1. INTRODUCTION

1.1 PURPOSE OF THE DOE SEISMIC EVALUATION PROCEDURE

U.S. Department of Energy (DOE) facilities need to have adequate measures for protection of public health and safety, for on-site worker life safety, for protection of the environment, and for investment protection in the event of natural phenomena hazards, specifically earthquakes. Due to the evolutionary nature of design and operating requirements as well as developments in engineering technology, DOE facilities embody a broad spectrum of design features for earthquake resistance. These features depend on factors such as vintage of the facility design and construction and hardware supplier practices at the time of design and construction. The earliest-vintage facilities often have the least design consideration for seismic and potentially exhibit the greatest difference between their design basis and what DOE requires today for seismic design criteria for new facilities.

Seismic evaluations of essential systems and equipment at many DOE facilities will be conducted over the next several years. For many of these systems and components, few, if any, seismic requirements applied to the original design, procurement, installation, and maintenance process and therefore, the evaluation of the seismic adequacy of existing systems and components presents a difficult challenge. The purpose of this Seismic Evaluation Procedure is to summarize a technical approach and provide generic procedures and documentation requirements that can be used at DOE facilities to evaluate the seismic adequacy of mechanical and electrical equipment.

This procedure is meant to comply with DOE Policy, Orders, and Standards as discussed in Section 1.2. The scope of equipment covered in this procedure includes active mechanical and electrical equipment such as batteries on racks, motor control centers, switchgear, distribution panels, valves, pumps, HVAC equipment, engine generators, and motor generators. In addition, this generic procedure includes guidelines for evaluating the seismic adequacy of tanks, heat exchangers, cable and conduit raceway systems, piping systems, HVAC ducts, architectural features and components, and relays.

The Seismic Evaluation Procedure is intended to provide DOE facility managers, safety professionals, and engineers with a practical procedure for evaluating the seismic adequacy of equipment and distribution systems. Often the approach used to review the seismic capacity of equipment is to conduct sophisticated evaluations that can be very time consuming, complex, and costly. Much of the available funding is spent on analysis rather than on the real objective of increasing the seismic capacity of equipment and distribution systems. This procedure is designed to be an extremely cost-effective method of enhancing the seismic safety of facilities and reducing the potential for major economic loss that can result from equipment and systems damaged or destroyed by an earthquake.

The following sections provide the background for the development of the DOE Seismic Evaluation Procedure. First, DOE Orders and Standards that address natural phenomena hazards are discussed since a purpose of the DOE Seismic Evaluation Procedure is to provide a procedure that satisfies the requirements of these Orders and their supporting standards. Second, a methodology that was developed for older nuclear power plants to satisfy safety issues raised in the late 1970s is discussed. This methodology or procedure is based on seismic experience data and screening evaluations. The nuclear power industry concluded that the methodology was the most viable option to resolve safety issues as compared with testing or analysis. Testing or analysis were often not viable due to problems of removal, decontamination, shipment of equipment for testing, access, and potential damage from in-situ testing. Next, the extension to DOE facilities of the procedure developed for nuclear power plants is discussed. Applications at nuclear power plants and DOE facilities have demonstrated that a seismic evaluation using the methodology based on experience data is the only viable option for many systems and components. Finally, the license which regulates the use of background material for the DOE Seismic Evaluation Procedure is discussed.

1.2 DOE ORDERS AND STANDARDS

The DOE Seismic Evaluation Procedure is intended to comply with DOE Policy, Orders, and Standards on natural hazards mitigation which allow for the seismic evaluation of systems and components by analysis, testing, or the use of earthquake experience data. These include DOE Order 420.1, "Facility Safety" (Ref. 5), and its Implementation Guide; a rule currently under development; and supporting Standards. The two supporting Standards most relevant to this procedure are DOE-STD-1020, "Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities" (Ref. 6) (see Section 2.4.1 of DOE-STD-1020) and DOE-STD-1021, "Natural Phenomena Hazard Performance Categorization Guidelines for Structure, Systems, and Components" (Ref. 7). DOE Order 420.1 is a replacement order for DOE Order 5480.28, "Natural Phenomena Hazards Mitigation" (Ref. 8).

DOE Orders and Standards for natural phenomena hazards mitigation are closely linked to those for safety analysis. DOE Order 5480.23 (Ref. 9) requires that safety analyses be performed that develop and evaluate the adequacy of a DOE nuclear facility's safety basis and that the analyses be documented in a Safety Analysis Report (SAR). To assist in preparing a SAR, DOE-STD-1027 (Ref. 10) and DOE-STD-3009 (Ref. 11) provide guidance on hazard categorization and SAR implementation, respectively. Using a graded approach unique to DOE, systems and components are subjected to different seismic design and evaluation criteria that correspond to safety system and facility hazard classifications. The graded approach and wide diversity of DOE facilities' functions and designs require that the methodology developed for equipment in commercial nuclear power plants, as discussed in the next section, be modified for use at DOE facilities.

1.3 USE OF SEISMIC EXPERIENCE DATA IN NUCLEAR POWER PLANTS

1.3.1 Background[1]

The requirements for seismic design of nuclear power plants from 1960 to the present have evolved from the application of commercial building codes, which use a static load coefficient approach applied primarily to major building structures, to more sophisticated methods today. Current seismic design requirements for new nuclear power plants consist of detailed specifications that include dynamic analyses or testing of safety-related structures, equipment, instrumentation, controls, and their associated distribution systems, such as piping, cable trays, conduit, and ducts. In the late 1970s, the U.S. Nuclear Regulatory Commission (NRC) expressed the concern that nuclear equipment seismically qualified to standards preceding IEEE-344-1975 (Ref. 12) might not provide sufficient assurance of seismic adequacy. This concern was reinforced through field inspections of older-vintage nuclear power plants where equipment was found to lack adequate anchorage.

The NRC initiated Unresolved Safety Issue (USI) A-46, "Seismic Qualification of Equipment in Operating Plants" (Ref. 13) in December of 1980, to address the concern that a number of older operating nuclear power plants contained equipment which may not have been qualified to meet newer, more rigorous seismic design criteria. Much of the equipment in these operating plants was installed when design requirements, seismic analyses, and documentation were less formal than the rigorous practices currently being used to build and license nuclear power plants. However, it was realized that it would not be practical or cost-effective to develop the documentation for seismic

[1] Based on Section 1.2 of SQUG GIP (Ref. 1)

qualification or requalification of safety-related equipment using procedures applicable to modern plants. Therefore, the objective of USI A-46 was to develop alternative methods and acceptance criteria that could be used to verify the seismic adequacy of essential mechanical and electrical equipment in operating nuclear power plants. The NRC pursued several options for the resolution of USI A-46, including use of shake table testing, in-situ testing, deterministic and probabilistic analytical methods, and seismic experience data. Most options proved not to be viable because of the unavailability of older model components for testing, the high costs of component replacements, and complications of testing radiologically contaminated equipment. The NRC concluded that the use of experience data could provide a reasonable alternative for resolution of USI A-46.

In early 1982, the Seismic Qualification Utility Group (SQUG) was formed for the purpose of collecting seismic experience data as a cost-effective means of verifying the seismic adequacy of equipment in operating plants. One source of experience data was the numerous non-nuclear power plants and industrial facilities which had experienced major earthquakes. These facilities contained industrial grade equipment similar to that used in nuclear power plants. Another source of seismic experience data was shake table tests that had been performed since the mid 1970's to qualify safety-related equipment for licensing of nuclear plants. To use these sources of seismic experience data, SQUG and the Electric Power Research Institute (EPRI) collected and organized this information and developed guidelines and criteria for its use. The guidelines and criteria provided the generic means for applying experience data to verify the seismic adequacy of mechanical and electrical equipment required to be used in a nuclear power plant during and following a safe shutdown earthquake (SSE). According to 10CFR100 Appendix A (Ref. 14), the SSE is defined as the earthquake which is based upon the maximum earthquake potential considering both regional and local geology, seismology, and local subsurface materials. For nuclear power plants, the SSE is also referred to as the Design Basis Earthquake. The ground motion at the nuclear facility associated with the SSE is used for the design of equipment, structures, and systems necessary for: the integrity of the reactor coolant pressure boundary, the capability to shut down and maintain the reactor in a safe shutdown condition, and the capability to prevent or mitigate potential offsite exposures.

1.3.2 Approach

The approach developed by SQUG and EPRI for verifying the seismic adequacy of mechanical and electrical equipment is consistent with the intent of NRC Generic Letter (GL) 87-02, "Verification of Seismic Adequacy of Mechanical and Electrical Equipment in Operating Reactors, Unresolved Safety Issue (USI) A-46" (Ref. 15), NUREG-1030 (Ref. 16), and NUREG-1211 (Ref. 17). The approach is also consistent with the EPRI Seismic Margins Assessment Program described in Reference 18. NRC approval of the approach was based on research done at several DOE national laboratories and on extensive independent review by the Senior Seismic Review and Advisory Panel (SSRAP). The summary of the SSRAP review is contained in Reference 19. In 1987, NRC GL 87-02 required utilities to respond to USI A-46, and encouraged participation in generic resolution by using the SQUG approach, documented in the Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment (Ref. 1). NRC accepted the SQUG GIP (also referred to as the Industry GIP) with a generic safety evaluation report (Ref. 2). There were a few exceptions that have since been resolved and are being incorporated into Revision 3 of the SQUG GIP (Ref. 4). The SQUG GIP consists of four sets of criteria:

1) the experience-based capacity spectrum must bound the plant seismic demand spectrum,
2) the equipment item must be reviewed against certain inclusion rules and caveats,
3) the component anchorage must be evaluated, and
4) any potentially significant seismic systems interaction concerns that may adversely affect component safe shutdown function must be addressed.

These SQUG criteria are in the form of screening evaluation guidelines. Items not passing the screen, called outliers, are not necessarily inadequate, but other seismic engineering methods must be used to further evaluate these items.

The screening evaluation adopted in the SQUG GIP is generally a conservative and rapid appraisal process that is used during a facility walkdown to verify acceptability or identify outliers by review of key physical attributes. A model of the screening evaluation process is shown in Figure 1.3-1. Items passing the screen are verified as acceptable and may be documented as such, or can be selected for a bounding sample analysis to validate the evaluation results. Items not passing the screen are not verified and are formally designated as outliers, which must be subject to more detailed review or upgrade before being accepted. The SQUG GIP screening evaluation process is performed primarily during in-plant walkdowns and for a limited set of equipment, or Safe Shutdown Equipment List (SSEL), required to bring a plant to hot shutdown and maintain it there for 72 hours. Prior to a screening evaluation, a systems review is conducted to assess the minimal and prioritized scope of equipment for the evaluation.

Results of the work in compiling earthquake experience data by SQUG found the following: (1) conventional power plant and industrial facility equipment are generally similar to that found in older, operating nuclear power plants and, (2) equipment, when properly anchored, will generally perform well in earthquakes at levels of shaking in excess of the SSE for many nuclear power plants. SQUG, EPRI, and SSRAP developed the caveats and inclusion rules that help to ensure functionality and structural integrity of equipment when using the experience-based methodology. Caveat and inclusion rules determine whether or not an item of equipment is sufficiently similar to data from past earthquake or testing experience. The SQUG program is considered by most, including the NRC and all of the SQUG utility members, to be a major engineering breakthrough and an overall success. Important methods utilized by SQUG include: utilization of screening criteria implemented during walkdowns that is coupled with review team engineering training, screening criteria primarily based on natural phenomena experience data that is supplemented with test and analysis, programmatic direction given by facility management and engineering, technical review and advice provided by an independent panel of industry experts, and establishing priority listing of systems and components based on systems analysis.

An important element of the SQUG GIP is its application by the use of specially trained and experienced seismic review teams who must exercise considerable judgment while performing the in-plant screening evaluations. Besides establishing strict qualification requirements for review team engineers, SQUG and EPRI provide a training course in the use of the implementation guidelines and procedures.

The EPRI / SQUG seismic evaluation methodology based on experience data has become a key element in the ongoing earthquake evaluations for commercial nuclear power plants. The experience-based evaluation methods address most plant components needed for safe shutdown in the event of a SSE. These components include 20 classes of electrical and mechanical equipment, cable trays and conduit systems, relays, anchorage, tanks and heat exchangers. For each type of component, the seismic evaluation methodology provides experience data that documents the performance of systems and components that have been subjected to earthquake motion. The data includes components in commercial and industrial facilities that were in the strong motion regions of major earthquakes. SQUG and EPRI have developed a seismic experience data base that includes the response of systems and components in about 100 (typically non-reactor) facilities located in areas of strong ground motion from 20 earthquakes. The earthquakes have Richter magnitudes in the range of 5.2 to 8.1, have peak ground accelerations from 0.10g to 0.85g, and have about 3 to 50 second durations. Soil conditions, building structure types, and location of equipment vary considerably within the data base.

The facilities surveyed and documented contain a large number of mechanical and electrical equipment, and control and distribution systems that are identical or very similar to those found in nuclear power plants. Information sources consist of interviews with facility management and operating personnel, walkdown inspections of facilities, photographs and performance data records of systems and components, facility operating logs, and the facility's inspection reports. Design criteria and specifications, component data books, and design drawings are additional sources of information. There is diversity in equipment design, size, configuration, age, application, operating conditions, manufacturer, and quality of construction and maintenance. The earthquake experience data are useful for determining common sources of seismic damage or adverse effects of equipment and facilities, thresholds of seismic motion corresponding to various types of seismic performance, and standards in equipment construction and installation to ensure the ability to withstand anticipated seismic loads.

As an expansion of the earthquake experience data, EPRI and SQUG also collected data on shake-table qualification tests from utilities, manufacturers, and test laboratories. Results were compiled from about 300 shake table tests of equipment components, covering 15 generic classes of equipment. The objective was to compile the information by class, and to obtain generic insights, if any, that could be used to assist utilities in evaluating these equipment classes in their plants. These generic equipment ruggedness data represent substantially higher levels of seismic motion than the earthquake experience data, but in most cases, are applicable to a narrower range of equipment parameters. EPRI and SQUG also obtained available electro-mechanical relay chatter shake table tests and performed additional tests for other relays. The relay test experience data base provides capacities for about 150 specific models of relays.

Another important element of seismic experience data is information on the anchor bolts that are commonly used to attach systems and components to the supporting building structure. EPRI and SQUG have summarized capacity information for expansion anchor bolts, covering about 1200 ultimate capacity tension and shear tests. Capacity data have also been compiled for other anchor types including welded attachments, cast-in-place bolts and headed studs, grouted-in-place anchors, and cast-in-place J-hooks.

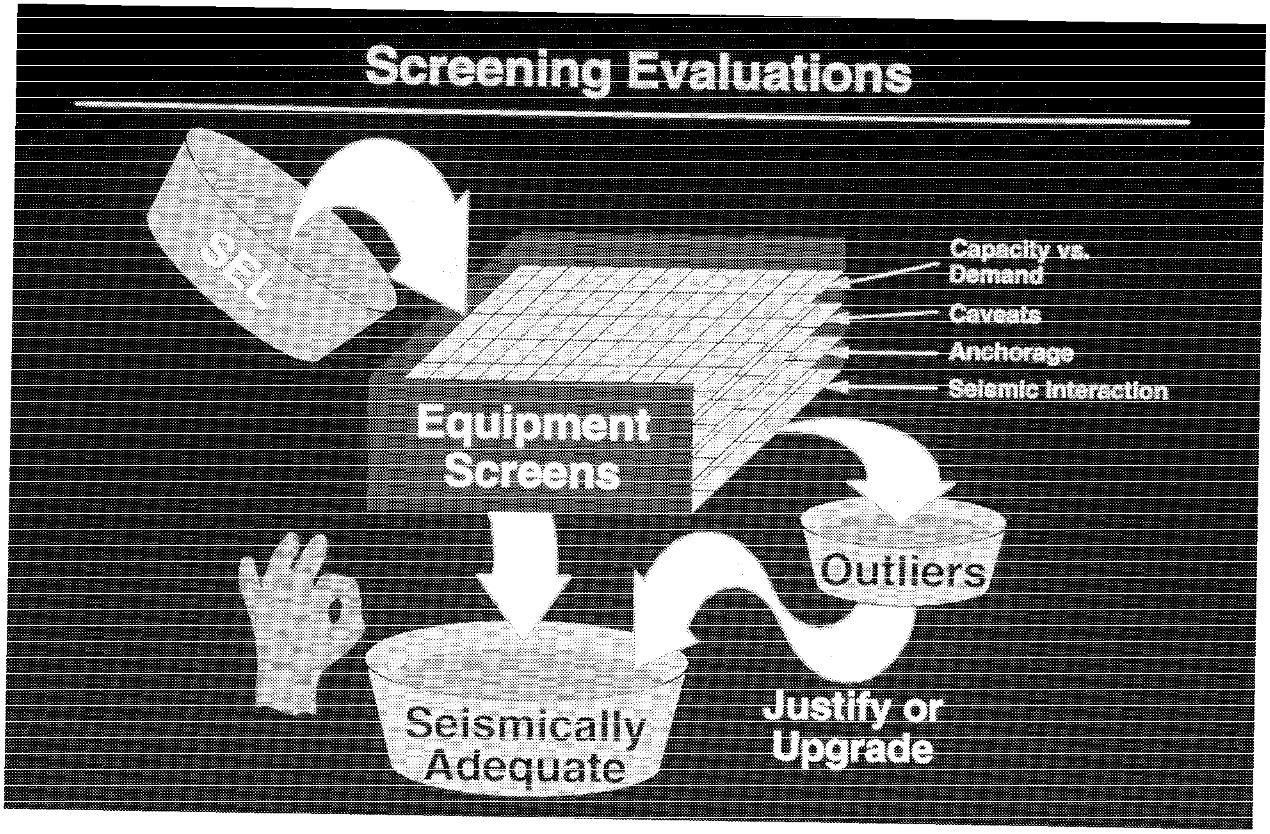

Figure 1.3-1 The DOE Seismic Evaluation Procedure contains the screening evaluation approach. The process begins with the development of the Seismic Equipment List (SEL).

1.4 USE OF SEISMIC EXPERIENCE DATA IN DOE FACILITIES

1.4.1 DOE Existing Facilities Program

A DOE Existing Facilities Program was implemented for the development of seismic evaluation guidelines for systems and components at existing facilities. A Program Plan (Ref. 20) for the Existing Facilities Program maximizes the use of past experience in conjunction with a walkdown screening evaluation process in order to meet the policy of applicable DOE Orders and Standards. The process of evaluating existing DOE facilities for the effects of natural phenomena hazards was patterned after the SQUG program for commercial nuclear power plants, which is discussed in Section 1.3. As discussed in Section 1.5, the SQUG and EPRI reference documents, which provide the basis for the use of experience data, are being used by DOE through a special agreement between Lawrence Livermore National Laboratory (LLNL) and EPRI. The use of seismic experience data, specifically the EPRI / SQUG data, for DOE seismic evaluations was recommended in a position paper (Ref. 21) authored by personnel from many DOE facilities. In addition, a letter (Ref. 22) from Robert Kennedy, a member of SSRAP who has also been involved in the technical review of the DOE Seismic Evaluation Procedure, endorses the use of experience-based seismic evaluations for equipment in existing DOE facilities.

A Walkthrough Screening Evaluation Field Guide (Ref. 23) was developed to assist in rapidly identifying major deficiencies at existing DOE facilities. The document was developed based on walkdown experience at nuclear power plants, revised after applying it to walkdowns at selected DOE facilities, and used as an interim methodology before the DOE Seismic Evaluation Procedure was fully developed. The purpose of the Field Guide was to direct walkthrough screening evaluations of DOE facilities in the technical area involving potential hazards caused by natural phenomena. Using the Field Guide, the walkthrough screening evaluation is a facility appraisal of key physical attributes. Items that pass the screen are considered to possess no obvious deficiencies and documented evaluation may be deferred. Items not passing the screen may be of concern such that detailed review or upgrade may be appropriate for these cases depending on potential risk. The methodology in the DOE Seismic Evaluation Procedure is a more thorough extension of the concepts developed in the Field Guide.

1.4.2 Development and Technical Review of the DOE Seismic Evaluation Procedure

The DOE Seismic Evaluation Procedure is based on Part II of Revision 2 of the SQUG GIP. Since DOE facilities, objectives, and criteria are different from those for commercial nuclear power plants, the DOE Seismic Evaluation Procedure has been enhanced with information from the SEP-6 (Ref. 3) developed for the Savannah River Site (SRS) and from several DOE guidance documents. In addition, DOE-specific requirements and guidance and equipment classes not contained in the SQUG GIP, such as piping systems and unreinforced masonry walls, have been included in the DOE Seismic Evaluation Procedure. The DOE classes of equipment are contained in Chapter 10 and their development and pedigree are discussed in Section 2.1.3.4.4. Nuclear power plant and NRC-specific requirements from the SQUG GIP have been removed and an attempt is made to reduce some of the repetition in the SQUG GIP and make the procedure less cumbersome to use. Additional information on the differences of the DOE Seismic Evaluation Procedure and the SQUG GIP is contained in the Foreword.

Since DOE facilities are not structurally equivalent to nuclear power plants, which are typically stiff, shear wall structures, the approach in the SQUG GIP for comparing seismic capacity with seismic demand has been modified for DOE usage. An assessment (Ref. 24) was done of the performance goals that are achieved when seismic experience-based screening evaluation methods are used. In contrast to the SQUG deterministic criteria, DOE facilities are required to demonstrate the ability to achieve probabilistic performance goals. As discussed in Chapter 5, experience data factors are used to scale in-structure response spectra that are derived from the Design Basis Earthquake (DBE) for a facility. The scaled in-structure spectra, or the Seismic Demand Spectrum (SDS), are compared with experience-based capacity spectra.

DOE facility management and operations personnel have played an important role in the development and review of the approach implemented by the DOE Seismic Evaluation Procedure. A Steering Group of selected individuals from the DOE operating contractors have ensured that appropriate priorities were established from the facility operations perspective. The Steering Group is a five-member panel, which is nominated by DOE and its consultants, and is considered a key element to the success of the overall approach presented in the DOE Seismic Evaluation Procedure. The Steering Group has the primary responsibility of reviewing the DOE Seismic Evaluation Procedure in conjunction with a check of technical content and potential impact to a site from a cost, schedule, or operations standpoint. In addition, the Steering Group played a decisive role in the selection of the technology transfer mechanisms for the facility evaluations. Members of the Steering Group and appropriate support personnel have met regularly to discuss and decide on issues affecting the procedures. Examples of issues for which the Steering Group provided a decisive role toward final outcome include implementation procedures, documentation requirements, scope of detailed system and component evaluation tools, peer review requirements, anticipated level of effort for the reviews, and system prioritization guidelines for a facility. The Steering Group also formed a technical review committee to conduct an independent and thorough technical review of the information in the DOE Seismic Evaluation Procedure. The review committee was modeled after SSRAP which was used for the technical review of the SQUG GIP. Members of the review committee were Robert Budnitz, Robert Kennedy, and Loring Wyllie. Since Robert Kennedy participated in the development of Section 10.5.1, he was not an independent technical reviewer of that section.

Two preliminary drafts of the DOE Seismic Evaluation Program were prepared in January and June of 1995. The June 1995 Draft was technically reviewed by staff at DOE, personnel at DOE sites, and several consultants. Based on the review comments, a second Draft of the DOE Seismic Evaluation Procedure (Ref. 25) was published in September 1995 for review by the DOE, personnel from DOE sites, technical consultants, and attendees of DOE training courses on the EPRI / SQUG methodology. A Final Draft of the Procedure (Ref. 26) was published in November 1996 and it incorporated detailed review comments from the technical reviews of the September 1995 Draft of the Procedure. Following a technical review of the Final Draft, minor modifications were made to the Procedure, except for Section 10.5.1 on Unreinforced Masonry (URM) Walls. Robert Murray and Robert Kennedy extensively revised Section 10.5.1 to incorporate review comments and enhance the methodology in that section.

The technical reviews of the DOE Seismic Evaluation Procedure, which are listed in Table 1.4-1, have provided information for improving portions of the procedure and for emphasizing the appropriateness of using experience data for evaluating the seismic adequacy of equipment. The primary charter of the technical reviews was to independently determine the adequacy of the technical content of the screening evaluation guidelines, including the safety margins that result from implementation of the criteria. For sections of the DOE Seismic Evaluation Procedure that are identical or technically equivalent to corresponding sections in the SQUG GIP, the technical aspects of these sections were reviewed as part of the SSRAP and other reviews of the SQUG GIP as listed in Table 1.4-1. While the technical reviews of the DOE Seismic Evaluation Procedure were modeled after SSRAP, the technical reviews of the DOE Procedure did not involve as many reviewers as the review of the SQUG GIP and did not require formalized consensus building between the DOE and the technical reviewers. Technical reviewers of the DOE Seismic Evaluation Procedure, especially the technical consultants, have extensive experience in the evaluation of the seismic adequacy of equipment and were members of SSRAP or were involved with the development of the SQUG GIP. The emphasis of the technical review of the DOE Seismic

Evaluation Procedure was the sections of the procedure that are different from the SQUG GIP and there was special focus on Chapter 10, which contains classes of equipment that are not in the SQUG GIP. The key technical consultants reviewing the DOE procedure included Robert Budnitz, Robert Kennedy, and Loring Wyllie as members of the technical review committee. These review efforts were supplemented by reviews by DOE staff and personnel at DOE sites, especially SRS and LLNL, and several engineers from EQE International who had extensive experience with the SQUG GIP.

In addition to the overall review of the DOE Seismic Evaluation Procedure, several sections of the procedure, as listed in Table 1.4-1, received specialized or additional review and in some cases, information about the reviews is referenced. The methodology in Reference 24, which is the basis for Chapter 5, was reviewed by John Reed and Section 10.1.1 on piping was reviewed by Ed Wais (Ref. 27). Section 10.4.1 on HVAC ducts is based on a procedure used at SRS (Ref. 28) and this procedure has been subjected to independent technical review by DOE staff, personnel at DOE sites, and technical consultants. Section 10.3.1 on underground tanks and Section 10.1.2 on underground piping are based on a DOE report that was developed at Brookhaven National Laboratory (Ref. 29) and has been reviewed by DOE staff, personnel at DOE sites, technical consultants, and the American Society of Civil Engineers, Dynamic Analysis of Nuclear Structures Committee. An independent review of Section 10.5.1 on unreinforced masonry walls was performed at the Lawrence Livermore National Laboratory.

Table 1.4-1 Technical Reviews of DOE Seismic Evaluation Procedure

Chapter or Section of the DOE Seismic Evaluation Procedure	Technical Aspects Reviewed as Part of SQUG GIP	Reviewed by Technical Consultants for the DOE	Specialized Review for the DOE
Chapter 1		X	
Chapter 2		X	
Chapter 3		X	
Chapter 4		X	
Chapter 5		X	X
Chapter 6	X	X	
Chapter 7	X	X	
Chapter 8	X	X	
Chapter 9	X	X	
Section 10.1.1		X	X
Section 10.1.2		X	X
Section 10.2		X	
Section 10.3.1		X	X
Section 10.3.2		X	
Section 10.4.1		X	X
Section 10.5.1		X	X
Section 10.5.2		X	
Section 10.5.3		X	
Chapter 11	X	X	
Chapter 12	X	X	
Chapter 13	X	X	
Chapter 14		X	

Additional information for the development of the DOE Seismic Evaluation Procedure has come from trial applications of the September 1995 Draft at the SRS, Rocky Flats Environmental Technology Center (RFETC), the Los Alamos National Laboratory (LANL), the Stanford Linear Accelerator Center (SLAC) and LLNL. Feedback from these applications of the DOE procedure have been incorporated as appropriate.

The technical review of the DOE Seismic Evaluation Procedure and the endorsement of its use for the DOE is summarized in a letter (Ref. 30) from a technical review committee consisting of Robert Budnitz, Robert Kennedy, and Loring Wyllie. This letter is attached at the end of the Foreward with the following three review comments:

(1) the use of the DOE Seismic Evaluation Procedure is endorsed for the seismic evaluations of existing DOE facilities,

(2) the use of additional equipment categories beyond those in the SQUG GIP is supported for the DOE Seismic Evaluation Procedure, and

(3) the use of the DOE Seismic Evaluation Procedure for new equipment is supported with caution.

It is intended that the DOE Seismic Evaluation Procedure will be revised and updated as appropriate. As screening procedures are developed and reviewed for other classes of equipment, these procedures can be added to the DOE procedure. Section 2.1.3.4 discusses some of the other classes of equipment that can be added to future versions of the DOE procedure. As the SQUG GIP is revised and the information in the earthquake experience database and shake table testing database is enhanced, the appropriate modifications will be made to the DOE Seismic Evaluation Procedure.

1.4.3 Applications at DOE Facilities

The SQUG experience-based seismic evaluation approach has been used at many DOE facilities. The most extensive application has been at the SRS which has reactors that are similar to commercial nuclear power plants. The SRS reactors were built in the 1950s when seismic qualification requirements were in their infancy. SRS became a member of SQUG in 1988, and used the SQUG GIP at its K, L and P reactors to evaluate the seismic adequacy of selected safety systems for their Design Basis Earthquake (DBE). The SRS reactor program included definition of the system scope requiring review; development of SRS facility-specific procedures; use of seismic screening evaluation walkdowns and calculations; and identification, resolution, and upgrading of outliers.

The seismic evaluation program at SRS expands the SQUG GIP in several areas including programmatic changes to enhance engineering assurance. Several technical changes were added to address unique needs at SRS such as additional steps for expansion anchor evaluation, development of capacity for lead cinch anchors, implementation of consistent guidelines for HVAC ducting (Section 10.4.1), and use of experience-based screening guidelines for piping (Section 10.1.1). SRS developed a Seismic Engineering Procedure (SEP-6) (Ref. 3) that includes sections on licensing, the SQUG GIP, and site-specific topics. Portions of the SRS-developed SEP are used in the DOE Seismic Evaluation Procedure.

The SRS seismic evaluation program was judged to be a success with roughly 60% of the items that were evaluated to be seismically adequate as-is. For the others, about 11% were resolved by additional evaluation and the remainder were resolved by upgrade. The typical upgrades consisted of anchorage enhancement and elimination of seismic interaction concerns by providing restraint or removal of the interaction source. The use of the experience-based evaluation approach enabled efficient identification of realistic seismic concerns at SRS. Maximum safety enhancement was achieved with a reasonable engineering effort.

The seismic experience-based approach is currently being used at SRS to evaluate non-reactor facilities. According to Reference 31, seismic qualification using experience data is a technical necessity and is the most economically attractive of the options to qualify existing equipment at SRS. At two SRS facilities, representative costs for seismic qualification using the methodology in the SRS SEP-6 demonstrate costs are 70% lower than the costs for qualification using conventional methods such as seismic testing or detailed engineering analyses.

Similar benefits from use of experience data were realized at the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory. Prior to facility restart, seismic verification of essential systems and components had to be demonstrated. Experience-based screening evaluations were used as a key part of the seismic evaluation and upgrade program. Several items were determined to be acceptable in their as-installed configuration. Backfit modifications were installed to increase seismic adequacy as needed. This included providing anchorage for some components, additional restraint for items where deflection considerations governed capacity, and correction of potential seismic systems interaction hazards.

Other applications of using experience data for the evaluation of seismic design issues at DOE facilities include the Princeton Plasma Physics Laboratory, the Idaho Chemical Processing Plant (ICPP), Y-12 at Oak Ridge, and RFETC. At Princeton, active electrical and mechanical equipment, fluid pressure boundary components, and seismic interaction effects were evaluated and resolved by use of experience-based methods. The seismic adequacy of critical fire protection components was evaluated using the experience-based approach at ICPP. Using the methodology in Section 10.1.1, the seismic adequacy of piping systems have been evaluated at Y-12 and RFETC.

The applications at SRS, HFIR, Princeton, and ICPP have proven the viability of using the methodology developed by EPRI / SQUG based on seismic experience data. Many of the results of these evaluations have withstood strict scrutiny during technical audits, peer reviews, quality control audits, and other independent reviews. The approach is also being applied to facilities at LANL, LLNL, and SLAC. Further discussion of the use of experience data for seismic evaluations is provided in Chapter 9 of the "Seismic Safety Manual" (Ref. 32), which was prepared for the DOE. With the experience from the nuclear power industry coupled with numerous applications at DOE sites, the consistent approach in the DOE Seismic Evaluation Procedure for the application of experience data provides DOE sites with an efficient tool for performing their necessary seismic evaluations.

1.4.4 Post-Earthquake Investigations

An important element of the development of the DOE Seismic Evaluation Procedure has been post-earthquake investigations after significant earthquakes. Each significant earthquake provides important lessons that reemphasize and provide new information about designing and retrofitting equipment for strong seismic motion. Since a major component of the EPRI / SQUG methodology is experience data, the data must be appropriately augmented and enhanced with information from recent and significant earthquakes. In many cases, recent earthquakes have provided information which emphasizes the procedures and screens already developed for the EPRI / SQUG methodology.

Post-earthquake investigations are vital to determine if any part of the methodology should be modified or developed further. With each significant earthquake, the experience database will be updated to reflect the results of post-earthquake investigations. Since the DOE Seismic Evaluation Procedure contains classes of equipment and distribution systems that are not included in the SQUG GIP, post-earthquake investigations sponsored by the DOE will focus on these classes of equipment. As data is gathered on these classes of equipment, rigorous procedures for determining equipment capacity can be developed based on the collected information.

Recent earthquakes have provided valuable information about the performance of equipment during seismic strong motion. Details about the performance of industrial facilities and their associated equipment during recent earthquakes are contained in many documents including References 33 and 34. Information in these references emphasizes the response of equipment similar to the types of equipment included in the DOE Seismic Evaluation Procedure. Figures 1.4-1 to 1.4-9 show examples of the performance of equipment, systems, and architectural features subjected to relatively strong seismic motion during recent earthquakes that are similar to the classes of equipment discussed in Chapters 8, 9, 10, and 11.

As appropriate, data from recent earthquakes can be incorporated into the DOE Seismic Evaluation Procedure. In Section 12.2, a potential method for resolving outliers, or equipment that does not meet the intent of the caveats in the DOE Seismic Evaluation Procedure, involves expanding the earthquake experience database to include the equipment or specific features of the equipment. The scope of the earthquake experience data documented in References 19 and 35 represents only a portion of the total data available. Extension of the generic experience equipment classes beyond the descriptions in the DOE Seismic Evaluation Procedure is subject to DOE review and to an external peer review. The external peer review is to be of similar caliber as that required during the original development of the earthquake experience database. An extension of the database must have as rigorous a basis as the information that is currently contained in References 19 and 35.

In addition to post-earthquake investigations, there is a significant amount of seismic data at DOE facilities in the form of shake-table test data. This DOE shake-table test data can be incorporated into the DOE Seismic Evaluation Procedure applying the same considerations for expanding the earthquake experience database as discussed above.

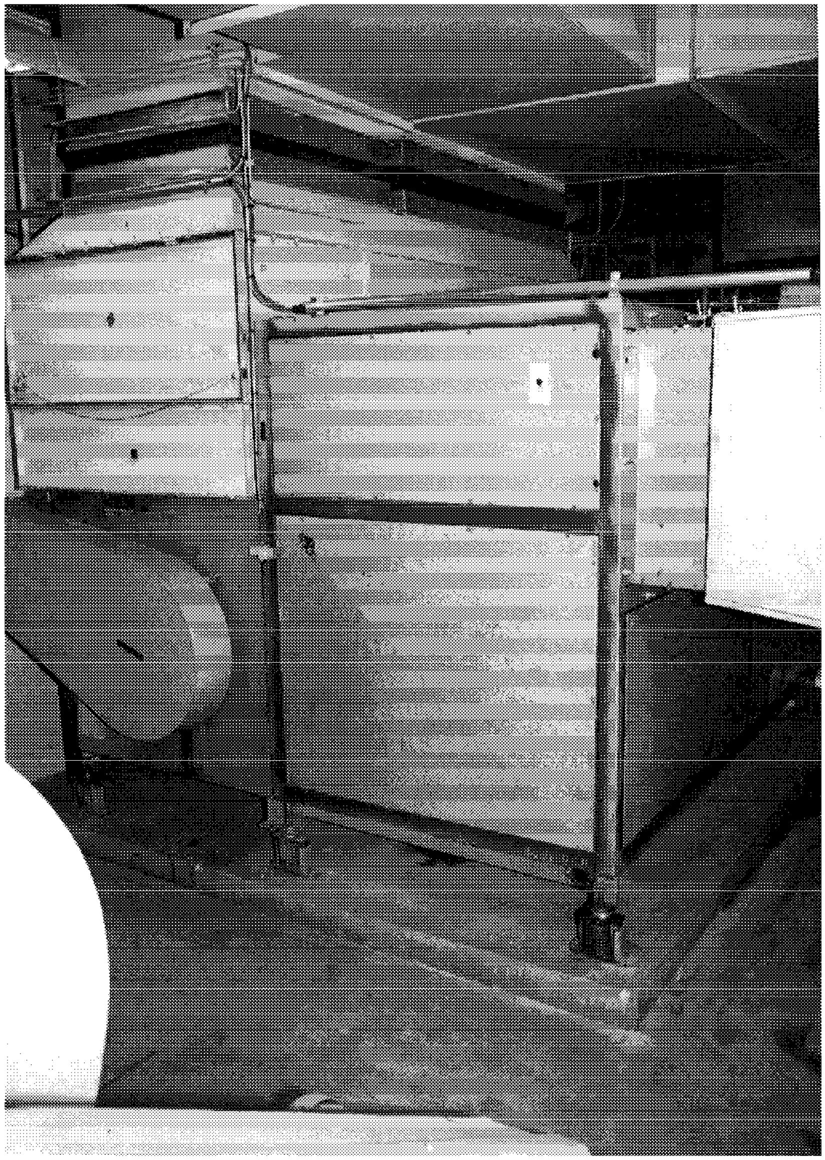

Figure 1.4-1a **Shown is an example of vibration isolators without adequate seismic bumpers. This air-handler unit suffered damage at an electrical substation during the 1994 Northridge Earthquake. (Reference 33)**

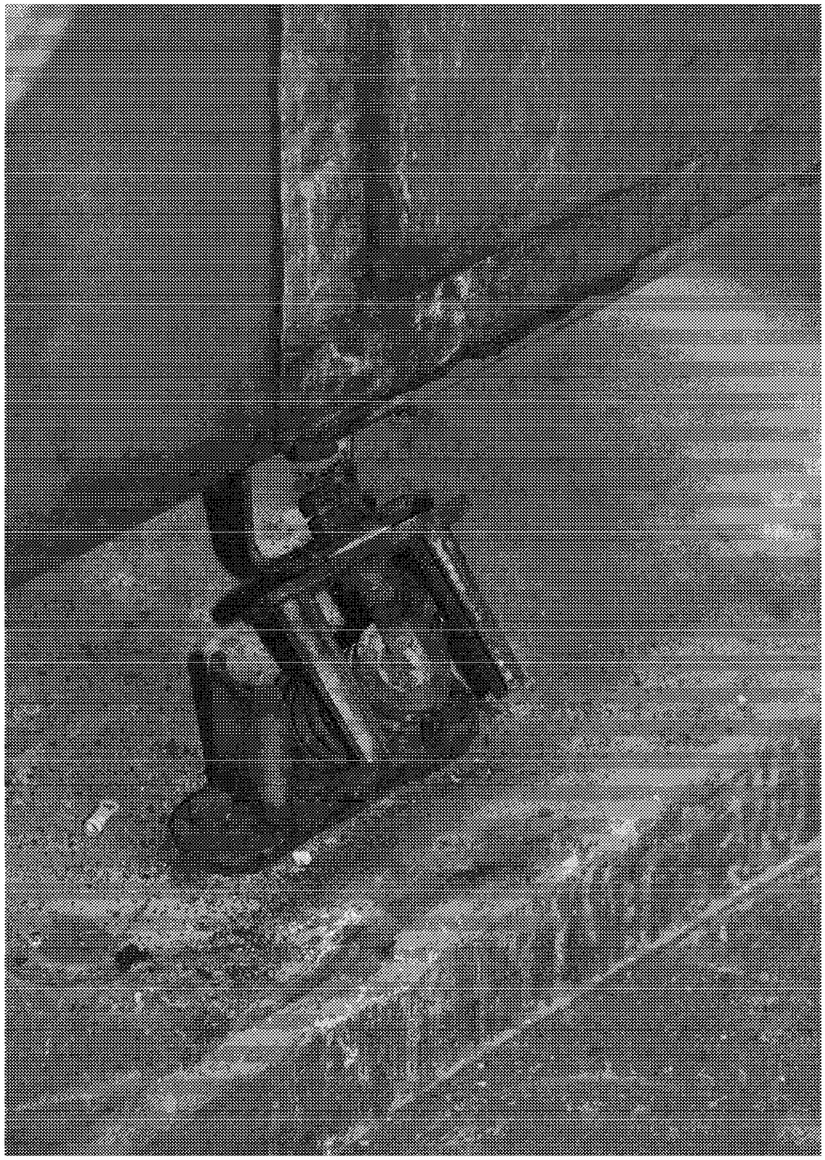

Figure 1.4-1b **Shown is a close-up of vibration isolators without adequate seismic bumpers. (Reference 33)**

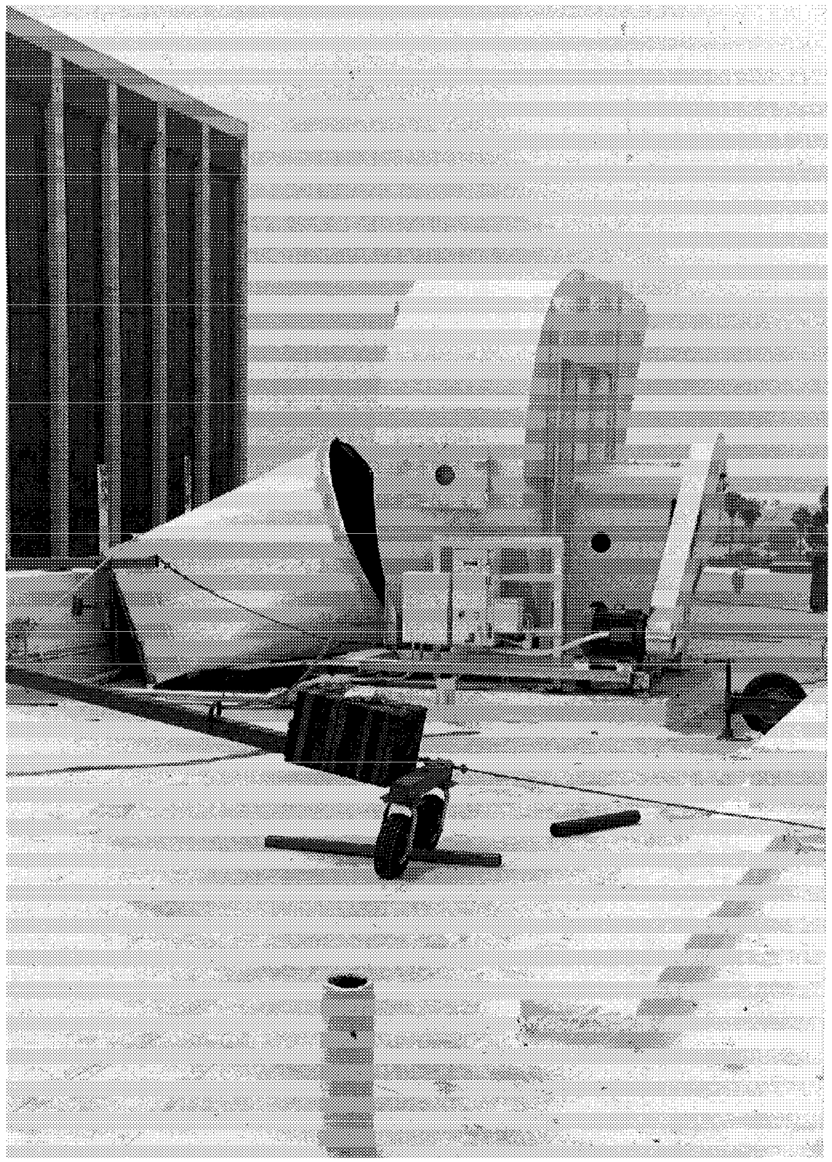

Figure 1.4-2 **On the roof of a six-story hospital, a plenum pulled loose from its fan enclosure during the 1994 Northridge Earthquake. (Reference 33)**

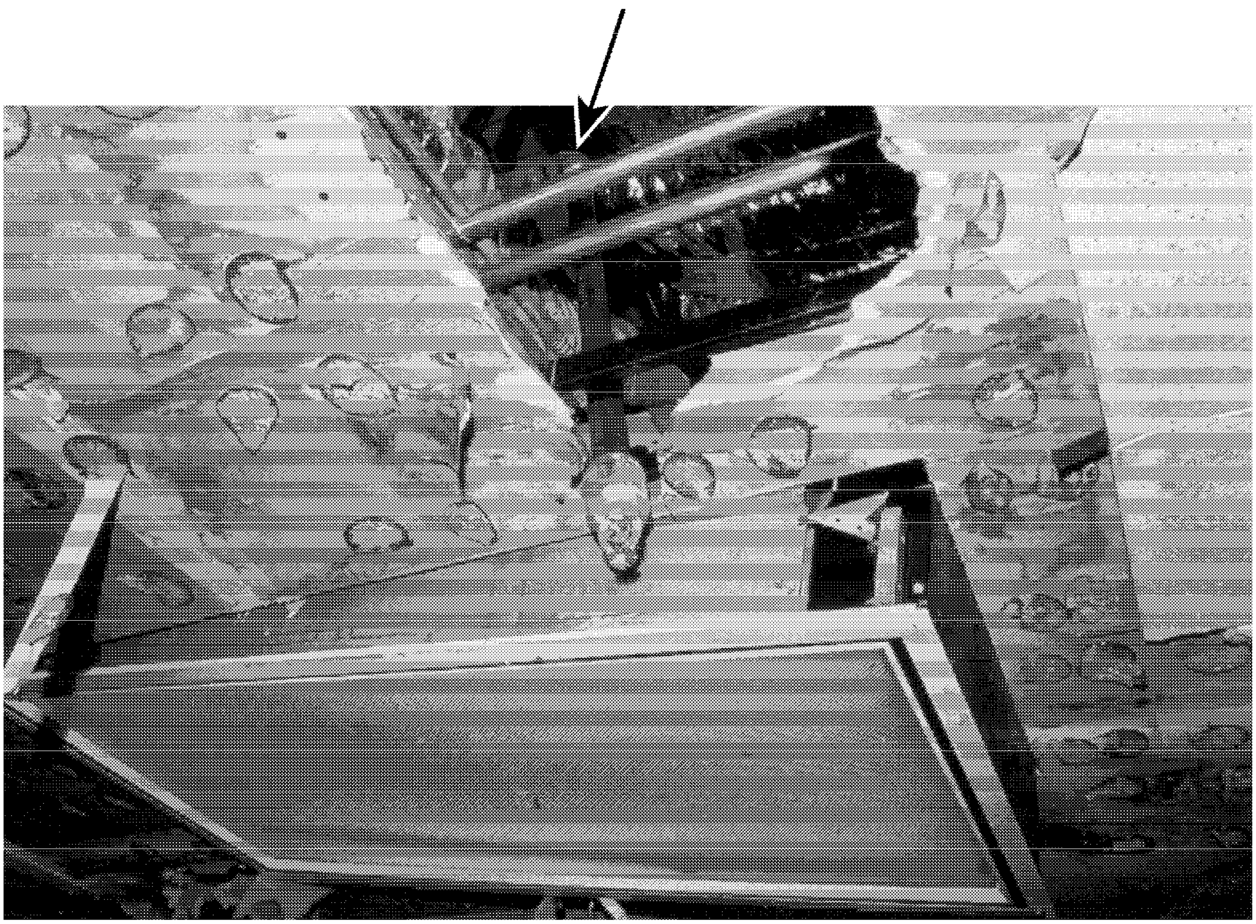

Figure 1.4-3 **Water spray following an earthquake was a major seismic interaction issue during and directly after the 1994 Northridge Earthquake. As shown in this figure, fire sprinkler piping broke at threaded elbow joints of the vertical branches that suspend the sprinkler heads. Damage to the fire sprinkler piping at several facilities caused these facilities to shut down following the earthquake, even though the buildings had no structural damage. (Reference 33)**

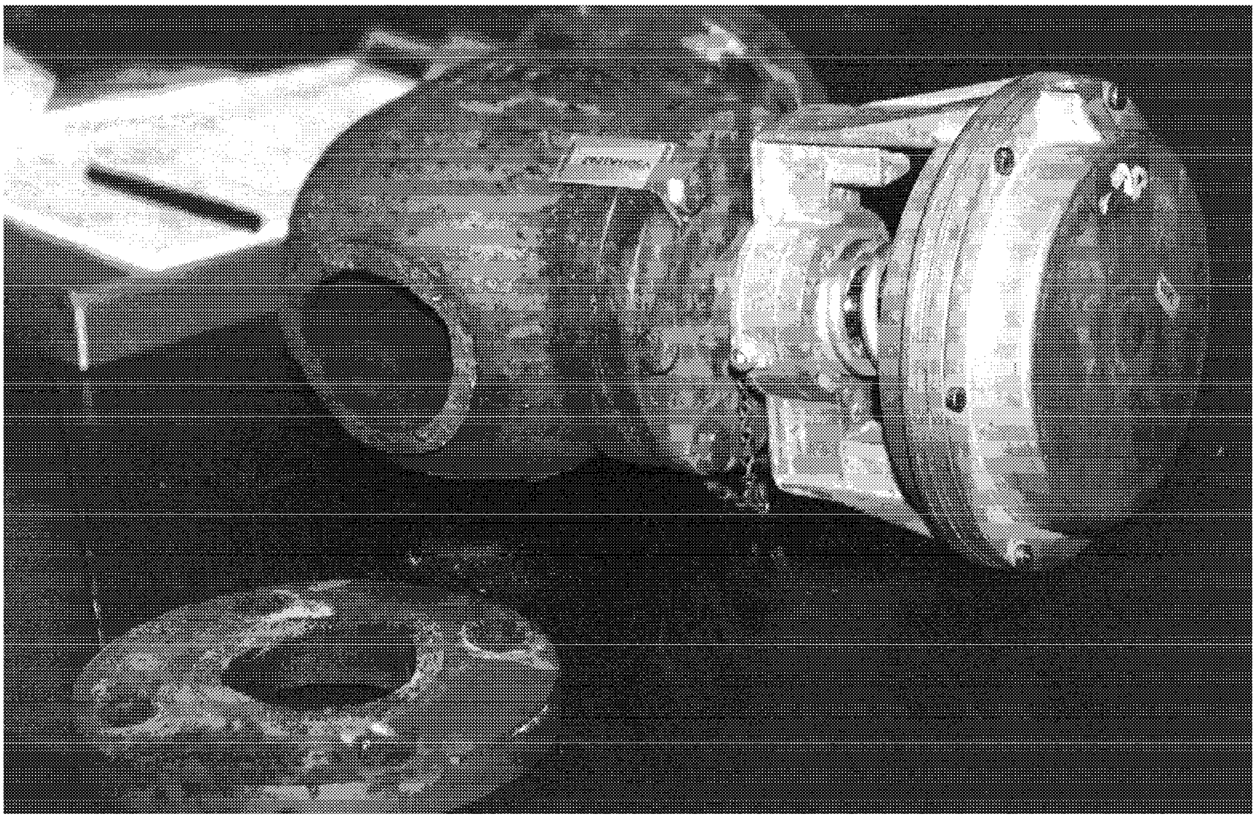

Figure 1.4-4 In a penthouse above the sixth story of a hospital, a cast-iron valve body failed near its flange due to inertial forces on a 4-inch diameter chilled water line and allowed water to leak down to the floors below. This occurred during the 1994 Northridge Earthquake. (Reference 33)

Figure 1.4-5 As a result of the pounding between the wings of a six-story building during the 1994 Northridge Earthquake, a fan came off of its support frame inside a penthouse. (Reference 33)

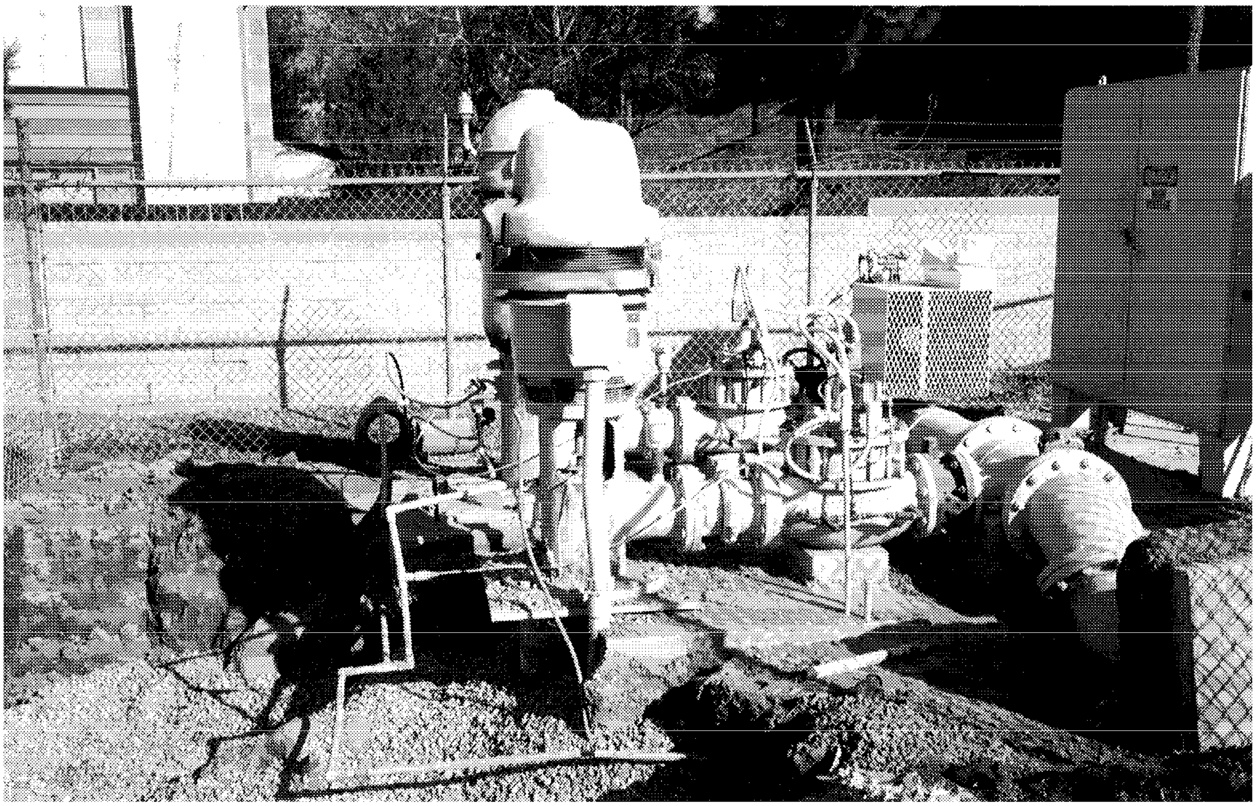

Figure 1.4-6a **Ground settlement at this lift station caused underground attached piping to crack and leak after the 1994 Northridge Earthquake. (Reference 33)**

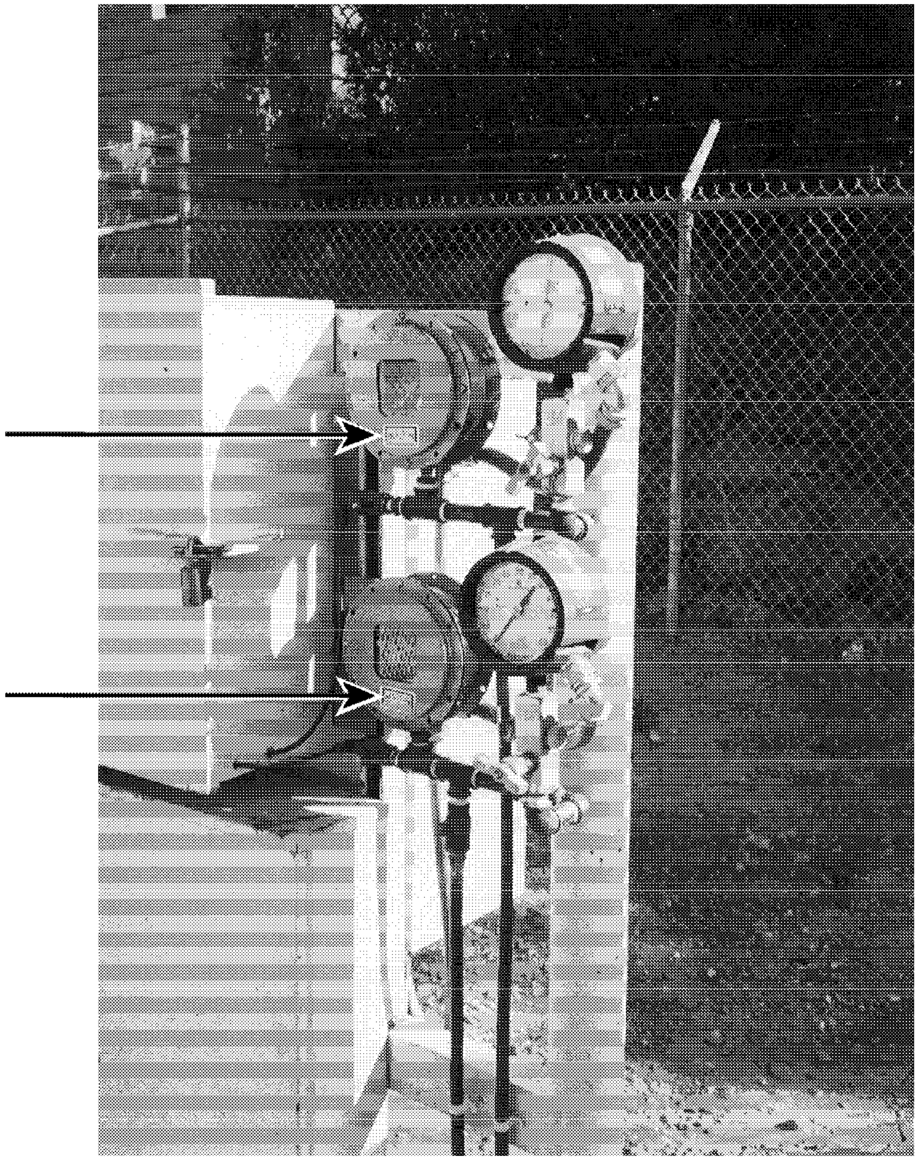

Figure 1.4-6b **Mercoid Switches connected to the pressure transmitters at a lift station may have caused an inadvertent trip of relays, or change of state of the control system. (Reference 33)**

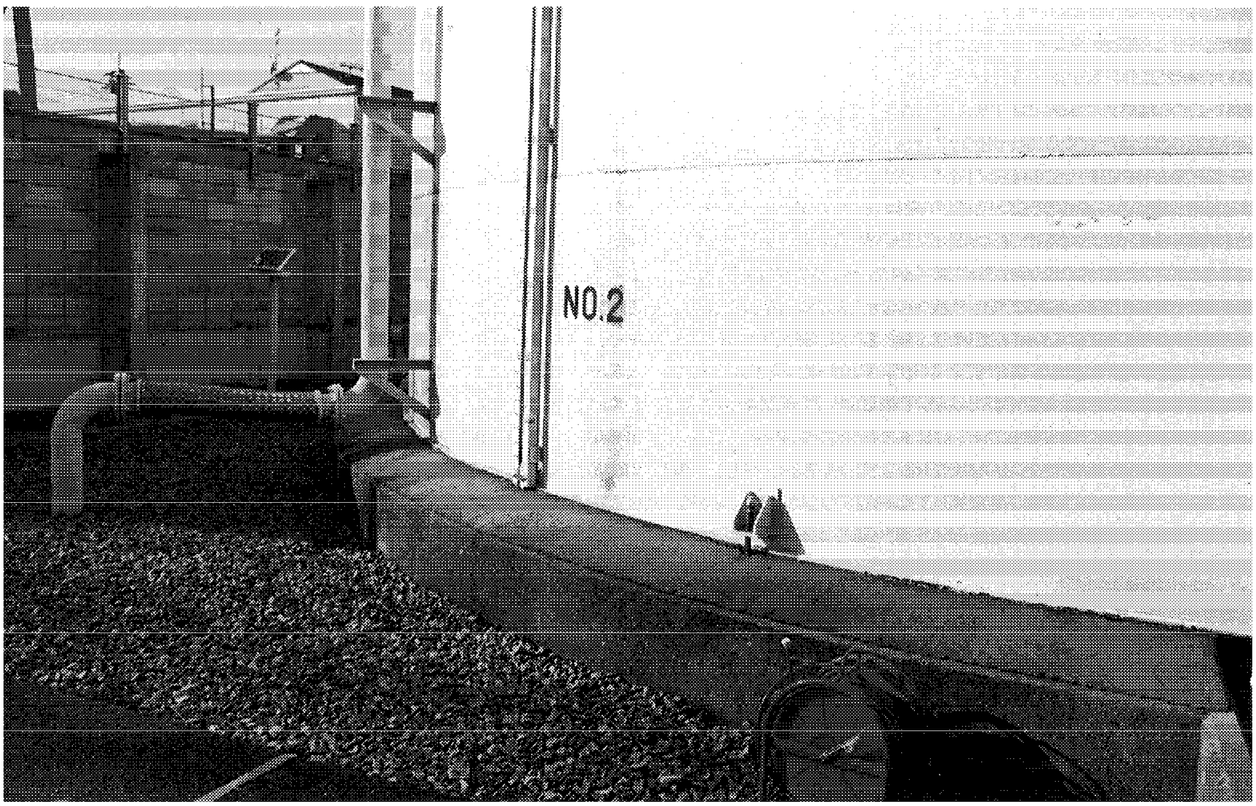

Figure 1.4-7a **This vertical, flat-bottom tank experienced the 1995 Kobe Earthquake (note both the flexible connection for the attached piping and the stretched/pulled anchor bolts at the base of the tank). (Reference 34)**

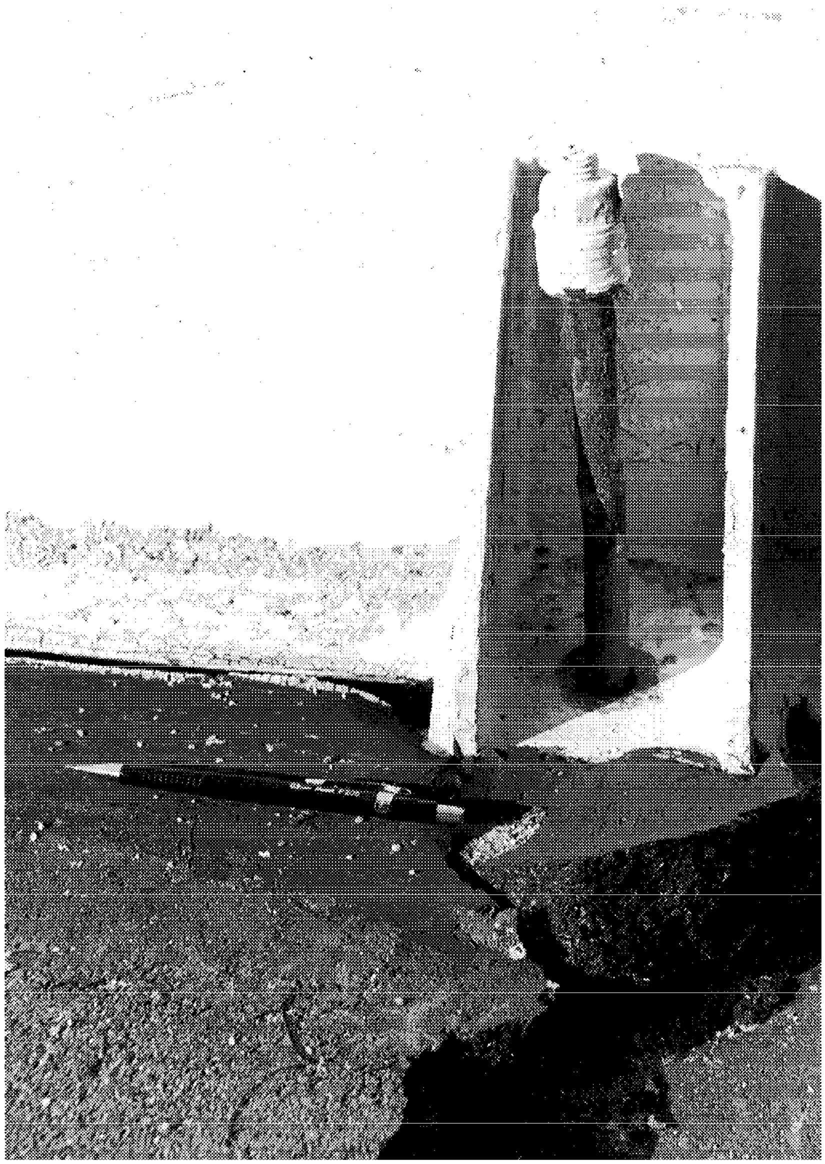

Figure 1.4-7b **Close-up of one of the anchor bolts which appeared to have experienced a combination of partial pull-out as well as stretching of the bolt as the tank tried to rock. (Reference 34)**

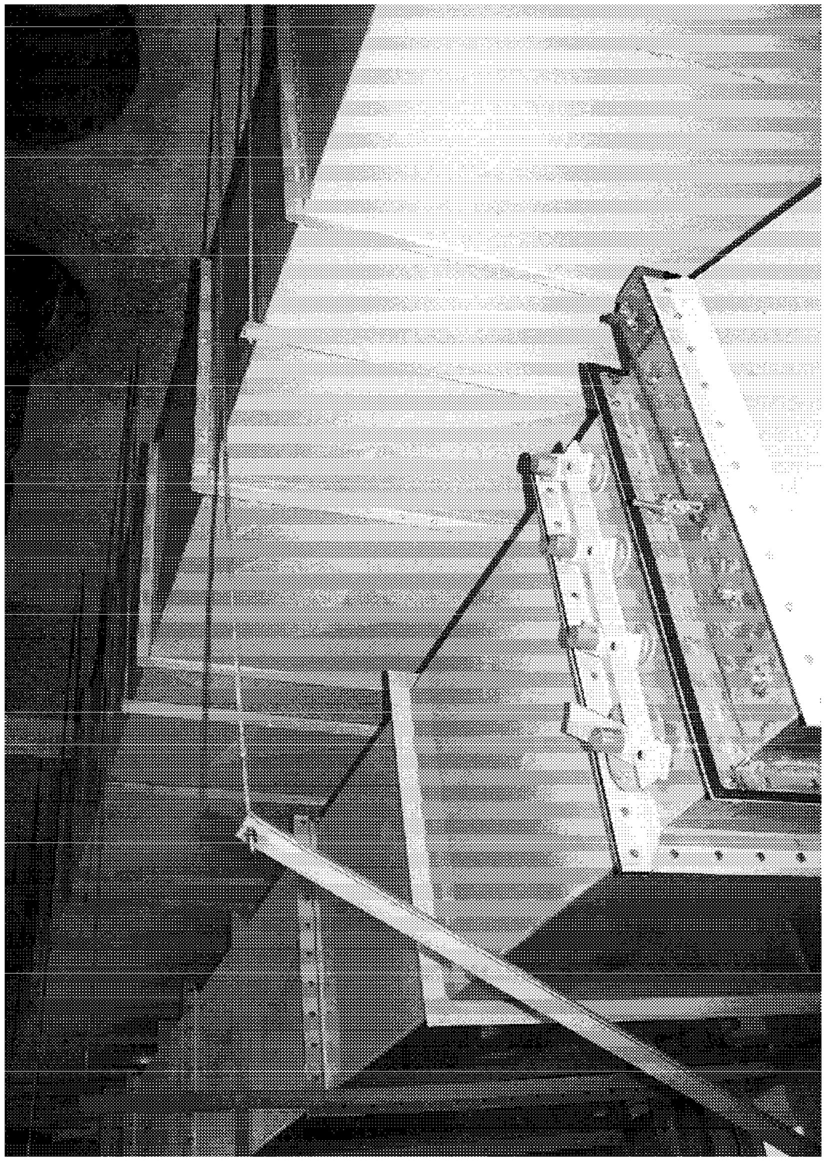

Figure 1.4-8a **Shown is a ductwork trapeze that is partially collapsed. During the 1995 Kobe Earthquake, one of the expansion anchors for the threaded rod support pulled out of the reinforced concrete ceiling. (Reference 34)**

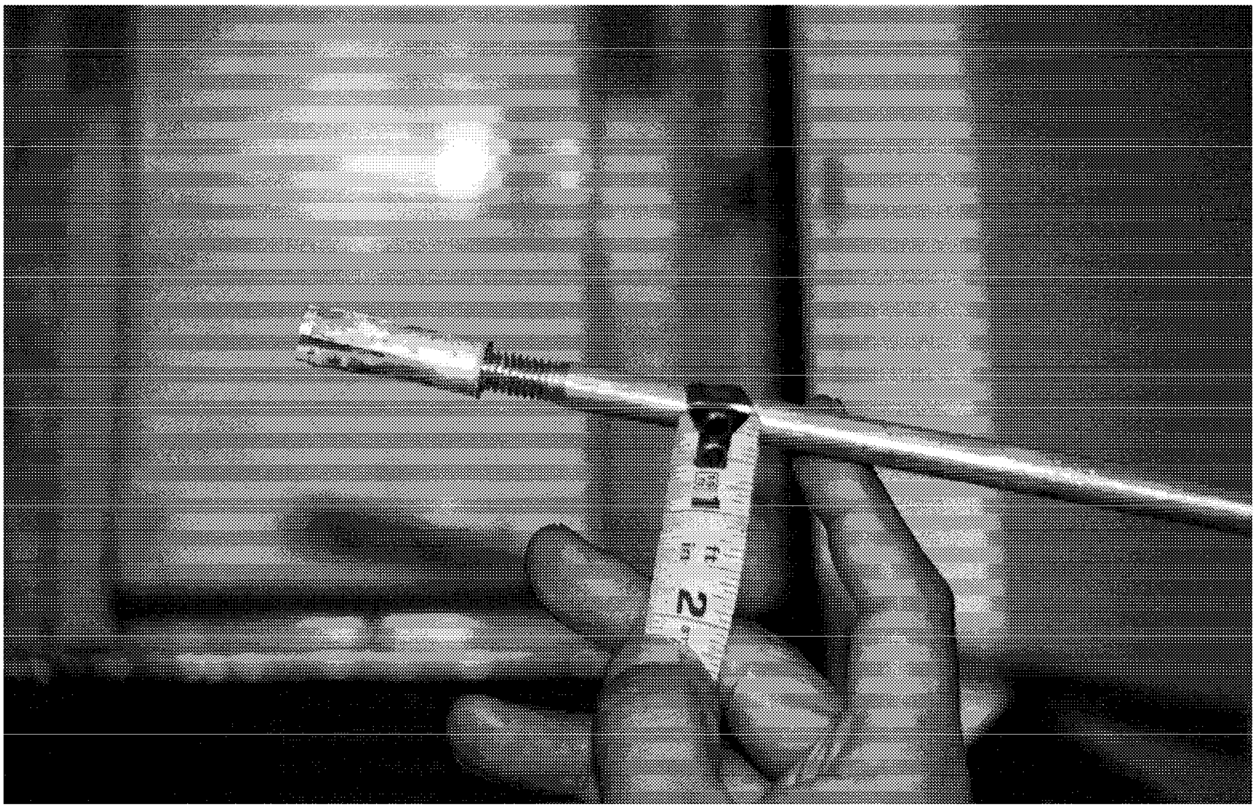

Figure 1.4-8b Shown is a close-up of the expansion anchor which pulled out of the reinforced concrete ceiling. It appears that there was inadequate expansion of the shell. (Reference 34)

Figure 1.4-9 **Large diagonal cracks in unreinforced masonry cladding (one-width thickness) over a reinforced concrete frame in an L-shaped building experienced damage during the 1994 Northridge Earthquake. (Reference 36)**

1.5 DOE LICENSE FOR EPRI / SQUG MATERIAL

An important step toward development of the comprehensive natural phenomena hazard evaluation guidelines for systems and components at DOE facilities was obtaining the proprietary reference documents and procedures developed by SQUG and EPRI. This was a key element of the DOE evaluation program because it allows DOE to take advantage of all the work performed to-date for several classes of equipment at commercial nuclear reactors. The EPRI / SQUG material is arranged into six volumes and copies of the material have been distributed throughout the DOE. Within the volumes there are twelve key reference reports (Ref. 35 and 40 to 50) that cover the technical areas of 20 classes of equipment, anchorage, electrical raceways, relays, and tanks and heat exchangers. A document which develops a methodology for assessment of nuclear power plant seismic margin (Ref. 18) is also available to the DOE. In addition, the SQUG GIP is contained in the volumes of material as a basis document for the DOE Seismic Evaluation Procedure. There are several documents in the volumes that summarize the SSRAP and NRC review of the EPRI / SQUG methodology (Ref. 2, 19, and 50) and provide additional information for piping and ducting systems (Ref. 39 and 51 to 55).

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