Seismic Margin Assessment of Mitigation Systems in Oskarshamn

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ABSTRACT

This paper describes a pilot study to estimate the seismic margin of mitigation systems in Oskarshamn Unit 1 nuclear power plant in Sweden. The mitigation concept developed by OKG/AB consists of the filter vented containment and an independent containment spray system. These systems are being designed to meet the seismic standards currently used in Sweden. Some of the components of these systems interface with the existing systems in Oskarshamn Unit 1 which are not designed to today's exacting seismic criteria. OKG/AB wants to ensure that the interfacing systems and components adequately support the successful performance of the mitigation concept in the event of a severe accident caused by an earthquake. A seismic margin assessment was proposed as a cost-effective approach to achieve this goal.

In this study, a review of the plant design documents was conducted and a walkdown of the mitigation systems along with the interfacing systems in Unit 1 was performed. The objective of this study has been to show how the different stages of seismic margin assessment are accomplished (i.e., walkdown, screening and seismic margin calculations). The margin assessment is based on the earthquake experience data and results and insights obtained in the performance of seismic PRAs. The study demonstrated that System 322 Containment Spray System has a High Confidence of Low Probability of Failure seismic capacity of larger than 0.15 g peak ground acceleration anchored to the USNRC Regulatory Guide 1.60 ground response spectrum provided the seismic adequacy of anchorage of the heat exchangers framing is further verified. Of all the components in this system, only the reactor building and the heat exchangers needed detailed evaluation and the rest were screened out based on the review and walkdown; this attests to the cost-effectiveness of the approach. In order to ensure that the mitigation concept is successful in the event of a severe accident caused by an earthquake, the other systems i.e., reactor scram system and the electrical system need to be assessed for seismic margins. The next phase of the margin assessment will focus on these systems.

INTRODUCTION

Earthquakes are very rare in Sweden. Presently there are studies being undertaken in the country to define the seismic hazard and to develop seismic design bases for nuclear power plants that capture the unique seismological features of Sweden. In the meantime, the mitigation systems in Oskarshamn Units 1 and 2 are being designed for a safe shutdown earthquake (SSE) of 0.15 g with the U.S. NRC regulatory guide 1.60 ground response spectrum. Oskarshamn Unit 3 is also designed for these criteria. It would be desirable to have the mitigation systems in Oskarshamn Units 1 and 2 including the interfacing systems qualified for these seismic criteria.

The systems that are of particular interest for this evaluation are:

- Reactor scram
- Containment isolation
- Systems for containment spray and containment venting

This evaluation is accomplished using the seismic margin review methodology (Budnitz et al 1985; Prassinos et al 1986 Ravindra et al 1987). It combines the best features of seismic PRA, earthquake experience data and seismic qualification test data. It is realized that seismic qualification by traditional methods of analysis and testing would be prohibitively expensive for the present purpose. The approach followed in the present study derives heavily from the seismic margin review methodology developed for the U.S.NRC and utilizes the EQE data base on performance of structures and equipment in power plants and industrial facilities during a number of major earthquakes around the world.

The seismic margin of a component/system is measured by the HCLPF capacity. It is defined as the peak ground acceleration for which there is a high confidence (95%) of low probability of failure (<5%). The HCLPF capacity is expressed in terms of the median capacity A_m, and variability parameters β_R (randomness) and β_U (uncertainty)

The objectives of this seismic margin assessment study are to:

- Demonstrate the feasibility and cost effectiveness of this methodology in assessing the seismic margins

- evaluate the seismic margin of the systems necessary for the OKG/AB mitigation concept in addressing severe accidents, and

- identify potential seismic vulnerabilities such as seismically inadequate anchorage and supports of equipment.

There are two phases to this study: Phase I reported herein consisted of review of available information on the plant design, walkdown of the systems and structures listed above, and screening out of certain equipment and systems based on their high seismic capacities. As a demonstration of this methodology, the seismic margin of the containment spray system (System 322) was evaluated. Phase II which will be undertaken later covers the assessment of seismic margins of the other mitigation systems and identification of potential seismic vulnerabilities.

WALKDOWN OF MITIGATION SYSTEMS

The walkdown focused on the systems needed for the functions of reactor scram (System 354), containment isolation, containment spray (System 322) and containment venting. It covered the containment, reactor building, electrical building and intake structure.

The purpose of seismic walkdown was to gain an understanding of the mitigation systems, equipment, and structures. Information gathered during the walkdown was used as input for initial screening of equipment and structures. Detailed data for subsequent fragility evaluation of screened in components were also collected. During the walkdown, particular attention was given to the identification of seismic vulnerabilities and potential system interactions.

Seismic walkdown of Oskarshamn 1, including discussions with OKG technical staff and plant personnel, was conducted over a span of one week.

Areas for walkdown were identified during initial discussions with plant engineers. They included equipment and structures comprising the following:

- System 322 (containment spray system) between the containment spray pumps and the spray headers
- System 354 (hydraulic scram system) - includes electrical cabling system from the control room to the CRDM and the fluid system incorporating the scram tanks and associated isolation valving
- Electrical System - includes the portions of the plant emergency electrical system which is required for the above two systems and for the new mitigation systems

EQE conducted a review and walkdown of the mitigation systems and their interfaces with Oskarshamn Unit 1. The following conclusions were reached based on the walkdown:

- No obvious deficiencies were found in the structures such as containment, containment internal structure, reactor building, electrical building and intake structure. However, the actual seismic margin evaluation of these structures are typically done using the design information and seismic response analysis.
- The light concrete walls enclosing rooms containing station batteries, motor generator sets, distribution centers and battery chargers and inverters appear to be made of individual blocks stacked on top of each other without any mortar or other bonding agent. Also, the presence of any grout fill or internal reinforcement could not be verified. Significant cracking was observed in many of the walls, which indicates a relatively low tensile strength. The seismic margins of these walls and the potential consequence of failure of these walls in an earthquake will be assessed in Phase II of this study.
- Valves and piping were assessed to be typical of those found in industrial facilities which have performed satisfactorily in major earthquakes. The walkdown did not find any potential problem areas (as identified in the earthquake experience data base) such as stiff length of piping between buildings, excessive cantilevered operators on valves, and inadequate clearance between valves and adjacent walls or columns.
- The floor mounted vertical tanks (water and nitrogen) with leg supports in the scram system could not be screened out because the legs and anchorage appeared to be minimal and need to be assessed for seismic margin. (Phase II)
- The only heat exchangers which were reviewed during the walkdown were the containment spray heat exchangers. While the heat exchangers themselves were judged to be typical of heat exchangers within the earthquake experience data base, seismic margin evaluation of the support framing and its attachment and anchorage was considered necessary.

- The batteries are lead antimony flat plate type batteries whose seismic performance in the aged condition has been judged to be unsatisfactory in recent laboratory tests by manufacturers in the US. In addition, the batteries are supported on two-step racks which are not anchored; no spacers are provided between the batteries and side rails do not exist. The seismic adequacy of the batteries and battery racks will be addressed in Phase II study.

- The transformer inside the battery charger is mounted on rollers and not laterally supported. This is vulnerable to electrical shorting in a seismic event. There is a smaller battery charger which is not anchored at all.

- The anchorage for motor control centers could not be verified satisfactorily because of congestion of cables in the base of the cabinets. A more thorough review of the anchorage will be conducted in Phase II of the study.

- Cable trays were found to be similar to those observed in industrial facilities that have performed satisfactorily in major earthquakes; hence no concern exists on the cable trays' capacity to withstand earthquakes postulated at the plant site.

SEISMIC MARGIN ASSESSMENT OF SYSTEM 322

As a demonstration of the practicality and cost-effectiveness of the seismic margin assessment methodology, the seismic margin for the containment spray system was evaluated in this study. The system was chosen because it is relatively simple; it consists of valves, piping and heat exchangers. The valves are fail-safe and there are no electrical components to be evaluated. The objective was to show how the different stages of seismic margin assessment methodology are accomplished; walkdown, screening, and seismic margin calculation.

By the seismic margin assessment methodology, components that are determined to have HCLPF capacities greater than the review earthquake level were screened out. Detailed seismic fragility evaluation for these components is not necessary. Review of seismic fragility evaluations of nuclear power plants and past earthquake experience data has demonstrated that certain generic categories of components can be screened out for the selected review earthquake level, provided that these components at Oskarshamn Unit 1 do not have any specific features that would imply lower seismic capacities. Based on this review and walkdown, the following components were screened out: valves, cable trays, and piping.

Seismic Margin Assessment of Reactor Building

The System 322 components are located in the reactor building. The lateral load resisting system for this structure consists primarily of reinforced concrete shear walls and floor slabs. Seismic margin evaluation of this building is based on an appropriate extrapolation of results of the linear elastic seismic response analysis performed for the USNRC R.G. 1.60 ground response spectrum anchored to 0.15 g pga (Larsson, 1988). The following structural elements were examined:

- West Exterior Wall
- North Exterior Wall
- Cylindrical Wall around Containment
- Floor Diaphragm

The failure modes investigated are 1) in-plane shear failure of the wall, 2) in-plane bending failure of the wall, 3) overall shear and bending failures of the cylindrical wall, 4) shear failure of the diaphragms, and 5) impact between cylindrical wall and containment. It was determined that the in-plane bending of the west exterior wall is the critical failure mode of the reactor building. By considering the safety margins and variabilities in factors such as inelastic energy absorption capacity, spectral shape, damping , modeling, mode combination and earthquake component combination (Ravindra et al, 1987), the ground acceleration capacity was calculated as:

Median Ground Acceleration Capacity = 0.66 g
β_R = 0.28 and β_U = 0.36
HCLPF Capacity = 0.23 g

Another failure mode of interest is the potential impact between the cylindrical wall and containment at earthquakes below the seismic capacity of the reactor building. The median relative displacement at the reactor building HCLPF capacity of 0.23 g is calculated to be less than the separation of 50 mm by more than a factor of 7, therefore the impact between the two structures is judged to be unlikely.

Seismic Margin Assessment of Containment Spray Heat Exchanges

The containment spray heat exchangers are located at grade within the containment building. Two similar units are supported off the ground on a structural steel frame. Each heat exchanger is supported at the mid-section of the casing by two welded brackets. During the walkdown, it was judged that the support for the heat exchanger and the anchorage of the frame attachment are not typical of the nuclear plants that were studied in the past PRAs and hence these heat exchangers could not be screened out as having a high seismic capacity. In searching through the earthquake experience data base, we concluded that the mid-height supported heat exchangers are commonly found in the chemical processing plants and oil refineries and that these heat exchangers have survived large earthquakes. However, major requirement in the use of earthquake experience data is that the anchorage be reviewed to ascertain that no vulnerabilities exist. For this purpose, a seismic response analysis of the heat exchanger and the support framing was performed. The mathematical model considered the heat exchangers, steel frame and attached piping as a total system to capture the gross interaction effects between these sub-structures. The forces in the primary supports (i.e., brackets connecting the heat exchangers to the framing and the base of the framing) were calculated for the USNRC R.G. 1.60 ground motion response spectra anchored to 0.15 g pga in the horizontal direction and 0.10 g pga in the vertical direction. The two most critical failure modes for the heat exchangers were determined to be the failure of machine bolts attaching the heat exchanger to the frame and the anchor bolts attaching the frame to the concrete. Both of these failure modes involve brittle load paths in that the bolts will fail in a brittle manner once they have reached their ultimate strengths. Based on the calculated seismic response and the safety margins and variabilities present, the machine bolts connecting the heat exchangers to the framing were determined to be adequate to withstand earthquakes larger than 0.15g pga. The anchor bolts connecting the framing to the concrete could not the confirmed to be cast-in-place during the plant walkdown and review. If they are indeed cast-in-place, their seismic capacity was calculated to be 0.12 g pga. It is possible to perform a non-linear time history analysis of the heat exchanger piping system to better estimate the seismic loads on the frame attachment than was possible with the linear response spectrum analysis. This could indicate that the seismic capacity of the framing base anchorage is larger than 0.15 g. This aspect will be examined in Phase II of this study.

SUMMARY AND CONCLUSIONS

The objective of this pilot study has been to demonstrate how the different stages of seismic margin assessment methodology are carried out (i.e., plant review and walkdown, screening of components and systems, and seismic margin calculations) in a cost-effective manner. The margin assessment is based on the earthquake experience data and the results and insights obtained in the performance of over 25 probabilistic risk assessments studies of nuclear power plants in the US, Europe and Taiwan. The study has demonstrated that the containment spray system has a HCLPF capacity larger than 0.15 g pga anchored to the USNRC R.G. 1.60 ground response spectrum provided the heat exchangers' frame anchorage is verified to be adequate.

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