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Seismic IPEEE Industry Insights

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ABSTRACT

The United States Nuclear Regulatory Commission initiated a formal review of the seismic margin of all operating nuclear power plants in the US with the issuance in 1991 of Generic Letter 88-20, Supplement 4 (Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities). Virtually all of the US Nuclear Utilities have submitted their responses for seismic IPEEE and these submittals are in the process of being reviewed by the NRC. The NRC's stated purpose of the IPEEE program is for each licensee to 1) develop an appreciation of severe accident behavior, 2) understand the most likely severe accident sequences that could occur at its plant under full power operating conditions, 3) gain a qualitative understanding of the overall likelihood of core damage and radioactive material release, and if necessary 4) reduce the overall likelihood of core damage and radioactive materials releases by modifying hardware and procedures that would help prevent or mitigate severe accidents. The objective of this paper is to provide an industry perspective on the results and the insights obtained from the utility seismic IPEEE submittals.

SEISMIC IPEEE

Earlier Seismic Probabilistic Risk Assessment (SPRA) studies indicate that the major contributions to seismically induced core melt frequencies for plants located in Central and Eastern United States (CEUS) come from earthquakes in the peak ground acceleration range of 2 to 4 times the Safe Shutdown Earthquake (SSE) accelerations (NUREG/CR-4334). Other studies indicate that substantial capacity exists beyond the design basis of these plants and that these plants are capable of withstanding earthquake motions significantly greater than the SSE (EPRI, 1988, NUREG/CR-4334). However, there was no systematic evaluation performed to quantify the margin that actually exists in nuclear plants. Thus, based on this apparent need to quantify the existing seismic margin at nuclear plant sites, the NRC and the utility industry performed research to address this issue of the plant seismic margin (NUREG/CR-5250, EPRI-1989, NUREG 1488).

The scope of the seismic IPEEE evaluations were originally defined within Generic Letter 88-20 Supplement 4 and NUREG 1407. In response to the NRC suggested scope and depth of review, the industry performed further studies on specific issues such as: seismic "binning"[1], relay chatter, soil failures, and containment performance. The NRC responded to the industry studies by modifying some of the requirements and issuing Generic Letter 88-20,

[1] Final binning agreed upon by the industry and the NRC are listed in NUREG-1407. They are reduced scope, 0.3g focused scope, 0.3g full scope, and seismic PRA for plants east of the Rocky Mountains, and 0.5g and seismic PRA for Western United States Plant sites.

Supplement 5. The seismic IPEEE programs have been conducted at all the US nuclear plants using the aforementioned guidelines, and the results are documented in individual submittals.

SUMMARY OF SEISMIC IPEEE RESULTS

Sixty (60) IPEEE submittal reports were collected and reviewed during Phase 1 of this EPRI project. These represent 70 nuclear plant sites and a total of 86 units. Phase 1 of this study focused on capturing summary and results data for all 86 units, rather than collecting in-depth information on specific units. Out of the sixty (60) submittals reviewed in Phase 1, 25 submittals (34 operating units) used seismic PRA methodology; 32 submittals (48 operating units) performed EPRI seismic margin; 2 submittals (2 operating units) performed NRC seismic margin evaluations; and 2 submittals (4 operating units) used site-specific seismic programs for IPEEE submittals. (Note: 2 units had submittals which reported results using both the PRA and margin methodologies).

The evaluation of seismic IPEEE results and insights is broken out as a function of the plant implementation methodology, since characterization of the results are so different between the seismic PRA and the seismic margin study.

Seismic PRA's: Seismic Core Damage Frequency Results

NUREG-1407 states that for the seismic IPEEE, it is not necessary to carry out complete uncertainty quantification defining a distribution of core damage frequencies in order to identify vulnerabilities. Mean point estimate using a single hazard curve and a single fragility curve for each component is sufficient to get insights into potential seismic vulnerabilities. The point estimate approach is valid only because the IPEEE objectives are to identify dominant sequences and components and, where possible, rank them. A histogram of mean annual seismic core damage frequencies (CDF's) of the 25 seismic PRA submittals which were reviewed in Phase 1 is shown in Figure 1. The CDF's range from 2.5E-7 to 2.26E-4 with a spread of about 3 orders of magnitude. Most of the plants' CDF values fall within the range of 1.0E-6 to 6.0E-05. Figure 2 presents a histogram showing the ratio of seismic CDF's to internal events CDF's. About 20% of the units reported the seismic CDF to be equal or greater than the internal events CDF.

Seismic PRA: Dominant Risk Contributors

The documentation guidelines of NUREG-1407 requires a description of dominant functional/systemic sequences leading to core damage along with their frequencies and percentage contribution to overall seismic core damage frequencies. All seismic PRA submittals reviewed provided descriptions of systems/sequences that contributed significantly to the overall seismic core damage frequencies. The system losses most frequently identified as being involved in the dominant sequences included the loss of offsite power, the failure of the emergency diesel generators (either seismic-induced or non-seismic), loss of the AC power system, loss of auxiliary feedwater systems, instrumentation and control system loss, and failure of NSSS. Table 1 summarizes individual components that were identified to be dominant risk contributors from the seismic IPEEE submittals reviewed. The most frequently observed dominant risk contributors are: electrical cabinets, tanks, surrogate elements[2], and building structures. Seismic interactions, transformers, battery chargers, and diesel generators are observed on a less frequent basis to be dominant risk contributors in the submittals. Chillers/HVAC, fans, pumps, relays (upon resolution of low ruggedness relays), cable trays, block walls, NSSS components, heat exchangers, valves, and piping rarely are seen to be dominant seismic risk contributors.

Seismic Margins: HCLPF Capacities

For those plants which chose to perform seismic margin evaluations for seismic IPEEE, either the EPRI SMA or the NRC SMA methodology was used to calculate a plant level High Confidence Low Probability of Failure (HCLPF) capacity. The two methods use different system analysis philosophies. The NRC method is based on an event/fault tree approach to delineate accident sequences. It involves determination of the HCLPF values for individual components and the examination of Boolean expressions for accident sequences initiated by a seismic event and ending in core damage to determine the HCLPF capacity for the plant. The EPRI method is based on a systems "success path" approach. The approach defines and evaluates the capacity of a subset of components required to bring the plant to a stable condition and maintain that condition for at least 72 hours.

Most of the focused or full scope plants reported plant HCLPF capacities equal to or greater than the plant review level earthquakes (e.g., 0.3g) after the resolution of A-46 outliers or implementation of plant improvements. Only six (6) submittals out of a total of the 60 reviewed for this study reported plant HCLPF capacities less than the plant Review Level Earthquake (RLE). Among these, two reported plant HCLPF capacities less than the design SSE level. The significance of these two reported HCLPF values (below the SSE) was addressed in each of their respective submittals and necessary actions or improvements were taken by the responsible utilities. Plant improvements and modifications of the governing components have already been implemented for one of the two plants. The final improved plant HCLPF capacity for that plant is 0.25g, which is governed by soil liquefaction in the area outside of Category I buildings. The second plant reported a HCLPF capacity of 0.09g, which is governed by cable tray supports. The utility reported in their submittal that more detailed evaluations of the cable tray supports will be performed (modifications will also be performed, if required) to increase their capacity.

For reduced-scope plants, the IPEEE evaluation is performed based on the plant's seismic design basis (i.e., SSE) as input. Thus, a reduced-scope evaluation does not convey the seismic margin over design SSE as would a focused or a full-scope SMA.

A list was generated as a part of this project of all the components that have HCLPF capacities less than the respective plant review level earthquake. These components with lower HCLPF values can be placed within the following groupings: anchorage of tank/heat exchangers, bad actor relays, block walls, cable raceway supports, condensate water storage tank, electrical cabinet anchorage, EDG peripherals, buildings–turbine building, emergency diesel generator building, and soil liquefaction.

[2] A surrogate element is added to the system logic model in series to represent the screened out components. The representation of this surrogate element was often done in a conservative manner which led to it being a dominant contributor to risk.

PLANT MODIFICATIONS AND UPGRADES

A significant portion of the plant improvements involved housekeeping and maintenance of a minor nature. A summary of the plant improvements that resulted from the seismic IPEEE, other than housekeeping and maintenance items, is presented in Table 2. Most of the plant improvements involve anchorage upgrade of electrical or control cabinets and prevention of seismic spatial interactions, followed by fastening of adjacent electrical cabinets, upgrade of heat exchanger anchorage, and replacing of bad-actor relays.

SPECIFIC SEISMIC IPEEE CONSIDERATIONS

The NRC specifically requested that several areas receive a specified focus during the seismic IPEEE reviews. These areas were identified based on their importance from past seismic PRA's and on the NRC review that these issues had not been consistently addressed in the original plant design basis. Some of the more important areas listed and their resolution were reviewed as a part of this project: plant walkdown, relay chatter, seismic-induced fires and internal flooding, soil failures and liquefaction, non-seismic failures and human actions, and containment performance.

The following perspectives provide a brief summary of the insights relating to these 6 specific areas:

- The plant walkdown is a key element of all seismic IPEEE reviews (both PRA's and margin studies). The utility engineers quickly realized the importance of using detailed walkdowns to identify as-built conditions and to look for failure modes that can only be identified in the field (concrete cracking, interactions, corrosion, etc.).

- The level of review conducted as a part of the seismic IPEEE review varied according to which "seismic bin" the plant was in. Most plants performed a review to identify relays with know low ruggedness (i.e. bad actor relays). These low ruggedness relays were found at a number of plants, but not on a very widespread basis. The resolution for these bad actor relays typically consisted of either replacement or the determination that the chatter effects were acceptable.

- The assessment of seismic-induced fires and flooding were typically undertaken as a part of the plant walkdown for seismic IPEEE. The general insight resulting from these reviews was that very few fire sources and very few flood sources exist within the plants that pose a credible seismically-induced risk. Several interesting fire protection system actuation consequences were identified at multiple plants that required upgrading to prevent undesired consequences following the earthquake. These scenarios included inadvertent spray from fire water lines and diesel choking due to cardox actuation coupled with closure of the diesel building dampers.

- The issues of soil failures and liquefaction were highly localized to plants founded on very soft soil layers. Very few problems were reported during the seismic IPEEE process.

- The treatment of non-seismic failures and human actions and the documentation of that treatment varied significantly from plant-to-plant. Only 2 of the PRA submittals reviewed identified non-seismic failures and human actions as contributing significantly to the seismic core damage frequency.

- The containment performance reviews conducted as a part of the seismic IPEEE program generally addressed the containment structures, containment isolation systems (including valves), containment cooling/spray and the containment bypass systems. The structures and mechanical components within these systems are typically inherently rugged and were rarely identified as problems in the submittals. The vulnerabilities which were identified were rare and typically consisted of filters, air recirculation fans, batteries (for a containment spray system) and relays.

CONCLUSIONS

The utility industry has performed a significant amount of specific seismic review in response to the seismic IPEEE program. The results of this review have demonstrated that while earthquakes typically contribute to the overall plant risk, they rarely ever control the risk. The utilities used the results of these studies to identify plant seismic vulnerabilities and, in many cases, performed plant upgrades in order to decrease the seismic risk. Both the NRC and the industry recognize the benefits of utilizing the results and conclusions of these studies. Consequently it is expected that the results from these seismic IPEEE programs are directly usable in support of risk-informed regulatory efforts in the future.

REFERENCES

1. Electric Power Research Institute (EPRI), "A Methodology for Assessment of Nuclear Power Plant Seismic Margin," NP-6041, Palo Alto, CA October 1998.

2. Electric Power Research Institute (EPRI), "Probabilistic Seismic Hazard Evaluation at Nuclear Plant Sites in the Central and Eastern United States: Resolution of the Charleston issue," NP-63950-D, April 1989.

3. Generic Letter 88-20, Supplement 5, "Individual Plant Examination of External Events for Severe Accident Vulnerabilities", September 8, 1995.

4. NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities," July 1990, (draft).

5. NUREG-1488, "Revised Livermore Seismic Hazard Estimate for 69 Nuclear Power Plant Sites East of the Rocky Mountains", April 1994.

6. NUREG/CR-4334, "An Approach to Quantification of Seismic Margins in Nuclear Power Plants," August 1985.

7. NUREG/CR-5250, "Seismic Hazard Characterization of 69 Nuclear Power Plant Sites East of the Rocky Mountains," January 1989.

8. USNRC, Generic Letter 88-20, Supplement No. 4, "Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities – 10 CFR 50.54(f)," June 28, 1991.

Table 1: IPEEE Seismic PRA Results
Dominant Risk Contributors: Component Types

Reference Plant Number	Number of Units	Tanks	Relays	Piping	Cable Trays	Valves	Diesel Generators	Electrical Cabinets	Pumps	Batteries/Chargers	Heat Exchangers	Transformers	Buildings	Seismic Interaction	Block Walls	Chillers/HVAC	Fans	Surrogate Element	NSSS Components
1	1														X				
2	1						X					X	X	X					
3/4	2	X						X								X		X	
5	2	X						X		X									
6	2	X										X	X						
7	2		X					X				X	X						
8	1			X						X						X	X		
9	1							X											
10	1	X											X	X					
11	1	X						X	X										
12	1																	X	
13	2	X						X		X									
14	1	X					X											X	
15	1	X					X											X	
16	3												X	X				X	
17	1	X					X						X						
18	1	X				X		X	X										
19	1	X						X	X				X	X	X				X
20	2				X			X				X						X	
21	2									X				X			X		
22	2							X				X	X					X	
23	1	X					X	X											
24	1	X					X				X			X					X
25	1							X										X	
TOTAL UNITS	**34**	**17**	**2**	**1**	**2**	**1**	**6**	**18**	**3**	**7**	**1**	**9**	**13**	**9**	**2**	**3**	**3**	**13**	**2**

Table 2: Summary of Plant Improvements

Issue Identified Needing Improvement	Number of Units Identifying this Issue
Block Wall Upgrades	4
Cabinet Anchorage Upgrades	21
Cable Tray/Raceway Modification	5
Cast Iron Yoke Upgrade	1
Control Room Ceiling	6
EDG Peripherals	7
Equipment on Vibration Isolators	2
Fastening of Adjacent Electrical Cabinets	11
Hx Anchorage	10
Median FRS	2
Mounting of Components Inside of Cabinet	3
Operator Actions & Procedures	8
Piping	1
Provide Backup Cooling	2
Replacing Bad Actor Relays	9
Seismic Spatial Interaction	20
Substation Spare Parts	2
Top Bracing of Control Panels	1

Figure 1: Mean Seismic CDF

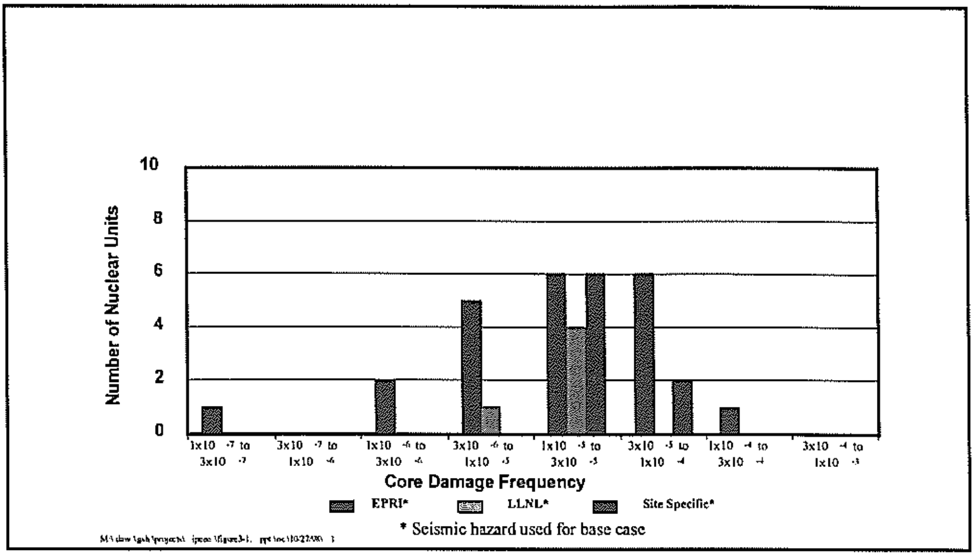

Figure 2: Seismic/Internal Event CDF's