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RISK-INFORMED PERFORMANCE-BASED SEISMIC DESIGN APPROACH FOR ADVANCED REACTORS

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ABSTRACT

The United States (U.S.) commercial nuclear power industry initiated the Licensing Modernization Project (LMP) to facilitate licensing and regulating the safety of advanced reactors. The LMP framework, as described in the Nuclear Energy Institute (NEI) guidance document NEI 18-04 (NEI, 2018), relies on risk-informed performance-based (RIPB) concepts and approaches that also incorporate the defense-in-depth philosophy. Chokshi et al. (2021), proposed a technologically inclusive seismic design approach that integrates RIPB seismic design concepts with the LMP framework. This paper discusses the integration of LMP and seismic design standard American Society of Civil Engineers (ASCE) 43-19 for the seismic design and iterative design process embedded in the methodology. By way of examples, the paper demonstrates potential benefits arising from the flexibility in a graded manner gained in assigning different seismic design categories (SDCs) (thus, different design basis ground motion levels) and different design performance limits (i.e., different limit states) to structures, systems, and components (SSCs) considering their risk-significance and other risk-informed decision-making factors. A simple shear wall design considering alternate SDC and limit state (LS) combinations for the same site is used to illustrate the effects on physical designs and functional fragilities for these combinations. In a companion paper in this conference, "Application Examples to Demonstration RIPB Seismic Design Concepts for Advanced Nuclear Power Reactors," the design based on the RIPB approach is explained through a demonstration example.

INTRODUCTION

The Licensing Modernization Project (LMP) proposed by the United States (U.S.) commercial nuclear power industry aims to improve the regulatory basis for licensing and regulating the safety of advanced nuclear power reactors. The LMP framework, as described in the Nuclear Energy Institute (NEI) guidance document NEI 18-04 (NEI, 2018), relies on risk-informed performance-based (RIPB) concepts, including approaches that incorporate the defense-in-depth (DID) philosophy. In Regulatory Guide 1.233, the U.S. Nuclear Regulatory Commission (NRC) endorsed, with clarifications, the LMP principles and methodology as described in NEI 18-04 (NRC, 2020). The LMP framework places an emphasis on understanding individual event sequences (or groups of them) and more directly applies probabilistic risk assessment (PRA) as a basis for much of the understanding that would support safety decision-making. Embedded in the NEI 18-04 RIPB framework is the selection of a set of design-basis external hazard levels (DBEHLs) to form an important part of design and licensing and determine the design-basis seismic events and other external events that the safety-related structures, systems, and components (SSCs) will be required to withstand. Chokshi et al. (2021) proposed a technologically inclusive seismic design approach that integrates the RIPB seismic design concepts within the LMP framework, wherein the safety margins of individual SSCs are built-in according to their contribution to system-level and plant-level risk, thereby reducing unnecessary conservatisms (or providing additional margins, as needed) and achieving a more balanced design in a graded manner. The iterative design process, discussed in Chokshi et al. (2021) and Stamatakos et al. (2021), is an integration of LMP and standard American Society of Civil Engineers /Structural Engineering Institute (ASCE/SEI) 43-19 (ASCE, 2019, henceforth referred as ASCE 43-19), which adopts a performance based and graded seismic design approach.

In this paper we describe the seismic design process in the LMP/ASCE 43 integration approach including the benefits and flexibility in ASCE 43-19 by assigning different seismic design categories (SDCs) (thus, different design basis ground motion levels) and different design performance limits [i.e., different Limit States (LS)] to SSCs considering their risk-significance and other risk-informed decision-making factors. A simple shear wall design is considered as an example to study alternate SDCs and LS combinations for the same site and it's impacts on physical designs and functional fragilities for these combinations. The proposed application of seismic probabilistic risk assessment (SPRA) insights during the design process is discussed and demonstrated in a companion paper (Chokshi et al. 2022).

A regulatory guide for trial use with several RIPB options is being developed by NRC to implement the RIPB seismic design concepts for advanced reactors. One of the options is the LMP/ASCE 43 integration approach described in this paper.

OVERVIEW OF LMP/ASCE 43 INTEGRATION PROCESS

The LMP/ASCE 43 integration process is an iterative process that supports a strategy achieving desired safety goals while allowing greater flexibility in seismic design in a graded manner to meet system-level acceptability criteria as well as plant-level acceptability criteria. The iterative design process starts very early at the conceptual stage with preliminary design and generic fragility information for SPRA. As the site- and plant specific data is available and the design of SSCs matures, detailed design and fragility evaluations are made. This design process meets the LMP criteria using combinations of variable seismic design requirements for individual SSCs and then examines their contributions to system-level performance using the SPRA. The LMP framework calls for an integrated decision-making process (IDP) that employs a risk metric frequency-consequence (F-C curve) incorporating annual frequency of occurrence of the event sequences (license basis events or LBEs) and the associated radiological dose at the site boundary, cumulative risk goals, DID considerations, and other decision factors. In this procedure, SPRAs and seismic design are interrelated (i.e., SPRAs are used to inform licensing decisions and aid the designer in assigning SSC design-performance targets goals and design LSs.) The output of the LMP/ASCE 43 integration process is the determination of SDCs and LSs for various SSCs (or groups of SSCs) to be used in the final seismic design.

The seismic design of SSCs builds on engineering approaches in structural/seismic engineering, maintains the familiar "deterministic" process for immediate use, and utilizes existing codes and standards to the maximum extent feasible. Chokshi et al. (2022) provides the details of LMP/ASCE 43 process and the subsequent detailed design process.

ASCE 43 SEISMIC DESIGN CATEGORIES

Of the many applicable industry codes and standards that apply to seismic design, ASCE 4-16 (ASCE/SEI, 2017) and ASCE 43-19 are considered the most important to the LMP/ASCE 43 integration approach because they incorporate many of the analysis and design requirements spread over regulatory guides and SRP sections (NRC, 2013). They address identification of target “safety levels” for a nuclear facility, define “seismic demands” for the physical design of SSCs, and identify consistent seismic design criteria for specific SSCs.

Two important considerations for seismic design of SSCs in the proposed LMP/ASCE 43 integration approach are the selection of the target performance category and the allowable damage state that the SSC can experience given the demands imposed by the earthquake ground motions that correspond to the target performance category. ASCE contains four SDCs, SDC 2,3,4, and 5.

SDC5 is the most stringent level, for example, it is applicable to a nuclear power plant or a nuclear material processing facility with a large inventory of radioactive material. ASCE 43-19 defines a target performance goal, P_F, for SDCs 2-5, representing a mean annual frequency of exceeding a specified limit state as shown in Table 1. The design response spectra (DRS) consistent with the SDCs is developed using the uniform hazard response spectra (UHRS) and probabilistic seismic hazard curves for a specific site in accordance with the guidance in ASCE 43-19.

Table 1: ASCE 43-19 Seismic Design Categories and Performance Targets

Seismic Design Category (SDC)	2	3	4	5
Target Performance Goal, P_F	4×10^{-4}	1×10^{-4}	4×10^{-5}	1×10^{-5}

A combination of the SDC (SDC2 through SDC5) and the LS (A, B, C, or D) defines the design basis earthquake and acceptance criteria for design of the SSC. The SDC5 and LS-D combination is similar to the conventional elastic design in the Standard Review Plan (NRC, 2013). Comparatively, LSs C to A allow non-linearity in the structural system to the extent that the permanent deformation and the damage levels are within the limits described qualitatively in Table 2. In practical terms, for strength-based design the limit states are accommodated in the design through the inelastic energy absorption factors given in ASCE 43-19, which also provides the acceptance criteria for deformation-based design approaches.

Table 2: ASCE 43-19 Qualitative Criteria for Limit States

Limit State	Expected Deformation	Damage Level
A	Large Permanent Deformation Short of Collapse	Significant Damage
B	Moderate Permanent Deformation	Generally Repairable
C	Limited Permanent Deformation	Minimal Damage
D	Essentially Elastic Behaviour	Negligible Damage

The actual LS exceedance frequency (i.e., the expected annual frequency that the LS will be exceeded) for an SSC is calculated by convolving a design performance “fragility” curve of the SSC with the control point seismic hazard curve. The design performance fragility of an SSC is defined as the probability of unacceptable performance of the SSC (i.e., probability of exceeding a given LS) over a range of ground motions [defined either as peak ground acceleration (PGA) or another specified spectral acceleration].

The seismic design requirements provided in ASCE 43-19, in conjunction with other design, detailing, and construction standards, are considered by seismic engineers to be sufficient to meet numerical target design performance goals in Table 1. To achieve the target performance goals, ASCE 43-19 relies on the consensus codes and standards such as ASCE 4-16 (ASCE/SEI, 2017), American Concrete Institute (ACI) 349-13 (ACI, 2013) for reinforced concrete structures and American National Standards Institute/American Institute for Steel Constructions (ANSI/AISC N690-18, 2018) for structural steel construction. These codes and standards produce (i) seismic demand at 80 percent non-exceedance probability for the specified input and (ii) the design strength at 98 percent exceedance probability (i.e., a 2 percent probability that the design strength is less than the target). Alternatively, ASCE 43-19 goals also are achieved by meeting two conditional probabilities (fragilities of the SSCs consistent with the target performance goal): (i) less than about a 1 percent probability of unacceptable performance for the design basis ground motion and (ii) less than 10 percent probability of unacceptable performance for ground motion equal to 150 percent of the design basis earthquake ground motion.

SEISMIC HAZARD AND DESIGN RESPONSE SPECTRA

For demonstrating the LMP/ASCE 43 integration process we selected a hard rock site calling it Site A (Chokshi, et al. 2021 and Stamatakos et al, 2021). The hazard curves and UHRS in Chokshi, et al. (2021) for Central Eastern United States (CEUS) existing power plant sites were obtained from the licensee submittals in response to Fukushima Near-Term Task Force (NTTF) Recommendation 2.1. The hazard curves in Figure 1 shows mean annual frequency of exceedance (MAFE) for a range of ground motions at different spectral frequency levels and PGA for Site A. The UHRS at MAFE 1×10^{-5}, 1×10^{-4}, 4×10^{-4}, and 1×10^{-3}, are shown in Figure 2a. PGA and the corresponding MAFE are 1.05g (1×10^{-5}), 0.33g (1×10^{-4}), 0.12g (4×10^{-4}) and 0.06g (1×10^{-3}). DRSs for three seismic design categories SDC5, SDC4, and SDC3 were developed using ASCE 43-19 as seen in Figure 2b. PGAs for SDC5, SDC4 and SDC3 are 0.5g, 0.25g, and 0.15g (Figure 2b) and the corresponding MAFE are 4.78×10^{-5}, 1.49×10^{-4}, and 3.11×10^{-4}, respectively. The mean PGA hazard curve (represented in black) in Figure 1 and DRS for the three SDCs in Figure 2b were used in the example analyses.

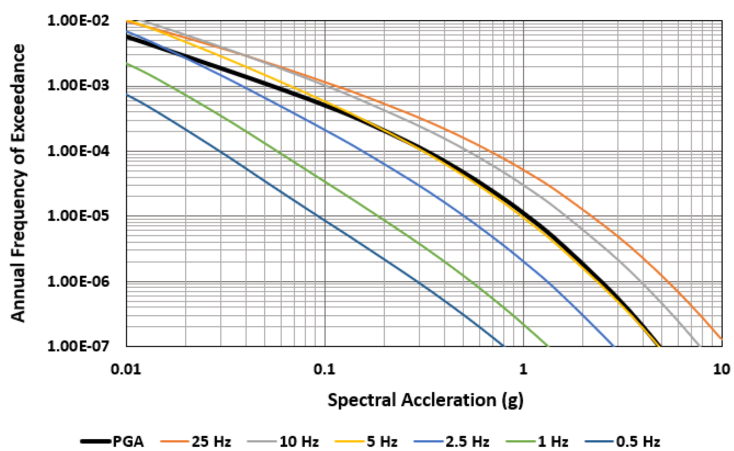
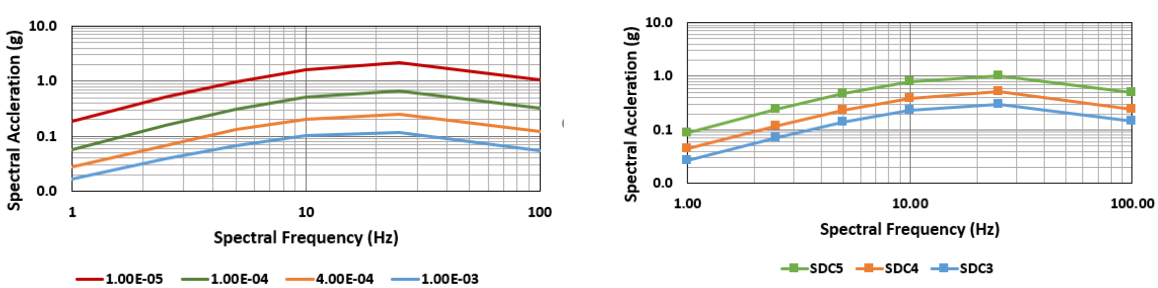


Figure 1. Mean Hazard Curves for a Hard Rock Site A



(a) UHRS **(b) DRS**

Figure 2. (a) UHRS at MAFE 1×10^{-5}, 1×10^{-4}, 4×10^{-4}, 1×10^{-3} for Site A; and (b) Evaluated DRS at SDC5, SDC4, and SDC3 Based on ASCE 43-19 Guidance

The above DRSs and hazard curves are used to characterize design and annual frequencies of failure for a simplified shear wall through the use of generic fragilities and design-specific fragilities in the following two sections.

EXAMPLE GENERIC FRAGILITY

This section describes how the functional fragilities of SSCs that are designed to the ASCE 43-19 criteria could be derived at very early stages of design using generic information. For this approach, the SSCs are assumed to be designed to the full limits of design criteria. In practice, there will be design margins that may vary from SSC to SSC. However, these design margins for SSCs are not relied on for fragility evaluations at the conceptual design stage. Seismic loading is typically the dominant load, but the design also could be controlled by other loads and load combinations. The SSC fragility is derived in terms of median PGA capacity and the composite variability. Other measures such as the spectral acceleration at a specified frequency also could be used. The generic estimates of safety factors and their variabilities are used for this stage of the fragility calculation. The fragility estimates could be modified at later stages using site- and plant-specific data.

Normally, fragility evaluation of an SSC takes into account the actual design data. For example, for a shear wall, the design data includes wall thickness, reinforcement, nominal concrete strength, and the earthquake-imposed load. If the response analysis has been performed to the DRS input, the critical shear wall among all the walls at a particular floor will be identified for fragility assessment. Because this level of data typically will not be available at the conceptual design stage, the objective at this stage is to demonstrate how the fragilities of SSCs are developed if they just meet the ASCE 43-19 criteria. Therefore, the shear wall is assumed to barely meet the ASCE 43-19 design criteria [such as DRS, seismic response analysis, ACI 349 standard (ACI, 2013) requirements etc]. At the conceptual (or design certification) stage, all that is known is that SSCs will be designed to meet the ASCE 43-19 design criteria. In practice, not all SSCs will be designed to the design limits; other loads and load combinations could govern generic variabilities (β values) that are used in the following calculations. The median ground acceleration capacity, A_m, can be written as:

$$A_m = F_T \times \text{DBE PGA, where, the total factor, } F_T = F_{Strength} F_\mu F_R \qquad 1$$

The strength factor, $F_{Strength}$, in equation 1 is the product of the factor reflecting the uncertainty in the material property (reinforcing steel) (F_{mat}) and in the shear failure formula ($F_{formula}$), F_μ is the inelastic absorption factor, and F_R is the response factor. The numerical values of these factors are based on Electric Power Research Institute (EPRI) TR-103959 (EPRI, 1994) and past SPRAs. The response factor, F_R, is obtained by invoking the ASCE 4-16 (ASCE/SEI, 2017) goal of achieving the 80 percent probability of non-exceedance of response for DBE shaking.

If the shear wall is designed to SDC5, and LS-D

F_{mat} = 1.20, β_c = 0.10; $F_{formula}$ = 2.0, β_c = 0.20; F_μ = 1.80, β_c = 0.20

$F_R = e^{(0.842\beta_R)} = 1.34$, where $\beta_R = 0.35$, DBE PGA = 0.5g from Figure 2b

Total factor of safety (F_T) is calculated as 5.80 and β_c = 0.46. The median ground acceleration capacity, A_m, of the shear wall designed to LS-D is given by 2.9 g and the High-confidence, low probability failure (HCLPF) capacity = 1.00 g. HCLPF capacity corresponds to approximately 1 percent probability of failure ($C_{1\%}$) on the mean composite fragility curve.

If the shear wall is designed to SDC5 and LS-C, the design demand is reduced by a factor representing the inelastic energy absorption (see Eq. 5-1a of ASCE 43-19). All other factors being the same, the median ground acceleration capacity also will be reduced by this factor. Table 5-1 of ASCE 43-19 gives this reduction factor as 1.5 for LS-C. Therefore, the median ground acceleration capacity of the shear wall designed to Limit State C is given by (2.9/1.5=) 1.93 g and HCLPF capacity = (1.00/1.5) = 0.67 g.

If the shear wall is designed at SDC–4 for LS-D, the input to the seismic demand analysis will be based on the performance goal of 4×10^{-5} per year. The DBE PGA is 0.25 g, rather than the value of 0.50 g for SDC5. The median ground acceleration capacity of the SDC4 shear wall is given by (2.9×0.25/0.50) = 1.45 g. and HCLPF capacity = 0.50 g.

By designing to SDC5 and LS-C, compared to SDC5/LS-D, the shear wall will have less reinforcement (assuming other design features such as span, height, and wall thickness are not varied). Designing for a lower LS would generally result in some cost savings. Similarly, by designing the wall as SDC4/LS-D, the shear wall will have less reinforcement with other design parameters fixed, because the DRS input is lower (Figure 2b). Designing for a lower SDC would generally result in some cost savings.

The generic fragility calculations assume that the overall seismic design, and hence the median capacity, is governed by the seismic loads and the results, including failure frequency, $P_{Failure}$, are summarized in Table 3. The generic median capacity for SDC4 is exactly half of the SDC5 median capacity because the design PGA is exactly half. Therefore, it is important to note that the use of generic fragilities derived from ASCE 4 and ASCE 43-19 assumptions may show greater benefit, but also may overestimate the risk compared to the actual plant design fragility values. This aspect is clearer in the next section. The functional failure frequencies increase by factors of 3 and 6 for SDC5/LS-C and SDC4/LS-D cases when compared to failure frequency of SDC5/LS-D case. A decision can be made on what is the appropriate design classification in terms of SDC and LS for this wall by examining its risk significance and other considerations through the plant SPRA and integrated decision-making process (Chokshi et al. 2021 and 2022).

Table 3: Results Summarized From Generic Functional Fragility Calculations

Design parameters	SDC5 and LS-D	SDC5 and LS-C	SDC4 and LS-D
PGA (g)	0.5g	0.25g	0.15g
A_m (g)	2.9 g	1.93 g	1.45 g
β_c	0.46	0.46	0.46
HCLPF (g)	1.0 g	0.66 g	0.50 g
$P_{Failure}$ (1/yr.)	1.4×10^{-6}	4×10^{-6}	8×10^{-6}

EXAMPE SHEAR WALL FRAGILITY

A squat reinforced concrete shear wall was designed using ASCE 43-19 [ASCE, 2019], ASCE 4 (ASCE/SEI, 2017), and ACI 349 (2013) for selected combinations of SDC and LS categories. The length and height of the wall were 30 ft (9.14 m) and 15 ft (4.6 m), respectively, and thickness of 2 ft (0.61 m). Additional mass was placed on the top of the wall to obtain a fundamental frequency of 8 Hz. Only in-plane failure modes and designs were explored, and the top mass was assumed to be restrained for the out-of-plane motion. The base of the shear wall, resting on hard rock, was assumed to be fixed. For calculating seismic forces, response spectrum analysis was used with in-plane and vertical excitations. Vertical ground motion was assumed to be 2/3rds of horizontal ground motion. Strength based design of the wall was performed for three design ground motions corresponding to seismic categories SDC5, SDC4, and SDC3 and three limit states LS-D, LS-C, and LS-B for each SDC. The seismic demands corresponding to the limit states were accounted for using the inelastic absorption factors, F_{μ}, given in ASCE 43-19. Compressive strength of concrete f_c' = 5000 psi (34.47 MPa), and yield strength of reinforcing steel f_y = 60 ksi (413.7 MPa) were used for the design. The height and length dimensions of the shear wall were fixed, but the reinforcement ratios accounted for the chosen combinations of SDC levels and LS categories. Two wall thicknesses 2 ft (0.61 m) and 1.5 ft (0.46 m) were considered in the analysis.

The mean design performance target was evaluated using a procedure similar to that given in Chapter C1of ASCE 43-19 for this specific design. The results for the actual mean performance target frequency, designated as, P_{Design}, for the SDC5/LS-D case is presented in Table 4. As expected, the P_{Design} for the walls have lower values compared to the target P_F because of other constraints encountered in a realistic design. The same observations were made for SDC4/LS-D and SDC3/LS-D in our calculations.

Table 4: Seismic Design Performance P_{Design} of Shear Wall Designed for SDC5

Wall thickness	2.0 ft (0.61 m)	1.5 ft (0.46 m)
Limit state	LS-D	LS-D
P_{Design}	4×10^{-6}	3.58×10^{-6}

The functional fragility for the shear wall was developed using the separation of variable (SOV) approach in accordance with the EPRI guidance report TR-103959 (EPRI, 1994). For the fragility evaluation, three failure mechanisms (diagonal shear cracking, flexure, and shear friction) were considered and a functional median drift criterion of 0.007 was used in accordance with EPRI guidance. The F_{μ} (inelastic absorption factor) was calculated using the Effective Frequency/Effective Damping methodology, and β_U, and β_R were estimated following the EPRI guidance. The shear wall fragility curve was convolved with the Site A seismic hazard curve (black curve in Figure 2) to obtain failure frequency, $P_{Failure}$, (1/yr.) for various SDC and LS combinations. We studied the impact of graded design and potential benefits offered by ASCE 43-19 considering alternate SDC and LS combinations for a concrete shear wall considered in this analysis. This is judged by understanding the effect on the probability of failure and quantity of reinforcing steel required in the design.

The design associated with the SDC5 and LS-D for the 2 ft (0.61 m) thick wall was assumed to be the base case and the performance of other shear walls is compared to the base case. Table 5 shows the median capacity (A_m), composite uncertainty (β_c), annual probability of failure, $P_{Failure}$, HCLPF, ratio of $P_{Failure}$ indicating a factor for increase in failure probability (1/yr.) with respect to the base case (SDC5/LS-D), and factor for decrease in steel required in design with respect to the base case. The following observations are made from the results in Table 5: (1) decrease in requirements of steel for LS-C and LS-B compared to LS-D for both thicknesses; (2) failure probability for LS-C and LS-B is slightly higher compared to LS-D for both thicknesses; (3) requirement of steel for 1.5 ft (0.46 m) thick wall is not significantly different than 2 ft thick wall; and (4) $P_{Failure}$ is comparatively higher for 1.5 ft (0.46 m) thick wall than 2 ft (0.61 m) thick wall. Similar trends were observed in each Table 6 and 7.

Following comparisons were noted between SDCs from the results in Tables 5 to 7; (1) failure probability is higher for SDC4 and SDC3 compared to SDC5 for all limit states; (3) failure probability in all cases is within the same order of magnitude and not significantly higher than base case, and (4) decrease in requirement of steel is significant for SDC-4 and SDC-3 compared to SDC5 for both 2 ft (0.61 m) and 1.5 ft (0.46 m) thick walls compared to LS-C and LS-B. For this example, the flexibility of graded design shows benefit in steel requirement for SDC 3 and 4 and thickness 1.5 ft (0.46 m) without substantial increase in probability of failure.

Table 5: Design and Performance Results for SDC5 for LS- D, C and B						
Design parameters	SDC-5 LS-D	SDC-5 LS-C	SDC-5 LS-B	SDC-5 LS-D	SDC-5 LS-C	SDC-5 LS-B
Wall Thickness	2.0 ft (0.61 m)			1.5 ft (0.46 m)		
PGA (g)	0.5	0.5	0.5	0.5	0.5	0.5
Median Capacity (A_m)	3.07	2.92	2.86	2.57	2.54	1.9
Uncertainty, (β_c)	0.43	0.45	0.45	0.42	0.44	0.33
HCLPF (g)	1.13	1.05	1.02	0.97	0.92	0.88
$P_{Failure}$ (1/yr) $(\times 10^{-6})$	1.11	1.34	1.44	1.79	1.94	3.29
Ratio $P_{Failure}$ [1]	1 (Base Case)	1.2	1.3	1.6	1.8	3.0
Reduction of Steel[1]	1 (Base Case)	2	2.3	1.1	2.1	2.5
(1) With respect to Base Case (SDC5/LS-D)						

Table 6: Design and Performance Results for SDC4 for LS- D, and C (results for LS-B not calculated)				
Design parameters	SDC-4 LS-D	SDC-4 LS-C	SDC-4 LS-D	SDC-4 LS-C
Wall Thickness	2.0 ft (0.61 m)		1.5 ft (0.46 m)	
PGA (g)	0.25	0.25	0.25	0.25
Median Capacity (A_m)	2.83	2.71	2.45	2.34
Uncertainty, (β_c)	0.46	0.47	0.45	0.43
HCLPF (g)	1.0	0.93	0.87	0.86
$P_{Failure}$ (1/yr) $(\times 10^{-6})$	1.51	1.77	2.19	2.37
Ratio $P_{Failure}$ [1]	1.4	1.6	2.0	2.14
Reduction of Steel [1]	2.6	3.9	2.8	4.3
(1) With respect to Base Case (SDC5/LS-D) in Table 5.				

Table 7: Design and Performance Results for SDC3 for LS- D, and C (results for LS-B not calculated)				
Design parameters	SDC-3 LS-D	SDC-3 LS-C	SDC-3 LS-D	SDC-3 LS-C
Wall Thickness	2.0 ft (0.61 m)		1.5 ft (0.46 m)	
PGA (g)	0.15	0.15	0.15	0.15
Median Capacity (A_m)	2.7	2.64	2.32	2.25
Uncertainty, (β_c)	0.48	0.47	0.46	0.47
HCLPF (g)	0.91	0.9	0.8	0.77
$P_{Failure}$ (1/yr) $(\times 10^{-6})$	1.83	1.93	2.63	2.9
Ratio $P_{Failure}$ [1]	1.6	1.7	2.4	2.6
Reduction of Steel [1]	4.3	5.7	4.7	7.1
(1) With respect to Base Case (SDC5/LS-D) in Table 5.				

CONCLUSION

In this paper, we have described some aspects of the RIPB seismic design approaches that are under development. One of the principal goals of this paper is to illustrate the potential benefits in seismic design that can be realized by allowing alternate seismic design categories and limit states for an SSC considering its risk-significance, safety functions, and other integrated decision-making process considerations. In our illustration, a simple shear wall structure was evaluated using both a generic fragility approach and design specific fragilities. One of the essential elements of the LMP/ASCE 43 integration Process discussed in this paper is to be able to adjust the fragilities while going through an iterative process to derive optimal SDCs and LSs for different SSCs. This contrasts with the current practice and approach of using a single SDC, SDC 5, and a single limit state, LS-D, for all safety related SSCs. A regulatory guide for trial use is being developed by NRC to provide guidance for these RIPB seismic design concepts for advanced reactors with several options in addition to the LMP/ASCE 43 integration approach described in this paper. A companion paper (Chokshi et. al. 2022) has a demonstration example that describes how the LMP/ASCE 43 integration is conceptually implemented.

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