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A CANADIAN REGULATORY PERSPECTIVE ON THE USE OF INDIRECT METHODS IN SEISMIC EVALUATION AND THEIR EVOLUTION

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ABSTRACT

Seismic Qualification (SQ) is a process to verify the ability of a structure, system, or component (SSC) to maintain its design-intended performance during and/or following the Design Basis Earthquake (DBE). Typically this is achieved through testing, analysis or combination of the two. Canadian Standards Association (CSA) Standard N289.1-18, *General requirements for seismic design and qualification of nuclear power plants*, provides SQ requirements and guidance for both direct methods (i.e., by test, analysis or combination of thereof) or indirect methods (e.g., experience-based method). The indirect methods were originally developed to verify the seismic adequacy of mechanical and electrical equipment installed in USA plants subjected to Generic Safety Issue (GSI) A-46, that needed reassessment of their seismic design. Currently, there are nineteen (19) operational nuclear power reactors in Canada. As per CSA N289.1-18, both direct and indirect methods as per CSA N289.1 have been used to demonstrate the seismic adequacy of SSCs in fitness for service (FFS) evaluations and refurbishments in Canadian nuclear power plants (NPPs). The purpose of this paper is to summarize Canadian SQ practices observed by the regulatory authority and discuss important technical elements that should be considered in SQ using indirect methods.

INTRODUCTION

The purpose of seismic qualification is to ensure that the structural integrity and the design intended function of SSCs important to safety[1] are maintained during and/or following the DBE. Different seismic qualification methods have been applied to SSCs in FFS evaluations and refurbishments in Canadian NPPs.

CSA Standard N289.1-18 [1], *General requirements for seismic design and qualification of nuclear power plants*, provides seismic qualification requirements and guidance for both direct methods (by test, analysis or a combination of analysis and testing) and indirect methods (by similarity, earthquake experience or seismic test databases). This paper focuses on the use of indirect methods.

Indirect methods have been used to qualify an 'already installed' SSC or to replace aged SSCs in Canadian NPPs [2]. As with direct methods, indirect methods have a certain number of advantages and limitations. Indirect methods could provide cost-effective options for assessing the seismic adequacy of essential components/equipment in operating plants. However, indirect methods may have a limitation to

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[1] Hereinafter referred to as SSCs

quantitatively demonstrate design margins per existing Canadian requirements because they were primarily developed as an alternative to the direct methods in order to address Generic Safety Issue (GSI) A-46, *Seismic Qualification of Equipment in Operating Nuclear Plants* [3]. USI A-46 was raised by the U.S. Nuclear Regulatory Commission (NRC) in the 1980′s because of extensive changes in the requirements for seismic qualification of SSCs over the years such as the requirement on the use of seismic induced loads [4] and hence the need for reassessment for some plants.

This paper discusses considerations for acceptable application of indirect methods for seismic qualification of SSCs in Canadian NPPs through the review of: 1) a history of seismic qualification in Canada; 2) current seismic qualification practices in Canada; 3) two typical indirect methods: a) similarity and experience-based method and b) Seismic Margin Assessment (SMA).

HISTORY OF SEISMIC QUALIFICATION IN CANADA

Currently, as per CSA N289.1-18 [1], both direct and indirect methods can be used to demonstrate the seismic adequacy of SSCs in FFS evaluations and refurbishments in Canadian NPPs. Six (6) operating power reactors in Canada were designed prior to the publication of CSA N289.3-M81 in 1981 [5]. This Standard specified design procedures for seismic qualification of nuclear power plants by analysis.

Since the mid-1990s, NPPs in Canada have started reaching the end of their design life. Canadian utilities have decided to extend the operating life of existing operating power reactors through planned refurbishment projects.

Seismic qualification of SSCs by direct methods, as per modern codes and standards, in certain existing operating power reactors designed prior to the publication of CSA N289.3-M81 has been challenging. To ensure continued plant safety, Seismic Margin Assessments (SMA) were performed to demonstrate margin for the site-specific Review Level Earthquake (RLE) and find any weaknesses that can limit the plant’s capacity to achieve and maintain a safe shutdown condition during and after a seismic event. The SMA results were reviewed and accepted by the Canadian nuclear regulatory authority, the Canadian Nuclear Safety Commission (CNSC), as an alternative to meeting modern seismic requirements.

In 2008, a new edition of CSA N289.1 [2] was published to specify seismic qualification requirements applicable to SSCs in Canadian NPPs. This 2008 version of CSA N289.1 specified that the following methods may be used in the seismic qualification of NPP SSCs:

- Analysis;
- Testing;
- A combination of analysis and testing;
- Similarity and earthquake experience or seismic test databases;
- Seismic margin assessment; and
- Seismic probabilistic safety assessment.

In 2018, CSA N289.1 [1] was revised to update seismic qualification methods. The new requirements now state that the SMA and Seismic Probabilistic Safety Assessment (SPSA) can only be used in the seismic evaluation of plants rather than the seismic qualification of plants. Seismic qualification by similarity and earthquake experience or seismic test databases (i.e., indirect methods) remain as an acceptable seismic qualification method in CSA N289.1-18. In addition, CSA N289.1-08 and CSA N289.1-18 allow the use of methodologies for commercial grade items and/or seismically rugged items in the seismic qualification of an SSC. The Generic Implementation Procedure (GIP) [3] and certain Electric Power Research Institute (EPRI) documents (e.g., SMA) [6] provide a list of seismically rugged items that were primarily identified by the review of seismic experience databases. Seismic ruggedness can be established and/or verified through direct methods (i.e., analysis, testing, a combination of thereof) as well.

CURRENT SEISMIC QUALIFICATION PRACTICES IN CANADA

Section 7.13 of CNSC regulatory document REGDOC-2.5.2 [7], *Design of Reactor Facilities: Nuclear Power Plants*, states that SSCs shall be seismically classified and qualified in accordance with Canadian national or equivalent standards. Seismic classification is a necessary design activity for SSCs required to cool the fuel, remove decay heat, and maintain a containment boundary. Furthermore, CSA N289.1 [1, 2] states that SSCs in CANDU® (CANada Deuterium Uranium) type NPPs shall be designed and constructed to ensure that the effects of an earthquake do not lead to unacceptable radiation exposure. The following two seismic categories are classified in CSA N289.1 to identify the extent to which SSCs shall remain operational during and/or after an earthquake:

- Seismic Category A include those SSCs that shall maintain their structural integrity and shall retain their pressure boundary integrity during and/or following an earthquake; and
- Seismic Category B include those SSCs that shall maintain their structural integrity and detailed functional requirements during and/or following an earthquake, and shall also retain their pressure boundary integrity, where applicable.

The seismic classification practices specified in CSA N289.1 are similar to what is specified in the U.S. Regulatory Guide (RG) 1.29 [8], *Seismic Design Classification*. This RG states that SSCs classified as Category I (i.e., similar to Canadian seismic Category B) must be designed to withstand the effects of the Safe Shutdown Earthquake (SSE) and maintain the specified design function if an SSE were to occur, and not cause failure or unacceptable structural interaction with failure of seismic Category I SSCs. The SSE is equivalent to the DBE used in the seismic qualification of SSCs in Canadian NPPs. In addition, International Atomic Energy Agency (IAEA) report NS-G-1.6 [9], *Seismic Design and Qualification for Nuclear Power Plants,* states that nuclear power plant items of seismic Category 1 (similar to Canadian seismic Category B SSCs) should be designed, installed and maintained by rigorous national practices for nuclear applications. The safety margin should be higher than the safety margin used in facilities with conventional risk to avoid unacceptable radiation exposure resulting from the failure of SSCs.

Both direct and indirect methods have been used in accordance with the requirements of CSA N289.1 for the seismic qualification of Category A and Category B SSCs. The following are three indirect evaluation methods specified in CSA N289.1-08 [2] and CSA N289.1-18 [1]: 1) Earthquake experience or seismic test databases and Similarity; 2) SMA; and 3) SPSA.

The seismic qualification practices that use indirect methods in Canada differ from those in other countries. For example, in the U.S., Experience-Based Seismic Equipment Qualification (EBSEQ) methods (i.e., GIP) are only allowed to demonstrate seismic adequacy of ‘already-installed’ SSCs in A-46 plants that needed reassessment of the original seismic design. Moreover, SMA and SPSA have been internationally used in safety evaluations rather than in seismic qualifications. In the next section, typical two indirect/evaluation methods, 1) similarity and experience-based method and 2) SMA, will be discussed to explore main technical issues that could be used to improve the quality and documentation of the indirect methods.

SIMILARITY AND EXPERIENCE-BASED METHOD

Canadian Requirements

Clause 5.3.5 of CSA N289.1-18 [1] states that similarity and earthquake experience or seismic test databases can be used as a seismic qualification method.

The purpose of seismic qualification by similarity is to demonstrate a similarity between the candidate specimen, which is the equipment to be qualified, and the target specimen, which is the qualified equipment by using existing, typically test, databases. Qualification by similarity has been used for components/equipment that have acceptably similar dynamic response characteristics to existing seismically qualified components/equipment or to a reference equipment class with established seismic capacity. The term ‵reference equipment class‵ represents a group of components/equipment sharing common attributes as defined by a set of inclusion rules and prohibited features. In the next section, types of Experience-Based Seismic Method (EBSM) and experience database will be discussed.

Issues on the Use of EBSM

The Experience-Based Seismic Method (EBSM) was originally developed using the experience databases to resolve safety issues (i.e., seismic qualification of equipment in operating NPPs) in the US A-46 (i.e., US NRC GSI A-46) plants with need for reassessment of original design. The experience database was established by the collection of data from the following sources [11, 12]. A statistically adequate sample size, representing both failures and successes of a given equipment class (e.g., valve, relay), is an important parameter to capture the variance in design, size, and operating environment:

- existing earthquake experience of nonnuclear plants located worldwide;
- existing seismic test results; and
- existing analysis to demonstrate the seismic capacity of equipment classes

The experience database was used in the development of the following four (4) methods. CSA N289.1 [1, 2] allows the EBSMs with relation to seismic Category A and seismic Category B SSCs:

- GIP and New and Replacement Equipment (NARE) [3];
- Experience-Based Seismic Qualification for Piping and Tubing as per EPRI report, 1019199 [10];
- Seismic Technical Evaluation of Replacement Items (STERI) [13] and/or Generic Seismic Technical Evaluation of Replacement Items (G-STERI) [14]; and
- Seismic Margin Assessment (SMA) [6]

In Canada, the DBE event is classified as Level C service loading condition as per the ASME *BPVC*, Section III, Division 1, NCA-2142 [15]. CSA N285.0 [16] requests documentations to demonstrate that design requirements for Class 1, 2, and 3 systems shall consist of requirements for seismic qualification. The design procedure for seismic qualification by analysis is specified in CSA N289.3 [17]. This Standard provides seismic qualification rules by analysis and adopts qualification rules in the ASME Code. The ASME Code Section III [15] mandates the use of combined loads (e.g., pressure induced loads with the seismic induced loads) in the code evaluation for the purpose of ensuring structural integrity of Pressure Retaining System and Component (PRSC) during the DBE event. The SQ result as per the ASME Code and the CSA N289.3 can quantitatively demonstrate remaining margins because an evaluated stress resulting from the combined loads is directly compared with an ASME Code allowable limit. Hence, a remaining margin to the allowable limit can be directly quantified. Hence, the ASME approach is more prescriptive, deterministic, and repeatable by different groups of experienced engineers. In addition, the non-mandatory, Annex D, in CSA N289.1 states limitations of experience-based methods. In particular, this Annex provides an additional requirement for pressure boundary components that the capability of the component to perform the specified pressure-retaining function in combination with an earthquake shall be addressed separately using appropriate criteria to ensure their structural integrity and functionality against the DBE.

In contrast, the EBSM has limitations to address ASME Code pressure boundary acceptance to quantitatively demonstrate a remaining margin in comparison to an ASME Code allowable limit. In particular, the seismic capacity of PRSC against the seismic induced fatigue crack initiation is one of design requirements specified in CSA N285.0 and CSA N289.3. The seismic induced fatigue is a function of the number of seismic cycles and a stress level at a given location, but the EBSM does not quantitatively demonstrate a remaining fatigue margin (i.e., a cumulative fatigue usage factor). Furthermore, the EBSM cannot quantitatively determine concurrent functional loads for applicable mechanical components. For example, the seismic induced concurrent loads are an essential input to design a nozzle at pumps and valves that are attached to the PRSC. Hence, the EBSM is considered as a qualitative approach. Check lists, which were developed using the experience database, are extensively used in the EBSM to ascertain seismic qualification of a component/equipment. The check lists are expected to be completed by a Seismic Review Team (SRT) [3, 6, 10, 11, 12] using data collected from several sources (e.g., walkdown, document/drawing review). Hence, judgments and assumptions made by SRT should be verified by conducting an independent peer review process which is considered an essential element to complete the seismic evaluation as per the EBSM.

The demonstration of similarity between the candidate specimen and the seismically qualified target specimen is a fundamental process for the EBSM. The following elements, but not limited to, need to be systematically reviewed because they directly affect the similarity between the candidate specimen and the target specimen:

- Key variables (e.g., size, shape, material properties, mass distribution, weight, mounting arrangement, center of gravity) which could affect dynamic characteristics;
- Dynamic characteristics of sub-assemblies affecting the functionality;
- Functional characteristics;
- Load transfer (e.g., structural load transferring characteristics);
- Operating and environmental conditions including the level and the type of concurrent loads;
- Bounding condition predicted at the end of the design life (e.g., dimension change due to degradation); and
- Quality of manufacturing and fabrication.

The main technical issues on the SMA will be discussed in a separate Section titled ″SEISMIC MARGING ASSESSMENT″ for further discussion. The rest of this section will discuss main technical issues which need to be described and clarified in a qualification report when one of the aforementioned EBSMs (i.e., GIP and NARE, EPRI 1019199, STERI-and G-STERI) is used to demonstrate seismic adequacy of a given SSC:

Firstly, use of GIP and the NARE: GIP was originally developed using seismic experience database which was established mainly through the collection of failure data from 20 equipment classes. Limitations and restrictions (i.e., caveats) for each equipment class is defined in the GIP to appropriately demonstrate the seismic capacity of each component/equipment. Rules to determine a seismic demand are provided in the GIP.

Based on the review of relevant documents referred to in this paper [3, 11, 12, 16 through 22], the following three key issues are outlined when a given equipment is qualified through the GIP and/or the NARE:

- Characterization of the earthquake experience motions: The earthquake experience ground motions need to be characterized by using several information and records (e.g., the ground motion recording, the free-field ground motion, the ground response spectrum) to characterize earthquakes selected as the basis for a reference equipment class;
- Amplification of a peak acceleration in an in-structure response: The layout of piping system together with type of support (e.g., anchor, a support for lateral movement, etc.) is a key element that directly affects: 1) in-structure response; and 2) stress/load level in a given piping system. Hence, further clarification needs to be provided that a maximum peak acceleration in the in-structure response of the piping system is bounded by the seismic demand evaluated as per the GIP method (e.g., Method A);
- Characterization of reference equipment class: A reference equipment class is a group of similar equipment that share a range of physical, functional, and dynamic characteristics and whose performance in earthquakes has been demonstrated. The following three items need to be considered to appropriately characterize a given reference equipment class: 1) The attributes of the equipment class; 2) Number of independent items; and 3) Reference equipment class functionality

Secondly, use of the EPRI report, 1019199: Guidelines and are provided for demonstrating the seismic adequacy of installed piping and tubing through evaluation processes, quite similar to the GIP and the SMA. This document collects seismic experience and test data for piping and tubing together with the experience database used in developing the GIP/SMA, along with the screening procedure used in a seismic walkdown that is part of an SMA. The purpose of this document is to propose seismic verification guidelines that reflect the lessons learned in various NPP seismic verifications. In 2009, an updated version of EPRI report, 1019199, *Experience-Based Seismic Verification Guidelines for Piping and Tubing*, was published [10]. The following limitations are stated in the EPRI report to qualify a given piping system as per evaluation criteria:

- Code class: These criteria apply to piping systems designed and constructed to the nuclear Class 2 and 3, and non-nuclear Class piping;
- Material: The pipe material shall be carbon steel, austenitic stainless steel or copper tubing (Type L) with ASME B31.1 [23] basic allowable stress (S_h) of at least 10 ksi. Cast iron materials, non-ferrous alloys such as brass and bronze, aluminum, and PVC materials are excluded; however, brass or bronze valves are acceptable;
- Material ductility: Piping materials shall be ductile at all service temperatures, having total elongation at rupture greater than 10%;
- The diameter-to-thickness ratio (D/t): The D/t of pipe shall be 50 or less (i.e., excluding thin wall pipe);
- Internal Pressure and Temperature: The maximum operating pressure shall be less than 3000 psi, and the maximum operating temperature shall be less than 800 ^{o}F;
- Threaded Joints: Threaded joints are considered outliers in the EPRI approach; and
- Buried Pipe: Buried piping has experienced many seismic failures and is excluded from the EPRI approach.

Thirdly, use of the STERI and G-STERI: CSA N289.1 allows the use of the seismic technical evaluation of commonly used replacement equipment and parts, which are classified as the Seismic Category A or Category B, using the Seismic Technical Evaluation of Replacement Items (STERI). Generic Seismic Technical Evaluation of Replacement Items (G-STERI) is the updated documents of the STERI [13], and the G-STERI [14] lists seismically insensitive and seismically rugged items together with their associated conditions and technical justifications. The G-STERI is based on earthquake experience data, test data (i.e., GEneric seismic Ruggedness Spectra (GERS), Seismic and Qualification Reporting and Testing Standardization (SQURTS), and specific tests), analytical experience, vendor catalogue information, and available sources of relevant input. However, the following limitations should be taken into consideration when using the STERI/G-STERI in the evaluations of SSCs:

- They are not applicable to seismic qualification of design as they were originally developed for use of commercial grade item to replace a component/equipment whose Original Equipment Supplier or Manufactures (OES/OEM) cannot maintain quality assurance programs with adequate controls for supplying nuclear equipment. In other words, they were not intended for use as a basis for providing compliance with a design code or standard;
- They do not provide seismic qualification methods; and
- They do not provide 1) a class composition rule in terms of the degree of similarity between component functional characteristics, physical and dynamic characteristics, and seismic capacity; and 2) the minimum number of independent equipment items within a given equipment class.

Based on the review of issues and limitations that need to be considered in the seismic qualification/evaluation by the each of the aforementioned three EBSMs, most importantly, the experience database does not sufficiently incorporate success data to provide records of sustaining equipment functionality during and following past earthquakes. Hence, an additional assessment as per ASME QME-1 [19] or IEEE 344 [20] needs to be conducted because those Standards provide evaluation procedures when a given component/equipment was/will be qualified as per the EBSM. These Codes and Standards are referred to in CSA N289.4 [21] to demonstrate the similarity between the candidate specimen and the target specimen. The purpose of the additional assessment as per the ASME QME-1 and/or IEEE 344 is to demonstrate the following elements:

- Inclusion rules and prohibited features used to refine the attributes of the equipment class;
- The minimum number of independent equipment items to cover statistically sufficient equipment having different physical characteristics or experience different seismic motion characteristics;

- Failures vs damage vs anomalies of SSCs resulting from the earthquakes to check the functionality of SSCs, during and following the earthquakes; and
- Similarity of the experience data to the equipment being evaluated at NPPs.

SEISMIC MARGIN ASSESSMENT

Canadian Requirements

The SMA has been used to evaluate SSCs in certain Canadian NPPs in need of reassessment of their original seismic design. In order to support this practice, Clause 5.3.8 of CSA N289.1-08 [2] states that *"the SMA methodology provides a means of quantifying the seismic capacity of SSCs required to perform essential safety functions during and following an earthquake"*. This methodology introduces the High Confidence Low Probability of Failure (HCLPF) capacity to express seismic capacity. The HCLPF indicates the level of earthquake ground motion (e.g., RLE) at which there is a 95% confidence in 5% probability of failure. In 2018, CSA N289.1 was revised to update seismic qualification methods. The new requirements in the CSA N289.1-18 [1] state that the SMA and SPSA are classified as the means of the seismic evaluation of plants.

In the next section, technical issues, which need to be addressed in a seismic qualification exercise by the SMA, will be discussed in terms of methods used in the determination of a seismic demand and the evaluation of a seismic capacity.

Issues on the Use of SMA

The SMA program was initiated to resolve the US NRC Advisory Committee on Reactor Safeguard (ACRS) safety concern on the capability of NPPs to withstand earthquakes greater than the SSE (equivalent to the DBE) [6, 12]. Hence, the underlying assumptions and margins between the SMA and design qualification are not identical because the SMA was primarily developed to resolve a concern on the capability of NPPs to withstand earthquakes greater than the DBE using probabilistic insight [6, 12].

The purpose of the SMA is to identify the most seismically vulnerable components/equipment (i.e., "weaker-link") in the prescribed path (e.g., referred to as "a success path" in the EPRI method) for safe shutdown to show the inherent seismic margin in the plant shutdown capacity following an earthquake greater than the DBE. In particular, the experience database, which was discussed in the previous section, is extensively used in the SMA. For example, check lists used in a screen process (i.e., ″screened-in″ or ″screened-out″ to determine SSCs required a further evaluation) were developed using the experience database. Therefore, SMA has been used internationally as a method for the seismic safety re-evaluation of already-installed SSCs. Hence, the following issues needs to be clarified when a given SSC is evaluated through the SMA to demonstrate its seismic capacity:

- Seismic demand: A third level response spectra at a given location (e.g., branch point, valve location) needs to be generated using a seismic model to use an appropriately determined seismic demand. The ″third level″ response spectra could be derived by a seismic analysis model (i.e., including a piping and civil structures) to generate a new response spectra at the branch locations (i.e., third level response spectra). For example, a nuclear class 1 feeder pipe is attached to the header which is the part of a Primary Heat Transport (PHT) piping system. Dynamic responses at the header could be amplified by the dynamic behavior of the PHT piping system;
- Large uncertainties exist in the similarity between 1) SSCs in nuclear plants, in particular, the CANDU specific components/equipment and 2) the conventional piping in terms of design features, degradations, failure mode and its location, loading conditions, operating conditions [22]. Hence, the systematic evaluation of similarity between the candidate specimen and the target specimen listed in the experience database is a fundamental element to validate/verify the experience database;

- Failure rates of the CANDU specific components: There would be limitations to derive seismic fragility function for CANDU specific components using experience data obtained from conventional piping and components. Large uncertainties exist in the similarity between a) the CANDU specific components (e.g., the feeder and the Fuel Channel) and b) the conventional piping in terms of design features, degradations, failure mode and its location, loading conditions, operating conditions;
- Effect of degraded mechanisms of CANDU specific components: A DBE could occur at any time during the operating life of CANDU specific components (e.g., feeders, fuel channels) such that a bounding condition predicted at the end of their design life needs to be used to demonstrate their seismic capacity. Since the condition of a given component at its end of operating life is affected by several parameters such as design features (e.g., pipe diameter, material property, supports), type of degradation mechanisms and their degradation rates (e.g., wall thinning at the tight radius bends, hydrogen embrittlement on pressure tube, radiation embrittlement on spacers), complex loading conditions (e.g., internal pressure, axial movement due to FC creep and axial thermal movement), and operating pressure and temperature, using the end of design life conditions for seismic qualification is more prudent;
- Underlying margins in SMA: The underlying assumptions and margins between 1) the EBSM and 2) the seismic design qualification are not identical. In particular, the seismic qualification as per the ASME Code is considered as Level 1 Defense-in-Depth (DiD) approach. Design margins in the ASME Code are intended to quantitatively demonstrate margins against uncertainties in key parameters (e.g., material, quality of manufacturing/fabrication, operating conditions, rate of degradations) affecting its structural integrity in a deterministic manner; and
- Uncertainty in fragility analysis: The fragility analysis could estimate the median seismic capability (fragility) of the component by demonstrating that an estimated Peak Ground Acceleration (PGA) for which the seismic response of a component/system exceeds the capacity resulting in failure. However, even though confidence level and failure probability numbers are produced by the probabilistic fragility approach, these quantitative probability statements shall always be considered together with their inherent uncertainties and the limits to the experience data base. Furthermore, the fragility analysis could not quantify seismically induced loads at a given location. The location-specific seismically induced loads (e.g., nozzle loads) should be used in the design of the CANDU specific components.

CONCLUSIONS

In Canada, the experience-based seismic methods (EBSMs) and SPRA have been used to evaluate both seismic Category A and seismic Category B SSCs as per CSA N289.1-08. The GIP and NARE, SMA, STERI and G- STERI, and EPRI approach for piping and tubing have been considered as the EBSM.

This paper reviews the history of the EBSMs to recognize the advantages and limitations of the EBSM by reviewing several relevant documents referred to in this paper. The results of this review indicate that seismic qualification using the EBSM could be a cost-effective method as an alternative approach when temporarily replacing components/equipment subject to obsolescence or when evaluating an existing non-qualified SSC to temporarily replace an existing qualified SSC. However, there is a weakness with using EBSM to explicitly demonstrate equipment functionality of key SSCs because the experience database used in the EBSM did not sufficiently incorporate success data providing records of sustaining equipment functionality during and following past earthquakes. In addition, it should be noted that the underlying assumptions and margins between 1) the SMA and 2) the seismic design qualification are not identical. Hence, this paper proposes that the following elements be considered and addressed when the EBSM is used in the seismic evaluation of the SSCs:

- Determination of a seismic demand by the consideration of the amplification of a peak acceleration in an in-structure response (e.g., a third level response spectra);

- Use of a bounding condition predicted at the end of their design life by the consideration of several parameters affecting the condition of a given SSC for end of life seismic qualification;
- Differences of the underlying assumptions and margins between 1) the SMA/SPRA and 2) the seismic design qualification as per ASME Code;
- Separate assessment for pressure boundary SSCs to assure functionality against pressure boundary component leaks and their operability (e.g., valves, pumps, valve shaft binding etc.) during and after the DBE event, should be provided for design documentation and record keeping;
- An additional assessment as per modern codes and standards (e.g., ASME OME-1-2017, IEEE 344-2020, CSA N289.1-18) to supplement or/and complement the limitations of the EBSM;
- Limitation of using the experience data to qualify the CANDU specific components;
- Verification process through an independent peer review; and
- Limitation of using the EBSM to SSCs in Small Modular Reactors (SMRs) due to the lack of OPerating EXperience (OPEX) of the SMRs.

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DISCLAIMER

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