Transactions, **SMiRT-26**
Berlin/Potsdam, Germany, July 10-15, 2022
Division VII

SEISMIC EVALUATION OF CLIFF EDGE EFFECTS FOR THE ICC FUNCTION AT RINGHALS NPP

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ABSTRACT

The main Post-Fukushima action in Sweden has been the implementation of an Independent Core Cooling function. The criteria to be taken into account include consideration of extreme external hazards. A $1x10^{-6}$ seismic hazard is to be considered per the Swedish Radiation Safety Authority. Inclusion of this extreme hazard ensures no cliff edge effects exist beyond the standard seismic qualification ($1x10^{-5}$ seismic hazard level). The evaluation approach used by Ringhals, for the beyond design basis evaluation is presented.

INDEPENDENT CORE COOLING FUNCTION

The main Post-Fukushima action in Sweden has been the implementation of an Independent Core Cooling (ICC) function. The following criteria have been taken into account:

- Extended Loss of AC Power for at least 72 hours
- Loss of normal access to Ultimate Heat Sink (LUHS) for at least 72 hours
- Extreme external hazards (a frequency of 10^{-6}/year to be taken into account)
- Independency requirements
- Physical protection (man-made events)

In order to meet these criteria, a fixed solution was required by the regulator. A separate building designed to manage extreme external hazards was erected for each unit. This building contains enough water for 72 hours. Two tanks are provided, one for the steam generators and one for make-up of the reactor coolant system. Each tank has external connections to facilitate refilling, should the need arise after the stipulated 72 hours. The pumps are driven by a diesel engine or by electrical motor that receives power from a diesel generator located inside this new building. Diesel storage is also provided that last at least 72 hours with the possibility to refill if needed.

Figure 1 below illustrates a schematic view of the installation of the independent feed water system that connects to current auxiliary feedwater system outside of the containment. All existing parts credited for the DEC (Design Extension Condition) scenarios have been evaluated to meet the same criteria as the new installations. For the new equipment, a single failure is not considered.

To strengthen the fuel pool cooling, a separate pump can provide water to the pool with the Feed and Boil principle. Upon loss of all electrical power the current cooling system will stop, and the temperature will rise until boiling starts. This pump will provide make-up water to ensure the continuous cooling of the fuel.

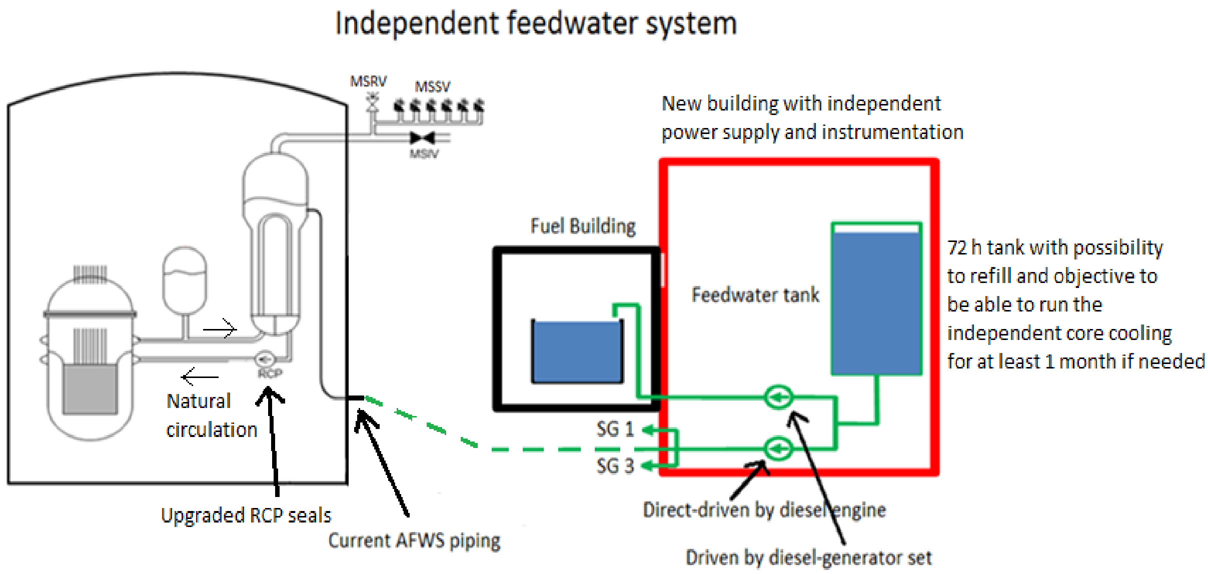

Figure 1. The independent feed water system including water supply to the spent fuel pool

For the independent volume control system (see Figure 2), the same principles are valid, but both pumps are driven by an electrical motor that receives power from the diesel generator. One pump is a displacement pump that provides water with high pressure to the reactor coolant system (RCS) for make-up of shrinkage and small leakage. The other pump is a centrifugal pump that provides water if the event occurs during outages in Modes 5 and 6 when RCS is open to the containment atmosphere. The independent volume control system connects to the current safety injection system outside the containment.

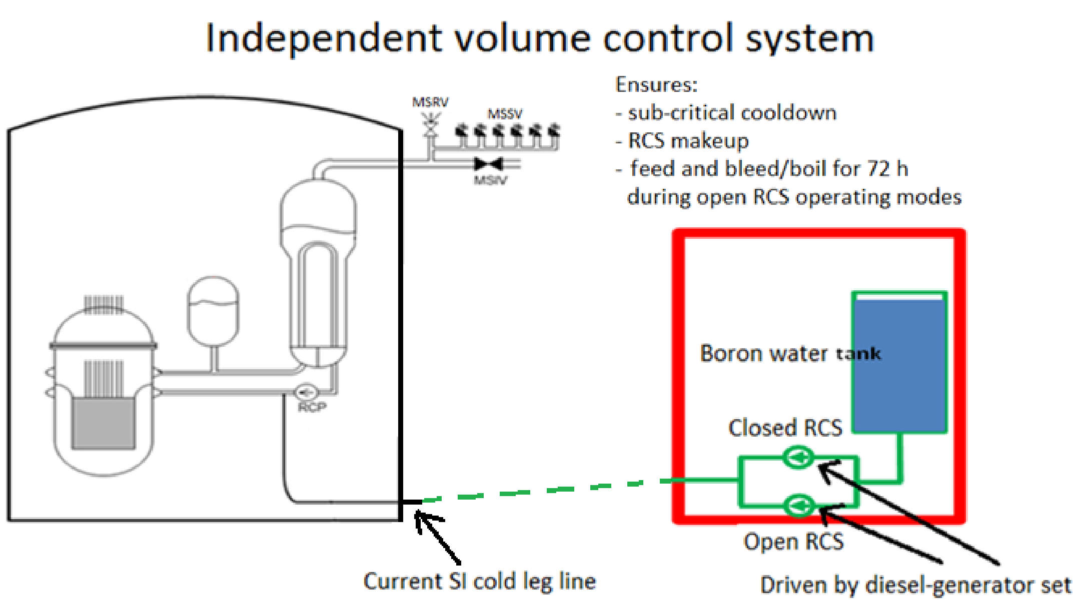

Figure 2. Schematic view of the independent volume control system

SEISMIC REQUIREMENTS RELATED TO ICC

The criteria that have been taken into account include consideration of extreme external hazards. A $1x10^{-6}$ seismic hazard is to be considered per the Swedish Radiation Safety Authority. According to a clarification from the regulatory body (SSM) the design values (seismic demand) can be increased by a factor 1,7 for evaluation of cliff edge effects. Inclusion of this extreme hazard ensures no cliff edge effects exist beyond the standard seismic qualification ($1x10^{-5}$ seismic hazard level).

The seismic requirements in Sweden (see Figure 3) used to demonstrate seismic adequacy of the ICC are applicable for both new and existing structures, systems, and components (SSCs) that are relied upon for ICC functionality.

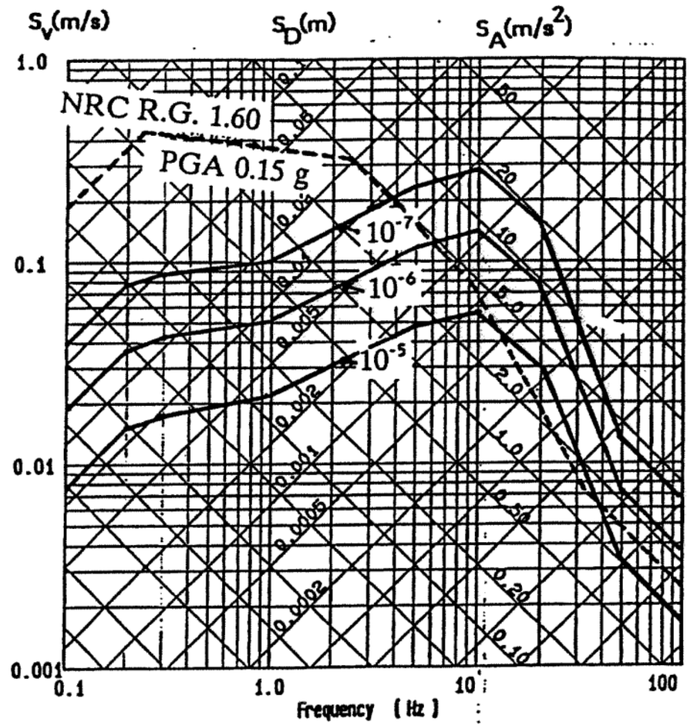

Figure 3. Comparison of the response spectra based on RG 1.60 scaled to PGA=0.15 g for horizontal acceleration and the Swedish hard rock envelope response spectra from SKI 92:3 for 10^{-5}, 10^{-6} and 10^{-7} annual events per site.

METHODS USED FOR EVALUATION OF CLIFF EDGE EFFECTS

Consideration of the 1×10^{-6} seismic hazard represents a significant increase over the standard 1×10^{-5} seismic hazard qualification level. This increased demand can present challenges in the qualification of existing ICC components if rigid adherence to standard design requirements is required. However, for the evaluation of cliff edge effects and consideration of the 1×10^{-6} seismic demand, SSM has accepted the use of more realistic evaluation methods and relaxed acceptance criteria.

The evaluation approach used by Ringhals, for the beyond design basis (BDB) evaluation, includes the aspects discussed in the following subsections.

HCLPF and $C_{10\%}$ Capacities

For a traditional seismic margin assessment, the conservative deterministic failure margin (CDFM) approach presented in EPRI NP-6041-SL is used to calculate the high confidence of low probability of failure (HCLPF) capacity of structures and components. The resulting HCLPF capacity that is calculated using the CDFM approach results in a 1% conditional probability of failure, equivalent to the typical design-basis performance objective of design codes.

The seismic demand utilized for the components within the ICC scope is a beyond-design-basis (BDB) demand. The BDB performance objective for these ICC components does not need to be the same as used for the design basis. As implemented at nuclear plants in the United States, a more appropriate measure of the capacity for beyond-design-basis events is the $C_{10\%}$ capacity, a 10% conditional probability of failure. The use of the $C_{10\%}$ approach recognizes that the same level of performance is not expected for the beyond-design-basis event as is for the design event itself. The development of the $C_{10\%}$ approach for use in US plants is documented further in Appendix H.5 of NEI 12-06, Diverse and Flexible Coping Strategies (FLEX) Implementation Guide.

The $C_{10\%}$ capacity can be estimated using a simple generic scale factor on the HCLPF capacity calculated using the CDFM approach. The HCLPF capacity represents a 1% conditional probability of failure of the component. As noted above, the $C_{10\%}$ capacity represents a 10% probability of failure. For a log-normally distributed component fragility, the HCLPF capacity is defined as:

$$HCLPF = A_m e^{(-2.326\,\beta_c)} \tag{1}$$

where A_m and β_c are the median capacity and composite variability, respectively.

The $C_{10\%}$ capacity is defined as:

$$C_{10\%} = A_m e^{(-1.282\,\beta_c)} \tag{2}$$

The $C_{10\%}$ then results in an increase in capacity equal to:

$$\begin{aligned} C_{10\%}/HCLPF &= A_m e^{(-1.282\,\beta_c)} / A_m e^{(-2.326\,\beta_c)} \\ C_{10\%}/HCLPF &= e^{[-1.282\,-\,(\,-2.326)]\beta_c} = e^{1.044\beta_c} \end{aligned} \tag{3}$$

Per Table 6-2 of the EPRI *Seismic Evaluation Guidance Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic*, Report 1025827, a generic composite variability, βc, can be estimated as 0.35.

Considering this variability, the $C_{10\%}$ increases from the HCLPF by:

$$C_{10\%}/HCLPF = e^{1.044*0.35} = 1.44 \tag{4}$$

The $C_{10\%}$ capacity is then calculated as:

$$C_{10\%} = 1.44\, HCLPF \tag{5}$$

As noted in the SPID, the composite variability ranges from 0.30 to 0.45, so the use of 0.35 is likely a conservative lower bound. The other composite variability values, 0.40 and 0.45, would results in $C_{10\%}$ capacity increases over the HCLPF of 1.52 and 1.60 respectively.

Ground Motion Incoherence

The seismic response of a structure is not only dependent on the structure itself; it is also influenced by the soil supporting the structure. A fixed-base analysis does not consider the effects of the supporting soil and may likely provide a conservative representation of the seismic response. For design, this conservatism is acceptable, but for a beyond-design-basis type evaluation, the goal is to determine more realistic characterization of the capacities and demands and reduce the amount of conservatism where appropriate.

To provide a more realistic representation of the seismic response for Ringhals 3 and 4 Containment Building, ground motion incoherence (GMI) was considered in an updated response analysis to more accurately represent the effect of the supporting soil on the structure response. GMI is the horizontal spatial variation of the input ground motion over the foundation of a structure. EPRI 3002012994, *Seismic Fragility and Seismic Margin Guidance for Seismic Probabilistic Risk Assessments*, notes that GMI occurs due to:

- Random spatial variation: scattering of waves due to heterogeneous nature of the soil or rock at the locations of interest and along the propagation paths of the incident wave fields
- Wave passage effects: systematic spatial variation due to difference in arrival times of seismic waves across a foundation

Random spatial variation produces a more significant reduction in foundation motion than wave passage effects. Wave passage effects are smaller and it may be difficult to justify an adequate representation. Therefore, only random spatial variation is typically considered in a GMI assessment.

Incoherency effects primarily affect the high frequency response. Noticeable decreases in the foundation response typically begin around 10 Hz and become more significant as the frequency increases.

The soil properties beneath the structures determine the extent of GMI reduction. Previous studies at Ringhals indicate that Ringhals Units 3 and 4 are founded on homogenous bedrock. The reported shear wave velocity of the Ringhals rock tends to vary from about 2,900 m/s at the surface to 3,500 m/s at 2 km depth. The lower bound of the shear wave velocity, 2,900 m/sec, is judged to be appropriate for the characteristics of the hard rock beneath the Ringhals site. For the Ringhals rock site, Abrahamson’s 2007 Hard Rock coherency function is judged appropriate for use to characterize the GMI. An example of the response decreases due to incoherency are shown in Figure 4.

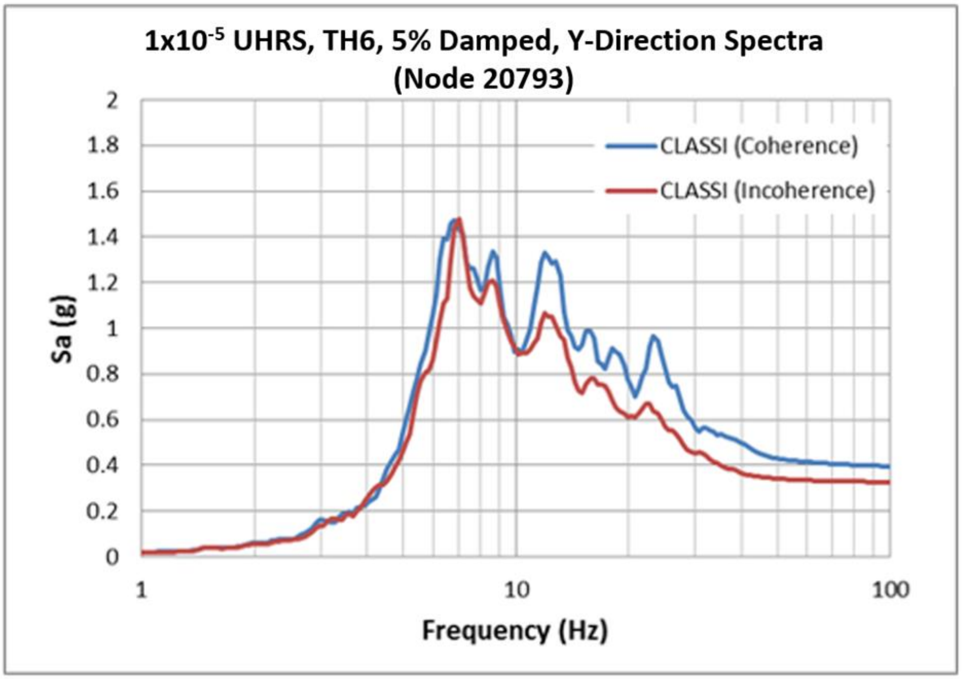

Figure 4. Example Comparison of Coherent and Incoherent Response at the Inner Containment Structure Slab at Elevation +115 m

Building Evaluations

For qualification of existing buildings, it is possible according to Eurocode, to use a behaviour factor to show that there is enough margin against cliff edge effects. Initially, this method was used for some buildings. However, due to a discussion of the concrete ductility, this method was not endorsed by the regulator. Following that, the design values have been increased by a factor 1.7 for evaluation of cliff edge effects for those buildings. Based on an agreement with the regulator more realistic material properties may be used in this evaluation. Hence, the concrete and reinforcement strengths used in the BDB evaluation of some structures were based on more realistic data (mean values) of material strengths.

Other credited buildings for the ICC function have been analysed with larger margins.

Seismic Interaction Walkdowns

The above detailed analytical approaches address the seismic response and seismic adequacy of specific ICC piping systems inside Containment. However, the analytical approaches do not consider any limitation in the capacity due to interaction effects from other adjacent components. Previous walkdowns have been performed at Ringhals, and no significant and credible interactions inside Containment were noted in the findings of these previous walkdowns. However, these conclusions are only valid at the response level considered during the walkdowns, the $1x10^{-5}$ uniform hazard response spectrum (UHRS).

Without additional confirmation, it is difficult to say with certainty that the conclusions from the previous walkdowns at the $1x10^{-5}$ seismic input also apply to the increased demand at the $1x10^{-6}$ input. At the higher $1x10^{-6}$ demand levels, accelerations increase, displacements of components increase, and anchorage demands increase. Due to these increased demands and limited knowledge of interaction potential above the documented $1x10^{-5}$ demand level, a focused seismic interaction walkdown of the piping systems was performed within the R3 and R4 Containment Building to identify and document any interaction issues at the $1x10^{-6}$ demand level.

The scope of the walkdowns included multiple systems throughout the Containment Building, including the Reactor Cooling, Residual Heat Removal, Safety Injection, Auxiliary Feedwater, Main Steam, and other various systems utilized in the ICCS.

The objective of the walkdowns were to:

- Verify if the conclusions from the previous $1x10^{-5}$ demand walkdowns were still valid for the $1x10^{-6}$ demand level.
- Identify equipment or structures that are not included in the ICCS but whose structural failure may impact the nearby ICCS components (i.e., seismic interaction concerns).
- Document the walkdown observations.

The methodology used in the walkdown was based on the seismic walkdown methods as described in EPRI NP-6041-SL. Since the objective of the walkdown was to identify seismic interaction issues at a higher demand level, the aspects of EPRI NP-6041-SL concerning seismic interactions served as the basis for the walkdown approach.

The EPRI NP-6041-SL guidance states that 100% walk-by of all components is not necessary for equipment classes that have “excessively large numbers of like elements,” which include distribution systems (piping, cable trays, conduit, and HVAC ducting). To accomplish an efficient review of the systems within the scope, the Seismic Review Team (SRT) performed walkdowns for these items on an area basis, which is similar to the sampling approach described in Appendix D to EPRI NP-6041-SL. The objective of an area walkdown is not to focus the observations on a single component but rather to identify any outliers or representative cases over a large area or along a distribution system that could potentially impact the systems in the scope.

For systems that are similar for all three loops of the Primary System, a more detailed area walkdown was performed for one loop. Briefer similarity walk-bys were performed for the two similar locations with a focus on identifying any unique differences from the initial detailed area walkdown.

Overall, the SRT observed that the ICCS components are generally well supported within the Ringhals 3 and 4 Containment Buildings and were free from interaction concerns. For the systems included in the walkdown, they are, for the most part, free from interaction issues up to and including the $1x10^{-6}$ seismic demand.

There were a small number of non-significant interaction outliers observed during the walkdown of Ringhals 3 and 4 Containment. Though not significant, outliers were resolved by further evaluation or modification to remove their outlier status.

Seismic Qualification of New Equipment in ICC

Seismic qualification of components within the ICC system was performed by test, by analysis, and by earthquake experience. With a wide range of evaluation approaches available for the seismic qualification of the ICC components, there is flexibility to select the most appropriate evaluation method that will result in an efficient and realistic seismic evaluation.

New components (pumps and diesel generators) were typically seismically qualified using the Seismic Qualification Utility Group (SQUG) New and Replacement Equipment (NARE) Guidelines. The purpose of the NARE Guidelines is to provide guidance on the use of seismic experience data in accordance with the rules of the SQUG GIP for performing seismic adequacy determinations of new and replacement equipment and parts for nuclear power plants.

For these new components, the seismic adequacy was assessed using the SQUG seismic equipment experience database. The inclusion rules and caveats were reviewed to assess the applicability of the experience database for the seismic adequacy of the components. The components were found to be covered by the caveats of the equipment class. Therefore, their functional capacity was characterized by the extended HCLPF Reference Spectrum from EPRI TR-1019200. As shown in Figure 5, The 5% damped horizontal $1x10^{-6}$ UHRS was then compared to the extended HCLPF Reference Spectrum to verify that the seismic capacity exceeds the seismic demand at the location of the components.

The NARE approach also relies on a walkdown to verify the caveats related to installation and interaction have been met. After installation of the pumps and surrounding components, confirmatory walkdowns were performed to verify the findings of the NARE evaluations. The NARE approach does not provide guidance for anchorage design. Design of the anchor was done outside of the NARE guidelines using traditional code-based design methodologies and the $1x10^{-6}$ seismic demand.

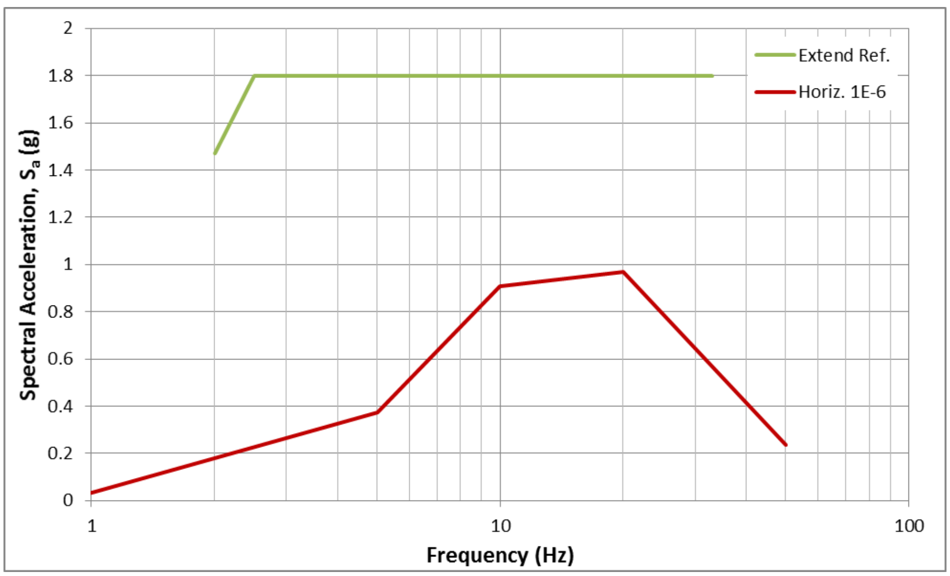

Figure 5. Comparison of Extended HCLPF Reference Spectrum and 5% Damped $1x10^{-6}$ UHRS Spectrum

CONCLUSION

Today the ICC function is approved by the regulator and implemented in the plant. However, some updated building analyses are still being reviewed by the regulator (those where the behaviour factor according to Eurocode was used).

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