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NRC RIC 2017 - Seismic Safety: Risk-Informed Performance-Based Approach

# Seismic Safety Review/Assessment of Current US Nuclear Design Standards

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## Outline

- Design Response Spectrum (DRS) per RG 1.208 and ASCE 43
- Basis for ASCE 43 DRS
- Component Performance (Risk) Goal v/s Plant-wide Risk
- Plant-wide 1.67 Seismic Margin Factor v/s ASCE 43 Performance
- Ground Motion Uncertainty Considerations
- Seismic Resiliency Considerations
- Risk-based Criteria for RTNS (AQ) and Seismic II/I SSCs
- Rigorous Verification of Seismic Design Capacities
- Summary

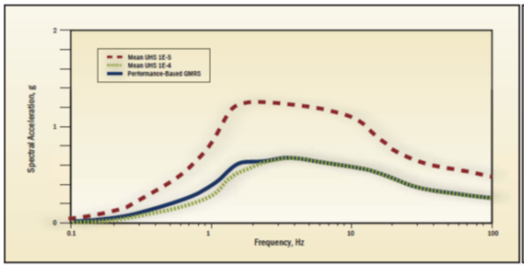




## Design Response Spectrum per RG 1.208 and ASCE 43

- RG 1.208 endorses ASCE 43 method (for Seismic Design Category 5) to obtain a performance-based spectrum at the GMRS horizon
- For Seismic Category I SSCs, ASCE 43 uses 1E-5 annual risk target to develop a mean-hazard based Design Response Spectrum (DRS)
- DRS is obtained from UHRS for 1E-4 and 1E-5 (see next slide)
- Seismic Category I SSCs are designed to withstand the DRS at Limit State D (essentially elastic response); i.e., ASCE 43 Seismic Design Basis (SDB) of 5D

## Design Response Spectrum per RG 1.208 and ASCE 43




Comparison of the Mean 1E-4 and 1E-5 UHRS and the Performance-Based GMRS
(Illustration from RG 1.208)





## Basis for ASCE 43 Design Response Spectrum

- ASCE 43 considers that its design provisions (including those of the downstream ACI/AISC/ASME/IEEE design standards) achieve the following conditional probabilities failure:
  - ≤ 1% probability of failure at DRS shaking
  - ≤ 10% probability of failure at 1.50-times DRS shaking (controls when $\beta_c < 0.39$)
- UHRS to DRS conversion satisfies the above conditions for fragility curves with composite logstandard deviation values ranging from 0.30 to 0.60
- The second condition helps constrain the risk value for hazard curves corresponding to higher confidence levels





## Component Performance (Risk) Goal v/s Plant-wide Risk

- ASCE 43 based design assures that each Seismic Category I SSC has less than 1E-5 annual risk of not achieving LS D seismic performance
- 1E-5 is SSC-specific performance goal; the plant-wide annual risk is expected to be a lot less than 1E-5 because of multiple system-based safety features and redundancies
- The above observation will not pan out as well if there is a single or a few major contributors to SCDF and LERF risk
- Major risk contributor(s) can be identified a priori if a preliminary Seismic PRA is performed, or if they are known from experience

## Plant-wide 1.67 Seismic Margin Factor v/s ASCE 43 Performance

- For ALWR Designs, NRC Staff established (SECY-93-087):

  (Plant-wide HCLPF/DRS) ≥ 1.67 for Seismic Core Damage

  where, the HCLPF value represents the plant High Confidence of Low Probability of Failure capacity for core damage (usually taken at 1% if composite logstandard deviation is used)
- Small inelastic response is acceptable for most SSCs in the calculation of the plant HCLPF, whereas ASCE 43 delivers $F_{1\%}$ at DRS for individual SSCs at LS D
- Per DC/COL/IG-20, the estimate of the plant HCLPF capacity is based on sequence-level HCLPF capacities and fragility for all sequences leading to core damage or containment failures







## Plant-wide 1.67 Seismic Margin Factor v/s ASCE 43 Performance

- Standard plants are typically designed using a CSDRS that exceeds the plant GMRS; this makes it viable to achieve the 1.67 margin factor
- Review of ASCE 43 $F_\mu$ values indicates that members of many structural systems can simultaneously withstand DRS at LS D and approximately 1.67xDRS at LS C; however, this is not true for equipment and systems

**TABLE 5-1. Inelastic Energy Absorption Factor, $F_\mu$**

| Limit State | Reduction Factor, $F_\mu$* LS-A | LS-B | LS-C |
|---|---|---|---|
| SMRF reinforced concrete moment frames | | | |
| Beams $(15 \leq \ell/h)$ | 5.25 | 4.0 | 2.5 |
| Beams $(\ell/h \leq 10)$ | 3.25 | 3.0 | 2.5 |
| Columns** | 2.0 | 1.75 | 1.5 |
| Reinforced concrete shear wall, in plane: | | | |
| Bending controlled walls, $\frac{h_w}{\ell_w} \geq 2.0$ | | | |
| $6\sqrt{f'_c} < f_v$ | 2.25 | 2.0 | 1.75 |
| $f_v < 3\sqrt{f'_c}$ | 2.5 | 2.25 | 1.75 |
| Shear controlled walls, $\frac{h_w}{\ell_w} < 2.0$ | 2.0 | 1.75 | 1.5 |



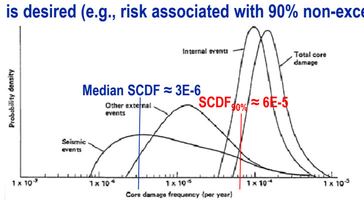




## Ground Motion Uncertainty Considerations

- While seismic design is based on mean hazard (and median fragility), there is now increasing recognition that there are significant epistemic uncertainties in ground motion hazard predictions
- This raises a concern about the risk volatility if higher confidence level is desired (e.g., risk associated with 90% non-exceedance of hazard)

From INL PRA Training Presentation




<u>Note</u>: The ground motion uncertainty influences the probability density function for SCDF, LERF, as well as the annual failure risk for individual SSC's

## *Ground Motion Uncertainty Considerations*

- ASCE 43 requirement to have ≤ 10% conditional probability of failure at 1.50xDRS helps reduce SSC's annual failure risk for higher confidence levels (and reduces the risk for mean hazard to below 1E-5 if it controls)
- The 1.50 value corresponds to the mean plus one standard deviation value of ground motion for logstandard deviation of ≈ 0.40
- Increase to a value of 2.0 (corresponding to logstandard deviation of ≈ 0.70) could be used as a means to address the risk impact associated with higher ground motion uncertainty (if it is an issue for some sites)
- The above change will affect the design of SSCs with low composite logstandard deviation values, but not so much for equipment/systems
- This change could be applied to design of risk-significant SSCs only







## *Seismic Resiliency Considerations*

- Resiliency signifies capacity to resist beyond-design-basis events
- The 1.67 seismic margin factor for plant-wide HCLPF capacity is a means to achieve resiliency
- Recent adoption of FLEX provisions is also a very effective measure to increase the plant resiliency
- Additionally, from code design standpoint, it is possible to overtly require additional resiliency at individual SSC level if an SSC is a priori known to be a dominant risk contributor
- Higher resiliency for selected SSCs could be achieved by overtly ensuring that their individual HCLPF capacity (or LS C capacity) is 2.0xDRS), the screening threshold used in the EPRI ESEP procedure







## *Risk-based Criteria for RTNS (AQ) and Seismic II/I SSCs*

- New plants feature many SSCs with RTNS or AQ classification, which are difficult to pin down in terms of seismic requirements
- The ANS 2.26 classification framework could be used to assign a performance goal (annual risk) for such SSCs, or an ad hoc target of 4E-5 could be adopted (corresponding to SDC 4) with LS D
- Similar consideration could apply to rad waste related facilities at NPPs (rather than adopting one-half SSE as their design basis)
- ANS 2.26 SDC 5 classification should be required for II/I SSCs whose failure can adversely impact proximate Seismic Category I SSCs; however, such SSCs can be designed to LS B, or C as long as the associated inelastic deformations are not problematic

## *Rigorous Verification of Seismic Design Capacities*

- ASCE 43 considers that its design (including use of ASCE 4 and relevant ACI/AISC/ASME/IEEE standards) achieves 1% conditional probability of failure against the design motion
- The above condition nominally corresponds to 98% non-exceedance of the code-based capacities, a condition that is generally satisfied; test and advanced simulation data can be utilized to verify if this criterion is met
- ASCE 43 provisions can be modified when the above condition is not satisfied (e.g., if there is 10% exceedance probability), or the code-based capacity equations need to be modified to assure 98% non-exceedance
- Out-of-plane (OOP) shear capacity for thick concrete members has been a known concern in this regard; ASCE 43-18 is addressing this issue by introducing an alternate equation for OOP shear capacity
- In-plane shear capacity equations for thick walls should also be revisited







## *Summary*

- ASCE 43 provisions are risk-based; they achieve 1E-5 annual risk for individual SSCs based on use of mean hazard and median fragilities
- There are some inherent requirements in ASCE 43 that help constrain risk volatility due to large ground motion uncertainties
- Also, ASCE 43 design using LS D implicitly provides seismic margin against beyond-design-basis (BDB) ground
- For risk-significant SSCs, the existing ASCE 43 requirements could be modified to achieve higher resilience and reduce risk volatility
- ASCE 43 requirements can be used to achieve risk-consistent design of RTNS and Seismic II/I SSCs
- Code capacities need to be revisited, as appropriate, to ensure that they satisfy the ASCE 43 expectation of 98% non-exceedance