

**Implementation of Risk Informed
Approaches Into Seismic Design Practices**

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Ingredients of Risk Informed Seismic Design

Graded Approach

- **Structures, Systems, and Components (SSCs) Which Have Significantly Different Failure Consequences Should Be Able to be Designed to Different Levels of Seismic Input and Different Levels of Design Rigor**

Performance Goals

- **Both Qualitative and Quantitative Performance Goals Should Be Established for Differing Categories of SSCs**

Qualitative Goals

- **What Constitutes Acceptable Performance?**

Quantitative Goal

- **What is a Target Acceptable Annual Probability of Seismic Induced Unacceptable Performance P_F ?**

Example

DOE-STD-1020-94: Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities

Table C-2 Qualitative Seismic Performance Goals

PC	Occupancy Safety	Concrete Barrier	Metal Liner	Component Functionality	Visible Damage
1	No structural collapse, failure of contents not serious enough to cause severe injury or death, or prevent evacuation	Confinement not required.	Confinement not required.	Component will remain anchored, but no assurance it will remain functional or easily repairable.	Building distortion will be limited but visible to the naked eye.
2	No structural collapse, failure of contents not serious enough to cause severe injury or death, or prevent evacuation	Concrete walls will remain standing but may be extensively cracked; they may not maintain pressure differential with normal HVAC. Cracks will still provide a tortuous path for material release. Don't expect largest cracks greater than 1/2 inch.	May not remain leak tight because of excessive distortion of structure.	Component will remain anchored and majority will remain functional after earthquake. Any damaged equipment will be easily repaired.	Building distortion will be limited but visible to the naked eye.
3	No structural collapse, failure of contents not serious enough to cause severe injury or death, or prevent evacuation	Concrete walls cracked; but small enough to maintain pressure differential with normal HVAC. Don't expect largest cracks greater than 1/8 inch.	Metal liner will remain leak tight.	Component anchored and functional.	Possibly visible local damage but permanent distortion will not be immediately apparent to the naked eye.
4	No structural collapse, failure of contents not serious enough to cause severe injury or death, or prevent evacuation	Concrete walls cracked; but small enough to maintain pressure differential with normal HVAC. Don't expect largest cracks greater than 1/8 inch.	Metal liner will remain leak tight.	Component anchored and functional.	Possibly visible local damage but permanent distortion will not be immediately apparent to the naked eye.

Target Annual Probabilities of Failure P_F

PC	P_F
1	1×10^{-3}
2	5×10^{-4}
3	1×10^{-4}
4	1×10^{-5}

Definitions

DRS - Design Ground Motion Response Spectra

**UHRS - Uniform Hazard Response Spectra
Specified at Hazard Exceedance Annual
Frequency H_D**

**DF - Design Factor Required to Convert UHRS
to DRS**

A_R - Hazard Slope Ratio:

$$A_R = \frac{SA_{0.1H_D}}{SA_{H_D}}$$

F_{SM} - Seismic Margin Factor:

$$F_{SM} = \frac{\text{HCLPF Capacity}}{\text{DRS}}$$

**HCLPF Capacity- Approximately Mean 1%
Probability of Failure Capacity**

R_P - Hazard to Failure Probability Ratio:

$$R_P = \frac{H_D}{P_F}$$

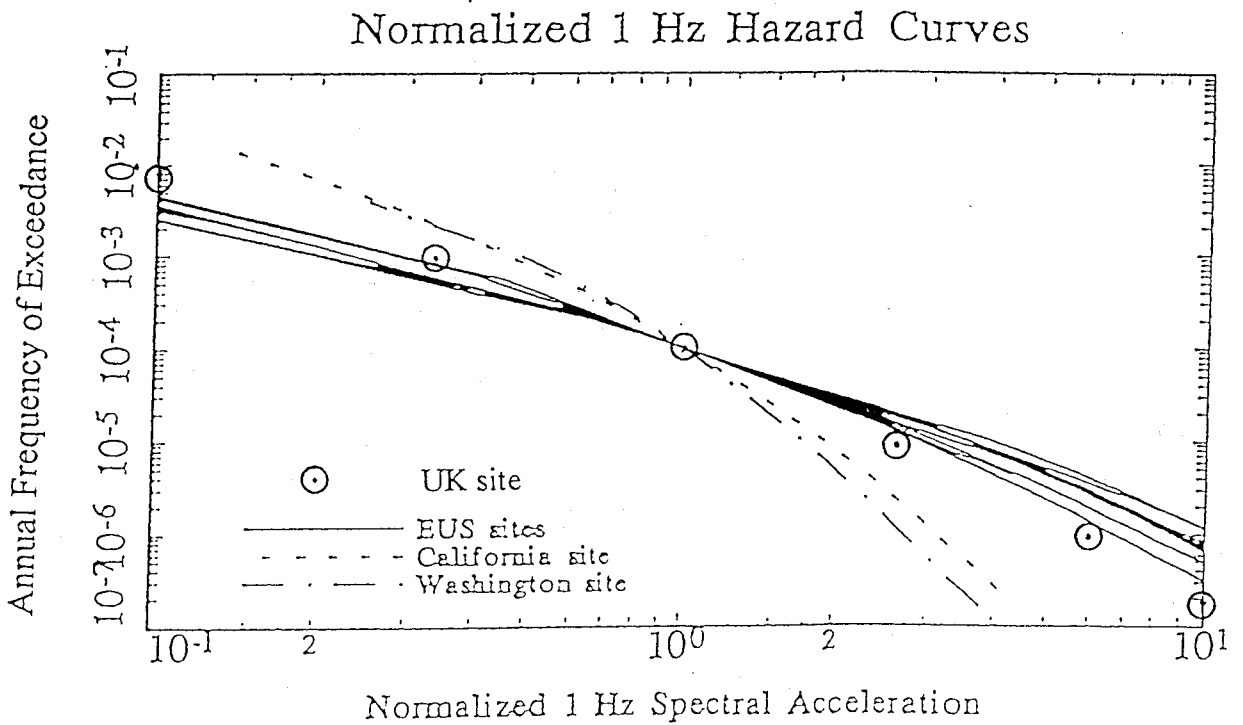
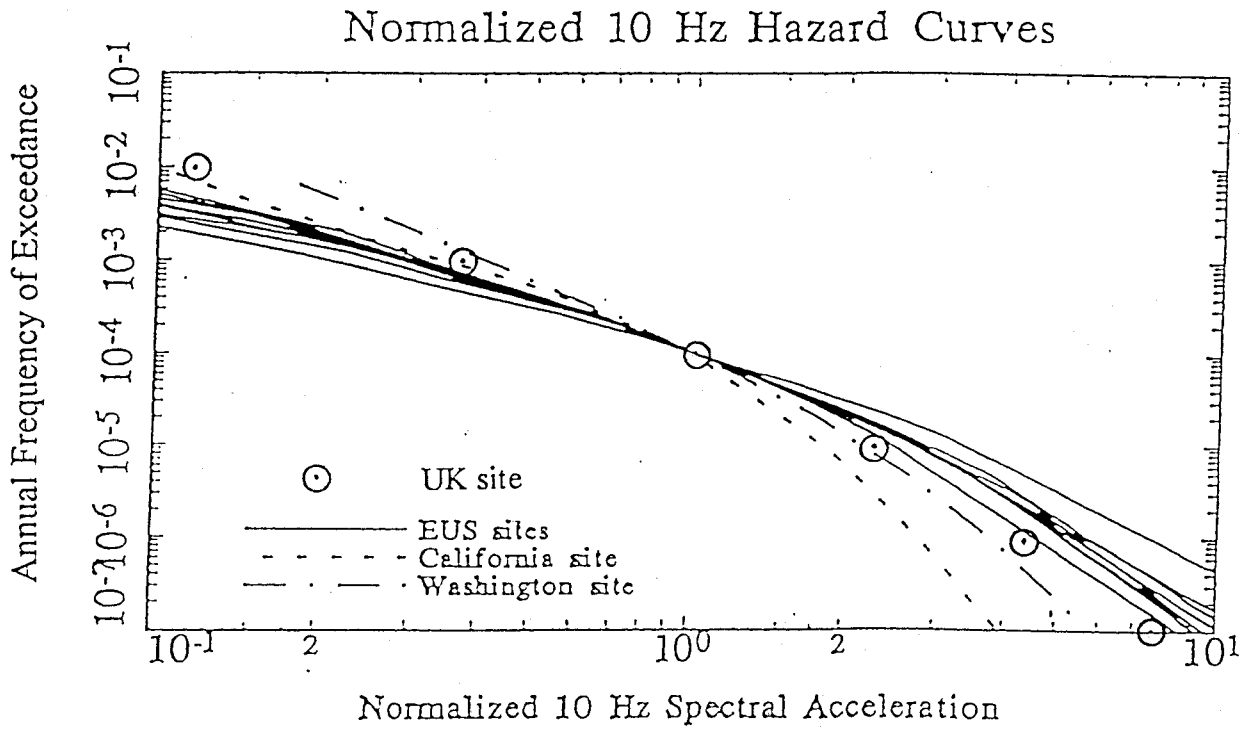


Figure 1: Seismic Hazard Curves Normalized By the Spectral Acceleration Value Corresponding to a 10^{-4} Annual Probability

Design Ground Motion

- **Need to Develop Risk Consistent Design Response Spectra (DRS) To Have Consistent Seismic Risk Independent of Site and SSC Natural Frequency**

$$\text{DRS} = \text{DF} * \text{UHRS}$$

- **Design Factor DF is a Function of Hazard Slope Ratio A_R , Seismic Margin Factor F_{SM} , and Hazard to Failure Probability Ratio R_P**

Desired R_P Range	$\text{DF} * F_{SM}^{1.2}$
20 to 40	$\max\{1.2, 0.6A_R\}$
10 to 20	$\max\{1.0, 0.6A_R^{0.9}\}$

Depending upon the desired R_P range and minimum F_{SM} selected, the design factor DF can be either generally less than or generally greater than unity. In all cases DF increases with increasing A_R ratios for A_R greater than about 1.8.

Example DF for Different F_{SM} and R_P Values

F_{SM}	Desired R_P Range	
	10 to 20	20 to 40
1.0	$\max\{1.0, 0.6A_R^{0.9}\}$	$\max\{1.2, 0.6A_R^{1.2}\}$
1.67	$\max\{0.6, 0.35A_R^{0.9}\}$	$\max\{0.7, 0.35A_R^{1.2}\}$

Example

$$R_P = 10 \text{ to } 20$$

$$F_{SM} = 1.0$$

$$DF = \max\{1.0, 0.6A_R^{0.9}\}$$

A_R	DF
1.5	1.0
1.75	1.0
2	1.12
2.25	1.24
2.5	1.37
2.75	1.49
3	1.61
3.25	1.73
3.5	1.85
3.75	1.97
4	2.09
4.25	2.21
4.5	2.32
4.75	2.44
5	2.55
5.25	2.67
5.5	2.78
5.75	2.9
6	3.01

References

1. Kennedy, R.P., *Establishing Seismic Design Criteria To Achieve an Acceptable Seismic Margin*, Plenary/5, Transactions of the 14th International Conference on Structural Mechanics in Reactor Technology, Lyon, France, August 1997
2. Kennedy, R.P., *Development of Risk-Based Seismic Design Criterion*, OECD-NEA Workshop on Seismic Risk, Tokyo, Japan, August 1999
3. McGuire, R.K., Silva, W.J., and Constantino, C.J., *Technical Basis for Revision of Regulatory Guidance on Design Ground Motion*, DRAFT, U.S. Nuclear Regulatory Commission, September 2000

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- **An Approach for Developing Risk Consistent Design Response Spectra (DRS) Has Been Established and Verified. However, Current Standard Review Plan and Design Codes and Standards Do Not Lead to a Consistent Seismic Margin Factor F_{SM} for All SSCs,**
 - **Must Define a Desired Hazard to Failure Probability Ratio R_P Range and a Seismic Margin Factor F_{SM} Before One Can Finalize a Risk-Consistent DRS for a Site.**

- **Seismic Margin Factor Based On Current Standard Review Plan, Codes and Standards**

$F_{SM} \approx 1.0$ to 1.5 Brittle Failure Modes

$F_{SM} \approx 1.5$ to 2.0 Ductile Failure Modes

- **DOE-STD-1020-94 Resolved Problem By:**

- 1) **Introducing an Inelastic Factor F_I and Requiring Code Capacity C to Exceed the Combined Non-Seismic Demand D_{NS} Plus Factored Seismic Demand D_S/F_I**

$$C \geq D_{NS} + \frac{D_S}{F_I}$$

- 2) **Conservatively Estimating That:**

$$F_{SM} \approx 1.0$$