Insights from Seismic System, Structure and Component Screening Approach

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When preparing SEL (Seismic Equipment List) which list the SSCs required for seismic fragility analyses, it would result in many System, Structure and Components (SSCs). For those SSCs, the fragility analysis should be conducted. However it is impractical to do fragility analysis for all those SSCs, therefore screening and selecting SSCs for detailed fragility analyses is one of the important tasks in Seismic PRA (SPRA). Screening SSCs can be done based on the generic data considering potential contribution to the risk given the generic seismic capacity. However, the seismic capacity that can be obtained from the generic data is limited. ASME/ANS RA-Sa-2009 (Ref. 1) *requires that the screening level should be high enough so that the contribution to core damage frequency and large release frequency from the screened-out SSCs is not significant. This paper explores the screening approach that could meet the requirement of ASME/ANS RA-Sa-2009* (Ref. 1) *using the typical seismic hazard derived for low seismic activity site.*

I. Introduction

The number of SSCs initially selected for SPRA is more than 1000 items in general. If generic components such as power operated valves and instrumentations are counted, the number would be even more. It is not practical to develop detailed fragility analysis for all those SSCs. So selecting SSCs for detailed fragility analyses is one of the tasks typically done in the SPRA by screening or assigning minimum seismic capacities based on generic experience data. ASME/ANS RA-Sa-2009 (Ref. 1) requires that the screening level should be high enough that the contribution to core damage frequency (CDF) and large release frequency (LRF) from the screened-out components is not significant. It also requires that specific fragility analyses should be done for safety significant SSCs. EPRI 1002989 (Ref. 2) and EPRI 1020756 (Ref. 5) suggest to determine screening fragilities based on the failure frequencies obtained by convolving candidate fragilities with seismic hazard curve. EPRI NP-6041-SL (Ref. 3) and NUREG/CR-4334 (Ref. 4) provide generic capacities for use in the screening with caveats that should be met for assigning the generic capacities. This paper applies the approach suggested in the references and provides insights from the application.

II. Methodology
II.A. Determination of Screening Fragilities

Before starting fragility analyses, a preliminary SPRA plant models are developed and the quantification of SPRA models are done by assigning generic seismic capacities to the SSCs in the model. Screening and prioritizing the SSCs for fragility analyses are performed using the results and insights obtained from the quantification. Some SSCs can be screened out and excluded from the plant models if the seismic-induced failure frequencies are lower than some pre-determined screening value. Some SSCs that have higher failure frequency than the screening value but do not contribute significantly to the CDF or LRF may not need detailed fragility calculations. These SSCs may be retained in the model with generic seismic capacities. Figure 1 illustrates the general approach for screening and prioritizing the SSCs for fragility analyses.

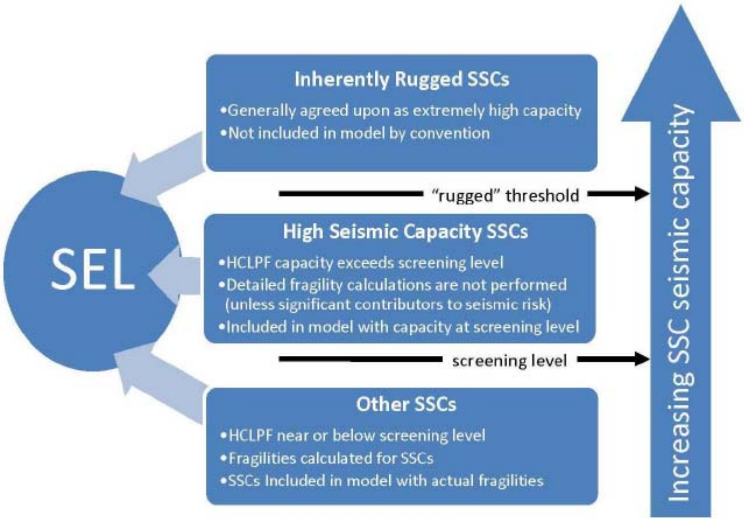

Figure 1 Capacity-Based Criteria for Fragility Analysis (Ref. 6)

ASME/ANS RA-Sa-2009 (Ref. 1) states that "The screening level chosen should be based on the seismic hazard at the site and on the plant seismic design basis and should be high enough that the contribution to core damage frequency and large early release frequency from the screened out components is not significant". But the Standard does not specify a specific frequency. EPRI 1002989 (Ref. 2) suggests to use 1.0E-7/yr frequency as "not-significant" while EPRI 1025287 (Ref. 6) suggests using 5E-7/yr.

It is suggested to consider the screening failure frequency of 1.0E-7/yr as that for excluding from the plant models and the screening failure frequency of 5.0E-7/yr as that for not requiring detailed fragility analyses.

II.A.1 Convolution of Single HCLPF capacity and Seismic Hazard

The simplest screening technique is to postulate that the impact of each SSCs failure leads directly to core damage and large early release and estimate the failure frequency by convolving the fragility of components with the mean seismic hazard curve. Assuming that, the convolution of screening HCLPF capacities with site specific seismic hazard would provide the point estimate of CDF and LRF for the SSCs having the HCLPF capacity. The convolution is done using following equation;

$$f' = \Phi\left[\frac{\ln(\frac{a}{Am}) + \beta_U \Phi^{-1}(Q)}{\beta_R}\right] \quad (1)$$

Q = P[f < | a]; i.e., the subjective probability (confidence) that the conditional probability of failure, f, is less than f′ for a peak ground acceleration a.

Φ-1[.] = the inverse of the standard Gaussian cumulative distribution of the term in brackets.

$$A_m = HCLPF \cdot \exp(-1.65 \cdot (\beta_R + \beta_U)) \quad (2)$$

A_m = Median Ground Acceleration Capacity

β_R = Random Variables

β_U = Uncertainty Variables

II.B. Generic HCLPF Capacity

The EPRI NP-6041-SL (Ref. 3) provides screening level HCLPF capacity for structures and components. Using the capacity, the minimum generic capacity, called Screening Level Capacity, can be estimated.

The screening level capacity is provided as Sa (Peak Spectral Acceleration) of 'less than 0.8g', '0.8g ~ 1.2g', 'higher than 1.2g' in EPRI NP-6041-SL (Ref. 3). These screening levels correspond to the seismic level specified in the IPEEE (Individual Plant Examination for External Events) (Ref. 7) as i.e., 0.3g bin and 0.5g bin. The seismic IPEEE done adopted the screening capacity for excluding the SSCs from the SPRA models. One of the insights from the Seismic IPEEE was that using the screening level capacity for screening out SSCs from the models caused potential significant SSCs to be excluded in the analysis prematurely. Based on the observation, ASME/ANS RA-Sa-2009 (Ref. 1) requires that the screening level chosen should be based on the seismic hazard at the site and on the plant seismic design basis and should be high enough that the contribution to core damage frequency and large early release frequency from the screened-out components is not significant. Therefore the screening must consider the probability of failure of screened out components and the impact of the failures on the CDF/LRF.

III. Application of the Screening Methodology

III.A. Risk-Based Screening

The failure frequencies for the several candidate HCLPF values are estimated by simple convolution of the seismic hazard with the HCLPF values. The seismic hazard is obtained from one of the seismicity site and the βc (Combined Uncertainty) is assigned to be 0.4 as suggested in EPRI 1019200 (Ref. 8). The results of the convolution are presented in the Table I below. As shown in the Table I, to screen out the SSCs from the plant model, the SSCs should have HCLPF capacity higher than 1.0g (PGA) if adopting the screening criterion of 1.0E-7 per year frequency suggested in EPRI 1002989 (Ref. 2).

TABLE I. Fragility and Seismic Hazard Convolution Results

HCLPF(PGA)	Median Capacity (PGA)	Probability of Failure per Year
0.360	0.920	1.82E-06
0.400	1.020	1.44E-06
0.500	1.270	8.20E-07
0.600	1.520	5.04E-07
0.700	1.780	3.27E-07
0.800	2.030	2.21E-07
0.900	2.290	1.54E-07
1.000	2.540	1.10E-07

EPRI 1020756 (Ref. 5) presents slightly different approach about determining screening criterion from that of EPRI 1019200 (Ref. 8). This approach estimates the CDF of candidate HCLPF values given a specific plant HCLPF capacity. Assuming that the plant HCLPF capacity is 0.5g, the conditional failure frequencies for candidate HCLPF values are estimated and the results are presented in Table II below. The estimation shows that the contribution of the SSCs with the seismic capacity higher than 0.70g, 0.80g, 0.90g HCLPF contributes 9.92E-08/yr, 5.04E-8/yr, and 2.74E-8/yr, respectively, to the seismic CDF.

TABLE II. Fragility and Seismic Hazard Convolution Results

HCLPF(PGA)	Median Capacity (PGA)	βC	Probability of Failure per Year
0.50 (Plant HCLPF)	1.27	0.4	5.81E-07
0.70	1.78	0.4	9.92E-08
0.80	2.03	0.4	5.04E-08
0.90	2.29	0.4	2.74E-08

It can be considering the screening criteria of 1.0E-7/yr failure frequency and the estimation above, following screening criteria can be adopted in the SPRA for the site.

- SSCs having HCLPF capacity of 1.0g PGA or higher can be removed from the plant logic model.
- A SSCs having generic HCLPF capacity of 0.6g PGA or higher does not require detailed fragility calculations unless it directly lead to large release.

III.B. Estimation of Generic HCLPF Capacity

The design basis earthquake level (Safe Shutdown Earthquake: SSE) adopted for new plants is in general 0.3g. For the 0.3g SSE plants, it is expected that 1.2g Sa screening caveats listed in the EPRI NP-6041-SL (Ref. 3) should be met. So the generic HCLPF capacities can be estimated by dividing the 1.2g Sa HCLPF capacities by the seismic demand at the location that SSCs are located. The seismic demand is estimated using the median in-structure response spectra (ISRS).

III.B.1.Ground Motion Incoherence

Some reduction in the high frequency Sa of input ground motion is expected for the structure due to incoherency effects of the ground motion. The ISRS is in general developed without consideration of the ground motion incoherency (GMI). This factor can be considered in the estimation of the seismic demand based on the EPRI 1002988 (Ref. 9). The dimension of the basemat of the example structure housing the safety related components is approximately 360 ft by 364 ft. The Reference 9 presents the reduction factors at important frequency due to GMI as Table III below.

Table III. Reduction Factors for 150 ft Foundation (Ref. 9)

Frequency, Hz	Reduction Factor, R150
0.2	1.0
1	1.0
5	1.0
10	0.9
20*	0.87
≥25	0.86

* Reduction factor determined by linear log-log interpolation.

The equivalent plan dimension De of the structure basemat is computed to be 362 ft by taking a geometric mean of the two side dimensions as follows.

$$D_e = \sqrt{360ft \times 364ft} = 362ft \qquad (3)$$

With this equivalent dimension, reduction factors are computed at various frequency points using the following equation.

$$RF = 1 - \frac{D_e}{150feet} \times (1 - RF_{150feet}) \qquad (4)$$

The ISRS reflecting the GMI factor is used as seismic demand for estimating the generic HCLPF capacities. .

III.B.2.Generic HCLPF capacity estimation

The 5% damped peak spectral accelerations of the ISRS reflecting the GMI factors are shown in Table IV at some representative plant locations. The screening level HCLPF capacity of SSCs that meets the 1.2g Sa screening caveats of Table 2-4 of EPRI NP-6041-SL (Ref. 3) is calculated using the equations below.

$$\text{Screening Level HCLPF Capacity} = (\text{SL} / \text{Sa\_Peak}) * \text{PGArock} \qquad (5)$$

where,

- SL screening level capacity in terms of spectral acceleration = 1.5 x 1.2g = 1.8g, Appendix B of EPRI 1019200 (Ref. 8).
- Sa_Peak = 5% damped 1.0E-5 UHRS peak horizontal spectral acceleration at the specific location
- PGArock = Peak ground acceleration of the 1E-5 UHRS at the top of Engineering Layer (i.e., 0.36g).

TABLE IV. Screening Level HCLPF Capacity (PGA) at each floor level

Elevation	Capacity (Sa, g)	Demand UHRS Peak (Sa, g)	Median PGA Capacity	Screening Level HCLPF Capacity (PGA)
55ft	1.8	0.68	2.65	0.96
78ft	1.8	0.9	2.00	0.73
100ft	1.8	1.12	1.61	0.58
120ft	1.8	1.39	1.29	0.47
136.5ft	1.8	1.63	1.10	0.40
156ft	1.8	1.89	0.95	0.35

The Table IV shows that no SSCs can have generic seismic capacities higher than 1.0g HCLPF which can be screened out to exclude from the plant model but the SSCs located below 78ft elevation can have higher seismic capacity than 0.6g HCLPF which does not require detailed specific fragility calculations.

III.C. Impact of Variability on the Screening Failure Probability

The convolution of the seismic induced failure probability provided in the Table I above is estimated using the HCLPF capacity and the corresponding composite logarithmic standard deviation (βc) of 0.4, which is suggested in EPRI 1002989 (Ref. 2). EPRI 1025287 (Ref. 6) indicates that the range of βc can be varied from 0.3 to 0.6 depending on the amount of available earthquake experiences and the SSCs type. The higher βc results in higher median capacity and in turn lower seismic-induced failure probability. The Table V below provides the recommended βc values depending on the SSCs type.

TABLE V. Recommended βc, βr, βu values for Various Types of SSCs

Type SSCs	Composite β_C	Randomness β_R	Uncertainty β_U
Structures & Major Passive Mechanical Components Mounted on Ground or at Low Elevation Within Structures	0.35	0.24	0.26
Active Components Mounted at High Elevation in Structures	0.45	0.24	0.38
Other SSCs	0.4	0.24	0.32

Sensitivity analyses are performed to see the impact of βc on the failure probability.

The failure probability depending on HCLPF capacity

- Base Case : βc = 0.4
- Case 1 : βc = 0.35
- Case 2 : βc = 0.45

The results of the failure probability estimation are presented in the Table VI below. As shown in the Table, the failure probability using the βc of 0.35 is increased up to HCLPF capacity of 0.8g while reduced in case of HCLPF capacity of higher than 0.8g. The failure probability using βc of 0.45 is reduced up to HCLPF capacity of 1.0g.

The Table VI also shows that the HCLPF capacity corresponding 1.0E-7/yr frequency is higher than 1.0g HCLPF capacity in case 1 and 0.9g HCLPF in case 2 while that corresponding to 5.0E-7/yr frequency (0.6g in base case) is higher (0.7g HCLPF) for 0.35 βc and lower (~ 0.55g) for 0.45 βc.

TABLE VI. Failure Frequencies of HCLPF Capacities with Different Logarithmic Standard Deviations

HCLPF (PGA)	βc = 0.4 (Base Case)		βc = 0.35 (Case I)			βc = 0.45 (Case II)		
	Median Capacity (PGA)	Probability of Failure per Year	Median Capacity (PGA)	Probability of Failure per Year	Differences	Median Capacity (PGA)	Probability of Failure per Year	Differences
0.36	0.92	1.82E-06	0.81	2.18E-06	16.5%	1.03	1.53E-06	-19.0%
0.4	1.02	1.44E-06	0.90	1.72E-06	16.3%	1.14	1.21E-06	-19.0%
0.5	1.27	8.20E-07	1.13	9.87E-07	16.9%	1.43	6.84E-07	-19.9%
0.6	1.52	5.04E-07	1.36	6.07E-07	17.0%	1.71	4.19E-07	-20.3%
0.7	1.78	3.27E-07	1.58	3.94E-07	17.0%	2.00	2.71E-07	-20.7%
0.8	2.03	2.21E-07	1.81	2.66E-07	16.9%	2.28	1.82E-07	-21.4%
0.9	2.29	1.54E-07	2.03	1.86E-07	17.2%	2.57	1.27E-07	-21.3%
1	2.54	1.10E-07	2.26	1.33E-07	17.3%	2.85	9.04E-08	-21.7%

The failure probability of generic HCLPF capacities in specific plant location

The failure probabilities of generic HCLPF capacities assigned to the SSCs based on the Table IV above and the results of the estimated is presented in the Table VII below.

TABLE VII. Screening Level HCLPF Capacity (PGA) at each floor level

Elevation	HCLPF (PGA)	βc = 0.4 (Base Case)	βc = 0.35 (Case I)		βc = 0.45 (Case II)	
		Median Capacity	Median Capacity	Probability of Failure per Year	Median Capacity	Probability of Failure per Year
55ft	0.96	2.65	2.17	1.51E-07	2.74	1.03E-07
78ft	0.73	2.00	1.64	3.49E-07	2.07	2.39E-07
100ft	0.58	1.61	1.32	6.66E-07	1.66	4.60E-07
120ft	0.47	1.29	1.06	1.16E-06	1.34	8.04E-07
136.5ft	0.40	1.10	0.91	1.72E-06	1.14	1.21E-06
156ft	0.35	0.95	0.78	2.37E-06	0.99	1.67E-06

The Table VII indicates that no SSCs with generic HCLPF capacities meet the screening criteria of 1.0E-7 for all cases considered. The Table VII also indicates that the SSCs located 100ft elevation or below can meet the criteria of 5.0E-7 when using βc of 0.45 while only the SSCs located 78 ft elevation or below can meet the criteria when using βc 0.4 or lower.

IV. SUMMARY

The screening of SSCs is one of the important steps in the SPRA. Two types of screening are considered, one for the screening out completely from the plant model and the other one for the requirement of detailed specific fragility calculation. According to the references available, it is considered that;

- The SSCs with seismic-induced failure probability lower than 1.0E-7/yr can be screened out from the plant model.
- The SSCs with seismic-induced failure probability lower than 5.0E-7/yr do not require detailed specific fragility calculations.

The two types of screening levels are estimated in view of HCLPF capacity for the example site which has relatively low seismic hazard. The results show that;

- The seismic capacity corresponding to 1.0E-7/yr failure frequency is 1.0g HCLPF.
- The seismic capacity corresponding to 5.0E-7/yr failure frequency is 0.6g HCLPF

To apply the screening approach, the generic HCLPF capacity is estimate for the SSCs in the example plants. The estimation shows that;

- No SSCs in the plant can be screening out based on generic seismic capacities.
- The SSCs located 78ft or below may not require detailed specific calculations.

The failure probability is estimated with 0.4 βc. A sensitivity analysis is performed to assess the impact of variability on the screening level. The sensitivity analysis confirms that the different βc does not affect the screening level.

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