique to nuclear power plants or for loads arising from simultaneous earthquake loading and loading due to accident or abnormal operating conditions. The EBSEQ is stated to apply to non-NSSS equipment and conventional electrical and mechanical equipment classes.

<u>Section 1.3 of the EBSEQ Procedure states that</u>:

- The EBSEQ method does not apply to non-normal concurrent loads (such as accident loads and BWR suppression pool loads). Such loads must be evaluated by supplemental tests or analysis, or other SEQ methods.

- The EBSEQ method does not address the effects of harsh environment

- The EBSEQ method does not verify the function of chatter-sensitive devices (*e.g.*, relays) during an earthquake.

- The EBSEQ method is not applicable to low-cycle, fatigue-sensitive items (*e.g.*, items shown to be affected by prior OBE cycles), as defined in the EBSEQ.

Application of the EBSEQ method covers concurrent normal operating loads. Concurrent accident loads must be addressed by supplemental analysis or testing as addressed in the EBSEQ Procedure. The licensee is responsible for selecting an appropriate technical approach for addressing these loads.

The EBSEQ method by itself is sufficient for a significant portion of the equipment in a plant since many equipment items in a plant either are not subject to accident loads or else the accident loads have no significant effect on the seismic capability of the equipment. For example, hydrodynamic loads are only significant for reactor building equipment in BWR Mark II and III plants. Harsh environment is only applicable to equipment located in harsh environment areas.

For pressure boundary components, the EBSEQ method does not address the pressure boundary code acceptance. Supplementary analysis is necessary. For example, valve body pressure stress is addressed as part of the ASME Code evaluation of the valve body while the EBSEQ method addresses the operator and yoke (outside ASME Code pressure boundary). If the equipment is already shown to meet the pressure requirements of the Code, then the EBSEQ method satisfactorily addresses the seismic requirement. The EBSEQ method does not address Class 1 fatigue analysis; however, Class 1 components (*e.g.*, reactor vessel, steam generators, etc.) are typically not covered by the equipment classes.

5.3.2 Use of the GIP Reference Spectrum for Capacity

NRC Issue Statement:

The GIP-2 reference spectrum (RS) is outdated, using ground motion data from events only through 1985, and limited in scope since only four response spectra were used for its creation. Furthermore, based on current seismic engineering techniques, two of the four ground motion estimates used to develop the RS (Sylmar Converter Station and Pleasant Valley Pumping Plant) are not appropriate estimates of the ground motion at these facilities. In particular, the ground motion estimate for the Sylmar Converter Station from the 1971 San Fernando earthquake is from the Pacoima Dam recording of the San Fernando earthquake scaled to a peak ground acceleration of 0.5 g. Also, the ground motion estimate for the Pleasant Valley Pumping Plant from the 1983 Coalinga earthquake is from the switchyard instrument located approximately 69-

feet above plant grade. These ground motion estimates may have been judged to be adequate for the mid-80s, when the RS was created; however, it is clear that much better estimates of ground motion at the database sites can be calculated using current seismic engineering techniques such as those outlined in the SQUG document dated February 17, 2000, “SQUG Procedure for Gathering and Validating Earthquake Experience Data.”

SEQUAL Response:

SEQUAL’s consultant has developed new ground motion estimates for the two sets of sites referred to above as Sylmar Converter Station and Pleasant Valley Pumping Plant using current seismic engineering techniques. The new ground motion estimates and their derivation are contained in Appendix E. SSRAP used the Pacoima Dam record scaled to 0.5g to represent the ground motion at the Sylmar Converter Station and the Rinaldi Receiving Station sites. It used the Pleasant Valley Pumping Plant switchyard record to represent several sites northeast of Coalinga. The SEQUAL consultant estimated ground motions for each of these sites individually.

Figure 5-1 shows a comparison of the new free-field spectra estimates for Sylmar Converter Station and Rinaldi Receiving Station sites with the spectrum used by SSRAP.

Figure 5-2 shows a comparison of the new free-field spectra estimates for the Coalinga sites with the original Pleasant Valley Pumping Plant switchyard spectrum used by SSRAP.

Figure 5-3 shows a plot of:

- (a) the El Centro spectrum,
- (b) the Llolleo spectrum,
- (c) the average of the Sylmar and Rinaldi spectra,
- (d) the average of the Coalinga sites’ spectra,
- (e) the average of spectra (a) to (d),
- (f) the average spectral acceleration of (e) over the 2.5 - 7.5 Hz. range, and
- (g) the original SSRAP Reference Spectrum.

The average spectral acceleration of (e) over the 2.5 - 7.5 Hz range is 1.18g.

It can be seen from Figure 5-3 that if the average of the four spectra (a) to (d) are smoothed to the shape of a broadband spectrum by taking the average over the frequency range of 2.5 to 7.5 Hz as a constant acceleration value, and then following a smooth curve to the ZPA value, it would be about the same as the original SSRAP Reference Spectrum.

It is also noted that the ground motion estimates for Sylmar and Rinaldi due to the Northridge earthquake (see Appendix E) are higher than those due to the San Fernando earthquake. If the Northridge estimates were used in place of the San Fernando estimates in the preceding analyses, the resulting average spectrum would exceed the SSRAP Reference Spectrum.

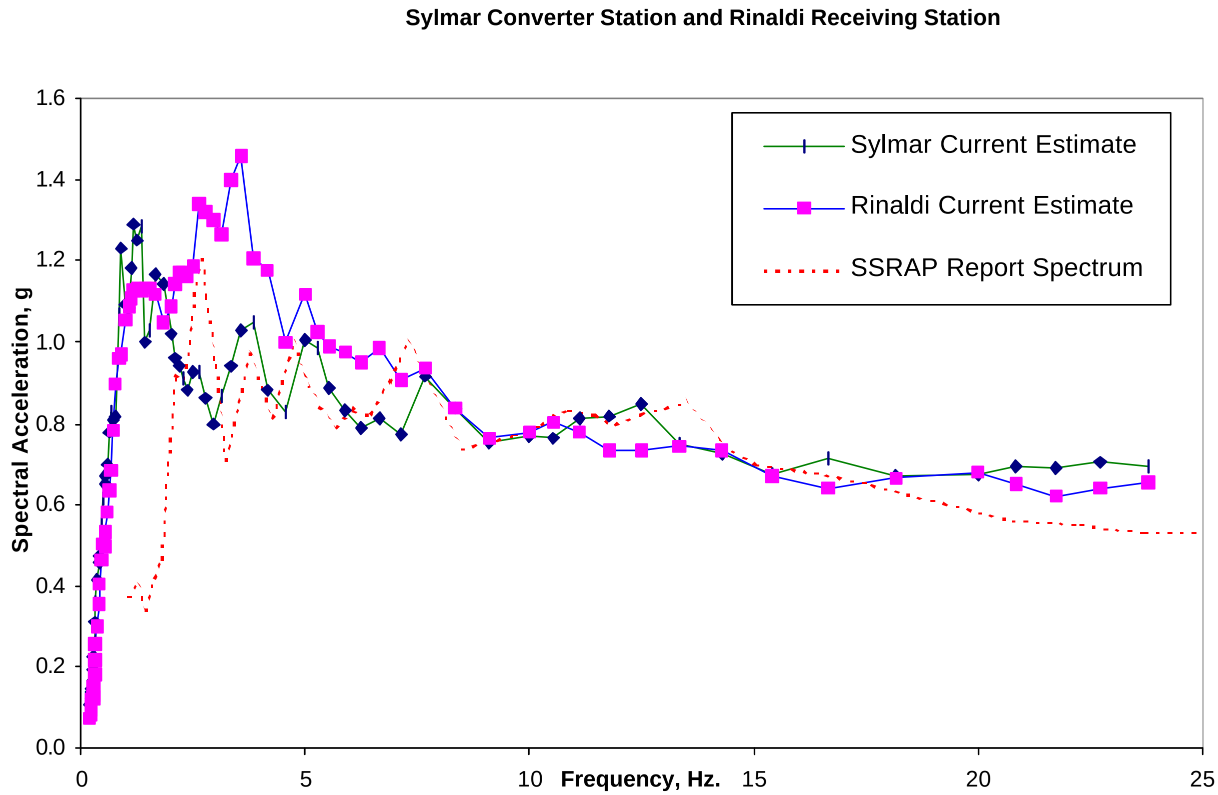

Figure 5-1. Comparison of New Free-Field Spectra Estimates for Sylmar Converter Station and Rinaldi Receiving Station Sites with SSRAP Report Estimates

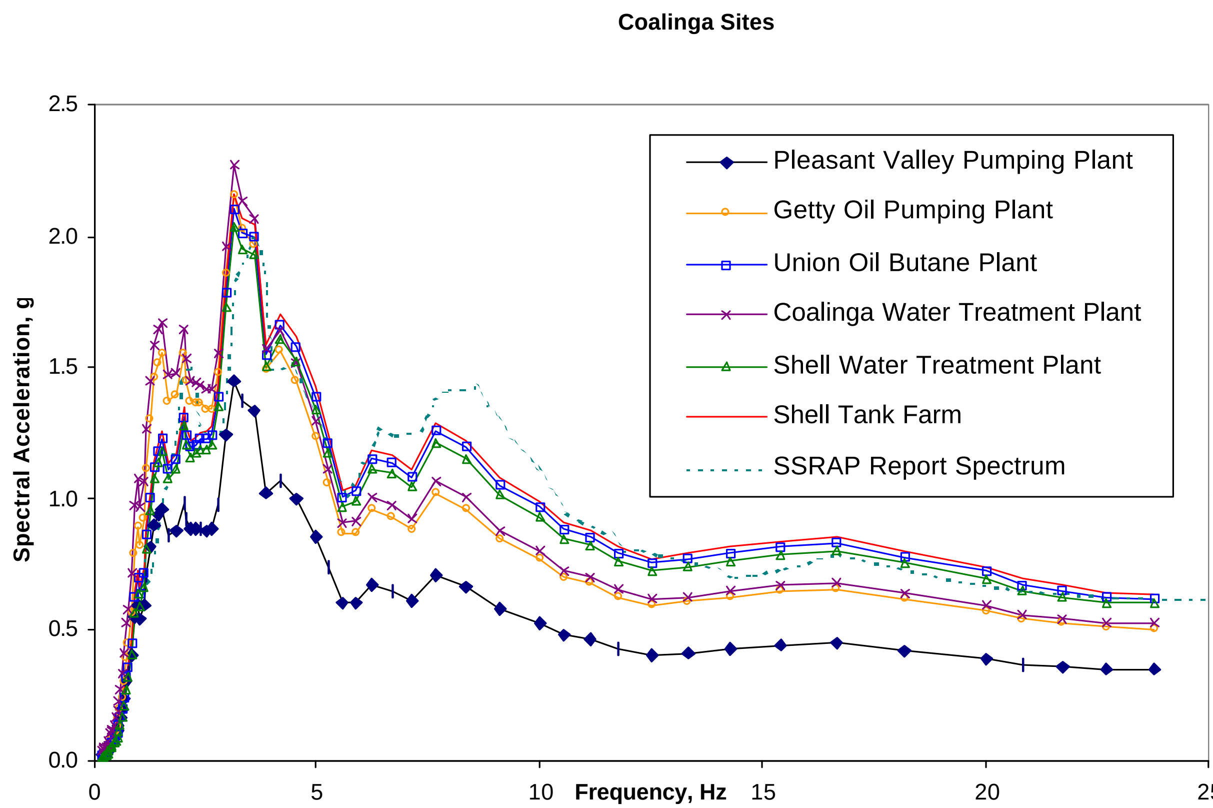

Figure 5-2. Comparison of New Free-Field Spectra Estimates for Coalinga Sites with Original Pleasant Valley Pumping Plant Switchyard Spectrum Used by SSRAP

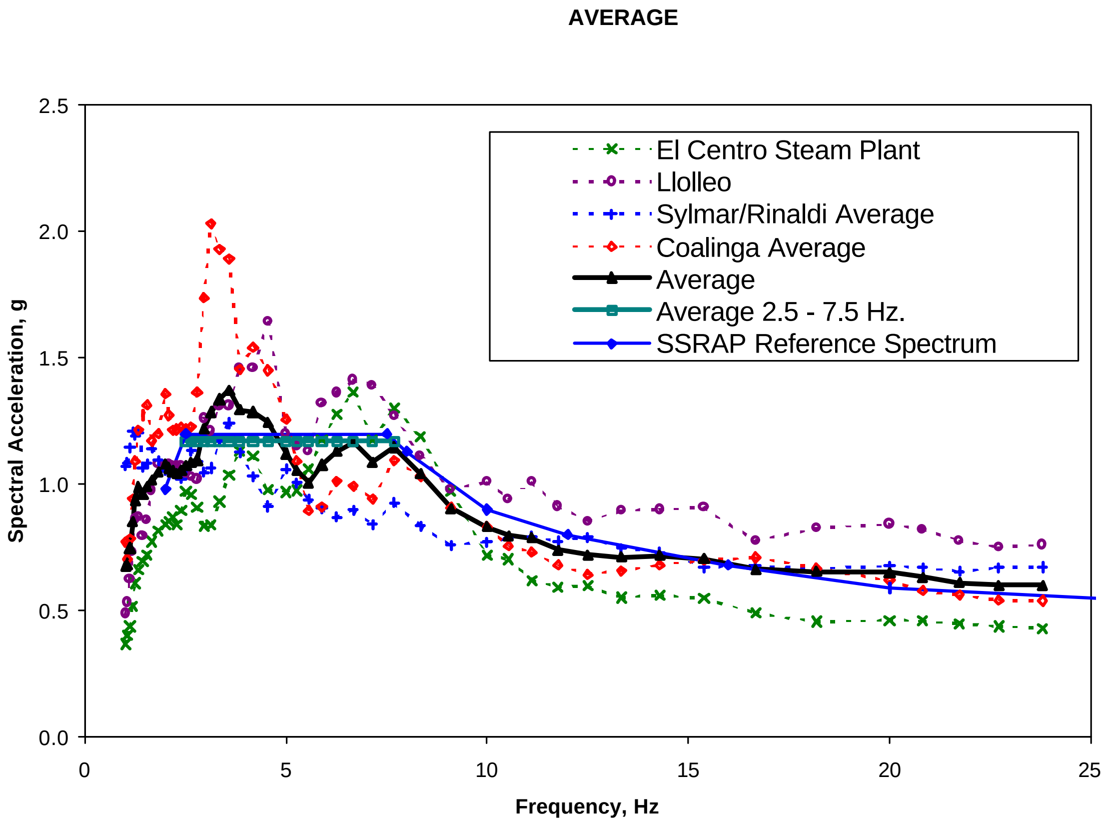

Figure 5-3. Ground Response Spectra for (a) El Centro Steam Plant, (b) Llolleo, (c) Sylmar/Rinaldi Average, (d) Coalinga Average, (e) Average of (a) to (d) Spectra, (f) Average 2.5 to 7.5 Hz, and (g) Original SSRAP Reference Spectrum

5.3.3 Use of GIP Method A for Demand

NRC Issue Statement:

The assumption made in GIP-2 that the in-structure response spectra (IRS) (seismic demand) at all elevations within 40-feet above the plant's grade are identical to the ground response spectrum is a generalization that is not technically justified for post-USI A-46 plants, since these newer plants have available calculated IRS. IRS for post-USI A-46 plants were developed using state-of-the-art analytical techniques and assumptions that are in general agreement with the Standard Review Plan (SRP). These IRS are part of the licensing basis for post-USI A-46 plants, which the staff considers to be substantially more reliable for estimating the seismic demand for plant structures than those specified on the basis of the alternative method in GIP-2.

SEQUAL Response:

The GIP was designed for comparison of conservatively derived equipment capacity to median-centered (*i.e.*, with no intentional conservatism in the calculated structural amplification) seismic demand. It is shown in Section 6 of this Topical Report that use of the GIP as per the EBSEQ Procedure in Appendix A, including the use of realistic, median-centered in-structure response spectra for demand, yields a level of seismic risk equivalent to conventional seismic qualification by testing or analysis using typical design basis in-structure response spectra for demand.

The SSRAP determined that median-centered amplification of free-field spectra would be about 1.5 for normal nuclear plant heavy steel frame or concrete shear wall structures up to about 40 feet above grade and for frequencies above 8 Hz. The Bounding Spectrum is the database capacity spectrum (Reference Spectrum) divided by this factor. Thus Method A (comparison of the Bounding Spectrum to the nuclear plant free-field design response spectrum) is the equivalent of comparing the equipment capacity spectrum to a median-centered floor response spectrum within 40 feet of effective grade, and for frequencies above 8 Hz.

A-46 plants were required to justify Method A use wherever the plant licensing basis floor response spectra significantly exceeded 1.5 times the design free-field spectrum. The SEQUAL plants would also do this, using the same approach as the A-46 plants; *i.e.*, by quantifying the conservatisms in the plant's licensing basis spectra compared to what median-centered spectra would have. This is stipulated in the EBSEQ Procedure. A discussion of the conservatisms in typical licensing basis floor response spectra is contained in Appendix C.

The Standard Review Plan requires use of an 84th percentile ground spectrum shape and median-centered (best-estimate) amplification for generation of in-structure response spectra for subsystem seismic design. The SEQUAL plants' free-field spectral shapes are 84th percentile. However, the SEQUAL plants' licensing basis floor spectra typically contain conservatisms in amplification similar to those of the A-46 plants. So SEQUAL plants should be able to use Method A the for same reasons, and under the same limitations, as A-46 plants.

5.3.4 Equipment Class Definitions

NRC Issue Statement:

The GIP-2 definitions of equipment classes are too broad for use in an experience-based seismic qualification methodology that would be expected to provide a level of confidence comparable to that established from seismic qualification by testing or dynamic analyses, which is currently required by Part 100. The equipment classes should not be based solely on equipment function, since equipment with the same function may be dynamically very different. Instead, the class groupings should also consider appropriate physical characteristics such as dimensions, weight, vibration frequency, and mounting configuration.

SEQUAL Response:

The categorization of equipment into 20 generic classes was a well thought out, iterative process between the SQUG members, their consultants who prepared the GIP, and the Senior Seismic Review and Advisory Panel (SSRAP). The Twenty Classes report (Reference 9.18) defines the parameters that were considered and the guidelines that were followed in defining the 20 classes of equipment. The types of equipment required for consideration were determined from a survey of licensees who were members of SQUG. The individual lists of equipment types were consolidated to form a master list of equipment types. The equipment types were then combined into classes based on the way they perform their safety functions and significance of their seismic vulnerabilities using the following general guidelines.

Each class encompasses the range of equipment included in the experience database. As an example, horizontal pumps driven by electric motors, steam turbines and piston engines were included in the class of horizontal pumps. The classification of horizontal pumps included kinetic (rotary impeller) pumps and positive displacement pumps. Kinetic pumps include single stage centrifugal pumps and multistage centrifugal and axial turbine type pumps. Positive displacement pumps include piston and rotary screw type pumps. Because of the rigid range frequency and robustness of horizontal pumps and their drivers as demonstrated by some 280 examples in the earthquake experience database, the different types of horizontal pumps and drivers are grouped into one class. A separation into subclasses would only result in identical seismic verification criteria (inclusion rules and caveats).

An equipment class includes all components typically attached to the same enclosure or skid. In the example for horizontal pumps, the class includes the pump, it's driver and reduction gear box as long as they are attached to a common skid, attached instruments and controls such as pressure gages or governors on steam turbine drivers, and attached piping, tubing and conduit up to the first effective anchor point.

The equipment classes considered more than just the function of the component. The following parameters were considered in defining the equipment classes.

- Construction: The physical structure of the equipment, including the enclosure and the basic components, was similar. This resulted in similar dynamic characteristics, which is an essential criterion. As an example, motor control centers in the database are usually constructed to NEMA and UL standards that dictate minimum parameters such as sheet metal thickness between stiffeners. Meeting these standards assures a minimum resistance to earthquake loads as defined by the seismic experience data. The GIP also provides typical sizes and weights of MCCs. One of the screening caveats requires that the enclosure configuration should be similar to NEMA standards. One of the size parameters given for typical database MCCs is a depth of 18 to 24 inches. In many nuclear power plants, MCCs with a depth of 13 inches are present. These shallower MCCs are not as stiff in the front to back direction, and thus have different dynamic characteristics than the majority of the database enclosures. Since these MCCs do not conform to the typical dimensions of database enclosures, they become outliers.

- Operation: The means by which the primary component, in particular it's moving parts, perform their function. In the example for horizontal pumps, rugged mechanical components move fluid by means of rotary or reciprocal motion. In this case, separating rotary from reciprocal motion pumps would only result in identical screening rules, thus the two types of motion in the broader class of horizontal pumps do not warrant separate classes.

- Capacity: The typical range of size and operating parameters were taken into account. The screening guidelines place restrictions on the size or operating parameters to assure representation in the earthquake experience database. An example is the separation of low and medium voltage switchgear and the restriction for medium voltage switchgear and transformers to 4.16kV. These separate classes were necessary to identify the separate equipment characteristics required to evaluate the equipment seismic performance and vulnerabilities. In the example for pumps, the database includes pumps from 5 to 2300 hp with flow rates of 45 to 36,000 gpm. This broad range of pumps had similar seismic performance characteristics and vulnerabilities; therefore, they were combined into a single equipment class.

- Application: The function the equipment typically serves in a nuclear power plant was considered. In general the function is similar in nuclear power plants and industrial facilities. Motor control centers supply power up to about 600 volts to small pump and fan motors and motor operated valves. Low voltage switchgear provide power to larger motors or to other heavier electrical loads such as to battery chargers or plant lighting. Even though the end item function in nuclear power plants may be different, the basic function of the equipment is essentially the same; *e.g.*, pump water or provide power.

As documented in the SSRAP Report, the bounds of database representation of the equipment classes were based upon SSRAP reviews of earthquake data on equipment collected through 1985 by the SQUG's consultant, EQE International, primarily at the following sites:

- Several conventional power plants (Valley Steam Plant, Burbank Power Plant, Glendale Power Plant and Pasadena Power Plant) and the Sylmar Converter Station subjected to the 1971 San Fernando earthquake (magnitude 6.5).

- The El Centro Steam Plant and smaller power plants subjected to the 1979 Imperial Valley earthquake (magnitude 6.6).

- Pumping stations and petrochemical facilities subjected to the 1983 Coalinga earthquake (magnitude 6.7).

- Several industrial facilities subjected to the 1984 Morgan Hill earthquake (magnitude 6.2).

- Several power plants, substations, water pumping stations and industrial facilities subjected to the 1985 Chile earthquake (magnitude 7.8).

- Several hydroelectric plants and industrial facilities near the epicentral region of the 1985 Mexico earthquake (magnitude 8.1).

These data are partially documented in References 13 through 22 of the SSRAP Report (Reference 9.14) and the Twenty Classes report (Reference 9.18).

In addition, much more limited reviews were conducted at several electrical substations for the 1971 San Fernando earthquake, the Ormond Beach Plant and one substation subjected to the 1973 Point Mugu earthquake (magnitude 5.9), the Ellwood Peaker Plant and the Goleta Substation subjected to the 1978 Santa Barbara earthquake (magnitude 5.1), the Humbolt Bay Power Plant subjected to the 1975 Ferndale earthquake and the 1980 Humbolt earthquake, and two small power plants subjected to the 1980 Adak, Alaska, earthquake. Limited literature reviews searching for reported failures of equipment were conducted for 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.

All members of SSRAP performed walk-throughs of the Sylmar Converter Station, Valley Steam Plant and Glendale Power Plant. Two SSRAP members walked through many of the database facilities in Chile. At least one SSRAP member had familiarity with the equipment in these classes at the El Centro Steam Plant and at some of the pumping stations and refineries used in the Coalinga database.

SSRAP established the bounds of the equipment classes (parameter ranges and caveats) after careful review of the full range of the available experience database, combined with the general experience of the SSRAP members (from test data, analysis, shipping and operational experience). In some cases the parameter ranges were extended beyond that contained in the database by drawing on this additional experience, and in some cases, through imposition of caveats, they were restricted.

SQUG and its consultants continued (and will continue in the future) to perform detailed reviews of equipment at power and industrial sites subjected to strong motion earthquakes after 1985. While much additional data was reviewed, the bounds of the equipment classes were not broadened. The additional data reviews strengthened the SSRAP conclusions regarding the physical characteristics, parameter ranges and caveats ranges used to define the equipment classes. Instances of equipment damage were investigated to determine whether additional restrictions on the equipment class definitions were warranted. To date, no changes have been required.

5.3.5 Use of Reference Spectrum for All Equipment Classes

NRC Issue Statement:

In developing an experienced-based methodology for seismic qualification of equipment, each class of equipment should have its own unique seismic capacity spectrum rather than a single generic spectrum for all types of equipment, as is done using the GIP-2 Reference Spectrum. Each class of equipment should be sufficiently populated to provide reasonable assurance that the equipment in the class will function during and after an earthquake. A unique seismic capacity spectrum for each equipment class is now possible, since there are a large number of industrial sites in the SQUG Electronic Earthquake Experience Database.

SEQUAL Response:

Appendix A of Reference 9.14 states that “SSRAP’s conclusions relied heavily on the earthquake experience data base from earthquakes of magnitude 6.0 and greater and facilities for which the estimated mean peak ground acceleration (average of two horizontal components) was equal to or greater than about 0.4g as listed in Table 2.1 of [Reference 9.18]. This database consisted primarily of data from the Sylmar Converter Station and the Rinaldi Receiving Station subjected to the 1971 San Fernando earthquake, the El Centro Steam Plant subjected to the 1979 Imperial Valley earthquake, the Pleasant Valley Pumping plant and oil field facilities northeast of Coalinga and near the epicenter of the 1983 Coalinga earthquake, and facilities near Llolleo and San Pedro subjected to the 1985 Chile earthquake."

Reference 9.14 also states that it "was SSRAP's judgment that a Reference Spectrum which provides a reasonable description of the ground motion level to which the earthquake experience data demonstrate seismic ruggedness could be obtained by averaging and smoothing these four representative response spectra. A significant number of data base equipment in each of the equipment classes was subjected to ground motion as high as that represented by the Reference Spectrum."

SSRAP determined the Reference Spectrum by plotting the average spectral ordinates of the four ground motion records at various frequencies, then smoothing the resulting curve to a broadband spectral shape. This was consistent with SRP Section 3.7.1.II.1.b, Option 2: Multiple Time Histories, which allows for use of multiple time histories that individually do not envelop the required response spectrum provided that (a) there be a minimum of four time histories, and (b) the average of the spectral ordinates of the four time histories envelop the required response spectrum at all frequencies.

Appendix D contains a study deriving a unique capacity spectrum for each class of equipment. It follows the methodology currently being considered for inclusion in industry standards for equipment seismic qualification. Not all of the resulting spectra are as high as the SSRAP Reference Spectrum at all frequencies. However, the average spectral acceleration in the frequency range of 2.5 to 7.5 Hz for each class is approximately equal to or greater than the GIP-2 Reference Spectrum. Considering the conservatism inherent in the derivations of many of the reference site ground motion estimates and that the equipment is likely to have been undercounted at the higher level post-1985 sites, the individual class spectra in Appendix D support the use of the Reference Spectrum as a capacity spectrum for all of the classes.

The study in Appendix D contains conservatively estimated independent equipment counts at the reference sites. Further investigation at these sites and at sites from more recent earthquakes would yield larger equipment counts and higher capacity spectra for several equipment classes. However, SEQUAL prefers the use of a single generic capacity spectrum rather than change to individual class spectra, even if some are higher, in order to maintain consistency in application of the EBSEQ method for both A-46 and non-A-46 plants.

5.3.6 Evaluation of Subassemblies

NRC Issue Statement:

Explicit evaluations of subassemblies within an item of equipment are not required by GIP-2. Without appropriate justification, this is not acceptable for seismic equipment qualification, since it ignores the likelihood that the subassemblies/devices in the experience database item may be considerably different from the subassemblies and devices in the qualification candidate equipment.

SEQUAL Response:

The GIP utilizes the "rule of the box" concept to include typical subassemblies and devices within or attached to a component in the seismic adequacy verification. The exception to this is the function of electrical contact type devices such as electro-mechanical relays, motor contactors, auxiliary contactors, switches, etc. These potentially seismic sensitive devices require an alternative evaluation. The basis for the rule of the box inclusion was the observed performance of similar host equipment that included subassemblies and devices typical in industrial applications. The Twenty Classes report (Reference 9.18) and the GIP, Appendix B (References 9.1 and 9.2) list and describe typical types of devices that are included in the database host equipment.

The GIP was developed for seismic adequacy verification of in-situ equipment, including the attached and internal subassemblies and devices since they are part of the database on seismic performance. These internal and external parts and subassemblies are addressed in the GIP by requiring that they be represented in the earthquake experience database and that the load path from the part or subassembly by verified.

Section 4 of the EBSEQ Procedure specifically addresses the issue of qualification of new and replacement parts within host equipment. While the GIP is used as a basis for the procedure, the EBSEQ process expands upon the GIP procedure and includes the following requirements:

- The host equipment must first be shown to meet the seismic qualification requirements specified in Section 3 of the EBSEQ Procedure. If the host equipment does not meet these requirements, then the new or replacement part must be qualified by alternate means.

- The load path from the new or replacement part must be evaluated to assure that the part will remain attached, will not degrade the structural adequacy of the host equipment and will not interfere with the function and structural integrity of the host equipment or other parts.

- An evaluation of the safety function requirements of the new or replacement part is necessary to determine if the part requires a verification of seismic adequacy or if it only requires verification of attachment and load path.

- If the part is required to perform a safety function, its seismic adequacy must be verified by demonstrating that it is represented in the GIP equipment classes or else a part-specific evaluation must be performed using GERS or part-specific qualification data. It is specifically required in Section 4.4.1(b) of the EBSEQ Procedure that a part-specific design difference evaluation be performed. Detailed procedures for the design difference evaluation are provided in Sections 3.3.1 and 3.3.2 of the EBSEQ Procedure.

5.3.7 Use of GIP as a Seismic Qualification Document

NRC Issue Statement:

GIP-2 is not written as a seismic qualification document but rather as a guide for successfully addressing USI A-46 implementation. It, also, contains significant amounts of material extraneous to the seismic qualification of equipment.

SEQUAL Response:

SEQUAL agrees with the NRC position on this issue. The EBSEQ Procedure in Appendix A is a stand-alone seismic qualification document without extraneous material. The SEQUAL plants would use this document for seismic qualification of new and replacement equipment.

6.0 Risk Informed Evaluation

The purpose of this Topical Report is to provide justification for the use of the experience-based seismic equipment qualification (EBSEQ) method being proposed by SEQUAL. Section 5 provided deterministic-based justifications for this method. Section 6 is designed to provide risk-informed justifications in light of current NRC and industry initiatives to utilize risk-informed evaluations in addition to traditional engineering analyses.

6.1 Background on "Risk-Informed"

The NRC established its regulatory requirements with the underlying philosophy that "no undue risk to public health and safety" results from licensed uses of Atomic Energy Act (AEA) facilities. The objective of these requirements has always been to ensure that the probabilities of accidents with the potential to adversely affect public health and safety are low. For nuclear reactor facilities, these probabilities were not quantified in a systematic way until 1975 when the NRC's Reactor Safety Study was published. Consequently, most of the NRC's regulations are deterministic and were developed without the benefit of quantitative estimates of risk. Current regulatory requirements are based mostly on experience, conventional engineering analysis, standards, testing programs, and expert judgment, including such factors such as engineering margins and the principle of defense-in-depth. However, since 1975, there have been significant advances in, and experience with, risk assessment methodology. Thus, the NRC has advocated certain changes to the development and implementation of its regulations to include the use of risk-informed and ultimately performance-based approaches. The NRC documented its commitment to risk-informed regulation by issuing the Probabilistic Risk Assessment (PRA) Policy Statement, which states, "The use of PRA technology should be increased in all regulatory matters to the extent supported by the state-of-the-art PRA methods and data, and in a manner that complements the NRC's deterministic approach and supports the NRC's traditional defense-in-depth philosophy." Subsequent to this policy statement, both the utility industry and the NRC have pursued efforts to use risk-informed insights for a broad range of decision-making (*e.g.*, rulemaking, assessments, licensing, inspection, enforcement, etc.). The application of risk-informed insights as a part of this Topical Report is a logical extension of the utility industry's commitment to provide defense-in-depth to the SEQUAL proposed change to the seismic design basis.

6.2 Risk-Informed Justification for the Proposed EBSEQ Method

As stated in Section 6.1 above, the NRC has indicated its intentions to move to seismic risk-informed regulatory decision-making. The objective of this action is to enhance safety by focusing industry and regulatory resources in seismic areas commensurate with their importance to public health and safety. In principle, such an approach could potentially provide flexibility in plant operation and design, which can reduce regulatory burdens without compromising safety.

SEQUAL asserts that the EBSEQ methodology, while different from the current licensing basis seismic equipment qualification methods in place for newer plants, nevertheless provides no undue risk to public health and safety. Furthermore, a simplified probabilistic risk assessment (PRA) comparison of the EBSEQ approach to the IEEE 344 Testing approach produced risk insights favorable to the EBSEQ approach. Simplifying assumptions were made in order to generate core damage frequencies for each of the two approaches to seismic qualification (*i.e.*, SEQUAL Approach = EBSEQ and Design Basis Approach = IEEE 344 Testing). The results of this study (Appendix B contains a description of the study) demonstrate that the EBSEQ does not increase the risk (measured in terms of core damage frequency) at these plants and, may in fact, lead to reduced risk.

The fundamental assumptions for this risk-informed comparison study include the following:

- Single component failure leads to core damage (very conservative)

- The seismic demand equals the seismic capacity for each of the two qualification approaches (*i.e.*, no margin between capacity and demand considered; this is also conservative relative to the actual CDF calculated, but allows for a consistency for comparison of the two methodologies).

- The “design basis” qualification approach is assumed to follow the current Standard Review Plan (SRP).

The approach utilized within this risk-informed comparison study consists of calculating two seismic fragilities for a generic component using two different sets of assumptions with respect to the seismic qualification:

- The component was qualified using current SRP criteria.

- The component was qualified using EBSEQ methods.

The fragilities are calculated using estimates of margins and variabilities present in different steps of the seismic qualification process. These fragilities are then convolved with the seismic hazard curves for each of the SEQUAL plants to determine the resulting CDF. As a sensitivity study, we calculated risk values using three different seismic hazard inputs: 1) EPRI Seismic Hazard Curves, 2) LLNL Seismic Hazard Curves, and 3) LLNL Seismic hazard based on the Spectral Acceleration Parameter at 5 Hz (5 Hz range felt by some to be a better indicator of damage for structures and equipment than the ZPA).

6.3 Results and Conclusions

The results of this risk study demonstrate that the SEQUAL proposed EBSEQ methodology provides seismic safety that is comparable to that provided by current SRP criteria. The CDF values summarized in Tables 6-1, 6-2, and 6-3 show that for the majority of the SEQUAL plants, there is actually a lower seismic CDF for the SEQUAL approach. A summary of the CDF results in the following:

- LLNL Uniform Hazard – All SEQUAL plants show lower seismic risk using SEQUAL approach

- EPRI Uniform Hazard – All but 2 SEQUAL plants show lower seismic risk using SEQUAL approach (Increases were insignificant for these two plant.)

- LLNL Uniform Hazard (Spectral Acceleration Parameter) – All SEQUAL plants show lower seismic risk using the SEQUAL approach

The average decrease in risk using the EBSEQ methodology was in the range of 1E-07 per year. Regulatory Guide 1.174 permits an increase in CDF of up to 1E-06 per year. The highest increase in risk using the EBSEQ methodology is on the order of 1E-10 per year, which is significantly less than the Regulatory Guide limit. Thus, from a risk-informed perspective, the EBSEQ methodology does not degrade the public health and safety and should be acceptable for use as an alternative seismic qualification method.

Table 6-1
Comparison of CDFs Using the LLNL Seismic Hazard Analysis Results

Site	SEQUAL CDF*	SRP CDF*	△CDF(SRP-SEQUAL)
Beaver Valley	1.43E-05	1.58E-05	1.42E-06
Braidwood	8.60E-07	9.14E-07	5.37E-08
Byron	1.37E-06	1.46E-06	9.37E-08
Catawba	5.90E-06	6.37E-06	4.75E-07
Comanche Peak	1.83E-06	2.00E-06	1.75E-07
Grand Gulf	6.99E-06	7.69E-06	6.93E-07
La Salle	5.64E-06	6.19E-06	5.52E-07
McGuire	3.84E-06	4.12E-06	2.79E-07
River Bend	7.36E-06	8.10E-06	7.38E-07
Sequoyah	3.51E-06	3.75E-06	2.46E-07
Shearon Harris	2.05E-06	2.19E-06	1.45E-07
Waterford	1.05E-05	1.16E-05	1.07E-06
Watts Bar	3.61E-06	3.86E-06	2.59E-07
Wolf Creek	1.33E-06	1.43E-06	1.03E-07
		Average =	**4.50E-07**

***CDF: Mean Annual Core Damage Frequency**
Assuming equipment failure leads directly to core damage

Table 6-2
Comparison of CDFs Using the EPRI Seismic Hazard Analysis Results

Site	SEQUAL CDF*	SRP CDF*	△CDF(SRP-SEQUAL)
Beaver Valley	4.98E-06	5.44E-06	4.66E-07
Braidwood	9.35E-09	9.23E-09	-1.20E-10
Byron	1.16E-07	1.15E-07	-1.70E-10
Catawba	2.35E-06	2.98E-06	6.27E-07
Comanche Peak	4.68E-08	4.87E-08	1.94E-09
Grand Gulf	NA	NA	NA
La Salle	1.73E-06	1.73E-06	4.59E-09
McGuire	1.18E-06	1.23E-06	5.60E-08
River Bend	1.23E-06	1.34E-06	1.10E-07
Sequoyah	3.03E-06	3.23E-06	2.00E-07
Shearon Harris	7.04E-07	7.47E-07	4.30E-08
Waterford	3.65E-07	3.93E-07	2.83E-08
Watts Bar	2.23E-06	2.33E-06	9.85E-08
Wolf Creek	3.36E-07	3.50E-07	1.40E-08
		Average =	**1.27E-07**

***CDF: Mean Annual Core Damage Frequency**
Assuming equipment failure leads directly to core damage

Table 6-3
Comparison of CDFs Using the LLNL Seismic Hazard Analysis
Based on Spectral Acceleration Parameter

Site	SEQUAL CDF*	SRP CDF*	△CDF(SRP-SEQUAL)
Beaver Valley	3.96E-05	4.25E-05	2.96E-06
Braidwood	3.75E-06	4.03E-06	2.78E-07
Byron	5.68E-06	6.11E-06	4.33E-07
Catawba	1.88E-05	2.04E-05	1.56E-06
Comanche Peak	2.79E-06	2.82E-06	3.41E-08
Grand Gulf	1.65E-05	1.78E-05	1.25E-06
La Salle	1.80E-05	1.93E-05	1.34E-06
McGuire	1.55E-05	1.68E-05	1.31E-06
River Bend	1.59E-05	1.69E-05	1.01E-06
Sequoyah	1.49E-05	1.62E-05	1.30E-06
Shearon Harris	8.95E-06	9.74E-06	7.85E-07
Waterford	1.85E-05	1.98E-05	1.29E-06
Watts Bar	1.51E-05	1.64E-05	1.32E-06
Wolf Creek	3.78E-06	4.10E-06	3.21E-07
		Average =	**1.08E-06**

***CDF: Mean Annual Core Damage Frequency**
Assuming equipment failure leads directly to core damage

7.0 Industry Activities

During and since the development of the experience-based methodology, other industry organizations actively followed the development and use of the method. A summary of these activities is given below.

- Nine foreign utilities and organizations have joined the SQUG group and have implemented the methodology to varying degrees in Belgium, Sweden, Great Britain, Germany, Switzerland, Spain, France and Korea.

- The U.S. Department of Energy (DOE) is a member of SQUG and has developed its own EBSEQ Standard based on the GIP. It is being used by the DOE to determine the seismic adequacy of many of its facilities.

- The Advanced Reactor Corporation (ARC) and DOE sponsored a pilot survey as part of its first-of-a-kind engineering (FOAKE) of Advanced Light Water Reactor (ALWR) plants to determine if the GIP method could be applied to modern equipment in advanced plants with design earthquake levels significantly higher than current eastern U.S. plants. This survey focused on eight conventional mechanical and electrical equipment types as examples and successfully demonstrated that the method is feasible even for design earthquakes at the ALWR level (*i.e.*, 0.3 g PGA).

In recognition that the EBSEQ methodology has gained acceptance and has been implemented successfully worldwide, the ASME and IEEE have concluded that the methodology should be incorporated in the U.S. National Standards. To this end, a joint ASME-IEEE working group was commissioned in 1993 to prepare revisions to both IEEE 344-1987 and ASME-QME to reflect the development of the experience-based method by SQUG, SSRAP, and the NRC. This effort has produced draft revisions that are now being considered by the cognizant committees in ASME and IEEE. Revisions to the standards to incorporate the EBSEQ method are expected to be issued in 2001.

8.0 Conclusions

The main conclusions of this Topical Report can be summarized as follows:

- The EBSEQ method is a mature and effective engineering method for seismically qualifying conventional mechanical and electrical equipment in nuclear power plants. It has been validated by numerous strong motion earthquakes worldwide.

- The EBSEQ method focuses attention and resources on seismically sensitive equipment features that are more risk-significant based on actual experience without any significant reduction in seismic design margins.

- Probabilistic studies show that the differences in the EBSEQ method as compared to the existing licensing basis standard for non-A46 plants (*i.e.*, IEEE 344-1975 plants) have no significant effect on calculated core damage frequency (CDF) for SEQUAL plants.

- The EBSEQ method meets all applicable regulations relevant to equipment seismic qualification, including GDC-2 and 10 C.F.R. Part 100, Appendix A. As a consequence, the method provides adequate assurance of the protection of the public health and safety.

- The EBSEQ method provides technical and economic advantages over other currently accepted SEQ standards. It is essential in the current nuclear plant operating environment that the non-A46 operating plants be permitted to use the same methods currently accepted by the NRC for the majority of the U.S. nuclear power plants for procurement of the same new and replacement equipment from the same commercial sources.

9.0 References

9.1 Seismic Qualification Utility Group (SQUG) Generic Implementation Procedure (GIP), Revision 2, Corrected 2/14/92 (GIP-2)

9.2 Seismic Qualification Utility Group (SQUG) Generic Implementation Procedure (GIP), Revision 3, Updated 5/16/97 (GIP-3)

9.3 NRC Supplemental Safety Evaluation Report No. 2 on GIP-2 forwarded by GL 87-02, Supplement No. 1, dated May 22, 1992.

9.4 NRC Supplemental Safety Evaluation Report No. 3 on GIP-3 dated December 4, 1997.

9.5 SQUG letter to NRC dated July 15, 1998 forwarded the report "Use of the Generic Implementation Procedure for New and Replacement Equipment and Parts, Revision 1."

9.6 SQUG letter to NRC dated August 18, 1998 with revision to page 4 of the NARE Guidelines (Reference 9.5) to include four restrictions on the use of Method A.

9.7 NRC letter to SQUG dated June 23, 1999, "Review of SQUG's Report on Use of the GIP for New and Replacement Equipment and Parts (NARE)."

9.8 SQUG letter to NRC dated October 25, 1999, "SQUG Report on Use of GIP for New and Replacement Equipment and Parts, Revision 2."

9.9 NRC letter to SEQUAL dated November 16, 1999, "Summary of Meeting with SEQUAL on September 17, 1999, to Discuss Use of Seismic Data for Equipment Qualification."

9.10 NRC letter to SEQUAL dated May 26, 2000, "Summary of Meeting with SEQUAL on March 20, 2000, to Discuss Use of USI A-46 GIP for Non-A46 Commercial Nuclear Power Plants."

9.11 NRC letter to SEQUAL dated August 24, 2000, "Areas in GIP-2 That Would Contribute to Reduction in the Seismic Design Margin for Equipment Qualified to the Requirements in Part 100 to 10 C.F.R."

9.12 IEEE 344-1975, "IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations."

9.13 NUREG-1211, "Regulatory Analysis for Resolution of Unresolved Safety Issue A-46, Seismic Qualification of Equipment in Operating Plants," February 1987.

9.14 Senior Seismic Review and Advisory Panel (SSRAP) Report, "Use of Seismic Experience and Test Data to Show Ruggedness of Equipment in Nuclear Power Plants," Revision 4.0, February 28, 1991.

9.15 NRC Letter to BWR Owners' Group dated March 3, 1999, Safety Evaluation of GE Topical Report NEDC-31858P, Revision 2, "BWROG Report for Increasing MSIV Leakage Rate Limits and Elimination of Leakage Control System," September 1993.

9.16 SQUG Letter to NRC dated June 27, 2000, "Procedure for Gathering and Validating Earthquake Experience Data – Revision 2 to Appendix A Containing Ten Examples of Ground Motion Estimate Derivations."

9.17 EPRI Report TR-110781, Rev. 0, "SQUG Electronic Earthquake Experience Database Users' Guide," May 1998.

9.18 EPRI Report NP-7149, "Summary of the Seismic Adequacy of Twenty Classes of Equipment Required for Safe Shutdown of Nuclear Plants," March 1991.

10.0 Appendices

A. SEQUAL Procedure for Performing Experience-Based Seismic Equipment Qualification (EBSEQ), Rev. 0, April 2001.

B. Risk Significance of Seismic Qualification Using EBSEQ Approach

C. Position Paper on Use of Method A

D. Capacity Spectra for Individual Equipment Classes

E. Revised SSRAP Reference Spectrum Ground Motion Estimates

Appendix A

Procedure for Performing Experience-Based Seismic Equipment Qualification (EBSEQ)

SEQUAL

April 2001
Revision 0

Procedure for Performing Experience-Based Seismic Equipment Qualification (EBSEQ)

Revisions

Rev. No.	Reason for Change	Date
0	Initial revision	04/17/2001

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Contents (cont'd.)

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1 Introduction

1.1 PURPOSE

The purpose of this document ("EBSEQ Procedure") is to provide a procedure for performing seismic equipment qualification using seismic experience data. It is based on applicable requirements contained in the Generic Implementation Procedure (GIP-2 and GIP-3) (References 1 and 2) and the NRC's Supplemental Safety Evaluation Report No. 2 (SSER No. 2) and No. 3 (SSER No. 3) (References 3 and 4). The version of the GIP that should be used with this procedure is Revision 3, Updated 5/16/97 (GIP-3) (Reference 2); use of the term "GIP" in this document refers to GIP-3.

1.2 SCOPE

This document may be used for verifying the seismic adequacy of the following types of equipment and systems:

- Mechanical and electrical equipment as covered by GIP Part II, Section 4 and Appendix B
- Relays as covered by GIP Part II, Section 6.4
- Tanks and heat exchangers as covered by GIP Part II, Section 7
- Cable and conduit raceway systems as covered by GIP Part II, Section 8

1.3 PROVISIONS AND LIMITATIONS

The provisions of the EBSEQ method to be implemented at non-A46 plants include the following:

- The scope of equipment to which the method may be applied includes only non-NSSS, conventional electrical and mechanical equipment classes defined in the EBSEQ. Not all seismic category equipment is covered by the methodology.
- Specific limitations on use of the EBSEQ method apply. Limitations include the following:

- The EBSEQ method does not apply to non-normal concurrent loads (such as accident loads and BWR suppression pool loads). Such loads must be evaluated by supplemental tests or analyses, or other SEQ methods.

- The EBSEQ method does not address the effect of harsh environments requiring pre-aging under current licensing basis requirements. Such applications require supplemental evaluations or use of other SEQ methods.

- The EBSEQ method does not verify the function of chatter-sensitive devices (e.g., relays) during an earthquake based on earthquake experience data; shake table test data must be used.

- The EBSEQ method is not applicable to low-cycle fatigue-sensitive items (e.g., items shown to be affected by prior OBE cycles), as defined in the EBSEQ.

- The use of EBSEQ to estimate seismic demand for building elevations less than 40 feet is restricted to buildings that do not exhibit significant amplification of motion. The limitations are stated in Attachment C.

• The EBSEQ method requires that personnel who make the seismic adequacy determinations possess specific seismic engineering experience, professional engineering licenses and completion of the SQUG training for Seismic Capability Engineers (SCEs). The qualification and training requirements for SCEs in GIP Sections 2.1.2 and 2.4 apply to EBSEQ.

2 Definition of Terms

The following terms are used in this procedure:

- Design Difference Evaluation - A comparison of the design of an item of equipment or part with the equipment or parts included in the GIP equipment classes.
- EBSEQ Procedure - An abbreviated name for this document, "Procedure for Performing Experienced-Based Seismic Equipment Qualification (EBSEQ)."
- Equipment - An assembly of subcomponents or subassemblies. As used in these guidelines, an equipment item refers to one of the equipment classes described in Appendix B of the GIP. An equipment item is the "host" for parts.
- Equivalency Evaluation - A technical evaluation performed to confirm that an alternate replacement item (not identical to the original) will satisfactorily perform its design basis functions and comply with the plant licensing bases. (Adapted from References 20 and 14)
- Equivalent Change -A change that does NOT result in a change to those bounded technical requirements that 1) ensure performance of design basis functions, or 2) ensure compliance with the plant licensing bases of either the item(s) or applicable interfaces. (Reference 14)
- Experience Data - Data concerning the seismic performance of equipment or parts during past earthquakes or shake table tests.
- Generic Equipment Ruggedness Spectra (GERS) - GIP equipment class-specific capacity spectra based on shake table tests and directly related test experience.
- Generic Implementation Procedure (GIP) - In this document, GIP refers specifically to GIP-3 (Revision 3, Reference 2). The GIP is the primary implementation document for use of earthquake experience and testing experience to verify the seismic adequacy of equipment at USI A-46 plants in the US. This procedure reference specific guidance, procedures and documentation (checklists) which are used in this EBSEQ procedure.
- Host Equipment - An item of equipment on which a part is mounted.
- Identical Item - The same part, make and model number, which exhibits the same technical and physical characteristics. (Reference 13)
- NARE - New and Replacement Equipment and Parts

- Part - A part is a subcomponent or subassembly of an equipment item.

- Reference Spectrum - 1.5 times the GIP Bounding Spectrum defined in the GIP, Part II, Section 4.2 and Figure 4-2.

- Seismic Capability Engineer (SCE) - Engineer who meets the qualification requirements for education, experience, and training, as defined in the GIP, Part II, Section 2, for evaluating the seismic adequacy of equipment using the GIP.

- Seismic Evaluation Worksheet (SEWS) Form – Checklists used in this procedure, provided in the GIP, for documenting EBSEQ of a specific component within a specific class of equipment.

- Technical Requirements - Parameters which define the function or performance of a given Structure, System, or Component (SSC) in a particular application/end-use or group of applications/end-uses. Examples of technical requirements include equipment capabilities, operating requirements, physical size, dimensions/tolerances, limits, material strength, and set points/logic. (Reference 14)

3
Qualification of New and Replacement Equipment

This section provides a procedure for seismic qualification of new and replacement equipment. The procedure may be used for seismic qualification of existing equipment (for example, for operability determinations) or modifications to existing equipment.

For seismic qualification of parts mounted in or on host equipment, see Section 4.

The procedure in this section for equipment is illustrated in Figure 3-1. The paragraph numbers given below correspond to those shown in Figure 3-1. This evaluation should be documented using the checklist in Attachment A, and supporting SEWS forms and analysis.

This section provides the steps for use of the GIP for seismic qualification of new and replacement equipment. These steps involve development and use of procurement and installation specifications to assure that replacement equipment will meet the GIP. Procurement and installation requirements should be developed based on the three screening evaluations of the GIP: (1) seismic capacity vs. demand screening, (2) anchorage and load path screening, and (3) the equipment class inclusion rules and caveat screening. In addition, walkdown of the new or replacement equipment, in accordance with the GIP, may be necessary following installation to assure that the anchorage is installed correctly and no seismic spatial interactions exist. These evaluations are covered below.

3.1 SEISMIC CAPACITY VS. DEMAND SCREENING

Requirements for performing the seismic capacity vs. demand screening evaluation are provided in Section 4.2 of the GIP. These requirements should be used to confirm that the seismic capacity of candidate new/replacement equipment is equal to or exceeds the plant-specific seismic demand. Discussions on seismic demand and seismic capacity follow.

3.1.1 Seismic Demand

The seismic demand for the new or replacement equipment may be defined as: (1) 1.5 times the plant-specific safe shutdown earthquake (SSE) ground response spectrum in accordance with Section 4.2.2 of the GIP (Method A), or (2) by plant in-structure response spectra for the SSE as described in Section 4.2.3 of the GIP (Method B). Use of 1.5 times the plant SSE ground response spectrum (Method A) must be in accordance with the conditions given in Attachment D. If plant in-structure response spectra are utilized to define the seismic demand (Method B), these spectra must be classified as either "conservative design" or "realistic, median-centered" spectra following the guidance in GIP Section 4.2.3.

Where the installed equipment has been evaluated previously using this EBSEQ procedure, the records of this evaluation should be reviewed. If the EBSEQ of the installed equipment involved use of the equipment fundamental frequency to justify excluding seismic spectral demand at and below certain frequencies, it is necessary to verify that either the replacement equipment has approximately the same fundamental frequency or greater, or assumptions regarding exclusion of seismic spectral demand at certain frequencies must be based on the estimated fundamental frequency of the replacement equipment.

3.1.2 Seismic Capacity

For mechanical and electrical equipment classes within the scope of the GIP, the seismic capacity of replacement equipment may be defined by one of the following as appropriate:

- Earthquake Experience Database. The seismic capacity is defined by the Bounding Spectrum as discussed in Section 4.2.1 of the GIP, provided the applicable inclusion rules and caveats for the earthquake experience equipment class are met.

- Generic Seismic Testing Database. Class-specific seismic capacity can be defined by Generic Equipment Ruggedness Spectra (GERS) (Reference 6), as discussed in Appendix B of the GIP and in Section 4.2.2 of the GIP provided the applicable inclusion rules and caveats for the generic seismic testing equipment class are met.

The capacity-demand evaluation should be made to confirm that candidate equipment will meet the seismic requirements. The equipment attributes needed to assure that inclusion rules and caveats are met can be covered by design and installation requirements, as described below in Section 3.2.

3.2 EQUIPMENT CLASS INCLUSION/CAVEAT SCREENING

Requirements and procedures for performing the equipment class inclusion rules and caveats screening are provided in GIP Section 4.3 and Appendix B. These requirements should be used to develop procurement and installation specifications.

The inclusion rules for each of the equipment classes are provided in Appendix B of the GIP for use when seismic capacity is based on the Bounding Spectrum or the GERS. The appropriate provisions should be included in procurement specifications that require the replacement equipment meet the GIP equipment class inclusion rules. These requirements also should prohibit any specific seismic vulnerabilities and unacceptable features (caveats) identified in Appendix B of the GIP.

3.3 DESIGN DIFFERENCES

The process of identifying design differences in new and replacement equipment and evaluating these differences for their effect on seismic capacity is intended to address the concern that newly designed equipment may not be as rugged as older and current vintage equipment. The earlier vintage equipment is adequate for SSE seismic loadings so long as it meets the requirements of this EBSEQ method. This EBSEQ is primarily based on equipment classes defined by the experience databases. Newly designed equipment may not be adequately represented by the earthquake experience databases. For example, vendors may make design improvements for functional reasons (e.g., use of modern materials) which could adversely impact seismic ruggedness. Vendor contacts and vendor literature are a good source for obtaining design and design change information for equipment for identification of the design differences. The process for addressing potential design differences consist of two steps. First, potential design differences are identified. Second, the effect of such design differences are evaluated. These two steps are covered below:

3.3.1 Identification of Design Differences

Design differences are identified by comparing the new or replacement equipment item with the equipment described in the GIP equipment classes. The design differences for newly designed equipment are identified using a number of different methods, including, for example, the following:

a. For new vintage equipment, any design differences, as compared to equipment designs represented in the applicable seismic experience databases upon which the GIP is based, are identified. The two experience databases are the earthquake experience database (when capacity is defined by the GIP Bounding Spectrum), and the generic seismic testing database (when capacity is defined by a GERS). This comparison focuses on the design attributes that may affect seismic performance. Table 3-1 lists design attributes that are considered as appropriate based on engineering judgment, documented tests, analyses or combinations thereof. It is the intent that consideration of these attributes be based primarily on judgment by experienced engineers meeting the qualifications of a Seismic Capability Engineer. Consideration of each of the Table 3-1 attributes shall be documented. (See the checklist in Attachment A).

b. The newly designed equipment can be compared with the earlier vintage equipment that is installed in the plant and that previously had its seismic adequacy verified. Again, the design attributes of Table 3-1 shall be considered and documented.

Representation of an item of equipment in one of the GIP earthquake experience or generic testing equipment classes is determined by qualified, trained Seismic Capability Engineers by assuring that applicable inclusion rules and caveats of Appendix B of the GIP are met. Additional sources of information for this evaluation include the earthquake experience databases (References 7 and 9) and the generic testing databases (References 6 and 12). In using the earthquake experience databases for this purpose, it should be noted that data from earthquakes that occurred after about 1985 were not available at the time that the GIP was being prepared, reviewed, and accepted. Attachment E contains a listing of those earthquakes and database facilities that can be used to establish representation in the GIP earthquake experience equipment classes.

If design differences of potential significance to seismic adequacy are identified, then an evaluation of the adequacy of the relevant design changes is performed as discussed in Section 3.2.3 below.

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

If potentially significant design differences are identified (See Section 3.3.1), the effect of the differences upon the seismic adequacy of the candidate equipment, relative to the GIP (and the applicable experience databases) must be evaluated and either accepted or identified for testing or analysis by other methods not discussed herein. In particular, each potentially significant design difference is evaluated to determine if the difference adversely affects seismic adequacy, violates any equipment-specific caveats or inclusion rules described in GIP Appendix B, changes the equipment fundamental frequency so that capacity versus demand comparisons (for the existing equipment) are invalidated or introduces new features not included in the existing equipment or in the experience databases. This evaluation may include use of the following methods as judged appropriate for the design difference under consideration:

a. The newly designed equipment (considering foremost its required function for the plant SSE) is verified for seismic adequacy based on the experience databases described in Section 3.3.1 above. In the case when capacity is defined by the Bounding Spectrum or 1.5 times the Bounding Spectrum, as shown in Figure 4-2 of the GIP, database content information can be obtained from Appendix B of the GIP, the SSRAP report (Reference 8), the Twenty Classes report (Reference 7), or the SQUG Electronic Database of Earthquake Experience (Reference 9). The specific earthquakes and facilities in References 7 and 9 that can be used for this purpose are listed in Attachment D. When capacity is defined by a GERS, database content information is described in the GERS reports (References 6 and 12). Verification of seismic adequacy includes each of the following checks. This evaluation should be documented using the checklist in Attachment A.

    1. Check whether design features that are present in the newly designed equipment have caused instances of damage in the experience database equipment. (Note: Data from References 7 and 9, including data from earthquake facilities not listed in Attachment E, should be checked to verify that damage has not occurred.)

    2. Check whether the experience database contains a significant number of equipment items that performed adequately and are representative of the new or replacement equipment. (Note: The earthquakes and facilities which may be used to establish representation in the GIP earthquake equipment classes are those listed in Attachment D.)

    3. Check that the newly designed equipment is equally or more rugged than the experience database equipment using judgment based on comparison of key design attributes. (Examples of applicable design attributes are provided in Table 3-1.)

b. The identified design difference for the equipment items 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.

The design difference determinations are based upon documented engineering judgment, analyses, and/or tests. Where reliance is placed on engineering judgment, such judgments must be made or approved by two Seismic Capability Engineers (SCEs) who meet the qualifications given in Part II, Section 2 of the GIP. The bases for the evaluation of the design differences are to be documented following the same approach and philosophy as outlined in the GIP and the associated training.

Note: 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 and changes that could have a significant effect on equipment ruggedness are evaluated. The level of detail expected is that level which is exercised by qualified Seismic Capability Engineers when performing the equipment and "rule of the box" evaluations as described in the GIP. The objective is to utilize experienced engineering judgment in combination with the sources of information described above to identify credible seismic vulnerabilities not considered in the experience equipment class inclusion rules and caveats.

3.4 ANCHORAGE/LOAD PATH SPECIFICATION REQUIREMENTS

Requirements for performing the EBSEQ anchorage adequacy screening evaluation are provided in GIP Section 4.4 and GIP Appendix C. These requirements should be used to develop provisions to be included in procurement and installation specifications. Note that for replacement equipment which requires a design change to its anchorage (e.g., does not utilize the same anchor bolts and pattern), and for new equipment expansion anchor designs, the allowable anchorage loads (i.e., factors of safety) currently recommended for new nuclear plants should be met. This means that factors of safety of 4 or 5, rather than 3 (as used in the GIP for nominal capacity of expansion anchors), should be applied to the manufacturer's mean ultimate capacities to establish allowable expansion anchor loads. Specific steps that apply to GIP anchorage adequacy requirements for new and replacement equipment are presented below.

a. Requirements for the anchorage seismic demand are included in Section 4.4.3 of the GIP. Capacity reduction factors must be applied if demand is approximated using either median-centered in-structure response spectra (Method B) or 1.5 times the SSE ground response spectra (Method A). A check whether there are any significant changes in equipment fundamental frequency should be also made, as described above.

b. Requirements for determining capacity are provided in Section 4.4.2 and Appendix C of the GIP. Installation and procurement requirements should be developed to assure that the capacity of the anchorage design for the replacement equipment, as calculated per Section 4.4.2 and Appendix C of the GIP (enhanced with a higher factor of safety for newly installed expansion anchors as discussed above), exceeds the demand determined per Section 4.4.3 of the GIP.

c. Requirements for demonstrating an adequate load path from the anchorage to the equipment center of gravity and massive equipment subcomponents is included in Checks 12 and 13 of Section 4.4.1 of the GIP, certain caveats and inclusion rules of Appendix B of the GIP, and in Reference 8. This guidance should be included as judged appropriate in the procurement and installation specifications. As in application of the GIP for evaluating the seismic adequacy of equipment, explicit analysis is not required. Documentation of engineering judgement and other evaluations is recommended.

d. Requirements for anchorage installation inspection are provided in Section 4.4.1 of the GIP. The fourteen (14) specific checks included in these requirements should be used to develop anchorage design, installation and inspection requirements to be included in procurement and installation specifications to assure that the as-designed anchorage will meet the GIP anchorage inspection requirements.

3.5 SEISMIC INTERACTION SPECIFICATION REQUIREMENTS

Requirements for identification and evaluation of seismic interaction concerns are included in Section 4.5 and Appendix D of the GIP. These concerns involve proximity effects, structural failure and falling, and flexibility of attached lines and cables. These requirements should be used in the installation specification to assure that none of these seismic interaction concerns exist in the replacement installation. (Alternatively, if it is known that no interaction hazards exist, this verification can be performed and documented after installation. See paragraph 3.6, below.)

3.6 POST-INSTALLATION EQUIPMENT WALKDOWN

Requirements for walkdowns of installed equipment is provided in Sections 4.4.1 and 4.5 of the GIP. These requirements should be used by SCEs to perform a post-installation walkdown of the new or replacement equipment. The specific steps for a post-installation walkdown of equipment are presented below.

a. Using the requirements of Section 4.4.1 of the GIP, the walkdown of the anchorage installation shall be performed to assure that the anchorage meets the GIP. Since the GIP anchorage requirements were incorporated into design and installation specifications as discussed in Section 4.4 above, the SCEs' review and approval of QA documentation verifying that installation specifications were met satisfies the intent of this walkdown. However, if anchorage verification requires judgement by SCEs due to cracked concrete, incorrectly installed anchors or other deviations from the installation specification or GIP provisions, judgements should be based on walkdown by two SCEs.

b. Using the requirements of Section 4.5 and Appendix D of the GIP, a walkdown of the replacement equipment shall be performed to assure that no seismic interaction concerns exist. The purpose of this walkdown is to confirm that the conclusions of any previous uses of the EBSEQ method have not changed as a result of plant configuration changes. If it is determined that sufficient plant configuration controls have been in place to satisfy this concern, elimination of the post-installation walkdown inspection may be justified on a case-specific basis.

3.7 DOCUMENTATION OF SEISMIC ADEQUACY

Documentation of seismic adequacy of new and replacement equipment shall meet the intent of provisions provided in the GIP, Part II, Section 4.6 and GIP Appendix G. Reviews and sign-offs in accordance with personnel qualification requirements of the GIP, Part II, Section 2 and any plant-specific QA procedures should be included. The checklist in Attachment B of this document should be used to document these evaluations. This checklist should be signed off by two Seismic Capability Engineers (SCEs) who each meet the qualification requirements in the GIP, Part II, Section 2.

3.8 SUPPLEMENTARY GUIDANCE FOR TANKS AND HEAT EXCHANGERS

Section 7 of the GIP on tanks and heat exchangers is acceptable for replacement of existing tanks and heat exchangers, as well as for the design and construction of new tanks and heat exchangers, except for new flat-bottom vertical tanks. For new flat-bottom vertical tanks, the following attributes, in addition to appropriate GIP criteria, are necessary to make them acceptable:

- The cast-in-place anchor-bolts and associated hardware (chairs, transfer plates, etc.) in Subsection 7.3.3 shall be designed and installed in accordance with embedment depth, edge distance, anticipated concrete cracking, and corrosion allowance specified in the GIP. The maximum strain in the anchor bolts shall not exceed that corresponding to the yield strength of the bolt material.

- In Step 16 of Subsection 7.3.3.3, use the following equation:

$$s_c = 0.6\left[\min.\left(s_{pe}, s_{pd}\right)\right][psi]$$

- In Subsection 7.3.7, the tank foundation (ring-type or otherwise) shall be designed to resist uplift and the overturning moment.

These special conditions are based on NRC recommendations for use of the GIP for NARE (Reference 19).

Table 3-1. Design Attributes Which Could Affect Seismic Performance of Equipment

1. Specific caveats and seismic vulnerabilities identified in the GIP for the applicable equipment class.
2. Mass of the item relative to its attachment or anchorage.
3. The structural stiffness of the item and its anchorage.
4. The item strength as affected by materials, section properties, and construction details.
5. The item anchorage method (footprint, support locations, etc.).
6. The strength of the anchorage and the load path to the major internal components.
7. Attachments (tubing, cables, electrical leads, etc.) to the item.
8. Natural frequencies, if they affect seismic capacity/design comparison.
9. Moveable subassemblies in certain equipment classes (e.g., breakers in switchgear and doors on cabinets) as discussed in Appendix B of the GIP.

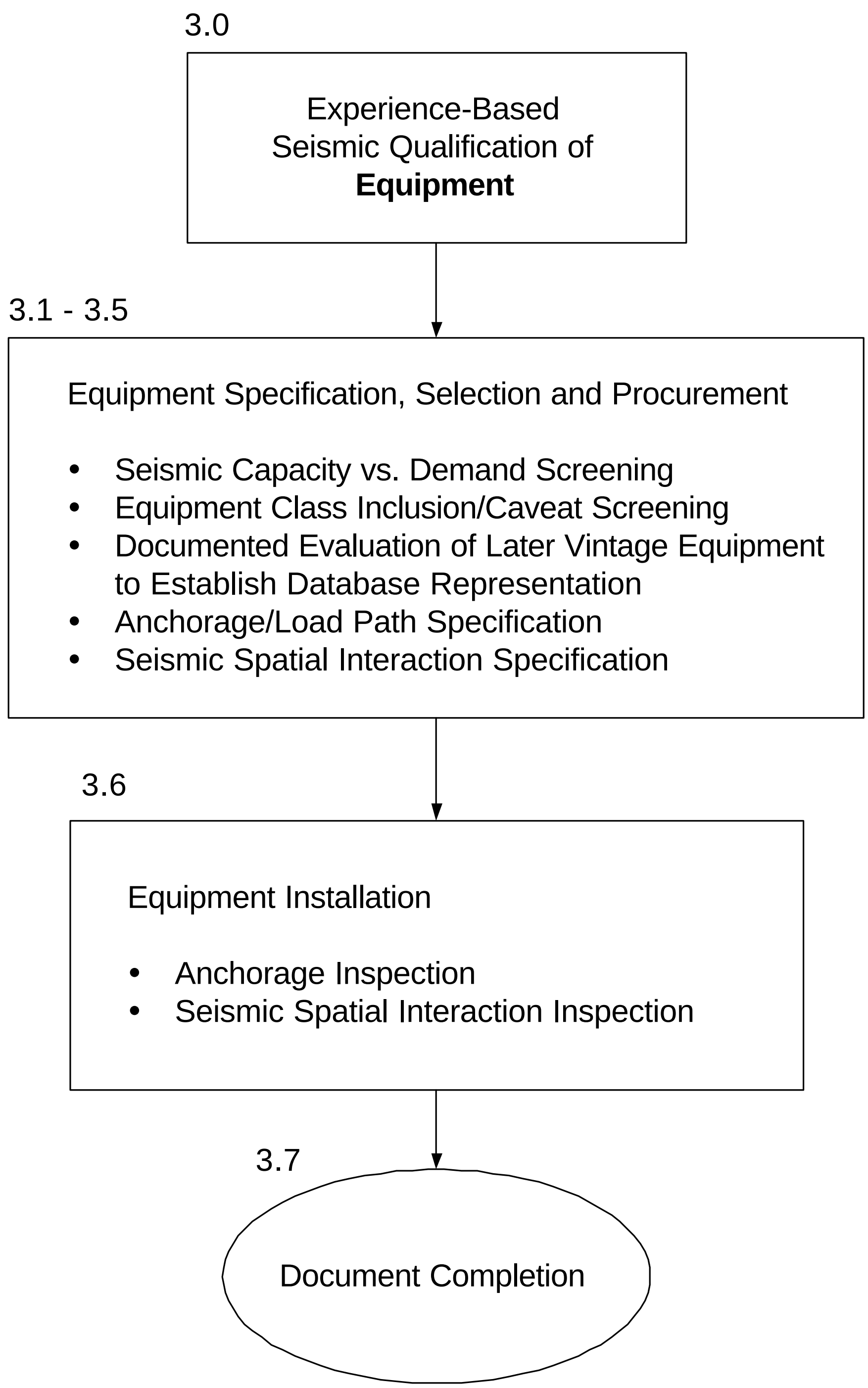

Figure 3-1. Application of EBSEQ Methodology for New and Replacement Equipment

4
Qualification of New and Replacement Parts

This section provides a procedure for seismic qualification of new and replacement parts that are mounted in or on a host item of equipment. (Note: The host equipment for a part must be seismically qualified using the EBSEQ procedure provided in Section 3.0.) In this EBSEQ procedure, the term "parts" also includes subcomponents and subassemblies of equipment assemblies. The process is illustrated in Figure 4-1. The paragraph numbers given below correspond to those shown in Figure 4-1. This evaluation should be documented using the checklist in Attachment B.

The main steps for verification of the seismic adequacy of new and replacement parts (and subcomponents) are included in the following subsections.

4.1 APPLICATION OF THE EBSEQ METHODOLOGY TO THE HOST EQUIPMENT

In order to verify the seismic adequacy of a replacement part using the EBSEQ methodology, the host equipment should be seismically qualified using the requirements in Section 3 of this procedure. If the EBSEQ methodology is not applicable to the host equipment (i.e., it is not within any of the GIP equipment classes) or the host equipment does not meet EBSEQ evaluation criteria, the seismic adequacy of the part cannot be verified using this procedure.

4.2 LOAD PATH EVALUATION OF HOST EQUIPMENT

An assessment of the load path from the replacement part mounting to the host equipment anchorage in accordance with GIP Section 4 and GIP Appendix B is necessary to assure that the replacement part:

a. Will remain attached,

b. Will not degrade the structural adequacy of the host equipment, and

c. Will not interfere with the required functions and structural integrity of the equipment and other parts.

For replacement items, the intent of the load path evaluation is to evaluate significant differences in the new versus old, seismically qualified configuration that could reduce the load path capacity or increase the seismic loading an unacceptable amount. Relatively minor increases in subcomponent weight (e.g., less than 10%) are not likely to require explicit evaluation. More significant changes require an evaluation of potential load path weak links, based on engineering judgement, using calculations to confirm judgements made, where appropriate. The level of detail of these evaluations should be comparable to that of the load path checks performed on the host equipment as covered by Section 3.

4.3 EVALUATION OF REPLACEMENT PART SAFETY FUNCTION/STRUCTURAL ADEQUACY

An evaluation of the replacement part should be performed to determine if the safety function or structural adequacy of the replacement part is required to support the functionality requirements of the host equipment (or other equipment as appropriate) or otherwise ensure compliance with the plant licensing basis. If the safety function or structural adequacy of the new/replacement part is required, verification of the seismic adequacy is required per Section 4.4. If the function and structural adequacy of the existing part are not required, verification of the seismic adequacy of the replacement part is not required.

4.4 SEISMIC CAPACITY VERIFICATION

The purpose of verification of the seismic adequacy of the new or replacement part is to demonstrate that the part will perform its required safety functions and that the applicable level of seismic adequacy of the host equipment (or other equipment as appropriate) is maintained after installation of the part.

The following candidate methods for seismic capacity determination are available:

- Demonstrate that the part is represented in the GIP equipment classes.
- Use part-specific qualification data (or GERS, if available) based on the approach given in the relay evaluation procedures of Section 6 of the GIP.

These seismic capacity methods are described in more detail below.

4.4.1 Representation of Part in GIP Equipment Classes

For host equipment whose seismic adequacy has been verified using this EBSEQ procedure, seismic qualification of replacement parts can be accomplished by demonstrating that the replacement part and its mounting are represented in equipment in the experience equipment classes.

For seismic verification of parts mounted in or on a host equipment item, the GIP methodology employs the "rule of the box." Sections 3.3.3 and 4.3 of the GIP require Seismic Capability Engineers to evaluate the parts mounted inside or on the "box" and to verify that there are no suspicious details or uncommon situations and so that unusual designs and characteristics which have not demonstrated seismic adequacy in earthquakes or shake table testing are identified.

Parts and their mountings that are represented in the experience equipment classes are considered seismically qualified based on the seismic capacity of the seismically qualified host equipment.

Following the same rationale, replacement parts can be demonstrated to be represented in experience equipment classes as follows.

a. The candidate part is demonstrated to be a common subcomponent of equipment in the earthquake experience or generic test databases. Sources of information for this determination include the following:

- Vendor contacts, drawings, catalogs, and direct inspection of equipment in the experience equipment classes.

- Equipment descriptions contained in Appendix B of the GIP, the SSRAP report (Reference 8), the GERS reports (References 6 and 12).

- Twenty Classes report (Reference 7), the electronic earthquake experience database (Reference 9). (As discussed in Sections 3.3.1 and 3.3.2, the data from these sources should be limited to those earthquake facilities in Attachment E.)

b. A part-specific design difference evaluation should be performed and documented to assure that any potentially significant design differences as compared to similar subcomponents represented in the experience databases do not adversely impact the part's seismic capacity. It should be performed following the same general process as that outlined in Sections 3.3.1 and 3.3.2 for equipment. Due consideration should be given to known or suspected attributes of the new part which could significantly reduce seismic ruggedness relative to seismic demand.

4.4.2 Part-Specific Qualification Data or GERS

Part-specific data obtained from shake table tests or analyses (seismic qualification reports or GERS) may be used to verify the seismic adequacy of new and replacement parts using the general approach for seismic capacity/demand screening given in Section 6 of the GIP, "Relay Functionality Review." Section 6 of the GIP is an overview of the detailed procedures contained in the EPRI Report NP-7148, "Procedure for Evaluating Nuclear Power Plant Relay Seismic Functionality" (Reference 10). The seismic adequacy of new and replacement relays should be verified using the approach contained in Section 6 of the GIP and References 15 and 16. Seismic adequacy of other types of parts may also be demonstrated using this general approach when similar appropriate seismic capacity data exist from part-specific tests, analyses, or GERS.

The overall approach described in Section 6 of the GIP for part-specific seismic capacity verification consists of the following elements.

a. Determination of In-Cabinet Amplification. For relays, there are several types of screens that can be used to establish the amplified response of a relay mounted in a cabinet. For example, an in-cabinet amplification factor or an in-cabinet response spectrum may be determined for use in conjunction with the seismic demand applied to the base of the cabinet which houses the relay.

   For other types of parts having similar mass and mounting configurations to relays, the methods given in Section 6 of the GIP and References 15 and 16 may be used for establishing the amplified response within a cabinet provided the cabinet types are covered by the guidelines in Appendix I of Reference 15.

b. Comparison of Seismic Capacity to Demand. For relays, the seismic capacity of a new or replacement relay may be compared directly to the seismic demand imposed upon it at the location in the cabinet where the relay is mounted. In addition, certain types of relays may also be evaluated for adequacy without directly comparing capacity to demand. For example, if the relays (or contact devices) are inherently rugged (e.g., solid state relays, manual switches), then no further evaluation is needed. Or if the relays are particularly sensitive to seismic loadings (i.e., they are on the Low Ruggedness Relays list in Appendix E of Reference 15), then they should not be considered for use in circuits where contact chatter is unacceptable.

For other types of parts, the seismic capacity of the parts (based on the results of available shake table tests) may be compared to the seismic demand imposed upon these parts at the location in the cabinet where the part is mounted. For parts that are significantly larger or are mounted in a more flexible configuration than relays, specific testing or analysis may be required to determine the seismic demand at the location of the part. Guidance provided in Reference 17 regarding criteria for decoupling the dynamic characteristics of a component from the host support structure may be consulted to determine if specific testing or analysis is required.

4.5 DOCUMENTATION REQUIREMENTS

The checklist given in Attachment B should be used to document the basis for representation of the part in the experience databases. Also, if a later vintage part is installed, the evaluation of the effect of design changes upon the seismic adequacy of the part should also be documented in the Attachment B checklist. This checklist should be signed off by two Seismic Capability Engineers (SCEs) who meet the qualification requirements in the GIP, Part II, Section 2.

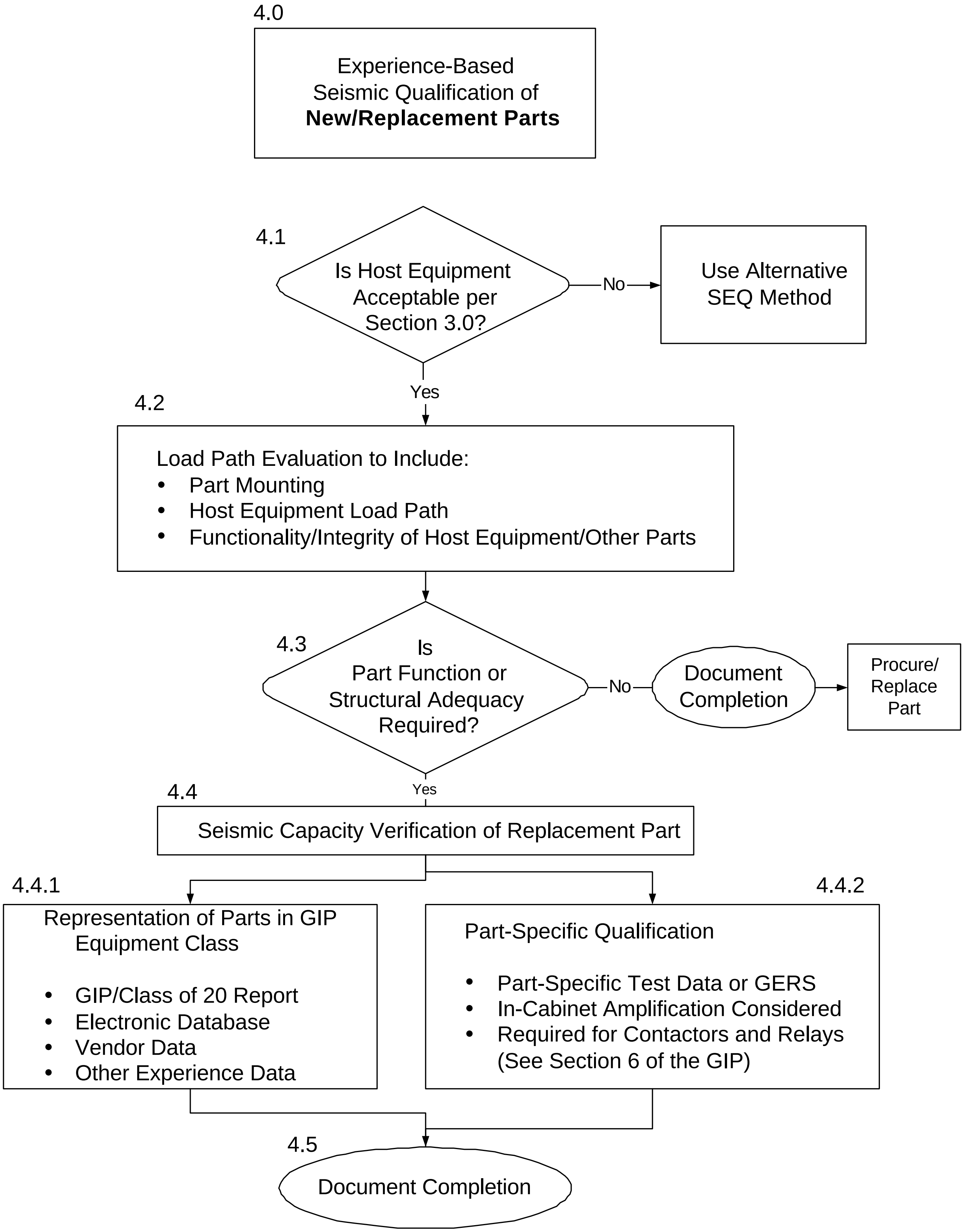

Figure 4-1. Application of EBSEQ Methodology for New and Replacement Parts

5 References

1. Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment, Revision 2, Corrected 2/14/92, Seismic Qualification Utility Group (SQUG), February 14, 1992.

2. Generic Implementation Procedures (GIP) for Seismic Verification of Nuclear Plant Equipment, Revision 3, Updated 5/16/97, Seismic Qualification Utility Group (SQUG), May 16, 1997.

3. "Supplemental Safety Evaluation Report No. 2 (SSER No. 2) on Seismic Qualification Utility Group's Generic Implementation Procedure, Revision 2, Corrected February 14, 1992 (GIP-2) for Implementation of GL 87-02 (USI A-46), Verification of Seismic Adequacy of Equipment in Older Operating Nuclear Plants," U.S. Nuclear Regulatory Commission, Washington, D.C., May 22, 1992.

4. "Supplemental Safety Evaluation Report No. 3 (SSER No. 3) on the Review of Revision 3 to the Generic Implementation Procedure for Seismic Verification of Nuclear Power Plant Equipment, Updated May 16, 1997, (GIP-3)," U.S. Nuclear Regulatory Commission, Washington, D.C., December 4, 1997.

5. Generic Letter 87-02, "Verification of Seismic Adequacy of Mechanical and Electrical Equipment in Operating Reactors, Unresolved Safety Issue, (USI) A-46," U.S. Nuclear Regulatory Commission, Washington, D.C., February 19, 1987.

6. EPRI Report NP-5223, Revision 1, "Generic Seismic Ruggedness of Power Plant Equipment in Nuclear Power Plants," Electric Power Research Institute, Palo Alto, CA, prepared by ANCO Engineers, Inc., August 1991.

7. EPRI Report NP-7149, "Summary of the Seismic Adequacy of Twenty Classes of Equipment Required for Safe Shutdown of Nuclear Plants, "Electric Power Research Institute, Palo Alto, CA, prepared by EQE, Inc., March 1991.

8. SSRAP Report, "Use of Seismic Experience and Test Data to Show Ruggedness of Equipment in Nuclear Power Plants," Senior Seismic Review and Advisory Panel (SSRAP), Revision 4.0, February 28, 1991.

9. EPRI Report TR-110781, Rev. 0, "SQUG Electronic Earthquake Experience Database Users' Guide," May 1998.

10. IEEE Std. 344-1975, "IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations," January 1975.

11. ANSI/IEEE Std. 344-1987, “IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations,” June 1987.

12. EPRI Report NP-7147, “Seismic Ruggedness of Relays,” Electric Power Research Institute, Palo Alto, CA, prepared by ANCO Engineers, Inc., August 1991.

13. EPRI Report NP-7148, “Procedure for Evaluating Nuclear Power Plant Relay Seismic Functionality,” Electric Power Research Institute, Palo Alto, CA, prepared by MPR Associates, Inc., December 1990.

14. EPRI Report NP-7148, Volume 2: Addendum, “Procedure for Evaluating Nuclear Power Plant Relay Seismic Functionality,” Electric Power Research Institute, Palo Alto, CA, prepared by MPR Associates, Inc., September 1993.

15. ASCE Standard No. ASCE 4-86, “Seismic Analysis of Safety-Related Nuclear Structures and Commentary on Standard for Seismic Analysis of Safety Related Nuclear Structures,” American Society of Civil Engineers, September 1986.

16. NRC Letter to BWR Owners’ Group dated March 3, 1999, Safety Evaluation of GE Topical Report NEDC-31858P, Revision 2, “BWROG Report for Increasing MSIV Leakage Rate Limits and Elimination of Leakage Control Systems,” September 1993.

17. NRC Letter to SQUG dated June 23, 1999, “Review of Seismic Qualification Utility Group’s Report on Use of the Generic Implementation Procedure for New and Replacement Equipment and Parts.”

6 Attachments

A

Seismic Qualification Checklist for New and Replacement Equipment Using EBSEQ Methodology

The purpose of this checklist is to evaluate and document the seismic qualification of new and replacement equipment using the EBSEQ Procedure, Section 3. Use the checklist in Attachment B for new and replacement parts.

1. Equipment description:

2. Is equipment in one of the GIP, Appendix B equipment classes? ____ Yes ___ No

   If NO, EBSEQ method cannot be used. Go to No. 8

3. Name of applicable GIP equipment class: ____________________________________

4. a. Basis for equipment seismic capacity

   ___ Earthquake Experience Database (Bounding Spectrum)
   ___ Seismic Testing Database (GERS)

   b. Basis for equipment seismic demand *(attach copy of seismic demand spectrum)*
   ___ In-structure response spectrum approved for USI A-46
   ___ 1.5 x SSE ground response spectrum
   ___ Other (Describe):

   c. Equipment seismic capacity exceeds demand? ___ Yes ___ No

   If NO, EBSEQ method cannot be used. Go to No. 8.

5. a. Does the item satisfy the applicable GIP class inclusion rules and caveats? ___ Yes ___ No

   Comments:

   If NO, EBSEQ method cannot be used. Go to No. 8.

   b. For each of the following design attributes, determine if there are any design differences that would have an adverse impact on seismic adequacy. Use the following guidance in completing this portion of the EBSEQ evaluation.

- If there is no design difference, note that conclusion in the comment area and check the YES box.

- If there is a design difference but it **does not** adversely impact seismic adequacy, document the difference and the adequacy determination in the comment area and check the YES box.

- If there is a design difference and it **does** adversely impact seismic adequacy, document the difference and the adverse impact in the comment area and check the NO box.

(1) Has the mass of the item relative to its attachment or anchorage been evaluated and shown not to adversely impact seismic adequacy? ___ Yes___ No

Comments:

(2) Has the structural stiffness of the item's internal anchorage been evaluated (e.g., the foot of a pump or the base of a cabinet) and shown not to adversely impact seismic adequacy? ___ Yes ___ No

Comments:

(3) Has the item strength as affected by materials, section properties, and construction been evaluated and shown not to adversely impact seismic adequacy? ___ Yes___ No

Comments:

(4) Has the item anchorage method (footprint, support location, etc.) been evaluated and shown not to adversely impact seismic adequacy? ___Yes___ No

Comments:

(5) Has the strength of the load path between the major internals and the item's anchorage been evaluated and shown not to adversely impact seismic adequacy? ___ Yes___ No

Comments:

(6) Have the natural frequencies, if they affect seismic capacity/ demand comparison, been considered and shown not to adversely impact seismic adequacy? ___ Yes ___ No

Comments:

(7) Have attachments (tubing, cables, electrical leads, etc.) to the item been evaluated and shown not to adversely impact seismic adequacy? ___ Yes___ No

Comments:

(8) Have moveable subassemblies as discussed in Appendix B of the GIP for certain equipment classes been considered and shown not to adversely impact seismic adequacy? ___ Yes___ No

Comments:

(9) Have the other significant attributes that could affect seismic performance been evaluated and shown not to adversely impact seismic adequacy? ___ Yes___ No

Comments:

If YES to all of the above design attributes, go to No. 6.

If NO to any of the design attributes, ESBEQ method cannot be used. Go to No. 8.

6. a. Equipment anchorage uses existing bolt pattern? ___ Yes___ No

If YES, proceed to No. 6.a.(1), below.
If NO, proceed to No. 6.a.(2), below.

(1) Anchorage adequate for EBSEQ methodology utilizing GIP rules for anchor capacity? ___ Yes___ No

If YES, go to No. 6.b.
If NO, EBSEQ method cannot be used. Go to No. 8.

(2) Anchorage adequate per EBSEQ methodology utilizing current licensing criteria factors of safety for expansion anchors? ___ Yes___ No

If YES, go to No. 7.
If NO, EBSEQ method cannot be used. Go to No. 8.

b. Anchorage meets GIP installation requirements? ___ Yes___ No

If YES, go to No. 7.
If NO, EBSEQ method cannot be used. Go to No. 8.

7. Installed equipment free of significant, credible seismic interaction concerns? ___ Yes___ No

   If YES, equipment is seismically adequate. Go to No. 8.
   If NO, EBSEQ method cannot be used. Go to No. 8.

8. Is equipment seismically adequate per the EBSEQ? ___ Yes___ No

   If NO, use other acceptable method per the plant licensing basis.

____

Seismic Capability Engineer Approval / Date

____

Seismic Capability Engineer Approval / Date

B

Seismic Qualification Checklist for New and Replacement Parts Using EBSEQ Methodology

The purpose of this checklist is to evaluate and document the seismic adequacy of new and replacement parts as described in the EBSEQ methodology as described, Section 4.

1. a. Part/subcomponent description

   b. Host equipment description:

2. GIP, Appendix B, equipment class applicable to host equipment? ___ Yes ___ No

   If NO, EBSEQ method cannot be used. Go to No. 9.

3. Name of GIP equipment class applicable to host: ____________________________

4. Host seismic adequacy verified per EBSEQ method in Section 3.0? ___ Yes ___ No

   If YES, attach SEWS or equivalent for host equipment to this checklist.

   If NO, EBSEQ method cannot be used. GO to No. 9.

5. Load path from part/subcomponent mounting to host anchorage adequate? ___ Yes ___ No

   If YES, go to No. 6.

   If NO, EBSEQ method cannot be used. Go to No. 9.

6. Is the safety function or structural adequacy of part/subcomponent required to support the functionality requirements of the host equipment or other parts? ___ Yes ___ No

   If YES, go to No. 7.

   If NO, part/subcomponent is seismically qualified and no further evaluation required. Go to No. 9.

7. Demonstrate seismic capacity of part/subcomponent

a. Is part/subcomponent a relay or contactor device or does part-specific qualification data exist? ___ Yes ___ No

If YES, go to No. 8.
If NO, go to No. 7.b.

b. Host equipment seismic capacity demonstrated using:

___ Bounding Spectrum
___ GERS
___ Other Method (Describe):

If Bounding Spectrum used, go to No. 7.c.
If GERS used, go to No. 7.d.
If Other Method used, go to No. 7.e.

c. Part/subcomponent is common in earthquake experience equipment class applicable to the host equipment? ___ Yes ___ No

Basis (e.g., listed in Appendix B of GIP):

If YES, go to No. 7.e.
If NO, go to No. 8.

d. Part/subcomponent is common in GERS equipment class applicable to Host? *(attach copy of applicable GERS to this checklist)* ____ Yes ___ No

Basis:

If YES, go to No. 7.e.
If NO, go to No. 8.

e. For each of the following design attributes, determine if there are any design differences that would have an adverse impact on seismic adequacy. Use the following guidance in completing this portion of the EBSEQ evaluation.

- If there is no design difference, note that in the comment area and check the YES box.
- If there is a design difference but it **does not** adversely impact seismic adequacy, document the difference and the adequacy determination in the comment area and check the YES box.
- If there is a design difference and it **does** adversely impact seismic adequacy, document the difference and the adverse impact in the comment area and check the NO box.

(1) Has the mass of the item relative to its attachment or anchorage been evaluated and shown not to adversely impact seismic adequacy? ___ Yes___ No

Comments:

(2) Has the structural stiffness of the item=s internal anchorage been evaluated (e.g., the foot of a pump or the base of a cabinet) and shown not to adversely impact seismic adequacy? ___ Yes___ No

Comments:

(3) Has the item strength as affected by materials, section properties and construction been evaluated and shown not adversely impact seismic adequacy? ___ Yes ___ No

Comments:

(4) Has the item anchorage method (footprint, support location, etc.) been evaluated and shown not to adversely impact seismic adequacy? ___ Yes ___ No

Comments:

(5) Has the strength of the item=s load path to the major internals been evaluated and shown not to adversely impact seismic adequacy? ___ Yes ___ No

Comments:

(6) Have the natural frequencies, if they affect seismic capacity/ demand comparison, been considered and shown not to adversely impact seismic adequacy? ___ Yes ___ No

Comments:

(7) Have attachments (tubing, cables, electrical leads, etc.) to the item been evaluated and shown not to adversely impact seismic adequacy? ___ Yes ___ No

Comments:

(8) Have moveable subassemblies as discussed in Appendix B of the GIP been considered and shown not to adversely impact seismic adequacy? ___ Yes ___ No

Comments:

(9) Have the other significant attributes that could affect seismic performance been evaluated and shown not to adversely impact seismic adequacy? ___ Yes___ No

Comments:

If YES to all of the above design attributes, part is seismically qualified. Go to No. 9.

If NO to any of the design attributes, go to No. 7.f.

f. Description of design difference(s) and potential impact on seismic adequacy.

g. Design difference has significant adverse impact on seismic adequacy? ___ Yes ___ No

If YES and answer to questions 7.b is ABounding Spectrum,@ EBSEQ method cannot be used. Go to No. 9.

If YES and answer to question 7.b is AGERS@ or AOther Method,@ go to No. 8.

If NO, provide basis below or on attached sheet. Part is seismically qualified. Go to No. 9.

8. Application of part-specific data using GIP relay evaluation methods.

a. Part-specific qualification data or GERS exists for part/subcomponent? ___ Yes ___ No

If NO, EBSEQ method cannot be used. Go to No. 9.

If YES, describe and attach data to this Checklist. Then, go to No. 8.b.

b. Appropriate in-cabinet amplification factor = ____________.

Basis:

c. Attach host equipment seismic demand spectrum.

d. Part-specific capacity or GERS exceeds part seismic demand (host equipment seismic demand multiplied by amplification factor). ___ Yes ___ No

If YES, part is seismically qualified. Go to No. 9.

If NO, GIP method cannot be used. Go to No. 9.

9. Is part seismically adequate per the EBSEQ methodology? ___ Yes ___ No

If NO, use other acceptable method per the plant licensing basis.

____

Seismic Capability Engineer Approval / Date

____

Seismic Capability Engineer Approval / Date

C

Special Conditions for Use of GIP Method for New and Replacement Equipment Seismic Demand

The use of Method A, as defined in Section 4, Part II, of the GIP, is subject to the following conditions and cautions:

(1) Method A is only applicable to reinforced concrete frame and shear wall structures and to heavily braced steel frame structures typical of nuclear power plants.

(2) For soil-supported structures where the SSE is clearly defined in the FSAR at an elevation below grade, any significant soil amplification effects between the defined location of the SSE GRS and the effective grade elevation needs to be considered when applying GIP Method A.

(3) The new/replacement equipment must be mounted in the nuclear plant only at elevations below about 40 feet above the effective grade.

(4) The new/replacement equipment, including its supports, must have a fundamental natural frequency greater than about 8 Hz.

In addition, plant-specific evaluation is required to justify use of Method A for those applications where available in-structure response spectra indicate that the building amplification above the ground motion may be significantly in excess of about 1.5. Specifically, the conservatisms inherent in the in-structure response spectra need to be evaluated on a structure-specific basis using a combination of qualitative and quantitative approaches to confirm that an amplification factor of free field ground motion at the location of the new/replacement equipment will be within about 1.5. The following factors should be considered, as applicable:

- Location of input motion to building
- Ground response spectra shapes
- Soil-structure interaction
- Ground motion incoherence
- Frequency (structural modeling)
- Structural damping
- Time history simulation
- Non-linear behavior (e.g., soil property profile variation, concrete cracking)

- Other published data on the conservatisms in calculational models compared to measured and/or modern best-estimate response spectra.

Accordingly, the use of Method A for EBSEQ application shall be consistent with the four restrictions given above and with additional plant-specific evaluations performed as outlined above or realistic median-centered in-structure response spectra shall be developed to verify that the amplification factor between the free-field response spectra and the applicable in-structure response spectra will be within about 1.5. The plant-specific evaluation should be documented and available for review on a case-by-case basis.

D

Earthquakes and Database Facilities Which May Be Used to Establish Representation in GIP Earthquake Experience Equipment Classes[1]

Earthquake Location / Year	**Database Facilities**[1]
San Fernando, CA / 1971	Sylmar Converter Station [8] Rinaldi Receiving Station [8] Burbank Power Plant [16]
Imperial Valley, CA / 1979	El Centro Steam Plant [8]
Coalinga, CA / 1983	Main (Getty) Oil Pumping Plant [8] Union Oil Butane Plant [8] Shell Water Treatment Plant [8] Coalinga Water Treatment Plant [8] Shell Tank Farm [8] Pleasant Valley Pumping Plant [8]
Chile / 1985	San Isidro Substation [8] Llolleo Water Pumping Plant [8] Vicuna Hospital [8] Concon Petroleum Refinery [8]
Petrolia, CA / 1992	PALCO Cogeneration Plant [16]
Whittier Narrows, CA / 1987	Commerce Refuse to Energy Plant [16]
Landers, CA / 1992	Coolwater Power Plant [16]

1 In Reference 17, the NRC provided a list of earthquake-facility pairs that they had reviewed and found acceptable for use to verify the seismic adequacy of equipment in nuclear power plants. The listed sites were found acceptable as part of the staff review of GIP-2 (Reference 3) and the staff review of the BWROG topical report NEDC-31858P (Reference 16). Reference 3 does not contain a list of sites but refers to the SSRAP Report (Reference 8) which gives the sites covered by the four response spectra used to develop the Bounding Spectrum. Reference 16 gives response spectra for the approved sites; however, SQUG has judged that only three of the sites in Reference 16 support the Bounding Spectrum capacity in the GIP. The list of earthquake-facility pairs in this Attachment include the sites considered as Reference Spectrum sites in Reference 8 (including Shell Tank Farm and Pleasant Valley Pumping Plant, which were included in Reference 8 but not listed in Reference 17) and the three sites from Reference 16 which, in SQUG's judgement, support the Bounding Spectrum capacity. Note that for these sites, the average spectral acceleration over the 3 to 8 Hz range exceeds 75% of the SSRAP Reference Spectrum. Also note that Reference 17 listed Burbank as a GIP-2 site; however, it is actually from Reference 16. The list of earthquake-facility pairs in this Attachment will be updated as response spectra for more sites are developed per NRC-approved procedures. The number in brackets following the database facility name is the reference number from Section 5 of the EBSEQ Procedure that contains the response spectrum for the site.

Appendix B

Risk Significance of Seismic Qualification Using EBSEQ Approach

Section 6 of this Topical Report provides the background and the results of the risk-informed assessment of the Experience-Based Seismic Equipment Qualification (EBSEQ) approach being recommended by SEQUAL. This appendix contains the underlying methodology, assumptions and the calculations for the risk numbers presented in Chapter 6. The objective of this appendix is to show that this EBSEQ method does not increase the risk (measured in terms of core damage frequency) at the SEQUAL plants and may, in fact, lead to reduced risk since the earthquake experience data method relies on a larger number of actual successes of as-installed equipment as opposed to a single test (IEEE 344) conducted under controlled conditions.

Comparison of EBSEQ Approach with NRC SRP

The EBSEQ approach for seismic qualification consists of the following basic steps:

- Use of the licensing basis input ground response spectrum (this is typically NRC Regulatory Guide 1.60 spectrum).
- Perform median centered seismic response analysis described in the SQUG GIP using median properties and model parameters.
- Compare the floor response spectrum demand on the component with the seismic capacity defined by the GIP Reference Spectrum (this is the Capacity vs. Demand comparison step).

Additional steps within the EBSEQ process include a system interaction review, an equipment class inclusion and caveat review, and an anchorage evaluation.

This approach is similar to the NRC Standard Review Plan (SRP) approach in the use of the input ground response spectrum (RG 1.60) but differs in response analysis (median-centered vs. SRP criteria) and the seismic capacity determination (testing methods vs. the earthquake experience capacity spectrum). The SRP requires that the seismic response analysis be done in a conservative manner and that the qualification of components being done using the test procedures given in IEEE Standards 323 and 344. Table B-1 contains a summary comparison of the capacity vs. demand portions of the two methods.

In this appendix, we will demonstrate that, from a seismic risk perspective, the two approaches are essentially equivalent and that the EBSEQ approach actually provides slightly greater confidence in the seismic adequacy of the equipment.

Methodology for Assessing the Risk Significance

The risk significance methodology consists of comparing the seismic induced core damage frequency of a plant qualified by the EBSEQ approach with that qualified using the NRC SRP method. This is accomplished by making several bounding assumptions:

- The seismic demand on the component (i.e., the floor response spectrum) is exactly equal to the seismic capacity (as given by the SQUG Reference Spectrum or by the required response spectra -RRS- used in the seismic qualification testing). This is a conservative assumption because the demand could be less than the capacity on many lower floors in the building. However, the assumption is consistently conservative between the two approaches (i.e., the capacity will likely be greater than the demand by some amount in both cases).

- The governing failure mode is the functional failure mode; structural and anchorage modes are assumed to have higher capacities (due to the presence of some ductility).

- Seismic failure of this component leads directly to core damage. This is a severely conservative assumption (from the CDF calculation perspective) because the plant has several safety trains and each train has multiple redundant components.

These assumptions should not affect the conclusions of this study since we are comparing the relative risks of two qualification procedures using the same set of assumptions.

The basic approach utilized within this risk-informed framework consists of using the seismic probabilistic risk assessment methodology which has been documented in numerous references, but most recently in a Draft Standard for Seismic PRAs being developed by ANS.

The seismic risk is characterized by the core damage frequency (CDF) which is obtained by convolving the component seismic fragility with the site-specific seismic hazard. The seismic fragility is described by a mean fragility curve (Figure B-1) with parameters such as median capacity A_m and composite logarithmic standard deviation β (Reed and Kennedy, 1994). These parameters (A_m and β) are estimated using the margins and variabilities present in different steps of the seismic qualification procedures. Different parameters (and different fragilities) will result from components qualified using the two different approaches (i.e., EBSEQ and SRP). The Case Study shown below highlights how these parameters are evaluated.

The site-specific mean seismic hazard curve developed by EPRI (1989) is used to convolve the hazard with the fragility to obtain the annual frequency of failure, which for the purposes of this study is assumed to be the seismic induced core damage frequency (CDF). Sensitivity studies with LLNL hazard curves are also presented in the conclusion of this section.

Case Study

We describe the risk evaluation methodology using a generic plant as a case study. It is assumed that the plant is designed to a SSE with the 84% NEP shape from NUREG/CR-0098. It should be noted that the SSE spectra shapes vary slightly between the SEQUAL plants. Most of the plants have been designed to RG. 1.60 spectrum whereas some are designed to different versions of Housner and Newmark-type spectra. However, the differences are considered to have minor impact especially in this study of comparing the two qualification approaches.

The seismic fragility of a component qualified using either the NRC SRP method or the SEQUAL EBSEQ method is calculated using the standard seismic PRA methodology.

The median ground acceleration capacity of the component is a function of the following conservatisms:

- Component Response
  - Conservatism in the 84% Non-Exceedance Probability (NEP) shape compared to median (50% NEP) shape of NUREG/CR-0098 spectrum (F_{SS})
  - Conservatism in median NUREG/CR0098 compared to the shape of the median Uniform Hazard Spectrum (F_{UHS})
- Component Capacity
  - IEEE 323 Overtest Factor (F_{IEEE})
  - Capacity Increase Factor (F_{CI})
  - Median Capacity Factor (F_C)

The median ground acceleration capacity, A_m, is calculated from the following equation:

$$A_m = F_{UHS} \bullet F_{SS} \bullet F_{IEEE} \bullet F_{CI} \bullet F_C \bullet SSE$$

Table B-2 summarizes the values for each of these variables for each of the approaches. Reed and Kennedy 1994 contains further descriptions of most of these variables.

Explanations for the derivations of some of these variable values are given in the sections below.

SRP Method

$$A_m = (2.12)\ \exp(1.28\hat{a}_S)\ (1.1)\ (1.1)\ (1.4)\ (0.15g)$$
$$A_m = 0.79g$$
$$\hat{a} = \text{log std dev. of ground acceleration capacity} \quad = \sqrt{\hat{a}_{RV}^{\ 2} + \hat{a}_{CV}^{\ 2}}$$
$$\hat{a}_{RV} = \text{log std dev. of response} = 0.30$$
$$\hat{a}_{CV} = \text{log std dev. of equipment capacity} = 0.24$$
$$\hat{a}_C = \sqrt{0.30^2 + 0.24^2} = 0.38\ (\text{combined variabili ty})$$
$$\text{HCLPF Capacity} = A_m \exp(-2.33\hat{a}) = 0.325g$$

In the following, we describe the basis for the factors used in the calculations above.

$F_{UHS} = \dfrac{\text{Median NUREG Spectrum}}{\text{Median UHS}}$: For the generic plant, we used the 10,000-year median UHS derived for each site from the EPRI hazard study. At a representative structural frequency of 5 Hz, the above ratio is 2.12. Note that the typical nuclear buildings have fundamental frequency ranging from 5 Hz to 10 Hz. For structures founded on soil, the effective soil-structure frequency could be lower. Therefore, for the purposes of this study, we have used 5Hz as a representative frequency.

SRP Response: It is estimated that the SRP procedure (use of 84% NEP input motion, treatment of soil property variation, - if appropriate - , conservative damping given in RG 1.61 and peak broadening) provides a floor response that has a 90% nonexceedance probability (Reference ASCE 4-98). The ratio between a 90% NEP value and the median is given by:

$F_{SS} = \exp(1.28\ \hat{a}_R) = 1.47$

TRS: IEEE standard requires that the TRS be specified as at least 10% above RRS. Therefore,
$F_{IEEE} = 1.1$

Actual Test Spectrum is, on the median, about 10% over the specified TRS (over the 5 – 10 Hz frequency range of interest), making
$F_{CI} = 1.1$

Median Equipment Capacity is judged to be about 1.40 times the qualification test level if the concern is for the equipment to function during the earthquake (Reed and Kennedy, 1994; page 3-70). Therefore,
$F_C = 1.40$

β_R is taken as 0.30 (This value is taken from past seismic PRAs as being appropriate for typical component response variability)

The log standard deviation of equipment capacity is 0.24 (Reed and Kennedy, 1994, page 3-70).

EBSEQ Method

A_m = (2.12) (1.25) (2.2) (0.15g) = 0.925g

β = 0.45

HCLPF Capacity = $A_m \exp(-2.33\beta)$ = 0.324g

In the above calculations of A_m and β, we made the following assumptions:

The design SSE spectrum is assumed to have the shape of 84% NEP NUREG/CR-0098 spectrum. The ratio of design spectrum/median NUREG spectrum is 1.25 (Newmark and Hall, 1978).

The median Equipment Capacity is taken as 2.2 times the Reference Spectrum based on a statistical evaluation of the number of equipment items that have been subjected to an average spectral level equivalent to the Reference Spectrum (30 samples for this case). Other studies have used a value of 2.38 times the Reference Spectrum as a measure of actual equipment capacity (Salmon and Kennedy, 1994). The logarithmic standard deviation of ground acceleration capacity is given by the same reference as 0.45.

Convolution

Using the median ground acceleration capacity and β, the probability of failure at different peak ground accelerations is calculated and plotted as a curve. This is known as the mean fragility curve. From a site-specific seismic hazard analysis, we have a mean seismic hazard curve that is a plot of the annual frequency of exceeding different acceleration values. These two curves are combined by an integration process called convolution to obtain the mean CDF. The process of convolution can be summarized as follows:

1. The peak ground acceleration range is divided into a number of small intervals.

2. The frequency of earthquakes occurring in each interval is obtained as the difference between hazard exceedance frequencies of the end points of the interval ($h_i - h_{i+1}$).

3. The probability that the component will fail (leading to core damage), given that the earthquake has occurred in this acceleration interval, is obtained by entering the fragility curve at the mid-point of the interval (P_{fi}). This probability is multiplied by the frequency of occurrence of earthquakes ($h_i - h_{i+1}$).

4. The products are calculated for all intervals and summed to obtain the mean CDF.

P_f = probability of component failure (which is assumed equal to the CDF) and is obtained by convolving the EPRI mean hazard curve with the fragility curve (defined by A_m, and β)

The results of the computer analysis give the following:

P_f = 2.35 E-6/yr (EBSEQ Case)

P_f = 2.98 E-6/yr (SRP Case)

ÄCDF (SRP-EBSEQ) = 6.3 E-7/yr

Results for all SEQUAL Plants

The above calculation was performed for all SEQUAL plants using the EPRI mean seismic hazard curve. The difference between plants arises from the shape of the median uniform hazard spectrum and the mean peak ground acceleration hazard curve. These differences are considered important compared to the minor difference in the design SSE spectrum shape compared to the 84% NEP NUREG/CR-0098 spectrum shape.

Table 6-2 shows that for most plants, the CDF calculated using the EBSEQ method is approximately equal to the CDF obtained using the NRC SRP qualification procedure. Since we are comparing the CDF values between the two approaches, questions of the appropriateness of the hazard curve, uniform hazard spectral shape and fragility model are not relevant as long as the same models/assumptions are made for the two approaches. Since the maximum increase in the implied CDF using the EBSEQ approach compared to the SRP method is of the order of 1E-10 , the R.G. 1.174 limit of 1E-06 per year is satisfied. Therefore, the EBSEQ approach should be acceptable from a risk-informed perspective.

Sensitivity Studies

We conducted two sets of sensitivity studies to verify the robustness of the above conclusion. First, we used the LLNL mean seismic hazard curve and the median 10,000-year uniform hazard spectrum for each site. Table 6-1 shows the results comparing the implied CDF calculated using the EBSEQ and SRP seismic qualification approaches. Again, it is seen that the two approaches give practically the same CDF values.

In the second set of sensitivity studies, the LLNL mean seismic hazard curve referenced to 5 Hz spectral acceleration at each site was used and the results are documented in Table 6-3. Again, it the two approaches give practically the same CDF values.

Conclusion

We have shown that the use of the EBSEQ methodology, on an individual component qualification basis, provides seismic safety that is comparable to that provided by current SRP procedures. The actual CDF values calculated within this study are conservative for two reasons: (1) the demand floor spectrum will typically be less than the reference spectrum; therefore, there is an additional safety margin not accounted for in this study, and (2) we have assumed that core damage results from the failure of the single component reviewed. The difference between the implied CDF from the two approaches (i.e., EBSEQ and SRP) shows a reduction in seismic risk for the vast majority of cases using the EBSEQ method. The maximum increase in risk using the EBSEQ method is significantly lower than that permitted in Regulatory Guide 1.174 for the plants reviewed (i.e., on the order of 1E-10 per year). Therefore, we conclude that the EBSEQ method meets the NRC risk informed application requirements given in R.G. 1.174.

Table B-1. Comparison of Capacity vs. Demand Methods

Qualification Element	EBSEQ Method	Standard Review Plan/ IEEE 344 Testing Qualification
SSE Input Shape	Regulatory Guide 1.60 (Approximately Equal to NUREG 0098 – 84% NEP)	Regulatory Guide 1.60
Response Calculation	Median Centered (No Intentional Conservatism)	SRP Criteria
Capacity Spectrum	Reference Spectrum (Assumes All Caveats Met)	TRS (Test Response Spectrum)
Required Number of Successes	30	1

Table B-2. Risk Comparison Table for Case Study Plant

Risk/Fragility Parameter	Symbol	EBSEQ Method	Testing Qualification Approach (per SRP)	Comments/Reference
Median Capacity				
Uniform Hazard Spectra Factor	F_{UHS}	2.12	2.12	SSE Shape Different from UHS Shape
Spectral Shape Factor	F_{SS}	1.25	1.47	Conservatism in Spectral Shape & Structural Response
IEEE 323 Factor	F_{IEEE}	1.0	1.1	IEEE 323 Requires 10% Overtest
Capacity Increase Factor	F_{CI}	1.0	1.1	Peaks & Valleys of Actual Test
Capacity Factor	F_C	2.2	1.4	Median Capacity Factor Based on 1 Test and on 30 Earthquake Samples
SSE ZPA	SSE	0.15g	0.15g	FSAR for Case Study Plant
Median Capacity	A_m	0.925g	0.792g	Calculated
Variabilities(Logarithmic Standard Deviation)				
Response Variability	β_R		0.30	Typical Value from Past PRAs
Capacity Variability	β_C		0.24	Reed and Kennedy, 1994
Combined Variability	β	0.45	0.38	0.45 Based on Salmon/Kennedy, 1994
HCLPF		0.324g	0.327g	HCLPF = $A_m \bullet \exp(-2.33\ \beta)$
Hazard		EPRI Mean Hazard	EPRI Mean Hazard	
Risk				Mean Fragility curve convolved with Mean Hazard curve
Seismic CDF		$2.35E^{-6}$/yr	$2.98E^{-6}$/yr	

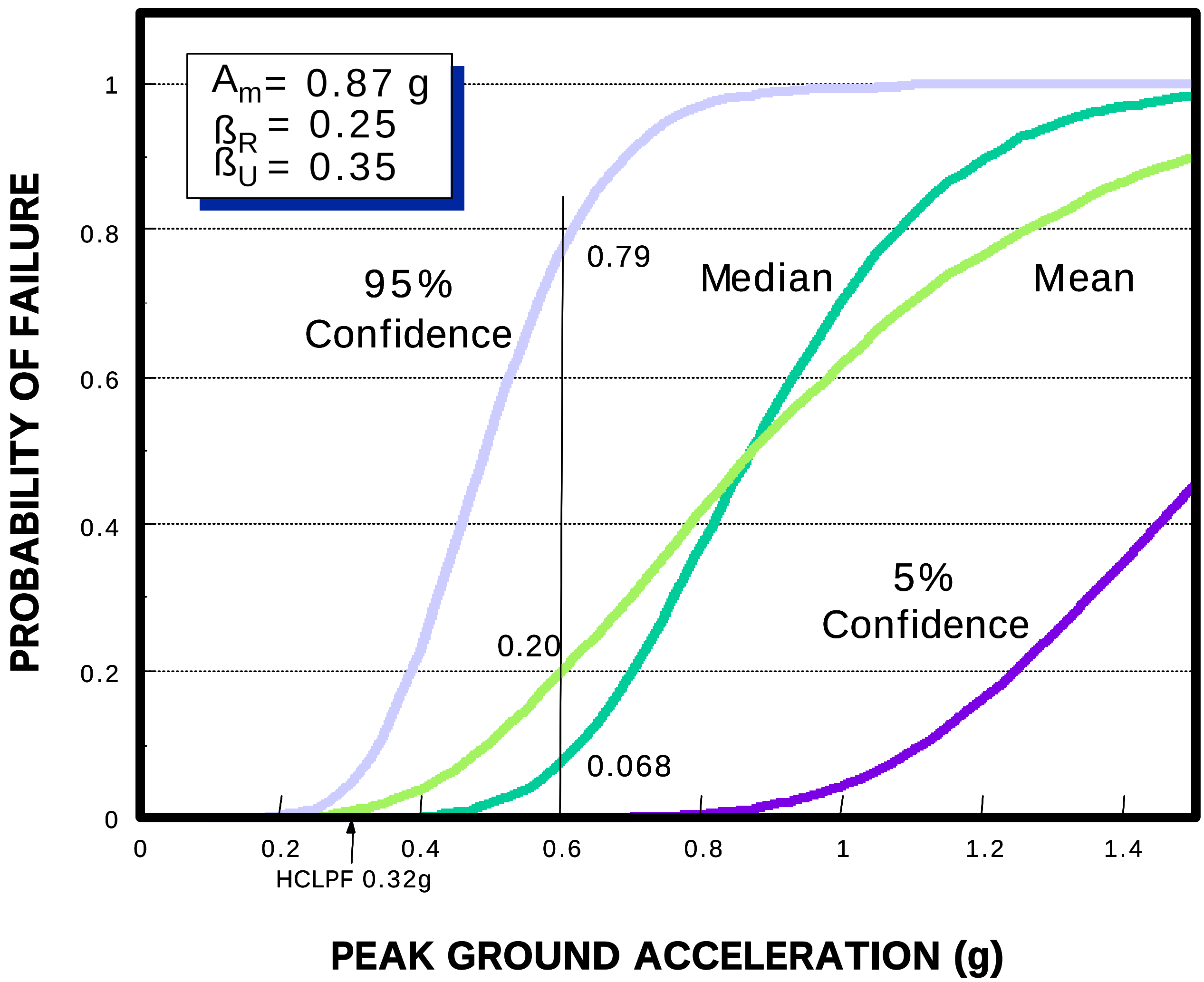

Figure B-1. Seismic Fragility Curve

Appendix B References

1. ASCE (1998) “ASCE Standard: Seismic Analysis of Safety-Related Nuclear Structures and Commentary” ASCE 4-98, Published by the American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, Virginia 20191-4400.

2. Newmark, N.M. and Hall, W.J. (1978) “Development of Criteria for Seismic Review of Selected Nuclear Power Plants,” NUREG/CR-0098, USNRC, 1978.

3. Reed, J.W. and Kennedy, R.P. (1994) “Methodology for Developing Seismic Fragilities,” EPRI TR-103959, Final Report June 1994, Electric Power Research Institute, Palo Alto, California.

4. Salmon, M.W., and Kennedy, R.P. (1994) “Meeting Performance Goals by the Use of Experience Data”, prepared for Lawrence Livermore National Laboratory and the US Department of Energy, UCRL-CR-120813, December 1994.

5. Sobel, P. (1993) “Revised Livermore Seismic Hazard Estimates for 69 Nuclear Power Plant Sites East of the Rocky Mountains,” NUREG-1488, USNRC, Washington D.C. October 1993.

6. SQUG (1992) “ Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment,” published by the Seismic Qualification Utility Group (SQUG) Revision 2 (1992), Electric Power Research Institute, Palo Alto, California.

Appendix C

Position Paper on the Use of Method A

Purpose

The purpose of this position paper is to provide supporting information for application of Method A as requested by the NRC. This paper describes many of the conservatisms that exist in computed in-structure response spectra and the safety significance of the difference between computed and actual building response.

1. Conservatism in Calculated ISRS

The process of calculating in-structure response spectra (ISRS) is a complicated analytical exercise requiring a significant amount of approximations, modeling assumptions and engineering judgments. As a result, the historical development of these ISRS has included a tremendous amount of conservatism that has typically served two purposes:

1. It has reduced the technical debate as to the correct modeling of the many parameters which are intrinsic to the ISRS calculational methodology, and;

2. It has reduced the costs associated with a very detailed state-of-the-art analysis, (which would attempt to trim out unnecessary conservatisms)

As a part of the A-46 program resolution methodology, the SSRAP developed and SQUG subsequently endorsed an alternate ISRS estimation technique (referred to as Method A within the GIP) which was much more median-centered and realistic than the typical design practice. SEQUAL maintains that the application of Method A is appropriate and technically justifiable for non-A46 plants as well. The fact that design ISRS may show amplifications greater than 1.5 is not surprising, nor does it negate the validity of Method A. In fact, as noted the SSRAP report it was even expected. As described below, three areas can be used to address the appropriateness of Method A:

A. Measurements of ISRS in Actual Earthquakes

B. Analytical Studies of the Conservatisms in Developing ISRS

C. Description of the Conservatisms Involved in Modeling and Calculating ISRS

A. Measurements of ISRS in Actual Earthquakes

SSRAP developed the Method A response estimation technique based on their research of both actual earthquake measurements and on recent "median-centered" analysis. They reference (SSRAP report page 102) the measured floor response spectra at elevations less than 40 feet above the grade for moderately stiff structures at the Pleasant Valley Pump Station, the Humbolt Bay Nuclear Power Plant, and the Fukushima Nuclear Power Plant where amplifications over the ground response spectra do not exceed 1.5 for frequencies above about 6 Hz. Other, more recent earthquake data from the Manzanillo Power Plant and SICARTSA Steel Mill in Mexico, as well as several facilities in California and Japan, has been recently reviewed by SQUG. This data also shows that stiff buildings (similar to typical nuclear structures) amplify very little at elevations less than 40 feet above grade for frequencies over 8 Hz.

B. Calculations of Overall Conservatism in Typical ISRS

Calculated ISRS have never been portrayed as representing the realistic expected response during an actual earthquake. As previously stated, ISRS typically contain many conservatisms which make them unrealistically high. The primary reason for the development of Method A was to establish a more median-centered method of establishing the structural response without having to embark on a brand new analysis of all the site buildings. (It should be noted that even the most modern, state-of-the-art ISRS contain significant conservatisms; even those classified as "median-centered", are often very conservative.) A NRC contractor (LLNL) concluded in a study for the NRC (NUREG/CR-1489) that typical calculated ISRS contain factors of conservatism of 1.5 to 8. Recent surveys by SQUG show similar levels of conservatism in calculated ISRS.

It was the contention of SSRAP that the ISRS for nuclear structures (considering the 40 foot and 8 Hz limitations) would be within about 1.5 times the ground response spectrum (GRS) if the plant were subjected to an actual earthquake. In deriving the Method A criteria, SSRAP recognized that due to the variety of ground motions, soil characteristics and structure characteristics there could be some possibility of exceedances to the 1.5 amplification, but still strongly justified Method A's applicability:

> "It is SSRAP's firm opinion that the issue of potential amplifications greater than 1.5 above about 8 Hz for high frequency input is of no consequence for the classes of equipment considered in this document except possibly for relay chatter[1]."

[SSRAP Report, Page 106]

The basis SSRAP gave for drawing this conclusion was that high frequency ground motions do not have much damage potential due to low spectral displacement, low energy content, and short duration. They further noted that the equipment covered does not appear

[1] Because of the SSRAP concern related to possible relay chatter at frequencies above 8 Hz, the SQUG methodology specifically addresses relays that are sensitive to high frequency vibration. Such relays are included on the Low Ruggedness Relays list in Appendix E of EPRI Report NP-7148.

to have a significant sensitivity to high frequencies (except possibly for relay chatter, which is addressed separately in the GIP).

C. Description of ISRS Conservatisms

The most significant sources of conservatism typically involved in the development of ISRS include the following:

- Location of Input Motion (variation from the free field input location)
- Ground Response Spectrum Shape
- Soil-Structure Interaction (Soil Damping, Wave Scattering Effects)
- Ground Motion Incoherence
- Frequency (Structural Modeling)
- Structural Damping
- Time History Simulation
- Non-Linear Behavior (e.g., soil property profile variation, concrete cracking)

The degree of conservatism involved in each of these parameters is specific to the site being reviewed, to the building being analyzed, to the floor level being considered, and often, to the equipment location within the specified floor level. Thus, it would take considerable effort to quantify the excess conservatisms inherent in the calculated ISRS at a particular site. However, on a qualitative level, it is easy to see the origins and levels of this conservatism. The following parameters are often the source of the major portions of the excess conservatism:

Location of Input Motion – The location of application of the plant defined SSE is typically part of the design basis documentation. The SSE should typically be defined at the ground surface in the free field as defined in the current Standard Review Plan criteria. For purposes of generating ISRS, some plants conservatively defined the input (currently identified as the "control point" location) at another location, such as the embedded depth of a building basemat. This conservatism can be significant depending on the specific plant/building configuration. The amounts of conservatism inherent in this control point placement are discussed in the SSI description below.

Ground Response Spectrum Shape – The SSE defined within the plant-licensing basis is the appropriate review level for the A46 program. Some utilities utilized alternative (conservative) spectral shapes for the earthquake levels utilized for their A46 resolution (i.e., submitted as part of their 120-day response letters). The amount of conservatism is directly related to the difference between these two spectral shapes at the frequencies of interest for the structures being reviewed. This factor can range from 1.0 to around 2.0 depending on the differences between the spectra.

Soil Structure Interaction (SSI) – Typical design analyses do not account properly for the phenomena of SSI, including the deamplification with depth that really occurs for embedded structures and for the radiation damping effects inherent at soil sites. Fixed-base analyses have been performed both for structures founded on rock and for structures founded on soil columns. For rock foundations, the fixed-base model has been shown to be slightly conservative depending on the rock/structure characteristics. For soil founded structures this assumption can vary between conservative and very conservative, depending on the frequency range of interest. Simplified SSI analyses using constant frequency-independent soil springs was quite prevalent in the past. These simplified analyses were typically also very conservative in that radiation and/or material damping were either conservatively eliminated or artificially limited during the analysis. Soil properties were also typically not adjusted to reflect anticipated soil strain levels. Significant reductions have been demonstrated over design type analyses using more modern techniques. These reduction factors are highly dependent on the specific soil conditions and structure configurations, but values of around 2 to 4 have been seen in past studies. As previously stated, even the most modern, state-of-the-art ISRS contain significant conservatisms; even those classified as "median-centered" can often be very conservative.

Ground Motion Incoherence – As has been documented in the EPRI Seismic Margin Report (EPRI NP-6041) there can be a deamplification effect on nuclear type structures due to the incoherence of ground motion. Conservative reduction factors as a function of frequency and building footprint have been documented within NP-6041 to account for the statistical incoherence of the input wave motion. These conservative values range from a factor of 1.1 to around 1.5. More recent studies have documented even greater reduction factors.

Time History Simulation – ISRS are typically generated using a time history that will approximate the intended earthquake defined by the design basis SSE. This process involves the generation of an artificial time history whose response spectra envelops the SSE. The amount of conservatism involved in the enveloping process is variable from plant to plant, but can range up to a factor of 2 or more if the analyst was not determined to minimize the degree of enveloping.

There are several additional sources of conservatism (e.g., structural damping, structural modeling, structural/soil non-linearities, etc.) which add to the overall conservatism in the calculation of ISRS. These additional conservatisms, coupled with those described above, certainly reinforce the overall levels of conservatism in ISRS of between 1.5 and 8 which were referenced by SSRAP (LLNL Report NUREG/CR 1489).

2. Not a Significant Safety Issue

The expected differences between calculated ISRS and actual building response do not represent a significant safety question. The lessons learned from review of hundreds of items of equipment at various sites that have experienced earthquakes which were significantly larger than those for Eastern U.S. nuclear plants are that missing anchorage, seismic interaction hazards, and certain equipment-specific weaknesses (incorporated into the GIP caveats) were the seismic vulnerabilities which cause equipment damage. These areas are conservatively addressed in the GIP.

The NRC staff acknowledged the seismic ruggedness of nuclear power plant equipment in the backfit analysis for USI A-46 in which they stated the following:

> " . . . subject to certain exceptions and caveats, the staff has concluded that equipment installed in nuclear power plants is inherently rugged and not susceptible to seismic damage." (NUREG-1211, page 16)

Method A is only applicable to stiff equipment with fundamental frequencies over about 8 Hz. As noted earlier in Section 1 of this paper, SSRAP and SQUG have agreed that excitations over 8 Hz have little damage potential due to low spectral displacements, low energy content and short duration. This judgment is supported by industry and NRC guidance for determining whether an operating basis earthquake (OBE) is exceeded following a seismic event at a nuclear power plant. EPRI Report NP-5930 and NRC Regulatory Guide 1.166 recognize that damage potential is significantly reduced for earthquake ground motions above 10 Hz. In other words, the question of what is the precise value of building amplification over 8 Hz has very little safety significance.

Conclusions

The discussion above leads to several conclusions:

- The results from actual measured ISRS on "nuclear type" structures support the 1.5 response levels advocated within Method A.

- Qualitative assessments of the conservatism inherent within the methods utilized to calculate ISRS have been provided above. These conservatisms are typically quite significant (as has been independently verified by median/modern assessments such as the LLNL study) and can/will result in ISRS that show amplifications well beyond the 1.5 factor from Method A. SEQUAL feels strongly that specific exceedances that may be beyond the 1.5 factor for non-A46 plants are due to these high conservatisms inherent in the ISRS methods and do not invalidate the application of Method A.

There is little safety significance in the expected differences between calculated ISRS and actual building response. The largest safety significant benefit is provided by appropriately reviewing equipment anchorage, seismic interaction hazards, and certain equipment-specific weaknesses where seismic vulnerabilities caused equipment damage. These reviews were a primary focus of the SQUG GIP process; therefore implementation of the GIP resulted in significant seismic safety enhancements for the A46 plants. SEQUAL expects that use of Method A for non-A46 plants will also result in similar seismic safety enhancements.

Appendix D

Capacity Spectra for Individual Equipment Classes

As discussed in Section 5.3.5, Use of Reference Spectrum for All Equipment Classes, this appendix contains a capacity spectrum derivation for each equipment class using the procedure being considered for inclusion in revisions to the ASME QME and IEEE 344 standards. The resulting capacity spectra are then compared to the SSRAP Reference Spectrum.

The proposed ASME/IEEE method used to determine an equipment class capacity spectrum includes the following four steps:

(1) Reference sites are selected (four minimum from at least four earthquakes) which contain equipment in the equipment class and have experienced significant earthquake ground motions. The earthquake experience ground motions are the average of two orthogonal horizontal components of the 5% critically damped response spectra derived from on-site records or conservative estimates.

The average horizontal, 5% critically damped ground response spectra for the earthquake-facility pairs (reference sites) used in this derivation are shown in Figures D-1 to D-20. The average spectral acceleration between 2.5 and 7.5 Hz and the SSRAP Reference Spectrum are also shown in these figures. These spectra come from References 9.14, 9.15, and 9.16, and Appendix E of this document.

(2) The number of independent equipment items in the class at each site (minimum of 30 total) is counted.

This was accomplished using the bar charts for each equipment class in the electronic database of seismic experience (WinSQUG) (Reference 9.17) augmented by informed estimates. Many of the sites recorded in the database as having zero or only one item obviously have more items at the site. Estimates of the number of independent items were made based on the kind of equipment normally found in the type of facility. These estimates can be confirmed at a later date through further investigation. Also, where sites had large data counts they were reduced to be conservative and account for equipment independence. No more than five items in a class were attributed to any single site. Tables D-1 and D-2 give the number of independent items estimated at each site plus the total number in each class at the sites being used.

(3) A capacity spectrum for the class is calculated using the weighted average of the individual site spectra. The weighting factor for an earthquake site is the number of independent items at the site divided by the total number of independent items at all of the earthquake sites considered. The resulting spectrum is smoothed and averaged to the shape of a broadband response spectrum.

For this study, the spectrum was averaged over the constant acceleration range of 2.5 to 7.5 Hz used for the SSRAP Reference Spectrum. Figures D-21 to D-40 show the weighted average spectrum obtained for each class and the average over the 2.5 to 7.5 Hz frequency range. They also show the SSRAP Reference Spectrum for comparison.

(4) If the total number of independent equipment items is less than 30, the capacity spectrum is multiplied by a knockdown factor. The knockdown factor varies from 0.7 for 15 items to 1.0 for 30 items. A data count of less than 15 items is not allowed.

For this study, four classes had estimated counts less than 30. The capacity spectra were not factored. It was felt that the data count estimates were conservative, and by taking more detailed site information and using more recent earthquake data not yet included in the electronic database the equipment counts could be increased to more than 30, except possibly for motor generators, and the results would remain valid.

The motor generators class has an equipment count in Table D-2 below 15. The Twenty Classes Report, Reference 9.18, acknowledged that this class had a low population. The report noted that the class of motor generators is physically similar to the class of horizontal pumps (with respect to the motor arrangement), and the low data count could be accepted on that basis. The capacity spectrum for horizontal pumps is higher than the Reference Spectrum, and this implies that the capacity spectrum for motor generators should also be higher than the Reference Spectrum.

Table D-1
Independent Items (Classes 1-10) Estimated at
Reference Sites for Capacity Spectra

Equipment Classes	Motor Control Centers 1	Low Voltage Switchgear 2	Medium Voltage Switchgear 3	Transformers 4	Horizontal Pumps 5	Vertical Pumps 6	Fluid Operated Valves 7	Motor Operated Valves 8	Fans 9	Air Handlers 10
Reference Sites										
Llolleo and San Pedro Sites*	4	4	2	2	2	2	5	5	2	2
El Centro	4	4	4	4	5	5	5	5	5	2
Sylmar San Fernando	5	5	2	4	0	0	0	0	5	5
Sylmar Northridge	5	5	2	4	0	0	0	0	5	5
Rinaldi San Fernando	1	1	0	1	0	0	0	0	1	1
Rinaldi Northridge	1	1	0	1	0	0	0	0	1	1
Pleasant Valley Pumping Plant	2	2	2	2	2	2	5	5	1	1
Shell Water Treatment Plant	3	3	2	2	4	3	5	5	2	1
Coalinga Water Treatment Plant	3	3	2	2	4	3	5	5	2	1
Getty (Main) Oil Pumping Plant	3	3	2	2	3	3	5	5	2	1
Union Oil Butane Plant	2	2	2	2	3	3	5	2	1	2
Pacific Lumber	3	1	1	2	4	3	5	5	2	1
AES Placerita Cogen	3	1	1	3	4	3	5	5	3	2
Whitewater Hydro	2	1	1	1	1	0	1	1	1	1
UC Santa Cruz Central Campus	3	3	0	3	3	1	0	0	5	3
UC Santa Cruz Cogen	3	1	1	3	4	3	5	5	2	1
Santa Cruz Water Treatment	2	2	1	2	4	3	5	2	1	1
Watkins-Johnson	2	1	0	2	2	0	0	0	4	2
Commerce Refuse to Energy	2	1	1	2	1	0	2	2	3	2
Devers Substation	1	1	0	1	0	0	0	0	1	1
Total	54	45	26	45	46	34	58	52	49	36

* Llolleo Pumping Plant, San Sebastian Substation, tank farm north of Port of San Antonio, Terquim tank farm, Vicuna Hospital, Port of San Antonio and San Isidro Substation

Table D-2
Independent Items (Classes 11-20) Estimated at
Reference Sites for Capacity Spectra

Equipment Classes	Chillers 11	Air Compressors 12	Motor Generators 13	Distribution Panels 14	Battery Racks 15	Battery Chargers and Inverters 16	Engine Generators 17	Instruments on Racks 18	Temperature Sensors 19	Control and Instrumentation Panels and Cabinets 20
Reference Sites										
Llolleo and San Pedro Sites*	1	2	0	3	3	1	2	2	3	1
El Centro	2	4	2	4	4	4	0	4	5	2
Sylmar San Fernando	2	2	2	5	5	2	2	2	1	2
Sylmar Northridge	2	2	2	5	5	2	2	2	1	2
Rinaldi San Fernando	0	1	0	1	1	1	0	1	1	1
Rinaldi Northridge	0	1	0	1	1	1	0	1	1	1
Pleasant Valley Pumping Plant	0	1	0	1	1	1	0	1	1	1
Shell Water Treatment Plant	1	1	0	3	2	1	1	2	2	1
Coalinga Water Treatment Plant	1	1	0	3	2	1	1	2	2	1
Getty (Main) Oil Pumping Plant	1	2	0	3	2	2	1	3	4	2
Union Oil Butane Plant	2	2	0	3	2	2	4	5	5	2
Pacific Lumber	1	1	0	2	2	2	1	5	5	2
AES Placerita Cogen	1	1	2	2	2	2	1	5	5	2
Whitewater Hydro	1	1	0	1	1	1	0	1	1	1
UC Santa Cruz Central Campus	2	5	2	5	1	2	4	1	1	1
UC Santa Cruz Cogen	1	1	2	2	2	2	2	5	5	2
Santa Cruz Water Treatment	1	1	0	1	1	1	1	2	2	1
Watkins-Johnson	2	1	0	2	1	1	0	2	1	2
Commerce Refuse to Energy	2	1	0	2	0	0	0	1	1	2
Devers Substation	0	1	0	1	1	1	1	1	1	1
Total	23	32	12	50	39	30	23	48	48	30

* Llolleo Pumping Plant, San Sebastian Substation, tank farm north of Port of San Antonio, Terquim tank farm, Vicuna Hospital, Port of San Antonio and San Isidro Substation

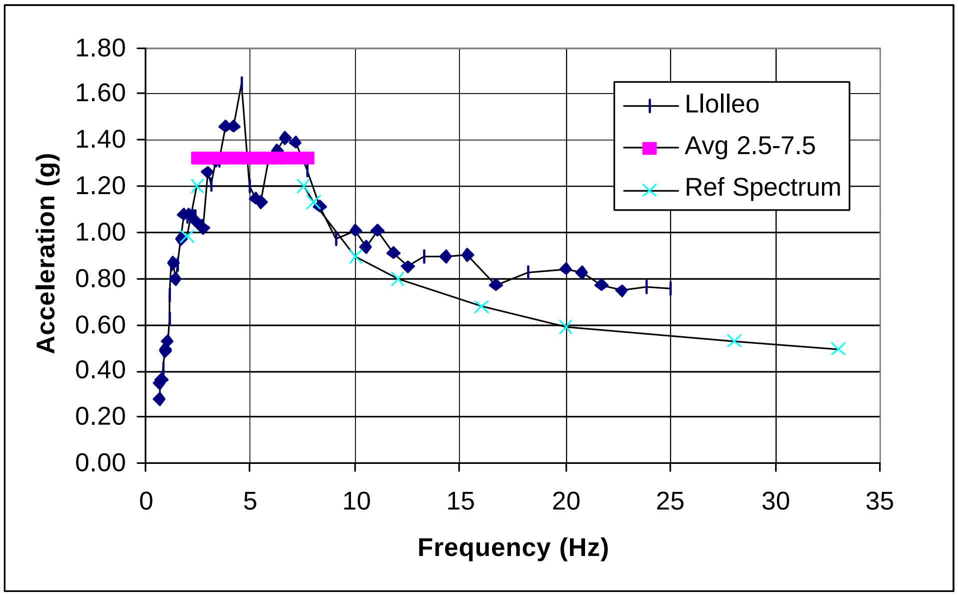

Figure D-1. Llolleo and San Pedro Sites
1985 Chile Earthquake (Ref. 9.14)

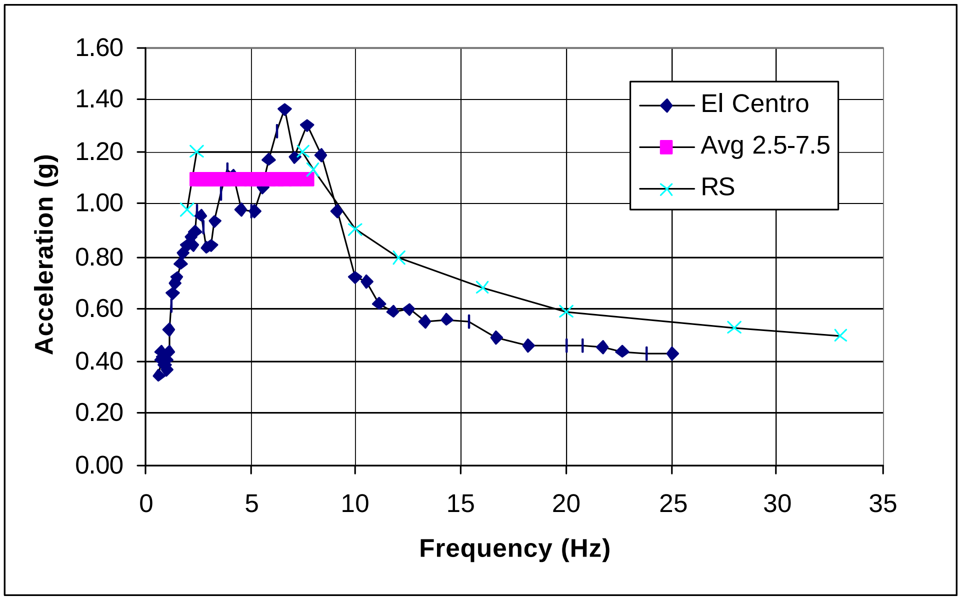

Figure D-2. E1 Centro Steam Plant
1979 Imperial Valley Earthquake (Ref. 9.14)

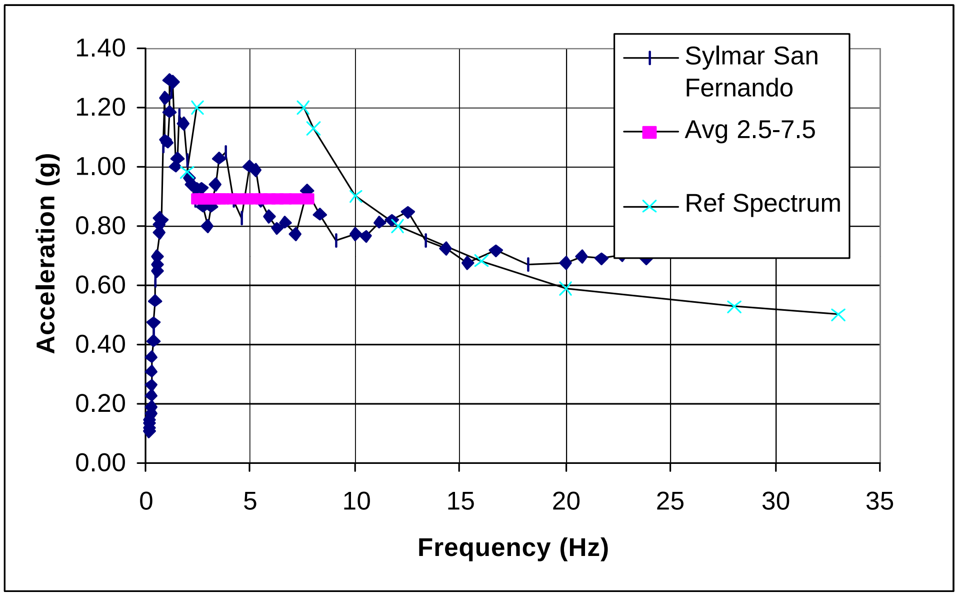

Figure D-3. Sylmar Converter Station
1971 San Fernando Earthquake (Appendix E)

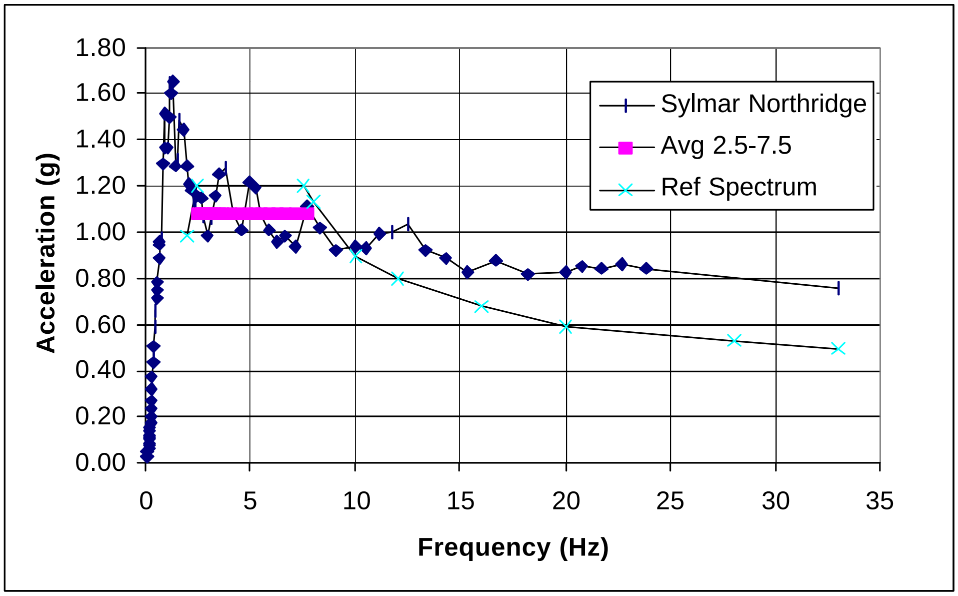

Figure D-4. Sylmar Converter Station
1994 Northridge Earthquake (Appendix E)

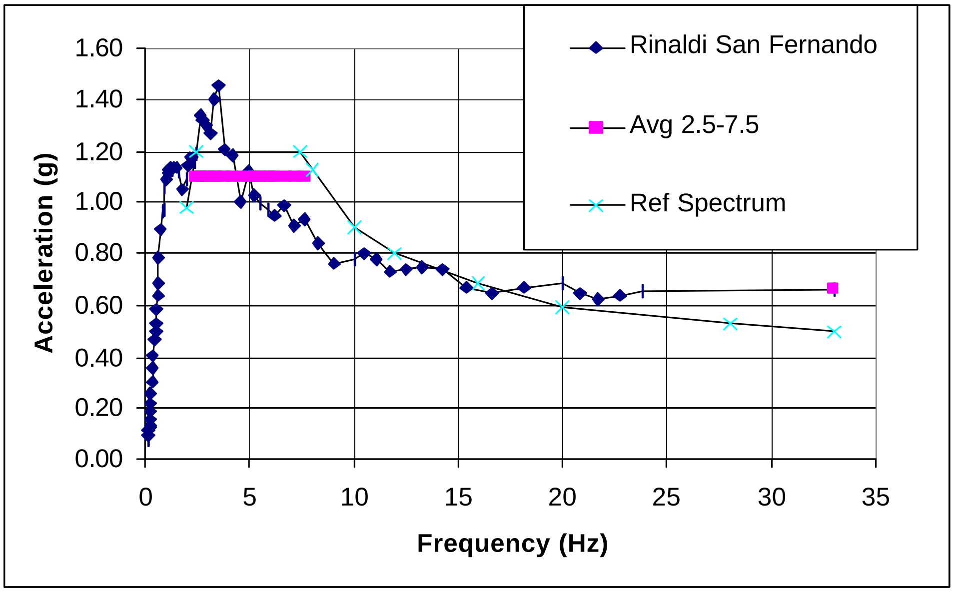

Figure D-5. Rinaldi Receiving Station
1971 San Fernando Earthquake (Appendix E)

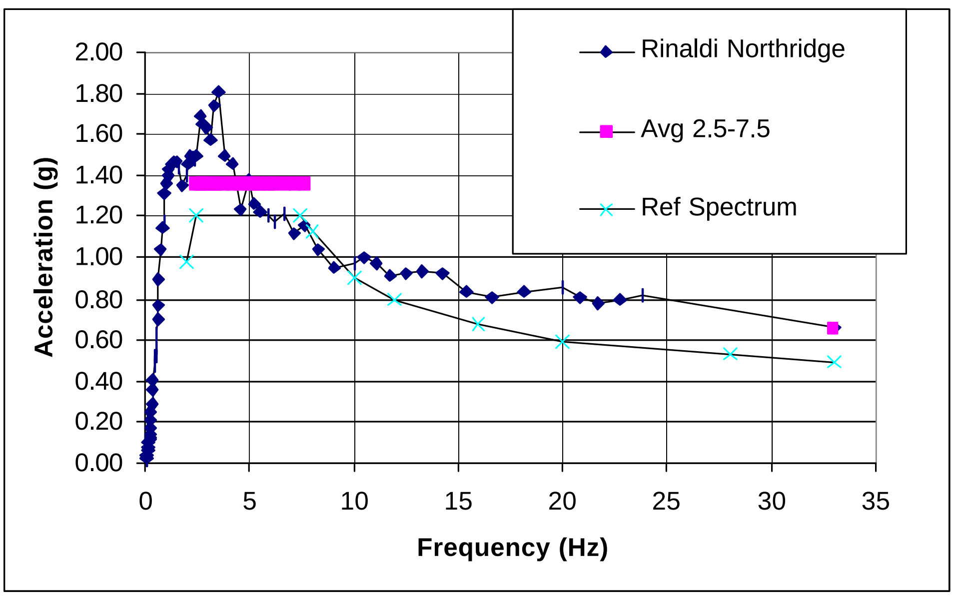

Figure D-6. Rinaldi Receiving Station
1994 Northridge Earthquake (Appendix E)

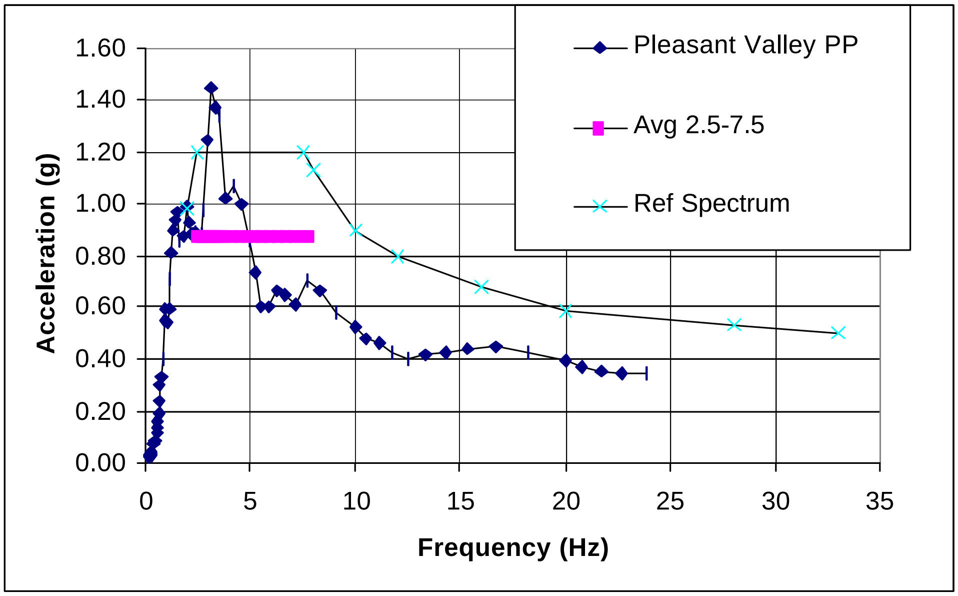

Figure D-7. Pleasant Vally Pumping Plant
1983 Coalinga Earthquake (Appendix E)

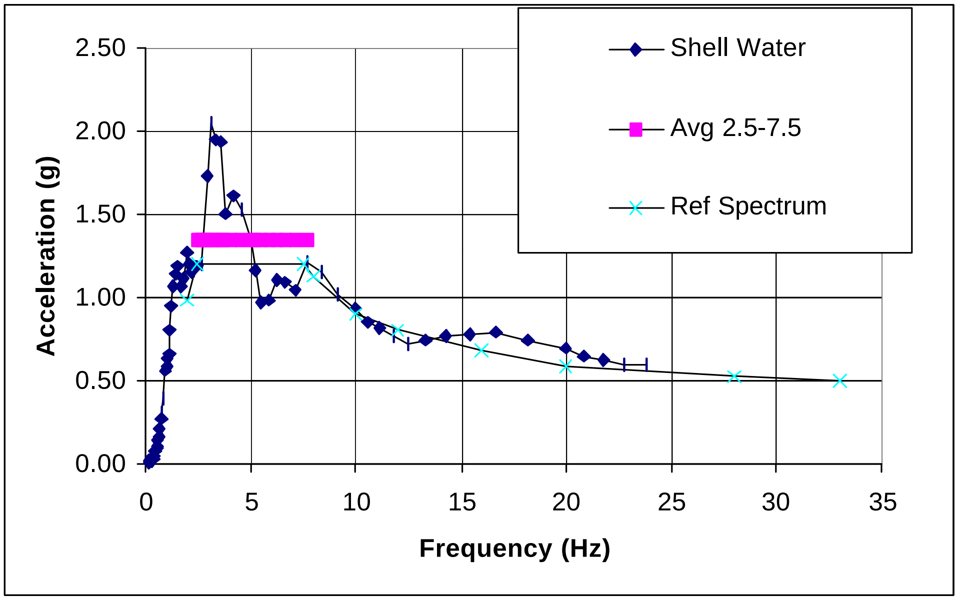

Figure D-8. Shell Water Treatment Plant
1983 Coalinga Earthquake (Appendix E)

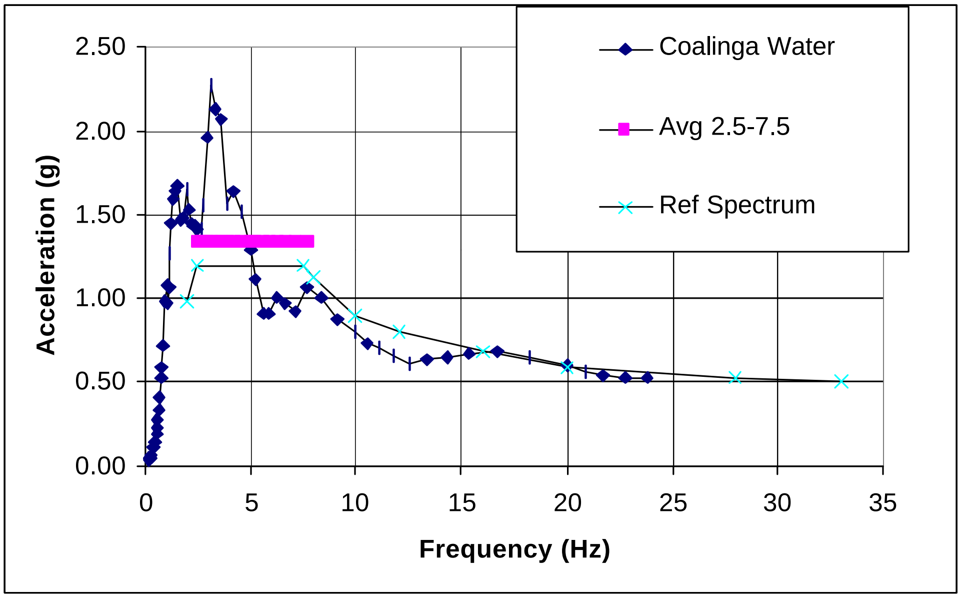

Figure D-9. Coalinga Water Treatment Plant
1983 Coalinga Earthquake (Appendix E)

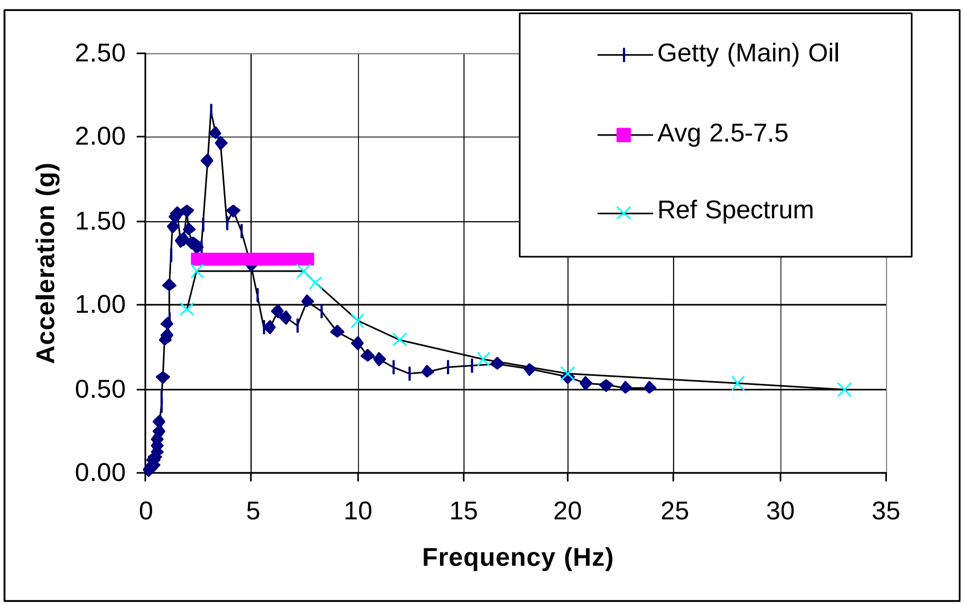

Figure D-10. Getty (Main) Oil Pumping Plant
1983 Coalinga Earthquake (Appendix E)

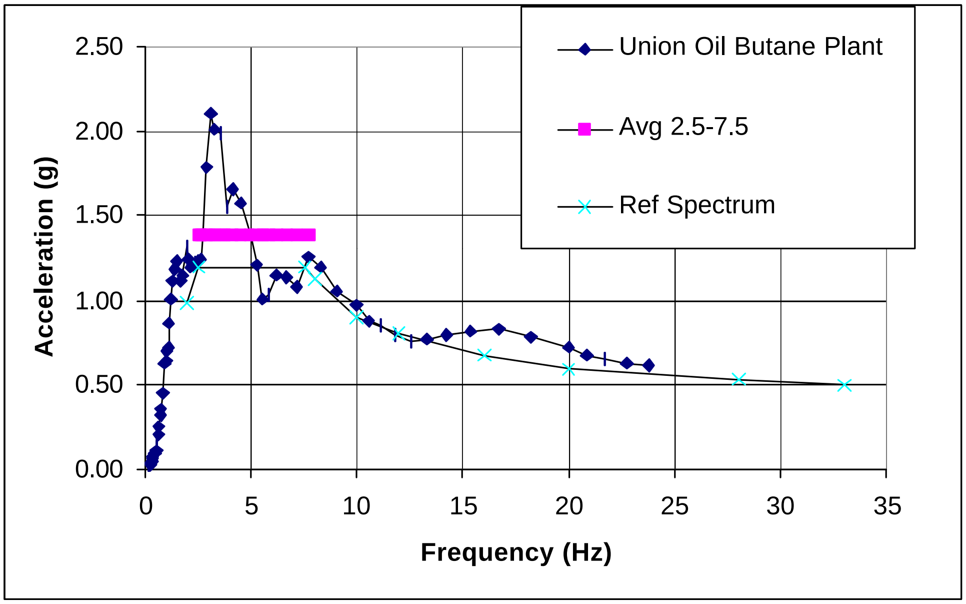

Figure D-11. Union Oil Butane Plant
1983 Coalinga Earthquake (Appendix E)

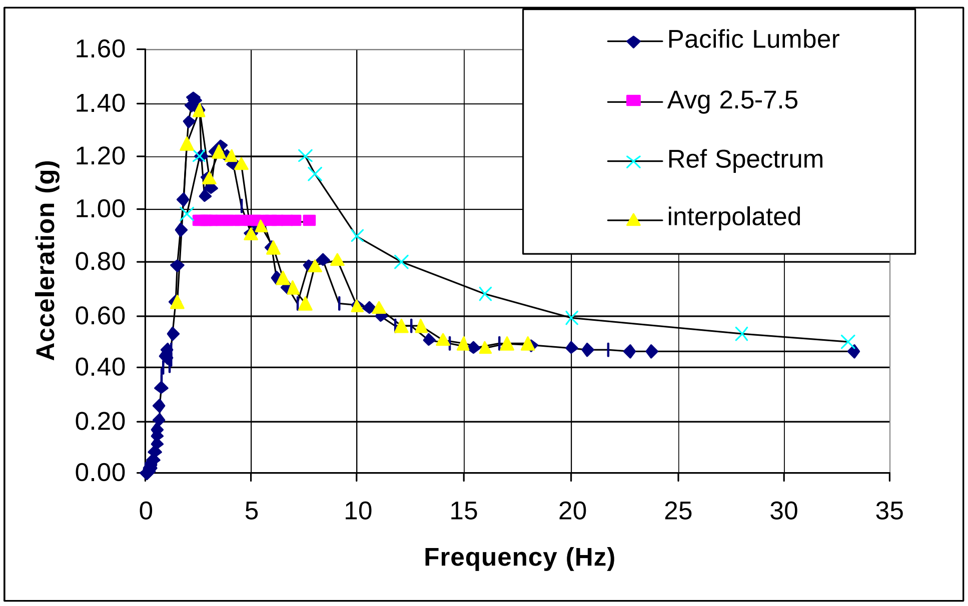

Figure D-12 Pacific Lumber Mill Cogen Plant
1992 Cape Mendocino Earthquake (Ref. 9.16)

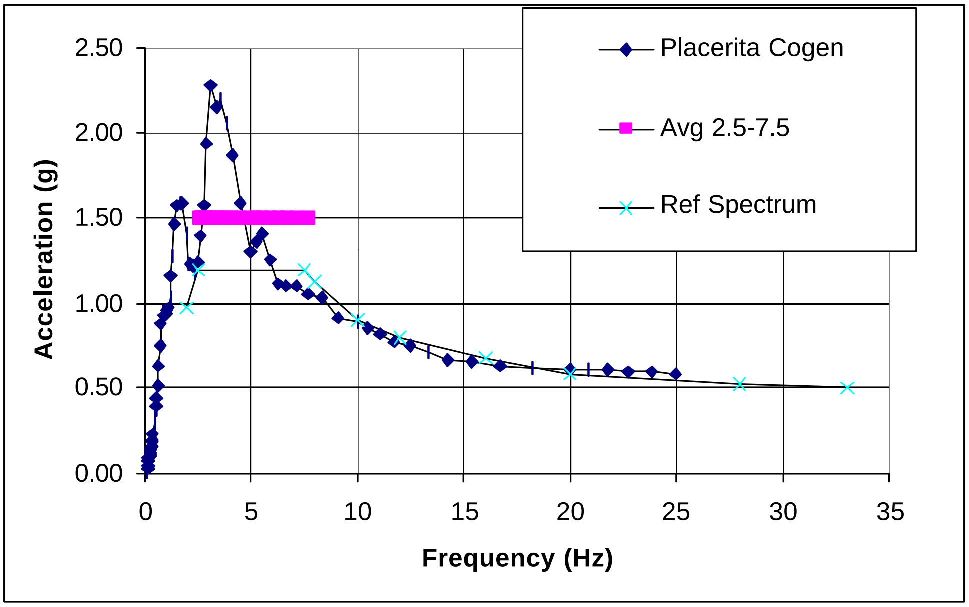

Figure D-13. Placerita Cogeneration Plant
1994 Northridge Earthquake (Ref. 9.16)

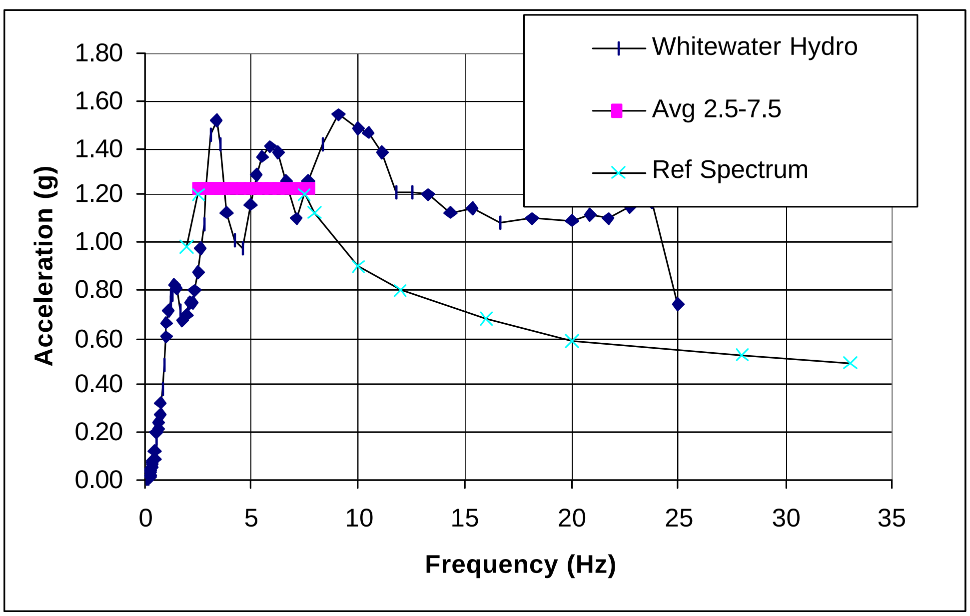

Figure D-14. Whitewater Hydroelectric Plant
1986 North Palm Springs Earthquake (Ref. 9.16)

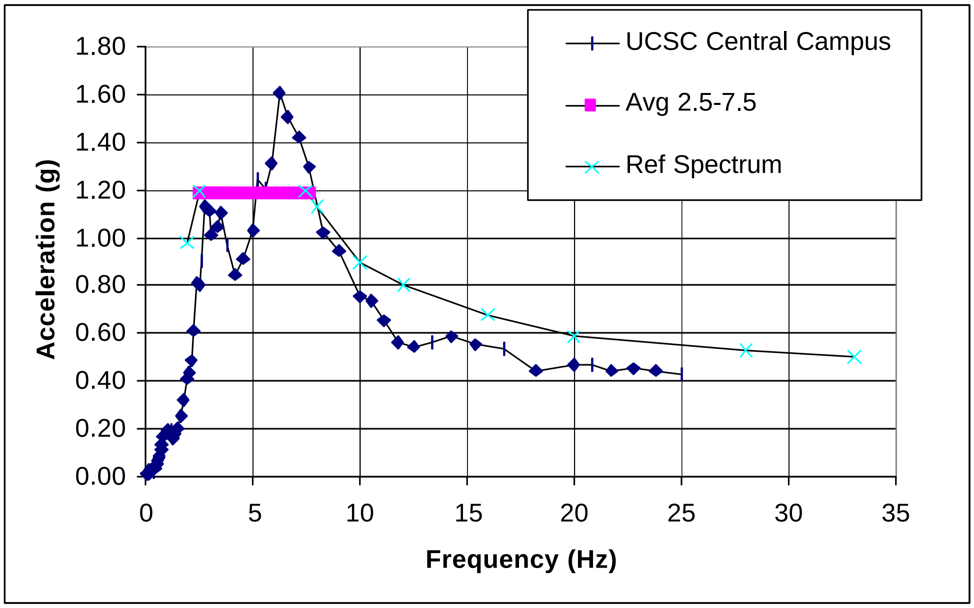

Figure D-15. UC Santa Cruz Central Campus
1989 Loma Prieta Earthquake (Ref. 9.16)

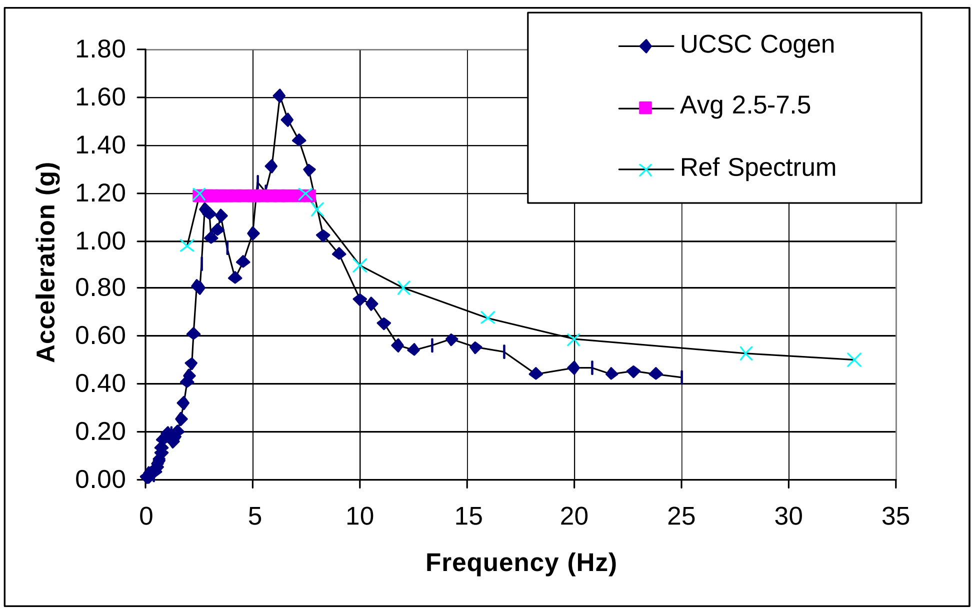

Figure D-16. UC Santa Cruz Cogeneration Plant
1989 Loma Prieta Earthquake (Ref. 9.16)
(same as UCSC Central Campus)

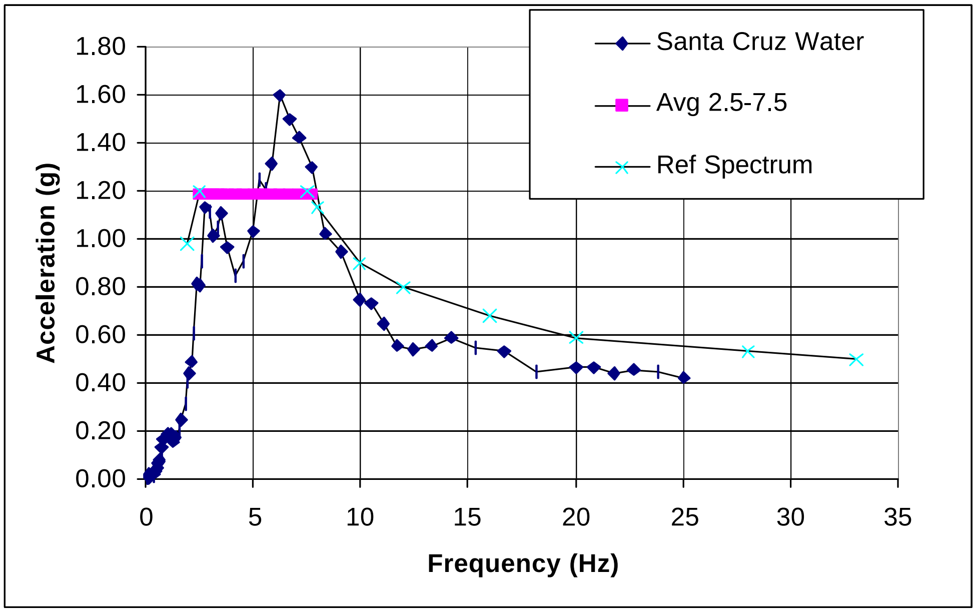

Figure D-17. Santa Cruz Water Treatment Plant
1989 Loma Prieta Earthquake (Ref. 9.16)

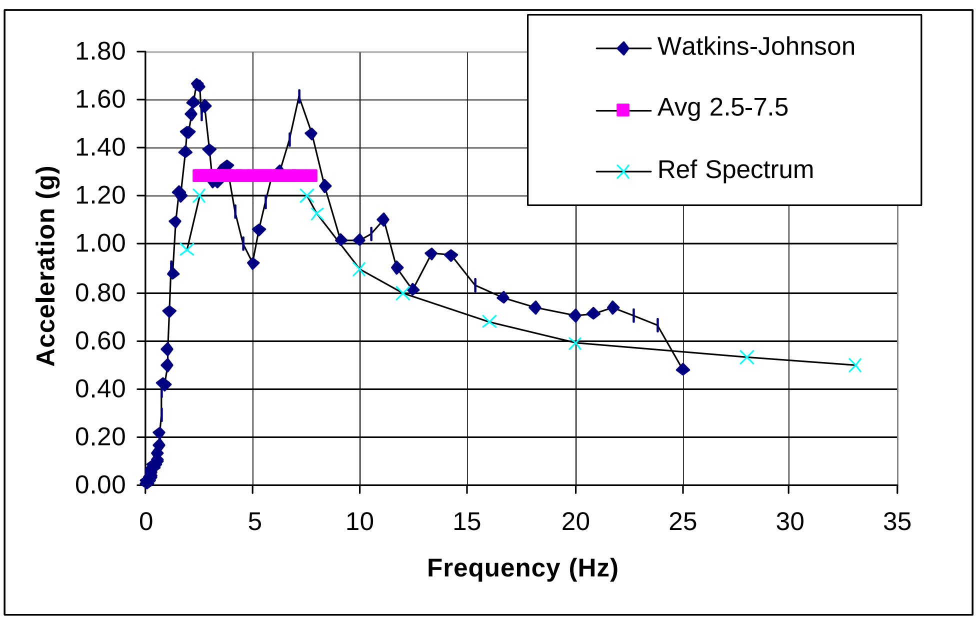

Figure D-18. Watkins-Johnson Instrument Plant
1989 Loma Prieta Earthquake (Ref. 9.16)

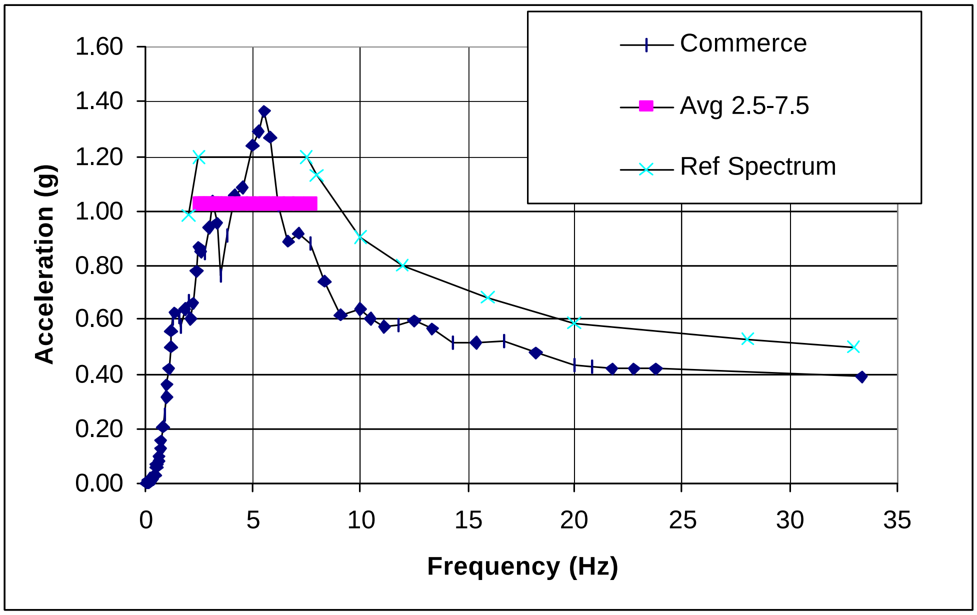

Figure D-19. Commerce Refuse to Energy Plant
1987 Whittier Narrows Earthquake (Ref. 9.15)

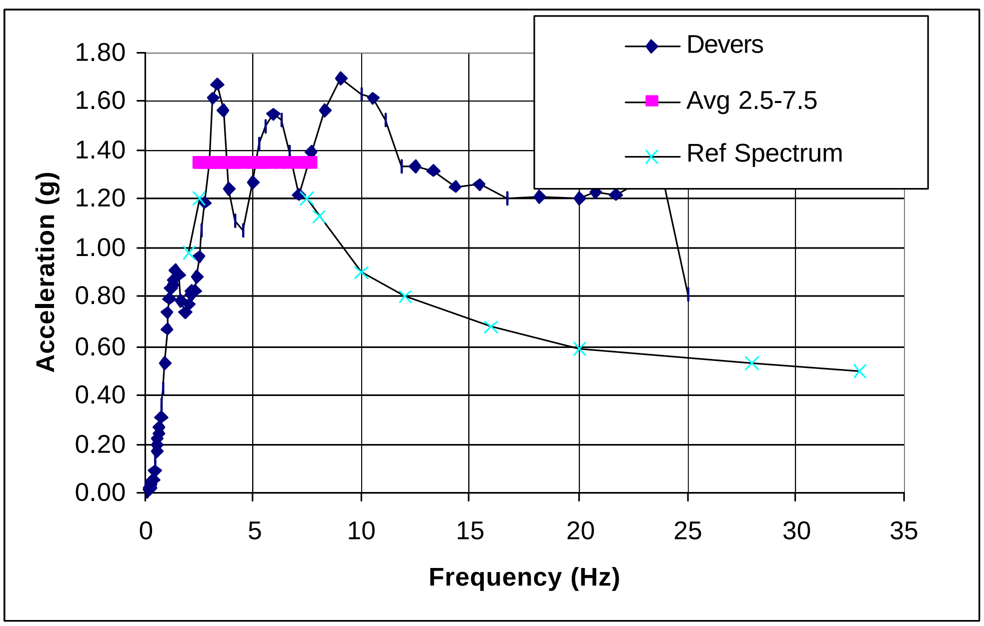

Figure D-20. Devers Substation
1986 North Palm Springs Earthquake (Ref. 9.16)

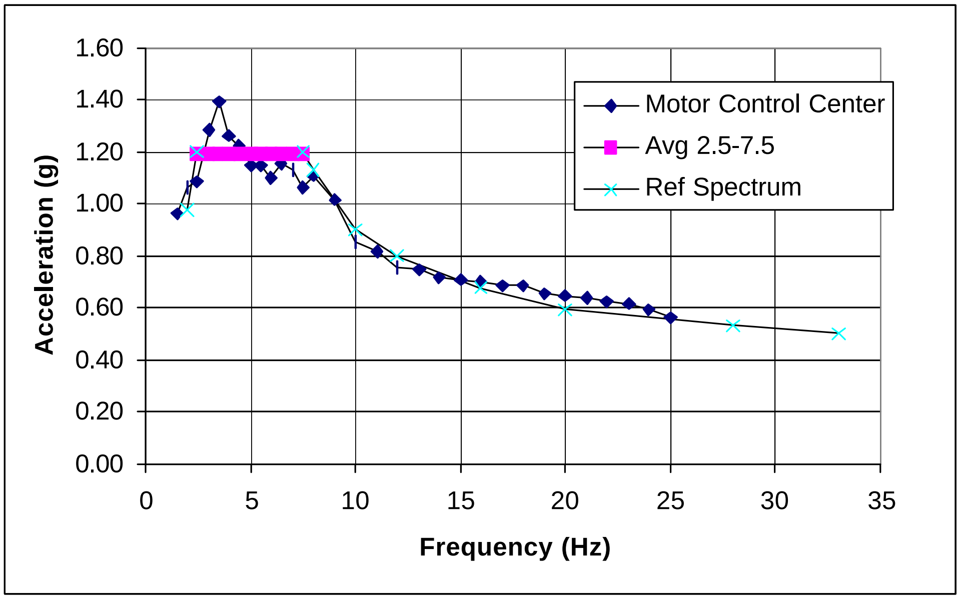

Figure D-21. Equipment Class 1 – Motor Control Centers

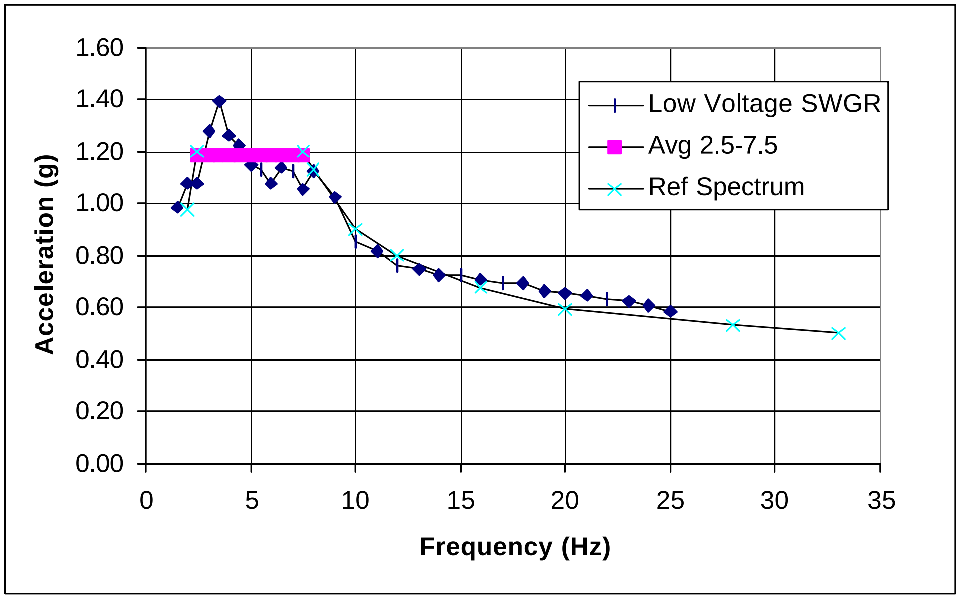

Figure D-22. Equipment Class 2 – Low Voltage Switchgear

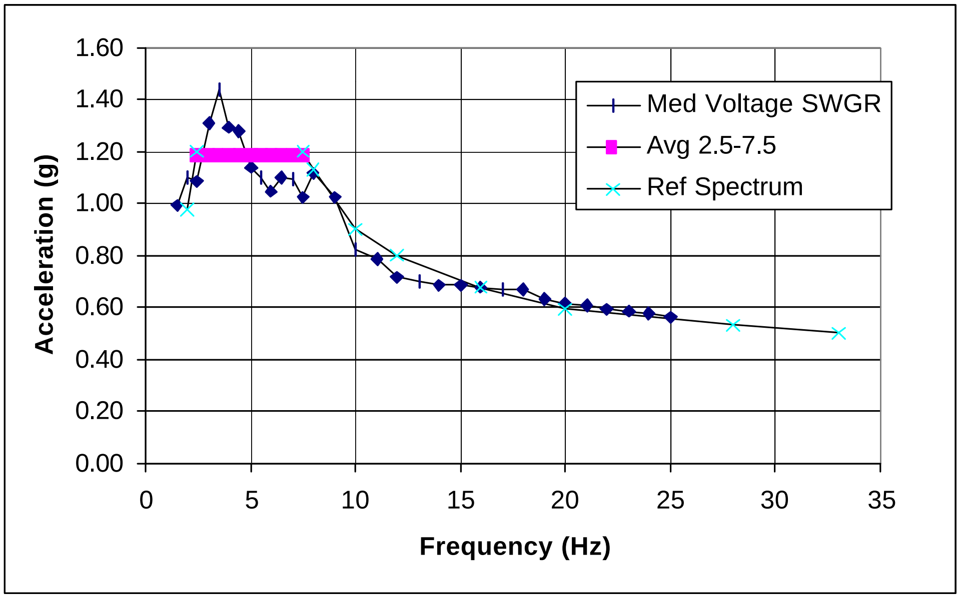

Figure D-23. Equipment Class 3 – Medium Voltage Switchgear

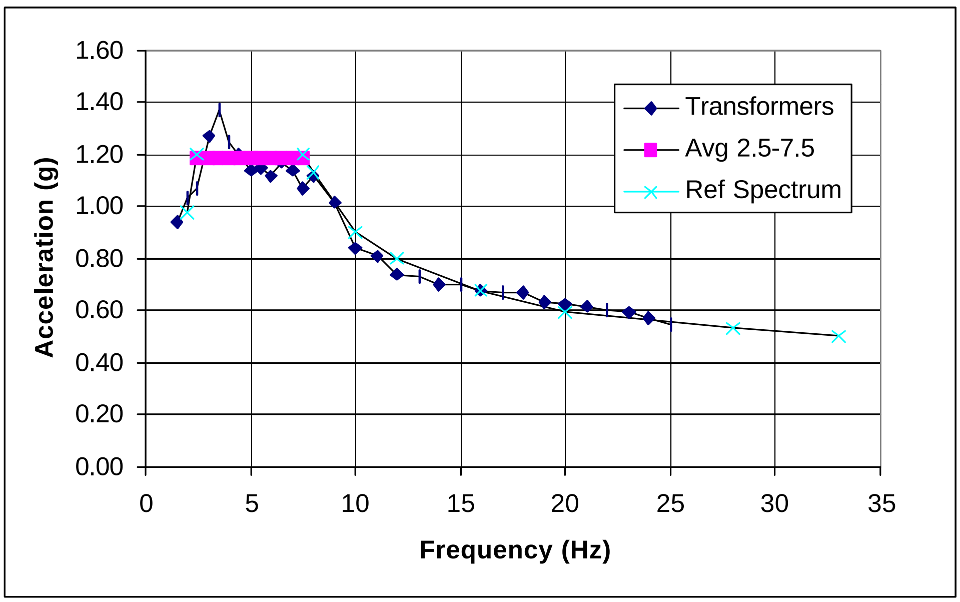

Figure D-24. Equipment Class 4 – Transformers

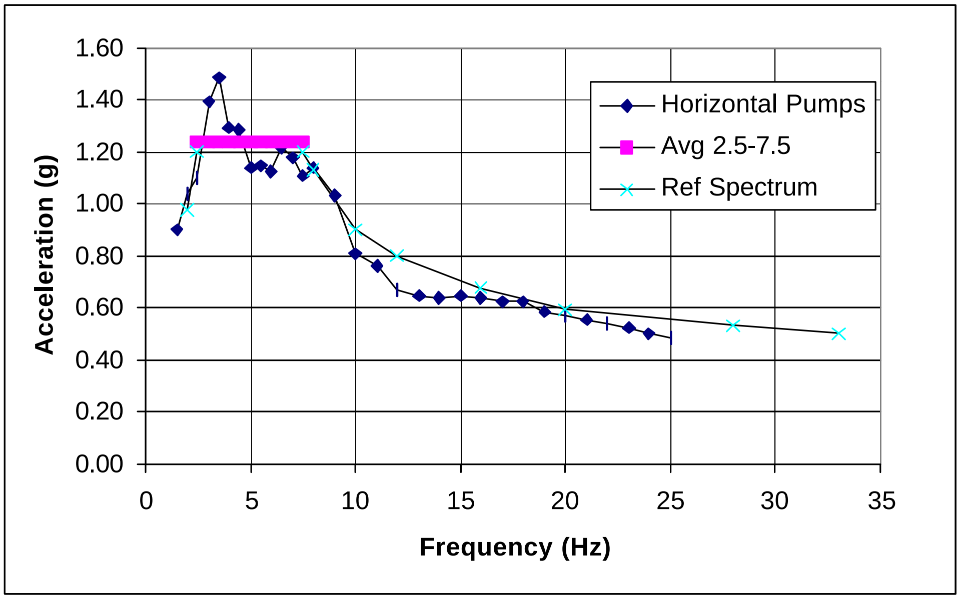

Figure D-25. Equipment Class 5 – Horizontal Pumps

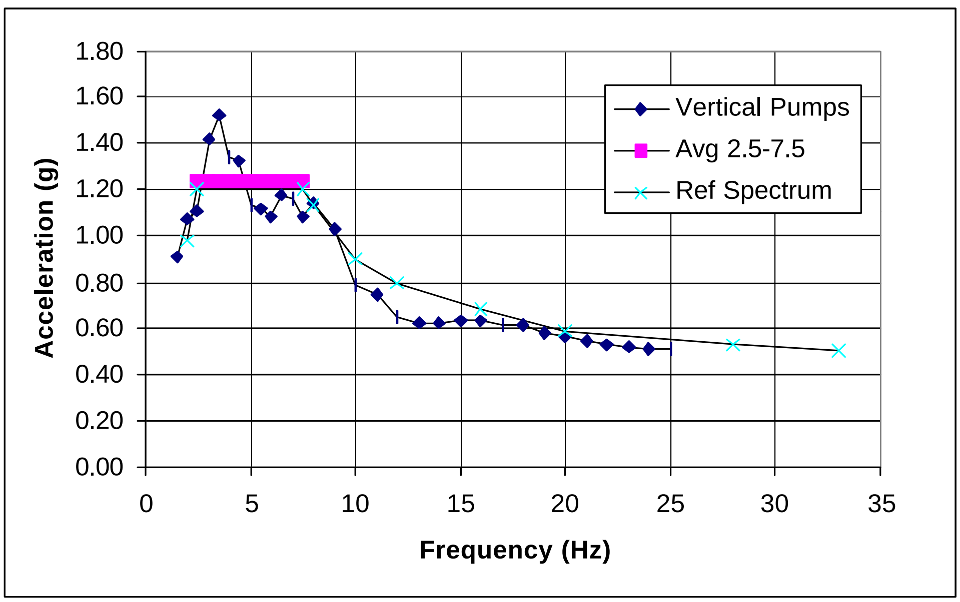

Figure D-26. Equipment Class 6 – Vertical Pumps

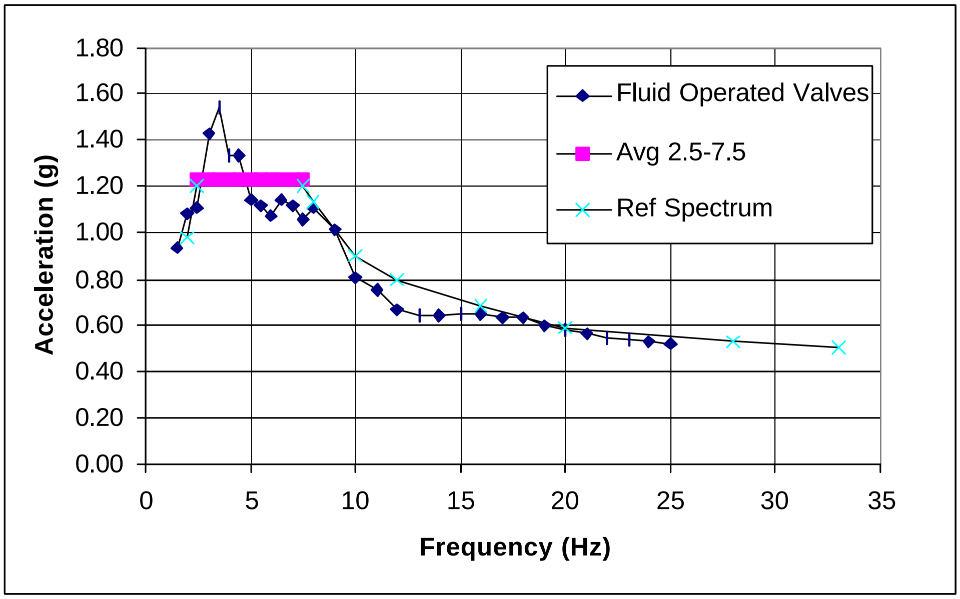

Figure D-27. Equipment Class 7 – Fluid Operated Valves

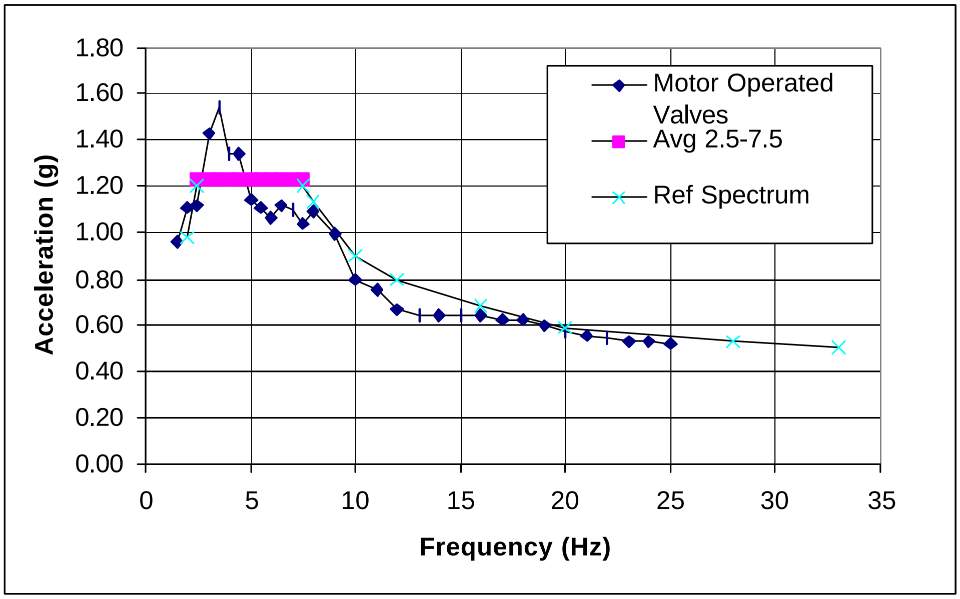

Figure D-28. Equipment Class 8 – Motor Operated Valves

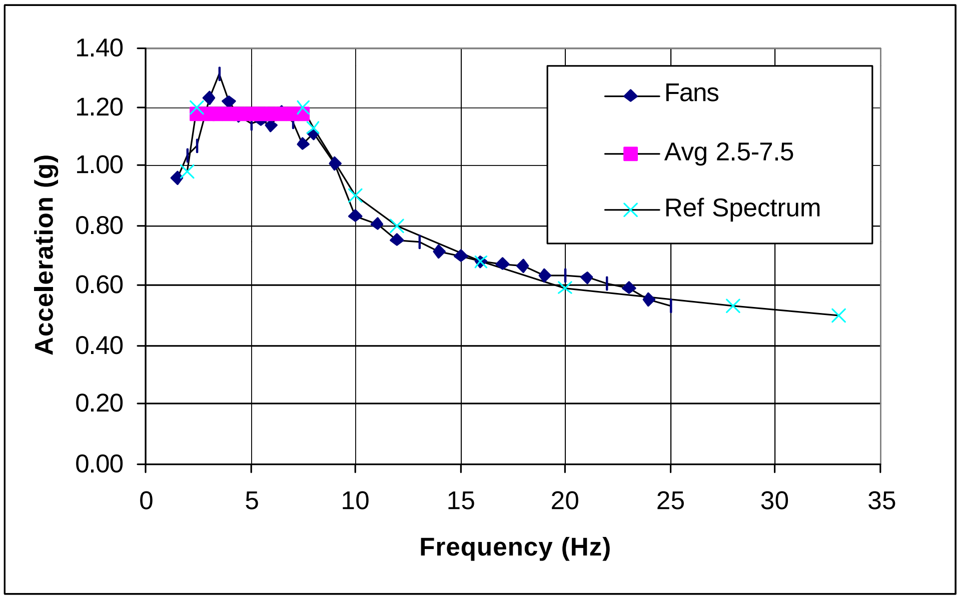

Figure D-29. Equipment Class 9 – Fans

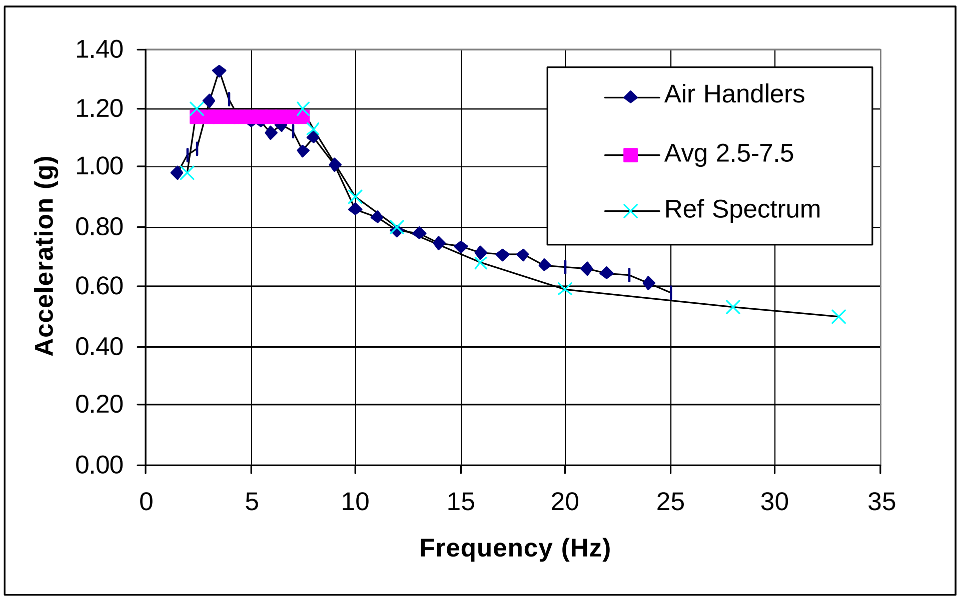

Figure D-30. Equipment Class 10 – Air Handlers

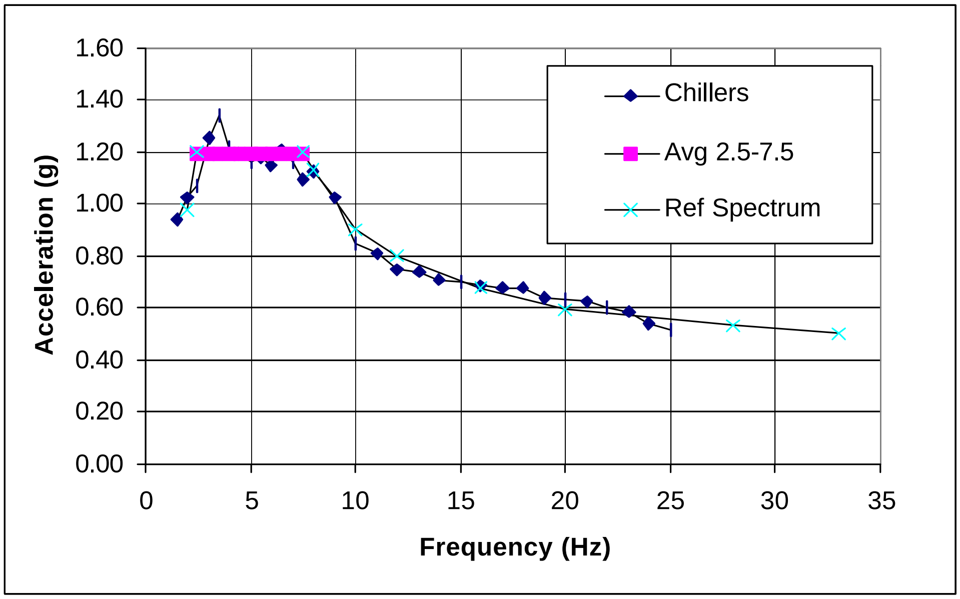

Figure D-31. Equipment Class 11 – Chillers

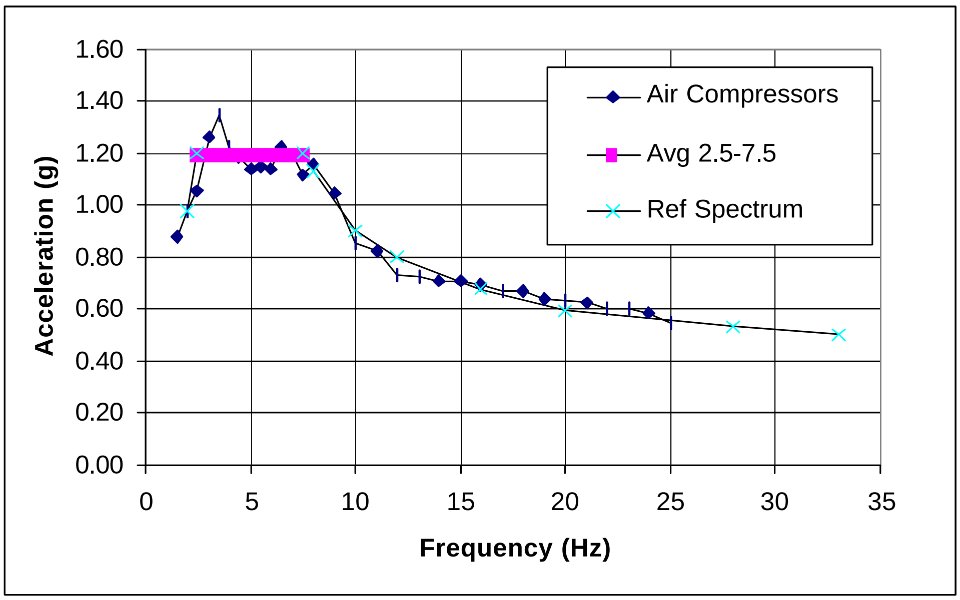

Figure D-32. Equipment Class 12 – Air Compressors

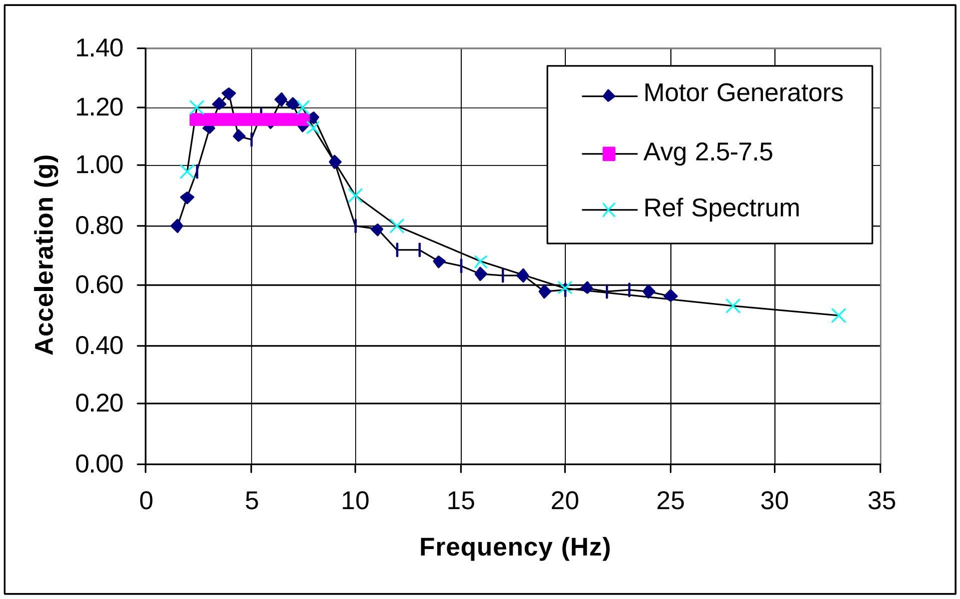

Figure D-33. Equipment Class 13 – Motor Generators

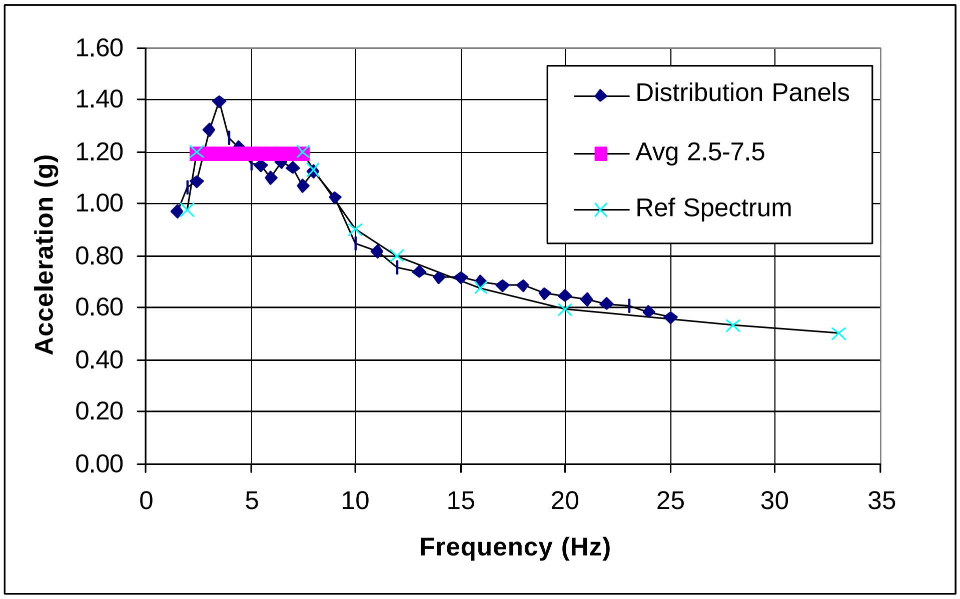

Figure D-34. Equipment Class 14 – Distribution Panels

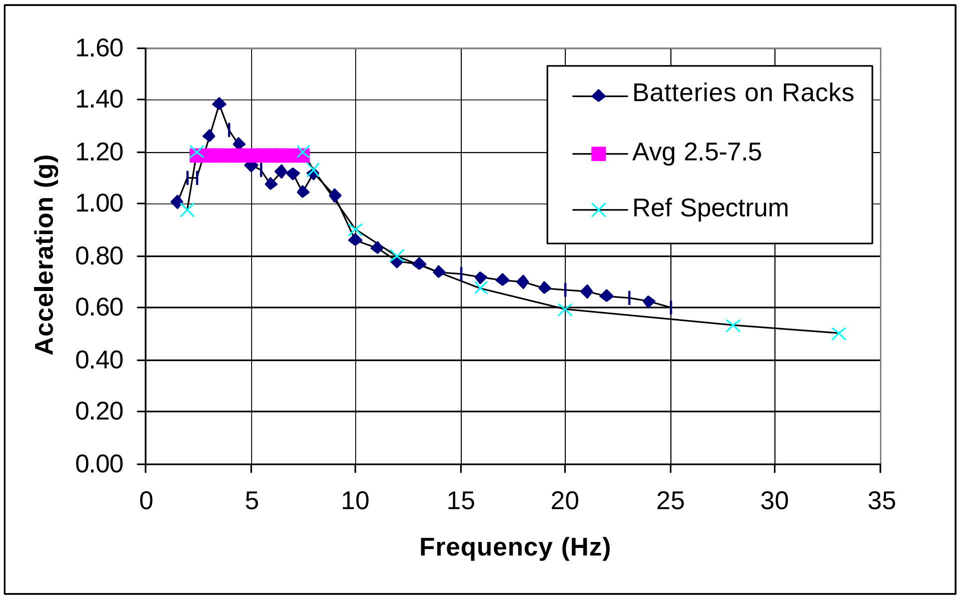

Figure D-35. Equipment Class 15 – Batteries on Racks

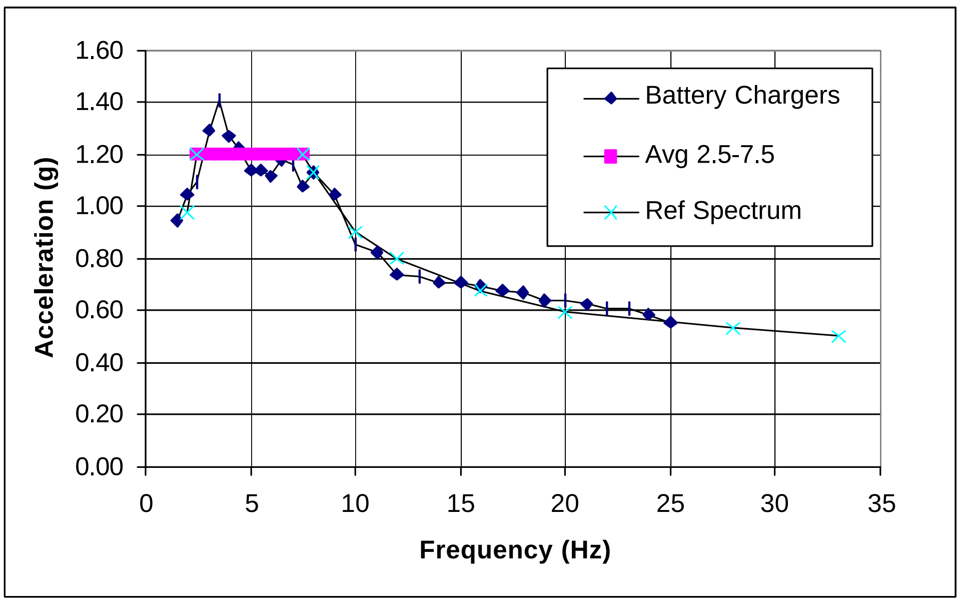

Figure D-36. Equipment Class 16 – Battery Chargers and Inverters

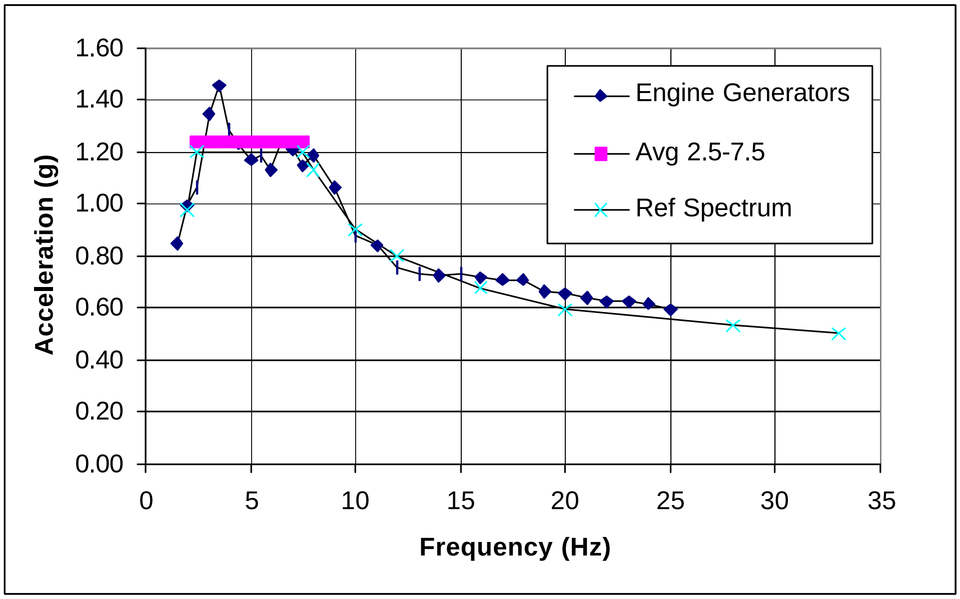

Figure D-37. Equipment Class 17 – Engine Generators

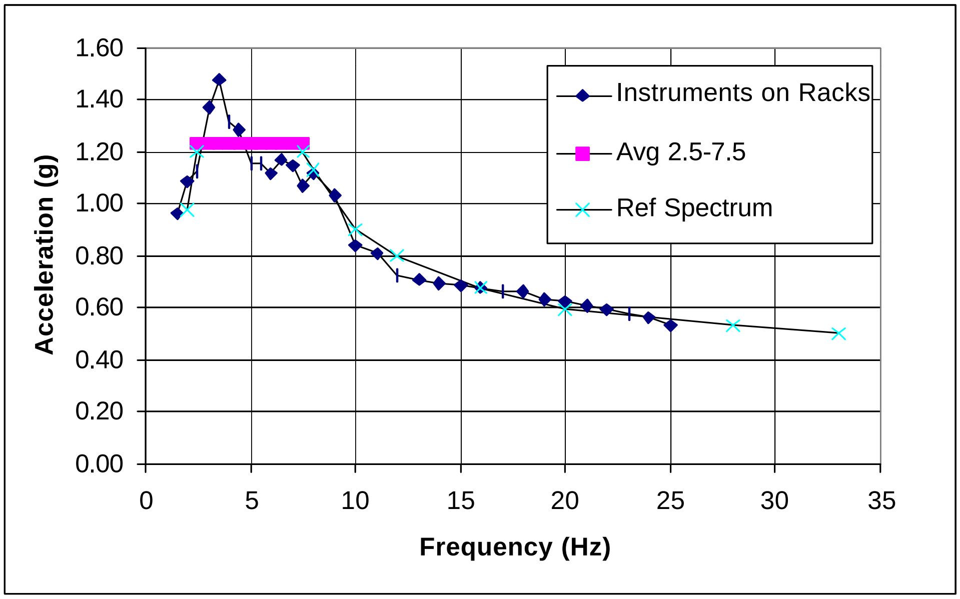

Figure D-38. Equipment Class 18 – Instruments on Racks

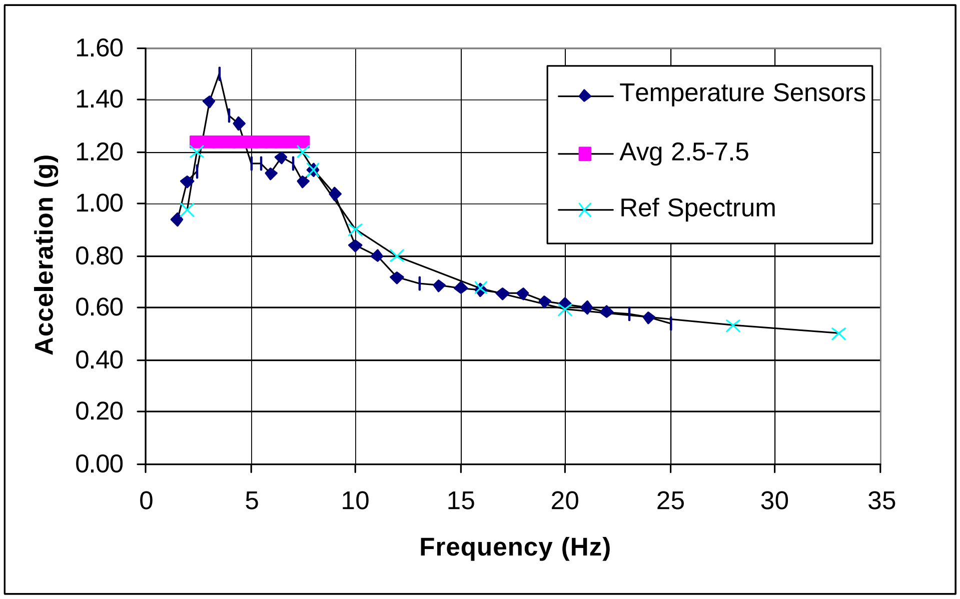

Figure D-39. Equipment Class 19 – Temperature Sensors

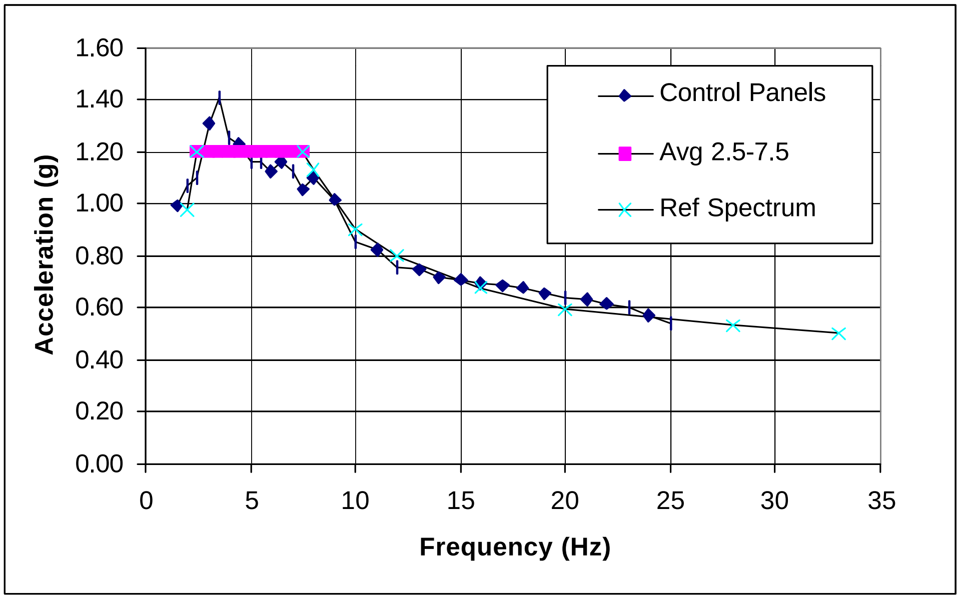

Figure D-40. Equipment Class 20 –
Control and Instrumentation Panels and Cabinets

Appendix E

Revised SSRAP Reference Spectrum Ground Motion Estimates

This appendix documents the development of earthquake response spectra for the two sets of sites referred to in the SSRAP Report as Sylmar Converter Station and Pleasant Valley Pumping Plant. SSRAP used the Pacoima Dam record scaled to 0.5*g* to represent the ground motion at the Sylmar Converter Station and the Rinaldi Receiving Station sites. They used the Pleasant Valley Pumping Plant switchyard record to represent several sites northeast of Coalinga. The ground motions at these sites have been re-estimated using current seismic engineering techniques.

The following sections document the development of earthquake response spectra for the following earthquake-facility pairs.

No.	Site	Earthquake
1	Rinaldi Receiving Station Mission Hills, California	1971 San Fernando
2	Sylmar Converter Station Sylmar, California	1971 San Fernando
3	Pleasant Valley Pump Plant Coalinga, California	1983 Coalinga
4	Coalinga Facility Sites Coalinga, California	1983 Coalinga
5	Rinaldi Receiving Station Mission Hills, California	1994 Northridge
6	Sylmar Converter Station Sylmar, California	1994 Northridge

E.1 Rinaldi Receiving Station, San Fernando Earthquake

The Rinaldi Receiving Station is located in the city of Mission Hills in the northern part of the San Fernando Valley, Los Angeles County, California. It is located just southwest of the upper edge of the deep rupture plane and just west of the shallow rupture plane of the February 9, 1971 moment magnitude (M_w) 6.7 San Fernando earthquake.

The San Fernando earthquake caused widespread destruction throughout the San Fernando Valley, San Gabriel Mountains, and West Los Angeles areas (Stover and Coffman, 1993). It created a zone of discontinuous surface faulting, named the San Fernando fault zone, that partly follows the boundary between the San Gabriel Mountains and the San Fernando-Tujunga Valleys and partly transects the northern salient of the San Fernando Valley. This latter zone of tectonic ruptures was associated with some of the heaviest property damage sustained in the region. Within the entire length of the surface faulting, which extended roughly east-west for about 15 km to within several kilometers of the Rinaldi site, the maximum vertical offset measured on a single scarp was about 1 meter, the maximum lateral offset was about 1 meter, and the maximum shortening (thrust component) was about 0.9 meters.

The most spectacular damage included the destruction of the Olive View and Veterans Administration Hospitals in the northern Sylmar area, the collapse of the 5/210 interchange just west of the San Fernando Valley Juvenile Hall and north of the Sylmar Converter Station, and the collapse of the 5/14 interchange further north in the San Gabriel Mountains. The earthquake was assigned a maximum intensity of XI on the Modified Mercalli Intensity (MMI) scale because of the considerable damage to the newly constructed Olive View Hospital. Shaking effects consistent with MMI IX to X were observed in San Fernando, Sylmar and the Van Norman Complex (Coffman and von Hake, 1973). The Rinaldi site is located just south of the Lower Van Norman Dam, which failed during the earthquake, in a region assigned intensity X at least in part due to this failure. However, the city centers of Mission Hills and Granada Hills, located a few kilometers south and east of the Rinaldi site, were assigned an intensity of VIII. It should be noted that according to new rules put in place by the U.S. Geological Survey at the time of the 1989 Loma Prieta earthquake, the maximum intensity assigned to any area would have been IX, not X or XI. Therefore, based on these new rules, the Rinaldi site appears to have damage consistent with intensity IX during the Northridge earthquake (see Sections E.5 and E.6) and intensity VIII to IX during the San Fernando earthquake.

E.1.1 Strong-Motion Recordings

There was no strong-motion recording at the Rinaldi Receiving Station. According to Coffman and von Hake (1973), the closest recordings to the Rinaldi site were located 10 kilometers northeast on the abutment of Pacoima Dam (USGS Station #279) and 7 kilometers south at the Holiday Inn in Van Nuys, then called 8244 Orion, Los Angeles (USGS Station #241). The Pacoima Dam recording, located on granitic rock on a steep ridge above the dam, is suspected of having significant topographic and dam-interaction effects. The Holiday Inn site is located on deep valley sediments in an area characterized as intensity VII, well below that at the Rinaldi site. According to Coffman and von Hake (1973), the Pacoima Dam recording had accelerations of 1.25*g*, 1.24*g* and 0.72*g* in the N76°W, S14°W and vertical directions, respectively. The Holiday Inn recording had accelerations of 0.27*g*, 0.14*g* and 0.17*g* in the North, West and vertical directions, respectively. Neither strong-motion recording is judged to be a reasonable representation of the ground motion at the Rinaldi site without making significant site-specific adjustments.

E.1.2 Earthquake Parameters

Allen and others (1973), Dillinger (1973) and Stover and Coffman (1993) report the following seismological parameters for the San Fernando earthquake:

Date:	February 9, 1971
Time:	14:01 Greenwich Mean Time (GMT)
Magnitude:	6.2 m_b, 6.5 M_S, 6.4 M_L
Epicenter:	34.412°N, 118.400°W
Depth:	8.4 km
Strike:	115° (southeast)
Dip:	40° to the northeast

Similar source parameters were obtained by many other seismologists (see Allen and others, 1973). According to these studies, the basic mechanism of initial faulting was that of a thrust fault striking about 110°, dipping about 50° to the northeast, and including a significant component of left-lateral slip in addition to the thrust component. This agrees remarkably well with the surface observations of faulting in the Sylmar-San Fernando area where Kamb and others (1971) reported the overall fault break to have a strike of 108° with northern dips averaging 42° and nearly equal amounts of north-south compression, vertical uplift (north-side up) and left-lateral slip. Hanks (1974) later revised the focal depth to 13 kilometers, deeper than that originally reported by Allen and others (1973).

There were many early attempts to derive a rupture model for the San Fernando earthquake with contradictory results. After much consideration, Heaton (1982), using long-period teleseismic body waves, strong ground motions and static vertical ground deformations, came to the conclusion that the earthquake may have been a double event that occurred on two separate, subparallel thrust faults. A similar rupture model was proposed by Hutchings (1994) based on a kinematic rupture model constrained by strong-motion recordings of the mainshock and two aftershocks and by seismological parameters determined by others. Both authors suggested that the earthquake originated on the Sierra Madre fault, where it terminated at a depth of 3 to 4 kilometers, then jumped to the San Fernando fault a few seconds later, where it ruptured to the surface. A summary of the rupture models for the two subevents determined by Hanks (1982) and Hutchings (1994) are given in the following table.

Parameter	Heaton (1982)		Hutchings (1994)	
	1st Event	2nd Event	1st Event	2nd Event
Depth to Top (km)	4	0	3	0
Strike	110° (SE)	105° (SE)	100° (SE)	100° (SE)
Dip	54° to NE	45° to NE	50° to NE	38° to NE
Rake	76°	90°	100°	100°
Focal Depth (km)	13	8	10	6
Rise Time (sec)	2.8	2.8	3.0	3.0
Radius (km)	8.4	7.3	7.0	7.0
Moment (dyne-cm)	0.7×10^{26}	1.0×10^{26}	0.5×10^{26}	1.0×10^{26}
Average Slip (m)	0.9	1.6	0.9	1.8
Stress Drop (bars)	53	108	64	127

The total seismic moment of 1.5–1.7×10^{26} dyne-cm is consistent with a moment magnitude of 6.7 based on the moment-magnitude relationship of Hanks and Kanamori (1979).

A comparison between the rupture models for the San Fernando and Northridge earthquakes shown in the following table indicates that these two earthquakes were remarkably similar. The rupture model for the Northridge earthquake is taken from Wald and others (1996). The rupture model for the San Fernando earthquake is an average of the two subevents from the Heaton (1982) and Hutchings (1994) models.

Parameter	1971 San Fernando	1994 Northridge
Depth to Top (km)	0–3.5	6
Strike	104° (SE)	122° (SE)
Dip	47° to NE	40° to SW
Rake	92°	101°
Focal Depth (km)	12	19
Radius (km)	10.5	9.7
Moment (dyne-cm)	1.6×10^{26}	1.3×10^{26}
Average Slip (m)	1.3	1.4
Avg. Stress Drop (bars)	88	74

The following distances from the Rinaldi site to the rupture planes of the San Fernando earthquake were calculated from the Hutchings (1994) rupture model and the epicentral coordinates determined by Allen and others (1973):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
Rinaldi R.S. San Fernando	15.1	205	4.8	8.1
Rinaldi R.S. Northridge	9.8	36	0.0	7.4

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture planes of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of these rupture planes, and Azimuth is the angle between the epicenter and the site measured clockwise from north. Similar parameters for the Northridge earthquake are shown for comparison. Note the similarity in the Rupture Distances for the two earthquakes.

The Rinaldi site was located just southwest of the deep rupture plane and, therefore, was subject to source directivity from this subevent. According to Somerville and others (1997), the degree to which a site is subjected to source directivity during a thrust earthquake can be quantified in terms of two parameters, ϕ, the angle between the fault rupture plane and the ray path to the site and Y, the fraction of the fault that ruptures in an up-dip direction towards the site. Based on the deep rupture plane defined by Hutchings (1994), these two parameters have values of $\phi = 16°$ and Y = 0.86 for the Rinaldi Receiving Station. These same values for the Northridge earthquake were $\phi = 21°$ and Y = 0.85. Since magnitude is an important parameter in determining rupture directivity effects, the equivalent magnitude for purposes of calculating these effects was assumed to be that corresponding to the deep rupture event. Based on an average seismic moment of 0.6×10^{26} dyne-cm for this subevent, its moment magnitude was estimated to be 6.5 based on the moment-magnitude relationship of Hanks and Kanamori (1979).

E.1.3 Local Site Conditions

As reported by Bardet and Davis (1996), cone penetration tests at the Rinaldi Receiving Station performed by the Earth Technology Corporation (1994) indicate that the site is underlain by silty sands and sandy silts with lenses of clay and gravel. The upper 7 meters have a relative density ranging from 20% to 60% and a standard penetration test (SPT) blow count between 3 and 20, with values above 40 in the gravel layers. These Holocene alluvial deposits, derived from San Fernando Creek, have shear-wave velocities ranging from 200 to 300 m/sec. The Plio-Pleistocene Pico Formation is encountered at a depth of 10 meters and has a shear-wave velocity approximately equal to 1100 m/sec. Although there was some ground cracking observed at the site, which has a water table below 10 meters, there was no direct surficial evidence of liquefaction, such as sand boils.

E.1.4 Recommended Response Spectrum

Because of the similarities in the seismological characteristics of the San Fernando and Northridge earthquakes, it was judged that the Rinaldi freefield recording from the Northridge earthquake could serve as a reasonable estimate of the expected response spectrum for the Rinaldi Receiving Station from the San Fernando earthquake after making some adjustments. The 5%-damped acceleration response spectra from the two horizontal components of this recording are shown in Figure E-19. These adjustments took into account differences in the source-to-site distances as well as the rupture directivity and hanging-wall/footwall effects between the two earthquakes.

The adjustment for distance was made using a weighted average of the ground motions calculated from the empirical attenuation relationships of Abrahamson and Silva (1997), Boore and others (1997), Campbell (1997), and Sadigh and others (1997), assuming a generic soil site with an average shear-wave velocity in the top 30 meters of approximately 310 m/s (Boore and Joyner, 1997). The exact shear-wave velocity used for the calculation is not critical, since the adjustment is based on the relative difference in the calculated ground-motion values for the different distance measures from the two earthquakes. Rupture directivity effects were calculated based on the empirical model of Somerville and others (1997) using the source-to-site distance and magnitude associated with the deep subevent. Hanging-wall/footwall effects were calculated using a weighted average of the empirical models proposed by Abrahamson and Silva (1997) and Somerville and Abrahamson (1995, 2000), where 50% weight was given to the Somerville and Abrahamson (1995) model because of the similarity in the other two models.

The spectra from the adjusted and original Rinaldi freefield recordings are compared in Figure E-1. The adjusted spectrum is uniformly lower by 20% at high frequencies because of the difference in hanging-wall/footwall effects. It is uniformly higher by a few percent at frequencies below 0.4 Hz because of the compensating effects of rupture directivity. The hanging-wall/footwall effects are less because the site is located on the footwall of the deep subevent and off the edge of the fault for the shallow subevent, whereas the site was located on the hanging wall of the Northridge earthquake. The rupture directivity effects are greater, even though the equivalent magnitude is smaller, because the site is located at a smaller angle with respect to the deep rupture plane than it was during the Northridge earthquake. The recommended 5%-damped acceleration response spectrum is shown in Figure E-2.

E.2 Sylmar Converter Station, San Fernando

The Sylmar Converter Station is located in the city of Sylmar in the northern part of the San Fernando Valley, Los Angeles County, California. It is located just southwest of the upper edge of the deep rupture plane and just west of the shallow rupture plane of the February 9, 1971 moment magnitude (M_w) 6.7 San Fernando earthquake.

The San Fernando earthquake caused widespread destruction throughout the San Fernando Valley, San Gabriel Mountains, and West Los Angeles areas (Stover and Coffman, 1993). It created a zone of discontinuous surface faulting, named the San Fernando fault zone, that partly follows the boundary between the San Gabriel Mountains and the San Fernando-Tujunga Valleys and partly transects the northern salient of the San Fernando Valley. This latter zone of tectonic ruptures was associated with some of the heaviest property damage sustained in the region. Within the entire length of the surface faulting, which extended roughly east-west for about 15 km to within several kilometers of the Rinaldi site, the maximum vertical offset measured on a single scarp was about 1 meter, the maximum lateral offset was about 1 meter, and the maximum shortening (thrust component) was about 0.9 meters.

The most spectacular damage included the destruction of the Olive View and Veterans Administration Hospitals in the northern Sylmar area, the collapse of the 5/210 interchange just west of the San Fernando Valley Juvenile Hall and north of the Sylmar Converter Station, and the collapse of the 5/14 interchange further north in the San Gabriel Mountains. The earthquake was assigned a maximum intensity of XI on the Modified Mercalli Intensity (MMI) scale because of the considerable damage to the newly constructed Olive View Hospital. Shaking effects consistent with MMI IX to X were observed in San Fernando, Sylmar and the Van Norman Complex (Coffman and von Hake, 1973). The Sylmar site is located just east of the Upper Van Norman Dam in a region assigned intensity X. It should be noted that according to new rules put in place by the U.S. Geological Survey at the time of the 1989 Loma Prieta earthquake, the maximum intensity assigned to any area would have been IX, not X or XI. Therefore, based on these new rules, the Sylmar site appears to have damage consistent with intensity IX during both the Northridge earthquake (see Sections E.5 and E.6) and San Fernando earthquake.

E.2.1 Strong-Motion Recordings

There was no strong-motion recording at the Sylmar Converter Station. According to Coffman and von Hake (1973), the closest recordings to the Sylmar site were located 8 kilometers northeast on the abutment of Pacoima Dam (USGS Station #279) and 10 kilometers south at the Holiday Inn in Van Nuys, then called 8244 Orion, Los Angeles (USGS Station #241). The Pacoima Dam recording, located on granitic rock on a steep ridge above the dam, is suspected of having significant topographic and dam-interaction effects. The Holiday Inn site is located on deep valley sediments in an area characterized as intensity VII, well below that at the Rinaldi site. According to Coffman and von Hake (1973), the Pacoima Dam recording had accelerations of 1.25*g*, 1.24*g* and 0.72*g* in the N76°W, S14°W and vertical directions, respectively. The Holiday Inn recording had accelerations of 0.27*g*, 0.14*g* and 0.17*g* in the North, West and vertical directions, respectively. Neither strong-motion recording is judged to be a reasonable representation of the ground motion at the Sylmar site without making significant site-specific adjustments.

E.2.2 Earthquake Parameters

Allen and others (1973), Dillinger (1973) and Stover and Coffman (1993) report the following seismological parameters for the San Fernando earthquake:

Date:	February 9, 1971
Time:	14:01 Greenwich Mean Time (GMT)
Magnitude:	6.2 m_b, 6.5 M_S, 6.4 M_L
Epicenter:	34.412°N, 118.400°W
Depth:	8.4 km
Strike:	115° (southeast)
Dip:	40° to the northeast

Similar source parameters were obtained by many other seismologists (see Allen and others, 1973). According to these studies, the basic mechanism of initial faulting was that of a thrust fault striking about 110°, dipping about 50° to the northeast, and including a significant component of left-lateral slip in addition to the thrust component. This agrees remarkably well with the surface observations of faulting in the Sylmar-San Fernando area where Kamb and others (1971) reported the overall fault break to have a strike of 108° with northern dips averaging 42° and nearly equal amounts of north-south compression, vertical uplift (north-side up) and left-lateral slip. Hanks (1974) later revised the focal depth to 13 kilometers, deeper than that originally reported by Allen and others (1973).

There were many early attempts to derive a rupture model for the San Fernando earthquake with contradictory results. After much consideration, Heaton (1982), using long-period teleseismic body waves, strong ground motions and static vertical ground deformations, came to the conclusion that the earthquake may have been a double event that occurred on two separate, subparallel thrust faults. A similar rupture model was proposed by Hutchings (1994) based on a kinematic rupture model constrained by strong-motion recordings of the mainshock and two aftershocks and by seismological parameters determined by others. Both authors suggested that the earthquake originated on the Sierra Madre fault, where it terminated at a depth of 3 to 4 kilometers, then jumped to the San Fernando fault a few seconds later, where it ruptured to the surface. A summary of the rupture models for the two subevents determined by Hanks (1982) and Hutchings (1994) are given in the following table.

	Heaton (1982)		**Hutchings (1994)**	
Parameter	**1st Event**	**2nd Event**	**1st Event**	**2nd Event**
Depth to Top (km)	4	0	3	0
Strike	110° (SE)	105° (SE)	100° (SE)	100° (SE)
Dip	54° to NE	45° to NE	50° to NE	38° to NE

Parameter	Heaton (1982)		Hutchings (1994)	
	1st Event	2nd Event	1st Event	2nd Event
Rake	76°	90°	100°	100°
Focal Depth (km)	13	8	10	6
Rise Time (sec)	2.8	2.8	3.0	3.0
Radius (km)	8.4	7.3	7.0	7.0
Moment (dyne-cm)	0.7 x 10^{26}	1.0 x 10^{26}	0.5 x 10^{26}	1.0 x 10^{26}
Average Slip (m)	0.9	1.6	0.9	1.8
Stress Drop (bars)	53	108	64	127

The total seismic moment of 1.5–1.7 $\times 10^{26}$ dyne-cm is consistent with a moment magnitude of 6.7 based on the moment-magnitude relationship of Hanks and Kanamori (1979).

A comparison between the rupture models for the San Fernando and Northridge earthquakes shown in the following table indicates that these two earthquakes were remarkably similar. The rupture model for the Northridge earthquake is taken from Wald and others (1996). The rupture model for the San Fernando earthquake is an average of the two subevents from the Heaton (1982) and Hutchings (1994) models.

Parameter	1971 San Fernando	1994 Northridge
Depth to Top (km)	0–3.5	6
Strike	104° (SE)	122° (SE)
Dip	47° to NE	40° to SW
Rake	92°	101°
Focal Depth (km)	12	19
Radius (km)	10.5	9.7
Moment (dyne-cm)	1.6 x 10^{26}	1.3 x 10^{26}
Average Slip (m)	1.3	1.4
Avg. Stress Drop (bars)	88	74

The following distances from the Sylmar site to the rupture planes of the San Fernando earthquake were calculated from the Hutchings (1994) rupture model and the epicentral coordinates determined by Allen and others (1973):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
Sylmar C.S. San Fernando	12.7	216	4.4	6.1
Sylmar C.S. Northridge	12.3	23	0.0	6.3

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture planes of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of these rupture planes, and Azimuth is the angle between the epicenter and the site measured clockwise from north. Similar parameters for the Northridge earthquake are shown for comparison. Note the similarity in the Rupture Distances for the two earthquakes.

The Sylmar site was located just southwest of the deep rupture plane and, therefore, was subject to source directivity from this subevent. According to Somerville and others (1997), the degree to which a site is subjected to source directivity during a thrust earthquake can be quantified in terms of two parameters, ϕ, the angle between the fault rupture plane and the ray path to the site and Y, the fraction of the fault that ruptures in an up-dip direction towards the site. Based on the deep rupture plane defined by Hutchings (1994), these two parameters have values of $\phi = 10°$ and Y = 0.86 for the Sylmar Converter Station. These same values for the Northridge earthquake were $\phi = 16°$ and Y = 0.85. Since magnitude is an important parameter in determining rupture directivity effects, the equivalent magnitude for purposes of calculating these effects was assumed to be that corresponding to the deep rupture event. Based on an average seismic moment of 0.6×10^{26} dyne-cm for this subevent, its moment magnitude was estimated to be 6.5 based on the moment-magnitude relationship of Hanks and Kanamori (1979).

E.2.3 Local Site Conditions

As reported by Bardet and Davis (1996), the Sylmar Converter Station is founded over the Grapevine Creek channel, on a Holocene alluvial deposit approximately 22 meters thick within the Mission Hills syncline. Soil deposits are classified as silty sand in the upper 3 to 4 meters, clayey sand to clayey silt from 4 to 5 meters, and silty sand to sandy silt at greater depths. Fallgren and Smith (1971), using seismic refraction techniques, measured a compressional-wave (P-wave) velocity of 305 m/sec above a depth of 4 meters and 1661 m/sec below this depth. According to Bardet and Davis (1996), these values correspond to shear-wave velocities of 120 to 150 m/sec and 275 m/sec, respectively, assuming that the larger P-wave velocities were measured below the water table.

Just across Interstate Highway 5 at the eastern extension of the Sylmar Converter Station, Earthquake Technology Corporation (1984), using downhole techniques, measured a shear-wave velocity of 195 m/sec above a depth of 4 meters and 277 m/sec to a depth of 15 meters in a similar alluvial deposit. They measured a shear-wave velocity of 436 m/sec in the underlying Middle-Pleistocene Saugus Formation to a depth of 43 meters. They measured P-wave velocities in this same boring of 536, 1737 and 1585 m/sec at depths of 0 to 4, 4 to 15, and 15 to 43 meters, respectively. The high P-wave velocities and low shear-wave velocities below the 4-meter depth suggest that the water table occurs at this depth, consistent with the P-wave refraction measurements to the west of I-5 at the Sylmar Converter Station.

Bardet and Davis (1996) suggest that the relative absence of high frequencies in the Sylmar Converter Station recording during the Northridge earthquake can be attributed to the nonlinear response of the alluvium, especially to the liquefaction and lateral spreading of the underlying soils, which was independently observed in this region by Davis and Bardet (1995). However, it should be noted that the liquefaction and lateral spreading referred to by Bardet and Davis was observed at the Los Angeles Reservoir and the San Fernando Power Plant Tailrace located 1000 meters south and 500 meters northwest of the Sylmar accelerograph site, respectively. Furthermore, a study of ground failure conducted by Stewart and others (1996) failed to mention any ground failure at the Sylmar Converter Station, although they documented such failure at the Lower and Upper San Fernando Dams, the Joseph Jensen Filtration Plant, the San Fernando Valley Juvenile Hall, and the City of San Fernando.

E.2.4 Recommended Response Spectrum

Because of the similarities in the seismological characteristics of the San Fernando and Northridge earthquakes, it was judged that the Sylmar freefield recording from the Northridge earthquake could serve as a reasonable estimate of the expected response spectrum for the Sylmar Converter Station from the San Fernando earthquake after making some adjustments. The 5%-damped response spectra from the two horizontal components of this recording are shown in Figure E-21. These adjustments took into account differences in the source-to-site distances as well as the rupture directivity and hanging-wall/footwall effects between the two earthquakes.

The adjustment for distance was made using a weighted average of the ground motions calculated from the empirical attenuation relationships of Abrahamson and Silva (1997), Boore and others (1997), Campbell (1997), and Sadigh and others (1997), assuming a generic soil site with an average shear-wave velocity in the top 30 meters of approximately 310 m/s (Boore and Joyner, 1997). The exact shear-wave velocity used for the calculation is not critical, since the adjustment is based on the relative difference in the calculated ground-motion values for the different distance measures from the two earthquakes. Rupture directivity effects were calculated based on the empirical model of Somerville and others (1997) using the source-to-site distance and magnitude associated with the deep subevent. Hanging-wall/footwall effects were calculated using a weighted average of the empirical models proposed by Abrahamson and Silva (1997) and Somerville and Abrahamson (1995, 2000), where 50% weight was given to the Somerville and Abrahamson (1995) model because of the similarity in the other two models.

The spectra from the adjusted and original Sylmar freefield recordings are compared in Figure E-3. The adjusted spectrum is uniformly lower by 18% at high frequencies because of the difference in hanging-wall/footwall effects. It is uniformly lower by only a few percent at frequencies below 0.25 Hz because of the compensating effects of rupture directivity. The hanging-wall/footwall effects are less because the site is located on the footwall of the deep subevent and off the edge of the fault for the shallow subevent, whereas the site was located on the hanging wall of the Northridge earthquake. The rupture directivity effects are nearly the same, even though the equivalent magnitude is smaller, because the site is located at a smaller angle with respect to the deep rupture plane than it was during the Northridge earthquake. The recommended 5%-damped acceleration response spectrum is shown in Figure E-4.

E.3 Pleasant Valley Pumping Plant (Coalinga)

The Pleasant Valley Pumping Plant (PVPP) is located 19 kilometers northeast of the city of Coalinga, Fresno County, California. It is located 8 kilometers northeast of the rupture plane of the May 2, 1983 moment-magnitude (M_w) 6.4 Coalinga earthquake. The Coalinga earthquake caused widespread damage in the city of Coalinga and the surrounding oil fields (Stover, 1987). It was assigned a maximum intensity of VIII on the Modified Mercalli Intensity (MMI) scale. Shaking effects consistent with MMI VIII were restricted to Coalinga and the surrounding oil fields, both located within Pleasant Valley and Anticline Ridge, which separates Pleasant Valley from the San Joaquin Valley to the east. The PVPP site is located just east of Anticline Ridge in the San Joaquin Valley at the margin of the intensity VIII region. The town of Avenal located 25 kilometers southeast of Coalinga within Pleasant Valley was assigned an intensity of VII. The towns of Cantua Creek located 22 kilometers northwest of the PVPP site, Five Points located 20 kilometers northeast of the PVPP site and Huron located 18 kilometers southeast of the PVPP site were assigned intensities of VII, VI and VI, respectively. The largest aftershock occurred on July 22, 1983 and was located 17 kilometers southwest of the PVPP site and 12 kilometers northwest of Coalinga. It had a local magnitude of 6.0 and was assigned a maximum intensity of VI.

E.3.1 Strong-Motion Recordings

There were two strong-motion recordings obtained at the PVPP site (USGS Station #1162) during the mainshock. One was on the basement floor of the plant approximately 17 feet below grade. The other was at the switchyard 280 feet southwest of the plant at the top of a slope about 70 feet above the plant grade. The discharge pipeline passes within 120 feet of the switchyard instrument. In addition to recordings in the basement and switchyard, an additional freefield recording was obtained at the PVPP site during the July 22 aftershock. This instrument was located away from the slope and discharge pipeline so as not to be influenced by these factors. Maley and others (1984) give a detailed description of the mainshock recordings and Silverstein (1985) give a detailed description of the aftershock recordings. A summary of this information is provided in the following table.

Parameter	May 2, 1983 Mainshock		July 22, 1983 Aftershock		
	Basement	Switchyard	Basement	Switchyard	Freefield
Structure	1-story bldg.	Inst. shelter	1-story bldg.	Inst. shelter	None
Location	Basement*	Ground level	Basement	Ground level	Ground level
Latitude	36.308° N	36.308° N	36.308° N	36.308° N	36.308° N
Longitude	120.249°W	120.249°W	120.249°W	120.249°W	120.249°W
PGA (g)	0.31 (045) 0.27 (135) 0.22 (Up)	0.60 (045) 0.52 (135) 0.38 (Up)	0.44 (045) 0.14 (135) 0.07 (Up)	0.59 (045) 0.33 (135) 0.30 (Up)	0.43 (360) 0.24 (270) 0.13 (Up)

*17 feet below grade

The reduced values of peak acceleration in the basement are consistent with the effects of embedment and soil-structure interaction. The reduced values of peak acceleration in the freefield as compared to the switchyard in the aftershock is consistent with the belief that the switchyard records had possibly been affected by topography and the close proximity of the discharge pipeline. The 5%-damped acceleration response spectra for the two horizontal components of the mainshock recordings (Maley and others, 1984) are shown in Figures E-5 and E-6 and the acceleration spectra for the two horizontal components of the three aftershock recordings are shown in Figures E-7 to E-9.

E.3.2 Earthquake Parameters

Eaton (1990) and Stover and Coffman (1993) report the following seismological parameters for the May 2 Coalinga mainshock and the July 22 aftershock.

Mainshock:

Date:	May 2, 1983
Time:	23:42:38 Greenwich Mean Time (GMT)
Magnitude:	6.2 m_b, 6.5 M_S, 6.7 M_L, 6.2 M_W
Epicenter:	36.233°N, 120.310°W
Depth:	10.0 km
Strike:	127° (southeast)
Dip:	23° to the southwest
Rake:	90° (thrust)

Aftershock:

Date:	July 22, 1983
Time:	02:39:54 Greenwich Mean Time (GMT)
Magnitude:	6.0 m_b, 5.7 M_S, 6.0 M_L, 5.9 M_W
Epicenter:	36.241°N, 120.409°W
Depth:	7.4 km
Strike:	355° (north)
Dip:	38° to the east
Rake:	102° (nearly pure thrust)

There has been considerable controversy as to whether the focal plane indicated above or the conjugate focal plane given by the same strike but dipping 67° to the northeast is the correct rupture plane. This controversy has been exasperated by the complex nature of the aftershock sequence. However, Eaton (1990) prefers the shallow southwest-dipping plane because it coincides with the most pervasive surface identified by the larger aftershocks. Eberhart-Phillips and Reasenberg (1990) propose two fault planes based solely on the trends in the aftershock sequence. Both of these planes have a strike of 139° with one dipping 75° to the northeast and the other dipping 50° to the southwest. Like Eaton, they prefer the shallow southwest-dipping plane, however its dip is substantially steeper than that determined by Eaton from first-motion data.

Using teleseismic broadband body waves, Choy (1990) found that the best fit to the displacements that could be obtained assuming a single rupture event had a focal mechanism with a strike of 300°, a dip of 65° to the northeast and a rake of 85° (almost pure thrust), representing almost exactly the second focal plane of Eaton. Likewise, Sipkin and Needham (1990) used both long- and short-period teleseismic first motions and kinematic source parameters determined by time-dependent moment-tensor inversion to derive similar mechanisms. The strike, dip and rake of the best first-motion solution are 307°, 70° to the northeast and 90° (thrust). This is very close to the strike, dip and rake of the best moment-tensor solution, which are 303°, 72° to the northeast and 97° (almost pure thrust). However, like the others who prefer the northeast-dipping plane, their solutions are based on a single fault plane.

Wentworth and Zoback (1990) believe that the geologic structure of the Coalinga area is the key to selecting the correct focal plane. The geologic structure of the region determined from shallow geophysical data identifies northeast-directed thrusts, which they call the Coalinga thrust zone, that terminate beneath the Coalinga anticline at a depth of about 10 kilometers in a series of upward-splaying reverse faults. The mainshock appears to have occurred at the base of a reverse-fault splay beneath the upper tier of the fold and produced a focal mechanism with a gently southwest-dipping focal plane that strikes parallel to the fold axis. Rupture propagated bilaterally back down the thrust and up the reverse fault. This complex mechanism is consistent with the coseismic elevation changes, the shallow southwest-dipping focal mechanism, the complex aftershock sequence and the structural geology. Stein (1985), using this same coseismic elevation data, found that the two-plane thrust model fit this deformation data equally well as a single fault plane dipping steeply to the northeast. However, he found that a single steeply northeast-dipping plane was superior to a single shallow southwest-dipping plane, possibly explaining why seismologists found that the northeast-dipping plane was the best solution of the considered single fault-plane solutions. Had these investigators used multiple southwest-dipping planes, they might have come to the opposite conclusion.

Based on the coseismic elevation changes, Wentworth and Zoback (1990) determined the following two-plane rupture model for the earthquake from dislocation theory:

Width (down-dip):	7 km (steep), 4 km (shallow)
Length:	16 km (both)
Depth to Top:	3.4 km (steep), 9.1 km (shallow)
Strike:	133° (southeast; both)
Dip:	55° southwest (steep), 10° southwest (shallow)
Rake:	90° (thrust; both)
Average Slip:	1.2 m (steep), 2.0 m (shallow)
Seismic Moment:	4.3×10^{25} dyne-cm (both)

The total seismic moment of 8.6×10^{25} dyne-cm is consistent with a moment magnitude of 6.6 based on the moment-magnitude relationship of Hanks and Kanamori (1979). Stein (1985) obtained a similar solution for the two fault-plane model and estimated a moment magnitude of 6.5. Seismological determinations of seismic moment referenced by Stein (1985) give moment magnitudes that range from 6.4 to 6.5. Choy (1990), using long- and short-period broadband teleseismic body waves, interpreted the earthquake as having two subevents with a total seismic moment corresponding to a moment magnitude of 6.3. The moment tensor solution of Sipkin and Needham (1990) gave a moment magnitude of 6.4. A moment magnitude of 6.4 is used in this study.

The following distances from the PVPP recording sites to the rupture planes of the Coalinga earthquake were calculated from the above rupture model and the epicentral coordinates determined by Eaton (1990):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
PVPP	10.0	33	7.7	8.4

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of this rupture plane, and Azimuth is the angle between the epicenter and the site measured clockwise from north.

E.3.3 Local Site Conditions

According to a surficial geologic map compiled by Wentworth and Zoback (1990), the PVPP site is located on Holocene alluvium. Beneath this alluvium lies a continuous sequence of Quaternary, Tertiary, Cretaceous and Jurassic sediments (Bartow, 1990). These sediments, which are over 5 kilometers thick, lie on top of the Cretaceous and Jurassic Franciscan assemblage. Crystalline basement lies at a depth of about 13 kilometers (Wentworth and Zoback, 1990).

Based on the above information, the site can be classified as Soil Profile Type S_D (Stiff Soil Profile) based on the site classifications given in the 1997 *Uniform Building Code* (UBC) (ICBO, 1997) and the correlation between geologic units and shear-wave velocity in California developed by Wills and Silva (1998). This Soil Profile Type has a shear-wave velocity in the top 30 meters that ranges between 180 and 360 m/s.

E.3.4 Recommended Response Spectra

Neither the basement recording nor the switchyard recording is judged to be a reasonable representation of the freefield ground motion at the PVPP site for the Coalinga earthquake because of soil-structure interaction and topographic effects. In order to adjust the spectra from these recordings to remove these effects, the spectrum from the freefield recording of the July 22 aftershock was compared to the spectra from the basement and switchyard recordings of this same event to come up with a set of frequency dependent adjustment factors. Two sets of adjustment factors were initially calculated, one based on the basement spectrum and one based on the switchyard spectrum. Figure E-10 compares the two estimated freefield spectra for the mainshock using these two sets of adjustment factors. The two estimated spectra are very similar, providing confidence in the approach. The recommended freefield spectrum is taken as the average of these two estimates as shown in Figure E-10. Figure E-11 compares the estimated freefield spectrum with the original basement and switchyard spectra. The recommended 5%-damped acceleration response spectrum is shown individually in Figure E-12.

E.4 Coalinga Facility Sites

The Coalinga Facility sites are located northeast of the city of Coalinga, Fresno County, California. They are located either over or within a few kilometers of the rupture plane of the May 2, 1983 moment-magnitude (M_w) 6.4 Coalinga earthquake. The sites of interest are the Getty Oil Pumping Plant (GOPP), Shell Tank Farm #29 (STF29), the Union Oil Butane Plant (UOBP), the Shell Water Treatment Plant (SWTP) and the Coalinga Water Treatment Plant (CWTP).

The Coalinga earthquake caused widespread damage in the city of Coalinga and the surrounding oil fields (Stover, 1987). It was assigned a maximum intensity of VIII on the Modified Mercalli Intensity (MMI) scale. Shaking effects consistent with MMI VIII were restricted to Coalinga and the surrounding oil fields, both located within Pleasant Valley and Anticline Ridge, which separates Pleasant Valley from the San Joaquin Valley to the east. All of the Coalinga Facility sites were located within the area assigned intensity VIII.

E.4.1 Strong-Motion Recordings

There were no strong-motion recordings at the Coalinga Facility sites. The closest recording site was 10 to 15 kilometers away at the Pleasant Valley Pumping Plant (PVPP; USGS Station #1162). One of the PVPP recordings was on the basement floor of the plant approximately 17 feet below grade (Fig. E-5). The other was at the switchyard 280 feet southwest of the plant at the top of a slope about 70 feet above the plant grade (Fig. E-6). T he discharge pipeline passes within 120 feet of the switchyard instrument. The estimated freefield spectrum at the PVPP site (see Section E.3) is shown in Figure E-12. The geographic coordinates and surficial geology of the PVPP and Coalinga sites are given in the following table.

Coordinates	PVPP	GOPP	STF29	UOBP	SWTP	CWTP
Latitude (°N)	36.308	36.190	36.240	36.207	36.230	36.214
Longitude(°W)	120.249	120.357	120.312	120.282	120.363	120.240
Geology	Qa	Qa	Te	Tsj	Qt	Qa

In this table Qa stands for Quaternary (Holocene) alluvium, Qt for Late Pleistocene to Pliocene Tulare Formation, Te for the Pliocene and Late Miocene Etchegoin Formation and Tsj for the Pliocene San Joaquin Formation (Wentworth and Zoback, 1990).

E.4.2 Earthquake Parameters

Eaton (1990) and Stover and Coffman (1993) report the following seismological parameters for the Coalinga earthquake:

Date:	May 2, 1983
Time:	23:42:38 Greenwich Mean Time (GMT)
Magnitude:	6.2 m_b, 6.5 M_S, 6.7 M_L, 6.2 M_W
Epicenter:	36.233°N, 120.310°W
Depth:	10.0 km
Strike:	127° (southeast)
Dip:	23° to the southwest
Rake:	90° (thrust)

There has been considerable controversy as to whether the focal plane indicated above or the conjugate focal plane given by the same strike but dipping 67° to the northeast is the correct rupture plane. This controversy has been exasperated by the complex nature of the aftershock sequence. However, Eaton (1990) prefers the shallow southwest-dipping plane because it coincides with the most pervasive surface identified by the larger aftershocks. Eberhart-Phillips and Reasenberg (1990) propose two fault planes based solely on the trends in the aftershock sequence. Both of these planes have a strike of 139° with one dipping 75° to the northeast and the other dipping 50° to the southwest. Like Eaton, they prefer the shallow southwest-dipping plane, however its dip is substantially steeper than that determined by Eaton from first-motion data.

Using teleseismic broadband body waves, Choy (1990) found that the best fit to the displacements that could be obtained assuming a single rupture event had a focal mechanism with a strike of 300°, a dip of 65° to the northeast and a rake of 85° (almost pure thrust), representing almost exactly the second focal plane of Eaton. Likewise, Sipkin and Needham (1990) used both long- and short-period teleseismic first motions and kinematic source parameters determined by time-dependent moment-tensor inversion to derive similar mechanisms. The strike, dip and rake of the best first-motion solution are 307°, 70° to the northeast and 90° (thrust). This is very close to the strike, dip and rake of the best moment-tensor solution, which are 303°, 72° to the northeast and 97° (almost pure thrust). However, like the others who prefer the northeast-dipping plane, their solutions are based on a single fault plane.

Wentworth and Zoback (1990) believe that the geologic structure of the Coalinga area is the key to selecting the correct focal plane. The geologic structure of the region determined from shallow geophysical data identifies northeast-directed thrusts, which they call the Coalinga thrust zone, that terminate beneath the Coalinga anticline at a depth of about 10 kilometers in a series of upward-splaying reverse faults. The mainshock appears to have occurred at the base of a reverse-fault splay beneath the upper tier of the fold and produced a focal mechanism with a gently southwest-dipping focal plane that strikes parallel to the fold axis. Rupture propagated bilaterally back down the thrust and up the reverse fault. This complex mechanism is consistent with the coseismic elevation changes, the shallow southwest-dipping focal mechanism, the complex aftershock sequence and the structural geology. Stein (1985), using this same coseismic elevation data, found that the two-plane thrust model fit this deformation data equally well as a single fault plane dipping steeply to the northeast. However, he found that a single steeply northeast-dipping plane was superior to a single shallow southwest-dipping plane, possibly explaining why seismologists found that the northeast-dipping plane was the best solution of the considered single fault-plane solutions. Had these investigators used multiple southwest-dipping planes, they might have come to the opposite conclusion.

Based on the coseismic elevation changes, Wentworth and Zoback (1990) determined the following two-plane rupture model for the earthquake from dislocation theory:

Width (down-dip):	7 km (steep), 4 km (shallow)
Length:	16 km (both)
Depth to Top:	3.4 km (steep), 9.1 km (shallow)
Strike:	133° (southeast; both)
Dip:	55° southwest (steep), 10° southwest (shallow)
Rake:	90° (thrust; both)
Average Slip:	1.2 m (steep), 2.0 m (shallow)
Seismic Moment:	4.3×10^{25} dyne-cm (both)

The total seismic moment of 8.6×10^{25} dyne-cm is consistent with a moment magnitude of 6.6 based on the moment-magnitude relationship of Hanks and Kanamori (1979). Stein (1985) obtained a similar solution for the two fault-plane model and estimated a moment magnitude of 6.5. Seismological determinations of seismic moment referenced by Stein (1985) give moment magnitudes that range from 6.4 to 6.5. Choy (1990), using long- and short-period broadband teleseismic body waves, interpreted the earthquake as having two subevents with a total seismic moment corresponding to a moment magnitude of 6.3. The moment tensor solution of Sipkin and Needham (1990) gave a moment magnitude of 6.4. A moment magnitude of 6.4 is used in this study.

The following distances from the PVPP and Coalinga sites to the rupture planes of the Coalinga earthquake were calculated from the above rupture model and the epicentral coordinates determined by Eaton (1990):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
PVPP	10.0	33	7.7	8.4
GOPP	6.4	222	0.7	8.7
STF29	0.8	347	0.0	3.7
UOBT	3.8	139	0.0	4.0
SWTP	4.8	266	0.0	6.6
CWTP	6.6	108	1.2	3.6

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of this rupture plane, and Azimuth is the angle between the epicenter and the site measured clockwise from north.

Because of their close proximity to the rupture planes, the Coalinga sites were subject to both source directivity and hanging-wall/footwall effects. According to Somerville and others (1997), the degree to which a site is subjected to source directivity during a thrust earthquake can be quantified in terms of two parameters, ϕ, the angle between the fault rupture plane and the ray path to the site and Y, the fraction of the fault that ruptures in an up-dip direction towards the site. The value of Y was derived from the entire rupture surface, whereas the value of ϕ was derived from the steeper fault plane, since that was the part of the fault that controlled directivity effect. Each of the sites were determined to be on the hanging wall, the footwall or off the edge of the fault based on the definitions of these terms given by Somerville and Abrahamson (1995). These parameters are summarized in the following table.

Parameter	PVPP	GOPP	STF29	UOBP	SWTP	CWTP
Y	0.64	0.64	0.64	0.64	0.56	0.45
ϕ	17	61	17	31	50	6
HW/FW	FW	HW	HW	HW	HW	FW

In the above table, HW signifies that the site is located on the hanging wall of the rupture plane and FW signifies that the site is located on the footwall of the rupture plane.

E.4.3 Local Site Conditions

The surficial geology of each of the Coalinga sites based on a geologic map compiled by Wentworth and Zoback (1990) is given in a table in Section F.3.1. Beneath these surficial sediments lies a continuous sequence of Quaternary, Tertiary, Cretaceous and Jurassic sediments (Bartow, 1990). These sediments, which are approximately 5 kilometers thick, lie on top of the Cretaceous and Jurassic Franciscan assemblage. Crystalline basement lies at a depth of about 13 to 15 kilometers, depending on the site (Wentworth and Zoback, 1990).

Based on the above information, the PVPP, GOPP and CWTP sites can be classified as Soil Profile Type S_D (Stiff Soil Profile) based on the site classifications given in the 1997 *Uniform Building Code* (UBC) (ICBO, 1997) and the correlation between geologic units and shear-wave velocity in California developed by Wills and Silva (1998). This Soil Profile Type has a shear-wave velocity in the top 30 meters that ranges between 180 and 360 m/s. The STF29, UOBP and SWTP sites can be classified as Soil Profile Type S_C, which has a shear-wave velocity in the top 30 meters that ranges between 360 and 760 m/s.

E.4.4 Recommended Response Spectra

It was judged that the estimated PVPP freefield spectrum could serve as a reasonable estimate of the expected response spectra for the Coalinga Facility sites after making some adjustments. These adjustments took into account differences in the source-to-site distances, geological conditions, rupture directivity effects and hanging-wall/footwall effects between the PVPP and Coalinga sites.

The adjustment for distance was made using a weighted average of the ground motions calculated from the empirical attenuation relationships of Abrahamson and Silva (1997), Boore and others (1997), Campbell (1997), and Sadigh and others (1997). Based on their surficial geology, the PVPP, GOPP and CWTP sites were assumed to correspond to a generic soil site with an average shear-wave velocity in the top 30 meters of approximately 310 m/s (Boore and Joyner, 1997). The STF29, UOBP and SWTP sites were assumed to correspond to a generic rock site with an average shear-wave velocity in the top 30 meters of approximately 620 m/s (Boore and Joyner, 1997). The exact shear-wave velocity used for the calculation is not critical, since the adjustment is based on the relative difference in the calculated ground-motion values for the different distance measures and site conditions between the PVPP site and the Coalinga sites. Rupture directivity effects were calculated based on the empirical model of Somerville and others (1997) using the parameters given in the table in Section F.4.2. Hanging-wall/footwall effects were calculated using a weighted average of the empirical models proposed by Abrahamson and Silva (1997) and Somerville and Abrahamson (1995, 2000), where 50% weight was given to the Somerville and Abrahamson (1995) model because of the similarity in the other two models.

Figure E-13 shows a comparison of the estimated spectra for the Coalinga sites. They all have greater high-frequency amplitudes than the PVPP site because they are located on the hanging wall of the rupture planes, or close to the hanging wall in the case of the CWTP site, and are located closer to these planes. The CWTP site is the only site that had its low-frequency amplitudes increased due to rupture directivity effects. However, the others still have greater low-frequency amplitudes than the PVPP site because of their shorter distances to the rupture planes. The correction for rock increased the high-frequency amplitudes but decreased the low-frequency amplitudes of the STF29, UOBP and SWTP sites, but these adjustments were not very large. The recommended 5%-damped acceleration response spectra for the Coalinga Facility sites are shown individually in Figures E-14 to E-18.

E.5 Rinaldi Receiving Station, Northridge Earthquake

The Rinaldi Receiving Station is located in the city of Mission Hills in the northern part of the San Fernando Valley, Los Angeles County, California. It is located directly over the upper edge of the rupture plane of the January 17, 1994 moment magnitude (M_w) 6.7 Northridge earthquake.

The Northridge earthquake caused widespread damage throughout the Los Angeles region (Dewey and others, 1995). It was assigned a maximum intensity of IX on the Modified Mercalli Intensity (MMI) scale. Shaking effects consistent with MMI IX were observed in Sherman Oaks, Northridge, Granada Hills, along the I-5 corridor just east of the Santa Susana Mountains, and in two neighborhoods of several blocks each in Santa Monica and west-central Los Angeles. Shaking effects consistent with MMI VIII were observed at many locations over a broad area of the San Fernando Valley, and also in parts of Santa Clarita Valley, Simi Valley, Santa Monica, west-central Los Angeles, Fillmore, the University of Southern California/County Hospital complex in Los Angeles, and in a 3-kilometer long, several blocks wide, area of Hollywood along Hollywood Boulevard. The Rinaldi site is located within the area identified as intensity IX.

E.5.1 Strong-Motion Recordings

A single freefield strong-motion recording was obtained in an instrument shelter located adjacent to the Rinaldi Receiving Station (Lindvall Richter Benuska, 1994). Lindvall Richter Benuska give the geographic coordinates of the instrument location as 34.281°N and 118.479°W. The instrument, owned by the Los Angeles Department of Water and Power (LADWP), recorded peak ground accelerations of 0.84*g*, 0.49*g* and 0.85*g* in the 228° (southwest), 318° (northwest), and vertical directions, respectively. The 5%-damped acceleration response spectra for the two horizontal components are shown in Figure E-19.

E.5.2 Earthquake Parameters

Scientists of the U.S. Geological Survey and the Southern California Earthquake Center (1996) report the following seismological parameters for the Northridge earthquake:

Date:	January 17, 1994
Time:	12:30 Greenwich Mean Time (GMT)
Magnitude:	6.7 M_w
Epicenter:	34.209°N, 118.541°W
Depth:	19 km
Strike:	280° to 290° (northwest)
Dip:	35° to 45° to the southwest
Mechanism:	Thrust

Similar source parameters were obtained by many other seismologists (e.g., *Bulletin of the Seismological Society of America*, 1996). According to these studies, the rupture initiated at the hypocenter in the southeast corner of the rupture plane and propagated up-dip to the north and northeast where the largest subevent occurred.

Using strong-motion, teleseismic, GPS, and leveling data, Wald and others (1996) determined the following rupture model for the earthquake:

Width (down-dip):	21 km
Length:	14 km
Depth to Top:	6 km
Strike:	122° (southeast)
Dip:	40° to the southwest
Average Rake:	101° (thrust)
Average Slip:	1.3 m
Seismic moment:	$1.3 \pm 0.2 \times 10^{26}$ dyne-cm (6.7 M_w)
Avg. Stress Drop	74 bars

The seismic moment of 1.3×10^{26} dyne-cm is consistent with a moment magnitude of 6.7 based on the moment-magnitude relationship of Hanks and Kanamori (1979).

The following distances from the Rinaldi site to the rupture plane of the Northridge earthquake were calculated from the above rupture model and the epicentral coordinates determined by Scientists of the U.S. Geological Survey and the Southern California Earthquake Center (1996):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
Rinaldi R.S.	9.8	36	0.0	7.4

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of this rupture plane, and Azimuth is the angle between the epicenter and the site measured clockwise from north.

The Rinaldi site was located above the northeastern part of the rupture plane and, therefore, was subject to source directivity. According to Somerville and others (1997), the degree to which a site is subjected to source directivity during a thrust earthquake can be quantified in terms of two parameters, ϕ, the angle between the fault rupture plane and the ray path to the site and Y, the fraction of the fault that ruptures in an up-dip direction towards the site. According to Somerville and others (1997), these two parameters have values of $\phi = 21°$ and X = 0.85 for the Rinaldi Receiving Station.

E.5.3 Local Site Conditions

As reported by Bardet and Davis (1996), cone penetration tests at the Rinaldi Receiving Station performed by the Earth Technology Corporation (1994) indicate that the site is underlain by silty sands and sandy silts with lenses of clay and gravel. The upper 7 meters have a relative density ranging from 20% to 60% and a standard penetration test (SPT) blow count between 3 and 20, with values above 40 in the gravel layers. These Holocene alluvial deposits, derived from San Fernando Creek, have shear-wave velocities ranging from 200 to 300 m/sec. The Plio-Pleistocene Pico Formation is encountered at a depth of 10 meters and has a shear-wave velocity approximately equal to 1100 m/sec. Although there was some ground cracking observed at the site, which has a water table below 10 meters, there was no direct surficial evidence of liquefaction, such as sand boils.

E.5.4 Recommended Response Spectrum

Because the Rinaldi freefield recording was obtained on site, it serves as the recommended response spectrum for the Rinaldi Receiving Station. This recommended 5%-damped acceleration response spectrum is shown in Figure E-20. This response spectrum is identical to that recommended by Boore (1997) for the same site.

E.6 Sylmar Converter Station, Northridge Earthquake

The Sylmar Converter Station is located in the city of Sylmar in the northern part of the San Fernando Valley, Los Angeles County, California. It is located directly over the upper edge of the rupture plane of the January 17, 1994 moment magnitude (M_w) 6.7 Northridge earthquake.

The Northridge earthquake caused widespread damage throughout the Los Angeles region (Dewey and others, 1995). It was assigned a maximum intensity of IX on the Modified Mercalli Intensity (MMI) scale. Shaking effects consistent with MMI IX were observed in Sherman Oaks, Northridge, Granada Hills, along the I-5 corridor just east of the Santa Susana Mountains, and in two neighborhoods of several blocks each in Santa Monica and west-central Los Angeles. Shaking effects consistent with MMI VIII were observed at many locations over a broad area of the San Fernando Valley, and also in parts of Santa Clarita Valley, Simi Valley, Santa Monica, west-central Los Angeles, Fillmore, the University of Southern California/County Hospital complex in Los Angeles, and in a 3-kilometer long, several blocks wide, area of Hollywood along Hollywood Boulevard. The Sylmar site is located within the area identified as intensity IX.

E.6.1 Strong-Motion Recordings

A single freefield strong-motion recording was obtained in an instrument shelter located adjacent to the building housing Valve Group 7 (Lindvall Richter Benuska, 1994). Lindvall Richter Benuska give the geographic coordinates of the instrument location as 34.311°N and 118.490°W. The instrument, owned by the Los Angeles Department of Water and Power (LADWP), recorded peak ground accelerations of 0.93*g*, 0.60*g* and 0.64*g* in the 142° (southeast), 052° (northeast), and vertical directions, respectively. The 5%-damped acceleration response spectra for the two horizontal components are shown in Figure E-21.

E.6.2 Earthquake Parameters

Scientists of the U.S. Geological Survey and the Southern California Earthquake Center (1996) report the following seismological parameters for the Northridge earthquake:

Date:	January 17, 1994
Time:	12:30 Greenwich Mean Time (GMT)
Magnitude:	6.7 M_w
Epicenter:	34.209°N, 118.541°W
Depth:	19 km
Strike:	280° to 290° (northwest)
Dip:	35° to 45° to the southwest
Mechanism:	Thrust

Similar source parameters were obtained by many other seismologists (e.g., *Bulletin of the Seismological Society of America*, 1996). According to these studies, the rupture initiated at the hypocenter in the southeast corner of the rupture plane and propagated up-dip to the north and northeast where the largest subevent occurred.

Using strong-motion, teleseismic, GPS, and leveling data, Wald and others (1996) determined the following rupture model for the earthquake:

Width (down-dip):	21 km
Length:	14 km
Depth to Top:	6 km
Strike:	122° (southeast)
Dip:	40° to the southwest
Average Rake:	101° (thrust)
Average Slip:	1.3 m
Seismic moment:	$1.3 \pm 0.2 \times 10^{26}$ dyne-cm (6.7 M_w)
Avg. Stress Drop:	74 bars

The seismic moment of 1.3×10^{26} dyne-cm is consistent with a moment magnitude of 6.7 based on the moment-magnitude relationship of Hanks and Kanamori (1979).

The following distances from the Sylmar site to the rupture plane of the Northridge earthquake were calculated from the above rupture model and the epicentral coordinates determined by Scientists of the U.S. Geological Survey and the Southern California Earthquake Center (1996):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
Rinaldi R.S.	12.3	23	0.0	6.3

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of this rupture plane, and Azimuth is the angle between the epicenter and the site measured clockwise from north.

The Sylmar site was located above the northeastern part of the rupture plane and, therefore, was subject to source directivity. According to Somerville and others (1997), the degree to which a site is subjected to source directivity during a thrust earthquake can be quantified in terms of two parameters, ϕ, the angle between the fault rupture plane and the ray path to the site and Y, the fraction of the fault that ruptures in an up-dip direction towards the site. According to Somerville and others (1997), these two parameters have values of $\phi = 21°$ and X = 0.85 for the Sylmar Converter Station.

E.6.3 Local Site Conditions

As reported by Bardet and Davis (1996), the Sylmar Converter Station is founded over the Grapevine Creek channel, on a Holocene alluvial deposit approximately 22 meters thick within the Mission Hills syncline. Soil deposits are classified as silty sand in the upper 3 to 4 meters, clayey sand to clayey silt from 4 to 5 meters, and silty sand to sandy silt at greater depths. Fallgren and Smith (1971), using seismic refraction techniques, measured a compressional-wave (P-wave) velocity of 305 m/sec above a depth of 4 meters and 1661 m/sec below this depth. According to Bardet and Davis (1996), these values correspond to shear-wave velocities of 120 to 150 m/sec and 275 m/sec, respectively, assuming that the larger P-wave velocities were measured below the water table.

Just across Interstate Highway 5 at the eastern extension of the Sylmar Converter Station, Earthquake Technology Corporation (1984), using downhole techniques, measured a shear-wave velocity of 195 m/sec above a depth of 4 meters and 277 m/sec to a depth of 15 meters in a similar alluvial deposit. They measured a shear-wave velocity of 436 m/sec in the underlying Middle-Pleistocene Saugus Formation to a depth of 43 meters. They measured P-wave velocities in this same boring of 536, 1737 and 1585 m/sec at depths of 0 to 4, 4 to 15, and 15 to 43 meters, respectively. The high P-wave velocities and low shear-wave velocities below the 4-meter depth suggest that the water table occurs at this depth, consistent with the P-wave refraction measurements to the west of I-5 at the Sylmar Converter Station.

Bardet and Davis (1996) suggest that the relative absence of high frequencies in the Sylmar Converter Station recording can be attributed to the nonlinear response of the alluvium, especially to the liquefaction and lateral spreading of the underlying soils, which was independently observed in this region by Davis and Bardet (1995). However, it should be noted that the liquefaction and lateral spreading referred to by Bardet and Davis was observed at the Los Angeles Reservoir and the San Fernando Power Plant Tailrace located 1000 meters south and 500 meters northwest of the Sylmar accelerograph site, respectively. Furthermore, a study of ground failure conducted by Stewart and others (1996) failed to mention any ground failure at the Sylmar Converter Station, although they documented such failure at the Lower and Upper San Fernando Dams, the Joseph Jensen Filtration Plant, the San Fernando Valley Juvenile Hall, and the City of San Fernando.

E.6.4 Recommended Response Spectrum

Because the Sylmar freefield recording was obtained on site, it serves as the recommended response spectrum for the Sylmar Converter Station, West Facility. This recommended 5%-damped acceleration response spectrum is shown in Figure E-22. This response spectrum is identical to that recommended by Boore (1997) as one of the possible estimates of freefield ground motion for the Valve Group 1–6 and Valve Group 7 buildings. He used as an alternative the recordings obtained in each of these buildings, with the caveat that they were likely contaminated by embedment and soil-structure interaction effects and that if this contamination were significant (this evaluation was left to others) then the estimates could not be considered as freefield. For purposes of this study, it is judged that the Sylmar freefield recording is the best estimate of *freefield* ground motion for all of the facility sites at the Sylmar Converter Station, West Facility. The East Facility has its own freefield recording that would more appropriately serve as an estimate of freefield ground motion at that facility.

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San Fernando, Calif., Earthquake (Mw 6.7, 2/9/71)
Comparison of Rinaldi Recordings

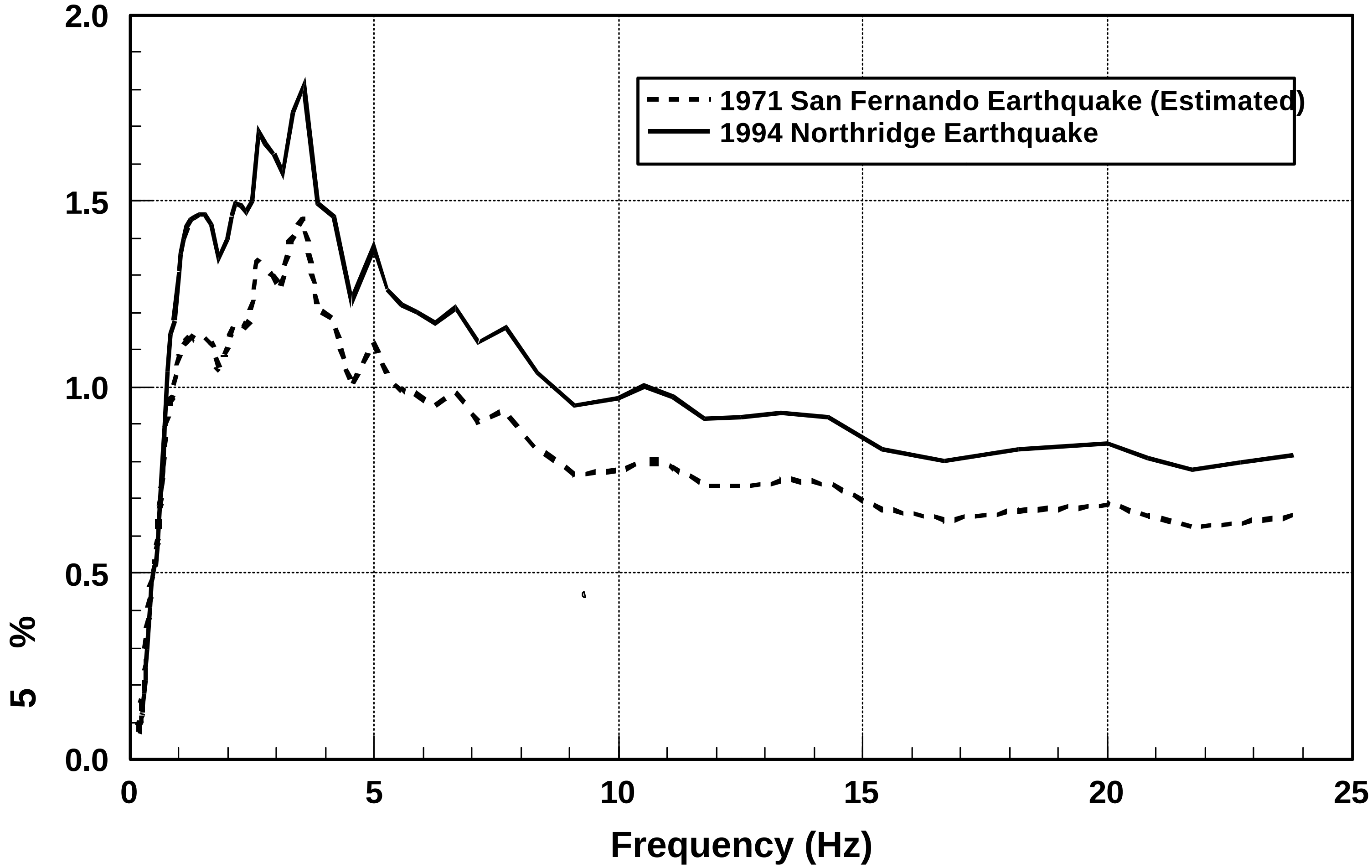


Figure E-1

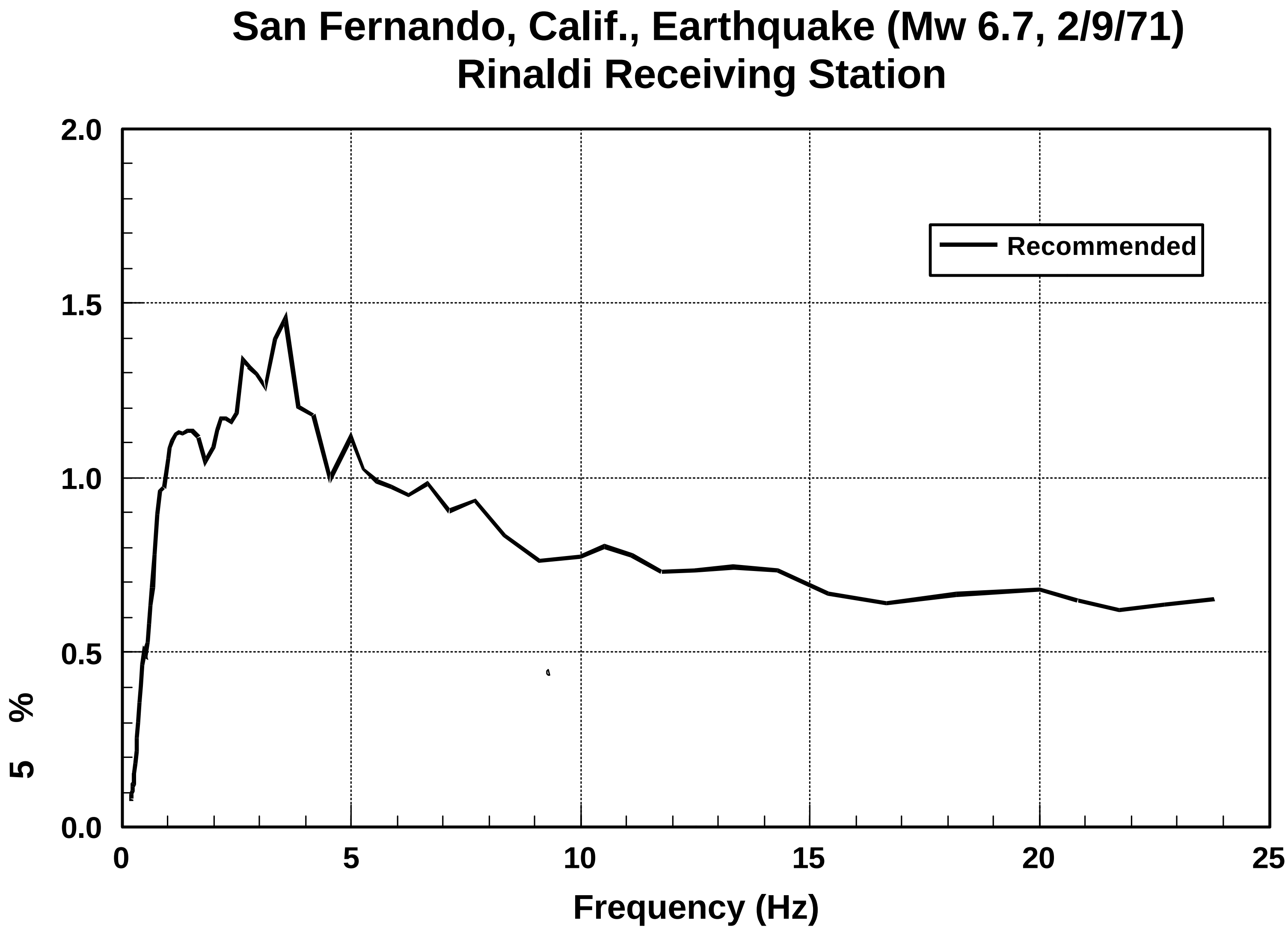

San Fernando, Calif., Earthquake (Mw 6.7, 2/9/71)
Rinaldi Receiving Station
Recommended
2.0
1.5
1.0
0.5
0.0
5 %
0
5
10
15
20
25
Frequency (Hz)

Figure E-2

San Fernando, Calif., Earthquake (Mw 6.7, 2/9/71)
Comparison of Sylmar Recordings

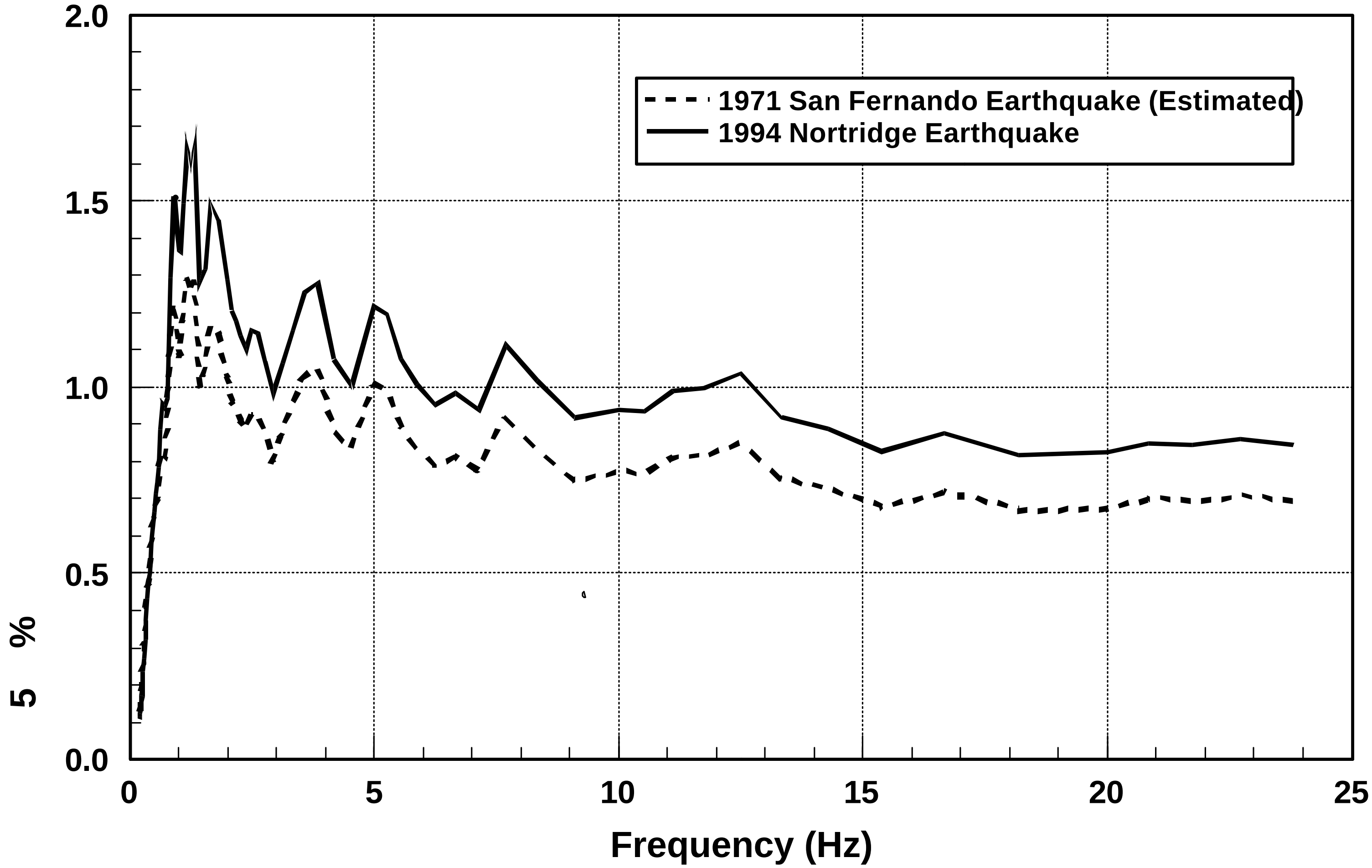


Figure E-3

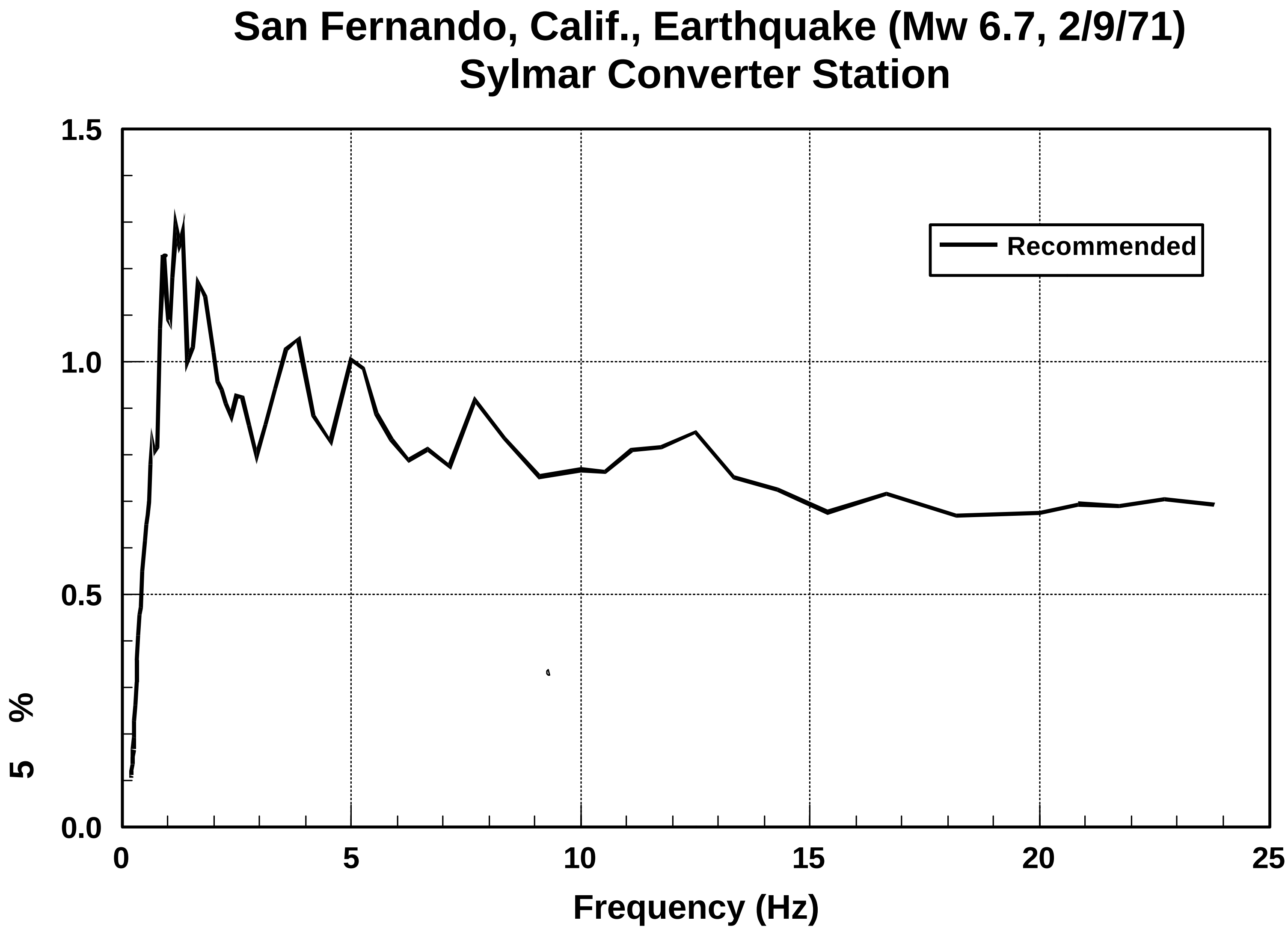

San Fernando, Calif., Earthquake (Mw 6.7, 2/9/71)
Sylmar Converter Station
Recommended
1.5
1.0
0.5
0.0
5 %
0
5
10
15
20
25
Frequency (Hz)

Figure E-4

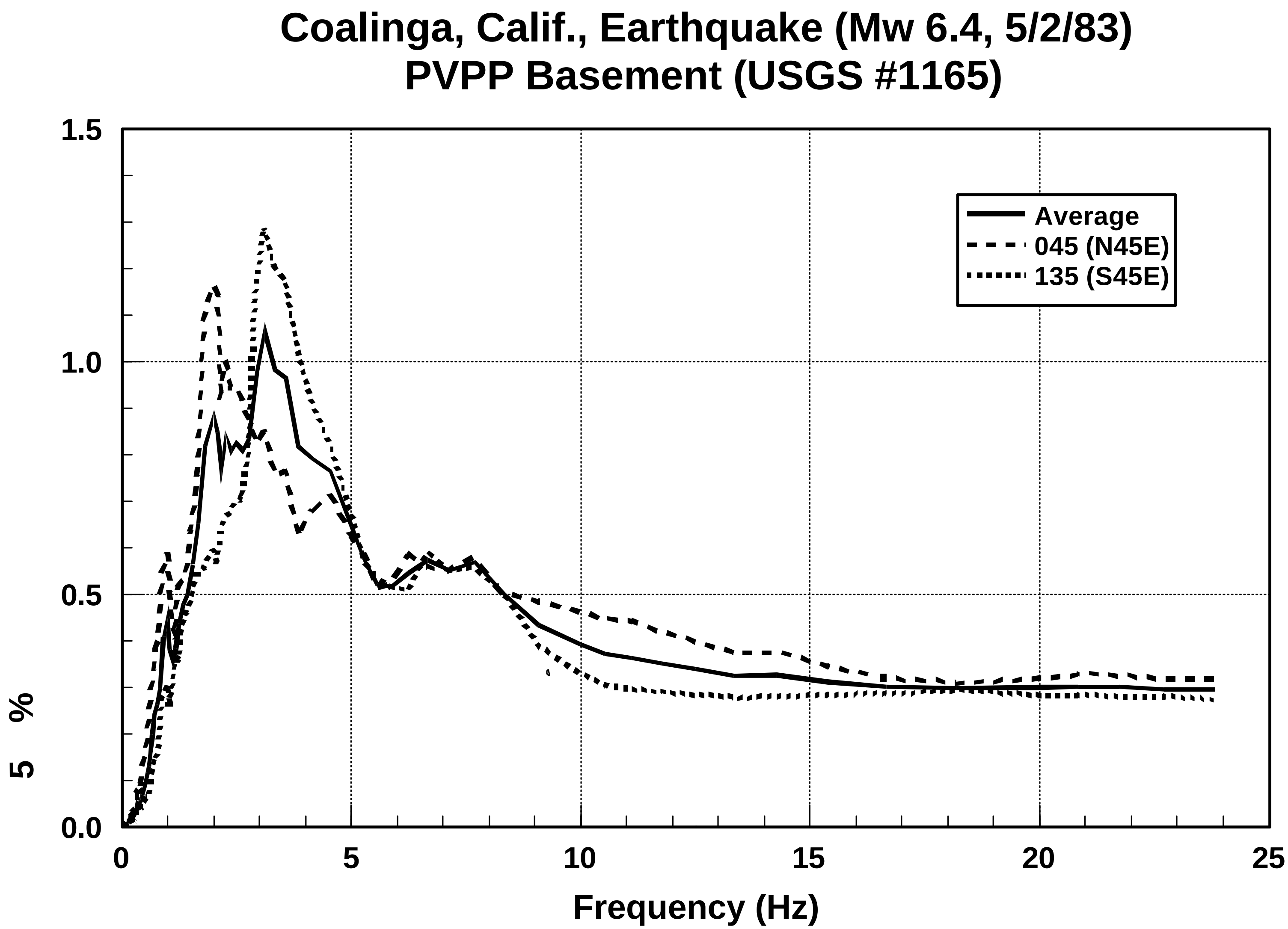

Coalinga, Calif., Earthquake (Mw 6.4, 5/2/83)
PVPP Basement (USGS #1165)
Average
045 (N45E)
135 (S45E)
1.5
1.0
0.5
0.0
5 %
0
5
10
15
20
25
Frequency (Hz)

Figure E-5

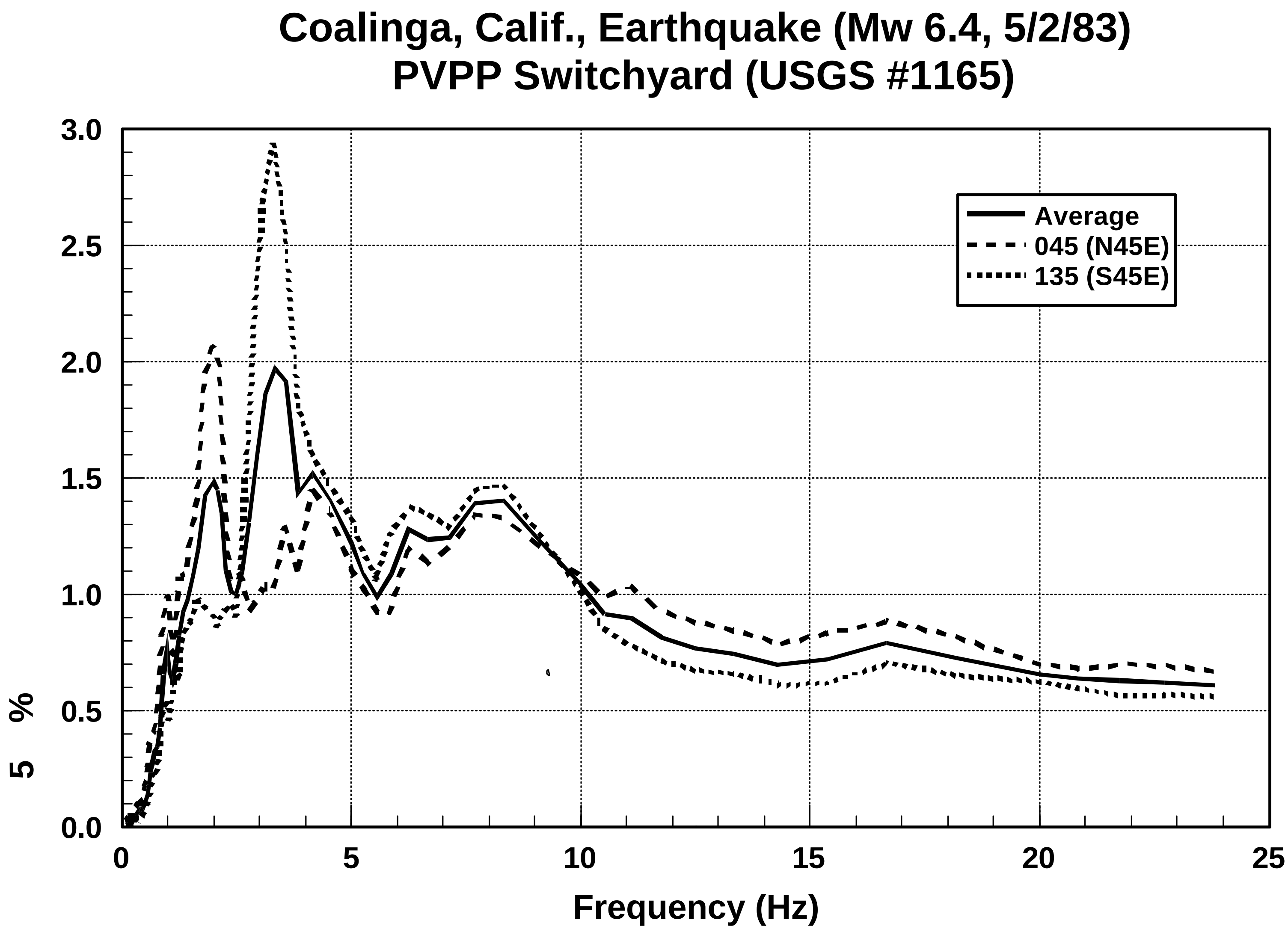

Coalinga, Calif., Earthquake (Mw 6.4, 5/2/83)
PVPP Switchyard (USGS #1165)
Average
045 (N45E)
135 (S45E)
5 %
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (Hz)

Figure E-6

Coalinga, Calif., Aftershock (ML 6.0, 7/22/83)
PVPP Basement (USGS #1165)

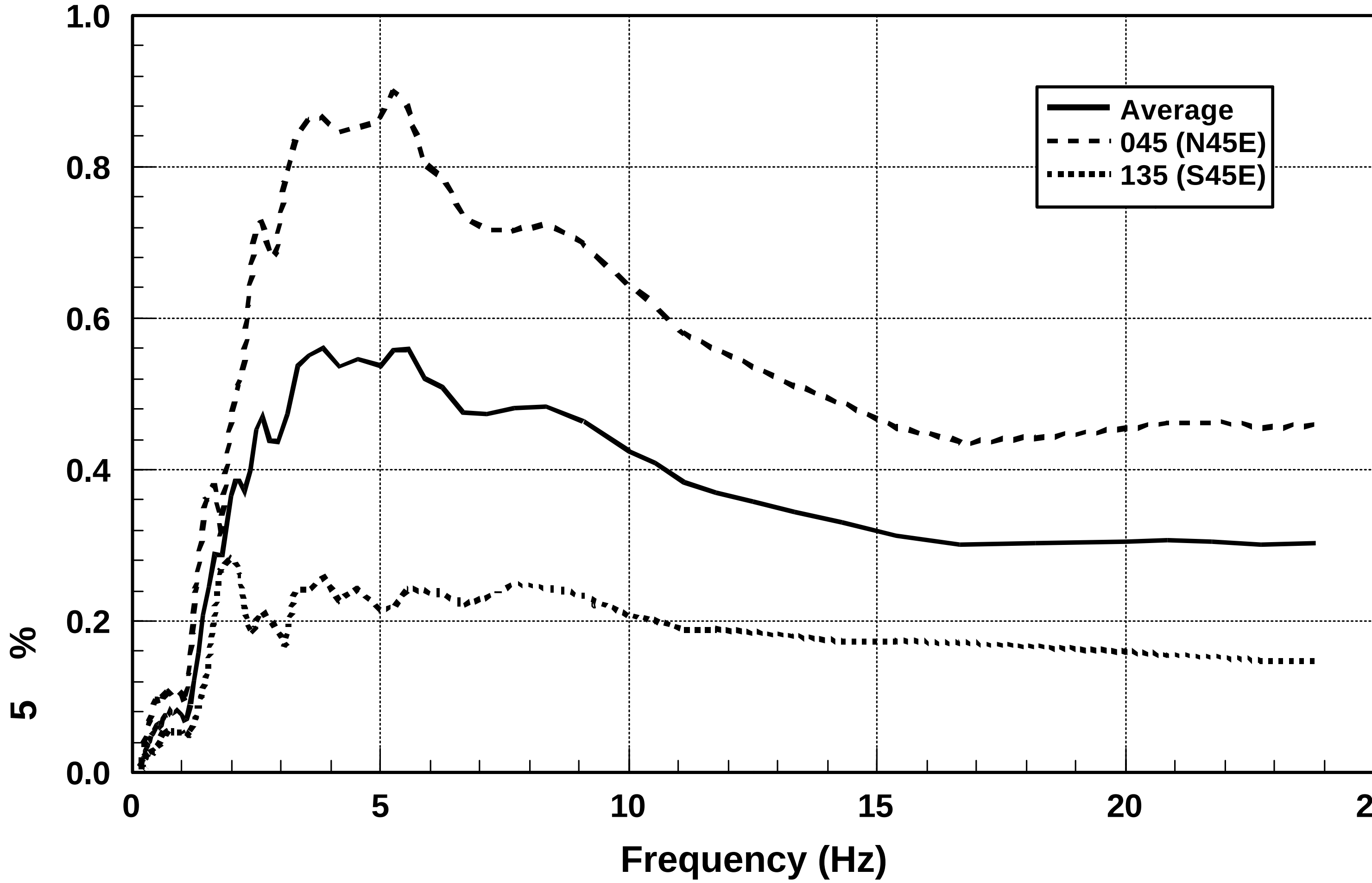


Figure E-7

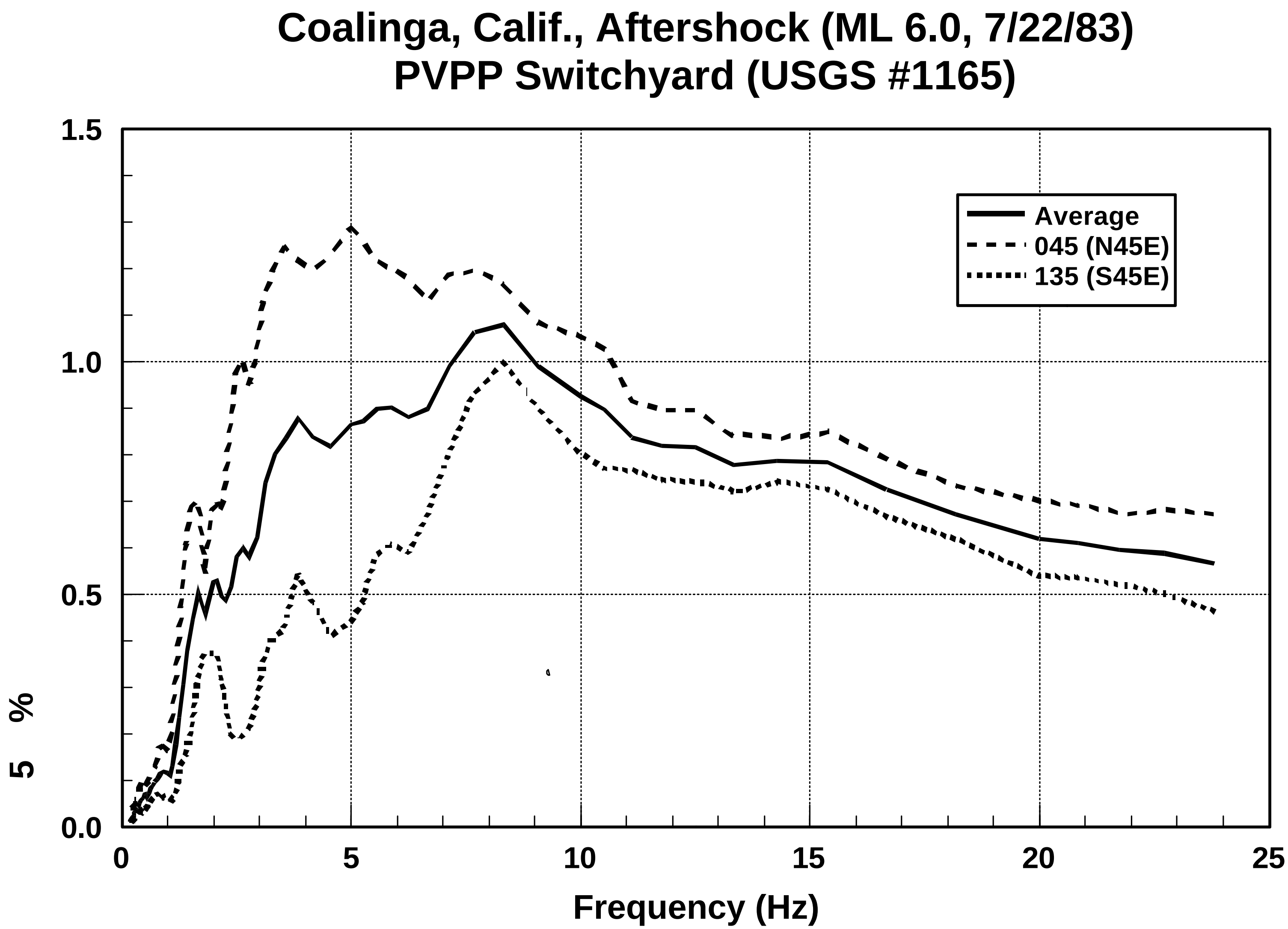

Coalinga, Calif., Aftershock (ML 6.0, 7/22/83)
PVPP Switchyard (USGS #1165)
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (Hz)
5 %
Average
045 (N45E)
135 (S45E)

Figure E-8

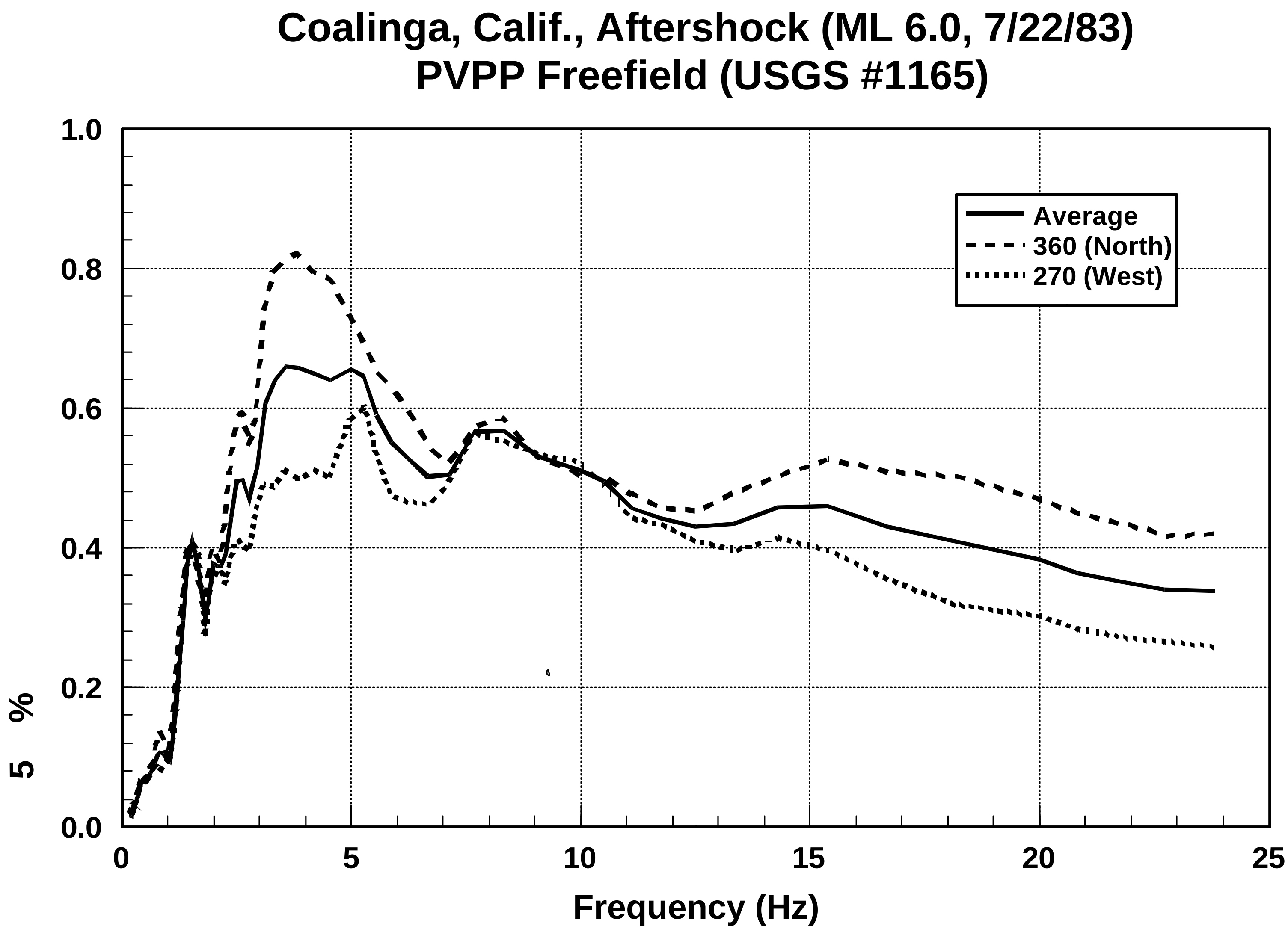

Coalinga, Calif., Aftershock (ML 6.0, 7/22/83)
PVPP Freefield (USGS #1165)
1.0
0.8
0.6
0.4
0.2
0.0
5 %
0
5
10
15
20
25
Frequency (Hz)
Average
360 (North)
270 (West)

Figure E-9

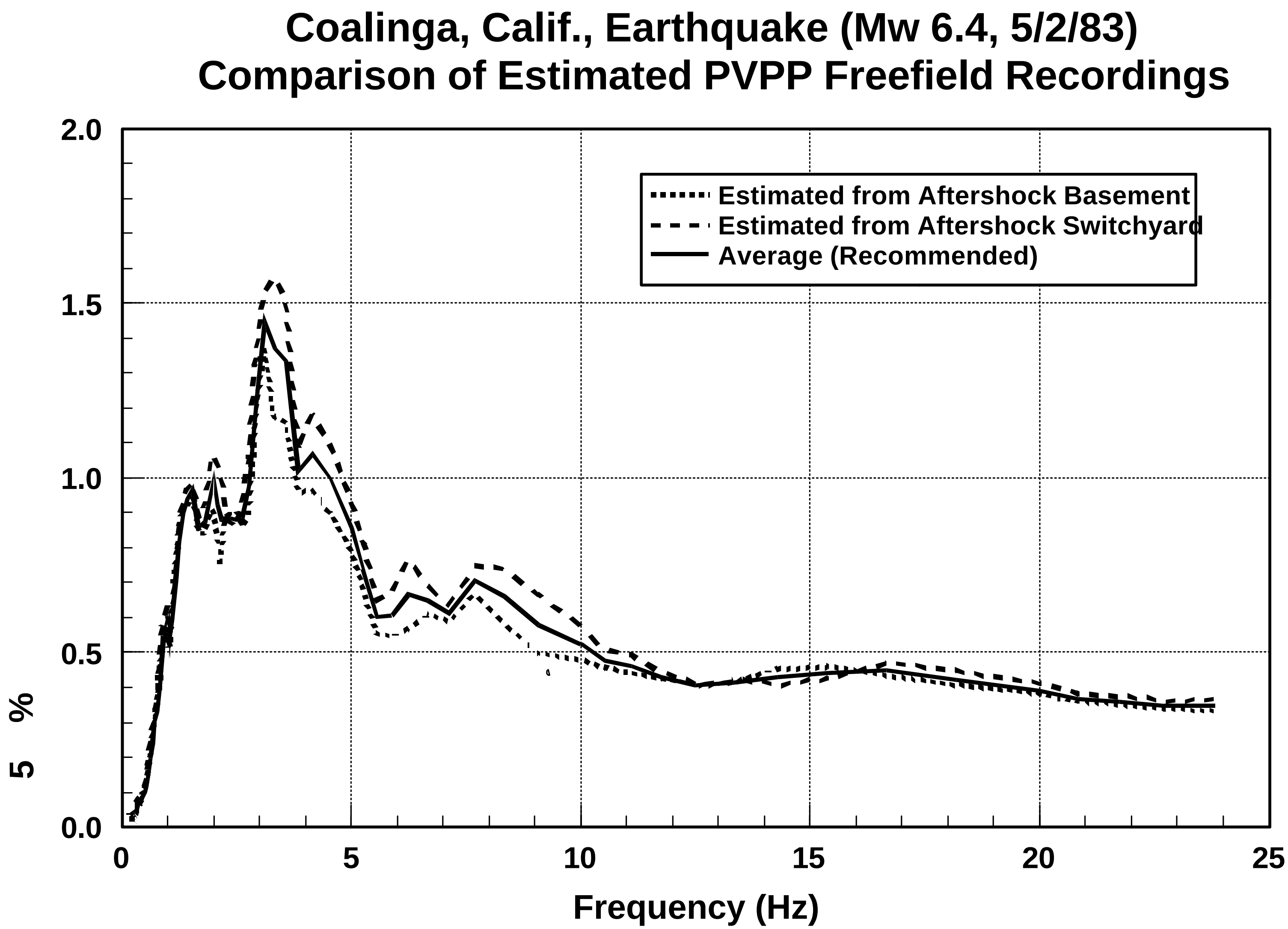
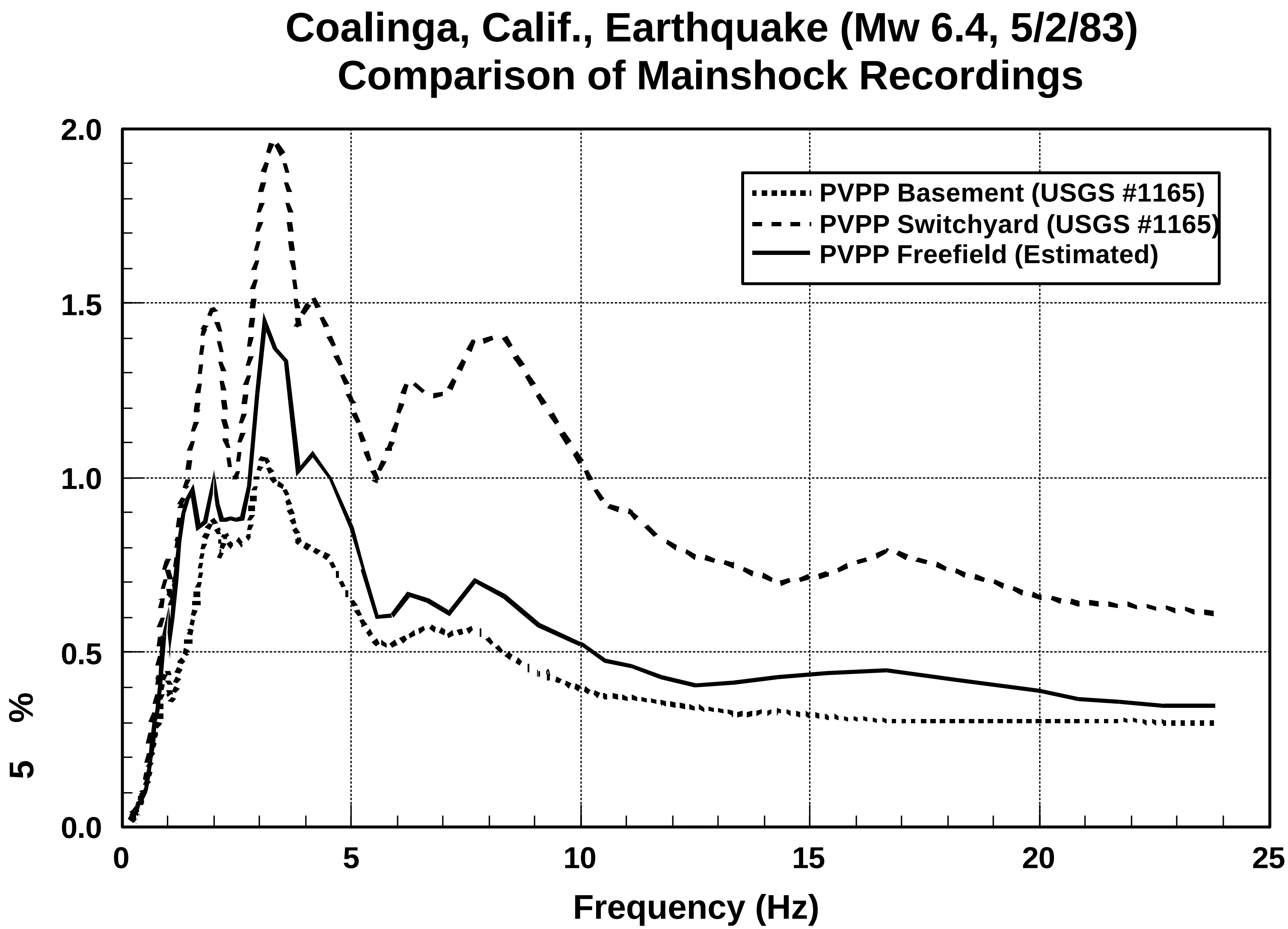

Coalinga, Calif., Earthquake (Mw 6.4, 5/2/83)
Comparison of Estimated PVPP Freefield Recordings
Estimated from Aftershock Basement
Estimated from Aftershock Switchyard
Average (Recommended)
2.0
1.5
1.0
0.5
0.0
5 %
0
5
10
15
20
25
Frequency (Hz)

Figure E-10



Coalinga, Calif., Earthquake (Mw 6.4, 5/2/83)
Comparison of Mainshock Recordings
PVPP Basement (USGS #1165)
PVPP Switchyard (USGS #1165)
PVPP Freefield (Estimated)
5 %
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
25
Frequency (Hz)

Figure E-11

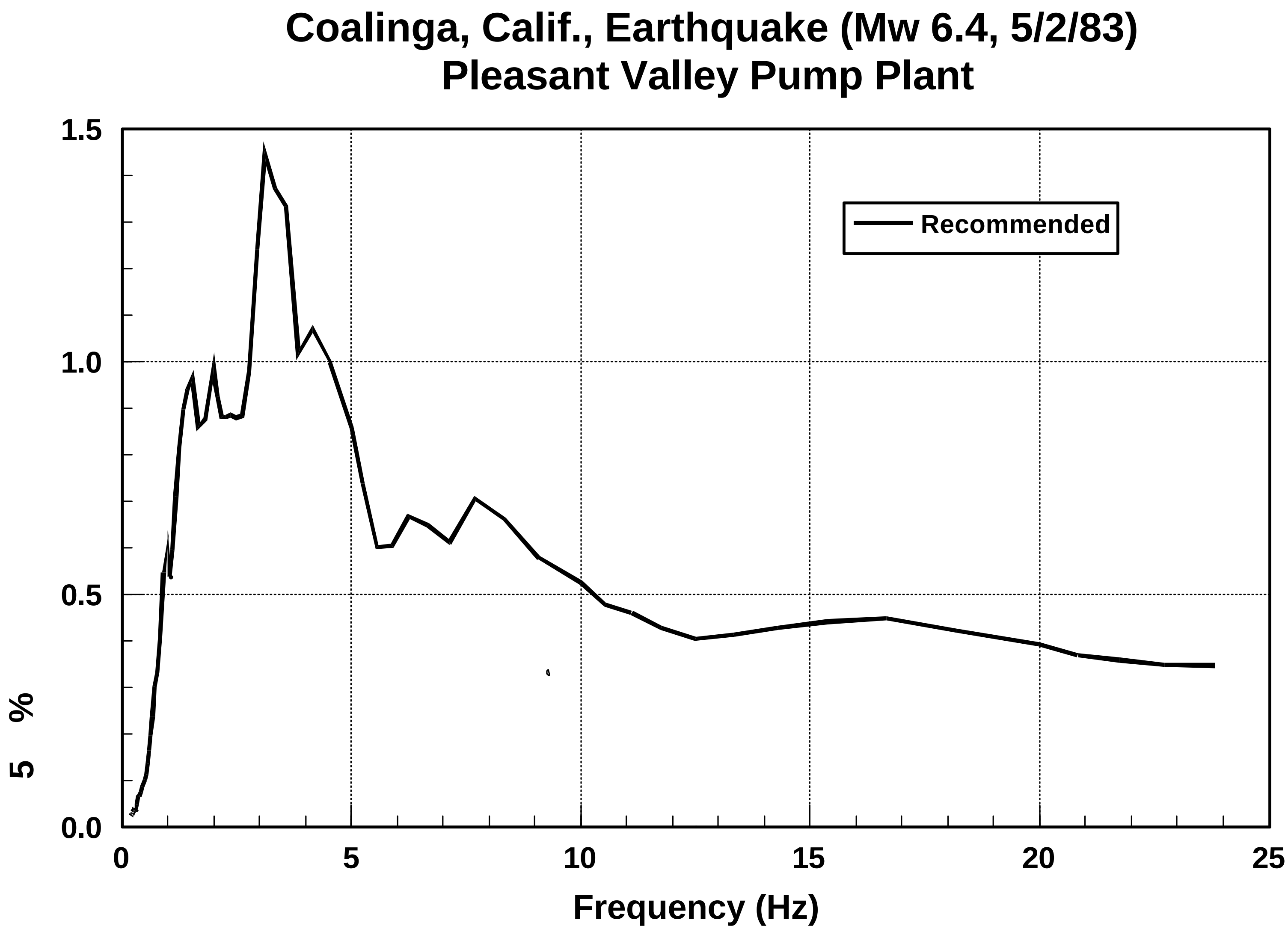
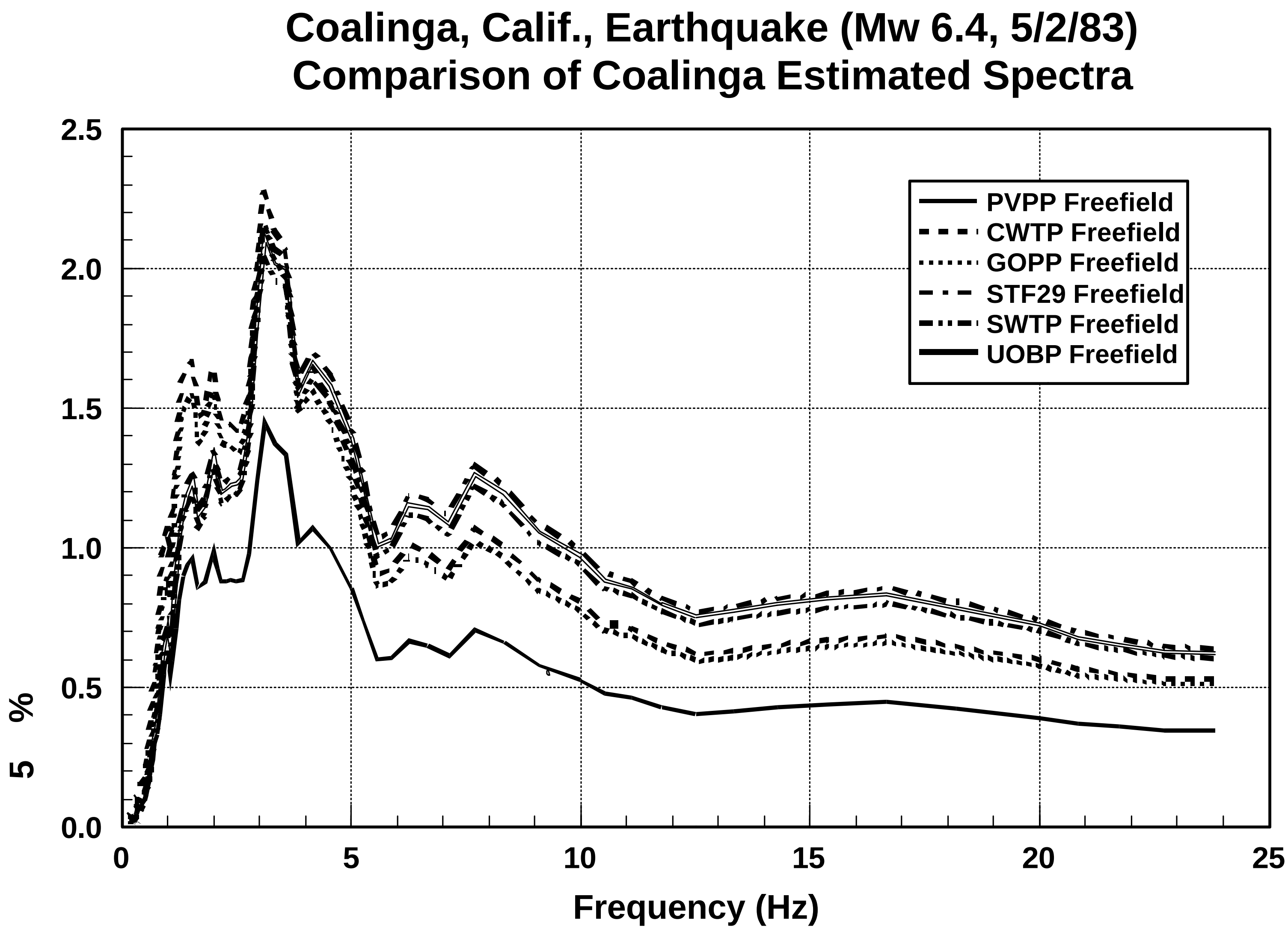

Coalinga, Calif., Earthquake (Mw 6.4, 5/2/83)
Pleasant Valley Pump Plant
1.5
1.0
0.5
0.0
5 %
0
5
10
15
20
25
Frequency (Hz)
Recommended

Figure E-12



Coalinga, Calif., Earthquake (Mw 6.4, 5/2/83)
Comparison of Coalinga Estimated Spectra
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (Hz)
5 %
PVPP Freefield
CWTP Freefield
GOPP Freefield
STF29 Freefield
SWTP Freefield
UOBP Freefield

Figure E-13

Coalinga, Calif., Earthquake (Mw 6.4, 5/2/83)
Getty Oil Pumping Plant

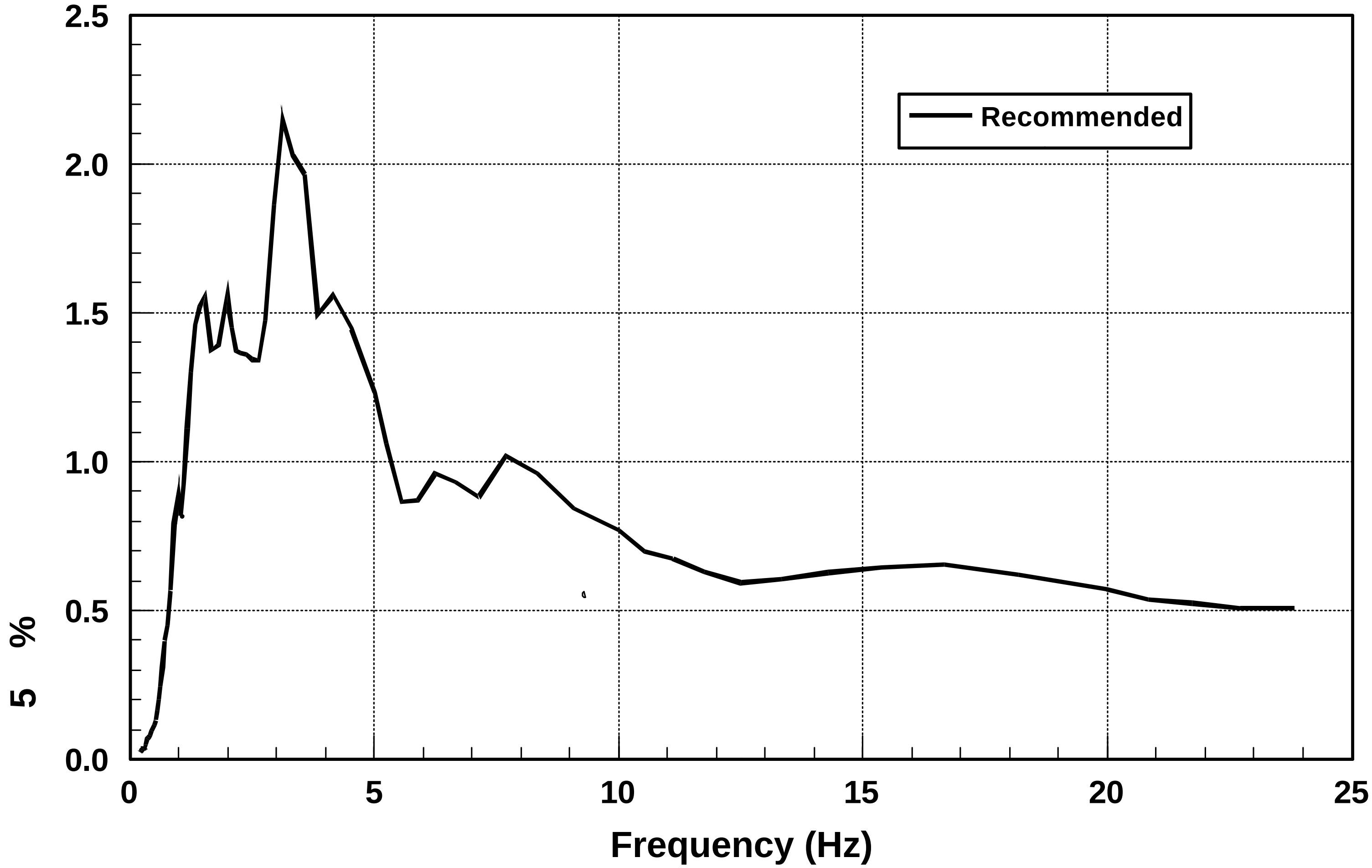


Figure E-14

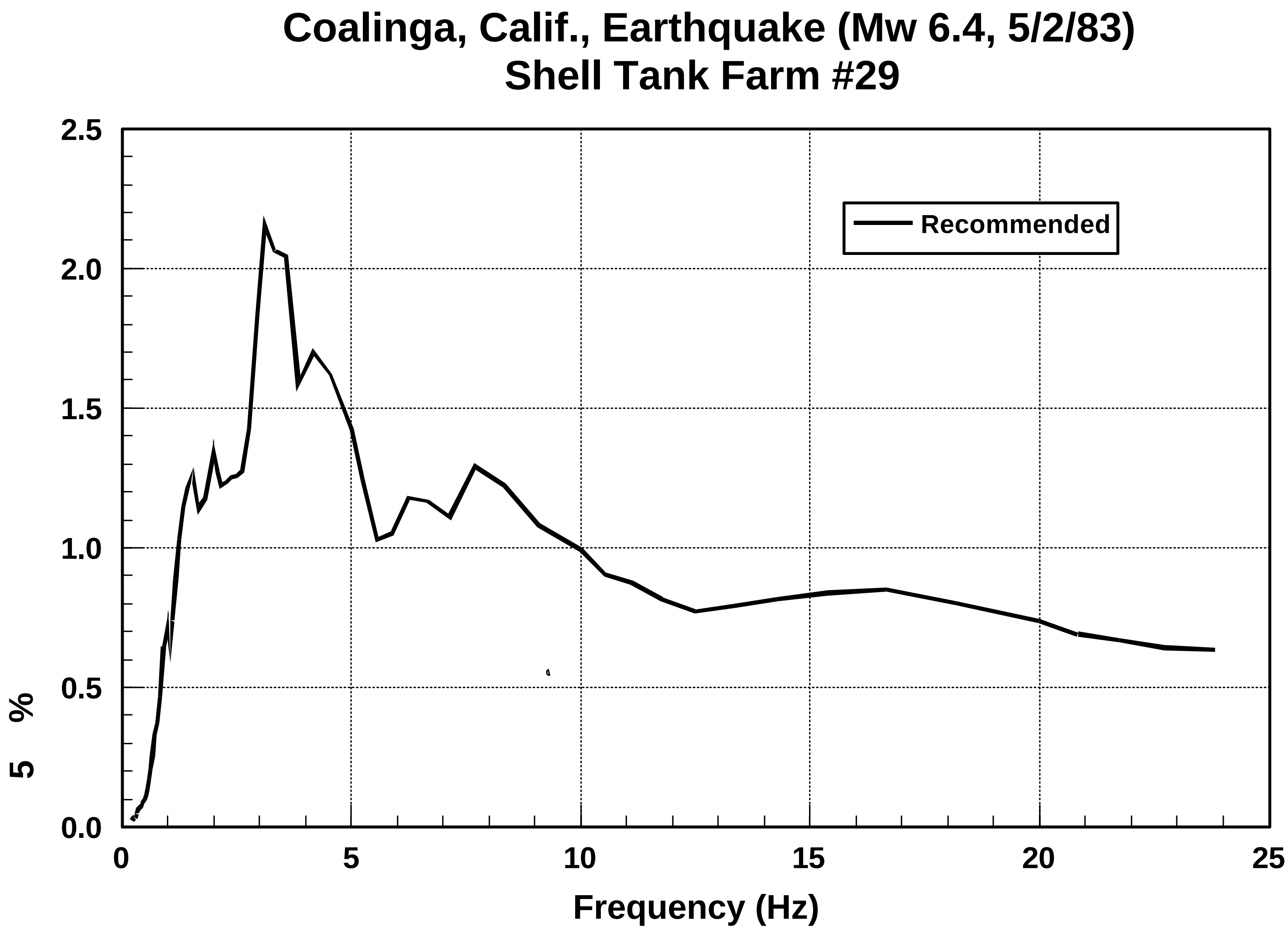
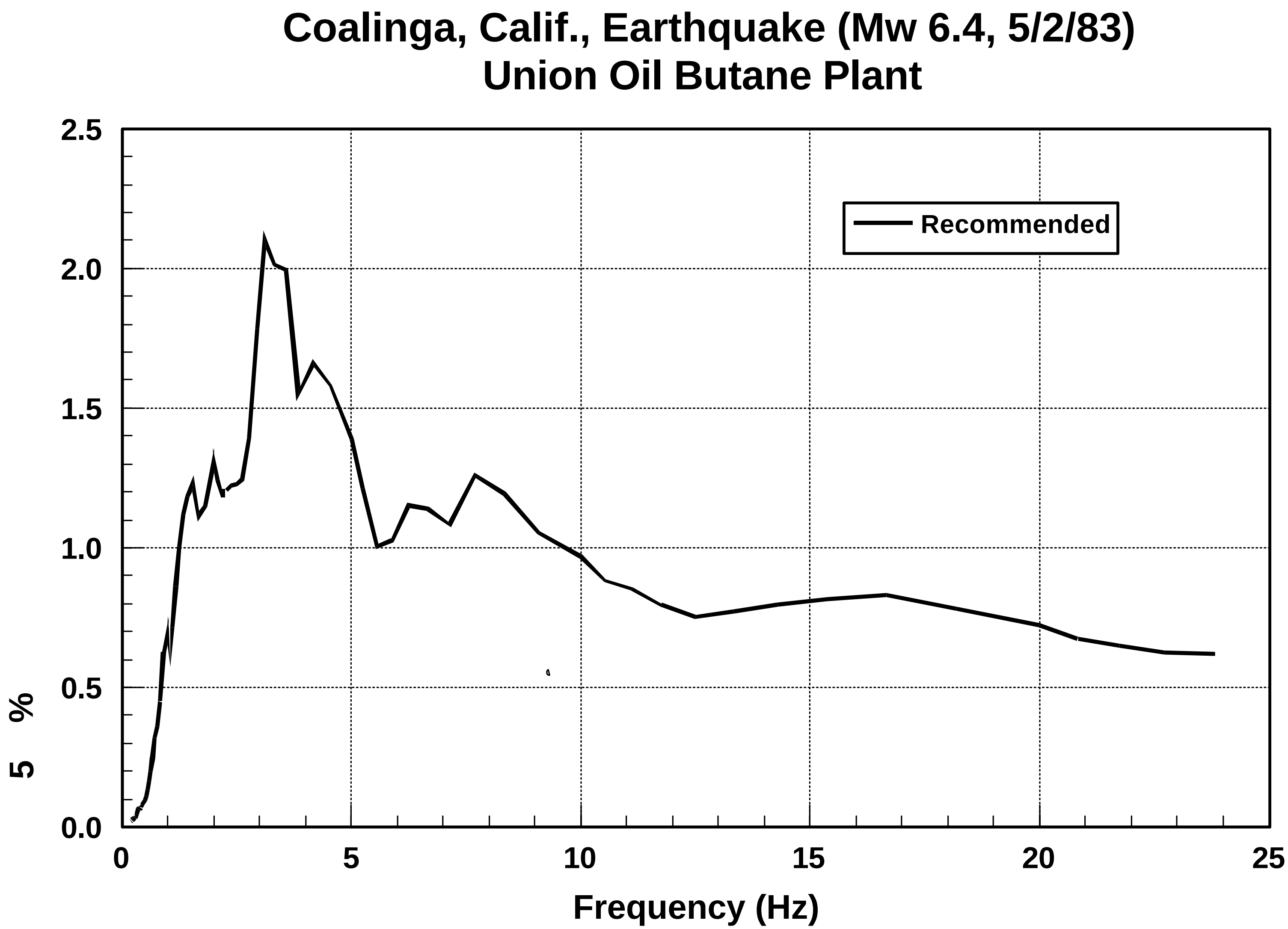

Coalinga, Calif., Earthquake (Mw 6.4, 5/2/83)
Shell Tank Farm #29
2.5
2.0
1.5
1.0
0.5
0.0
5 %
Recommended
0
5
10
15
20
25
Frequency (Hz)

Figure E-15



Coalinga, Calif., Earthquake (Mw 6.4, 5/2/83)
Union Oil Butane Plant
2.5
2.0
1.5
1.0
0.5
0.0
5 %
0
5
10
15
20
25
Frequency (Hz)
Recommended

Figure E-16

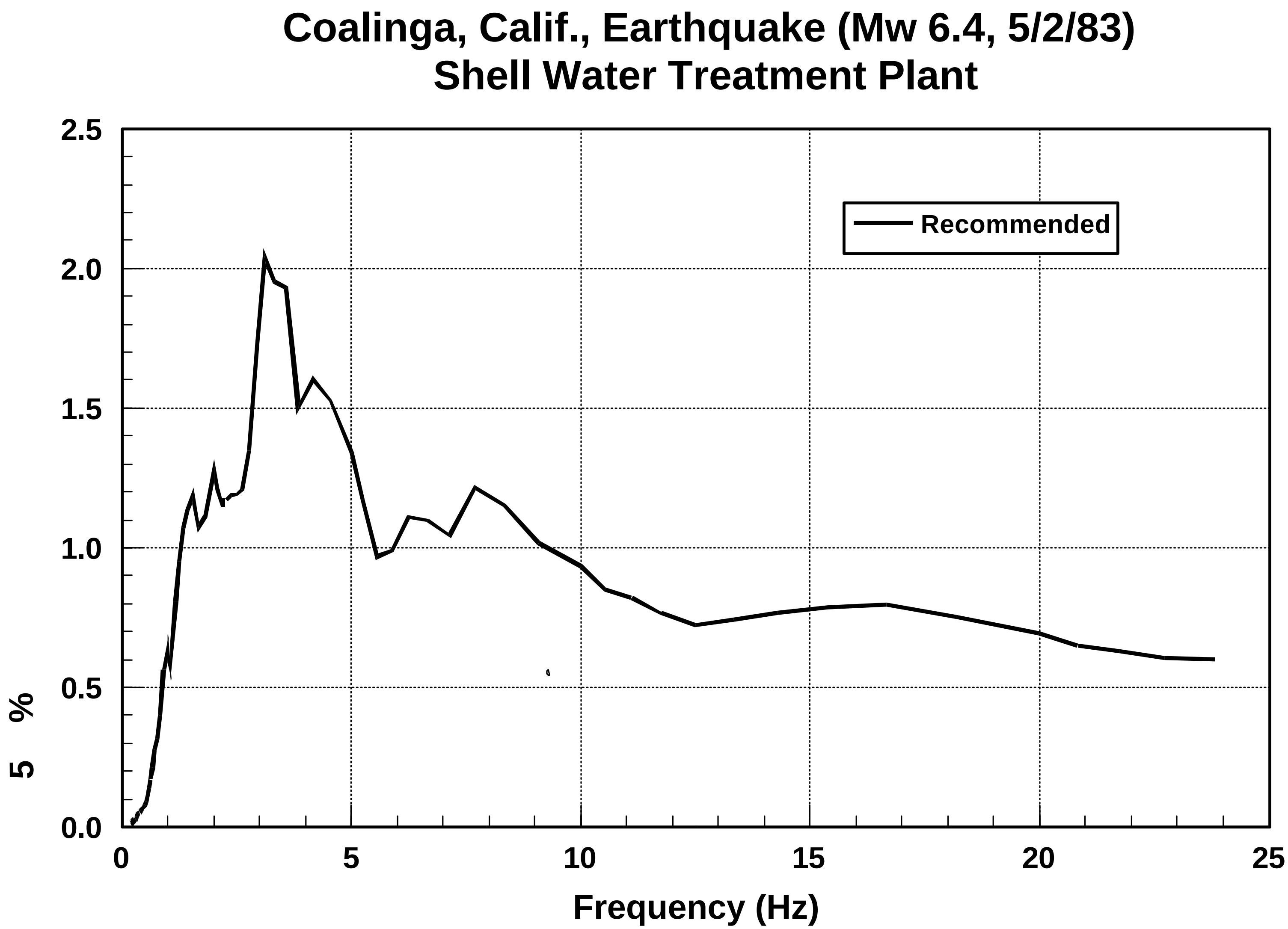

Coalinga, Calif., Earthquake (Mw 6.4, 5/2/83)
Shell Water Treatment Plant
Recommended
2.5
2.0
1.5
1.0
0.5
0.0
5 %
0
5
10
15
20
25
Frequency (Hz)

Figure E-17

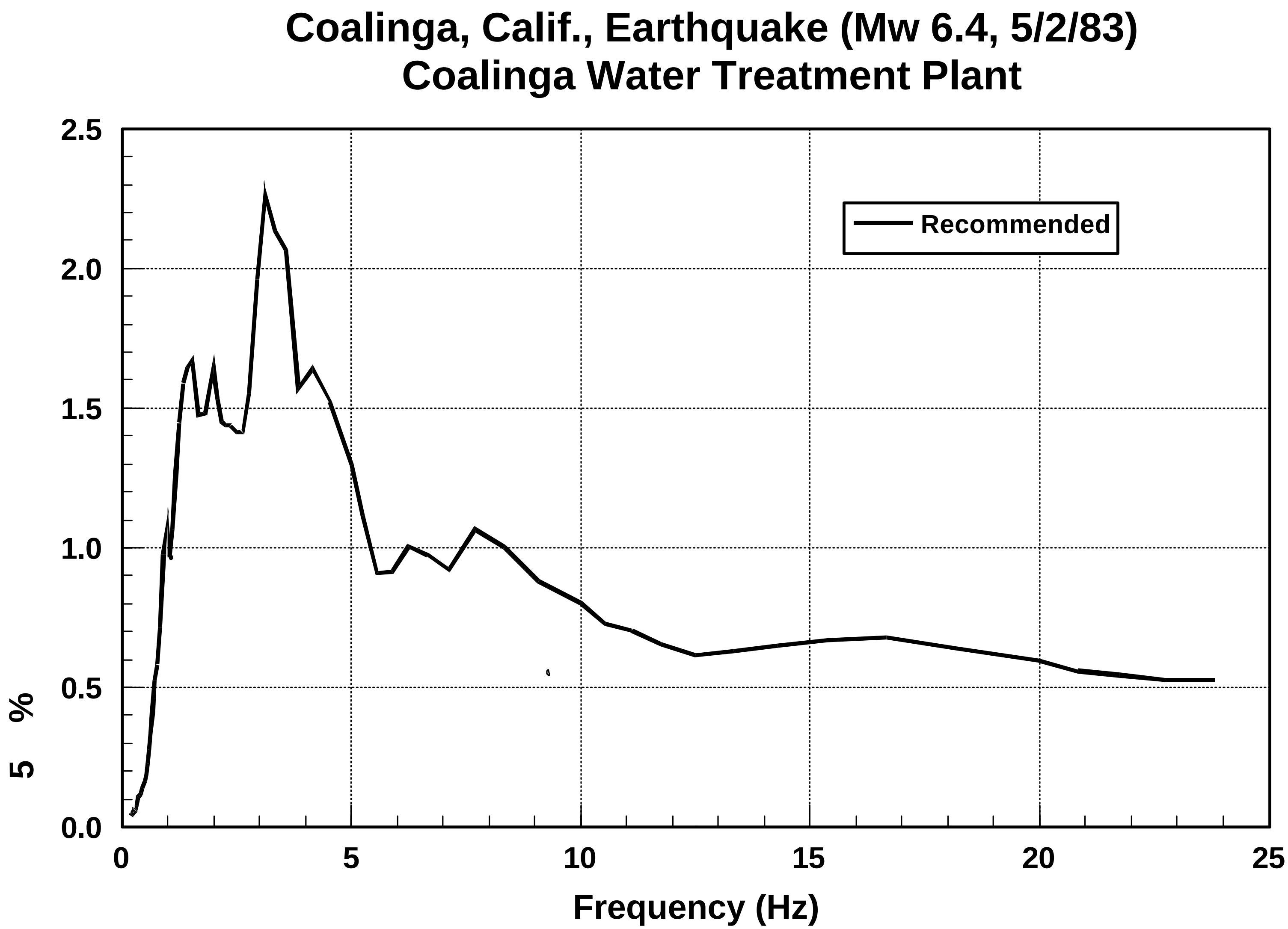

Coalinga, Calif., Earthquake (Mw 6.4, 5/2/83)
Coalinga Water Treatment Plant
2.5
2.0
1.5
1.0
0.5
0.0
5 %
0
5
10
15
20
25
Frequency (Hz)
Recommended

Figure E-18

Northridge, Calif., Earthquake (Mw 6.7, 1/17/94)
Rinaldi Receving Station (LADWP Rinaldi)

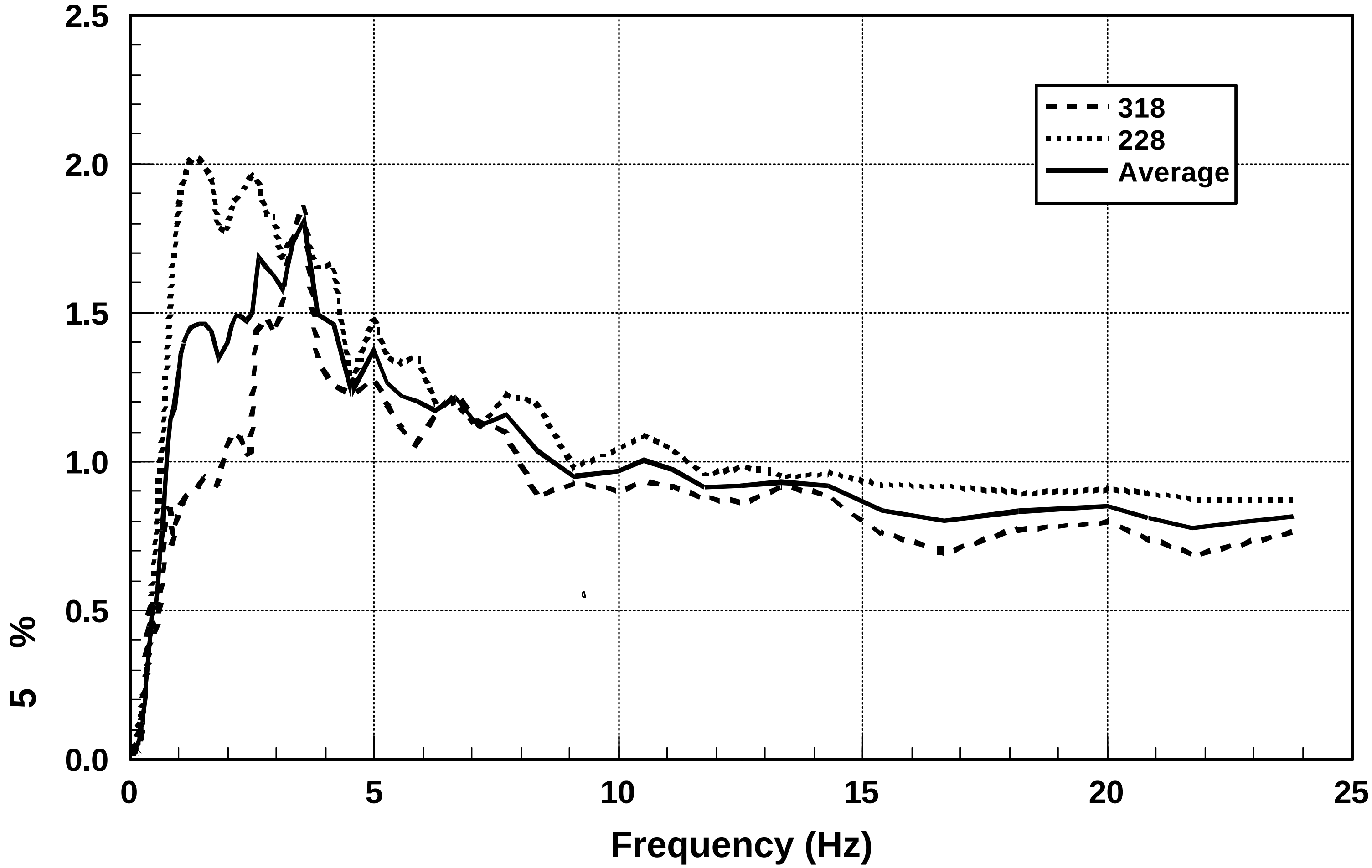


Figure E-19

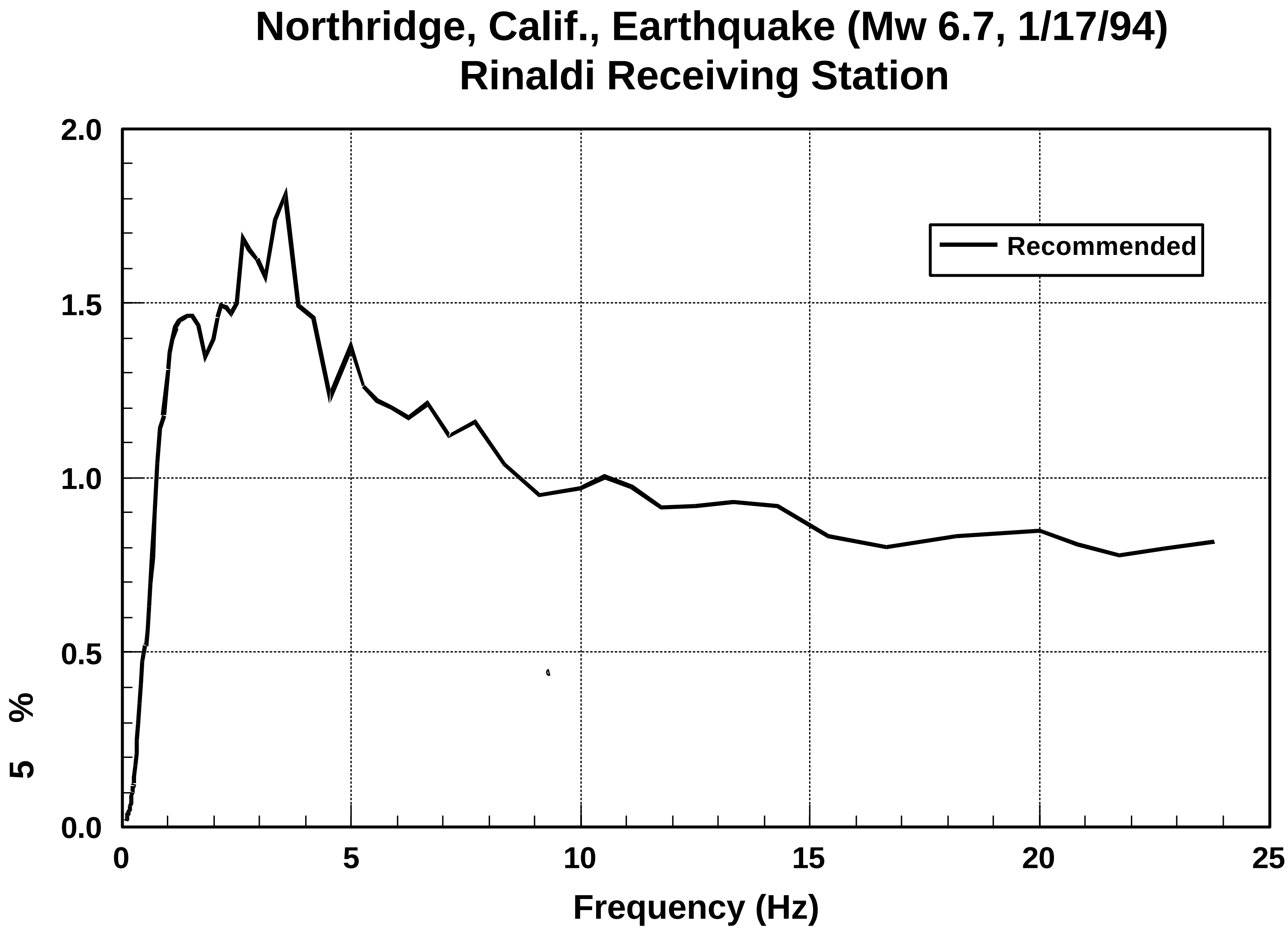

Northridge, Calif., Earthquake (Mw 6.7, 1/17/94)
Rinaldi Receiving Station
2.0
1.5
1.0
0.5
0.0
5 %
0
5
10
15
20
25
Frequency (Hz)
Recommended

Figure E-20

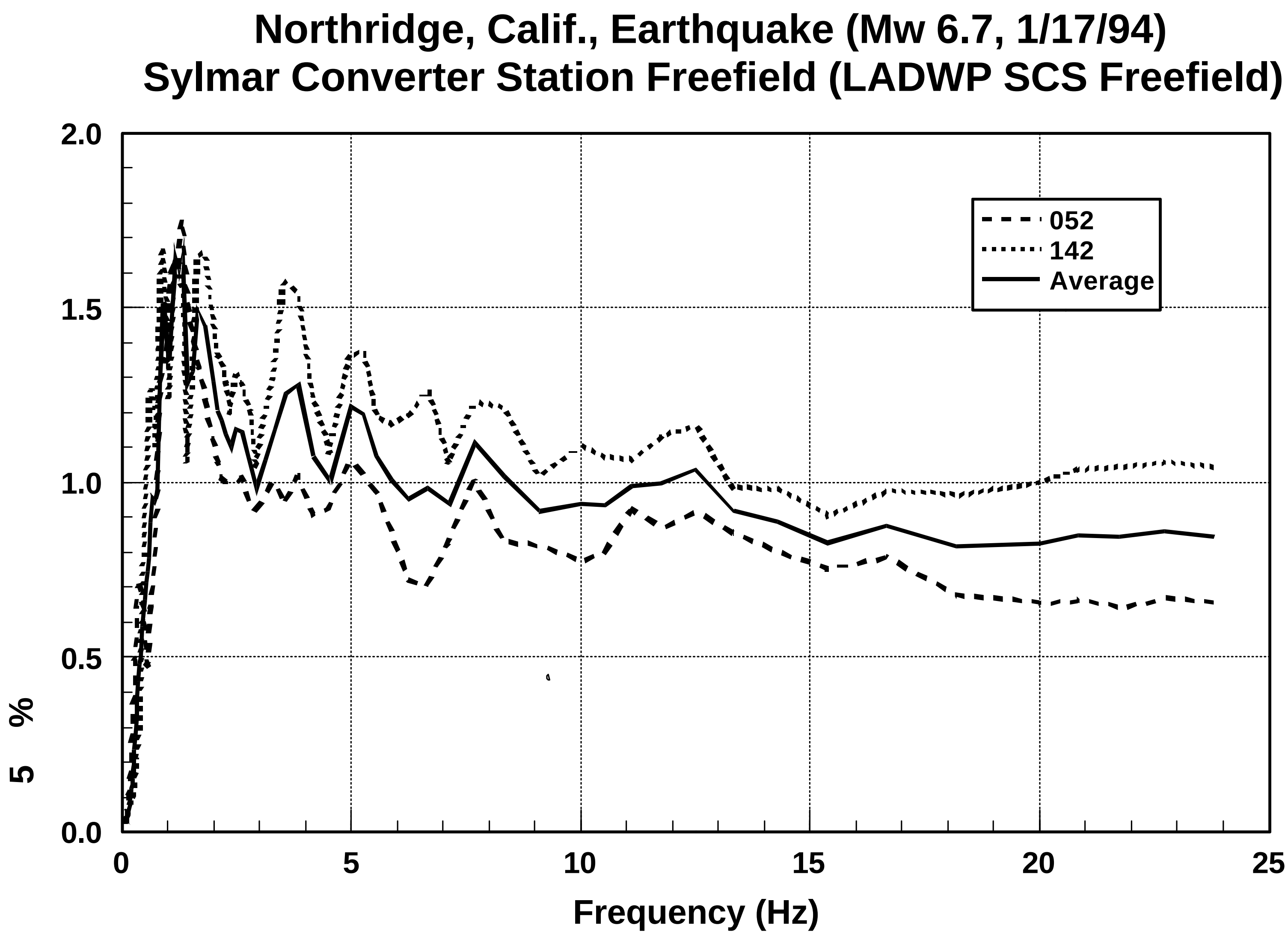

Northridge, Calif., Earthquake (Mw 6.7, 1/17/94)
Sylmar Converter Station Freefield (LADWP SCS Freefield)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (Hz)
5 %
052
142
Average

Figure E-21

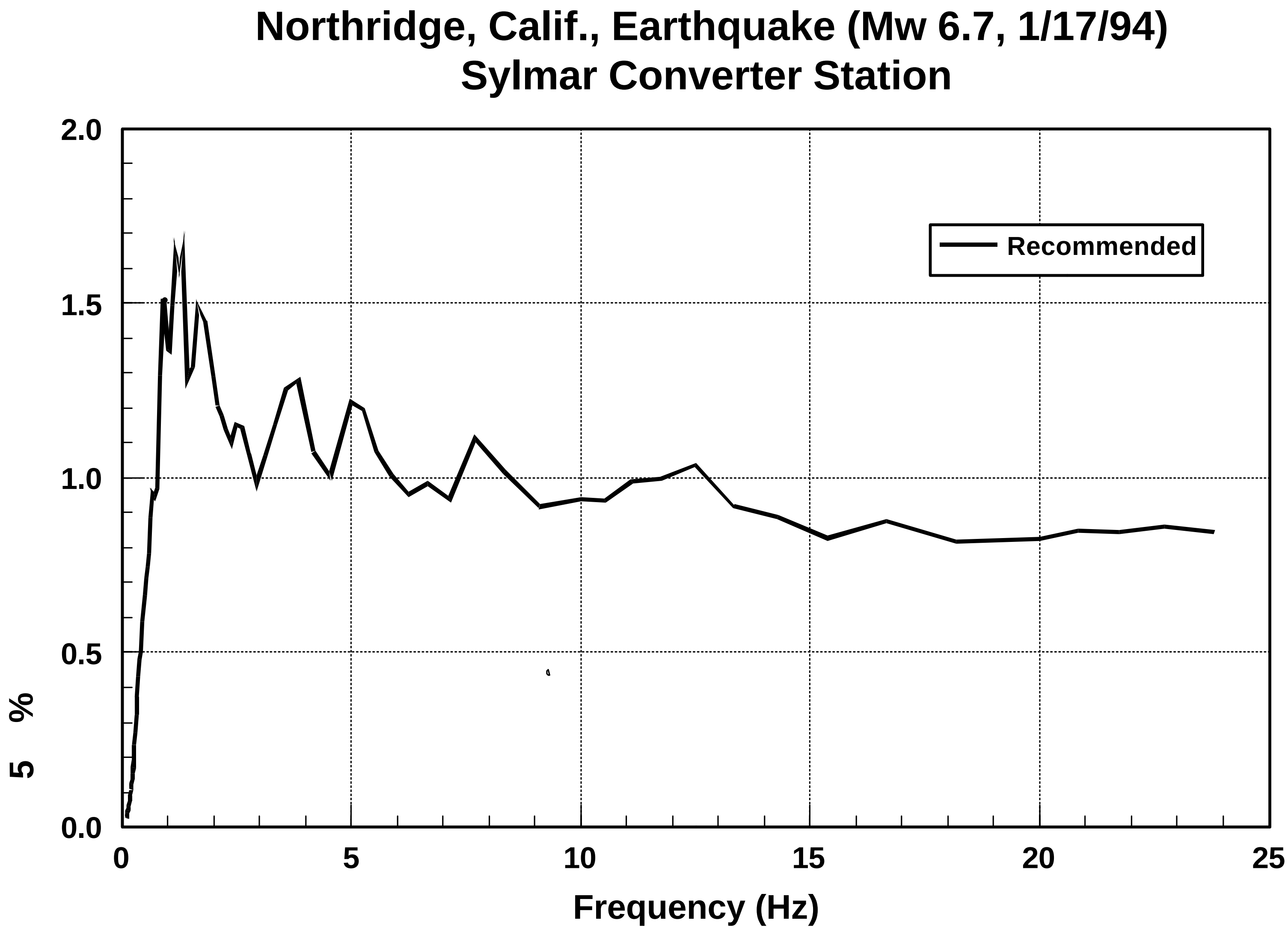

Northridge, Calif., Earthquake (Mw 6.7, 1/17/94)
Sylmar Converter Station
2.0
1.5
1.0
0.5
0.0
5 %
0
5
10
15
20
25
Frequency (Hz)
Recommended

Figure E-22