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OVERVIEW OF SEISMIC ISSUES IN DC AND COL APPLICATION REVIEWS

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ABSTRACT

A new process for licensing nuclear power plants was established by the U.S. Nuclear regulatory Commission (NRC) under Title 10 of Code of Federal Regulation Part 52 (10 CFR Part 52), which provides requirements for early site permits (ESP), standard design certification (DC) and combined license (COL) applications. In this process, an application for a COL may incorporate by reference (IBR) a DC, an ESP, both or neither. This approach allows for early resolution of safety and environmental issues. The safety issues resolved by DCs and ESPs processes are not reconsidered during a COL review. However, a COL application that IBRs a DC needs to demonstrate pertinent site specific parameters are confined within the safety envelopes established by the DC. This paper provides an overview of site parameters related to seismic designs and associated seismic issues encountered in DC and COL application reviews using the 10 CFR Part 52 process.

Since the seismic design and analysis of nuclear power plant (NPP) structures, systems and components (SSC) are treated in DCs as a bounding to future potential sites, the design ground motions and associated site parameters are often conservatively specified, representing envelopes of site-specific seismic hazards and parameters. In order for a COL applicant to IBR a DC, it needs to demonstrate the site-specific hazard in terms of ground motion response spectra (GMRS) is enveloped by the certified design response spectra (CSDRS) of the DC. It also needs to demonstrate that the site-specific seismic parameters such as foundation bearing capacities, soil profiles, etc. are confined within the site parameter envelopes established by the DC. For the non-certified portion of the plant SSCs, the seismic design and analysis should be performed with respect to the site-specific GMRS and associated site parameters.

This paper discusses the seismic issues which are encountered in the safety reviews of DC and COL applications. Practical issues dealing with comparing site-specific features to the standard designs and lessons learned are also discussed.

INTRODUCTION

General Design Criterion (GDC) 2 of 10 CFR Part 50[1], Appendix A, requires in part that structures, systems, and components (SSCs) important to safety be designed to withstand the effects of earthquakes without loss of capability to perform their safety functions. The earthquake threshold which safety-related SSCs are designed against is defined as the safe shutdown earthquake (SSE) established in 10 CFR Part 50, Appendix S and 10 CFR Part 100[2], Appendix A. The SSE is established based on the evaluation of the maximum earthquake potential with the maximum induced vibratory ground motion for which safety-related SSCs are designed to remain functional. Appendix S to Part 50 further defines an operating basis earthquake (OBE) following which the safety-related SSCs should remain function for continued operation of the reactor. Per 10 CFR Part 20[3] and Appendix S to Part 50 requirements, instrumentations must also be provided so that the seismic response of NPP features important to safety can be promptly evaluated after an earthquake and shutdown of the plant is performed if the vibratory ground motion exceeds that of OBE. Detailed guidance for seismic instrumentation and evaluation is provided in Regulatory Guides (RG) 1.12[4] and 1.166[5].

The licensing process for the existing power reactors was based on Part 50 which issues an operating license in accordance with the Atomic Energy Act (AEA) of 1954[6], as amended, Section 185a, after the plant construction was completed. The NPP seismic design and analysis were performed based on site-specific geological, seismological, geophysical and geotechnical information. SSE was typically specified at the free-field surface and was determined in terms of the site hazard-based peak ground acceleration associated with a prescribed broad-band, smooth design response spectrum such as RG 1.60 spectra[7]. The corresponding seismic design and analysis typically followed the design acceptance criteria of the NRC Standard Review Plan (SRP)[8], which the NRC staff uses for performing safety reviews.

In contrast to the Part 50 licensing process, the process for new reactor licensing established under Title 10 of Code of Federal Regulation Part 52 (10 CFR Part 52)[9] provides requirements for granting combined license (COL) which can incorporate by reference (IBR) early site permits (ESP) and standard design certification (DC). Since Part 52 permits a COL application to IBR a DC, an ESP, both or neither, the licensing process allows for early resolution of safety and environmental issues. The safety issues resolved by DCs and ESPs processes will not be revisited during a COL review. However, a COL application that IBRs a DC needs to demonstrate pertinent site-specific parameters are confined within the envelopes established by the DC. The application of the Part 52 licensing process to new reactor applications also raised new seismic issues which require careful considerations by both the industry and the NRC staff. A clear and unambiguous understanding of these issues will facilitate the staff safety reviews of applications. This paper provides an overview of site parameters related to seismic designs and discuss associated seismic issues encountered in DC and COL application reviews using the 10 CFR Part 52 process.

BACKGROUND

In the early 1970's, the seismic designs of nuclear power plants were based on the concept of the safe shutdown earthquake (SSE), which was codified into the federal regulations with the publication, in December 1973, of Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," to 10 CFR Part 100, "Reactor Site Criteria." The NRC subsequently published a series of Regulatory Guides in support of Appendix A, including RG 1.60, "Design Response Spectra of Nuclear Power Reactors." The process for determining design seismic loads includes the site-specific investigation of local and regional seismology, geology and geotechnical engineering, and estimates the site-specific, hazard-based peak ground acceleration (PGA). The site-specific SSE is typically defined at the ground surface of the free-field (needed for seismic instrumentations in accordance with RGs 1.12 and 1.166) as a broad-band, smooth spectrum such as RG 1.60 spectra, anchoring to PGA. For surface founded structures, the process for applying the SSE as the seismic input is straightforward. However, when the structure is embedded into the ground, the SSE needs to be de-convolved to the foundation level for the seismic analysis. For shallow embedded foundations, the SSE could be conservatively applied at the base of the foundation without further reduction (neglecting embedment effect) or estimates the motion at the foundation basemat consistent with the surface SSE input motion; this is typically done using the convolution analysis such as SHAKE. However, convolving down (de-convolution) the surface motion characterized with a broad band smooth spectrum always results in unwanted spectral reduction at the soil column frequency. Therefore, the de-convolution is usually not advisable in developing the foundation level seismic input. The standard review plan (SRP) limits the reduction to no more than 40% of the surface SSE motion and also the SSE should be applied at the outcrop of upmost competent material in the free-field for seismic analyses of structures.

The NRC later published RG 1.165[10] to provide a hazard-consistent approach for determining the SSE ground motions. This approach incorporated the state-of-the art technology at the time and applied the probabilistic seismic hazard analysis (PSHA) method in determining site-specific SSE ground motions. RG 1.165 stipulates that a PSHA can be used as a means to determine the SSE and to account for uncertainties in the seismological and geological evaluations arising from fault geometry, rupture characteristics, seismicity and ground motion modeling. However, the RG relies on a "reference probability" as that probability of exceeding, on an annual basis, the SSE at future NPP sites. This reference probability of 10-5/yr is calculated based on the distribution of median probabilities of exceeding the SSE at 29 sites in the Eastern United States (EUS) (NUREG-1488). Subsequent to the trial use of RG 1.165 by the nuclear industry in early site permit (ESP) applications, the industry expressed concerns that the use of the guideline, especially the selection of the reference probability, may lead to regulatory and technical instability in the licensing of future plants. As mentioned above, the reference probability is computed as the median probability obtained from the distribution of median probabilities of exceeding the SSE at 29 sites in the EUS. The sites selected were intended to represent relatively recent designs that used RG 1.60 spectra or similar as their design bases. The purpose is to ensure an adequate level of conservatism in determining the SSE consistent with recent licensing decisions. However, RG 1.165 also requires that PSHAs for the 29 sites need to be updated at periodic intervals; as a result, the computed reference probability may differ from 10-5/yr if substantial changes to only a few PSHAs occur. Therefore, seismic activity in the vicinity of one (or a few sites) will result in changes in the SSE estimates at a site which may be located at a remote distance from the affected site (or sites). This could result in additional expenditure and resource spending for a future site for potential changes to the SSE, even though no changes of seismic activity at the site has been identified.

In order to address the seismic issues associated with the Part 52 licensing process for new reactors, the industry initiated the new reactor seismic issues resolution program to work and to coordinate its effort with the NRC to address issues pertaining to the seismic designs of new reactors. Two critical issues were addressed: 1) the implementation of the performance-based approach for developing site-specific ground motions, and 2) evaluation methodology for high frequency ground effects.

The performance-based approach for developing site-specific ground motions was implemented through the publication of RG 1.208[11] which provides a method for developing risk-consistent site-specific ground motions based on PSHA results. The performance-based approach with stipulated target performance goal is consistent with the risk goals described in the 1986 Commission's policy statement for the Operations of Nuclear Power Plants (51 FR 28044). It also avoided the technical and regulatory issues associated with the application of RG 1.165. Currently, majority of COL applications developed site-specific ground motions based on the performance-based approach described in RG 1.208.

To address the high frequency seismic issues in DC and COL applications, the staff developed an Interim Staff Guidance (ISG) through holder participation, which described a process for assessing the high frequency ground motion impacts on seismic designs of new reactors. The ISG supplements the guidance provided in SRP Section 3.7.1 and RG 1.206[12] to provide the staff's expectations consistent with the requirements of 10 CFR Part 52.

In addition to issues related to design basis seismic analyses, 10 CFR Part 52.47 requires design-specific probabilistic risk assessment (PRA) for standard designs of nuclear power plants. The design-specific PRA includes both internal and external events. Since a fully developed seismic PRA would require a specific site with PSHA results, it would not be practical to implement such process for DC which typically relies on bounding approaches for determining seismic loads. To this end, the NRC staff via SECY-93-087[13] proposed and the Commission approved in Staff Requirement Memorandum (SRM) a PRA-based seismic margin assessment (SMA) approach. The PRA-based SMA determines sequence-level high confidence, low probability of failures (HCLPF) for all seismic sequences leading to core damage or containment failures up to approximately 1.67 times the ground motion of the design basis SSE.

In the next section, an overview of seismic issues related to design-basis seismic analysis and seismic margin assessment will be provided in light of the Part 52 licensing process. Discussions are focused on the treatment of seismic design issues in standard designs and site-specific seismic analyses in COL applications incorporating DCs by reference. Discussions are also provided with respect to site response and soil-structure interaction (SSI) analyses consistent with the target performance goal.

OVERVIEW OF SEISMIC ISSUES AND DISCUSSIONS

Two categories of seismic issues need to be addressed under the Part 52 licensing process: design-basis seismic analysis and seismic margin assessment. The Part 52 process involves DCs associated with standard designs and COLs which apply standard designs to particular sites. For seismic designs, DCs typically employ bounding approaches toward seismic designs in which site parameters are selected to envelope potential future sites for the design. A COL application incorporating by reference (IBR) a standard design is required under Part 52 to demonstrate that the site-specific parameters are enveloped by the respective DC; therefore, the plant if designed and built in accordance with the DC will operate safely. Since the site-specific seismic features for a particular site are often complex, demonstration of the site-specific parameters within the bound of the respective DC is not a straightforward process. Although SRP provides review guidance, a recently published ISG provides an implementation of the demonstration process. The aspects of consistency issues in site response and respective SSI analysis are also discussed.

Certified Seismic Design Response Spectra (CSDRS)

CSDRS are site-independent seismic design response spectra as approved under Subpart B of 10 CFR Part 52, and are applied as the seismic design response spectra for approved certified standard designs of power plants. CSDRS are typically selected as broad-band, smooth spectra which envelop the SSEs for potential future sites for the design. In accordance with Appendix S of Part 50, CSDRS should be defined at the free-field surface. However, for SSI analyses, CSDRS are typically conservatively applied at the foundation level free-field outcrop. Advantages of this treatment are 1) the Par 50 Appendix S requirement for the minimum foundation input of 0.1g with appropriate spectra is met and 2) avoid the difficulties associated with de-convolution analyses for developing the foundation level seismic input.

The SSI analysis for standard designs can then be carried out either accounting for the actual embedment or assuming a surface founded structures (truncated soil columns). If embedded structures are analyzed as surface structures, the site response analysis should account for the full soil column effect before truncated at the foundation level. Thus, the resulting truncated soil column includes the effect of the soils being removed for SSI analysis. To ensure the seismic analysis for the standard design is applicable to a particular site, the respective COL application should show that the site-specific seismic parameters are bounded by the range of values specified for the standard design, therefore, assuring safety of the seismic design for the standard plant to be built at this particular site.

Ground Motion Response Spectra (GMRS)

GMRS are site-specific response spectra determined by COLs using performance-based probabilistic methodology. RG 1.208 describes a performance-based methodology for developing GMRS with a site-response analysis using a set of randomized soil profiles. The set of soil profiles (the use of 60 profiles are deemed sufficient) are selected to capture the variability of the soil response at a given site. The site response analysis is then carried out by convolving the PSHA calculated mean UHRS for the generic rock (with shear wave velocity (Vs) of 9200 ft/s) through the set of randomized soil profiles to determine the soil amplifications at the ground surface. Therefore, the resulting surface mean spectra or GMRS will maintain the same hazard level as the generic rock UHRS. Similar mean spectra can also be established at the foundation level, referred to as foundation input response spectra (FIRS) which are typically used as input to SSI analyses. The calculated FIRS and GMRS are consistent in the sense that both share the same hazard value as the generic rock UHRS.

Various opinions exit regarding where the GMRS should be defined: free-field surface vs. upmost competent material. First, as discussed in the background section of this paper, the competent material was introduced to overcome the difficulties associated with de-convolution analysis when SSE is specified at the free-field surface; therefore, SSE should be anchored at the upmost competent material as outcrop motion for seismic analysis. Since only convolution analyses are involved when applying RG 1.208 method, the issues associated with deconvolutions do not apply to the upward convolved free-field analysis. Second, GMRS is designated for establishing SSE/OBE and therefore should be unique for the given site. As required by Appendix S of Part 50, SSE should be defined at the free-field surface for operating the plant and for seismic instrumentation as described in RGs 1.12 and 1.166. Lastly, the GMRS-consistent FIRS should be used to meet the minimum foundation input motions required by Appendix S. In the event that the FIRS does satisfy this requirement, an alternate approach based on the minimum foundation seismic threshold should be devised to establish the foundation input motion for seismic analyses of structures; however, the GMRS established at the free-field surface should not be modified since it provides the basis for defining SSE for the plant site. Based on the discussion, it is the writers' opinion that the GMRS should be established at the free-field ground surface and GMRS-consistent FIRS should be used for seismic analyses of structures.

Consistent Site and SSI analyses

The site response analysis as described in RG 1.208 involves a probabilistic process. Although theoretically the same probabilistic approach could be extended to SSI, practical implementation will have unquantified impacts on the final seismic results. Site response analyses typically use 1-D shear column models which have very predictable vibration modes when randomized properties are utilized. However, the same randomized process when applied to a structure may potentially create distorted, unrealistic structural vibration modes, and may even result in numerically unstable structural configurations. Therefore, it may not be advisable to perform probabilistic SSI unless adequate correlations between the randomized structural properties can be established and properly implemented.

Typical seismic design process involves deterministic SSI analyses which are based on three soil columns with mean, mean plus sigma and mean minus sigma soil properties (sigma represents one standard deviation). The resulting in-structure response spectra (ISRS) are enveloped and broaden for use in the seismic design. Much discussion had been made between the staff and the industry with respect to the implementation of a consistent site and SSI process such that the performance-based approach is preserved. Two issues are discussed herein. The first issue is related to site-specific SSI analysis, and the second issue pertains to COL demonstrating the site-specific seismic demands being enveloped by the respective DC.

With respect to SSI analyses, the soil profiles and seismic input should be consistent with the respective probabilistic site response analysis. To this end, the three soil profiles typically employed in the deterministic SSI should correspond to the mean, mean plus/minus one standard deviation soil columns resulting from the probabilistic site response analysis. It should keep in mind that three soil profiles representing mean and upper and lower bound should maintain the minimum coefficient of variation of 0.5 on soil shear modules. FIRS is recommended as the seismic input to the SSI analysis. Should FIRS be less than 0.1g then an appropriate spectra (such as RG 1.60 spectra) anchored to 0.1g should be used. If an embedded structure is analyzed as the surface structure, the site response analysis should be performed for the entire soil column. The resulting strain-compatible profiles are then truncated at the foundation depth. The FIRS is developed by convolving the generic rock UHRS through the set of truncated soil profiles to obtain the surface response. Note that the soil properties need not be degraded again in the truncated site response analysis.

Regarding the COL demonstrating site-specific seismic demands being enveloped by the respective DC, it is important that consistency is maintained with respect to assumptions and modeling considerations between COL and DC. If the seismic analysis is based on a truncated soil profiles, then the respective COL should utilize the same configuration for making comparisons. Consistency in assumptions in site and SSI analyses between COL and DC will adequately determine whether the seismic demands for the COL site are bounded by the respective DC.

Incorporation by Reference (IBR) of DC Seismic Designs by COL

DCs provide seismic designs for standard plants, based on bounding the potential future sites. A COL site can build a standard plant through incorporating the respective DC by reference. The COL also needs to address site-specific design issues for the portion of the proposed plant that is outside of the DC space. In accordance with the Part 52 licensing process, the COL application will demonstrate the site seismic parameter and ground motions are encompassed by the values established by the respective DC.

In addition to the issues related to consistent site and SSI response analyses discussed above, a process was also provided by the staff ISG [14] to provide guidance for systematic assessment of site-specific seismic evaluations provided in COL applications incorporating standard designs by reference. Following the ISG will ensure the SSCs in the DC and COL spaces be adequately designed and operated in accordance with the NRC regulations.

PRA-based Seismic Margin Assessment (SMA)

To meet 10 CFR Part 52.47 for design-specific PRA for standard designs of nuclear power plants, SECY-93-087 proposed and the Commission approved in Staff Requirement Memorandum (SRM) a PRA-based seismic margin assessment (SMA) approach. The PRA-based SMA uses the seismic sequences which are typically established in a fully developed seismic PRA. The difference between the seismic PRA and PRA-base SMA is that the seismic PRA quantifies the risk contribution by convolving sequence-level fragility with the site-specific hazard while the PRA-base SMA determines sequence-level HCLPF for all seismic sequences leading to core damage or containment failures up to approximately 1.67 times the ground motion of the design basis SSE.

The distinctions between the PRA-based SMA and the conventional SMA methodologies (the NRC method [15] and EPRI method [16]) developed for IPEEE program should be clearly recognized. First, the conventional SMA methods were targeted at the existing plant with a specific site with fully developed ground motion characteristics which is not available for standard designs. Second, with the operating plants, the as-designed and as-built information, as well as operating experiences are available that the conventional SMA can rely on for screening structures, systems and components (SSC), none of which are afforded for the standard designs. Without these site and plant specific information, the PRA-based SMA relies on a review-level earthquake (RLE) determined by 1.67 times the ground motion of the design basis SSE rather than the median-centered site-specific spectra utilized by the conventional SMA. Furthermore, PRA-based SMA evaluates the sequence-level HCLPF for all seismic sequences leading to core damage or containment failures, as opposed to the conventional SMAs relying on evaluations of either success paths or limited failure sequences.

It should also be understood that the PRA-based SMA performed for DCs and associated COL holder commitments should only be relied upon to demonstrate the seismic margin for the standard designs, and for the detailed seismic risk insights, fully developed seismic PRAs will be performed by COL holders before the loading of initial fuels and subsequent periodic updates as required by 10 CFR 50.71(h)(1) and (2).

CONCLUSIONS

This paper provided an overview of the 10 CFR Part 52 process for DC and COL applications with respect to seismic designs and margin issues. Specific seismic issues were identified pertaining to standard designs and the design-centered COL applications which IBR the respective DCs. Detailed discussions of encountered seismic issues were provided with respect to: CSDRS, GMRS, consistent site and SSI analyses, the IBR process by COLs, as well as the PRA-based SMA evaluations. The insights and discussions of the seismic issues as provided in this paper should provide clarifications of seismic analyses related to DC and COL applications and assist in the review efforts of respective DC and COL applications.

DISCLAIMER NOTICE

This paper was prepared by staff of the U.S. Nuclear Regulatory Commission (NRC). It may present information that does not currently represent an agreed upon NRC staff position. The findings and opinions expressed in this paper are those of the authors, and do not necessarily reflect the views of the NRC.

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