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ENCLOSURE 4

SG&H Report 160268-R-01 Development of ASR Load Factors for Seismic Category I Structures (Including Containment) at Seabrook Station, Seabrook, NH Revision 0 (Seabrook FP# 101039)

REPORT APPROVAL SHEET

SIMPSON GUMPERTZ & HEGER

Engineering of Structures and Building Enclosures

Client: NextEra Energy **Project No.** 160268

Project: Susceptibility Evaluation of Category I Structures at Seabrook Station, Seabrook, NH

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Objective:

Develop ASR load factors for Seismic Category I structures at Seabrook consistent with the methodology of the original design basis documents.

Revision	Descriptions
0	Initial document

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EXECUTIVE SUMMARY

The Seabrook Updated Final Safety Analysis Report (UFSAR) and accompanying documents define the loading and acceptance criteria used to establish the licensing basis for Seabrook Station (Seabrook) [Ref. 1]. These documents do not address the effects of alkali-silica reactivity (ASR), which was identified to occur at Seabrook. ASR is a chemical reaction that can occur in concrete under certain conditions and cause cracking and expansion in unrestrained or partially restrained structures, systems, and components (SSCs). ASR can affect SSCs by creating additional loading and/or altering concrete material properties.

An examination of the design standards defined in the UFSAR and applicable to the original design of the Seismic Category I structures at Seabrook led to the development of ASR load factors. Factored ASR demands should be used in combination with other design loadings specified in UFSAR Tables 3.8-1, 3.8-14, and 3.8-16. NextEra Energy (NEE) investigated the effects of ASR on concrete material properties at Seabrook in a separate study [Ref. 4].

The primary conclusions of the review of the design basis documents and development of ASR load factors are as follows:

- The reinforced concrete Seismic Category I structures other than the Containment Building (CB) were designed in accordance with ACI 318-71 [Ref. 6]. The CB was designed in accordance with ASME Boiler and Pressure Vessel Code, Section III – Division 2, 1975 [Ref. 7]. The reinforced concrete Interior Containment Structures were designed in accordance with ACI 318-71.
- By using inspection data collected from more than twenty Seismic Category I structures throughout Seabrook and properly categorizing ASR-related cracking into four zones that correspond to parameters currently used in the Seabrook Structural Monitoring Program, load factors for ASR-related strains (demands) have been developed for use in evaluation of the Seismic Category I structures, including the CB, at Seabrook.
- For reinforced concrete Seismic Category I structures other than the CB, typically use ASR load factors of 2.0 for ASR effects in combinations with static loads, 1.7 for those with static plus wind loads, and 1.3 for those with static plus seismic loads.
  - Reduce the ASR load factors by 25% when ASR effects are combined with thermal or other transient loading.
  - Use an ASR load factor of 1.0 when ASR effects are combined with unusual loads, such as the safe-shutdown earthquake (SSE).
  - When ASR strains are greater than 0.05% (0.5 mm/m), the ASR load factors may be reduced by 20%, but shall not be taken as less than 1.0.
- For the CB, use an ASR load factor of 1.0 for all load combinations.

- For reinforced concrete Containment Internal Structures, use ASR load factors similar to those for reinforced concrete Seismic Category I structures other than the CB, except that ASR load factors developed for wind load combinations are not applicable.

- For initial screening evaluation of the CB, use conservative ASR strain demands based primarily on visual observations. If detailed analysis is needed, make CI measurements and reduce the conservatism in the ASR demands as permitted in Table 3.

- The conclusions reported herein apply to all Seismic Category I structures located at Seabrook when the severity of ASR is below the level at which material properties begin to degrade as established by the large-scale testing program conducted at FSEL [Ref. 4].

SYMBOLS AND NOTATIONS

ACI	American Concrete Institute
ASME	American Society of Mechanical Engineers
ASR	Alkali-Silica Reaction
B&PV	Boiler and Pressure Vessel
β	Reliability Index
CB	Containment Building
CCI	Combined Cracking Index
CEB	Containment Enclosure Building
CI	Crack Index
D	Dead Load
E_o	Operating Basis Earthquake
FSEL	Ferguson Structural Engineering Laboratory (The University of Texas at Austin)
H	Static Lateral Earth Pressure
H_e	Dynamic Lateral Earth Pressure
k_{ASR}	Ratio of Factored ASR Demand to Total Factored Demand
L	Live Load
NEE	NextEra Energy
OBE	Operating Basis Earthquake
RCE	Root Cause Evaluation
S_a	Loading from ASR
SGH	Simpson Gumpertz & Heger Inc.
SSC	Structure, System, and Component
SSE	Safe Shutdown Earthquake
UFSAR	Updated Final Safety Analysis Report

1. INTRODUCTION

Chapter 1 provides an introduction to the work presented in this document. Section 1.1 identifies the objective of the document. Section 1.2 provides background on the need for development of ASR load factors. Section 1.3 identifies the scope of work, and Section 1.4 defines several key terms used in this document.

1.1 Objective

The objective of this report is to summarize the development of appropriate load factors for alkali-silica reactivity (ASR) and their use in structural evaluation of all Seismic Category I structures, including the Containment Building (CB), at Seabrook.

1.2 Background

In accordance with the Seabrook UFSAR [Ref. 1], the reinforced concrete Seismic Category I structures other than the CB were designed in accordance with the strength design methodology of ACI 318-71 [Ref. 6]. The CB was designed in accordance with ASME Boiler and Pressure Vessel Code, Section III – Division 2, 1975 [Ref. 7]. The reinforced concrete Interior Containment Structures were designed in accordance with ACI 318-71.

Table 3.8-16 of the Seabrook UFSAR defines the load combinations used in the original design of the Seismic Category I structures other than the CB. Table 3.8-1 of the Seabrook UFSAR defines the load combinations used in the original design of the CB. Table 3.8-14 of the Seabrook UFSAR defines the load combinations used in the original design of the Interior Containment Structures. Neither of these tables includes effects of ASR, which NEE discovered to occur at Seabrook and can negatively affect a structure, system, or component (SSC) by creating additional loading, causing unwanted deformation, and altering concrete material properties.

The physical manifestation of ASR, in the form of cracking and effects of bulk/global deformation is documented and reviewed under the NEE-Seabrook Structural Monitoring Program. In 2014, NEE identified evidence of apparent movement of the Containment Enclosure Building (CEB) and prompted a Root Cause Evaluation (RCE) of apparent deformation of the CEB. The RCE determined that ASR was the prime contributor to global structural deformations.

ASR can create an external load and/or an internal load on an SSC. As an external load, ASR-induced expansion of concrete backfill outside of a structure may create pressures and/or deformations not anticipated in the original design basis. Internal expansion of reinforced concrete may produce cracking, deformation, and tension in steel reinforcement and compression in concrete not anticipated in the original design basis.

The effects of ASR on concrete material properties have been examined through a research and large-scale physical testing program conducted at the Ferguson Structural Engineering Laboratory (FSEL) at the University of Texas at Austin. Key findings from that effort are reported in Reference 4 and include the following:

- Combined Cracking Index (CCI) methodology, particularly the procedure used at Seabrook, provides a reasonable approximation of true engineering strain and is an acceptable methodology for monitoring in-plane expansion.
- Material properties and design code-based relationships such as shear strength of concrete, anchorage to concrete capacity, and performance of reinforcement lap splices, were not reduced in ASR-affected concrete with in-plane expansion levels significantly higher than those observed at Seabrook.

These conclusions support the use of CI/CCI in approximating in-plane expansion and the use of design basis properties and code-based strength relationships in evaluating the Seabrook structures for effects of ASR.

1.3 Scope

This report provides load factors for ASR to augment the original design basis load combinations defined in Tables 3.8-1, 3.8-14, and 3.8-16 of the Seabrook UFSAR to be used with appropriate acceptance criteria.

1.4 Key Terms and Definitions

The following paragraphs define technical terms used in this document to explain the development of ASR load factors.

1.4.1 Alkali-Silica Reactivity

Alkali-silica reactivity (ASR) is a chemical reaction between the alkali content contained in cement and reactive silica minerals contained in some concrete aggregates. The reaction produces a gel that swells if moisture is present. ASR can be identified through petrographic examination and is often indicated in service by random map cracking.

1.4.2 Cracking Index and Combined Cracking Index

The Cracking Index (CI) is a crack mapping process to quantitatively characterize the severity of cracking. It includes measurement and summation of crack widths along a set of perpendicular lines on the surface of a concrete element being investigated and then normalizing these values in each direction for comparison to other conditions. The Federal Highway Administration (FHWA) uses the CI method in conjunction with petrography to investigate deterioration of concrete elements. The Combined Cracking Index (CCI) is an alternative metric closely related to CI to express the severity of cracking by normalizing the cracking in both directions. A typical ASR-monitoring location produces two CI values and one CCI value.

CI and CCI at Seabrook are used to characterize the severity of cracking on concrete structures. Values are typically reported in mm/m. As noted in Reference 4, the CCI methodology provides a reasonable approximation of true engineering strain and is an acceptable methodology for monitoring in-plane expansion. Seabrook CI and CCI values are converted to % strain by dividing the values by 10, e.g., CCI = 1.0 mm/m = 0.1% strain.

1.4.3 ASR Severity Zones

ASR severity zones are four categories established to identify regions of a structure based on representative CI measurements of ASR cracking. Table 1 provides the limits of each zone. The lowest three zones (Zone I, Zone II, and Zone III) are established to align with the criteria for Tier 1: Acceptable with Deficiencies – Qualitative Monitoring Required, Tier 2: Acceptable with Deficiencies – Quantitative Monitoring and Trending Required, and Tier 3: Unacceptable – Structural Evaluation Required as defined in the Seabrook Structural Monitoring Program (SMP) [Ref. 3]. The fourth zone (Zone IV), which represents regions with the highest amount of ASR-related cracking, falls within the SMP Tier 3 criteria and is established herein to set the upper limit on Zone III for use in structural evaluation and development of ASR load factors. CI measurements below the lower limit of Zone I (< 0.1) imply a strain less than 0.01%, which is less than 5% of the yield strain of ASTM A615 Grade 60 reinforcement. These strains are judged to be negligible, and portions of the structure categorized into this zone are expected to meet the SMP Tier 1 – Acceptable criteria.

1.4.4 Reliability Index

Reliability Index (β) is a statistical metric often used in structural engineering to establish or evaluate the difference between strength and load. Reliability Index and limit state probability are inversely related, so a structure with a high reliability index has a low probability of failure. Reliability Index is defined as shown below.

$$\beta = \bar{Z}/\sigma_Z$$

Where Z is a function that defines the excess strength with respect to the combined load effect, and where $Z < 0$ represents structural deficiency. In this definition, $\bar{Z}$ and σ_Z are the mean and standard deviation of Z, respectively. For some probability distributions, such as normal and log-normal, a closed-form equation for β is known. In cases where a closed-form equation is not known, β may be computed using Monte Carlo simulation, in which a statistically significant number of sample strength and load values are randomly generated, and the probability of failure and reliability index can be computed directly.

1.5 Revision History

1.5.1 Revision 0

- Initial document

2. DEVELOPMENT OF ASR LOAD FACTORS FOR SEISMIC CATEGORY I STRUCTURES OTHER THAN CONTAINMENT

Chapter 2 describes the development of ASR load factors for the reinforced concrete Seismic Category I structures other than the CB. Section 2.1 identifies the approach taken to establish the ASR load factors. Section 2.2 summarizes the results of a review of relevant documents. Section 2.3 describes the methodology used to develop the ASR load factors. Section 2.4 identifies assumptions incorporated into the methodology and provides justification for use, and Section 2.5 summarizes the key results of the study.

2.1 Approach to Establish ASR Loading

Efforts to develop ASR load factors for reinforced concrete Seismic Category I structures other than the Containment Building should result in values that maintain the reliability levels that were found [Ref. 2] to be inherent in the original design code, ACI 318-71 [Ref. 6]. Although the introduction of ASR loads represents an increase to the total demands acting on the structures, it is still possible to maintain the code intended reliability indices since the original design usually is based on conservative assumptions and analyses, and as a result provides an additional margin compared to code requirements. To achieve this goal, NEE took the following approach:

- Perform a critical review of ACI 318-71 and associated documents to establish the reliability inherent in the original design codes.
- Aggregate the inspection data showing the presence and severity of ASR throughout the facility and characterize it in a manner useful for structural evaluation.
- Account for the variety and complexity of the load combinations stated in the design basis documents.

2.2 Results of Document Review

The literature review into the basis of the ACI 318-71 load combinations identified a document by Ellingwood et al. [Ref. 2] that explored the basis for the construction of load combinations and then back-calculated reliability indices for pre-1980s design codes. Ellingwood et al. found that the reliability indices implied in pre-1980s design codes were, on average, 3.0, 2.5, and 1.75 for static, wind, and seismic load combinations, respectively. Additionally, Reference 2 is the basis for the current probability-based limit state design requirements in ASCE/SEI 7 [Ref. 11], ACI 318 [Ref. 12], and ANSI/AISC 360 [Ref. 13].

Also included in Ellingwood et al. are key statistical parameters used in the development of ASR load factors. Ellingwood et al. define the ratio of mean to nominal resistance ($\overline{R}/R_n$) as 1.05 for flexure and 1.09 for shear. The authors also define the coefficient of variation of resistance (V_R) as 0.11 for flexure and 0.17 for shear. These parameters are included in Table 4 of SGH Document 160268-CA-01 [Ref. 8] as part of a summary of computation inputs used to develop ASR load factors for reinforced concrete Seismic Category I structures other than the CB.

2.3 Methodology

2.3.1 ASR Categorization

Based on findings from the research performed at FSEL [Ref. 4] and elsewhere [Ref. 5], CI measurement data will be used to establish the distribution and severity of ASR in each of the reinforced concrete structures at Seabrook. The data will be reviewed to define ASR regions on each structure, with each region being represented by a mean ASR CI value for each in-plane direction. Each region will be categorized into one of the four ASR severity zones shown in Table 1.

2.3.2 Development of ASR Load Factors

The most recent set of CI measurements at each available monitoring grid as of 1 April 2016 is considered to develop ASR load factors. The data come from 108 grids (total of 216 data sets, when considering two orthogonal directions), which are located on more than twenty different structures or components at Seabrook. The data was collected on a range of different structural elements, such as walls, floors, roofs, etc., and incorporate both interior and exterior exposures. Table A1 of Appendix A provides a summary of each of the grids that includes the structure, exposure, date of latest measurement, and CI values as of 1 April 2016.

Log-normal probability distributions to represent the data within each ASR severity zone identified in Table 1 are developed. The distributions were fit to match the mean and standard deviation of the data within each zone and were adjusted to provide conservatism. Section 4.1 of SGH Document 160268-CA-01 [Ref. 8] provides technical details of this process.

With the ASR effects now characterized, the next step is to account for the variability in the ASR and non-ASR demands, both of which vary between structures and within a structure. The ACI 318-71 design code uses factored load combination demands for non-ASR loads. Therefore, the ASR load should also have a load factor to be added to the original load combination groups.

To address the variability in the factored loading, two load configurations are developed – one that concentrates the non-ASR demand in lateral loads and another more evenly between lateral and gravity loads. The calculations presented in Ref. 8 showed the final results were insensitive to the selection of load configurations.

To further address loading variability and recognizing that ASR demands associated with each of the severity zones vary in magnitude and in relation to non-ASR demands, a parameter, k_{ASR}, is defined to represent the ratio of factored ASR demand to total factored demand. This k_{ASR} ratio varies from 0.4 at Zone I (lowest ASR severity) to 1.0 at Zone IV (highest ASR severity). Figure 1 shows that the required load factors for ASR in Zone I increases as a function of k_{ASR}, and that static load combinations (which target a reliability index of 3.0) generally require higher load factors than wind and seismic load combinations (which target reliability indices of 2.5 and 1.75). Figure 2 shows that ASR load factors associated with Zone II are lower than those in Zone I; this is because ASR loads in Zone II (as well as Zones III and IV) have a significantly lower coefficient of variation than those in Zone I. In fact, ASR load factors selected for Zone I at a k_{ASR} ratio of 0.4 are conservative relative to the load factors at all ratios in Zones II through IV. This finding indicates that a region of a structure with concrete falling into Zone II or higher (i.e., with CI of 0.5 mm/m and higher) have larger ASR demands, but require a smaller ASR load factor to meet the target reliability indices because the ASR variability in these higher zones is lower. The final selected load factors are presented in Table 2 for each of the design basis load combinations.

Sections 6 and 7 of SGH Document 160268-CA-01 provide a more detailed discussion of the methodology, including the definition and use of statistical terminology and computations used to generate and verify the ASR load factors.

2.4 Assumptions

As stated in the previous section, the methodology includes the use of log-normal probability distributions to represent the ASR CI data within a given severity zone. Curves fit through the data were examined, and the curves were adjusted to ensure that they produced equivalent or conservative results compared to the unadjusted curves.

Computation of reliability indices with log-normal distributions uses a closed-form solution method that incorporates some simplifying assumptions. A Monte Carlo simulation performed for one set of parameters that includes 100,000 randomly computed resistances, non-ASR demands, and ASR-related demands, verified that the approach used to calculate reliability indices is valid and produces reasonable results.

The methodology uses two bounding load configurations to proportion non-ASR demands within design basis load combinations. The results showed that the computation of ASR load factors was insensitive to the selection of the proportions of factored loads.

2.5 Summary

The following summarizes the key results for development of ASR load factors for the reinforced concrete Seismic Category I structures other than the CB:

- Use CI grids coupled with visual inspection to determine the severity of ASR.
- Characterize regions of each of the structures into one of the four defined ASR severity zones identified in Table 1 based on the mean CI measurements in a particular region.
- Apply ASR load factors in accordance with Table 2. This table is based on Table 3.8-16 of the Seabrook UFSAR and includes an additional (highlighted) column showing ASR load factors for each of the required design load combinations. Also added to the UFSAR table is Note 5, which states that when ASR strains are greater than 0.05% (0.5 mm/m), the ASR load factors may be reduced by 20% but shall not be taken as less than 1.0.
- The methodology presented in this chapter represents a rational analysis and maintains the reliability that is inherent to ACI Standard 318-71.

3. DEVELOPMENT OF ASR LOAD FACTORS FOR THE CONTAINMENT BUILDING

Chapter 3 describes the development of ASR load factors for the CB. Section 3.1 identifies the approach taken to establish the ASR load factors. Section 3.2 summarizes the results of a review of relevant documents. Section 3.3 describes the methodology used to develop the ASR load factors. Section 3.4 identifies assumptions incorporated into the methodology and provides justification for use, and Section 3.5 summarizes the key results of the study.

3.1 Approach to Establish ASR Load Factors

Efforts to develop ASR load factors for the CB must result in values that maintain the level of performance that is inherent to the original design code, 1975 ASME Boiler & Pressure Vessel Code (B&PV) [Ref. 7]. To achieve this goal, NEE took the following approach:

- Perform a critical review of the 1975 ASME B&PV and associated documents to understand the reliability intended by the original code authors.
- Aggregate the inspection data showing the presence and severity of ASR within the CB and characterize it in a manner useful for structural evaluation.
- Account for the variety and complexity of the load combinations stated in the design basis documents.

3.2 Results of Document Review

The literature review of relevant documents showed that Table 3.8-1 of the Seabrook UFSAR [Ref. 1] is based on Table CC-3230-1 of the 1975 ASME B&PV. The ASME B&PV Code is generally based on working stress design and elastic behavior with limited inelastic behavior allowed under certain conditions. Article CC-3000, Design, requires consideration of loads and compliance with corresponding limit states under Service load and Factored load conditions. Under Service load conditions, which represent conditions during construction and normal plant operation, all load factors are 1.0, and service-level limit states apply. Factored loads incorporate severe and extreme environmental and abnormal/accident conditions that act infrequently. Most loads are factored by 1.0, but some are factored by 1.25, 1.3, or 1.5 as part of specific combinations. Limit states are significantly higher for Factored conditions than for Service conditions.

The literature review found that the loads and load factors in ASME B&PV Table CC-3230-1 are deterministic and were developed in the early to mid-1970s through the judgment of knowledgeable and experienced code-writers. The code-writers recognized the uncertainty in loading; they included load factors of 1.25 and 1.5 for the OBE and other factors greater than

1.0 for live load, accident pressure, and rupture of high-energy pipe in particular load combinations. However, the load factor for the SSE is always 1.0 since a larger earthquake was not deemed credible.

Additional discussion is provided in Section 2 of SGH Document No. 160268-L-01 [Ref. 9].

3.3 Methodology

The primary intent of the methodology is to develop ASR loads that have a very small likelihood of exceedance and use an ASR load factor of 1.0. This approach for ASME code-checking, of using an extreme loading with a load factor of 1.0 is fundamentally different from reliability-based approaches commonly used in codes such as ACI 318 (and which are employed for the Non-containment Category 1 structures), where mean load values are used with a load factors greater than 1.0. This different approach is appropriate for ASME code-checking for two reasons:

(1) It is consistent with the deterministic philosophy used in the development of ASME Table CC-3230-1.

(2) The limited CCI measurements on the Containment Building do not allow a probabilistic approach to load-factor determination.

Similar to the methodology described to develop ASR load factors for the Seismic Category I structures other than the CB, NEE will use visual survey and CI measurements to determine the presence and distribution of ASR in the CB. The existing CI data will be reviewed to understand the current distribution and severity of ASR in the CB.

Once the data are collected and reviewed, the CB or regions will be categorized into one of the four ASR severity zones shown in Table 1. As a conservative approach to account for the variability in visual inspections and CI measurements, the maximum CI value in each of the regions will be used to categorize a particular region into an ASR severity zone.

For an initial screening evaluation that will primarily rely upon visual observations rather than CI measurements, the strain loads associated with the ASR severity zone boundaries shown in Table 1 are expanded by 25% as shown in the second and third columns of Table 3. If the screening evaluation results in overstressed portions of the structure, NEE may make additional inspections and CI measurements and rezone the potential problem area(s). A detailed evaluation may then be performed with ASR strain loads in the rezoned area based on the highest CI measurement in the zone without the 25% increase, using the values in the fourth and fifth columns in Table 3. For all evaluations of the CB, NEE will use the appropriate strain limits as ASR-related demands with a load factor of 1.0 in combination with other factored design basis loadings.

Similar to the methodology used to develop ASR load factors for the Seismic Category I structures other than the CB, NEE will regularly monitor the exterior surface of the CB for changes in ASR severity, and reanalyze as conditions warrant.

3.4 Assumptions

The primary assumption inherent in the methodology discussed above is that determining appropriate ASR severity zones for the CB through visual inspection and crack measurements is somewhat subjective but achievable. This assumption is partially addressed by the fact that NEE-approved inspectors have been performing CI measurements in accordance with NEE-approved written procedures [Ref. 10]. In addition, conservatively selecting design strain limits for each zone provides margin to account for variability in visual observations and crack measurements.

3.5 Summary

The following summarizes the key results for development of ASR load factors for the CB:

- Use CI grids coupled with visual inspection to determine the severity of ASR.
- For an initial conservative screening evaluation, characterize regions of the CB into one of the four defined ASR severity zones identified in Table 1 based on the maximum CCI value in that zone, and use the expanded strain limits for evaluation (Columns 2 and 3 of Table 3).
- If the screening evaluation identifies potential problem areas, make additional CI measurements, rezone the CB as warranted, and reevaluate the CB using the strain limits identified in Columns 4 and 5 of Table 3. While the analysis will typically use the strain values at the high end of the zones to evaluate a particular region, use the strain demands at the low end of the range in adjacent or other regions where appropriate if they produce a more severe confining effect on the region under review.
- Use an ASR load factor of 1.0 for all load combinations as shown in Table 4.

4. DEVELOPMENT OF ASR LOAD FACTORS FOR THE INTERIOR CONTAINMENT STRUCTURES

Chapter 4 describes the development of ASR load factors for the reinforced concrete Interior Containment Structures. Section 4.1 summarizes the approach, and Section 4.2 summarizes the key results.

4.1 General

Table 3.8-14 of the Seabrook UFSAR [Ref. 1] indicates that the load combinations applicable to the Interior Containment Structures are based on ACI 318-71 [Ref. 6]. Therefore, the approach used and methodology followed to develop ASR load factors for the reinforced concrete Interior Containment Structures are similar to those described in Chapter 2 for the reinforced concrete Seismic Category I structures other than the CB. Given these similarities, the proposed ASR load factors applicable to Interior Containment Structures design load combinations are similar. Because the Interior Containment Structures are located inside the CB, loadings such as earth pressure, wind, and tornado effects do not apply. This allows a reduction and simplification of the design load combinations. Table 5 presents ASR load factors for load combinations applicable to the design of the Interior Containment Structures.

4.2 Summary

Similar to the approach described in Chapter 2 for the reinforced concrete Seismic Category I structures other than the CB:

- Use CI grids coupled with visual inspection to determine the severity of ASR.
- Characterize regions of each of the reinforced concrete Interior Containment Structures into one of the four defined ASR severity zones identified in Table 1 based on the mean CI measurements in a particular region.
- Apply ASR load factors in accordance with Table 5. This table is based on Table 3.8-14 of the Seabrook UFSAR and includes an additional (highlighted) column showing ASR load factors for each of the required design load combinations. Also added to the UFSAR table is Note 5, which states that when ASR strains are greater than 0.05% (0.5 mm/m), the ASR load factors may be reduced by 20% but shall not be taken as less than 1.0.
- The methodology presented in this chapter represents a rational analysis and maintains the reliability that is inherent to ACI Standard 318-71.

5. SUMMARY AND CONCLUSIONS

The primary conclusions of this study are as follows:

- The reinforced concrete Seismic Category I structures other than the Containment Building (CB) were designed in accordance with ACI 318-71 [Ref. 6]. The CB was designed in accordance with ASME Boiler and Pressure Vessel Code, Section III – Division 2, 1975 [Ref. 7]. The reinforced concrete Interior Containment Structures were designed in accordance with ACI 318-71.

- By using inspection data collected from more than twenty Seismic Category I structures throughout Seabrook and properly categorizing ASR-related cracking into one of four zones that correspond to parameters currently used in the Seabrook Structural Monitoring Program, ASR-related strains (demands) and load factors have been developed for use in evaluation of each of the Seismic Category I structures, including the CB, at Seabrook.

- For reinforced concrete Seismic Category I structures other than the CB, typically use ASR load factors of 2.0 for ASR effects in combinations with static loads, 1.7 with static plus wind loads, and 1.3 with static plus seismic loads.

  - Reduce the ASR load factors by 25% when ASR effects are combined with thermal or other transient loading.
  - Use an ASR load factor of 1.0 when ASR effects are combined with unusual (extreme) loads, such as the safe-shutdown earthquake (SSE).
  - When ASR strains are greater than 0.05% (0.5 mm/m), the ASR load factors may be reduced by 20%, but shall not be taken as less than 1.0.

- For the CB, use an ASR load factor of 1.0 for all load combinations.

- For reinforced concrete Containment Internal Structures, use ASR load factors similar to those for reinforced concrete Seismic Category I structures other than the CB, except that ASR load factors developed for wind load combinations are not applicable.

- For initial screening evaluation of the CB, use conservative ASR strain demands based primarily on visual observations. If detailed analysis is needed, make CI measurements and reduce the conservatism in the ASR demands as permitted in Table 3.

- The conclusions reported herein apply to all Seismic Category I structures, including the CB, located at Seabrook when the severity of ASR is below the level at which material properties begin to degrade as established by the large-scale testing program conducted at FSEL [Ref. 4].

6. TABLES

Table 1 – ASR Severity Zones

Zone	Relative ASR Severity	Visual Appearance of ASR Cracking Indicative of CI in Indicated Range (mm/m)	Comparable Seabrook SMP ASR Crack Criteria***
I	Low	CI < 0.5*	Tier 2 Qualitative
II	Moderate	0.5 ≤ CI < 1.0	Tier 2 Quantitative
III	High	1.0 ≤ CI < 2.0	Tier 3
IV	Very High	> 2.0**	

* CI < 0.1 can be ignored for CB evaluation since categorization is based on maximum CI.

** CI = 3.5 mm/m used as upper limit for all Seismic Category I structures other than the CB.

*** Seabrook SMP ASR criteria are based on CCI, rather than CI values used herein.

Table 2 – Category I Structures Other Than CB or Its Internals Basic Load Combinations and Load Factors
(Modified from Table 3.8-16 of Ref. 1 to Include ASR Loads and Load Factors)

TABLE 3.8-16 CATEGORY I, STRUCTURES OTHER THAN REACTOR CONTAINMENT STRUCTURE OR ITS INTERNALS BASIC LOAD COMBINATIONS AND LOAD FACTORS

				Loading (1), (4)																					
				All Structures							Concrete Only			Certain Structures, Where Appropriate											
	Material																	Pipe Break Loads (Rr)							
Design Conditions			Required Strength	Dead Load and Hydrostatic Load	Live Load	Operational Temperature	Operating Basis Earthquake	Safe Shutdown Earthquake	Wind	Tornado Wind	Lateral Earth Pressures	Earth Pressure due to OBE	Earth Pressure due to SSE	ASR Loads (6)	Operational Piping Loads	Accident Pressure	Accident Piping Loads	Jet Impingement Loads	Missile Impact Loads	Jet Force Reaction	Internal Missile Loads	Accident Temperature	Design basis Flood	Unusual Snow Load	Stress Limit (5) or Design Criteria
	Loading Notations			D	L	T_o	E_o	E_s	W	W_t	E	H_e	H_s	S_a	R_o	P_a	R_a	R_{rj}	R_{rm}	R_{rr}	M	T_a	F	Ls	
Normal Load	Structural Steel		S	1.0	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			≤F, Per AISC
				1.0	1.0	-	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
				1.0	1.0	-	-	-	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-			
				0.67	0.67	0.67	-	-	-	-	-	-	-	-	0.67	-	-	-	-	-	-	-			
				0.67	0.67	0.67	0.67	-	-	-	-	-	-	-	0.67	-	-	-	-	-	-	-			
				0.67	0.67	0.67	-	-	0.67	-	-	-	-	-	0.67	-	-	-	-	-	-	-			
	Concrete		U	1.4	1.7	-	-	-	-	-	1.7	-	-	2.0	-	-	-	-	-	-	-	-			ACI 318-71
				1.4	1.7	-	1.9	-	-	-	1.7	1.9	-	1.3	-	-	-	-	-	-	-	-			
				1.4	1.7	-	-	-	1.7	-	1.7	-	-	1.7	-	-	-	-	-	-	-	-			
				1.05	1.28	1.28	-	-	-	-	1.28	-	-	1.5	1.28	-	-	-	-	-	-	-			
				1.05	1.28	1.28	1.43	-	-	-	1.28	1.43	-	1.0	1.28	-	-	-	-	-	-	-			
				1.05	1.28	1.28	-	-	1.3	-	1.28	-	-	1.28	1.28	-	-	-	-	-	-	-			
				1.2	-	-	-	-	1.7	-	1.7	-	-	1.7	-	-	-	-	-	-	-	-			
				1.2	-	-	1.9	-	-	-	1.7	1.9		1.3	-	-	-	-	-	-	-	-			
Unusual Load	Structural Steel	Elastic		0.63	0.63	0.63	-	0.63	-	-	-	-	-	-	0.63	-	-	-	-	-	-	-			≤F, Per AISC
			S	0.63	0.63	0.63	-	-	-	0.63	-	-	-	-	0.63	-	-	-	-	-	-	-			
			(2)	0.63	0.63	-	-	-	-	-	-	-	-	-	-	0.63	0.63	-	-	-	-	0.63			
			(2)	0.63	0.63	-	0.63	-	-	-	-	-	-	-	-	0.63	0.63	0.63	0.63	0.63	0.63	0.63			
				0.59	0.59	-	-	0.59	-	-	-	-	-	-	-	0.59	0.59	0.59	0.29	0.29	0.29	0.59			
		Plastic		1.1	1.1	1.1	-	1.1	-	-	-	-	-	-	1.1	-	-	-	-	-	-	-			AISC, Part II
			Y	1.1	1.1	1.1	-	-	-	1.1	-	-	-	-	1.1	-	-	-	-	-	-	-			
				1.1	1.1	-	-	-	-	-	-	-	-	-	-	1.7	1.1	1.1	1.1	1.1	1.1	1.1			
			(*)	1.1	1.1	-	1.4	-	-	-	-	-	-	-	-	1.4	1.1	-	-	-	-	1.1			
			(*)	1.1	1.1	-	-	1.1	-	-	-	-	-	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1			
	Concrete		U	1.0	1.0	1.0	-	1.0	-	-	1.0	-	1.0	1.0	1.0	-	-	-	-	-	-	-			ACI 318-71
				1.0	1.0	1.0	-	-	-	1.0	1.0	-	-	1.0	1.0	-	-	-	-	-	-	-			
				1.0	1.0	-	-	-	-	-	1.0	-	-	1.0	-	1.5	1.0	-	-	-	1.1	1.0			
				1.0	1.0	-	1.25	-	-	-	1.0	1.25	-	1.0	-	1.25	1.0	1.0	1.0	1.0	-	1.0			
				1.0	1.0	-	-	1.0	-	-	1.0	-	1.0	1.0	-	1.0	1.0	1.0	1.0	1.0	1.0	1.0			
				1.0	1.0	1.0	-	-	1.0	-	-	-	-	1.0	1.0	-	-	-	-	-	-	-	(3)	1.0	
				1.0	1.0	1.0	-	-	1.0	-	-	-	-	1.0	1.0	-	-	-	-	-	-	-	1.0	1.0	

(1) In above load combinations, the peak values of P_a, T_a, R_a, R_{rj}, R_{rr}, R_{rm} and M shall be combined (when acting concurrently) unless time history analysis is performed to justify otherwise.
(2) Elastic cases to be checked for overall stability by the plastic load combination cases as indicated by (*).
(3) For design bases flood load case, elevation shall be the effective maximum ground water elevation i.e., El. + 20'-0".
(4) See Subsection 3.8.4.3 for discussion of loadings.
(5) (F_s = Allowable Stress)
(6) Where ASR strains are greater than 0.05% (0.5 mm/m), ASR load factors may be reduced by 20% but shall not be taken as less than 1.0.

Table 3 – ASR-Related Strain Loads for Analysis of the CB

Zone	Strain Load (%) for Screening Evaluation		Strain Load (%) for Detailed Evaluation	
	Low	High	Low	High
I	0.01	0.06	0.01	0.05
II	0.04	0.13	0.05	0.10
III	0.08	0.25	0.10	0.20
IV	0.15	*	0.20	**

* The high strain load for Zone IV is to be 25% greater than the largest observed strain in the zone from CI measurements and/or visual inspection.

** The largest observed strain in the zone from CI measurements may be used.

Table 4 – Containment Building Basic Load Combinations and Load Factors (Modified from Table 3.8-1 of Ref. 1 to Include ASR Loads and Load Factors)

TABLE 3.8-1 CONTAINMENT LOAD COMBINATIONS AND LOAD FACTORS(5)

Design Conditions	Category	Load Combination Number	LOADING[6]														R				
																	R_r (DBA Local Effects)				
			Dead Load	Live Load	ASR Load	Test Pressure	Accident Pressure	Test Temperature	Normal Temperature	DBA Temperature	Operating Basis Earthquake	Safe Shutdown Earthquake	Wind Load	Tornado	Normal Pipe Reaction	DBA Thermal Pipe Reaction	Reaction of Ruptured High Energy Pipe	Jet Impingement Loads	Impact of Ruptured High Energy Pipe	Pressure Variations	Design Basis Flood
	Loading Notation		D	L	S_a	P_t	P_a	T_t	T_o	T_a[1]	E_o	E_{ss}	W	W_t	R_o	R_a	R_{rr}	R_{rj}	R_{rm}	P_v[2]	F[3]
Service Load	Test	1	1.0	1.0	1.0	1.0	-	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-
	Normal	2	1.0	1.0	1.0	-	-	-	1.0	-	-	-	-	-	1.0	-	-	-	-	1.0	-
	Severe Environmental	3	1.0	1.0	1.0	-	-	-	1.0	-	1.0	-	-	-	1.0	-	-	-	-	1.0	-
Factored Load	Severe Environmental	4	1.0	1.3	1.0	-	-	-	1.0	-	1.5	-	-	-	1.0	-	-	-	-	1.0	-
	Extreme Environmental	5a	1.0	1.0	1.0	-	-	-	1.0	-	-	-	-	1.0[7]	1.0	-	-	-	-	1.0	1.0
		5b	1.0	1.0	1.0	-	-	-	1.0	-	-	1.0	-	1.0[7,8]	1.0	-	-	-	-	1.0	-
	Abnormal	6a	1.0	1.0	1.0	-	1.5[4]	-	-	1.0[4]	-	-	-	-	-	1.0	-	-	-	-	-
		6b	1.0	1.0	1.0	-	1.0[4]	-	-	1.0[4]	-	-	-	-	-	1.25	-	-	-	-	-
	Abnormal/Severe Environmental	7	1.0	1.0	1.0	-	1.25[4]	-	-	1.0[4]	1.25	-	-	-	-	1.0	1.0	1.0	1.0	-	-
	Abnormal/Extreme Environmental	8	1.0	1.0	1.0	-	1.0[4]	-	-	1.0[4]	-	1.0	-	-		1.0	1.0	1.0	1.0	-	-

(1) Includes effect of normal operating thermal loads and accident loads. For all abnormal load conditions, structure should be checked to assure that accident pressure load without thermal load can be resisted by the structure within the specified allowable stresses for this condition.

(2) Negative pressure variations inside the structure shall not be considered simultaneously with outside negative pressure due to tornado loadings.

(3) For this load case, the design basis flood elevation shall be the max. ground water elevation, i.e., El. +20'-0".

(4) Load cases examined for maximum pressure and its coincident liner temperature and maximum liner temperature with its coincident pressure.

(5) All load factors shall be taken as 1.0 for the design of steel liner.

(6) See Subsection 3.8.1.3 for discussion of loadings.

(7) W_t includes missile effects only.

(8) For this load case, loadings from E_{ss} or W_t included individually.

Table 5 – Interior Containment Structures Basic Load Combinations and Load Factors (Modified from Table 3.8-14 of Ref. 1 to Include ASR Loads and Load Factors)

TABLE 3.8-14 INTERIOR CONTAINMENT STRUCTURES BASIC LOAD COMBINATIONS AND LOAD FACTORS

Design Conditions	Material / Loading Notations		Load Case Number	Dead Load and Hydrostatic Load (D)	Live Load (L)	ASR Loads (S_a)	Accident Pressure (P_a)	Operational Temperature (T_o)	Accident Temperature (T_a)	Operating Basis Earthquake (E_o)	Safe Shutdown Earthquake (E_{ss})	Operational Piping Loads (R_o)	Accident Piping Loads (R_a)	Jet Force Reaction (R_{rr})	Jet Impingement Loads (R_{rj})	Missile Impact Loads (R_{rm})	Internal Missile Loads (M)	Stress Limit or Design Criteria
Normal Load	Structural Steel		1S	1.0	1.0	-	-	-	-	-	-	-	-	-	-	-	-	≤F_s Per AISC
			2S	1.0	1.0	-	-	-	-	1.0	-	-	-	-	-	-	-	
			3S	0.67	0.67	-	-	0.67	-	-	-	0.67	-	-	-	-	-	
			4S	0.67	0.67	-	-	0.67	-	0.57	-	0.67	-	-	-	-	-	
	Concrete		1C	1.4	1.7	2.0	-	-	-	-	-	-	-	-	-	-	-	ACI 318-71
			2C	1.4	1.7	1.3	-	-	-	1.9	-	-	-	-	-	-	-	
			3C	-	-		-	-	-	-	-	-	-	-	-	-	-	
			4C	1.05	1.28	1.0	-	1.28	-	1.43	-	1.28	-	-	-	-	-	
Unusual Load	Structural Steel (2) (3)	Elastic	5S	0.53	0.63	-	-	0.63	-	-	0.63	0.63	-	-	-	-	-	≤F_s Per AISC
			6S	0.53	0.63	-	0.63	-	0.63	-	-	-	0.63	-	-	-	-	
			7S	0.53	0.63	-	0.63	-	0.63	0.53	-	-	0.63	0.63	0.63	0.63	0.63	
			8S	0.59	0.59	-	0.59	-	0.59	-	0.59	-	0.59	0.59	0.59	0.59	0.59	
	(3) (4)	Plastic	5S	1.1	1.1	-	-	1.1	-	-	1.1	1.1	-	-	-	-	-	AISC, Part II
			6S	1.1	1.1	-	1.7	-	1.1	-	-	-	1.1	-	-	-	-	
			7S	1.1	1.1	-	1.4	-	1.1	1.4	-	-	1.1	1.1	1.1	1.1	1.1	
			8S	1.1	1.1	-	1.1	-	1.1	-	1.1	-	1.1	1.1	1.1	1.1	1.1	
	Concrete (4)		5C	1.0	1.0	1.0	-	1.0	-	-	1.0	1.0	-	-	-	-	-	ACI 318-71
			6C	1.0	1.0	1.0	1.5	-	1.0	-	-	-	1.0	-	-	-	-	
			7C	1.0	1.0	1.0	1.25	-	1.0	1.25	-	-	1.0	1.0	1.0	1.0	1.1	
			8C	1.0	1.0	1.0	1.0	-	1.0	-	1.0	-	1.0	1.0	1.0	1.0	1.0	

LOADING[1]

(F_s = Allowable Stress)

(1) See Subsection 3.8.3.3 for discussion of loadings.

(2) In above load combinations, the peak values of P_a, T_a, R_a, R_{rj}, R_{rr}, R_{rm} and M shall be combined (when they act concurrently) unless time history analysis is performed to justify otherwise.

(3) For these load combinations either elastic or plastic design may be used.

(4) Load combinations 7S, 8S, 7C and 8C are also checked without R_{rr}, R_{rj}, R_{rm}.

[5] Where ASR strains are greater than 0.05% (0.5 mm/m), ASR load factors may be reduced by 20% but shall not be taken as less than 1.0.

7. FIGURES

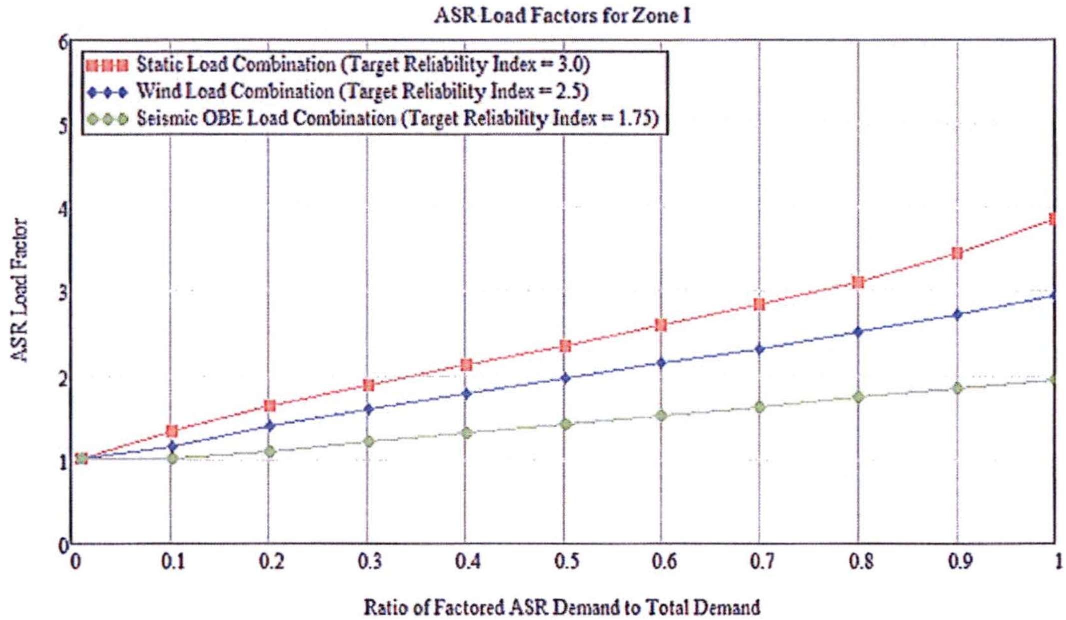

Figure 1 – Impact of Ratio of ASR Demands to Total Demands on ASR Load Factor for Zone I [Ref. 8]

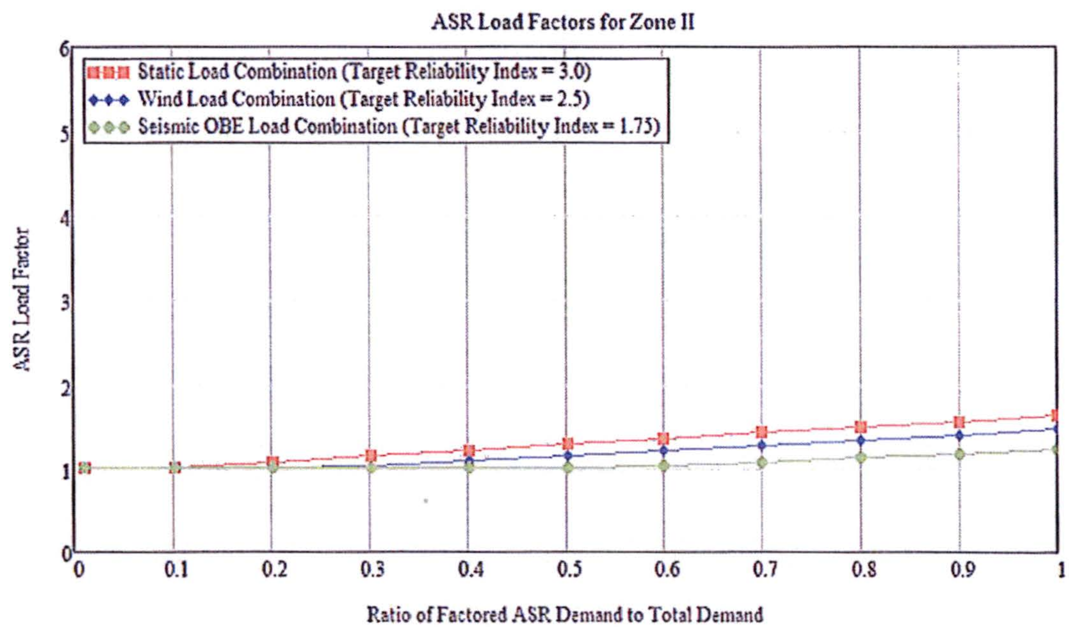

Figure 2 – Impact of Ratio of ASR Demands to Total Demands on ASR Load Factor for Zone II [Ref. 8]

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Appendix A
Crack Index Measurement Data as of 1 April 2016

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Table A1 – Crack Index Measurement Data

Grid Label	Structure	Exposure	Placement	Axis 1 Direction	Axis 2 Direction	Axis 1 CI (mm/m)	Axis 2 CI (mm/m)	Date Last Measured	Reference Document
CBAZ-317	Containment Building	Interior	Wall	Horizontal	Vertical	0.43	0.34	Feb. 2012	110594-SVR-01-R0
CE101-01	Containment Building	Interior	Wall	Horizontal	Vertical	0.43±0.11	0.71±0.13	Aug. 2014	120555-SVR-17-R0
CE101-02	Containment Building	Interior	Wall	Horizontal	Vertical	0.50±0.13	0.79±0.11	Aug. 2014	120555-SVR-17-R0
MF102-01	Containment Building	Interior	Wall	Horizontal	Vertical	1.81±0.19	1.62±0.20	Dec. 2015	120555-SVR-28-R0
CE101-01A (CI-10)	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.17±0.05	0.24±0.07	Jan. 2015	120555-SVR-23-R0
CE101-02A (CI-15)	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.17±0.05	0.79±0.13	Jan. 2015	120555-SVR-23-R0
CEBE-01S	Containment Enclosure Building	Exterior	Wall	Horizontal	Vertical	0.67±0.16	0.82±0.20	Apr. 2014	120555-SVR-13-R0
CEBI-01	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.95±0.16	1.16±0.21	Oct. 2015	120555-SVR-27-R0
CI-1	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.19	0.08	Dec. 2011	110594-CA-01-R0
CI-11	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.28	0.50	Dec. 2011	110594-CA-01-R0
CI-12	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.11	0.39	Dec. 2011	110594-CA-01-R0
CI-13	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.72	0.14	Dec. 2011	110594-CA-01-R0
CI-14	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.08	0.03	Dec. 2011	110594-CA-01-R0
CI-2	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.19	0.06	Dec. 2011	110594-CA-01-R0
CI-3	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.06	0.00	Dec. 2011	110594-CA-01-R0
CI-4	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.08	0.08	Dec. 2011	110594-CA-01-R0
CI-5	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.14	0.14	Dec. 2011	110594-CA-01-R0
CI-6	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.14	0.03	Dec. 2011	110594-CA-01-R0
CI-7	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.08	0.06	Dec. 2011	110594-CA-01-R0
CI-8	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.22	0.08	Dec. 2011	110594-CA-01-R0
CI-9	Containment Enclosure Building	Interior	Wall	Horizontal	Vertical	0.11	0.14	Dec. 2011	110594-CA-01-R0
CBE-01	Control and Diesel Generator Bldg.	Exterior	Wall	Horizontal	Vertical	0.61±0.15	0.58±0.15	Aug. 2014	120555-SVR-17-R0
DG101-01	Control and Diesel Generator Bldg.	Interior	Wall	Horizontal	Vertical	0.40±0.08	1.00±0.16	Aug. 2014	120555-SVR-17-R0
DG102-01A	Control and Diesel Generator Bldg.	Interior	Wall	Horizontal	Vertical	0.27±0.05	1.21±0.13	Aug. 2014	120555-SVR-17-R0
DG102-01B	Control and Diesel Generator Bldg.	Interior	Wall	Horizontal	Vertical	0.22±0.06	0.99±0.14	Aug. 2014	120555-SVR-17-R0
DGE-01	Control and Diesel Generator Bldg.	Exterior	Wall	Horizontal	Vertical	0.88±0.19	0.53±0.12	Aug. 2014	120555-SVR-17-R0
SGH CI-DGB	Control and Diesel Generator Bldg.	Interior	Wall	Horizontal	Vertical	0.66±0.10	1.49±0.25	Dec. 2015	120555-SVR-28-R0
MF205-01	East Pipe Chase	Exterior	Wall	Horizontal	Vertical	0.38±0.10	0.54±0.13	Aug. 2014	120555-SVR-17-R0

Table A1 – Crack Index Measurement Data

Grid Label	Structure	Exposure	Placement	Axis 1 Direction	Axis 2 Direction	Axis 1 CI (mm/m)	Axis 2 CI (mm/m)	Date Last Measured	Reference Document
MF206-01	East Pipe Chase	Interior	Wall	Horizontal	Vertical	0.81±0.10	0.90±0.13	Jan. 2015	120555-SVR-23-R0
MF207-01	East Pipe Chase	Interior	Slab	E-W	N-S	1.41±0.22	1.13±0.20	Dec. 2015	120555-SVR-28-R0
MF302-01	East Pipe Chase	Interior	Slab	N-S	E-W	0.99±0.19	1.53±0.17	Dec. 2015	120555-SVR-28-R0
MF303-01	East Pipe Chase	Interior	Slab	E-W	N-S	2.07±0.20	2.26±0.15	Dec. 2015	120555-SVR-28-R0
MF304-01	East Pipe Chase	Interior	Wall	Horizontal	Vertical	0.86±0.10	0.69±0.14	Jan. 2015	120555-SVR-23-R0
MFE-01	East Pipe Chase	Exterior	Wall	Horizontal	Vertical	1.13±0.16	0.35±0.09	Dec. 2015	120555-SVR-28-R0
CBST1-01	Electrical Cable Tunnels	Interior	Wall	Horizontal	Vertical	0.12±0.03	0.77±0.20	Aug. 2014	120555-SVR-17-R0
CBST1-02	Electrical Cable Tunnels	Interior	Wall	Horizontal	Vertical	0.48±0.13	0.53±0.11	Aug. 2014	120555-SVR-17-R0
EF101-01	Electrical Cable Tunnels	Interior	Slab	E-W	N-S	1.36±0.38	0.61±0.16	Dec. 2015	120555-SVR-28-R0
EF102-01	Electrical Cable Tunnels	Interior	Wall	Horizontal	Vertical	0.83±0.15	0.81±0.15	Aug. 2014	120555-SVR-17-R0
EF202-01	Electrical Cable Tunnels	Interior	Wall	Horizontal	Vertical	0.78±0.13	0.72±0.15	Aug. 2014	120555-SVR-17-R0
MF101-01A	Electrical Cable Tunnels	Interior	Wall	Horizontal	Vertical	0.85±0.15	2.13±0.27	Dec. 2015	120555-SVR-28-R0
MF101-01A Index2	Electrical Cable Tunnels	Interior	Wall	Horizontal	Vertical	0.60±0.06	1.32±0.25	Dec. 2015	120555-SVR-28-R0
MF101-01B	Electrical Cable Tunnels	Interior	Wall	Horizontal	Vertical	0.24±0.05	1.07±0.13	Aug. 2014	120555-SVR-17-R0
MF101-01C	Electrical Cable Tunnels	Interior	Slab	E-W	N-S	1.32±0.27	0.69±0.15	Dec. 2015	120555-SVR-28-R0
MF201-01	Electrical Cable Tunnels	Interior	Slab	N-S	E-W	0.28±0.08	0.19±0.05	Jun. 2015	120555-SVR-25-R0
SGH CI-BET	Electrical Cable Tunnels	Interior	Wall	Horizontal	Vertical	0.86±0.17	1.58±0.31	Dec. 2015	120555-SVR-28-R0
CI-W03-Wall	Electrical Vaults	Exterior	Wall	Horizontal	Vertical	1.71±0.13	2.07±0.14	Dec. 2015	120555-SVR-28-R0
CI-W04-Wall	Electrical Vaults	Exterior	Wall	Horizontal	Vertical	1.04±0.09	0.85±0.10	Oct. 2014	120555-SVR-19-R0
CI-W05-Wall	Electrical Vaults	Exterior	Wall	Horizontal	Vertical	0.24±0.05	1.55±0.12	Dec. 2015	120555-SVR-28-R0
CI-W06-Wall	Electrical Vaults	Exterior	Wall	Horizontal	Vertical	1.33±0.13	1.08±0.13	Dec. 2015	120555-SVR-28-R0
CI-W07-Wall	Electrical Vaults	Exterior	Wall	Horizontal	Vertical	0.89±0.14	0.96±0.15	Oct. 2013	120555-SVR-09-R0
CI-W08-Wall	Electrical Vaults	Exterior	Wall	Horizontal	Vertical	0.81±0.13	0.82±0.12	Oct. 2014	120555-SVR-19-R0
CI-W10-Wall	Electrical Vaults	Exterior	Wall	Horizontal	Vertical	0.61±0.07	0.68±0.10	Nov. 2014	120555-SVR-19-R0
CI-W11-Ceiling	Electrical Vaults	Exterior	Slab	N-S	E-W	0.51±0.08	0.45±0.09	Oct. 2013	120555-SVR-09-R0
CI-W11-Wall	Electrical Vaults	Exterior	Wall	Horizontal	Vertical	1.12±0.13	1.34±0.17	Dec. 2015	120555-SVR-28-R0
EF103-01	Emergency Feed water Pump Bldg.	Interior	Wall	Horizontal	Vertical	0.46±0.08	0.73±0.12	Jun. 2015	120555-SVR-25-R0
EFE-01	Emergency Feed water Pump Bldg.	Exterior	Wall	Horizontal	Vertical	0.40±0.09	0.74±0.17	Aug. 2014	120555-SVR-17-R0

Table A1 – Crack Index Measurement Data

Grid Label	Structure	Exposure	Placement	Axis 1 Direction	Axis 2 Direction	Axis 1 CI (mm/m)	Axis 2 CI (mm/m)	Date Last Measured	Reference Document
EFST-01	Emergency Feed water Pump Bldg.	Interior	Wall	Horizontal	Vertical	0.57±0.12	1.44±0.22	Dec. 2015	120555-SVR-28-R0
SGH CI-EFW	Emergency Feed water Pump Bldg.	Interior	Wall	Horizontal	Vertical	0.88±0.17	0.96±0.18	Dec. 2015	120555-SVR-28-R0
FB105-01	Fuel Storage Building	Interior	Wall	Horizontal	Vertical	1.02±0.08	0.67±0.11	Aug. 2014	120555-SVR-17-R0
FB106-02	Fuel Storage Building	Interior	Wall	Horizontal	Vertical	0.33±0.07	0.69±0.10	Aug. 2014	120555-SVR-17-R0
FB106-03	Fuel Storage Building	Interior	Wall	Horizontal	Vertical	0.34±0.06	1.50±0.23	Aug. 2014	120555-SVR-17-R0
FSBE-01	Fuel Storage Building	Exterior	Wall	Horizontal	Vertical	0.58±0.10	0.34±0.09	Aug. 2014	120555-SVR-17-R0
MF103-02	Mechanical Penetration	Interior	Wall	Horizontal	Vertical	1.04±0.26	2.27±0.37	Dec. 2015	120555-SVR-28-R0
MF105-01	Mechanical Penetration	Interior	Wall	Horizontal	Vertical	2.27±0.25	1.76±0.20	Dec. 2015	120555-SVR-28-R0
PAVRE-01	Pre-Action Valve Building	Exterior	Wall	Horizontal	Vertical	0.51±0.12	0.54±0.13	Aug. 2014	120555-SVR-17-R0
PABE-01	Primary Auxiliary Building	Exterior	Wall	Horizontal	Vertical	0.42±0.09	0.21±0.05	Aug. 2014	120555-SVR-17-R0
PB103-01	Primary Auxiliary Building	Interior	Wall	Horizontal	Vertical	1.33±0.23	1.03±0.22	Dec. 2015	120555-SVR-28-R0
PB205-01	Primary Auxiliary Building	Interior	Wall	Horizontal	Vertical	2.17±0.38	3.25±0.36	Dec. 2015	120555-SVR-28-R0
RHREVR-01	RHR Vault	Exterior	Slab	N-S	E-W	0.58±0.12	0.97±0.16	Dec. 2015	120555-SVR-28-R0
RV101-01	RHR Vault	Interior	Wall	Horizontal	Vertical	0.82±0.15	1.48±0.20	Dec. 2015	120555-SVR-28-R0
RV102-01	RHR Vault	Interior	Wall	Horizontal	Vertical	0.40±0.12	0.53±0.16	Aug. 2014	120555-SVR-17-R0
RV301-01	RHR Vault	Interior	Wall	Horizontal	Vertical	1.09±0.23	3.00±0.54	Dec. 2015	120555-SVR-28-R0
RV302-01	RHR Vault	Interior	Wall	Horizontal	Vertical	0.96±0.22	1.82±0.43	Dec. 2015	120555-SVR-28-R0
RVST2-01	RHR Vault	Interior	Wall	Horizontal	Vertical	1.33±0.31	1.51±0.37	Dec. 2015	120555-SVR-28-R0
CT101-01	Service Water Cooling Tower	Interior	Wall	Horizontal	Vertical	0.53±0.15	0.37±0.11	Aug. 2014	120555-SVR-17-R0
CT102-01	Service Water Cooling Tower	Interior	Wall	Horizontal	Vertical	0.94±0.23	0.94±0.23	Aug. 2014	120555-SVR-17-R0
CT104-01	Service Water Cooling Tower	Interior	Wall	Horizontal	Vertical	0.19±0.05	0.61±0.09	Jan. 2015	120555-SVR-23-R0
CTE-01N	Service Water Cooling Tower	Exterior	Wall	Horizontal	Vertical	1.92±0.28	0.61±0.13	Dec. 2015	120555-SVR-28-R0
CTE-01S	Service Water Cooling Tower	Exterior	Wall	Horizontal	Vertical	1.08±0.17	1.21±0.16	Dec. 2015	120555-SVR-28-R0
CTE-02S	Service Water Cooling Tower	Exterior	Wall	Horizontal	Vertical	0.72±0.17	0.74±0.18	Dec. 2015	120555-SVR-28-R0
MF202-02	West Pipe Chase	Exterior	Wall	Horizontal	Vertical	0.97±0.19	1.22±0.21	Dec. 2015	120555-SVR-28-R0
MF203-01	West Pipe Chase	Interior	Slab	E-W	N-S	0.60±0.13	0.60±0.13	Dec. 2015	120555-SVR-28-R0
MF204-01	West Pipe Chase	Interior	Slab	SW-NE	SE-NW	2.09±0.13	2.45±0.30	Dec. 2015	120555-SVR-28-R0
CST101-01	Condensate Storage Tank	Interior	Slab	E-W	N-S	1.37±0.19	1.20±0.16	Dec. 2015	120555-SVR-28-R0

Table A1 – Crack Index Measurement Data

Grid Label	Structure	Exposure	Placement	Axis 1 Direction	Axis 2 Direction	Axis 1 CI (mm/m)	Axis 2 CI (mm/m)	Date Last Measured	Reference Document
CST101-01A	Condensate Storage Tank	Interior	Wall	Horizontal	Vertical	1.26±0.13	0.58±0.13	Jan. 2015	120555-SVR-23-R0
CSTE-01	Condensate Storage Tank	Exterior	Wall	Horizontal	Vertical	1.25±0.29	0.82±0.18	Dec. 2015	120555-SVR-28-R0
CSTR-01	Condensate Storage Tank	Exterior	Slab	E-W	N-S	1.30±0.15	1.08±0.14	Aug. 2014	120555-SVR-17-R0
DSE-01	Discharge Structure	Exterior	Wall	Horizontal	Vertical	1.17±0.16	1.59±0.15	Dec. 2015	120555-SVR-28-R0
DSI-01A	Discharge Structure	Interior	Wall	Horizontal	Vertical	0.46±0.09	0.42±0.09	Aug. 2014	120555-SVR-17-R0
DSI-01B	Discharge Structure	Interior	Wall	Horizontal	Vertical	0.43±0.10	0.32±0.07	Aug. 2014	120555-SVR-17-R0
DSR-01	Discharge Structure	Exterior	Slab	E-W	N-S	1.32±0.18	0.78±0.10	Dec. 2015	120555-SVR-28-R0
EHRE-01	Equipment Hatch Structure	Exterior	Slab	E-W	N-S	0.72±0.15	1.22±0.23	Apr. 2014	120555-SVR-13-R0
ISE-01	Intake Structure	Exterior	Wall	Horizontal	Vertical	0.58±0.09	0.26±0.07	Aug. 2014	120555-SVR-17-R0
ISER-01	Intake Structure	Exterior	Slab	N-S	E-W	0.64±0.13	1.29±0.20	Aug. 2014	120555-SVR-17-R0
CBMAIE-01	Ctrl. Rm. Makeup Air Intake Platform	Exterior	Slab	E-W	N-S	1.01±0.17	0.89±0.18	Dec. 2015	120555-SVR-28-R0
MSBE-01	Missile Shield for Equipment Hatch	Exterior	Wall	Horizontal	Vertical	0.96±0.19	0.39±0.11	Aug. 2014	120555-SVR-17-R0
RCAT-01	RCA Tunnels	Interior	Wall	Horizontal	Vertical	0.15±0.04	0.63±0.11	Aug. 2014	120555-SVR-17-R0
RCAT-02	RCA Tunnels	Interior	Wall	Horizontal	Vertical	0.73±0.13	1.12±0.14	Jan. 2015	120555-SVR-23-R0
345BKR-01	Switch Yard	Exterior	Slab	N-S	E-W	0.76±0.18	0.76±0.19	Aug. 2014	120555-SVR-17-R0
RAT-01	Switch Yard	Exterior	Slab	N-S	E-W	1.13±0.19	0.84±0.16	Aug. 2014	120555-SVR-17-R0
SF6BD-01	Switch Yard	Exterior	Slab	E-W	N-S	0.82±0.21	1.10±0.30	Aug. 2014	120555-SVR-17-R0
CW202-01	Service/Circ. Water Pump House	Interior	Wall	Horizontal	Vertical	0.63±0.15	1.07±0.22	Jan. 2015	120555-SVR-23-R0
SW102-01	Service/Circ. Water Pump House	Interior	Wall	Horizontal	Vertical	0.67±0.10	1.20±0.19	Aug. 2014	120555-SVR-17-R0
SWE-01N	Service/Circ. Water Pump House	Exterior	Wall	Horizontal	Vertical	1.18±0.18	0.89±0.15	Dec. 2015	120555-SVR-28-R0
SWE-01S	Service/Circ. Water Pump House	Exterior	Wall	Horizontal	Vertical	1.02±0.23	1.04±0.15	Dec. 2015	120555-SVR-28-R0
WB316-02	Waste Process Building	Interior	Slab	N-S	E-W	0.52±0.08	0.54±0.10	Jan. 2015	120555-SVR-23-R0
WBE-01	Waste Process Building	Exterior	Wall	Horizontal	Vertical	0.80±0.19	0.70±0.10	Aug. 2014	120555-SVR-17-R0
WBST2-02	Waste Process Building	Interior	Wall	Horizontal	Vertical	1.81±0.27	1.17±0.22	Dec. 2015	120555-SVR-28-R0

Appendix B
Independent Verification

REPORT INDEPENDENT VERIFICATION CHECKLIST

SIMPSON GUMPERTZ & HEGER

Engineering of Structures
and Building Enclosures

Project Number:160268	Report No. and Revision No.: 160268-R-01, Rev. 0	Report Type: Full Report

Scope of Review: Review of Report and Appendices

Method of Verification = Design Review (Alternate Calculations and Qualification Tests are not permitted)

Y	N	N/A	
☒	☐	☐	Are assumptions, opinions, judgments, and technical approaches correct?
☒	☐	☐	Are assumptions used to perform the design or analysis activity adequately described and reasonable?
☒	☐	☐	Are applicable codes, standards, and regulatory requirements properly identified, and are their requirements met?
☒	☐	☐	Was an appropriate design or analysis method used?
☒	☐	☐	Have the supporting calculations, drawings, figures, and tables been reviewed for technical completeness and compliance with QANF procedures?
☒	☐	☐	Were design inputs correctly selected and incorporated into design?*[1]
☒	☐	☐	Are results interpreted correctly?
☒	☐	☐	Are results, conclusions, and recommendations reasonable?
☒	☐	☐	Are the organization and clarity of the report adequate?
☐	☐	☒	Are the necessary design inputs for interfacing organization specified in the design documents or in supporting procedures or instructions?
☐	☒	☐	Were Checker(s) assigned to perform independent verification? And if so, are the Report Checker Assignment and Review Sheets used, properly completed, and attached?
☐	Other items for checklist, if necessary, added by the PIC or PM.		
☐			
☐			

Independent Verifier:

Glenn R. Bell		7/27/2016
Printed Name	Signature	Date

*Any calculations, comments, or notes generated as part of this review should be signed, dated, and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

Notes:

*[1] Design inputs were properly selected from the referenced documents; the results presented in this report will be used in future design confirmation calculations.

REPORT INDEPENDENT VERIFICATION COMMENT SHEET

SIMPSON GUMPERTZ & HEGER

Engineering of Structures and Building Enclosures

Report Number: 160268-R-01

Independent Verifier: Glenn R. Bell

Comments	Resolution
Section1.4.3 – Verify the Structural Monitoring Program applies to the Containment Building.	Verified. See Section 2.2 of the Seabrook SMP.
Section 1.4.4 – Discussion of Reliability Index seems more appropriate than discussion on Reliability.	Revised section.
Section 2.2 – List parameters references to the SGH calculation from Ellingwood et al.	Added ratio of mean to nominal resistance and coefficient of variation of resistance.
Section 2.3.2 – Add table of CI grids to report.	Added as Appendix A.
Add note that strains below the Zone I limit 0.01% are negligible.	Added text in Section 1.4.3.
Section 3.3 – Third paragraph is confusing. Review and rewrite.	Rewrote the paragraph based on comments and updated information.

Resolved by (Preparer): **Michael Mudlock** Michael Mudlock

Accepted by (Indep. Verifier): **Glenn R. Bell** Glenn R Bell

Attachment 1
External Peer Review Documentation

Note: Bruce R. Ellingwood PhD, PE, NAE, F SEI, Dist M ASCE, (College of Engineering Distinguished Professor, Department of Civil and Environmental Engineering, Colorado State University) performed a peer review of Revision B of this document (160268-R-01), which did not address the development of ASR load factors for the reinforced concrete Interior Containment Structures. As stated in Chapter 4 of Revision 0 of this document, because ACI 318-71 governs the design of these structures, the discussion and conclusions provided in Chapter 2 of this document apply to Chapter 4. Since Dr. Ellingwood reviewed and accepted the conclusions of Chapter 2, we did not believe additional peer review of this document was necessary.

Bruce R. Ellingwood, Ph.D., P.E., N.A.E.
826 Rockwood Lane
Estes Park, CO 80517
Tel: (970) 586-3064

July 15, 2016

MEMORANDUM

To: Simpson, Gumpertz & Heger
Said Bolourchi, Ph.D., P.E., Senior Principal

Re: Review of Report 160268-R-01: Development of ASR Load Factors for Seismic Category I Structures at Seabrook Station, Seabrook, NH (SGH Project 160268)

Refs:

1. Simpson Gumpertz & Heger Inc., "Computation of Load Factors for ASR Demands for Seismic Category I Structures Other Than Reactor Containment", SGH Document No. 160268-CA-01, Revision B, June 2016.

2. Simpson Gumpertz & Heger Inc., "Load Factors and Load Combinations for Analysis of ASR Effects on Seabrook Station Containment Building", SGH Document No. 160268-L-01, Revision A, July 2016.

3. Ellingwood, B.R. Review of Computation of Load Factors for ASR Demands for Seismic Category I Structures Other Than Reactor Containment, Revision B (SGH Project No. 160268), July 12, 2016

4. Ellingwood, B.R. "Review of Load Factors and Load Combinations for Analysis of ASR Effects on Seabrook Station Containment Building, dated 9 June 2016 (SGH Project No. 160268), July 11 2016.

The subject report summarizes work performed by Simpson, Gumpertz & Heger (SGH), to develop load factors and load combinations for alkali-silica reaction (ASR) - related demands, which are intended to be incorporated into the existing load combinations defined in the Updated Final Safety Analysis Report (UFSAR) for NextEra Energy Seabrook Station Category I Structures and Containment. The ASR load requirements for the Category I structures are intended to maintain the reliability indices that were inherent in the original design load combinations provided in *ACI Standard 318-71*. The ASR load requirements for the Containment are intended to provide the same margin of safety as that provided in the *ASME Boiler and Pressure Vessel Code, Section III, Division 2/ACI Standard 359-74* (hereinafter the *ASME Code*). The details of the approach taken are summarized in Refs. 1 and 2.

Refs. 1 and 2 were reviewed independently, and the results of these reviews were communicated in Refs. 3 and 4 to SGH. Subsequently, these review comments were discussed at length with SGH personnel. Refs. 1 – 4 are hereby incorporated by reference in this review of Report 160268-R-01. In my opinion, all review comments in Refs. 3 and 4 have been addressed by SGH satisfactorily, and no issues raised in these reviews remain to be resolved.

In my opinion, the methods employed in Report 160268-R-01 for revising the load combinations in the UFSAR for the Seabrook Station for ASR demands on Category I structures are, in general, consistent with the state of the art of structural reliability assessment and the development of probability-based load and resistance factors for structural design. Furthermore, the methods employed for revising the load combinations for the Containment, while not based on principles of structural reliability, are entirely consistent with the conservative deterministic approach to safety assurance historically taken in developing the *ASME Code*.

Sincerely,

Bruce R. Ellingwood

Bruce R. Ellingwood, Ph.D., P.E., N.A.E.