Seismic Qualification of Equipment in Operating Nuclear Power Plants

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INTRODUCTION

The issue of Seismic Qualification of Mechanical and Electrical Equipment in Operating Nuclear Power Plants was designated as Unresolved Safety Issue (USI) A-46 in December 1980. The safety concern was that equipment in nuclear plants with construction permit (CP) applications docketed before about 1972 had not been reviewed to the current licensing criteria for seismic qualification of equipment (Regulatory Guide 1.100; Institute of Electrical and Electronics Engineers (IEEE) Standard 344-1975 and Standard Review Plan Section 3.10 (NUREG-0800)). Therefore, this equipment may not have been adequately qualified to ensure its survival and functionality in the event of a safe shutdown earthquake (SSE). Plants with a CP application docketed after about 1972 have been qualified according to the current licensing criteria and their compliance has been audited by the NRC staff. All plants whose compliance with the current licensing criteria could not be verified are required to be reviewed for the seismic adequacy of equipment under the USI A-46 program.

The NRC staff determined that it was not feasible to require older operating plants to meet current licensing requirements. Therefore, a number of alternative procedures were investigated. The alternative selected, which forms the basis for the A-46 implementation provisions, was the use of earthquake experience data, supplemented by test experience data. The compilation of earthquake and test experience data was used to develop a data base, with appropriate rules and restrictions, that can be used to verify the seismic capability of most nuclear plant equipment below certain specified bounds of earthquake motion. This alternative provides a reasonable and cost effective means of ensuring that the intent of Generic Design Criteria (GDC) 2 of 10 CFR Part 50, Appendix A is met.

Development of earthquake and test experience data to address USI A-46 was suggested by the Seismic Qualification Utility Group (SQUG) in 1982. SQUG and its contractors performed a pilot study to determine the feasibility of using actual earthquake experience to evaluate the susceptibility of nuclear power plant equipment to seismic loads. The SQUG concluded, and the NRC agreed, that the use of experience data was feasible. In 1983, the SQUG proposed the formation of a panel of consultants, the Senior Seismic Review and Advisory Panel (SSRAP), to independently assess the feasibility of using experience data and to provide expert advice and consultation. In 1984, the Electric Power Research Institute (EPRI) began an effort to collect and evaluate existing seismic test data on nuclear plant equipment. The SQUG, EPRI, and SSRAP investigations were closely monitored by the NRC Staff.

USI A-46 was technically resolved in 1987 and resulted in the issuance of Generic Letter 87-02 (Ref. 1) and the associated supporting documents (Refs. 2 and 3). Plants not reviewed to current licensing criteria are required to perform an evaluation of the seismic adequacy of those systems and components needed to bring the plant to a hot shutdown condition and maintain it there for 72 hours.

Plant review procedures are outlined in a SQUG developed Generic Implementation Procedure (GIP) (Ref. 4). The NRC accepted the GIP with some open items in a Generic Safety Evaluation Report (SER) (Ref. 5). Plant specific implementation will start following final acceptance of the GIP.

This paper discusses the many lessons learned from the A-46 investigation and identifies the areas where further research and investigation are warranted.

LESSONS LEARNED FROM USI A-46

When the SQUG initiated the collection of seismic experience data, the objective was to gain an understanding of equipment failure modes. The pilot program (Ref. 6) involved the collection of data on seven classes of equipment from fourteen conventional power plants and industrial facilities that experienced four California earthquakes (Richter magnitude 5.1 to 6.6). The pilot program showed that, in general, anchored equipment survived earthquakes and performed well, even when subjected to significant ground motion.

There are several general lessons that became apparent early in the program. As a result of the early findings, equipment seismic concerns were narrowed to four areas:

1. Equipment anchorage
2. Equipment functionality
3. Outliers
4. Seismic System Interaction

The SQUG pilot program was later expanded to include twenty classes of equipment in over one hundred facilities that experienced thirteen earthquakes that have occurred in the United States and Latin American countries since 1971 (Ref. 8).

In each of the four areas of concern mentioned above, specific guidelines were developed by SQUG, by the Electric Power Research Institute (EPRI), and by their contractors. Recommendations of how experience and test data should be used in the evaluation of seismic ruggedness of equipment in operating nuclear power plants were developed by the SSRAP (Ref. 7). To date, not all identified problems have been resolved. However, as a result of these investigations, a better understanding of these areas was developed. Lessons learned from each of the areas is discussed below.

Equipment Anchorage

Experience data showed that in most cases even minimal anchorage survived earthquakes and precluded displacement of equipment. That is, anchorage which would be determined by current analysis procedures to be grossly inadequate survived even though some yielding and displacement occurred. However, anchorage was found to be a vital link in the survival and functioning of all equipment, and a rigorous and thorough anchorage walkdown inspection must be a key part of any seismic review.

The EPRI/SQUG anchorage review guidelines (Ref. 9) provide a conservative but efficient way to perform equipment anchorage reviews for equipment in operating nuclear plants. Note that the EPRI/SQUG Procedures may not be judged as conservative when compared to current design practice.

The EPRI/SQUG anchorage review guidelines provide detailed inspection procedures for fasteners such as expansion anchor bolts, cast-in-place bolts and headed studs, grouted-in-place bolts, and welds to embedded steel plates and channels. Several open issues are yet to be resolved before the finalization of the anchorage review guidelines. A number of the open issues were caused by recent test evidence provided to the NRC by an expansion anchor manufacturer, that the edge distance and spacing criteria recommended for their products may be inadequate for the bolts to develop their full strength. These open issues are being investigated by EPRI and SQUG, with close monitoring by NRC and the SSRAP to assess the impact on the anchorage review guidelines.

Equipment Functionality

The issue of equipment functionality during the strong motion part of an earthquake became focused on electrical relays and similar devices (switches, contactors, etc.). Relays, as discussed here, include those similar devices that may chatter during an earthquake. Concerns regarding the functionality of valves and valve operators, pumps and motors, and other equipment required to operate during the earthquake were resolved during the program by development of appropriate review caveats. An example is a caveat that pumps and their drivers be mounted on the same rigid base.

Seismic experience data indicated that electrical relays will survive earthquakes without structural damage and with a very few exceptions will function after the earthquake. The A-46 investigations clearly showed that the structural adequacy of relays was of little concern.

The earthquake experience data was not conclusive on the functionality (chatter) of relays during the actual earthquake motion. However, there was no evidence in the experience data base that relay chatter caused any equipment malfunctions or other problems at any of the data base facilities. Plant operators at one conventional power plant in Chile, which had undergone several strong motion earthquakes, told the A-46 investigation team that relay chatter had never presented a problem to them. Because of requirements to "lock-in" a signal in safety-related electrical circuits in nuclear power plants, it is recognized that the circuits in nuclear plants may react differently than circuits in conventional plants. Also, the consequences of relay chatter may be significantly greater in nuclear plants.

Because there was no information in the experience data base on performance during earthquakes, EPRI initiated a program to collect test information on relays. This program was expanded to collect test data on seventeen other classes of equipment to provide additional information on both structural integrity and functionality. This included both seismic qualification tests and some fragility tests. The test information was used to develop Generic Equipment Ruggedness Spectra (GERS) (Ref. 10). The relay GERS represent bounding fragility levels for classes of relays.

The A-46 approach for conducting review of relays is a two step approach which is described below.

1. System Review: A review of the electrical schematics is performed to determine if relay chatter or change of state will defeat the system function, or place the component or system in an unsafe condition. A detailed review procedure was developed by EPRI (Ref. 11) and is included as part of the SQUG A-46 implementation review procedure. The results of two trial plant A-46 implementation reviews revealed

that the number of essential relays for which chatter is unacceptable is much less than previously thought.

2. Determine Relay Seismic Capacity: If it is determined during the systems review that relay chatter is unacceptable, then the seismic capacity (chatter level) of that relay must be verified. To do this, the input spectra at the relay mounting location (seismic demand) must be determined and compared to the applicable GERS (seismic capacity) for that relay type. If the relay input spectra is not bounded by the GERS, then several other options are available. The relay can be replaced by a higher seismic capacity relay that has been qualified, the circuit can be changed so that chatter will not be a problem, or a specific test of that item or a more detailed evaluation can be performed (e.g., develop more realistic floor spectra).

Several difficult issues were identified in developing the relay review procedures.

1. Relay Identification: Early in the process of collecting relay test data, it became apparent that model numbers (HGA, SG, etc.) were not adequate descriptions of relays with regard to seismic capacity. Sub-model numbers (HGAXXX) indicate modifications and minor differences which in some instance change the seismic capacity. It was not practical to obtain and test every variation of each model. Work is still underway (under EPRI and NRC contracts) to understand these differences. With the limited amount of test data available and the summary nature of the available test reports, this is a very difficult issue to resolve.

2. In-Cabinet Amplification: The seismic input to the relay at the mounting location is dependent on the amplification through the cabinet of the floor response at the cabinet base. Developing a generic amplification factor is extremely difficult due to such factors as the variations in cabinet dimension and stiffness, mounting configuration, relay location, and the location and mass of other devices in the cabinet. This issue is not resolved at this time and further work is being done.

3. Variability of Seismic Capacities: There is some experimental evidence that for a given individual relay, the measured fragility may change from test to test even on the same tables with the same inputs. Further, identical relays tested on the same tables in the same test may have significantly different fragilities. In addition, there are a number of parameters which are difficult to control that can appreciably affect seismic capacity. They include contact gap, spring stiffness or adjustment, orientation, contact corrosion, etc. The tentative conclusion drawn by the authors is that pending resolution of this issue, significant conservatism must be applied to relay fragilities.

4. Paucity of Available Fragility and Qualification Test Data: There is a limited amount of test data available. Most test data is proprietary and the owners of the data are reluctant to provide sufficient information about the test to help understand the seismic characteristics. This will remain as an unresolved area until additional test data is made available or until significantly more independent testing is done. (This also applies to certain other equipment).

5. IEEE Criteria for Chatter Duration: The traditional criteria used to define relay contact chatter is defined in IEEE Standard 501 to be 2