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Risk Informed Design and Analysis Criteria for Nuclear Structures

Earthquake Resilience of Nuclear Facilities

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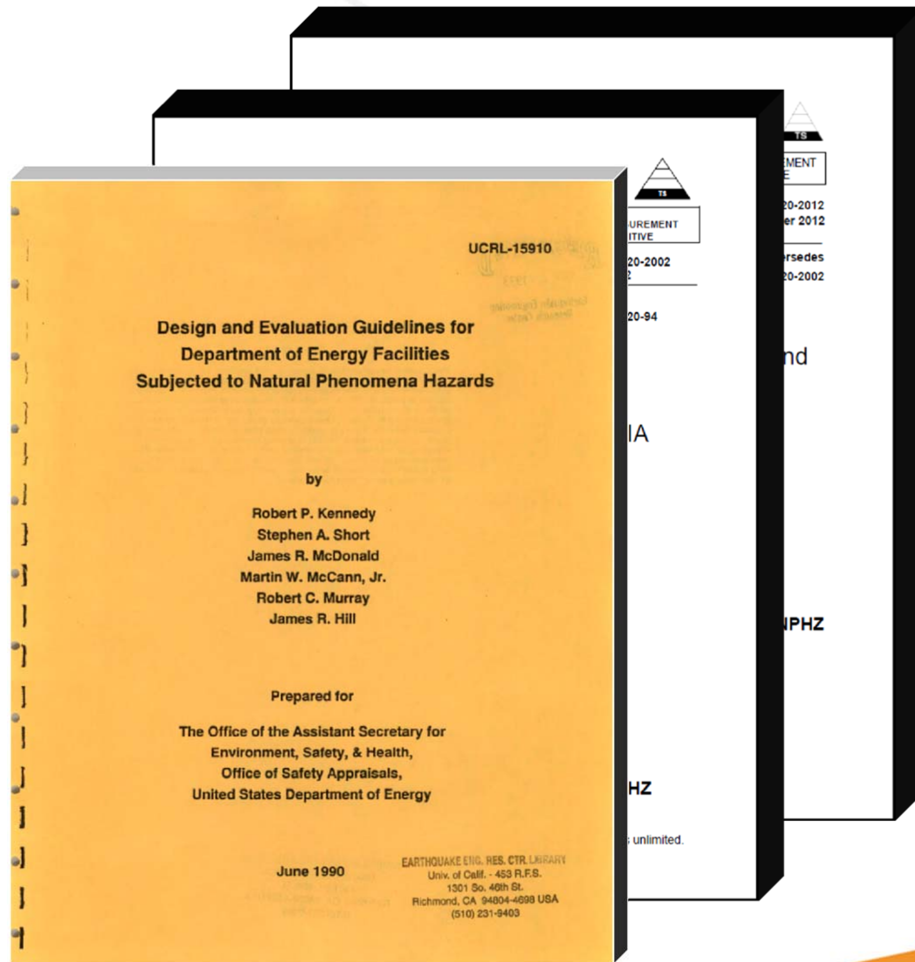
6/8/2015

Presentation Topics

- Performance Goal Based Design Philosophy of DOE STD-1020, ASCE-4, ASCE-43
- Use of a Graded Approach
- Target Limit States
- Uncertainties in Ground Motion
- Uncertainties in Component Capacities
- Use of Risk Models for Decision Making
- Summary

Performance Goal Based Design Philosophy of DOE-STD-1020

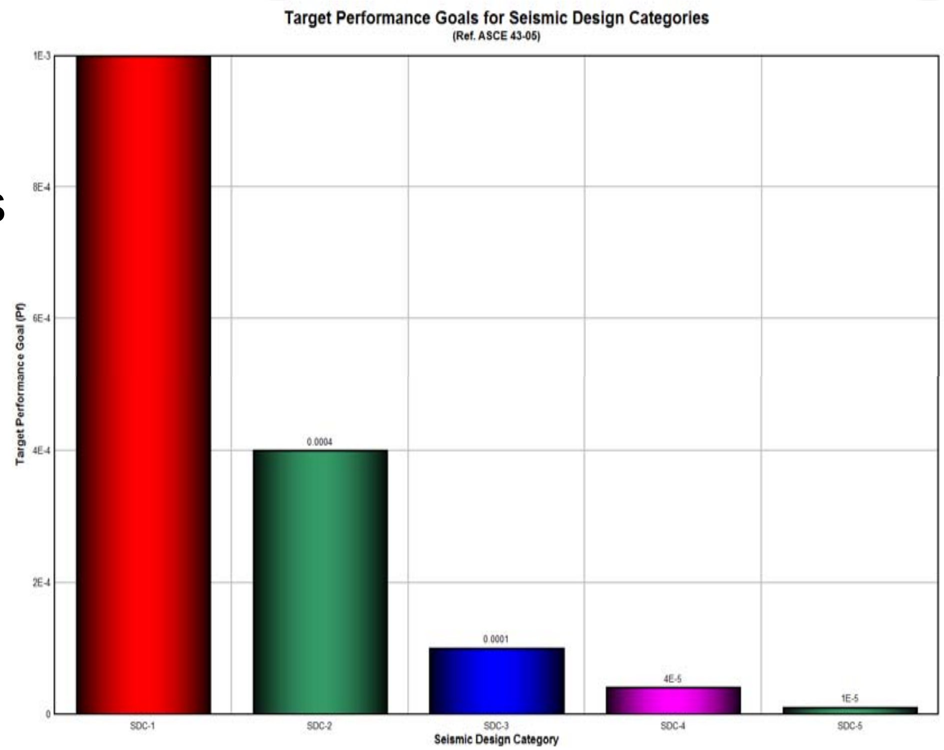
- Originated in UCRL-15910 (1990)
- Adapted for use by DOE in STD-1020-1994 (1994)
- Reaffirmed in DOE-STD-1020-2012 (2012)



UCRL-15910

Use of a Graded Approach

- More stringent criteria should be used for hazardous facilities
- Less stringent criteria should be used for normal occupancy structures
- Target Performance Goals are Annual Frequencies of Unacceptable Performance
  - SDC 1 – $P_f = 1x10^{-3}$
  - SDC 2 – $P_f = 4x10^{-4}$
  - SDC 3 – $P_f = 1x10^{-4}$
  - SDC 4 – $P_f = 4x10^{-5}$
  - SDC 5 – $P_f = 1x10^{-5}$



SDC – 1 P_f = 1x10-3

SDC – 5 P_f = 1x10-5

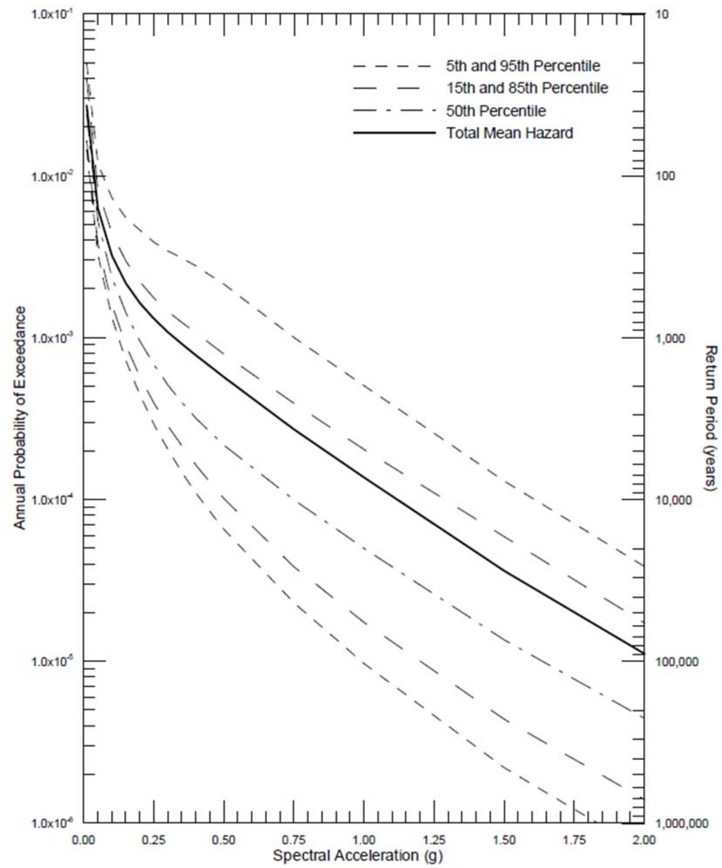
Target Limit States

- Limit States Must be tied to Performance
- ASCE 43-05 first introduced limit states in 2005
- Meant to address common II/I issue

Limit State	Qualitative Description of Permissible Behavior
A	Large Permanent Distortion (Short of Collapse)
B	Moderat Permanent Distortion
C	Limited Permanent Distortion
D	Essentially Elastic

Uncertainties in Ground Motion

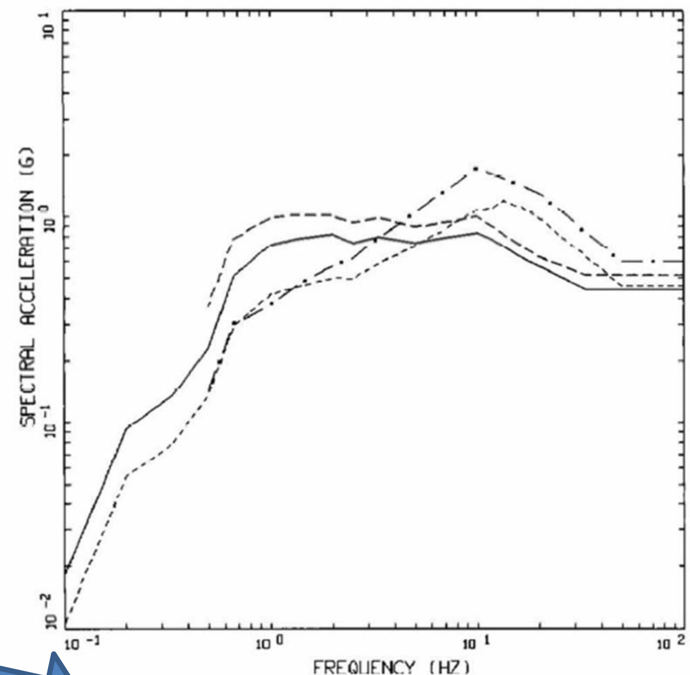
- There are large uncertainties in the ground motion
- ASCE-4 and ASCE-43 defined the "hazard" as the uniform hazard response spectral shape associated with a 4×10^{-4} annual frequency of exceedance
- A properly conducted PSHA incorporates all uncertainties (source, path, etc.) into estimate of mean UHRS



Seismic Hazard Curves for 1.0 Horizontal Spectral Acceleration

Ground Motion to be Used in ASCE 4 Methodology *for Design*

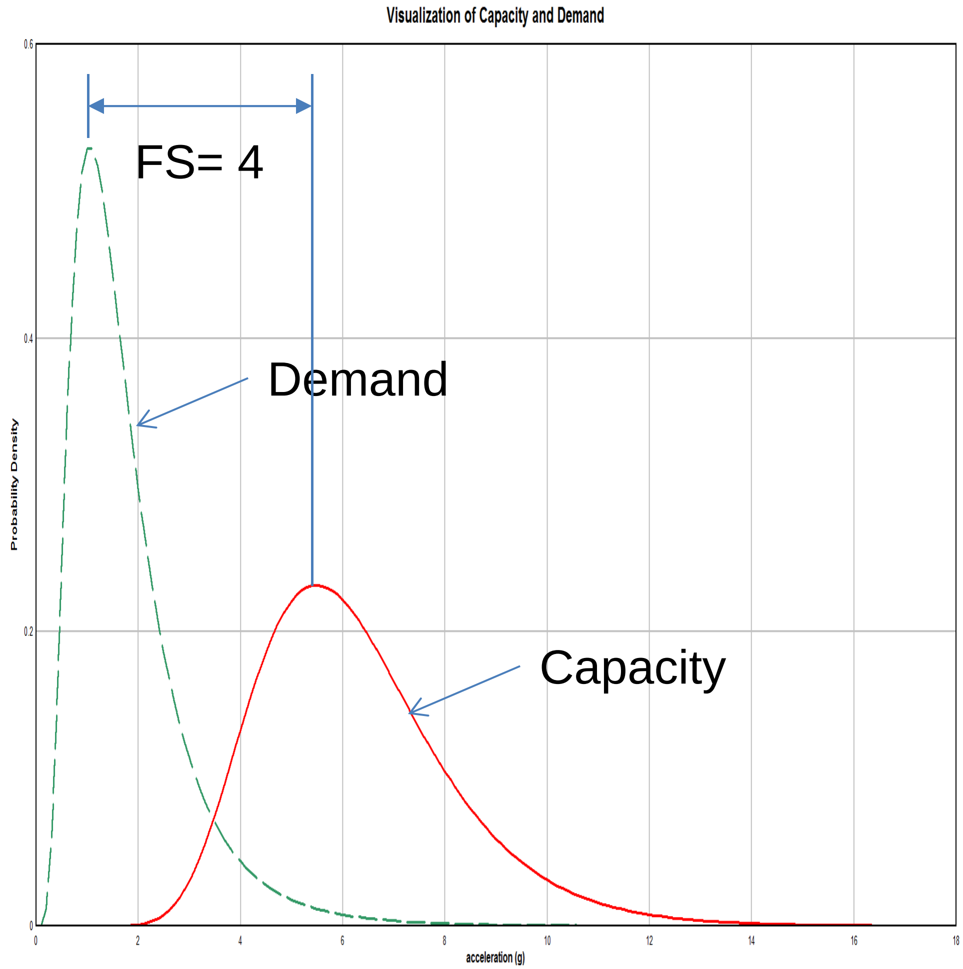
- Use Mean UHRS
- UHRS are scaled by a design factor to get DRS
- DRS = DF x DRS
- Design Factors were derived
  - Slope of most hazard curves
  - Risk reduction required



CMRR 2,500 YEAR
MEAN UHRS:HORIZONTAL, VERTICAL

Uncertainties in Capacities

- There are uncertainties in component capacities
  - Strength of material
  - Damping
  - Mode combination
  - Ductility (inelastic energy absorption)
  - Code Strength equations
- ASCE 4 assumes that code capacities produce
  - 98% NEP for ductile failures
  - 99% for brittle failures



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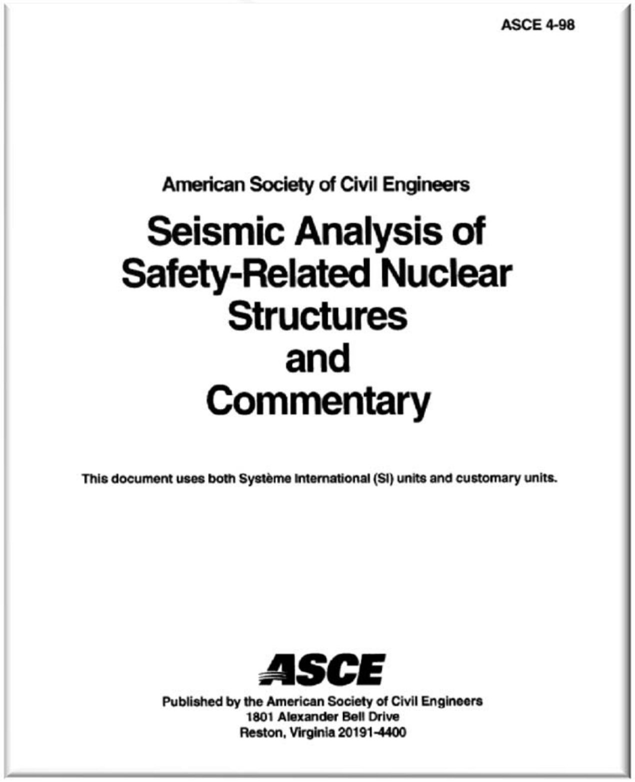
Conservatisms in ASCE 4

- 1% HCLPF is achieved
  - Response is at about 80% NEP
  - Capacities defined at 2% NEP
  - Inelastic energy absorption at 5% NEP (ductile failure modes)
- ASCE 4
  - Aims at 80% NEP response
  - Only slightly conservative damping, SSI effects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This document uses both Système International (SI) units and customary units.

ASCE

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Use of Risk Models for Decision Making

- The target performance goals are only goals
- Each decision maker (NRC, DOE, etc.) must decide what to do
  - P_f = 1.2x10-4 vs 1.0 x 10-4
  - Some cost and importance of the facility must be considered
  - What about a cost benefit metric

$$\text{Salmon Number} = \frac{\mathit{Risk\ Reduction\ Achieved}}{\mathit{Cost}}$$

- ASCE 4/43-05 are aimed at component failures. What is really needed is a risk model with a defined damage state (loss of confinement, CDF, etc)

Summary

- Target performance can be achieved by defining design basis ground motion from results of a probabilistic seismic hazards assessment, and introducing known levels of conservatism in the design above the DBE.
- ASCE 4, 43, DOE-STD-1020 defined the DBE at 4x10-4 and introduce only slight levels of conservatism in response.
- ASCE 4, 43, DOE-STD-1020 assume code capacities shoot for about 98% NEP
- There is a need to have a uniform target (98% NEP) for code developers (ACI, AISC, etc.) aim for.
- In considering strengthening options, one must also consider cost/risk reduction achieved.

Thank you!

- Feel Free to contact me

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