

COMPARISON OF SEISMIC DESIGN CODES AND RISK TARGETS FOR MODERATE RISK SDC-3 NUCLEAR FACILITIES

DOE/NRC NATURAL PHENOMENA HAZARDS WORKSHOP

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Exception: SDC-3 SSC may be designed, including site characterization and probabilistic seismic hazard analysis, per the NE-STD-1020 rules for SDC 2 SSC except with use of an importance factor $I=2.0$. Alternatively, they may be designed per NE-STD-1020.

Department of Energy – Office of Nuclear Energy

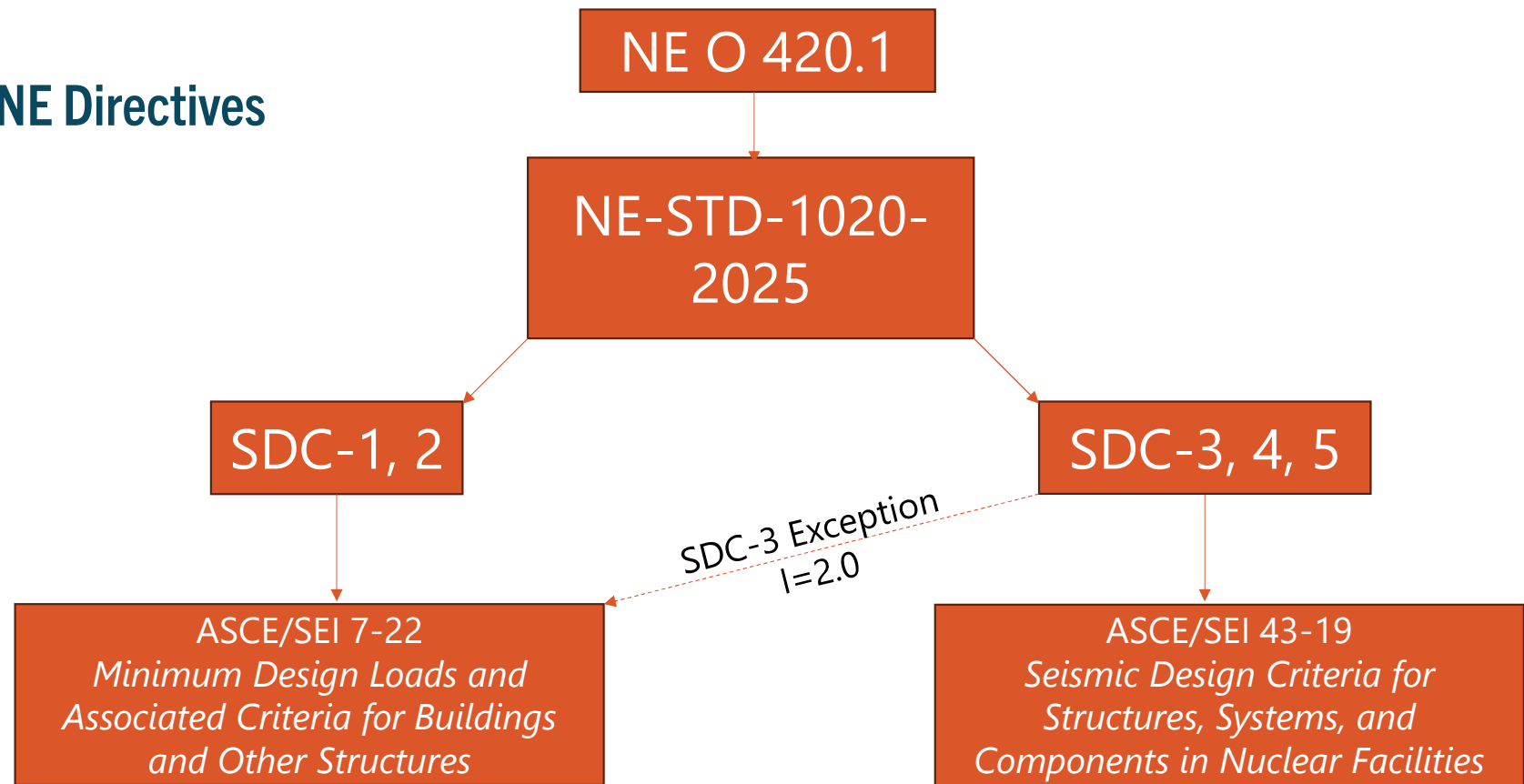
NE Order 420.1, *Facility Safety*
August 2025

AGENDA

- Background
- Risk Assessment
- ASCE/SEI 7-22 vs ASCE/SEI 43-19
- Recommendations

BACKGROUND

DOE-NE Directives



Performed in the context of advanced reactor tests

Other Traditional NDC-3 Requirements

- Programmatic Requirements
 - Periodic hazard assessment update review
 - Major modification – review required if periodic hazard assessment review is overdue
 - NE O 414.1D – Graded approach to Quality Assurance
- Design interface with other NPHs (wind, flood, precipitation, volcanic hazards)
 - Section 2.4.3 of NE-STD-1020-2025
 - NDC-1,2 → IBC-2024 → ACI 318, AISC 360
 - NDC-3,4,5 → ACI 349-13, AISC N690-18

Objective

ASCE 7
Importance
Factor (I)



ASCE/SEI 43-19
SDC-3 Target
Performance Goal
 $1 \times 10^{-4}/\text{yr}$

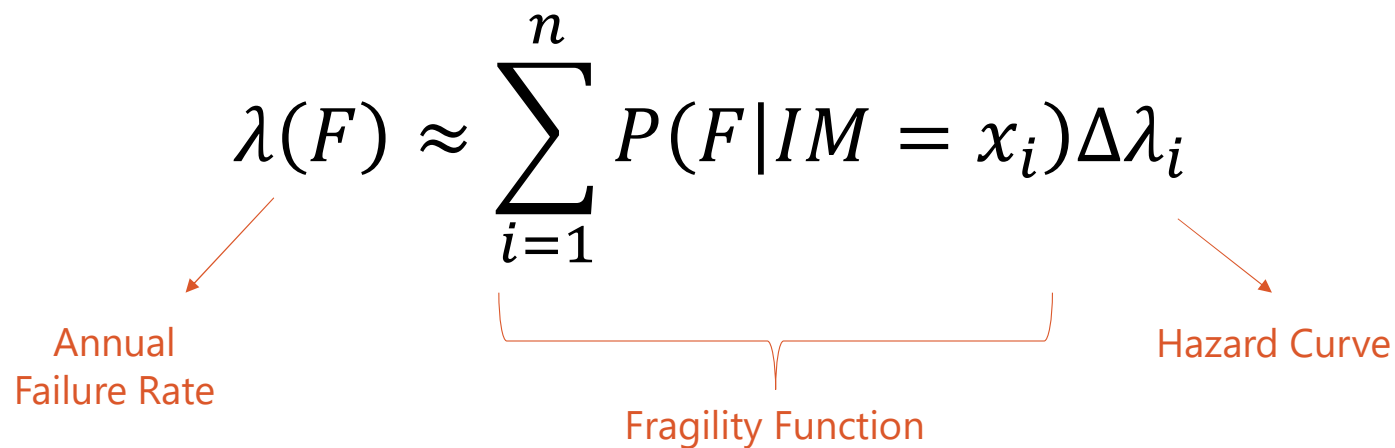
Risk Equation

$$\lambda(F) \approx \sum_{i=1}^n P(F|IM = x_i) \Delta\lambda_i$$

Annual Failure Rate

Fragility Function

Hazard Curve

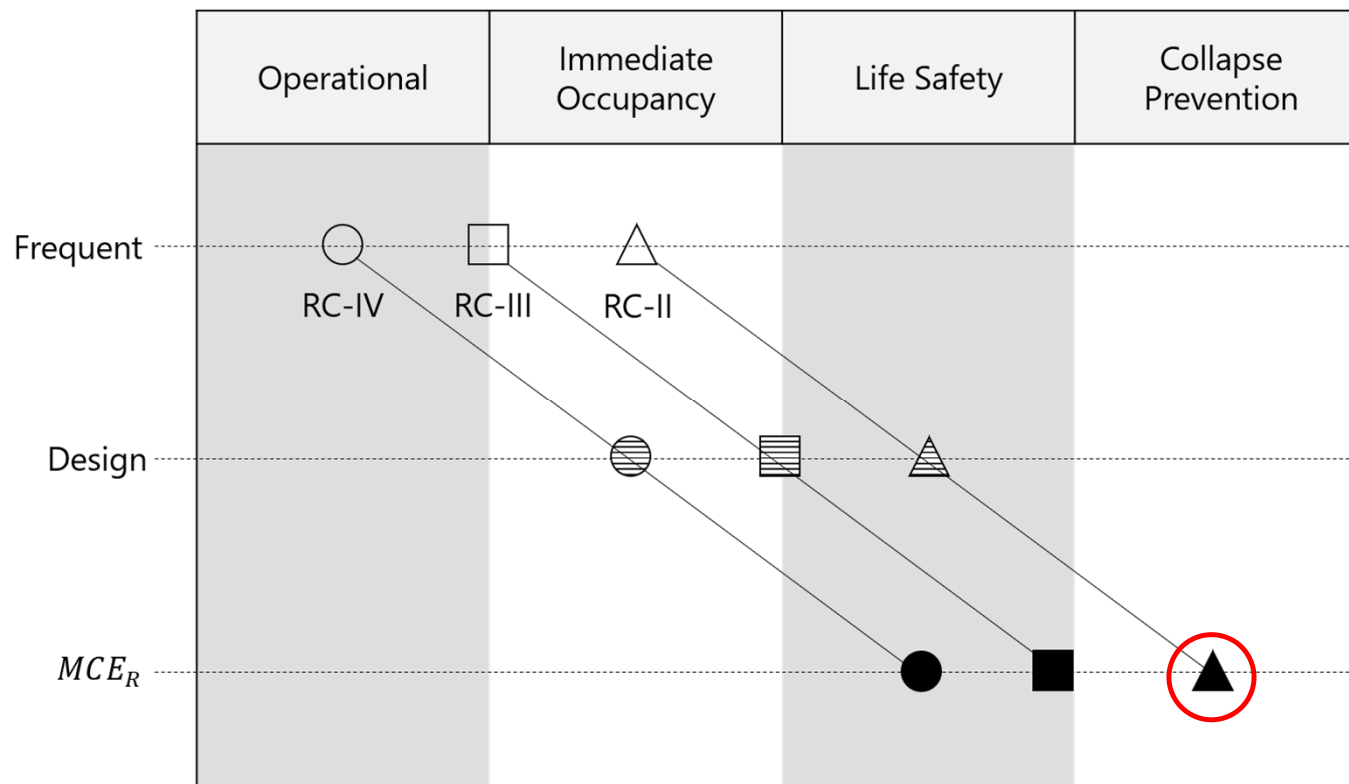


The diagram shows the equation $\lambda(F) \approx \sum_{i=1}^n P(F|IM = x_i) \Delta\lambda_i$. A red arrow points from $\lambda(F)$ to the text 'Annual Failure Rate'. A red bracket under the summation term $\sum_{i=1}^n P(F|IM = x_i) \Delta\lambda_i$ points to the text 'Fragility Function'. A red arrow points from $\Delta\lambda_i$ to the text 'Hazard Curve'.

Methodology: Shift the fragility function with an Importance Factor to achieve an annual failure rate equivalent to 1×10^{-4}

Baker, J., Bradley, B., and Stafford, P. (2021)

Performance Level – ASCE/SEI 7-22



Reproduced
from Figure
C11.5-1 of
ASCE/SEI 7-22

Collapse Prevention

Fragility Function

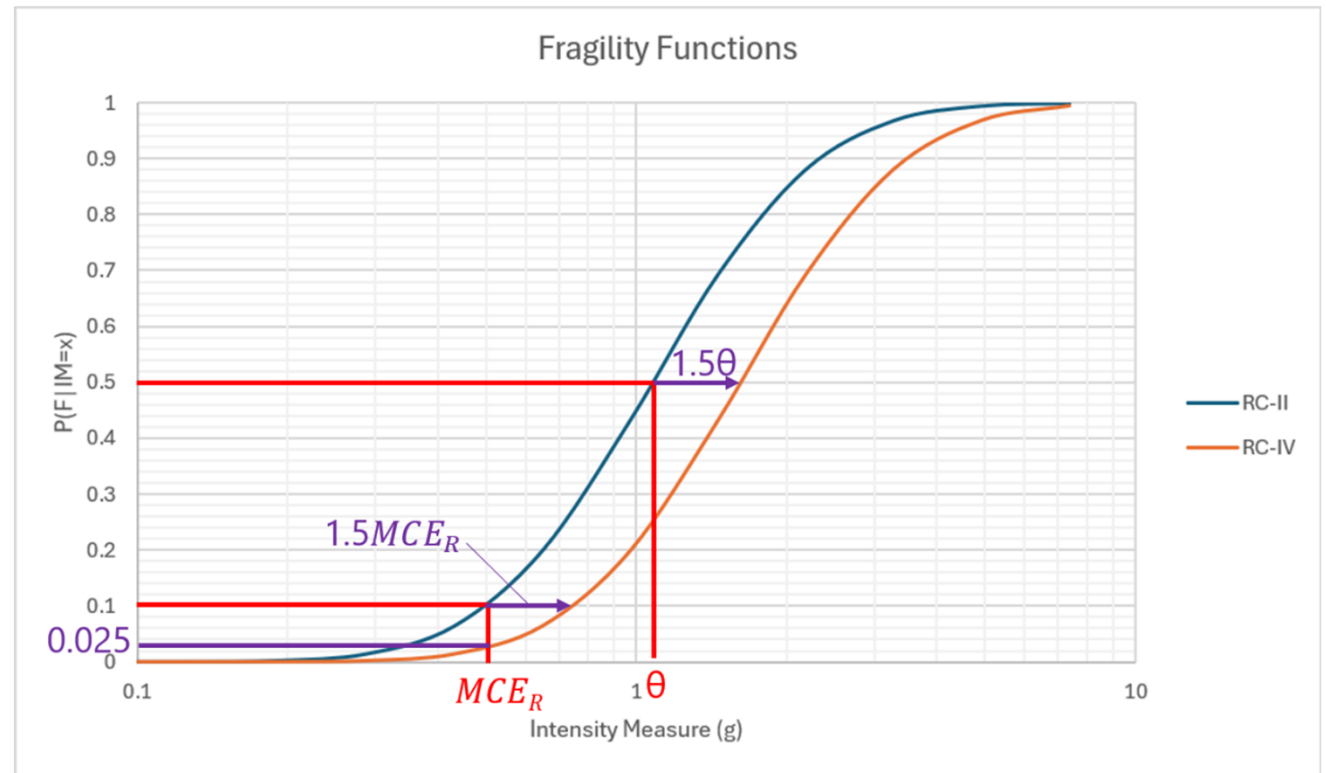
$$P(F|IM = x) = \Phi\left(\frac{\ln\left(\frac{x}{\theta}\right)}{\beta}\right)$$

RC-II

$$0.1 = \Phi\left(\frac{\ln\left(\frac{MCE_R}{\theta}\right)}{0.6}\right)$$

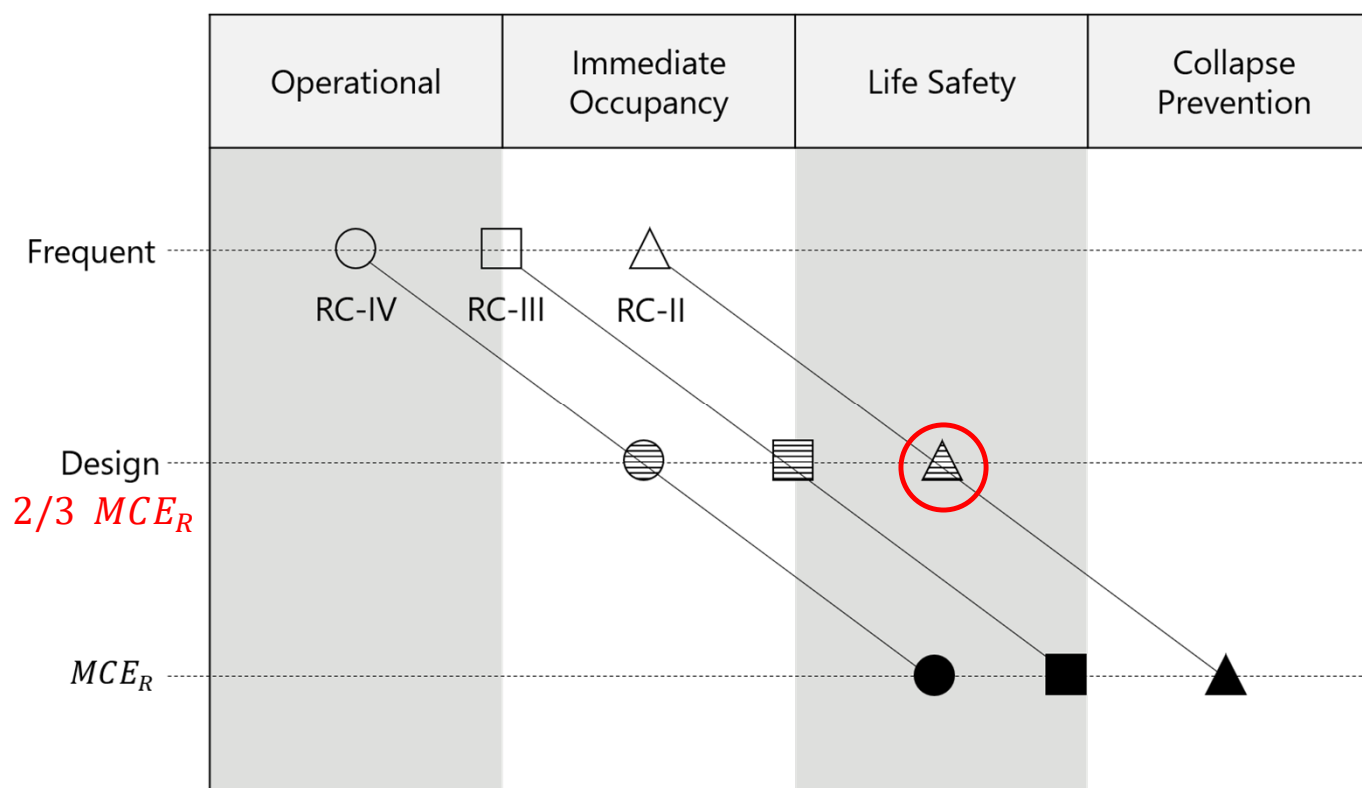
RC-IV

$$0.025 = \Phi\left(\frac{\ln\left(\frac{MCE_R}{1.5 \cdot \theta}\right)}{0.6}\right)$$



Importance Factor shifts the fragility function to the right

Performance Level – ASCE/SEI 7-22



For advanced reactor tests, the minimum performance level of interest is life safety

Life Safety – structure has damaged components but retains a margin of safety against the onset of partial or total collapse

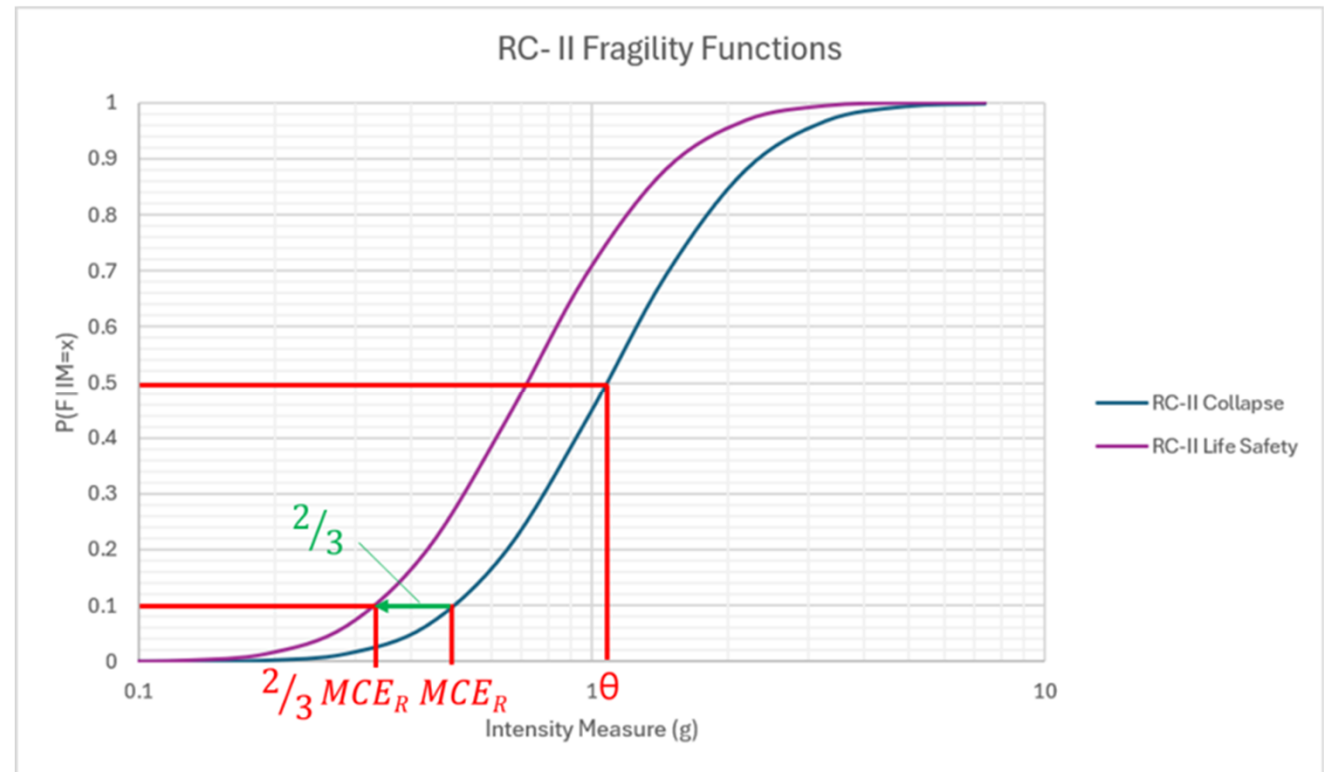
Life Safety

RC-II Collapse

$$0.1 = \Phi\left(\frac{\ln\left(\frac{MCE_R}{1.0 \cdot \theta}\right)}{0.6}\right)$$

RC-II Life Safety

$$0.1 = \Phi\left(\frac{\ln\left(\frac{2/3 MCE_R}{1.0 \cdot \theta}\right)}{0.6}\right)$$



Risk assessment can be performed for any performance level if you are anchoring to a consistent fragility function

RISK ASSESSMENT

Procedure

1) Retrieve hazard curves from the Dynamic Hazard Curves module in the USGS Earthquake Toolbox to define $\Delta\lambda_i$.

2) Retrieve the MCE_R from the USGS Risk-Targeted Ground Motion Tool.

3) Compute θ for RC-II life-safety.

$$0.1 = \Phi \left(\frac{\ln \left(\frac{2/3 MCE_R}{1.0 \cdot \theta} \right)}{0.6} \right)$$

4) Iterate I until an annual failure rate of 1×10^{-4} is attained.

$$1 \times 10^{-4} = \sum_{i=1}^n P(F|IM = x_i) \Delta\lambda_i$$
$$P(F|IM = x_i) = \Phi \left(\frac{\ln \left(\frac{x}{I \cdot \theta} \right)}{0.6} \right)$$

Results

Location	Spectral Period (s)	Site Class	2018 Sa ratios (1×10^{-5})/ (1×10^{-4})	Importance Factor – 2018 Maps
Pittsburgh, PA	0.2	BC	3.1	1.8
Galveston, TX			3.7	1.9
Nashville, TN			2.0	1.7
Spokane, WA			2.5	1.8
Materials and Fuel Complex, ID	0.01		2.1	1.6
	0.2		2.1	1.6
	1		1.9	1.5
	5		1.8	1.5

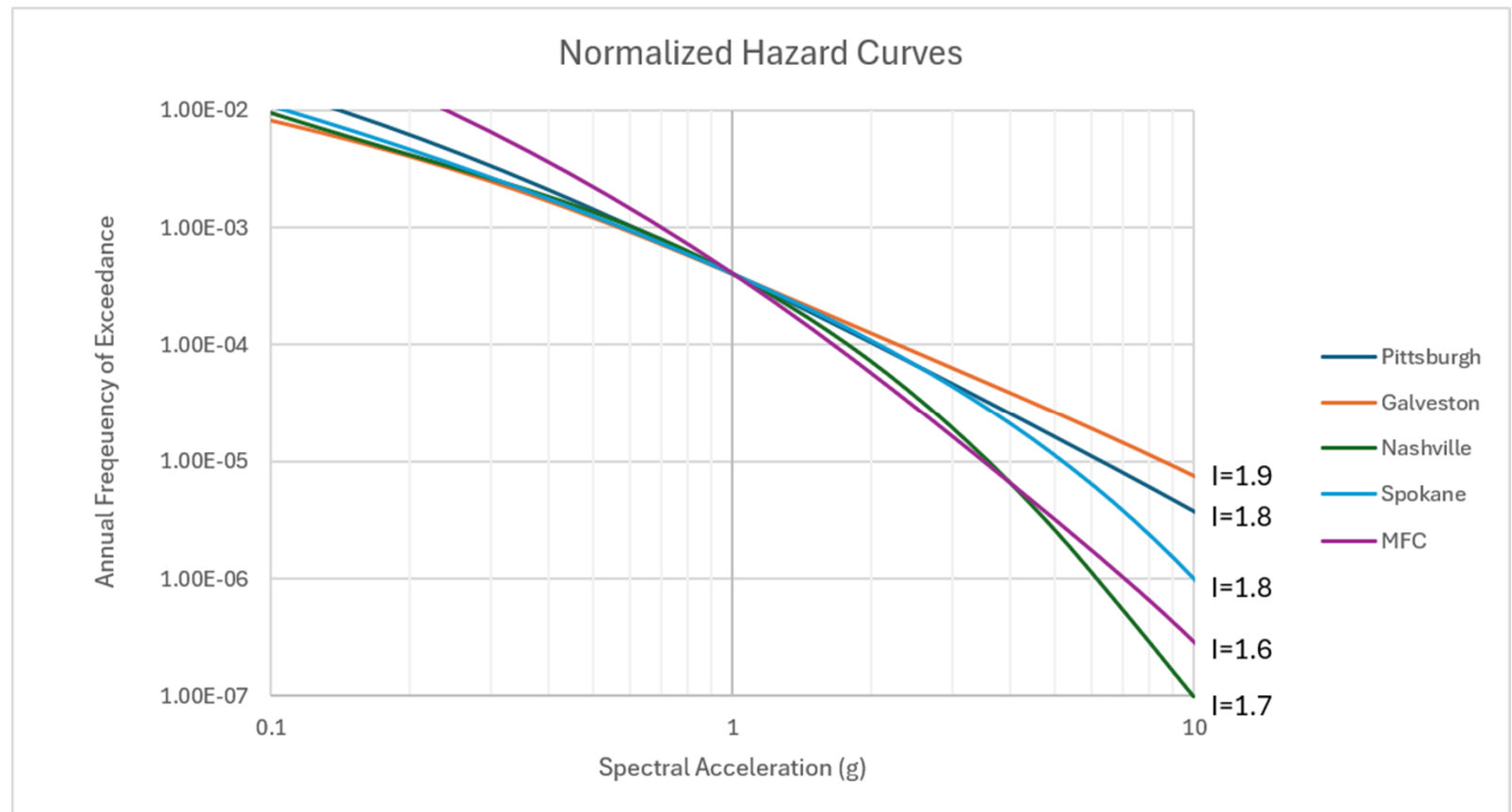
Limited positive sensitivity between spectral acceleration ratio and Importance Factor

RISK ASSESSMENT

Location- 0.2 s period

$$\uparrow \frac{\Delta Sa}{\Delta AFE}$$

- = Flatter Slope
- = $\uparrow$ Annual failure rate
- = $\uparrow$ Importance Factor



Summary and Conclusions

- Larger changes in S_a with AFE (flatter slopes) = larger Importance Factor as expected
- Limited positive sensitivity between Importance Factor and S_a ratio
- CEUS sites require a larger Importance Factor
- Importance Factors are similar for spectral periods between 0.01 and 5.0 s
- Site Class has minimal impact and Site Class A and BC produce bounding Importance Factors
- Importance Factor is relatively insensitive to the choice of the 2018 and 2023 NSHM
- Recommend maintaining the Importance Factor of 2.0 in NE O 420.1

OTHER DIFFERENCES BETWEEN ASCE/SEI 7-22 AND ASCE/SEI 43-19

Limit States

- ASCE/SEI 43-19 C5.1.3 – ASCE/SEI 41 (2013) life safety deformation limit is roughly equivalent to Limit State A of this standard
- Recommend adding the stipulation that the NE O 420.1 SDC-3 exception is expected to achieve Limit State A

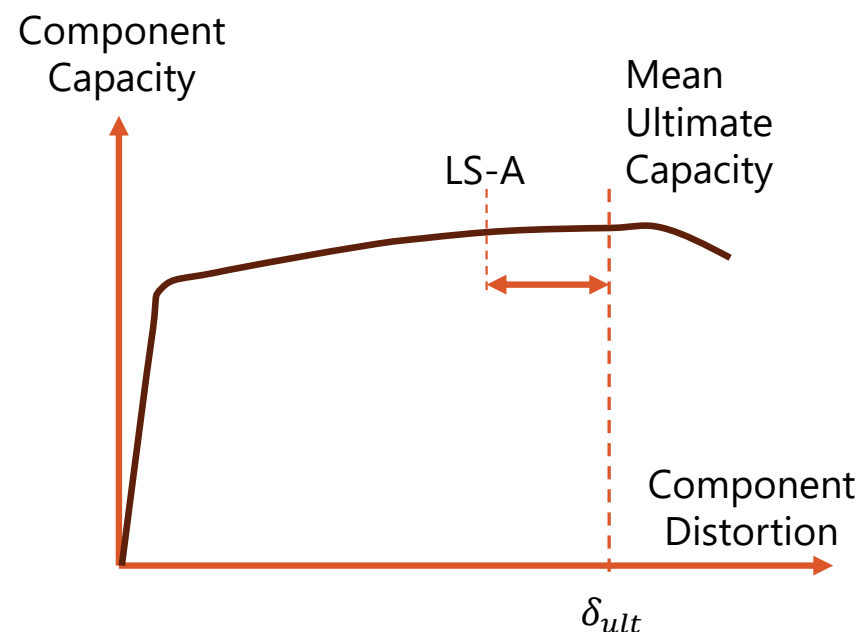


Figure C5-2 (ASCE/SEI 43-19)

OTHER DIFFERENCES BETWEEN ASCE/SEI 7-22 AND ASCE/SEI 43-19

Considerations in assessing performance

- Ordinary and noncritical structural members
 - System interaction effects
 - 13.2.4 – Consequential Damage
- Nonstructural components
 - Position retention vs. operational reliability
 - Designated seismic systems
- Site-specific hazard approaches
 - 80% of the MCE_R
- Seismic Design Categories

Risk Category	Conditional Probability given MCE_R	
	Critical	Ordinary/ Noncritical
II	10%	25%
III	5%	15%
IV	2.5%	9%

Section 1.1.1 (2020 NEHRP Provisions)

SDS	RC I/II/III	RC IV
$S_{DS} < 0.167$	A	A
$0.167 \leq S_{DS} < 0.33$	B	C
$0.33 \leq S_{DS} < 0.50$	C	D
$0.50 \leq S_{DS}$	D	D

Table 11.6-1 (ASCE/SEI 7-22)

RECOMMENDATIONS

- Exception
 - Maintain the Importance Factor of 2.0 and add that expected performance is Limit State A
 - Add wording indicating that programmatic elements still apply (QA/QC, NPH update, major modification)
 - Acknowledge potential interface between the seismic exception and other NPH design requirements (concrete and steel codes)
 - Make the report publicly available
- Future Work
 - Guidance on application of commercial vs. nuclear concrete/steel codes
 - Specific guidance for 20-yr NPH update (e.g. site-specific criteria or future NSHM maps)
 - Guidance on suitability of IBC-2024 QA/QC requirements with respect to NE O 414.1
 - Define binning scheme for ASCE/SEI 7-22 Seismic Design Categories

REFERENCES

Department of Energy – Office of Nuclear Energy (2025), NE O 420.1 – *Facility Safety*.

Department of Energy – Office of Nuclear Energy (2025), NE-STD-1020-2025, Chg. 1 – *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities*.

American Society of Civil Engineers (2022), ASCE/SEI 7-22 – *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*.

American Society of Civil Engineers (2019), ASCE/SEI 43-19 – *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities*.

Department of Energy (2019), DOE O 420.1C, Chg. 3 – *Facility Safety*.

Department of Energy (2016), DOE-STD-1020-2016 – *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities*.

American Concrete Institute (2013), ACI 349-13 – *Code Requirements of Nuclear Safety-Related Concrete Structures and Commentary*.

American Institute of Steel Construction (2018), ANSI/AISC N690-18 – *Specification for Safety-Related Steel Structures for Nuclear Facilities*.

American Concrete Institute (2019), ACI 318-19 – *Building Code Requirements for Structural Concrete and Commentary*.

American Institute of Steel Construction (2016), ANSI/AISC 360-16 – *Specification for Structural Steel Buildings*.

Baker, J., Bradley, B., and Stafford (2021), *Seismic Hazard and Risk Analysis*. Cambridge: Cambridge University Press.

United States Geological Survey (2026), Dynamic Hazard Curves, *USGS Earthquake Hazard Toolbox*.

https://earthquake.usgs.gov/nshmp/hazard/dynamic?commonReturnPeriods=2475&latitude=null&longitude=null&maxDirection=false&model=DYNAMIC_CONUS_2018_R1&returnPeriod=2475&siteClass=BC&truncate=false&imt=PGA&sourceType=Total&vs30=760

Makdisi, A. J. (2022), Procedure for Calculating Risk-Targeted Ground Motion Values. <https://code.usgs.gov/ghsc/erp/erp-rtgm-calculator/-/blob/1.0.2/documentation/pages/2-Risk-Targeted-Calc-Procedure.md>

American Society of Civil Engineers (2017), ASCE/SEI 41-17 – *Seismic Evaluation and Retrofit of Existing Buildings*.

Building Seismic Safety Council of the National Institute of Building Sciences (2020), FEMA P-2082-1 – *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures*.

CONTACT INFORMATION

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