D 9/8

Seismic Capability of Equipment in Operating Plants in the Light of Experience Data

G. Bagchi, V.S. Noonan

United States Nuclear Regulatory Commission, Washington, D.C. 20555, U.S.A.

Abstract

For equipment that is already operating in a plant but lacks explicit data demonstrating its seismic capability, a viable alternative to explicit qualification of such equipment is discussed in this paper. Based on information about the operability of similar equipment under actual earthquake events of significant magnitude, conclusions can be drawn about the seismic capability of such equipment.

This paper discusses an effort on collection of experience data, feasibility of the use of such data and guidelines and caveats for application of experience data to operating nuclear plant equipment.

1. Introduction

Criteria for seismic qualification of equipment in nuclear power plants evolved from simple analytical requirements to the more elaborate current requirements involving complex analysis and testing on shake tables. Margins available for equipment in operating plants to withstand the effect of a safe shutdown earthquake may vary from equipment to equipment and from plant to plant depending upon the method of qualification and the vintage of a plant. Thus, the uncertainty about the seismic capability of equipment in operating plants led to the designation of unresolved safety issue (USI) A-46, "Seismic Qualification of Equipment in Operating Plants." Probabilistic risk assessment studies have indicated that seismic contribution to the core melt probability can be significant. Also, staff review of the seismic design of older operating plants under the Systematic Evaluation Program has indicated a need to improve supports and anchorages to safety-related equipment. These are some of the reasons for the NRC concern regarding seismic qualification of equipment in operating plants.

The task action plan for USI A-46 consisted of the following tasks:

(1) Identification of seismic-sensitive systems and equipment;

(2) Assessment of adequacy of existing seismic qualifications;

(3) Development and assessment of in-situ testing methods to assist in qualification of equipment;

(4) Seismic qualification of equipment using seismic experience data;

(5) Development of methods to generate generic floor response spectra.

Technical findings related to the above tasks are reported in references 1 through 6. However, task 4 provides the most feasible alternative to explicit reevaluation of equipment based on currently acceptable methods.

2. Industry Efforts

In parallel with the NRC effort to study the concerns underlying USI A-46, plant owners formed a group called Seismic Qualification Utility Group (SQUG). SQUG retained EQE Inc. of San Francisco to gather information on equipment behavior under actual earthquakes. Very few nuclear power plants have experienced strong ground motion. However, there are numerous instances of conventional power generating stations and large industrial facilities experiencing significant earthquake events.

Past reports on damages due to earthquakes tended to concentrate on overall damages to structures and equipment. But detailed examinations by experienced investigators indicate that when properly anchored and supported, equipment performs satisfactorily as indicated by their performance following the earthquake. Failures of equipment due to inadequate anchorage and interference from adjacent obstructions have been observed. However, properly anchored equipment seem to survive strong ground motion satisfactorily. There are a number of power plants and other industrial facilities that experienceed major earthquakes and can be used for observation of equipment behavior due to earthquakes. Details of earthquake events, plants involved, ground motion records, equipment and plant behavior, etc. can be obtained from References 5,7,8,9 and 10. The industry approach has been to select nuclear plants and data base plants (those facilities that experienced a major earthquake) on the basis of seismic design levels for nuclear plants and observed peak ground acceleration for data base plants. A substantial number of nuclear and data base plants were visited respectively under the SQUG effort. Of these facilities more detailed review was performed for the following nuclear plants: Dresden 3, Calvert Cliffs 1 and Pilgrim 1; nonnuclear facilities: Valley Steam Plant, Burbank Power Plant, Glendale Power Plant, Pasadena Power Plant, Sylmar Converter Station, El Centro Steam Plant, Coalinga Pumping Station and Petrochemical complex.

From a preliminary review of equipment types that are common between industrial facilities and nuclear power plants the following equipment types were studied: motor control centers, 480-volt switchgear, metal clad switchgear, motor-operated valves, air-operated valves, horizontal pumps and motors, and vertical pumps and motors. Unit substation transformers were later included in the equipment list. As the initial phase of the study was being concluded, the 1983 Coalinga, California, earthquake provided additional data on equipment behavior under earthquakes. Coalinga data is significant, in that several aftershock events of large magnitude occurred at the same site.

Data base plants were typically designed to static coefficients of 0.1g for steel structure, 0.13g for concrete structures, 0.2g at center of gravity for equipment anchorage and 0.2g for piping. Seismic loading experienced by the data base plants was characterized in terms of response spectra using recorded time histories representative of the free field peak acceleration values, since recorded motions inside building structures were not generally available. At least in one case, El Centro steam plant was studied under NRC sponsorship using the recorded ground motion, and significant amplication of the free-field ground motion was calculated at higher elevations of the power plant building. Although, the equipment located at higher elevations of data base plants may have experienced motion higher than that recorded at the field-field, the equipment loading was conservatively represented by free-field recorded motion. Energy distribution in the input motion through the frequency range of interest was examined by developing power spectral density of recorded ground motions. Thus, the industry effort on investigation of equipment behavior under earthquake experience has so far produced a significant amount of data from a number of earthquake events on equipment of various stages of natural aging. The industry efforts on collection and analysis of earthquake experience data are described in references 7 through 10.

3. Independent Review of Experience Data

In order to perform an independent review of the earthquake experience data, the Senior Seismic Review and Advisory Panel (SSRAP) was set up by the owner's group and was endorsed by the NRC. The SSRAP consists of the following members:

Dr. R. P. Kennedy of Structural Mechanics Associates, Newport Beach, CA.
Dr. W. A. von Riesemann of Sandia National Laboratories, Albuquerque, NM.
Dr. Paul Ibanez of ANCO Engineers, Culver City, CA.
Dr. A. J. Schiff of Purdue University, IN.
Mr. Loring A. Wyllie, Jr. of H. J. Dagenkolb Associates, San Francisco, CA.

SSRAP performed a detailed assessment of data provided by EQE Inc., consultants to SQUG. SSRAP performed walk-through of several data base plants as well as nuclear power plants, and held meetings with representatives of several major equipment manufacturers to review changes to equipment design for various vintages dating back to the fifties. SSRAP also conducted meetings with SQUG and the NRC staff to consider specific concerns on the characterization of the experience data. SSRAP produced the first report in February, 1984 providing recommendations on the use of earthquake experience data for the eight equipment categories for which detailed information was provided to them.

Major conclusions made by SSRAP are as follows:

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

SSRAP report pointed out several important caveats and exclusions. The need for ensuring proper anchorage and support, preventing impact between equipment and adjacent structures by providing adequate clearance, preventing misalignment between pump and its drive or a valve and its actuator by avoiding relative displacement are areas highlighted in the SSRAP caveats. SSRAP has excluded from its study the issue of integrity of utilities to the equipment such as air supply, electric power, etc. SSRAP judged that for excitations below the seismic spectral bounds recommended by SSRAP, it is not necessary to perform explicit seismic qualifications of the eight classes of existing equipment operating nuclear power plants to demonstrate functionality after strong shaking has ended.

In order to arrive at the recommended spectral bounds SSRAP has used smoothed average horizontal response spectra to characterize the equipment loading to account for the fact that orientation of equipment with respect to the direction of excitation determines the severity of the loading experienced. The averaged and smoothed horizontal response spectra were then further reduced by a factor of 1.5 to enable these spectra to be compared with horizontal ground spectra at nuclear plants for equipment located within 40 feet of ground. For equipment above that level the comparison should be with the floor response spectra of the nuclear plant and the bounding spectra multiplied by the factor 1.5 to remove the multiplication factor of 1.5. SSRAP recommended three spectral bounds based on the equipment categories that experienced those motion bounds; these curves are show in Figure 1.

4. Applicability and Use of Experience Data

Provided that equipment behavior data are available from several earthquake events of magnitudes comparable to those considered for the design of nuclear power plant equipment, actual experience data contains more information than otherwise available from a seismic qualification testing program. In a qualification testing program the seismic input loading to equipment is derived from analytical models of buildings and soil-structure interaction systems. Characterization of seismic input to the equipment usually ends up with signifi cant amount of over estimation. Analysis of earthquake experience data indicates that where analytical models predict failure none is observed in the actual event. A recent study[6] by the Lawrence Livermore Laboratory concluded on the basis of comparing experience data and current requirements embodied in the Standard Review Plan, Regulatory Guides and national standards that it is feasible to use experience data for determining seismic capability of equipment in operating plants.

The Advisory Committee on Reactor Safeguards (ACRS) conducted several meetings to look into the applicability of the experience data, and has endorsed the feasibility of its use. The ACRS, however, indicated the need for developing experience data on more classes of equipment, more work needed to develop explicit guidelines for use in the evaluation of seismic capability of equipment, and in general more work needed to define the scope of equipment to be considered under USI A-46.

Before this earthquake experience data can be used, these concerns would have to be addressed, and the NRC staff may consider additional restrictions on their use. Recommendations of the SSRAP provide a solid basis for the use of earthquake experience data for the eight classes of equipment studied.

5. Other Activities

Efforts to gather test data developed throughout the industry is now under way sponsored by the Electrical Power and Research Institute. Earthquake experience data augmented by information of seismic testing of equipment should provide a valuable tool not only for the industry in filling up the voids in documentation, but also to the public in developing an understanding of the inherent ruggedness of equipment to seismic loading.

Equipment supports and restraints are important to ensure not only their structural integrity but their dynamic characteristics. In order to ensure uniform criteria from plant to plant and equipment to equipment, efforts are now under way to develop detailed criteria for judging the adequacy of supports and anchorages of equipment.

Both the industry and the NRC staff are now concentrating on the issue of the scope of equipment. There are some equipment that must operate both during and following a seismic event. It is evident from the data base on the eight classes of equipment that equipment operability is maintained when adequate anchorage and restraint is provided. Even the equipment beyond the eight classes that are necessary for seismic safety of a plant, can be hardened for seismic resistance by assuring adequate anchorage. The scope of equipment should include those that must function during the period of strong ground motion, and those that are necessary to maintain the plant in a hot shutdown condition. In addition, it is necessary to assure that inadvertent change in position of relays during the period of strong ground motion does not prevent hot shutdown of the plant. Verification of seismic capability of existing equipment can be accomplished by a team of experienced engineers, familiar with the equipment function and their seismic behavior, by actual plant walk-through. During the plant walk-through such things as adequacy of anchorage, interference with adjacent components and structures can be noted, and necessary modifications can be made. With all the activities under way, it should be possible to implement the resolution of the USI A-46 on a generic basis.

6. Conclusion

When properly anchored, the ability of equipment in nonnuclear facilities to withstand severe earthquakes comes from their inherent ruggedness that is necessary to perform their normal function. It is very important to bring the perspective of equipment performance during past earthquakes to evaluate equipment in nuclear facilities. As the technical community investigates equipment response in past earthquakes, limitations and assumptions in our current analytical models will be better understood.

7. References

1. "Identification of Seismically Risk Sensitive Systems and Components in Nuclear Power Plants Feasibility Study," by A. Azarm, J. Boccio, P. Farahzard, NUREG/CR-3357, June 1983.
2. "Correlation of Methodologies for Seismic Qualification Tests of Nuclear Plant Equipment," by D. D. Kana and D. J. Pomerening, SWRI Report No. SWRI-6582-002, Contract NRC-04-81-185, Task 2 Summary Report, June 1, 1983.
3. "The Use of In-Situ Procedures for Seismic Qualification in Currently Operating Plants," by S. Sadik and B. W. Dixon. INEL interim report, December 1982.
4. "Seismic and Dynamic Qualification of Safety-Related Electrical and Mechanical Equipment in Operating Nuclear Power Plants. Development of a Method to Generate Generic Floor Response Spectra," by J. Curreri, C. Constantino, M. Subudhi, M. Reich, NUREG/CR-3266.

5. "Program for the Development of an Alternative Approach to Seismic Equipment Qualification," by P. I. Yanev, S. W. Swan, EQE report (2 Volumes) prepared by SQUG, September 1982.
6. "Correlation of Seismic Experience Data in Non-Nuclear Facilities with Seismic Equipment Qualification in Nuclear Plants, (A-46)," by P. D. Smith and R. G. Dong. NUREG/CR-3017, August 1983.
7. "Seismic Experience Data Base," prepared by EQE Incorporated, San Francisco, CA, December 1984.
8. "Seismic Experience Data Base Average. Average Horizontal Data Base Site Response Spectra," prepared by EQE Incorporated, San Francisco, CA, December 1984.
9. "Plots Of Power Spectral Density For Ground Motion Records Used In The SQUG Seismic Experience Data Base," prepared by EQE Incorporated, San Francisco, CA, December 1984.
10. "Investigation of Equipment Performance In Foreign Earthquakes And The 1964 Alaska Earthquake," prepared by EQE Incorporated, San Francisco, CA, December 1984.
11. "Use of Past Earthquake Experience Data to Show Seismic Ruggedness of Certain Classes of Equipment In Nuclear Power Plants," Senior Seismic Review and Advisory Panel, February, 1984.