Sensitivity of Parameters Affecting Seismic Risk

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Outline

- Purpose
- Seismic Risk
- Regulatory Context
- Seismic hazard and fragility curves
- Annual probability of unacceptable performance, P_F
- Parametric study
- Results
- Conclusions

Purpose

This study provides insights on sensitivity of seismic risk to parameters in the hazard and fragility curves

Seismic Risk

- The probability of occurrence of a seismically initiated event sequence depends on performance of structures, systems, or components (SSCs) in the event sequence

- The mean annual probability of unacceptable performance of an SSC during a seismic event, or seismic risk, is determined by convolving the mean seismic hazard curve with the mean fragility curve of the SSC

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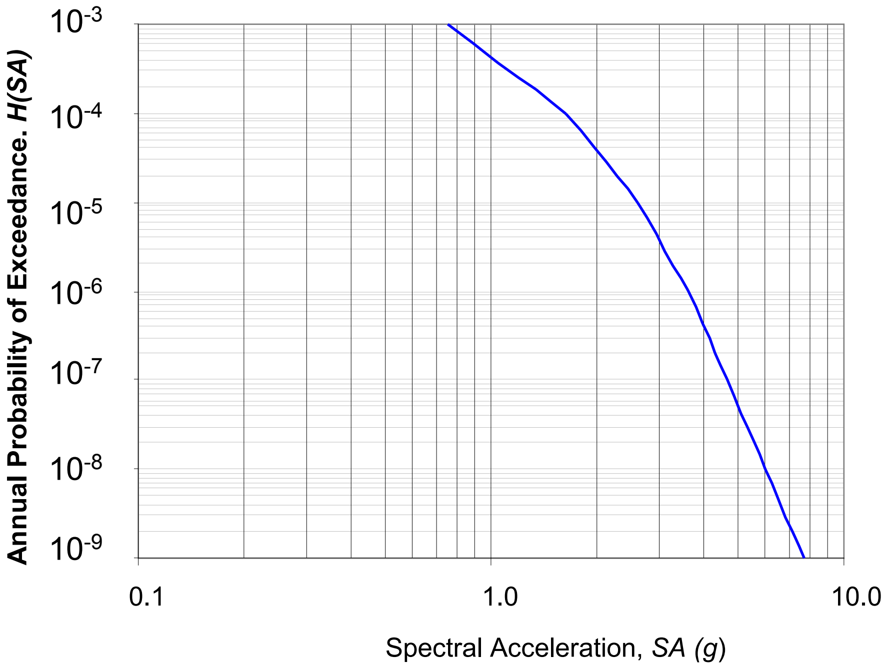
Regulatory Context

- The *Code of Federal Regulations*, Title 10, Part 63, for licensing of the potential repository at Yucca Mountain, NV, requires U.S. Department of Energy (DOE) to
  - comply with dose performance objectives
  - perform preclosure safety analysis and evaluate potential event sequences for hazards, including seismic events

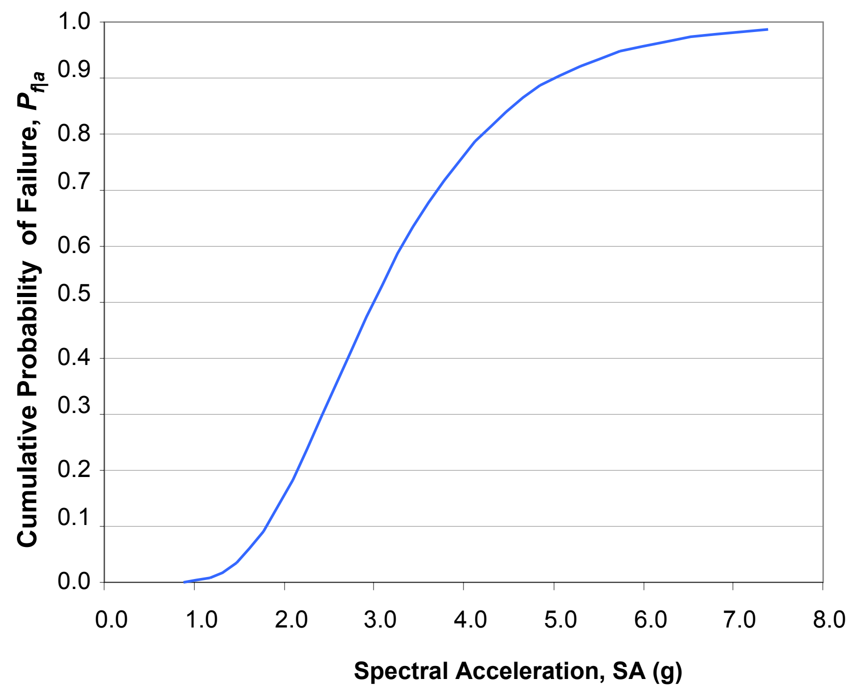
- Dose performance objectives can be met by showing that
  - a potential event sequence that may release radioactivity has a chance of less than 1 in 10,000 of occurring before permanent closure; or
  - radiological dose resulting from the event sequence is less than the regulatory dose performance objective

Seismic Hazard and Fragility Curves



An Example Seismic Hazard Curve, *H(a)*, for Spectral Acceleration at 10 Hz

(*a* represents spectral acceleration *SA*)



An Example Fragility Curve, $P_{f|a}$ with $C_{50\%}$ = 3.0 g and β = 0.4 for Spectral Acceleration at 10 Hz

$C_{50\%}$ - median capacity

β - log standard deviation

Annual Probability of Unacceptable Performance, P_F

$$P_F = \int_0^{\infty} P_{f|a} \left(-\frac{dH(a)}{da} \right) da$$

Numerical Integration

Hazard curve discretized into N equal intervals

Product of hazard exceedance value and fragility for each segment

Sum product over N intervals

$$P_F = 2.26\text{x}10^{-5}$$

Closed-Form Solution

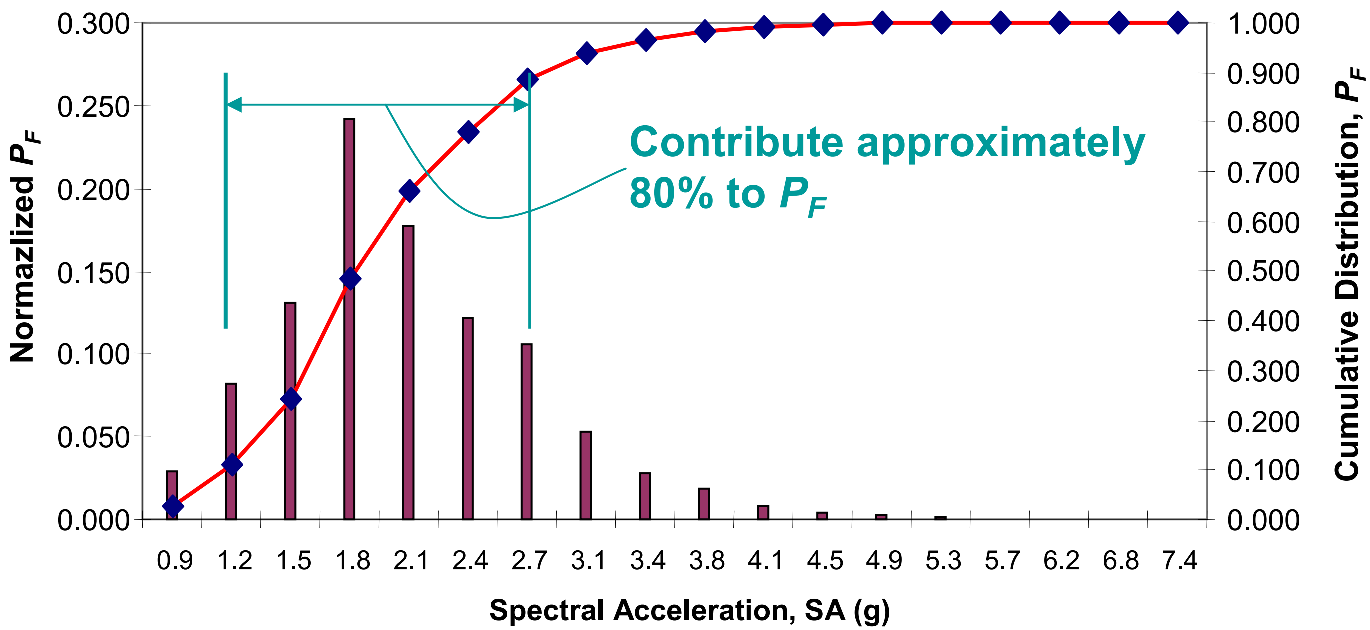
$$H(a) = K_1 a^{-K_H}, \; \mathbf{K_H = 1/log\ (A_R)}$$

$$P_F = K_1 (C_{50\%})^{-K_H} e^{0.5(K_H \beta)^2}$$

$$P_F = 3.4\text{x}10^{-5}$$

A_R - seismic hazard curve slope parameter
K_1 - constant

Annual Probability of Unacceptable Performance, P_F (continued)



Histogram and cumulative distribution of P_F vs. spectral acceleration - numerical integration

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Parametric Study

Effects of the following parameters on P_F were studied:

A. Discretization steps - numerical integration

B. Low-probability range of the seismic hazard curve - numerical integration

C. Slope of the hazard curve – closed-form solution

D. Log standard deviation of the fragility curve, β - numerical integration

A. Discretization Steps – Numerical Integration

n Number of discretization steps	P_F $(\times 10^{-5})$	Ratio = $P_{F,n} / P_{F,120}$
6	2.018	0.8835
12	2.235	0.9785
18	2.263	0.9908
24	2.272	0.9947
30	2.277	0.9969
60	2.283	0.9996
120	2.284	1.0000

Provides reasonable accuracy

Note: H(a) and $P_{f|a}$, as shown in Slide 6

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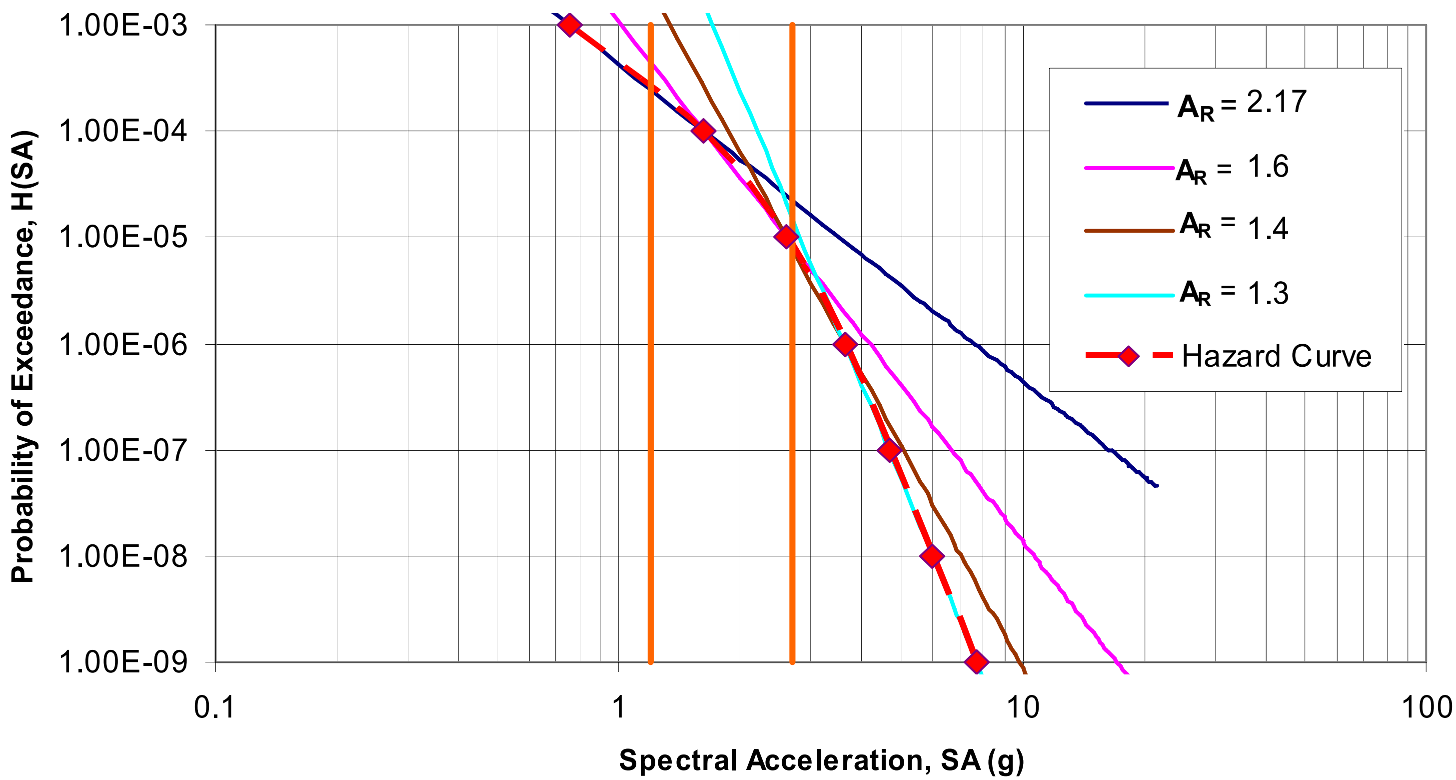
B. Low-Probability Range of the Seismic Hazard Curve – Numerical Integration

(1)	(2)	(3)
Annual Probability of Exceedance of Hazard Curve, *H(SA)*	**Probability of Unacceptable Performance, P_F (x10^{-5})**	**Ratio Column 2/P_F @ 10^{-9}**
10^{-5}	1.766	0.78
10^{-6}	2.186	0.97
10^{-7}	2.254	0.99
10^{-8}	2.262	1.0
10^{-9}	2.263	1.0

Contribution below this range negligible (applies to the rows 10^{-6} and 10^{-7})

Note: H(a) and $P_{f|a}$, as shown in Slide 6

C. Slope of the Hazard Curve – Closed-Form Solution



Hazard Curve and the Linearized Forms of the Hazard Curve

C. Slope of the Hazard Curve – Closed-Form Solution (contd.)

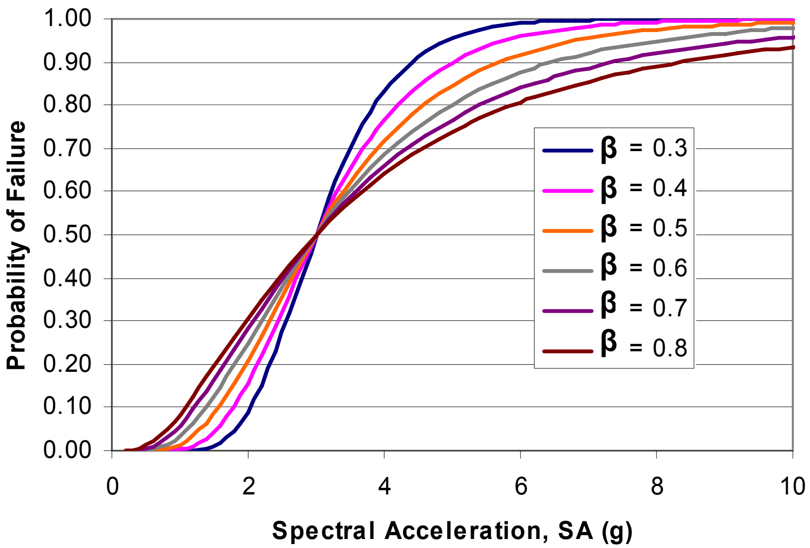
H(a)	**SA**	A_{R*}	K_H	K_1	P_F ($\times 10^{-5}$)
10^{-3}	0.753	-	-	-	
10^{-4}	1.627	2.17	2.99	0.000428	3.28
10^{-5}	2.603	1.6	4.90	0.00109	3.40
10^{-6}	3.627	1.4	6.94	0.00765	17.6
10^{-7}	4.663	1.3	9.16	0.134	471.0
$^*A_R = SA_{0.1H(a)}/SA_{H(a)}$, where a is spectral acceleration.					

P_F by numerical integration = 2.26E–5

Note: $P_{f|a}$ as shown in Slide 6

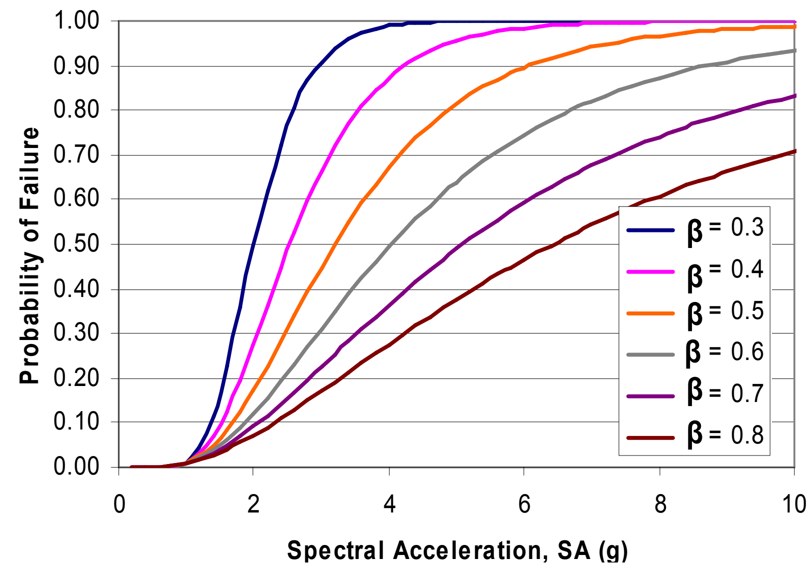
D. Log standard deviation of the fragility curve, β – numerical integration

Fragility Curve anchored at $C_{50\%}$



$C_{50\%}$ = 3.0g and β varies from 0.3-0.8

Fragility Curve anchored at $C_{1\%}$



$C_{1\%}$ = 1.0g and β varies from 0.3-0.8

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D. Log standard deviation of the fragility curve, β – numerical integration (contd.)

P_F with Varying β for $C_{50\%}$= 3.0g

β	P_F (x10^{-5})	Ratio $P_{F,(\beta)}/P_{F(\beta=0.3)}$
0.3	1.29	1.0
0.4	2.28	1.8
0.5	3.82	3.0
0.6	5.87	4.6
0.7	8.24	6.4
0.8	10.7	8.3

Increases

P_F with Varying β for $C_{1\%}$= 1.0g

β	P_F (x10^{-5})	Ratio $P_{F(\beta)}/P_{F(\beta=0.3)}$
0.3	6.85	1.0
0.4	4.32	0.63
0.5	3.06	0.45
0.6	2.38	0.35
0.7	1.99	0.29
0.8	1.75	0.25

Decreases

Note: H(a), as shown in Slide 6

Conclusions

- In the numerical integration method,
  - approximately 18 points on the hazard curve provided reasonable accuracy in calculating probabilities of unacceptable performance in the example presented
  - contribution of the seismic hazard curve beyond 10^{-7} probability of exceedance is negligible for this study

- For the closed-form solution method,
  - the use of slope of the seismic hazard curve, between and 10^{-4} and 10^{-5}, gives performance results comparable to the numerical integration method

Conclusions (continued)

- Probability of unacceptable performance of SSCs
  - increases as log standard deviation, β, increases for the case where the fragility curve is based on the median capacity
  - decreases as log standard deviation, β, increases for the case where the fragility curve is based on the 1 percent probability of failure capacity. Using this approach, capacity at probability of failure greater than 1 percent is over-predicted when unrealistic value of β is used