USE OF EARTHQUAKE EXPERIENCE DATA

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ABSTRACT

At many of the older existing U.S. Department of Energy (DOE) facilities, the need has arisen for evaluation guidelines for natural phenomena hazard assessment. The effect of a design basis earthquake at most of these facilities is one of the main concerns.

Earthquake experience data can provide a basis for the needed seismic evaluation guidelines, resulting in an efficient screening evaluation methodology for several of the items that are in the scope of the DOE facility reviews. The experience-based screening evaluation methodology, when properly established and implemented by trained engineers, has proven to result in sufficient safety margins and focuses on real concerns via facility walkdowns, usually at costs much less than the alternative options of analysis and testing.

This paper summarizes a program that is being put into place to establish uniform seismic evaluation guidelines and criteria for evaluation of existing DOE facilities. The intent of the program is to maximize use of past experience, in conjunction with a walkdown screening evaluation process.

INTRODUCTION

DOE facilities need to have adequate measures for ensuring life-safety and confinement of hazardous materials when subject to natural phenomena hazards. To place the needs for an evaluation program into perspective, DOE currently controls facilities with financial assets on the order of $100 billion. The yearly financial losses due to natural phenomena hazards and accidents are on the order of $10 million. As an example, the January 1980 Livermore, California, Earthquake and its aftershocks resulted in about a $4 million loss between Lawrence Livermore National Laboratory and Sandia National Laboratory Livermore.

Due to the evolutionary nature of design requirements, together with engineering technology advances, existing DOE facilities embody a broad spectrum of design features for resistance to natural phenomena hazards. These design features depend on factors such as the time period for the facility design and construction, as well as hardware supplier practices at that time. The level of design documentation for DOE facilities has also changed. As updated criteria have been established, facility engineers typically evaluate newer installations using the more recent criteria, with more rigorous documentation. Thus, the earliest designed and constructed facilities may have the least design documentation yet potentially exhibit the greatest difference between their design basis/as-constructed condition versus current design criteria.

THE ROLE OF UCRL-15910

Natural phenomena hazard definitions and safety goals for DOE facilities are addressed in "Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards," UCRL-15910, [1]. UCRL-15910 provides uniform design and evaluation guidelines for protection against natural phenomena hazards at DOE sites. General performance goals for a facility are established, depending on facility characteristics such as off-site and on-site potential hazards as well as cost and mission dependence. The performance categories range from general use (i.e., normal building code provisions) to highly hazardous use (approaching nuclear power plant design provisions). The performance goals and natural hazard levels are expressed in probabilistic terms, and the design and evaluation procedures are presented in deterministic terms, thus conforming closely to common engineering practice for ease of application. Estimation of the consequences at the systems level are not within the UCRL-15910 scope.

Although the UCRL-15910 guidelines apply to both new facilities (i.e., design) and existing facilities (i.e., evaluation, modification, and upgrade), the intended audience is primarily the engineers who will be conducting the facility design or re-design, and not those who will be performing the as-constructed evaluations of existing facilities.

The existing facility seismic hazard evaluations need to extend beyond the role of UCRL-15910. Seismic evaluation guidelines are needed that include the following additional elements:

- Screening evaluation criteria and procedures for evaluation of existing facilities to be implemented by walkdown, including training programs to facilitate implementation
- Methodology for systems screening as well as performance evaluation of equipment components and distribution systems
- Methodology based on earthquake experience data to supplement procedures based primarily on analysis and testing

Over the years, the safety of older operating nuclear power plants has been reviewed against a substantial number of major safety issues that have evolved since the respective operating licenses for those plants were issued. The U.S. Nuclear Regulatory Commission (NRC) established several programs for the resolution of these safety issues in order to determine the adequacy of older facilities. Unresolved Safety Issue (USI) A-46 was established for "Seismic Qualification of Equipment in Operating Nuclear Power Plants," NUREG 1030, [2]. The cost- and safety-effective screening evaluation methodology that was developed by the Seismic Qualification Utility Group (SQUG) can supplement UCRL-15910 and provide a model for the DOE facility evaluation programs.

SEISMIC QUALIFICATION UTILITY GROUP

SQUG was formed in 1982 to pursue the use of earthquake experience data as a primary basis for evaluating the seismic adequacy of equipment. The first task undertaken by SQUG was a pilot study to assess eight general classes of power plant electrical equipment (e.g., motor control centers, switchgear) and mechanical equipment (e.g., motor-operated valves, horizontal pumps). The study investigated the past earthquake performance of these equipment types, primarily from studies of documented performance of and visits to power and industrial facilities subjected to strong ground motion (in general, above 0.30g peak ground acceleration only) from the 1971 San Fernando Earthquake. The equipment found in these power and industrial facilities were then compared to the equipment from several older operating nuclear power plants.

The SQUG pilot study had two major findings. First, it was found that the conventional power plant and industrial facility equipment in the developed "seismic experience data base" are similar to those found in older operating nuclear power plants. The second major finding by SQUG was that the equipment in the seismic experience data base, when sufficiently anchored, generally performed well in earthquakes at levels of shaking in excess of the defined "safe shutdown earthquake" (SSE) for most nuclear power plants.

These two significant findings led SQUG to the conclusion that an experience data base methodology for verifying seismic adequacy represented the best available method for USI A-46 resolution.

In 1983, the Senior Seismic Review and Advisory Panel (SSRAP) was formed as an independent peer review body by the mutual agreement of SQUG and the NRC. SSRAP worked closely with SQUG and the Electric Power Research Institute (EPRI) in reviewing the seismic experience data and other equipment performance (shake-table test) data and anchorage capacity information. With these reviews, SQUG, EPRI, SSRAP, and the NRC worked steadily to establish the experience-based acceptance criteria and implementation procedure used to ensure functionality and structural adequacy of equipment for the A-46 nuclear plant SSE events, with realistic capacity and demand estimates, and with consistent factors of safety.

EXPERIENCE-BASED SCREENING EVALUATION

Screening evaluation is a generally conservative and rapid appraisal process that is used during a facility walkdown to verify acceptability or to identify "outliers" by review of key physical attributes. Figure 1 illustrates one model of a screening evaluation process. Items passing the screen are verified as acceptable and may be documented as such, or can be selected for further validation of screening evaluation results, using a bounding sample analysis process. 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 Generic Implementation Procedure (GIP), [3], screening evaluation process is performed primarily during in-plant walkdowns, and for a limited set of equipment required to bring a plant to hot shutdown and maintain it there for 72 hours. Thus, prior to a screening evaluation, a systems review must be conducted to assess the minimal (and prioritized) scope that need be subject to screening evaluation. The SQUG screening evaluation process is illustrated in Figure 2.

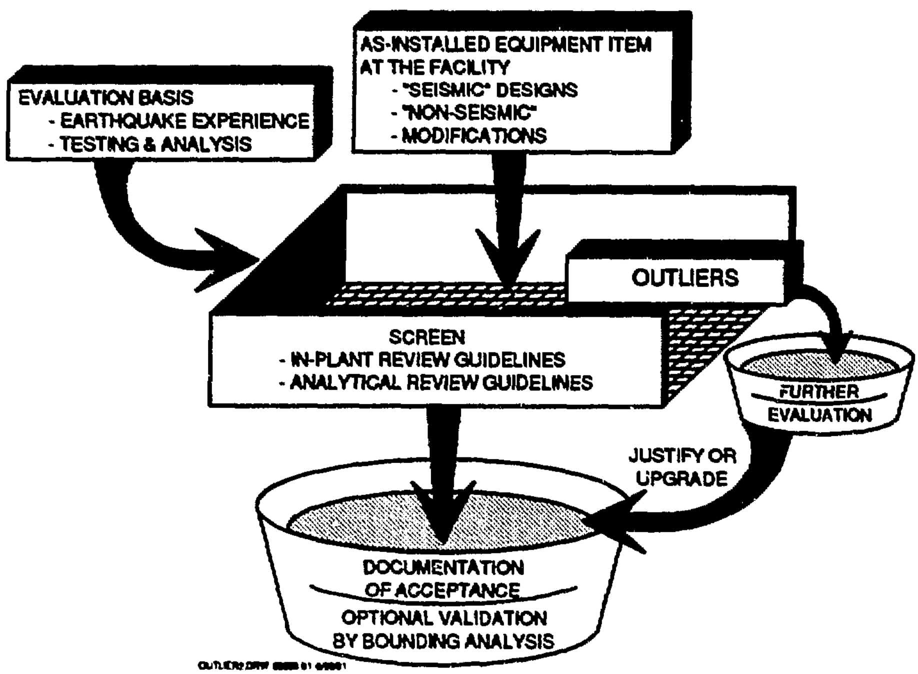

Figure 1: Evaluation screening criteria

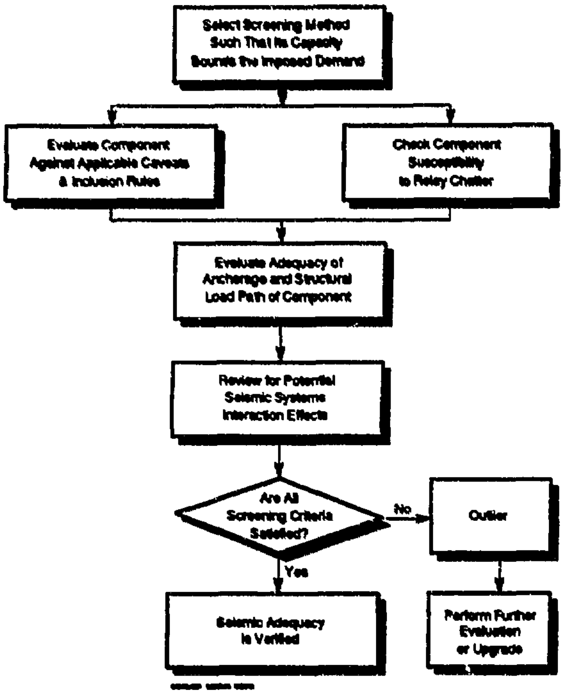

Figure 2: SQUG screening evaluation used in the GIP

The basic seismic evaluation guidelines developed by SQUG consist of four primary criteria to verify adequacy (i.e., ensure functionality and maintain structural integrity). These four primary criteria include: (1) verifying that the seismic demand response spectrum is properly enveloped by the seismic experience data base bounding spectrum; (2) reviewing the equipment component by the established inclusion rules and caveats; (3) evaluating the adequacy of the equipment component anchorage; and (4) checking that there are no significant seismic systems interaction concerns that may adversely affect the equipment component functionality.

For the first criterion, a seismic capacity "bounding spectrum" has been established based on the recorded (or estimated) ground motion response spectra at the seismic experience data base facility sites. The seismic experience data bounding spectrum is shown in Figure 3. For equipment components in nuclear plants located less than about 40 feet above grade elevation, seismic demand (for comparison with the average data base spectrum of Figure 3) may be estimated by using a generic building amplification factor of 1.5 times the plant SSE spectrum. Above the 40-

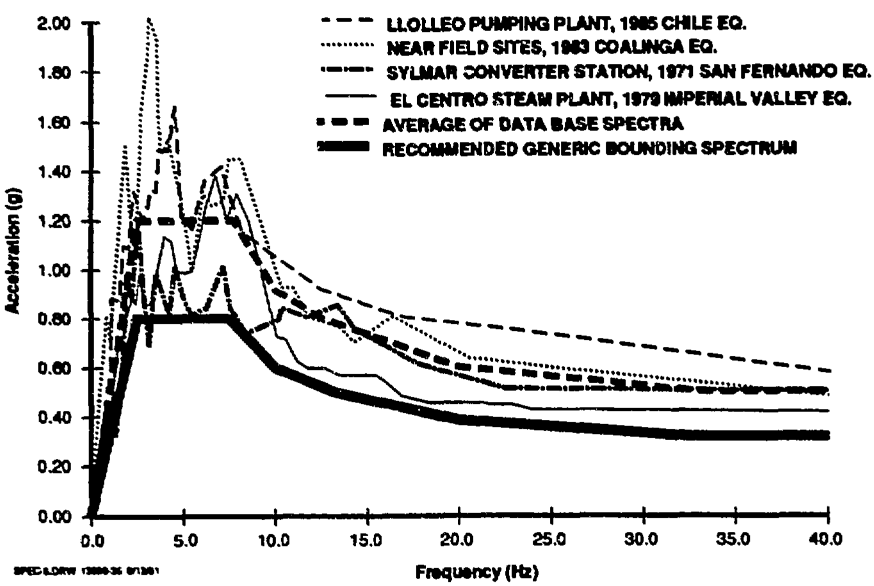

Figure 3: The seismic experience data base bounding spectrum is based on the rough average of ground motion experienced at data base facilities.

foot elevation, realistic median-centered floor-response spectra may be used for comparison with the average data base spectrum. The SQUG-developed criterion includes several detailed application rules for this comparison of seismic capacity versus demand.

The second criterion consists of detailed inclusion rules and caveats that have been established for each generic class of equipment. The inclusion rules are used to ensure that a specific equipment component represents a generic equipment class of the seismic experience data base. The inclusion rules address critical parameters such as component size, weight, operational limits, construction materials, rigidity, etc., as applicable to the seismic ruggedness of each equipment class. The caveats are provided so that any known seismic hazards (many as demonstrated by the earthquake) data may be identified. For electrical equipment (panels), example caveats are: adjacent cabinets should be bolted together, there should be no large cutouts in the cabinet panels, and doors must be positively latched shut. For mechanical equipment, example caveats are: component and motor driver should be mounted to a common rigid skid; attached piping should be restrained to prevent excessive loads from being transmitted into nozzles and anchorage; and vibration isolators should be avoided if possible, but, if used, should be outfitted with a system of bumpers to restrain seismic loads in all directions of motion.

The third criterion consists of a detailed review of the adequacy of the equipment component anchorage. This includes a fairly rigorous check of the adequacy of the anchor's installation attributes (e.g., proper embedment and edge distance, possible cracks in the concrete), a calculational review of the capacity and demand on the equipment anchorage, and a judgmental review of the strength and stiffness of the anchorage load path through the equipment component. As an example of the guidelines, for certain types of properly installed concrete expansion anchors, capacity is based on mean test ultimate capacities divided by 3. Seismic demand is based on 1.25 times median-centered floor response spectra, at 5% damping for most equipment components.

The fourth and final criterion is the review for potential seismic systems interaction effects. The general categories of interaction effects addressed by SQUG include proximity, falling, and potential differential displacement of support points. The developed guidelines are mainly qualitative in nature and focus on only the realistic potential hazards as demonstrated in past earthquakes. Most proximity-related seismic interactions (impacts) have been shown by the seismic experience data to be insignificant. However, any impacts to cabinets with sensitive relays should be avoided. As another example, air-operated valves on flexible piping systems may be damaged if the valve stem is made of cast iron and the valve impacts an adjacent hard structure. Examples of falling-hazard interactions include unanchored equipment, unreinforced masonry and concrete-block walls, and inadequately designed suspended ceiling systems. Other plant systems such as piping, cable trays, and ducting have rarely collapsed and fallen in past earthquakes, and receive only limited attention in the reviews. Differential displacement hazards exist when components or systems are routed between independent structures that may impose excessive seismic anchor movements. Differential displacement hazards also exist for conduit or tubing attached to nonrigid equipment if there is insufficient flexibility to accommodate any anticipated seismic motion.

The SQUG GIP now addresses twenty generic classes of mechanical and electrical equipment plus vertical flat-bottom storage tanks, horizontal tanks, heat exchangers, and conduit and cable tray raceway systems and supports. The primary steps in the SQUG GIP are shown in Figure 4 and include selecting evaluation personnel, identifying required equipment, detailed evaluation, and the documentation process.

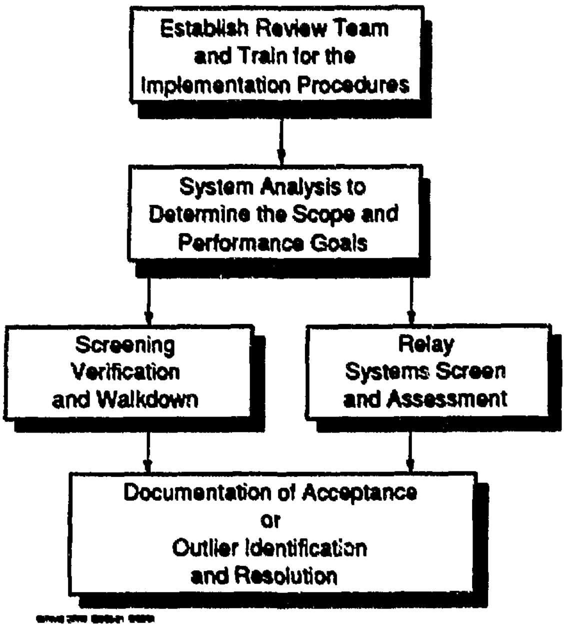

Figure 4: Elements of the SQUG GIP

For the seismic screening evaluation, much of the effort relies on engineering judgment being exercised during in-plant evaluations. For this reason, SQUG has established guidelines for the qualifications of engineers using the GIP, including a minimum of five years of related seismic qualification experience and a professional engineering license. In addition, SQUG is providing an in-depth, week-long training program for seismic review team members who will be applying the GIP.

The SQUG program is considered by most, including the NRC as well as all of its utility members, to be a major engineering breakthrough and an overall success. Although the USI A-46 program scope and driving issues are somewhat different than those at the DOE facilities, the evaluation program for the DOE sites can, in general, be modeled directly after the SQUG efforts. Important methods used by SQUG to be adopted by this DOE guidelines development effort include:

- Use of screening criteria implemented during walkdowns, coupled with review team engineering training
- Screening criteria primarily based on earthquake experience data, supplemented with test and analysis
- Programmatic direction given by facility management and engineering
- Working-level input to the program and participation by the regulators
- Technical review and advice provided by an independent panel of industry experts
- Prioritization of systems/components requiring review by way of systems analysis

The SQUG guidelines can be prioritized and mapped into the performance objectives for the various components of the DOE facilities to parallel the basic criteria established by UCRL-15910. Site visits are being performed at several DOE facilities to gain additional insight into the specific needs for seismic evaluation guidelines. The new information gained during the site visits enables a more comprehensive and focused set of detailed evaluation guidelines.

To date, four facility reviews at two separate DOE sites have been performed (and the results of other earlier plant evaluations have been compiled). These site visits concentrated on equipment systems and components during walkdowns. The site visit experiences have shown that interviews with plant operators, prior to and during the facility reviews, are extremely important. This interaction with the operators is where the majority of the critical information regarding system and component performance objectives, and facility review scope can be obtained. In addition, considerable data were collected regarding the range of mission-dependent components that can be anticipated during the reviews, and the analysis complexity that may be needed for their assessment.

SCREENING GUIDELINE DEVELOPMENT

As a starting point, the screening guidelines will begin with the standard equipment classes defined by the SQUG effort. Once the process becomes well defined, general criteria and procedures can be written for more unique types of mission-dependent items.

Other efforts have developed experience-based screening evaluation guidelines for structures, systems, and components other than those addressed in the SQUG program. The methodology developed by the Applied Technology Council (ATC) provides a good starting point for seismic evaluation of building structures, [4]. In addition, piping system screening evaluation techniques, [5 and 6], and HVAC duct system simplified criteria, [7], which are also primarily based on earthquake experience, will be adopted for this DOE facility review effort. Comprehensive earthquake experience reviews have been successfully performed at DOE facilities, [8], and the lessons learned will also be extremely valuable.

CONCLUSIONS

Earthquake experience data should continue to provide a valuable tool for verification of the seismic adequacy of DOE facilities. The screening evaluation guidelines developed by SQUG and others can be incorporated into UCRL-15910 format performance goals and component performance categories for expedient reviews to improve facility safety.

Now in the infancy stages for the DOE, the use of earthquake experience data can benefit from the lessons learned to date and the ongoing evaluations in the industry.

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