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DETERMINATION OF DESIGN BASIS EARTHQUAKE CONSIDERING SAFETY GOALS OF SEISMIC PROBABILISTIC SAFETY ASSESSMENT FOR NUCLEAR ENERGY FACILITIES IN CANADA

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ABSTRACT

In the design of Canadian nuclear energy facilities against seismic events, a question is often raised about: "*how do we ensure that a structure, system, or component (SSC) would have adequate seismic capacity to withstand a beyond design basis earthquake (BDBE) while it is only seismically qualified to a design basis earthquake (DBE)?*". In this paper, an overview of the performance-based seismic design and qualification for nuclear SSCs is provided, which is considered a potential technical solution to address seismic adequacy of the facility to withstand BDBE when Canadian codes and standards are used. A technical strategy is then proposed to implement portions of the performance-based seismic design approach applicable for Canadian nuclear energy facilities associated with the determination of DBE and limit states of structures.

INTRODUCTION

In the design of Canadian nuclear energy facilities against seismic events, two major streams of methodology are generally utilized and supplemented to each other: rigorous seismic qualification based on design basis earthquake (DBE) and seismic evaluation based on beyond design basis earthquake (BDBE) or design extension condition (DEC) for seismic events. The BDBE is severer or higher in amplitude than the DBE (CSA, 2023; CSA, 2021; CSA, 2020). A question is often raised about: "*how do we ensure that a structure, system, or component (SSC) would have adequate seismic capacity to withstand a BDBE while it is only seismically qualified to the DBE?*".

ASCE 43 (ASCE, 2005; ASCE, 2019) was able to address this question from a high-level perspective by applying scale factors on top of the uniform hazard spectra (UHS) that are obtained from the probabilistic seismic hazard assessment (PSHA) to define the DBE. The scale factors have considered the slope of the seismic hazard curves and the level of ductility and conservatisms embedded in the US design codes and standards represented by generic seismic fragility curves. As such, a general and approximate performance goal in terms of probability of failure can be achieved consistently over different nuclear sites. This approach can build up confidence that the seismic design margin developed in the design stage is adequate for achieving the seismic capacity of the facility to withstand BDBE when the seismic probabilistic safety assessment (SPSA) is performed in a later stage of a project.

In Canada, the PSHA has been used for the determination of seismic hazard for seismic design, qualification, and evaluation of nuclear facilities. However, the level of DBE is not explicitly connected to the performance goal of SSCs important to safety that are designed and/or qualified using this defined DBE when following Canadian codes and standards, such as CSA N287.3-14 (R2024) (CSA, 2024a) for concrete containment structures and CSA N291-19 (R2024) (CSA, 2024b) for nuclear safety-related structures.

The purpose of this paper is to provide an overview of the performance-based seismic design and qualification for nuclear SSCs, which is considered a potential technical solution to address seismic adequacy of the facility to withstand BDBE when Canadian codes and standards are used. A technical strategy is proposed to implement portions of the performance-based seismic design approach applicable for Canadian nuclear energy facilities associated with the determination of DBE and limit states of structures. The implementation strategy is established based on assessment of seismic design philosophy, codes and standards, and industrial needs for nuclear energy facilities in Canada, with supplement from currently available PSHA and safety goals of SPSA for Canadian nuclear power plants (NPPs). The proposed strategy can be used to build up confidence that an SSC would have adequate seismic capacity to withstand a BDBE and meet the SPSA safety goals when it is seismically qualified to the pre-determined DBE.

In this paper, a brief historical overview of performance-based earthquake engineering and its application in design and qualification of nuclear energy facilities is first presented. Challenges and industrial needs pertaining to the determination of DBE and limit states of structures following Canadian codes and standards are then discussed. A technical strategy is thus proposed to be implemented for overcoming these challenges and meeting the industrial needs.

PERFORMANCE-BASED EARTHQUAKE ENGINEERING

Performance-based earthquake engineering has been a hot topic in both academia and industry over the last three decades. It has been recognized as the seismic design methodology of the future. It allows the design team to work together to determine the appropriate levels of ground motion and performance objectives for the building structures and the non-structural components in order to meet the owner's expectations. Performance-based earthquake engineering involves a broadband of disciplines including earth sciences, engineering, and social sciences.

The concept of performance-based earthquake engineering was initially framed and standardized in SEAOC Vision 2000 Committee (1995) and FEMA 273 and 274 (1997). They address performances primarily at the system level in terms of risk of collapse, fatalities, repair costs, and post-earthquake loss of function. As shown in Figure 1, the earthquake design level has been mapped into a matrix to be corresponded to the earthquake performance level depending on different objectives. This is considered as the initial concept of the performance-based seismic design.

PERFORMANCE-BASED SEISMIC DESIGN FOR NUCLEAR FACILITIES

The concept of performance-based earthquake engineering has been implemented into the seismic design of nuclear facilities in US (ASCE, 2017; DOE-STD-1020-02, 2002; DOE-STD-1020-12, 2012; DOE-STD-1020-16, 2016; Kennedy, R.P., 2007; USNRC, 1997; USNRC, 2007; USNRC, 2014). It provides a graded approach to suite the seismic performance goals of various types of nuclear facilities to ensure that the nuclear safety requirements are met consistently during or after an earthquake event. In Canada, discussions on implementing the performance-based seismic design for nuclear facilities have been initiated in the industry.

Historically, the seismic design philosophy for nuclear facilities in US has been gradually moved from “deterministic” to “probabilistic”. The threshold of the year is considered as 1997, as shown in Figure 2, when the USNRC Regulation 10 CFR 100.23 Geologic and seismic siting criteria, replaced 10 CFR 100.10(c)(1), i.e., Appendix A to Part 100—Seismic and Geologic Siting Criteria for Nuclear Power Plants, removed the prescriptive guidance in the rule itself and moved the guidance to the standalone Regulatory Guide 1.165 (USNRC, 1997). Guide 1.165 (USNRC, 1997) acknowledged the uncertainty in the

seismic/geologic knowledge base and required that the uncertainties be estimated through an appropriate analysis; and explicitly accepted the use of PSHA to satisfy this uncertainty requirement.

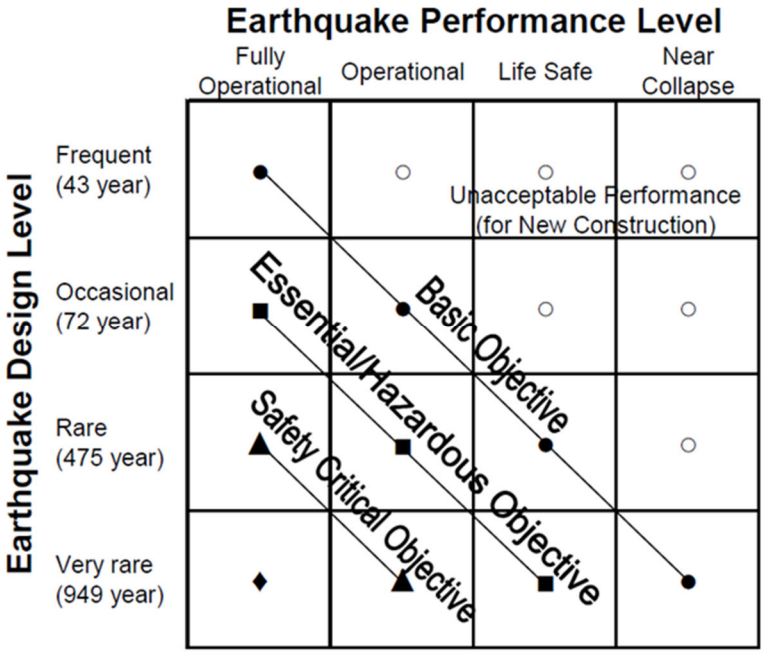

Figure 1: Earthquake Design and Performance Levels (SEAOC Vision 2000 Committee, 1995).

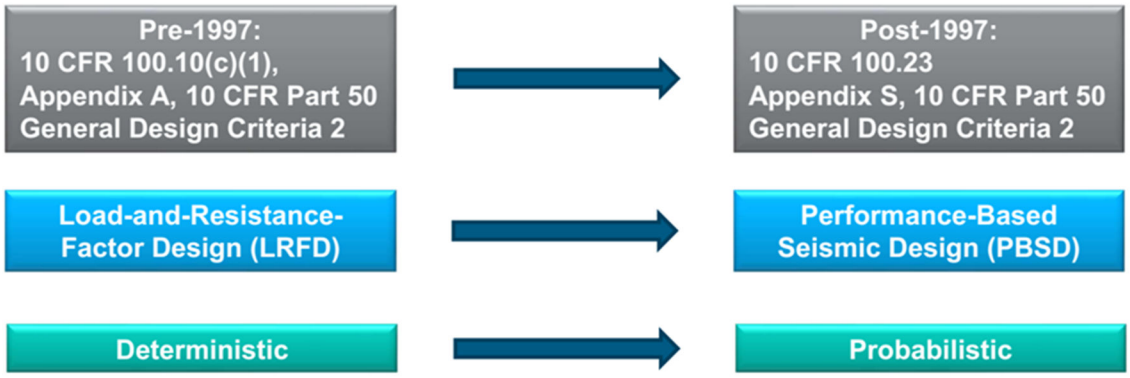

Figure 2: USNRC Seismic Design Regulation Moving from Deterministic to Probabilistic Approach.

Table 1 presents the key US Department of Energy (DOE) standards and US Nuclear Regulatory Commission (NRC) guidance for seismic design of nuclear facilities before and after 1997. The seismic design as guided in DOE-STD-1020-94 (1994) and USNRC (1973) has used deterministic approaches for DOE facilities and nuclear power plants.

Table 1: US DOE Standards and US NRC Guidance Related to Seismic Design.

Pre-1997
USNRC (1973). *Regulatory Guide 1.60, Revision 1, Design Response Spectra for Seismic Design of Nuclear Power Plants*.
DOE-STD-1020-94 (1994), *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, Washington, DC.
Post-1997
USNRC (1997). *Regulatory Guide 1.165, Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion*.
DOE-STD-1020-02 (2002), *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, Washington, DC.
ASCE (2005). *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, ASCE/SEI 43-05*.
USNRC (2007). *Regulatory Guide 1.208, A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion*.
DOE-STD-1020-12 (2012), *Natural Phenomena Hazards Analysis and Design Criteria for Department of Energy Facilities*, Washington, DC.
USNRC (2014). *Regulatory Guide 1.60, Revision 2, Design Response Spectra for Seismic Design of Nuclear Power Plants*.
DOE-STD-1020-16 (2016), Natural Phenomena Hazards Analysis and Design Criteria for Department of Energy Facilities, Washington, DC.
ASCE (2017). *Seismic Analysis of Safety-Related Nuclear Structures, ASCE 4-16*.
ASCE (2019). *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, ASCE/SEI 43-19*.

ACSE 43-05 (ASCE, 2005) is considered the key and the first standard detailing the performance-based seismic design for nuclear facilities. The 2019 edition of ASCE 43 (ASCE, 2019) has used the same concept. The graded approach adopted in ASCE 43 primarily covers the seismic design criteria from the following three aspects:

1. Determination of Seismic Design Category (SDC), which is mainly based on the results of the unmitigated consequence analysis associated with the failure of the SSC, checking against worker dose limits and offsite public dose limits. The designation of SDC defines the target performance goal in terms of annual probability of failure.
2. Development of scale factors on UHS to obtain design basis earthquake (DBE) based on the target performance goal determined in Item 1 and the slope of seismic hazard curve.
3. The determination of limit state which is based on functional and occupancy requirements from the safety analysis of the facility.

This paper focuses on Item 2 for the development of DBE and its potential implementation for the seismic design and qualification of Canadian nuclear facilities. Item 3 for the use of limit state of structures will be briefly discussed.

BACKGROUND CALIBRATIONS OF PERFORMANCE-BASED SEISMIC DESIGN

With focus on the development of DBE and its potential implementation for the seismic design and qualification of Canadian nuclear facilities, the calibrations and justifications behind the seismic design procedure and requirements in ASCE 43 (ASCE, 2005; ASCE, 2019) follow the major steps below:

1. Assess design margin in current codes and standards, given a defined DBE
    - Assume the design margin, as an initial point for the iteration, in the current codes and standards for the seismic design of nuclear facilities, i.e., less than about a 1% probability of unacceptable performance for the DBE ground motion, and less than about a 10% probability of unacceptable performance for a ground motion equal to 150% of the DBE ground motion.
    - Based on the consideration that the seismic fragility can be described by a lognormal distribution, the margin factors can be estimated based on the assumed margin above, and conservatisms embedded in the current seismic design codes and standards from the perspectives of capacity, demand, and ductility.
    - The above two steps are repeatedly performed until the assumed margin is achieved.

2. Determine target performance goal
    - The target performance goal was estimated based a statistical analysis of mean seismic core damage frequency (CDF) for the seismic probabilistic risk assessment (SPRA) (also known as SPSA in Canada) for a number of nuclear power plants in US (Kennedy, R.P., 2007).
    - The target performance goal for SSCs is a mean frequency per year for seismic-induced onset of significant inelastic deformation (FOSID).
    - This performance goal corresponds to significantly less damage than would be required to reach core damage.
    - A conservative bias is introduced by choosing the FOSID as the qualitative performance goal.

3. Given that the seismic margin (i.e., seismic fragility), seismic hazard (i.e., seismic hazard curves), and the target performance goal (i.e., mean annual frequency of seismic-induced onset of significant inelastic deformation) are determined, a design/scale factor, which describe the difference between the actual seismic hazard and the seismic hazard demand required in the design to achieve the target performance goal [i.e., the safety factor (seismic margin) between the uniform hazard spectrum (UHS) and the SSC seismic capacity], can be derived based on closed-form formulations of seismic hazard and fragility curves and their convolution.

4. Through these closed-form formulations in Step 3, the following four quantities are linked:
    - Design margin in current codes and standards, given a defined seismic input (seismic fragility/capacity of an SSC when using these codes and standards);
    - Seismic hazard/demand (UHS from PSHA);
    - Target performance goal; and
    - Safety factor (seismic margin) between the UHS and the SSC seismic capacity.

5. Thus, we can solve for the safety factor (design/scale factor after simplification) required to achieve the target performance goal, given the input UHS, and the design margin in current codes and standards.

ADVANTAGES OF PERFORMANCE-BASED APPROACH AND NEEDS FROM CANADIAN NUCLEAR INDUSTRY

The advantages of the performance-based seismic design approach are summarized below:

- Consistent seismic risk at different sites. To achieve the risk-consistency goal (consistent design conservatism), it is critical to consider not only the UHS but also the slopes of seismic hazard curves.
- Consistent criteria for limit states. The limit states can be selected based on the permissible deformation limit for the SSC established from functional considerations, through the inelastic energy absorption factor (or equivalent) and/or the deformation limits.
- No need to modify other codes and standards. The design conservatism/margin introduced by other codes and standards has been reflected in this procedure. Whether the conservatism/margin is good enough to achieve the performance goal is adjusted by applying the design/scale factor on the UHS.
- Probability level of UHS does not govern. In the derivation of design/scale factor, when the UHS probability level increases, the amplitude of the UHS decreases, and the design/scale factor increases accordingly to compensate the design margin, and vice versa. This is what it was supposed to be since the UHS probability level is only an intermediate quantity in the course of risk assessment and reflect only the hazard level rather than the risk level.

In the current seismic design and qualification for Canadian nuclear facilities, the following standards are followed for the determination of DBE:

- CSA N289.1 (CSA, 2023) provides guidance on the selection of seismic category and earthquake level, and general requirements for seismic design.
- CSA N289.2 (CSA, 2021) provides guidance on performing the PSHA.
- CSA N289.3 (CSA, 2020) defines the probability level of a DBE.

In these CSA standards, the probability level of design basis earthquake (DBE) is not connected with the performance (performance goal) of the facility that is designed using this design earthquake. The following questions in this regard need to be answered:

- Can the SSC perform as expected when an earthquake event occurs?
- How much conservatism has the design introduced?
- Are the levels of conservatism consistent at every site?
- How do we ensure that an SSC would have adequate seismic capacity to withstand a beyond design basis earthquake (BDBE) while it is only seismically qualified to a design basis earthquake (DBE)?

Based on the discussions above, these questions can readily be answered through the process of performance-based seismic design approach.

The following discussions and example are used to further demonstrate why it is so urgent for the Canadian nuclear industry to consider the concept of performance-based seismic design in the determination of DBE for designing the nuclear SSCs.

In ASCE 43-05 (ASCE, 2005), the scale factor is set as a function of a slope factor which quantify the spectral acceleration difference between the probability levels for DBE, e.g., annual probability of exceedance (APE) of 10^{-4} and for BDBE (e.g., APE of 10^{-5}), i.e., the slope of seismic hazard curve. When this difference is lower than a factor of ~2, the scale factor is approximately 1; this implies that the UHS with APE of 10^{-4} without applying the scale factors is adequate to be used as a DBE directly, and with this design, the level of ductility and conservatisms embedded by using the applicable US codes and standards is sufficient to withstand the additional seismic effects from a BDBE.

When the difference between DBE and BDBE is higher than ~2, the scale factor will be larger than 1. This suggests that the UHS with APE of 10^{-4} without applying the scale factors is no longer adequate since the increase (> a factor of 2) of the BDBE on the top of the DBE exceeds the seismic capacity from the ductility and conservatisms embedded in the design. As such, the raw UHS has to be increased. In current CSA standards for seismic design and qualification of nuclear power plants (CSA, 2023; CSA, 2021; CSA, 2020), this crucial step has not been captured.

Figure 2 shows two sample seismic hazard curves (Goda, K, 2019) for illustration purpose. Based on the seismic hazard curve with relatively steep slope for Vancouver, the spectral acceleration at 3.3Hz is ~1.5g corresponding to APE of 10^{-4} for DBE, and ~2.6g for APE of 10^{-5} for BDBE. The ratio of BDBE to DBE at this specific vibration frequency is less than 2 and thus no increase is required on the DBE in order preserve margin for BDBE. However, this ratio will be much more than 2 for the seismic hazard curves with relatively mild slope for Montreal, which implies that the DBE needs to be increased for tackling BDBE in a later stage of the project. If CSA standards (CSA, 2023; CSA, 2021; CSA, 2020) are used to determine the DBE for the Montreal case, the design would be in a high risk that it may not be adequate for BDBE.

Note that, in a seismic PSA, meeting the BDBE is not a direct requirement since the PSA has used core damage frequency and large release frequency as the acceptance criteria for safety goals; however, the level of BDBE named checking level earthquake or review level earthquake has been used for seismic screening in a seismic PSA and is considered good indictor for the seismic capability of the plant for seismic loads higher than the DBE.

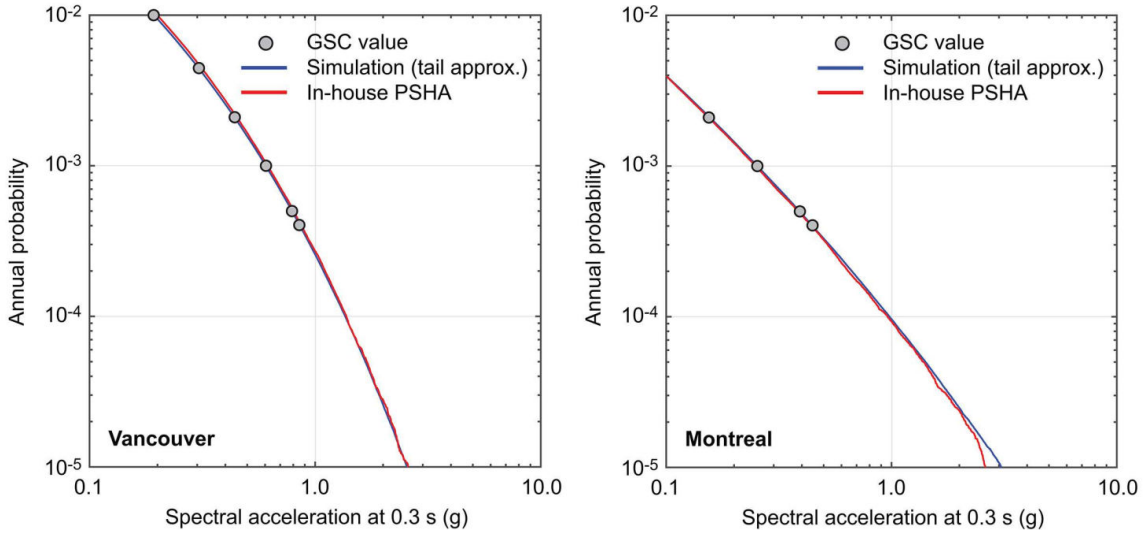

Figure 2: Sample Seismic Hazard Curves (Goda, K, 2019).

PROPOSED APPROACH FOR SEISMIC DESIGN OF CANADIAN NUCLEAR FACILITIES

To implement the performance-based seismic design approach for nuclear facilities in Canada, the following recommendations are made for long-term future work:

- Calibrations and justifications compatible with Canadian nuclear design philosophy:
  - Connections with existing regulations, design codes, and standards (e.g., CSA, 2024a; CSA, 2024b).

  - No modifications are required for these codes and standards. Current codes and standards are well supportive to this procedure.
  - Design margin between DBE and the capacity of the SSCs designed using these codes and standards needs to be assessed, by considering Canadian nuclear design philosophy (e.g., essentially elastic design for structures, or ASME Level C stress limits for pressure retaining components).

- Utilizing existing PSHA and SPSA results of NPPs in Canada:
  - UHS and seismic hazards curves from PSHA at Canadian sites need to be analysed, especially the hazard curve slopes, to define appropriate hazard level and slope factor.
  - Core damage frequencies from SPRA at Canadian sites need to be statistically analysed, based on which a consensus is to be reached on the target performance goal (probability of unacceptable performance).
  - Due to the limited number of NPPs in Canada, the scale factors may be derived based on specific site data (including seismic hazard and SPSA results) directly rather than obtaining generic scale factors as specified in ASCE 43.

By performing the work above, a performance-based seismic design procedure, which is suitable to the new builds in Canada and compatible with the Canadian nuclear design philosophy, can be established.

It is noted that the use of scale factors as per ASCE 43 would only help to build up confidence that the seismic design margin developed in the design stage is adequate for BDBE, from a high level perspective. The safety goal in terms of core damage frequency and large release frequency still needs to be formally confirmed through seismic PSA and PSA for other events. However, it would be very practical if this can be considered in advance during the design stage to avoid major design changes in the case that PSA finds the existing design inadequate.

Given that the above long-term strategy could take some time to be implemented, the following intermediate strategies could be used to meet the industrial needs in short term:

1. In some sites, the slope of seismic hazard curves is quite steep as such the difference between DBE and BDBE is small, e.g., between 1.5 and 2. In this case, the scale factor is not required.
2. Many of the new build design are developed based on existing design/reference design. A full or preliminary seismic PSA or seismic margin assessment has been performed, and the information are readily available to provide a general idea for the seismic capacity of SSCs that are credited in the seismic PSA. From the existing seismic PSA information, recommendations can be made to upgrade the seismic capacity of some of the SSCs but not for all. Preliminary seismic PSA may also be performed in parallel to the design, to build up confidence to tackle the BDBE.
3. In the case that seismic PSA information are not available, the approach in ASCE 43 may be used with care. The rationales why the approach in ASCE 43 should be used with care for nuclear facilities in Canada are discussed below:
   - The approach of determining the DBE in ASCE 43 is derived based on the concept of performance-based seismic design. The performance goals are specified based on a statistical analysis of seismic PSA results of a number of NPPs in US, and the seismic hazard data used are specific for US sites.
   - The scale factors specified in ASCE 43 have been derived based on a set of generic seismic fragility curves representing the inherent seismic ductility and design margin embedded in the US design codes and standards.

- Thus, without further studies, it is uncertain whether the scale factors specified in ASCE 43 are applicable to the design of Canadian nuclear facilities when Canadian codes and standards are used.

Note that non-mandatory Guidance, Section 5.13 of CNSC REGDOC-2.5.2 has mentioned about the definition of DBE based on ASCE 43. This has indicated that the door for the use of performance-based seismic design approach is open from the regulatory perspective. What is required from the industry is to find out a practical way of implement the concept.

DISCUSSIONS ON LIMIT STATE OF STRUCTURES

As mentioned above, the performance-based seismic design approach also requires the determination of multiple limit states which are based on functional and occupancy requirements from the safety analysis of the facility. In CSA N287.3 (CSA, 2024a) and N291 (CSA, 2024b), only one limit state has been specified which is essentially elastic (ductility and overstrength factors = 1) for seismic load. For structures that are not safety-related and not required to be qualified to DBE but are required to ensure structural integrity under the DBE, there are no detailed and practical design requirements to follow for other limit states (with larger permanent deformation than "essentially elastic") when using the CSA N series standards for the design of nuclear facilities.

CSA N287.3 (CSA, 2024a) and N291 (CSA, 2024b) standards make references to CSA A23.3 for concrete structural design and CSA S16 for steel structural design. On the other hand, the National Building Code of Canada (NBCC) in its application for seismic design is also fully compatible with CSA A23.3 and S16. The NBCC seismic design clauses have implemented various limit states by applying the importance factors to adjust the ductility and overstrength factors (similar to the concept of inelastic energy absorption factor in ASCE 43). In general, the use of importance factor of 1.5 for post-disaster (immediate occupancy during and after a seismic event) following NBCC can be considered equivalent to a limit state of "limited permanent deformation". This limit state could be applicable to the structures that are not safety-related and not required to be qualified to DBE but are required to ensure structural integrity under the DBE. Further studies are required to confirm this equivalency and its applicability in designing non-safety-related nuclear structures.

Once the equivalency mentioned above is established, for the design of the non-safety-related building structures, the DBE-based seismic inputs at the foundation level of the structure, in terms of ground response spectra or time histories, should be determined following CSA N289 standards. This DBE-based seismic input should be compared with the seismic input as per NBCC, and the enveloped seismic input should be used in the design. The design should then be performed following NBCC. To achieve adequate seismic ductility in the design, it is suggested that the design should have at least moderate ductility while regular ductility reduction factors can be used in the design. Thus, in one shot of design, we will be able to meet both NBCC requirements and the DBE interaction requirements without overdesigning the structure to fully meet the CSA N series standard.

CONCLUSION

This paper has reviewed the existing materials related to performance-based seismic design, and existing codes and standards that have implemented the performance-based seismic design approach for nuclear facilities. Based on these reviews, a strategy to implement performance-based seismic design for nuclear facilities in Canada has been proposed.

REFERENCES

ASCE (2005). *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, ASCE/SEI 43-05*.

ASCE (2017). *Seismic Analysis of Safety-Related Nuclear Structures, ASCE 4-16*.

ASCE (2019). *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, ASCE/SEI 43-19*.

CSA (2023). *CSA N289.1, General Requirements for Seismic Design and Qualification of Nuclear Power Plants*.

CSA (2021). *CSA N289.2, Ground Motion Determination for Seismic Qualification of Nuclear Power Plants*.

CSA (2020). *CSA N289.3, Design Procedures for Seismic Qualification of Nuclear Power Plants*.

CSA (2024a). *CSA N287.3-14 (R2024), Design Requirements for Concrete Containment Structures for Nuclear Power Plants*.

CSA (2024b). *CSA N291-19 (R2024), Requirements for Nuclear Safety-related Structures*.

DOE-STD-1020-94 (1994), *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, Washington, DC.

DOE-STD-1020-02 (2002), *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, Washington, DC.

DOE-STD-1020-12 (2012), *Natural Phenomena Hazards Analysis and Design Criteria for Department of Energy Facilities*, Washington, DC.

DOE-STD-1020-16 (2016), Natural Phenomena Hazards Analysis and Design Criteria for Department of Energy Facilities, Washington, DC.

FEMA 273 and 274 (1997), *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, Federal Emergency Management Agency (FEMA), Washington, DC.

Goda, K (2019). *Nationwide Earthquake Risk Model for Wood-Frame Houses in Canada, Frontiers in Built Environment*, Volume 5, Article 128.

Kennedy, R.P. (2007). *Performance-Goal Based (Risk Informed) Approach for Establishing the SSE Site Specific Response Spectrum for Future Nuclear Power Plants*, Transactions, SMiRT 19, Toronto.

SEAOC Vision 2000 Committee (1995). *Performance-Based Seismic Engineering,* Report prepared by Structural Engineers Association of California (SEAOC), Sacramento, California.

USNRC (1973). *Regulatory Guide 1.60, Revision 1, Design Response Spectra for Seismic Design of Nuclear Power Plants*.

USNRC (1997). *Regulatory Guide 1.165, Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion*.

USNRC (2007). *Regulatory Guide 1.208, A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion*.

USNRC (2014). *Regulatory Guide 1.60, Revision 2, Design Response Spectra for Seismic Design of Nuclear Power Plants*.