

ADDITIONS AND ENHANCEMENTS TO THE SQUG EARTHQUAKE EXPERIENCE DATABASE

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ABSTRACT

In order to expand the use of earthquake experience data for seismic verification of new and replacement equipment at nuclear power plants, Seismic Qualification Utility Group (SQUG) has undertaken several significant additions to and enhancements of the earthquake experience database. These include:

- Preparing and submitting, for U.S. Nuclear Regulatory Commission (NRC) staff review, procedures for gathering and validating earthquake experience data.
- Developing free-field ground response spectra for many of the earthquake experience data sites (earthquake-facility pairs) in accordance with procedures reviewed and approved by NRC staff.
- Implementing (in the electronic database) an equipment experience capacity spectrum calculation for equipment classes.
- Documenting detailed investigations of reports of earthquake damage to equipment that might have required a change to the SQUG Generic Implementation Procedure (GIP) (special damage reports).
- Gathering and validating earthquake experience data from new earthquakes and sites.
- Gathering and validating earthquake experience data for new categories of overhead cranes, HVAC ducting and dampers, piping and tubing.
- Developing guidelines for applying the earthquake experience methodology in non-nuclear applications (Commercial GIP).
- Developing a web-based, searchable electronic database of earthquake experience data (eSQUG).
- Dedicating the web-based electronic database in accordance with nuclear quality assurance (QA) standards.
- Locating the web-based electronic database on a secure Electric Power Research Institute (EPRI) server.

INTRODUCTION

Beginning in 1981, the nuclear power industry, through EPRI SQUG, sponsored investigations of electric power and industrial facilities experiencing strong-motion earthquakes in order to collect information (earthquake experience data) on the seismic performance of equipment representative of nuclear power plant safety-related systems. The purpose of this effort was to provide a basis for an alternative method to seismic qualification by analysis and/or testing for seismic capability verification of existing equipment in older nuclear power plants.

After 10 years this program acquired information on several thousand items of equipment, representing over 120 sites and 24 strong-motion earthquakes. The data included photographs and slides from surveys of earthquake sites; manufacturers' literature representing a portion of the specific equipment found at earthquake sites; copies of log books, damage reports, maps, sketches, schematics, drawings, and graphs collected from the operators of the earthquake-affected facilities; notes and interviews recorded on audio tape during site investigations; and accelerographs, intensity maps, and published or unpublished literature from organizations such as the Earthquake Engineering Research Institute, the United States Geological Survey, and the California Division of Mines and Geology. The detailed information was stored in its original hard copy form in a library (Figure 1) maintained by EQE International, EPRI's primary contractor for earthquake investigations. Beginning in 1990, a portion of the information in the library was placed in an electronic database for archiving purposes and to facilitate retrieval and use of the data in resolving USI A-46, *Verification of Seismic Adequacy of Mechanical and Electrical Equipment in Operating Nuclear Power Plants* [1] outliers and in applying the methodology to new and replacement equipment.

Earthquake experience data form the underlying justification for much of the methodology SQUG developed to resolve USI A-46 [1]. An initial data collection effort in 1981-1982 was documented in [2]. Further data were collected in 1982-1985 for use by the Senior Seismic Review and Advisory Panel (SSRAP). These data, and the process used to collect them, were documented in the SQUG Twenty Classes Report [3]. The SSRAP review was documented in the SSRAP Report [4]. The NRC review of the SSRAP Report was documented in [5]. The NRC review noted that collection of earthquake experience data continued after 1985, but the data were not included in the SSRAP review. It requested that SQUG develop a procedure for collecting and validating earthquake experience data, to be submitted for NRC staff review and approval.



Figure 1: Original Library of Earthquake Experience Data

The SQUG seismic verification methodology has been extended to the demonstration of seismic adequacy of new and replacement equipment (NARE). The SQUG NARE guidelines [6] have been reviewed by the NRC [7]. This review indicated that SQUG should enhance the earthquake ground motion information in the earthquake experience database.

PROCEDURE FOR GATHERING AND VALIDATING EARTHQUAKE EXPERIENCE DATA

SQUG prepared a formal procedure to be used to collect and validate post-1985 data [8]. The procedure specifies independent peer review and QA requirements. The NRC review is documented in [9]. The main elements of the data collection process are: type of data collected; ground motion estimates; treatment of damage, failures and anomalies; screening and documentation; qualifications of personnel; and peer review. The procedure discusses each element in detail. The sequence of elements is shown schematically in Figure 2. SQUG has also prepared standard data forms for recording the equipment information.

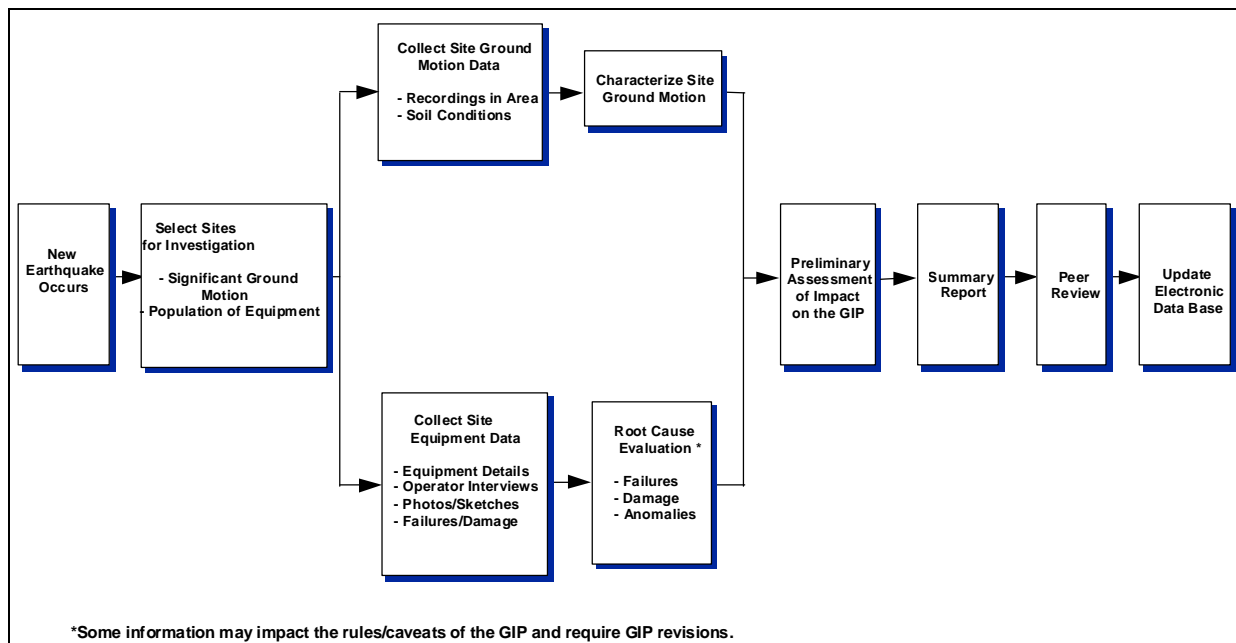


Figure 2: Schematic of SQUG Procedure for Gathering and Validating New Earthquake Experience Data

PROCEDURE FOR DEVELOPING FREE-FIELD GROUND RESPONSE SPECTRA FOR DATABASE SITES

In its review of the SQUG NARE guidelines [9], the NRC stated that earthquake experience data needed to include a ground response spectrum for the earthquake and site (earthquake-facility pair) associated with the equipment record. SQUG developed a procedure for estimating the ground-motion response spectrum applicable to a given earthquake and an individual database site (earthquake-facility pair) [8]. The procedure considers five scenarios, which depend on the number and location of strong-motion recordings that are available from the earthquake that affected the site; considers local soil conditions; requires an independent review by a seismologist knowledgeable in ground motion estimation; and requires that the process be controlled under a QA program meeting the requirements of 10 CFR 50, Appendix B [10].

Strong-Motion Recordings

There are five possible scenarios depending on the availability of strong-motion recordings:

1. A recording at the database site,
2. One or more recordings within a few kilometers of the database site,
3. One or more recordings within a few to a few tens of kilometers of the database site,
4. One or more recordings from the earthquake, but all recordings are farther than ten or so kilometers of the site, or
5. No recordings from the earthquake.

A Recording at the database site. Use the recording directly to represent the spectrum at the database site. The available geological and/or geotechnical data are reviewed to ensure that the database site and the recording are located on the same local site conditions. If not, the recording is modified to account for local site conditions.

One or more recordings within a few kilometers of the database site. The average of these recordings is used to represent the spectrum at the database site without modification as long as the recording and the database sites are much closer together than the distance to the fault rupture plane. Under such conditions, the recording and database sites will have acceptably similar spectra as long as the sites have similar local soil conditions. If the recording locations are relatively close to the earthquake rupture plane, the recordings are corrected for differences in amplitude using an appropriate set of near-source spectral attenuation relationships. If the recording sites have significantly different local soil conditions, the recordings are modified to account for local soil conditions. Note that an attenuation relationship is considered to be “appropriate” if it was developed using strong-motion recordings from earthquakes with similar tectonic environments, crustal properties, and seismological parameters. When scaling recordings using attenuation relationships, earthquake-specific estimates of magnitude, closest distance to fault, and style of faulting are used.

One or more recordings within a few to a few tens of kilometers of the database site. In this case, the recordings are far enough away that it is necessary to scale their spectral amplitudes to be more representative of the distance from the database site to the earthquake fault-rupture plane. This is done using a set of appropriate spectral attenuation relationships. Only those recordings that have similar azimuths with respect to the hypocenter and fault-rupture plane are used to ensure that they represent similar source radiation pattern and directivity effects. If not, the recordings are adjusted to account for these effects using an empirical source directivity and near-fault effects model, as well as other observations such as the geographic distribution of Modified Mercalli Intensity (MMI). The spectrum at the database site is estimated by averaging the scaled recordings that have local site conditions similar to those at the database site. If it is necessary to use recordings on different site conditions, they are modified to account for local site conditions.

Recordings are farther than ten or so kilometers of the site. In this case, adjust a set of appropriate spectral attenuation relationships representing similar site conditions as the database site with those recordings that are located on these same site conditions. This will provide a set of attenuation relationships that represent the mean ground motions from the earthquake. Use these adjusted attenuation relationships to estimate the mean spectrum at the database site, then, if needed, adjust this spectrum for any differences in source radiation pattern and directivity effects as described in Scenario 3.

No recordings from the earthquake. In this case, use an appropriate set of attenuation relationships to estimate the spectrum at the database site based on only the seismological parameters and rupture characteristics of the earthquake as determined from seismological studies. These parameters and characteristics will include one or more of the following: magnitude, seismic moment, stress drop, rupture characteristics, focal depth, and fault-

rupture geometry (i.e., length, width, and dip). Use these parameters to construct a seismological model of the earthquake, which will in turn be used to estimate a spectrum at the database site from the attenuation relationships.

Consideration of Local Site Conditions

It is usually not necessary to have detailed geotechnical data to determine whether the recording and database sites have similar site conditions and, therefore, do not require modification. In most cases, general geologic information from large-scale geologic maps is sufficient for determining whether both sites fall within the same soil profile type as defined in the *International Building Code* (IBC) [11] and the National Earthquake Hazards Reduction Program (NEHRP) Recommended Seismic Provisions [12]. The only time that this information will not be sufficient will be when both sites are located in an area of complex geology where its classification into an IBC/NEHRP soil profile type is ambiguous. Further, sites that have the same IBC/NEHRP soil profile type will have local site conditions that are sufficiently similar as to not require an adjustment for soil effects. If an adjustment is required, it will be done using empirical site factors based on an appropriate set of published attenuation relationships and/or IBC/NEHRP site factors.

SQUG has developed ground response spectra in accordance with this procedure for 70 sites in the database. The spectra have been digitized and stored in the online database, eSQUG [14]. Figure 3 shows an eSQUG screen with a plot of an earthquake-facility ground response spectrum and links to the digitized files.

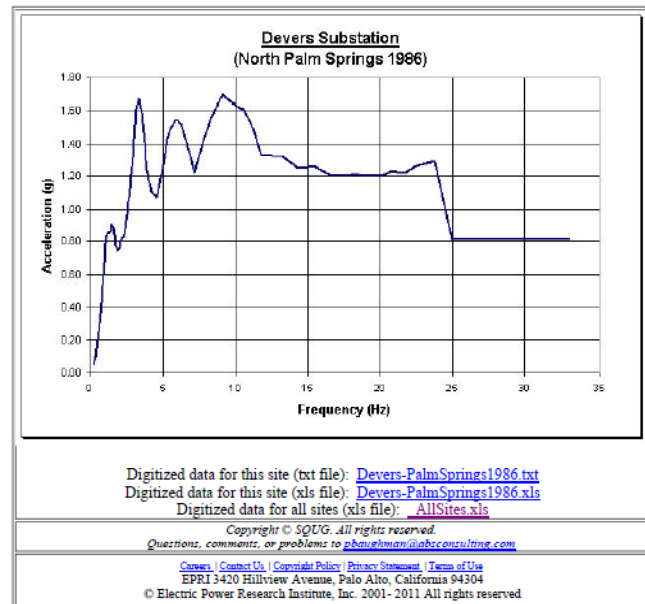


Figure 3: Plot of Ground Response Spectrum with Links to Digitized Values

EQUIPMENT EXPERIENCE CAPACITY SPECTRUM CALCULATION

IEEE Std. 344-2004 [13] adopted provisions for calculating an Earthquake Experience Spectrum (EES) to represent the demonstrated seismic capacity of an equipment class based on earthquake experience data. The EES is calculated using a weighted average of the estimated ground response spectra from the earthquake-facility pairs for the earthquake experience data representing the equipment class. SQUG developed a spreadsheet to facilitate determining an EES for an equipment class represented by data in the database. The estimated spectra for the earthquake-facility pairs in the database are digitized and stored in the spreadsheet. The User enters the number of independent data points for each earthquake-facility pair, and the spreadsheet determines the EES by calculating the weighted average of the spectral ordinates at each frequency. This spreadsheet is contained in the current version of the SQUG online database, eSQUG [14].

SPECIAL DAMAGE REPORTS

Part of SQUG's mission is to monitor earthquake damage reports and to investigate reports that indicate a potential need to change the GIP. Eleven investigations have been carried out, examining damage reports from five earthquakes. The investigations have been documented in a variety of ways, from newsletter articles to white papers. For archiving purposes, they have been added to the SQUG online database, eSQUG [14].

ADDITION OF NEW EARTHQUAKE EXPERIENCE DATA

SQUG has continued to investigate earthquakes and add data to the database. Table 1 lists the earthquakes in the database from which SQUG collected data subsequent to those described in the Twenty Classes Report [3]. The earthquake investigation results have also been published as EPRI reports.

Table 1: Additional Earthquakes and Sites

Earthquake	Magnitude	MMI	Sites	Sites w/Spectra	Equipment Records*
1989 Loma Prieta	7.1	VIII	25	7	286
1992 Cape Mendocino	7.0	VIII	4	1	58
1992 Landers/Big Bear	7.6	VIII	4	1	89
1993 Guam	8.0	VIII	9	1	87
1994 Northridge	6.7	IX	14	4	409
1995 Manzanillo	7.6	VIII	1	1	82
1999 Taiwan	7.6	VII	8	6	33
1999 Turkey	7.4	VIII	8	8	47
2006 Hawaii	6.7	VIII	6	6	85

*A record may include multiple units of equipment.

ADDITION OF NEW CATEGORIES OF DATA

SQUG has developed experience-based seismic capability screening criteria for new categories of equipment. These criteria have been published in EPRI reports. The data forming the basis for the screening criteria have been added to the online database, eSQUG [14]. The new categories are listed in Table 2 along with the EPRI reports.

Table 2: New Data Categories

Category	No. of Records	Data Source
Overhead Cranes	77	EPRI 1012022 [15]
HVAC Dampers	16 (sites)	EPRI 1014698 [16]
HVAC Duct	28 (sites)	EPRI 1014698 [16]
Piping	32 (sites)	EPRI 1012023 [17]
Tubing	4 (sites)	EPRI 1019199 [18]

GUIDELINES FOR NON-NUCLEAR APPLICATIONS

Critical non-nuclear facilities are required to seismically qualify important systems and equipment to the provisions of ASCE/SEI 7-05 [19]. However, there is a need for a procedure for seismic qualification by experience data, as required by ASCE/SEI 7-05, Section 13.2.6, "Experience Data Alternative for Seismic Capacity Determination." To address this need, SQUG developed guidelines for using earthquake experience data for the seismic qualification of equipment in non-nuclear facilities, consistent with the requirements of ASCE/SEI 7-05 (Commercial GIP). The report [20] summarizes what requirements are sufficient to ensure that an item of equipment can perform its intended safety function after a design earthquake. The report also provides additional guidance on ensuring that an item of equipment can perform its intended safety function during an earthquake as well as following an earthquake.

WEB-BASED, SEARCHABLE ELECTRONIC DATABASE (eSQUG)

The first electronic database system utilized the DOS operating system and optical disc storage of the photo images. A later release replaced the optical disc with a CD-ROM. The images were converted to digital form. Finally the system was upgraded to the Windows™ operating system. The next evolution was to create a web-based system, eSQUG [14]. This system is resident on an EPRI web site. The User can access the system from any location with internet access and does not need to have special software installed or have physical possession of the database. Updates to the system can be accomplished without distributing CD-ROMs to a large number of Users.

Each equipment record has a brief title and description, followed by nine common elements: 1) earthquake, 2) site, 3) peak ground acceleration, 4) name of nearest instrument, 5) distance to instrument, 6) elevation, 7) location, 8) effects (yes/no), and 9) operability (yes/no). Additional features of the system include: a memo field with additional information on the performance of the equipment; a link to estimated free-field response spectrum for the site; and keyworded thumbnail images of the equipment, which can be expanded into full size images. In

addition to the equipment records, there are records for the sites and the earthquakes. The digitized ground response spectra for the earthquake-site pairs can be accessed from the site records.

Data records can be accessed through three basic queries: 1) query by category, 2) query by record, and 3) query by keyword (Figure 4). Figure 5 shows a sequence of screens that might appear when performing a keyword query.

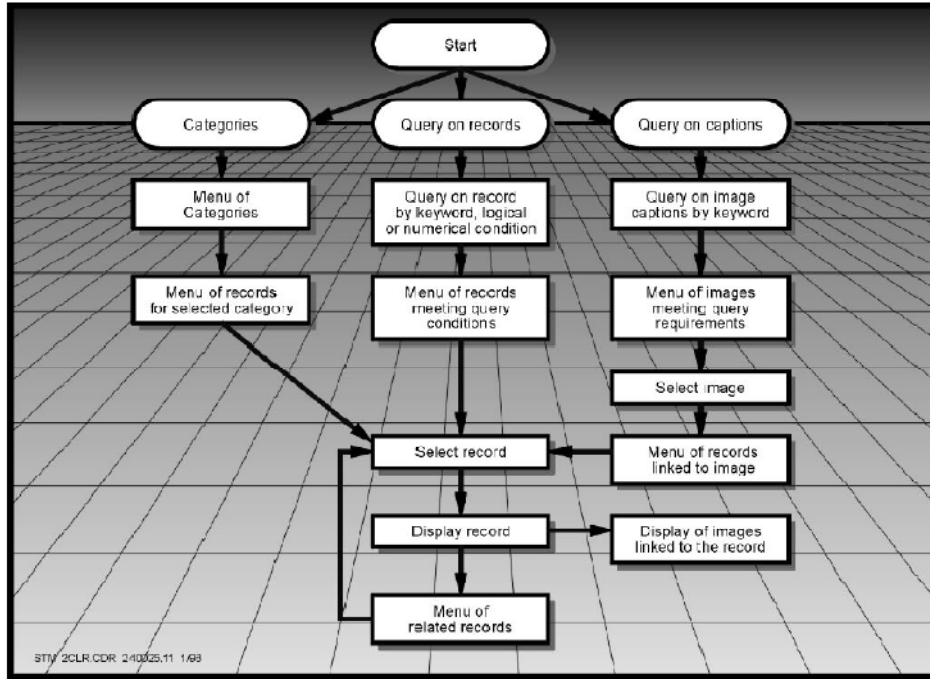


Figure 4: eSQUG query sequences

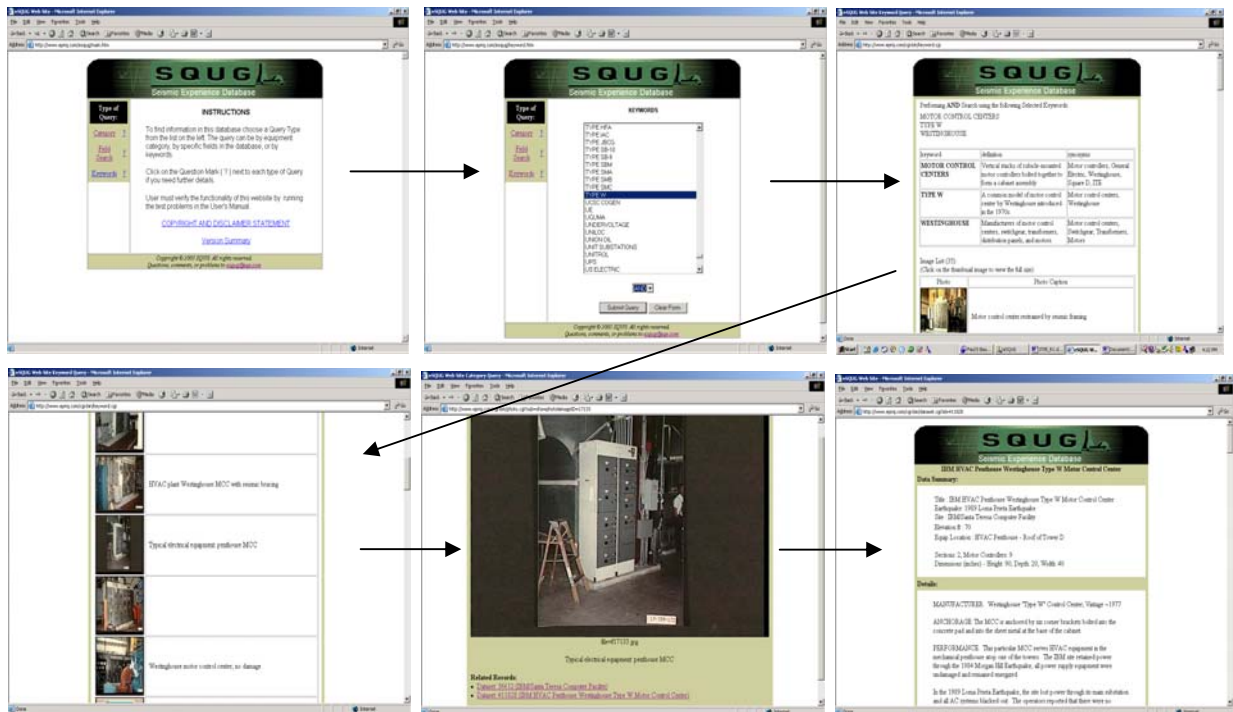


Figure 5: Sequence of steps in searching the online database by keyword

DEDICATING THE ELECTRONIC DATABASE IN ACCORDANCE WITH NUCLEAR QA REQUIREMENTS

There were two original versions of the electronic database: a) the CD-ROM version entitled WinSQUG, and b) the online version entitled eSQUG. The database itself consisted of records containing earthquake site and equipment information; a file containing images; and tables which related the records and the images. The records and images were the same for both versions of the database. The database management software was different as necessitated by the different operating environments. Neither version of the electronic database was developed under nuclear QA requirements.

EPRI undertook an effort to provide a "QA" version of the online electronic database eSQUG [14]. The methodology for doing this was to "dedicate" the original commercial grade database for use in activities subject to 10CFR50, Appendix B [10], ANSI N45.2 [21] and 10CFR21 [22], and to implement future changes following QA procedures.

EPRI Procedure QAP-7.2 [23] provided guidance on commercial grade dedication (CGD). The electronic database meets the definition of a commercial grade item (CGI) insofar as its use in seismic qualification affects the safety function of a structure, system or component, or part thereof, and it was not designed and manufactured (i.e., developed) as a basic (safety-related) component.

The following aspects were considered in the CGD of the online version of the electronic database (the CD-ROM version was not dedicated): 1) the suitability of information in the hard copy database for use in Appendix B activities; 2) validation that information taken from the hard copy database and entered into the records and tables in eSQUG was entered correctly; 3) verification that the eSQUG database manager software functions correctly; and 4) verification that programming enhancements were implemented correctly. Item 1 was documented by using a combination of CGD Method 2, "Commercial Grade Survey of Supplier," and Method 4, "Acceptable Supplier/Item Performance Record." Item 2 was documented through an application of Method 1, "Special Tests and Inspections." Items 3 and 4 were accomplished by performing a standard software verification and validation in accordance with EPRI-approved QA procedures. Currently, data collected in the field is documented and entered into the electronic database by procedure under an EPRI-approved QA program.

LOCATING THE DATABASE ON A SECURE SERVER

EPRI installed the online electronic database on the secure EPRIQ server. This ensures that integrity of the verified data is maintained, as access to the data and the database manager software is restricted to the EPRI administrator. User access to the eSQUG is controlled through a login procedure and only approved Users have access. The current version of eSQUG conforms to EPRI security requirements.

CONCLUSION

The additions and enhancements to the SQUG earthquake experience database have resulted in a valuable tool for use in seismic qualification of new and replacement equipment. The enhanced post-1985 data can be used to resolve seismic verification outliers. The added earthquake experience data for cranes, HVAC duct, and piping have been used in applications at nuclear power plants. The enhanced quality and security of the data, plus the additional data from more recent earthquakes and for additional equipment categories, will enable wider use of earthquake experience data in the future.

SQUG continues to monitor reports of equipment damage from earthquakes. Where reports indicate that equipment or systems covered by the SQUG GIP might have been adversely affected by an earthquake, SQUG pursues its own investigation to determine whether a change to the GIP might be required. In addition, data on the successful performance of equipment is collected from sites experiencing earthquake motions with high ground response spectra. This new data will further enhance the earthquake experience database for use in seismic qualification and seismic risk assessment.

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