D 9/3

A Summary of the Seismic Qualification Utilities Group (SQUG) Program

P.I. Yanev, S.W. Swan

EQE, Inc., 121 Second Street, San Francisco, California 94105, U.S.A.

N.P. Smith

Commonwealth Edison Company, One First National Plaza, Chicago, Illinois 60690, U.S.A.

J.E. Thomas

Duke Power Corporation, 422 South Church Street, Charlotte, North Carolina 28242, U.S.A.

Abstract

In 1980, the Nuclear Regulatory Commission (NRC) initiated Unresolved Safety Issue (USI) A-46 to address the seismic adequacy of equipment in operating nuclear power plants. In 1982, the Seismic Qualification Utilities Group (SQUG) was formed to determine the feasibility of using earthquake experience data in lieu of seismic testing or analysis for nuclear power plant equipment. Data were collected at numerous power plant and industrial sites in California that had experienced ground accelerations from 0.35g to 0.60g. Based on the data, SQUG concluded that rigorous seismic testing and analysis of the classes of equipment studied is not necessary or justifiable in view of their successful performance in past earthquakes. This conclusion applies to operating plants and raises the question in regard to the need for future testing or analyses of certain equipment.

1. Background

In December of 1980, the Nuclear Regulatory Commission (NRC) initiated Unresolved Safety Issue (USI) A-46 to address the question of the seismic adequacy of equipment in 49 operating nuclear power plants (72 units) that were not licensed to current criteria. To resolve USI A-46, the NRC expected to develop criteria for reverification of the seismic adequacy of the equipment in those plants.

Much of the equipment in these operating plants was installed when design requirements, seismic analysis, and documentation were less formal than current practice. It was realized that providing documentation for the seismic qualification or requalification of equipment using procedures applicable to plants currently under design would be costly and impractical. As an alternative, an innovative proposal was made in mid-1981 to use earthquake experience data of equipment performance to resolve USI A-46. The idea was presented to the Director of the Office of Nuclear Reactor Regulation (NRR) of the NRC and the NRC staff. The NRC recognized the potential value of the proposed research and urged the utilities to explore the idea further. As a result, the Seismic Qualification Utilities Group (SQUG) was formed in January of 1982.

2. The SQUG Program for Eight Classes of Equipment

A pilot program to demonstrate the feasibility of using earthquake experience in lieu of formal seismic qualification of equipment was completed in September of 1982 (Yanev and Swan,

[1]). This program demonstrated that selected types of equipment in the data base facilities are similar to equipment in operating nuclear plants. It further demonstrated that explicit seismic qualification of those equipment types should not be required in view of its performance in strong earthquakes. The last conclusion is currently supported by the program data base for nuclear sites with zero period ground accelerations of less than about 0.50g.

The procedure used in the program was simple. Data on equipment were collected at several nuclear power plants and at various commercial facilities (data base plants) that had experienced strong ground motion. Name plate, anchorage, general configuration data, and natural frequency of vibration data were collected at both types of facilities to show similarity. Ground motion records near the data base plants were collected for comparison with response spectra for the nuclear plants.

In order to limit the scope of the program, the collection of data concentrated on eight categories of equipment that represent a large portion of the safety-related systems of nuclear power plants. These are: metal-clad switchgear (2.4 kV - 4.16 kV), low-voltage switchgear (480 V), motor-control centers (MCCs), vertical pumps and their motors, horizontal pumps and their motors, air-operated valves (AOVs), motor-operated valves (MOVs), low-voltage transformers (4.16 kV - 480 V).

Walkdowns of nuclear power plants were conducted in order to gain a basis for comparisons with the experience data base. Very detailed data were collected at several of these plants.

Numerous earthquakes have affected power facilities in the recent past (Yanev, [2]). The existing literature was surveyed to determine which earthquakes and which facilities could provide useful and reliable information. It was determined that substantial information could be collected from five California earthquakes: San Fernando, 1971, magnitude 6.5; Point Mugu, 1973, magnitude 5.9; Santa Barbara, 1978, magnitude 5.7; Imperial Valley (El Centro), 1979, magnitude 6.6; Coalinga, 1983, magnitude 6.7; Coalinga aftershocks, 1983, magnitudes 5.1, 5.0, 5.2, 5.9, 5.0, and 5.1. Data collection and interviews with plant personnel were conducted at the 23 facilities listed in Table I.

Most of the examined facilities experienced peak ground (or free-field) acceleration in excess of 0.30g. Several of the facilities experienced accelerations in excess of 0.50g. Some of these facilities were located in areas that suffered heavy to extreme damage from the earthquakes. The Coalinga sites and the Sylmar Converter Station are located in the near-source areas for their respective earthquakes. Several of the aftershocks were in themselves strong earthquakes.

The Sylmar Converter Station has become the classical example in the literature of damage to equipment. The station was completed just prior to the earthquake. It suffered extensive damage which amounted to about 60 percent of its value. Most of the damage was (1) due to inadequate anchorages and (2) to porcelain components of large substation equipment. The Sylmar Converter Station contains numerous items of properly anchored equipment of the types addressed by the program. One of the most important findings of the SQUG program was that anchored equipment was not damaged and remained functional after the earthquake.

Table I summarizes the peak ground accelerations that were used for each site. Several of the sites were instrumented with free-field and some in-structure accelerometers. The values in the table are based on these recordings and on attenuation studies of the motion.

Most of the equipment of interest in the data base plants is located at elevations within 40 feet above grade. The structures housing the equipment are typically either reinforced concrete shear wall structures or braced steel frame structures. Thus, much of the equipment is contained within buildings that have similar characteristics to nuclear power plant structures.

The maximum original seismic design criteria to which the data base structures, equipment, and piping were constructed are summarized in Table II. For the older plants the seismic criteria may be much lower than those listed.

Most engineers have the impression that conventional power facilities in California are designed for very high seismic loads. As shown in Table II, that is not the case. The equipment is typically anchored and the piping is not seismically braced. The reason for the apparently low design criteria is simple - the plants have performed well in the past.

Table III summarizes the overall performance of the power facilities that were evaluated in detail for the eight classes of equipment. The last three columns describe the overall performance of each unit. "Remained On Line" indicates that the unit continued to operate through the earthquake and continued to send power to the grid. The plant systems were not significantly affected in any way to disrupt operation. Operability and structural data can be obtained. "Tripped Off Line But Still Operating" indicates that the plant separated from the grid, usually due to protective relaying. The plant continues to operate and generate steam and remains on "station service." Structural and operability data can be collected at such a plant. "Lost Station Power" indicates that all power to and within the plant was lost and the plant shut down. Structural and limited operability data on equipment can be collected. As can be seen, two units remained operating at or above 0.40g. All units continued to operate at or below 0.35g.

The next step in the project was to evaluate the individual performance of the equipment items within the eight classes. The sizes of the data samples that were collected are summarized in Table IV. Detailed data on a total of about 2,000 major electrical components and 1,000 mechanical items were collected. Only one air-operated valve out of this entire sample was damaged. The damage was due to impact with an adjacent structure and not to inertial forces.

The primary conclusions of the pilot program were that seismic damage to equipment is rare as long as reasonable precautions for anchorage are taken, and detailed qualification is unwarranted and unnecessary, with certain limitations, for the addressed classes of equipment.

Data collection activities were closely monitored by members of the NRC Staff and by their consultants. Through the course of the program, numerous meetings and discussions were held between the SQUG, EQE, the NRC, and their consultants. Representatives from all involved organizations toured several of the affected power facilities.

The pilot program was completed in the fall of 1982, and a report summarizing the program was submitted to the NRC (Yanev and Swan [3]). Numerous meetings were held among the NRC and the SQUG early in 1983 to discuss the NRC's comments and questions. The NRC then issued a general endorsement of the use of experience data in lieu of formal qualification of equipment in operating plants in the report "Seismic Qualification of Equipment in Operating Plants, A Status Report on Unresolved Safety Issue A-46," NUREG-1018, September 1983 (Chang, [4]). In this report the NRC states:

"(Our) assessment leads to the conclusion that the use of experience data for equipment qualification provides the only reasonable alternative to current criteria."

Another critical review was provided by the Lawrence Livermore National Laboratory (LLNL) (Smith, [5]). In their correlation study of seismic experience data in non-nuclear facilities with seismic equipment qualification in nuclear plants, LLNL performed a comparison based on a weighted set of issues that govern seismic equipment qualification and concluded:

"The current requirements in existing NRC and national standards were evaluated against this common set of issues, and they were estimated to score 91 out of 156 points overall, or about 60%. Experience (earthquake) data was estimated to score 97 out of 156 overall, or also about 60%. Since the current requirements and experience data scored about the same (60%), this led to our conclusion that it was feasible to use experience data on seismic EQ (Equipment Qualification) issues."

Although at that point the SQUG program had demonstrated the feasibility of using experience data, it did not definitively resolve the issue of how and to what extent experience data could be applied. An agreement was reached between the NRC and the SQUG that a panel of recognized seismic experts would be formed to evaluate the extent to which experience data would be used. The Senior Seismic Review and Advisory Panel (SSRAP), composed of five members, was appointed in the spring of 1983. The five members were mutually agreed upon by the NRC and the SQUG. The members were selected to represent a diversity of experience and backgrounds.

The NRC and the SQUG agreed that the SSRAP would have the following mission: (1) review the SQUG program, (2) determine the limits to which experience data could be applied to the seismic qualification of equipment, (3) recommend additional areas where the program should be expanded.

The members of the SSRAP performed walk-throughs of several data base facilities and nuclear plants to judge similarity between the equipment in nuclear power plants and that in the conventional plants from which past earthquake experience data were collected. The NRC, SQUG, and SSRAP also had discussions with representatives from vendors of some of the classes of equipment.

At the request of the SSRAP, EQE conducted additional work to reformulate the data, define additional parameters within the data base, define the limitations of the data, investigate the performance of equipment in additional earthquakes, investigate failure reports in the literature, and investigate further the ground motions that were used in the data base. The SSRAP also addressed issues that were raised by the NRC.

The SSRAP completed its review of the SQUG program in February of 1984. The primary conclusions were (SSRAP, [6]):

- Equipment in nuclear plants is generally similar and at least as rugged as that installed in conventional plants.
- This equipment, when properly anchored and with certain reservations, has an inherent seismic ruggedness and has a demonstrated capability to withstand substantial seismic motion without structural damage.
- Functionality after strong shaking has been demonstrated, but the absence of relay chatter during strong shaking has not been demonstrated.

- With several important restrictions and exclusions, it is the SSRAP judgment that below certain seismic motion bounds it is unnecessary to perform explicit seismic qualification of existing equipment within the eight categories addressed for operating nuclear plants, in order to demonstrate functionality following an earthquake.
- The existing experience data base reasonably demonstrates the seismic ruggedness of this equipment up to these seismic motion bounds.

It is also recommended that a thorough walkdown should be made of each nuclear plant to check (1) equipment anchorage, (2) falling or impacting hazards from adjacent equipment, and (3) unusual or nontypical conditions.

The SSRAP conclusions further specified the bounds of seismic motion within which equipment could be qualified by experience data. The bounds are defined in terms of 5 percent damped horizontal ground response spectra. These spectra bounds are intended for comparison with the 5 percent damped design horizontal free-field response spectrum at a nuclear plant. The comparison of these seismic bounds with design horizontal ground response spectra is acceptable for equipment mounted less than about 40 feet above grade (the top of the ground surrounding the building). For equipment mounted more than about 40 feet above grade, comparisons of 1.5 times these spectra are made with horizontal floor spectra. The criteria are met so long as the 5 percent damped design horizontal spectrum lies below the appropriate bounding spectrum at frequencies greater than or equal to the fundamental frequency range of the equipment. This estimate can be made judgmentally by experienced engineers without the need for analysis or testing (SSRAP, [6]). In effect, any nuclear plant with a free-field design basis peak ground acceleration of about 0.25g or less is able to make extensive use of the experience data base. It is expected that the 0.25g acceleration level will be increased substantially when additional data are collected and treated.

3. Current Status

In early 1985 the NRC finalized their Regulatory Analysis of USI A-46 Requirements for submittal to CRGR. The staff endorses use of SQUG data for final resolution of A-46. An implementation phase will be required for plants to verify their equipment is covered by SQUG data and SSRAP criteria. The staff also requested and SQUG is developing a generic approach for resolution of all plants. The staff concluded that USI A-46 will apply only to plants that received an operating license before approximately 1977. Specifically, the actions to date are expected to have the following implications:

- All of the operating nuclear plants in the United States, with design-basis seismic ground accelerations of 0.30g or less, should be able to make extensive use of the experience data base. Plants located in areas with design-basis ground accelerations exceeding 0.30g should also be able to make use of the findings of the SQUG program.
- It is expected that a plant walkdown will be required for application of experience data. The walkdown would check primarily for adequate equipment anchorage and would verify that the equipment fits within the range of generic characteristics developed by SQUG.

- By using experience, effort and expense will be concentrated on the few critical equipment items which have been shown by past experience to be sensitive to seismic motion.

Based on NRC remaining concerns, SQUG has developed a generic list of types of equipment beyond the eight classes that are required to remain operational during or after a seismic event to reach hot shutdown. A parallel effort has been initiated to collect seismic test data for various equipment and to incorporate SQUG experience data into a method for assuring adequacy of anchorages.

The NRC staff representatives have verbally concurred with the SQUG plans. We feel that the SQUG efforts have very substantially reduced the potential impact of USI A-46 and the planned work will minimize the required effort for final resolution.

4. References

/1/ YANEV, P.I., SWAN, S.W., "Pilot Program Report Summary: Program for the Development of an Alternative Approach to Seismic Equipment Qualification," prepared for Seismic Qualification Utilities Group by EQE Incorporated, San Francisco, California (September, 1982).

/2/ YANEV, P.I., "Effects and Implications of Past Earthquakes on Power Plants," Proceedings of the American Power Conference, Volume 43, Chicago, Illinois, 1981.

/3/ YANEV, P.I., SWAN, S.W., "Volumes I and II: Pilot Program Report; Program for the Development of an Alternative Approach to Seismic Equipment Qualification," prepared for Seismic Qualification Utilities Group by EQE Incorporated, San Francisco, California (September, 1982).

/4/ CHANG, T.Y., "Seismic Qualification of Equipment in Operating Plants," Status Report, Unresolved Safety Issue A-46, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, NUREG-1018 (September, 1983).

/5/ SMITH, P.D., DONG, R.G., "Correlation of Seismic Experience Data in Non-Nuclear Facilities with Seismic Equipment Qualification in Nuclear Plants (A-46)," prepared for U.S. Nuclear Regulatory Commission by Lawrence Livermore National Laboratory, Livermore, California, NUREG/CR-3017 (August, 1983).

/6/ SENIOR SEISMIC REVIEW AND ADVISORY PANEL (SSRAP), "Use of Past Earthquake Experience Data to Show Seismic Ruggedness of Certain Classes of Equipment in Nuclear Power Plants" (February, 1984).

TABLE I

NON-NUCLEAR DATA BASE FACILITIES

Earthquake		Facility	Recorded or Estimated-PGA*(g)
San Fernando 1971	1.	Sylmar Converter Station	0.50
	2.	Rinaldi Receiving Station	0.40
	3.	Valley Steam Plant	0.40
	4.	Saugus Substation	0.40
	5.	Burbank Power Plant	0.35
	6.	Glendale Power Plant	0.30
	7.	Pasadena Power Plant	0.20
	8.	Vincent Substation	0.20
Point Mugu 1973	9.	Ormond Beach Power Plant	0.20
	10.	Santa Clara Substation	0.10
Santa Barbara 1978	11.	Goleta Substation	0.28
	12.	Ellwood Peaker Plant	0.35
Imperial Valley 1979	13.	El Centro Steam Plant	0.51
	14.	Magmamax Geothermal Power Plant	0.25
Coalinga 1983 and Aftershocks	15.	Main Oil Pumping Plant	0.60
	16.	Shell Water Treatment Plant	0.60
	17.	Shell Tank Farm	0.60

TABLE I (Continued)

Earthquake		Facility	Recorded or Estimated-PGA*(g)
Coalinga 1983 and Aftershocks	18.	Union-76 Butane Plant	0.60
	19.	Coalinga Water Filtration Plant	0.60
	20.	Pleasant Valley Pumping Plant	0.60
	21.	San Luis Canal Pumping Stations	0.35
	22.	Gates Substation	0.35
	23.	Kettleman Gas Compressor Station	0.25

* Peak ground acceleration or ZPA.

TABLE II

TYPICAL SEISMIC DESIGN CRITERIA OF DATA BASE PLANTS

- STEEL STRUCTURES

  0.20g static equivalent shear load at base of structures. No dynamic analyses conducted.

- CONCRETE STRUCTURES

  0.13g, or less, static equivalent shear load at base of structure. No dynamic analyses conducted.

- EQUIPMENT AND ANCHORAGE

  0.20g static force applied at center of gravity; no seismic considerations for structural integrity and operability; no seismic qualification considerations.

- PIPING

  Generally no seismic design criteria at all; very few high pressure lines were designed for 0.20g static lateral loads applied in one direction at a time; a few seismic stops and snubbers were observed.

TABLE III

SUMMARY OF THE OVERALL PERFORMANCE OF THE DATA BASE PLANTS

				Performance During Earthquake		
Power Plant and Unit	Size MW	Vintage	Peak Ground Acceleration (g)	Remained on Line	Tripped Off Line, But Still Operating	Lost Station Power
Sylmar						
Converter Station	1440	1970	0.50***	-	-	X
El Centro						
Unit 1*	20	1948	0.50			
Unit 2*	30	1952	0.50			
Unit 3	44	1957	0.50	-	X	-
Unit 4	80	1968	0.50	-	-	X
Valley						
Unit 1	100	1954	0.40	-	-	X
Unit 2*	100	1954	0.40			
Unit 3	160	1955	0.40	X	-	-
Unit 4	160	1956	0.40	-	-	X
Burbank						
Olive:						
Unit 1	44	1958	0.35	-	X	-
Unit 2	44	1961	0.35	-	X	-
Magnolia:						
Unit 1*	10	1940s	0.35			
Unit 2	10	1940s	0.35	X	-	-
Unit 3	20	1950s	0.35	X	-	-
Unit 4*	30	1950s	0.35			
Unit 5*	20	1968	0.35			

TABLE III (Continued)

Power Plant and Unit	Size MW	Vintage	Peak Ground Acceleration (g)	Performance During Earthquake: Remained on Line	Tripped Off Line, But Still Operating	Lost Station Power
Glendale						
Unit 1*	20	1941	0.30			
Unit 2*	20	1947	0.30			
Unit 3	20	1953	0.30	X	-	-
Unit 4	44	1959	0.30	X	-	-
Unit 5	44	1964	0.30	X	-	-
Pasadena						
Unit 1	45	1955	0.20	X	-	-
Unit 2**	45	1957	0.20			
Unit 3	71	1965	0.20	X	-	-
Unit 4**	45	1949	0.20			

* Not operating at time of earthquake.
** On hot standby at time of earthquake.
*** 0.50g or greater.

TABLE IV

SUMMARY OF DETAILED EQUIPMENT INVENTORY

Equipment Type	Electrical Assemblies*	Electrical Components**	Mechanical Items
1. Motor-Control Centers	81	1280	-
2. 480 V Switchgear	24	308	-
3. Metal-Clad Switchgear	31	331	-
4. Motor-Operated Valves	-	-	131
5. Air-Operated Valves	-	-	475
6. Vertical Pumps (w/motors)	-	-	128
7. Horizontal Pumps (w/motors)	-	-	129
8. Transformers (4.16 kV-480 V)	24		
TOTALS	160	1919	863

* An assembly may be a row of motor-control centers of switchgear cabinets.
** Components are motor controllers and circuit breakers.