NEXTera ENERGY SEABROOK

October 17, 2017

10 CFR 50
Docket No. 50-443
SBK-L-17170

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555-0001

Seabrook Station

Non-Proprietary Enclosure 1 to SBK-L-17156

References:

1. NextEra Energy Seabrook, LLC letter SBK-L-16071, "License Amendment Request 16-03, Revise Current Licensing Basis to Adopt a Methodology for the Analysis of Seismic Category I Structures with Concrete Affected by Alkali-Silica Reaction," August 1, 2016 (ML16216A240).

2. NRC, "Request for Additional Information Regarding License Amendment Request Related to Alkali-Silica Reaction (CAC No. MF8260)," August 4, 2017 (Accession Number ML17214A085).

3. NextEra Energy Seabrook LLC, letter SBK-L-17156, "Response to Request for Additional Information Regarding License Amendment Request 16-03 Related to Alkali-Silica Reaction (CAC No. MF8260)", October 3, 2017.

In Reference 1, NextEra Energy Seabrook, LLC (NextEra Energy Seabrook) submitted letter SBK-L-16071, requesting an amendment to the license for Seabrook Station Unit 1. Specifically, the proposed change revises the NextEra Energy Seabrook Updated Final Safety Analysis Report (UFSAR) to include methods for analyzing seismic Category I structures with concrete affected by an alkali-silica reaction (ASR).

In Reference 2, the NRC requested additional information to complete the review of the License Amendment Request 16-03.

In Reference 3, NextEra Energy Seabrook submitted letter SBK-L-17156, responding to the Request for Additional Information (RAI) in Reference 2. Enclosure 1 of SBK-L-17156 is proprietary.

The Enclosure provides a non-proprietary version of Enclosure 1 from SBK-L-17156 (Reference 3).

This letter contains no new or revised Commitments.

If you have any questions regarding this correspondence, please contact Mr. Kenneth Browne, Licensing Manager, at (603) 773-7932.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on October 17, 2017.

Sincerely,

NextEra Energy Seabrook, LLC

Eric McCartney
Regional Vice President - Northern Region

Enclosures:

Non-Proprietary Version of Enclosure 1 to SBK-L-17156, Response to Request for Additional Information for License Amendment Request 16-03, Revise Current Licensing Basis to Adopt a Methodology for the Analysis of Seismic Category I Structures with Concrete Affected by Alkali-Silica Reaction

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Enclosure 1 to SBK-L-17170

Non-Proprietary Version of Enclosure 1 to SBK -L-17156
Response to Request for Additional Information for License Amendment Request 16-03,
Revise Current Licensing Basis to Adopt a Methodology for the Analysis of Seismic
Category I Structures with Concrete Affected by Alkali-Silica Reaction
(NON-PROPRIETARY)

RAI-M1

Background

Section 3.2.3 of the LAR notes that adjustments to Seabrook design code methodologies are unnecessary if ASR through-thickness expansion levels remain below limits established during the MPR Associates / Ferguson Structural Engineering Laboratory (MPR/FSEL) structural testing. These expansion limits are identified for flexure, reinforcement anchorage, shear, and structural attachments in Tables 2 and 4 of the LAR, and proposed Table 3.8-18 markup of the Seabrook UFSAR, which references Section 2.1 of MPR-4288, "Seabrook Station: Impact of Alkali-Silica Reaction on the Structural Design Evaluations" (Seabrook FP# 101020). Because the proposed methodology to analyze ASR affected structures assumes through-thickness expansion remains below the identified limits, the NRC staff needs to understand what the limits are and how frequently they will be monitored.

Issue

a. The limits identified in Table 4 do not match the limits identified in Tables 2 and 3.8-18, so it is not clear what the limits are.

b. The proposed markup for UFSAR Section 3.8.4.7.2 notes that all locations meeting Tier 3 criteria will be monitored for Combined Cracking Index on a 6-month inspection interval and will be added to the through-thickness expansion monitoring via extensometers; however, it is not clearly stated how often through-thickness measurements will be taken.

Request

1. Identify the through-thickness limits that will be used for the monitoring of Seabrook structures and referenced in the UFSAR.

2. State the interval at which through-thickness measurements will be taken and provide a justification for the interval. Update the proposed UFSAR Section 3.8.4.7.2 to include the interval of through-thickness measurements.

NextEra Energy Seabrook Response to RAI-M1, Request #1

The through-thickness expansion limit that will be used for monitoring is [redacted]%.

Table 2 of the License Amendment Request (LAR) presents the conclusions of NextEra Energy Seabrook, LLC's (NextEra Energy Seabrook) evaluations of various structural design issues. Specifically, Table 2 reflects the conclusion of MPR-4288 (Reference 20), which indicates that the structural limit state of flexure, reinforcement anchorage and shear can be addressed by verifying that through-thickness expansion is below certain threshold values. These values are [redacted]% for flexure and reinforcement anchorage, and [redacted]% for shear. These values reflect the maximum expansion levels observed in the MPR/FSEL test programs.

This approach is clarified in Section 3.5.1 of the LAR, which states that "...although the expansion limit for flexure and reinforcement anchorage from the large-scale test programs is [redacted]%, the lower value of [redacted]% for shear is included in the UFSAR and the Structures Monitoring Program (SMP) for these limit states." The more limiting threshold is selected as the acceptance criterion. Table 4 of the LAR presents the ASR expansion limits that NextEra Energy Seabrook plans to impose and specifies a through-thickness expansion limit of [redacted]% for flexure and reinforcement anchorage.

To avoid a discussion of proprietary information, Table 3.8-18 of the NextEra Energy Seabrook UFSAR Supplement references FP#101020 (which is MPR-4288) for the ASR expansion limits. To more explicitly align the ASR expansion limits in Table 3.8-18 with Table 4 from the LAR, NextEra Energy Seabrook will add a footnote stating that the most limiting (i.e., lowest) acceptance criterion for through-thickness expansion among the applicable limit states will be used as the overall through-thickness expansion monitoring limit. Enclosure 2 provides a markup of the applicable UFSAR page.

NextEra Energy Seabrook Response to RAI-M1, Request #2

Through-thickness expansion will be monitored on a six-month interval, consistent with CCI for in-plane expansion monitoring of Tier 3 locations. This approach is currently included in the Alkali-Silica Reaction (ASR) Aging Management Plan (AMP) (Reference 1) and will be included in the Structures Monitoring Program (Reference 7), which is referenced by the LAR.

ASR is a relatively slow-moving process (Reference 52) and the concrete at Seabrook Station has been in existence for decades. Trending of in-plane expansion at Seabrook Station shows minimal change since monitoring started in 2011 (Reference 10). There is no reason to expect a sudden acceleration of ASR development. Hence, structural implications will not change significantly in a short period of time. Thus, six months is an appropriate interval for expansion monitoring.

NextEra Energy Seabrook will add a statement providing the six-month through-thickness monitoring interval and the justification behind the interval to Section 3.8.4.7.2 Alkali-Silica Reaction (ASR) Monitoring in the UFSAR. Enclosure 2 provides a markup of the applicable UFSAR page.

RAI-M2

Background

Section 3.2.3 of the LAR notes that adjustments to Seabrook design code methodologies are unnecessary if ASR through-thickness expansion levels remain below limits established during the MPR/FSEL structural testing. All of the limits are based on through-thickness expansion, which was selected as the monitoring parameter based on the performance of the specimens in the MPR/FSEL structural testing. Section 5.1.4 of MPR-4288 states that "a limit on in-plane expansion is not necessary, as expansion [as observed in the testing program] is predominately in the through-thickness direction."

ASR is a volumetric expansion phenomenon, and cracking can preferentially occur in any direction, depending on various factors. Section 5.1.4 of MPR-4288 states that during MPR/FSEL structural testing, the in-plane expansion plateaued, but expansion continued in the through-thickness direction. Although Section 4.3 of MPR-4288 notes the beam test specimens were designed to be representative of the structural characteristics of safety-related structures at Seabrook, it is not clear that the Seabrook structural systems will exhibit similar expansion behavior as the MPR/FSEL test beams. In the December 23, 2016, response to license renewal RAI B.2.1.31A-A1, the licensee also stated that a small number of Tier 3 locations at Seabrook exhibit in-plane expansion that exceeds the plateau in-plane expansion observed in the large-scale test program (LSTP).

Issue

The above statements in MPR-4288 appear to assume that the structures at Seabrook will behave in a similar fashion to the test specimens, although the LAR does not discuss actions that have been taken or will be taken to validate or corroborate this hypothesis for in situ Seabrook structures. Preliminary expansion results from Seabrook appear to indicate that in-plane expansion may not plateau at the same level as that seen in MPR/FSEL structural testing, and that expansion behavior may be different between the test specimens and Seabrook structures.

a. It is not clear to the NRC staff if a review of data from Seabrook structures will be conducted to verify the apparent assumption that Seabrook structures are behaving in a similar fashion to the MPR/FSEL test specimens.

b. Based on preliminary operating experience with in-plane expansion, the NRC staff needs additional information on why limits on in-plane or volumetric expansion are not proposed in the monitoring program.

c. The NRC staff needs to understand how it was determined that MPR/FSEL test program conclusions continue to apply to Seabrook locations with in-plane expansion beyond the plateau levels seen in the test program.

Request

1. Explain whether (and how) the apparent assumption that ASR expansion in Seabrook structures will behave similarly to the test specimens (i.e., in-plane expansion will plateau at relatively low levels and through-thickness expansion will dominate, and overall ASR behavior is similar) will be validated or corroborated through the service life of the plant.

2. Provide justification for the statement that "a limit on in-plane expansion is not necessary," considering the operating experience noted above and its potential impact on structural capacity. Explain how it can be determined that Seabrook structures are behaving similarly to the test specimens regarding expansion impact on structural limit states (i.e., flexure, shear, reinforcement anchorage) without quantitative limits on in-plane or volumetric expansion. If limits are proposed, provide a technical justification for the limit and associated monitoring interval.

3. Explain how it was determined that areas at Seabrook exceeding the expansion (either in-plane or volumetrically) seen during testing are bound by the test results regarding structural limit states.

4. Update the UFSAR and LAR as necessary to reflect the responses provided to the above requests.

NextEra Energy Seabrook Response to RAI-M2, Request #1

As discussed in the most recent submittal of the ASR AMP from December 2016 (Reference 1), NextEra Energy Seabrook will perform a periodic assessment of expansion behavior. This action will include a comparison of in-plane expansion to through-thickness expansion that will check that expansion is initially similar in all directions but becomes preferential in the through-thickness direction. NextEra Energy Seabrook is completing an initial assessment of expansion behavior and plans to perform a follow-up assessment no later than 2025. Should the License Renewal be approved, NextEra Energy Seabrook will perform additional assessments of expansion behavior every 10 years.[1] The interval between assessments is intended to allow time for noticeable expansion so changes in expansion behavior can be identified.

NextEra Energy Seabrook maintains the ASR AMP for the purpose of the License Renewal Application, but also maintains the provisions of the ASR AMP in the Structures Monitoring Program (SMP) (Reference 7) that is currently being implemented. NextEra Energy Seabrook will update the SMP (Reference 7) to match the content from the ASR AMP. The LAR refers to the SMP for details on expansion

[1] The LAR addresses the current licensing basis whereas the License Renewal Application (which is in review by the NRC) addresses the period of extended operation (PEO). Periodic assessments of expansion behavior during the PEO are mentioned solely to provide the NRC staff with a complete picture of the effort and facilitate consistency between two licensing processes.

monitoring, so the action to update the SMP will also update the LAR by reference. (The NRC RAIs refer to the "ASRMP", which appears to be a reference to Section 3.8.4.7.2 of the UFSAR Markup pages in the LAR. The information discussed in this UFSAR section is located in the SMP.)

In addition to the periodic assessment of expansion behavior and routine monitoring, NextEra Energy Seabrook has committed to perform an in-plant corroboration study to check that the correlation between elastic modulus and expansion that is defined in MPR-4153 (Reference 5) is applicable at Seabrook Station. Although the primary objective of this study is to check the correlation, it also provides assurance that expansion behavior observed in the MPR/FSEL test programs is comparable to the plant. Additional details on the corroboration study are provided in the RAI-M3 response, and Appendix B of this report.

<u>NextEra Energy Seabrook Response to RAI-M2, Request #2</u>

As discussed in the most recent submittal of the ASR AMP from December 2016 (Reference 1) and clarified in the response to the more recent RAI B.2.31A-A1-1 (Reference 3), NextEra Energy Seabrook will apply acceptance criteria for both through-thickness expansion and volumetric expansion. NextEra Energy Seabrook has adopted the recommendations from MPR-4273 (Reference 5), which was included with the LAR submittal, and includes a description of the approach for monitoring volumetric expansion. The equation for calculating volumetric expansion includes a term for in-plane expansion, so NextEra Energy Seabrook will be considering in-plane expansion within the monitoring approach. Accordingly, application of a criterion solely for in-plane expansion is not necessary. In fact, such a criterion would not be appropriate, as discussed in the response to Request #3.

The limit on volumetric expansion will be [redacted]%, which is the maximum volumetric expansion observed on a test specimen from the MPR/FSEL Shear Test Program. This limit is more restrictive than the maximum volumetric expansion observed on a test specimen for the MPR/FSEL Reinforcement Anchorage Test Program, which was [redacted]%. (Reference 5)

As discussed in the recent response to RAI B.2.31A-A1-1, NextEra Energy Seabrook will determine volumetric expansion concurrently with monitoring of in-plane and through-thickness expansion. For Tier 3 locations, such monitoring will occur every six months.

The justification for a six-month monitoring interval is the same as for in-plane and through-thickness expansion monitoring. ASR is a relatively slow-moving process and the concrete at Seabrook Station has been in existence for decades. Expansion monitoring at Seabrook Station over the last several years has confirmed that changes to the condition of the concrete resulting from ASR progression are very slow (Reference 8 and 10). There is no reason to expect a sudden acceleration of ASR development that would result in rapid structural degradation. The six-month interval is judged to be conservative and sufficient to detect any unexpected degradation acceleration prior to exceeding any of the applicable limits described above.

NextEra Energy Seabrook Response to RAI-M2, Request #3

Based on current in-plane and through-thickness expansion values (References 8 and 10), the maximum observed volumetric expansion is [redacted]%, which is well below the [redacted]% limit.

With respect to in-plane expansion, the highest Combined Cracking Index (CCI) value observed to date from the plant (2.48 mm/m or 0.248%; Reference 10) is slightly greater than the highest CCI value from the MPR/FSEL test programs ([redacted] mm/m; Reference 9). However, NextEra Energy Seabrook does not evaluate ASR progression solely on in-plane expansion, because this approach is not necessary or appropriate. Appendix A provides a detailed discussion of the rationale for this conclusion. Key points are summarized as follows:

- In-plane expansion is already being monitored, because it is a component of the calculated volumetric expansion. Volumetric expansion is an appropriate approach for monitoring ASR progression, since ASR-induced expansion is a volumetric effect.

- In-plane expansion will also be periodically evaluated as part of an expansion behavior assessment. Specifically, the December 2016 submittal of the AMP (Reference 1) committed to a periodic check that overall expansion behavior at Seabrook Station is comparable to the MPR/FSEL test specimens. This periodic check includes a comparison of in-plane expansion to through thickness expansion of all monitored points, and is expected to show that in-plane expansion curtails at low levels while through-thickness expansion continues to increase. This commitment supplements the volumetric expansion limit to assure comparable expansion behavior between the plant and the MPR/FSEL test programs.

- In-plane expansion at levels slightly greater than observed in the MPR/FSEL test programs (i.e., within the volumetric expansion criterion) will not adversely impact structural performance. ASR-induced expansion in the in-plane directions produces chemical prestressing in concrete with two-dimensional reinforcement mats, like the configuration at Seabrook Station. As described in literature and demonstrated in the MPR/FSEL test programs, chemical prestressing benefits shear capacity and does not adversely affect flexural capacity or reinforcement anchorage performance at the levels of expansion observed in the MPR/FSEL test programs. The test results showed no indication that this effect would be lost at slightly higher levels of ASR progression. In fact, moment-curvature calculations performed to support analysis of the test data indicate that the Code equations for moment and yield capacity would continue to be valid at in-plane expansion levels of 0.4% (Reference 9).

- In-plane expansion at Seabrook Station is presently consistent with in-plane expansion observed in the laboratory specimens. The highest CCI value from the MPR/FSEL test programs was [redacted] mm/m (Reference 9); presently, the highest value from the plant is 2.48 mm/m (Reference 10). The average CCI value from the MPR/FSEL test specimens that reached the "plateau" was [redacted] mm/m; presently, the average CCI value for Tier 3 locations at Seabrook Station is 1.32 mm/m (Reference 10). The MPR/FSEL test programs identified that the two-dimensional reinforcement mats confined in-plane expansion to approximately [redacted]%, based on measurements of embedded reference pins (Reference 6). Subsequent expansion was primarily in the through thickness direction. Reinforced concrete at Seabrook Station will reach a similar "plateau" with in-plane expansion values from ASR that should be comparable to the test data. In fact, since there are more data points from the plant, it is not surprising that the maximum CCI value from the plant is further from the average "plateau" value. Measured CCI values at the plant are consistent with expected expansion behavior.

- Measurement of in-plane expansion for some locations at Seabrook Station is not directly comparable to that from the MPR/FSEL test programs. At Seabrook Station, external loads (e.g., load applied by expansion from backfill) can initiate cracking or exacerbate (i.e., open up) existing cracks, both of which impact CCI measurements. In contrast, the MPR/FSEL test programs isolated the effect of ASR, so the in-plane cracking was predominantly from expansion of ASR gel. To this end, all expansion measurements were prior to the application of an external load. Therefore, other factors may cause the apparent CCI at Seabrook Station to exceed the observed CCI of the test specimens.

    - Load testing as part of the test programs produced cracking from the applied load that increased the apparent in-plane expansion. Although this apparent expansion could not be directly measured during load testing, it is estimated to have produced in plane expansion levels much higher than observed at the plant.

- The acceptance criterion for volumetric expansion is conservatively based on the in plane expansion from the test specimens before load testing, which does not include the influence of applied load on apparent expansion.

- An extensive literature review performed throughout the course of the multi-year ASR project has not identified any indication from industry documents or researchers that direction of expansion has a significant effect on applicability of Code equations for shear capacity, flexural capacity or reinforcement performance, with the exception of chemical prestressing, which benefits or has no effect on structural performance for these limit states within the range of ASR progression addressed by the MPR/FSEL test programs. (In-plane expansion can adversely affect the axial compression limit state, which NextEra Energy Seabrook explicitly evaluates as part of building-specific structural analyses.)

NextEra Energy Seabrook Response to RAI-M2, Request #4

NextEra Energy Seabrook will update the Structures Monitoring Program to reflect the monitoring strategy for volumetric expansion. In addition, Table 3.8-18 of the UFSAR will be updated to include the volumetric expansion criterion.

RAI-M3

Background

Section 3.2.3 of the LAR states that adjustments to Seabrook design code methodologies are unnecessary if ASR through-thickness expansion levels remain below limits established during the MPR/FSEL structural testing. Section 3.5.1 states that extensometers will be installed to monitor future expansion but that the expansion prior to extensometer installation must be estimated. To estimate prior through-thickness expansion, LAR Section 3.5.1 states that an empirical correlation will be used that was developed based on data from the MPR/FSEL structural testing, and forms a technical basis for direct application of LSTP results regarding structural limit states to Seabrook structures by monitoring expansion limits. The correlation curve relates reduction in normalized concrete elastic modulus measurements with through-thickness expansion for levels of ASR expansion achieved in the LSTP. Since this correlation is an empirical, first-of-a-kind correlation that has not been corroborated with data from Seabrook structures or other ASR-affected structures in the field, it may need to be validated throughout the service life of the plant.

Issue

In the December 23, 2016, response to license renewal RAI B.2.1.31 A-A4, the licensee noted that the correlation will be corroborated once at least 2 years prior to the period of extended operation by taking cores in the vicinity of three extensometers. However, no technical justification is provided for the adequacy of three locations or for corroborating the correlation with one point in time. The NRC staff is not clear how the proposed approach will corroborate that the correlation methodology remains valid as ASR progresses through the service life of the plant, if it is not reevaluated. In addition, there is no discussion of any evaluation planned for some future date(s) or expansion levels to quantitatively corroborate that the correlation between through-wall expansion and reduction in normalized concrete elastic modulus continues to match the proposed curve. Further, it is not clear (1) what criteria will be used to determine whether the data correlates and (2) how locations will be selected such that the measurements adequately bound the population of Tier 3 locations.

Request

1. Explain how it will be determined whether the data taken for Seabrook structures match the correlation curve derived from large-scale test specimens.

2. Provide a technical basis for the adequacy of taking three measurements at Seabrook at a single point in time to corroborate the correlating curve derived from large-scale test specimens. In addition, discuss how locations will be selected such that the measurements adequately bound the population of Tier 3 locations.

3. Provide a technical justification that the timing of the corroboration activity (and number of times it will be performed) is sufficient to demonstrate that an adequate validation of the correlation curve exists and will be ensured through the life of the plant. The response should address both the adequacy of the correlation, as well as the similarity of ASR behavior between the test specimens and the structures at Seabrook.

NextEra Energy Seabrook Response to RAI-M3

The purpose of the corroboration study, as described in the December 23, 2016 response to RAI B.2.1.31A-A4 (Reference 1), is to use in-plant data to corroborate the empirical correlation presented in MPR-4153 (Reference 5). NextEra Energy Seabrook considers that the correlation has already been validated by the assessment presented in MPR-4153 using literature data, and that the corroboration study is a check of that conclusion. The details of the corroboration study are consistent with this perspective.

This response provides an overview of the technical basis for the correlation and then proceeds to respond to the specific topics from the RAIs. The detailed procedure for conducting the corroboration study is included in Appendix B.

Technical Basis for the Correlation

Consensus with Published Sources

The foundation of the approach for determining expansion in the through-thickness direction prior to installing an extensometer is the universal agreement among published sources that elastic modulus decreases with ASR progression (References 11, 12, 13, and 14). This relationship has been investigated quantitatively by many researchers (References 15, 16, 17, and 18). Therefore, the relationship between elastic modulus and expansion cited in MPR-4153 reflects the existing knowledge base, and is not first-of-a-kind.

NextEra Energy Seabrook could have used the literature data to produce a generic correlation between reduction of elastic modulus and expansion that is entirely independent of the MPR/FSEL test programs. However, NextEra Energy Seabrook opted for a more precise relationship that was more representative. The relationship between elastic modulus and expansion that is presented in MPR-4153 is based exclusively on data from the MPR/FSEL test programs, which has several important advantages:

- All data are from cores removed from reinforced concrete that has a reinforcement configuration that is comparable to Seabrook Station. Accordingly, the test data reflect ASR development in a stress field that was more representative of an actual plant structure than literature data, which are typically based on unconfined cylinders.

- The cores were obtained from test specimens that have a concrete mixture design that is as representative of Seabrook Station as practical.

- The test programs were conducted under a Nuclear Quality Assurance program that satisfies the requirements of 10 CFR 50, Appendix B.

In summary, the correlation presented in MPR-4153 is a refinement of the well-documented relationship between elastic modulus and ASR-induced expansion that improves the precision for specific application at Seabrook Station.

Evaluation of Correlation in MPR-4153

MPR-4153 included an evaluation of the literature data relative to the correlation, which confirmed that the trends are comparable and provides reasonable assurance that the correlation can be applied at the plant. Although the literature data do not have the advantages of the test specimens discussed above, it is still valuable for an evaluation and corroboration of the correlation.

The literature data are from a variety of test specimens, including unconfined test cylinders and prisms that have a structural context that is different from the large-scale reinforced beams in the MPR/FSEL test programs. Even with these differences, the data show a trend that is comparable to the correlation. Considering that the structural members at Seabrook Station have a structural context that is much more similar to the MPR/FSEL test specimens (reinforcement configuration, concrete mixture design, large-scale size, etc.), it is reasonable to conclude that the relationship between elastic modulus and through-thickness expansion at the plant will also reflect the correlation.

In addition, NextEra Energy Seabrook will also perform a corroboration study using in-plant data, as discussed in Reference 1. The scope and methodology of the corroboration study is commensurate with the fact that an evaluation of other information (i.e., independent laboratory data) has already concluded the correlation is applicable to concrete at Seabrook Station. By its nature, the corroboration study cannot provide a fully independent data set, because through-thickness expansion data since original construction cannot be obtained using the extensometers. Thus, the corroboration study is a check of the original evaluation performed using laboratory data in MPR-4153.

NextEra Energy Seabrook Response to RAI-M3, Request #1
Approach for Corroboration Study

The concept of the corroboration study is to obtain expansion data from the plant that can be used to check the accuracy of the correlation and conservatism of the methodology in a manner that is as independent as practical. The discussion below provides a summary of the approach. Appendix B provides a detailed discussion of how the corroboration study will be performed with supporting examples.

For expansion in the through-thickness direction, the extensometer provides the capability to obtain a direct measurement of differential expansion for the period of time since the extensometer was installed. NextEra Energy Seabrook plans to monitor total through-thickness expansion by adding the measured differential expansion (from the extensometer) to the pre-instrument expansion determined using the correlation at the time the extensometer was installed.

After sufficient through-thickness expansion has occurred since extensometer installation, NextEra Energy Seabrook will perform the corroboration study by obtaining new cores from the vicinity of 20% of the extensometers[2], determining the elastic modulus, and using the correlation to estimate total through-thickness expansion.

In summary, this value will be compared to the expansion determined using the sum of the differential expansion measured by the extensometer and the pre-instrument expansion (using the correlation) at the time the extensometer was installed. Agreement between the two results will demonstrate satisfactory corroboration. (See

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[2] The number of cores taken at a given extensometer location will vary depending on how many usable test specimens can be obtained from a given core. The goal is to obtain at least four test specimens per extensometer location—two specimens for modulus testing and two specimens for compression testing.

Appendix B for a detailed explanation of the approach for analyzing data and defining acceptance criteria.)

The MPR-4153 methodology includes a [redacted]% reduction of the normalized elastic modulus to provide conservatism in the treatment of the data. The corroboration study will use this aspect of the methodology to establish an acceptance criterion. Specifically, the corroboration is successful if the expansion determined using the [redacted]% reduction exceeds the best estimate expansion (determined using the extensometer measurement and the correlation without the offset). Extensometer locations that fall outside the acceptance criterion will be evaluated with regard to the implications for corroboration of the correlation and the conservatism in the methodology. If necessary, NextEra Energy Seabrook may adjust the reduction of normalized elastic modulus to ensure the expansion-to-date values are conservative.

NextEra Energy Seabrook Response to RAI-M3, Request #2

Number of Locations and Selection Criteria

In the December 2016 RAI response submittal (Reference 1), NextEra Energy Seabrook stated that three locations would be included in the corroboration study. Since the time of that submittal, the remainder of the extensometers have been installed and locations have been identified with greater through-thickness expansion than were known when Reference 1 was submitted. Therefore, the applicable range of the correlation has increased. NextEra Energy Seabrook will increase the minimum number of locations involved in the corroboration study to 20% of the extensometer locations, which corresponds to eight of the 38 ASR-affected locations that are presently instrumented. The sample size of 20% is consistent with typical sampling rates identified in the NRC GALL for inspections and tests of a variety of components and systems. If NextEra Energy Seabrook installs more extensometers prior to conducting the corroboration study, additional locations may be necessary to satisfy the 20% requirement.

NextEra Energy Seabrook will select locations for the corroboration study that exhibit differential expansion that meet the following two criteria:

1. Differential through-thickness expansion measured with an extensometer is at least 0.1%. This criterion ensures that the true expansion levels are sufficiently different to effectively check the correlation.

2. The set of locations cover the range of "best-estimate" through-thickness values observed at Seabrook Station at the time of the corroboration study.[3]

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[3] In this context, "best-estimate" refers to the through-thickness expansion value determined using the MPR-4153 correlation without applying the [redacted]% reduction to the normalized elastic modulus.

The largest best-estimate pre-instrument through-thickness expansion to date is [redacted]% (Reference 19). It is not expected that corroboration of the curve will be necessary at greater than [redacted]% best-estimate expansion, because any future extensometers will be installed in areas that have just transitioned from Tier 2 to Tier 3 and will therefore be at lesser ASR progression. The extensometers that have been installed cover a range of ASR progression levels. These locations were initially identified based on the measured in-plane expansion, which was determined to be up to 0.25% (Reference 10). Additional extensometers will be installed at other locations if in-plane expansion proceeds to the point that it exceeds 0.1%. Because ASR progression will be identified earlier in such cases than for the initial series of extensometers, the exhibited through-thickness expansion is expected to be less than the maximum identified from the initial series.

However, in the future, if NextEra Energy Seabrook installs a new extensometer and identifies pre-instrument expansion that exceeds [redacted]%, then NextEra Energy Seabrook will obtain and analyze additional cores to extend the range of the corroboration study.

NextEra Energy Seabrook Response to RAI-M3, Request #3
Timing

Although the impact of ASR is expected to be more pronounced as concrete ages, time is not an explicit parameter of interest in the MPR-4153 correlation, which relates modulus of elasticity to expansion level. Accordingly, the basis for sampling in the corroboration study relates to having appropriate expansion levels, as previously discussed.

Nevertheless, NextEra Energy Seabrook will perform the corroboration no later than 2025, and, should License Renewal be approved, once 10 years after the initial study, as discussed below.[4] The timing for the corroboration studies is selected to provide enough time for a noticeable change in through-thickness expansion between extensometer installation and the initial study, and between the initial study and the subsequent study. A long interval is necessary as ASR expansion is a slow process. This approach will corroborate that the MPR-4153 correlation is independent of the rate of ASR progression.

Initial Corroboration Study

NextEra Energy Seabrook plans to perform the initial corroboration study prior to the end of its current operating license when both of the location selection criteria can be satisfied. It is possible that there will not be enough locations with differential expansion of 0.1% prior to the end of the current operating license or that these locations do not

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[4] The LAR addresses the current licensing basis whereas the License Renewal Application (which is in review by the NRC) addresses the period of extended operation (PEO). The subsequent corroboration study during the PEO is mentioned solely to provide the NRC staff with a complete picture of the effort and facilitate consistency between two licensing processes.

sufficiently cover the applicable range of the correlation. If the set of extensometer data do not support meeting the location selection criteria, NextEra Energy Seabrook will still perform the corroboration study in 2025 using the best available data.

Subsequent Corroboration Study

NextEra Energy Seabrook will repeat the corroboration study to confirm that expansion behavior at Seabrook Station continues to reflect expansion behavior of the test specimens. NextEra Energy Seabrook will perform the repeat corroboration study 10 years after the initial corroboration study. In the event that the location selection criteria (i.e., differential expansion measurement of 0.1% with the extensometer for a set of locations across the range of the correlation that applies at Seabrook Station) have not been satisfied at the time of the repeat corroboration study, NextEra Energy Seabrook will evaluate the need to repeat or augment the corroboration study when the criteria are met.

RAI-T1

<u>Background</u>

LAR Section 2.1.1 states, in part:

> *... the structures and concrete anchors are operable but degraded, and structures, systems, and components housed within the structures are operable. NextEra is currently evaluating all seismic Category I structures at Seabrook with indications of ASR to verify that structures continue to satisfy the ACI 318-71 and ASME Code acceptance criteria, as appropriate...*

LAR Section 3.1 .3 states, in part:

> *Seabrook station uses cast-in-place anchorages and post-installed anchors. The strength of the concrete in which an anchor is embedded must be sufficient to ensure the anchor is capable of sustaining loads equal to the ultimate loads specified by the anchor manufacturer.*

LAR Table 4 provides ASR expansion limits for structural limit states, including concrete anchors, that are based on the ASR expansion limits to which anchors were tested in the Seabrook-specific MPR/FSEL LSTP.

<u>Issue</u>

LAR Enclosure 2 (MPR-4288), Subsection 3.2.4 states that cast-in-place anchorages in use at Seabrook include embedded plates (with Nelson studs), embedded Unistrut type channels, Richmond studs, and anchor bolts. Further, the LAR states that post-installed anchors in use at Seabrook include both expansion anchors (Hilti Kwik bolts) and undercut anchors (Drillco Maxi-Bolts). In LAR Enclosure 3 (MPR-4273), Section 5.1.1 states that the Hilti Kwik Bolt 3 expansion anchor and the Drillco Maxi-Bolt undercut anchor were used in the test program to represent anchors in Seabrook structures.

Request

1. Provide the technical justification explaining why the Hilti Kwik Bolt 3 and the Maxi-Bolt post-installed anchors were chosen for testing in the LSTP Anchor Test Program, as opposed to the other anchor types (manufacturer) installed at Seabrook.

2. Provide the technical justification explaining why cast-in-place anchors (equipment anchors for pumps, motors, etc.) were not included in the test program and why the test results are applicable to cast-in-place anchors at Seabrook.

NextEra Energy Seabrook Response to RAI-T1, Request #1

It is important to highlight that the purpose of the MPR/FSEL Anchor Test Program was to identify the effect of ASR on the load-transfer mechanism between the anchor and the concrete (i.e., the effect of ASR on anchor capacity). The testing was not intended to requalify the anchors at Seabrook Station. The path through which load is transferred from the anchor to the concrete is the primary consideration for representativeness among anchors.

As discussed in the test report for the Anchor Test Program, MPR-3722 (Reference 21), the Hilti Kwik Bolt 3 (KB3) and Drillco Maxi-Bolt were selected for testing because they represent the load-transfer mechanism of all anchors at Seabrook Station. The anchor size and embedment depth were selected to be consistent with the anchor population at Seabrook Station.

Hilti Kwik Bolt 3

The KB3 is a wedge-type expansion anchor that is installed by hammering the anchor into a drilled hole and set by applying torque to the nut. This torque draws the expansion cone into the expansion element. The expansion anchor is torque-controlled because the expansion element needs to be forced between the expansion cone and the drilled hole with sufficient preload to sustain the proper friction fit, but without damaging the expansion element. External load is transferred by the frictional resistance from the conical wedge to the spreading element, and from the spreading element to the surrounding concrete (Reference 22).

The KB3 is presently the preferred torque-controlled expansion anchor for NextEra Energy Seabrook. It is a more modern version of the Kwik Bolt 1 (KB1), Kwik Bolt Super, and Kwik Bolt 2 (KB2) anchors that have also been used at Seabrook Station. Design changes during evolution of the anchor bolt were minor (e.g., surface geometry of expansion wedges to promote engagement with concrete, compatibility with particular installation tools, adding protection of the bolt threads during installation) (References 23 through 27). The KB3 is also representative of the Hilti Kwik Bolt Super, which was also used at Seabrook Station. The Kwik Bolt Super is similar to the KB1, but has a larger loading capacity. In summary, the basic design of the anchor family has not significantly changed (Reference 21). All of the Hilti Kwik Bolt designs interact with the concrete in the same way and transfer load from the bolt to the concrete using the frictional resistance of the expansion wedge on the concrete.

The test data from the Anchor Test Program indicate that the failure mode was anchor pullout or load drop by greater than 30% for the vast majority of tests ([redacted] or ~90%) (Reference 21). These failure modes are directly related to the frictional load transfer mechanism, and are most common with expansion-type anchors (Reference 22). Thus, the results demonstrate that the Anchor Test Program effectively examined performance of the frictional load transfer mechanism that is characteristic of expansion anchors.

Drillco Maxi-Bolt

The Drillco Maxi-Bolt is the only undercut anchor used at Seabrook Station. Therefore, there was no need to consider other manufacturers for undercut anchors.
An undercut anchor is installed in a special drilled hole in cured concrete. The hole is drilled twice: first with a conventional drill bit, second with an undercutting tool that creates a larger diameter cone-shaped pocket at the desired embedment depth. The anchor is installed by hammering the anchor into the drilled hole and set by applying torque to the nut to expand the anchor into the cone-shaped pocket.

The approach for the MPR/FSEL test program included testing of the Maxi Bolts at the proper embedment depth and testing at a reduced embedment depth. At the proper embedment depth, steel failure was the mode by which the anchors failed. Because the purpose of the test program was to investigate concrete degradation, another set of tests was conducted with reduced embedment depth that would produce concrete failure. These tests showed concrete breakout as the failure mode. These results were expected considering that undercut anchor bolts rely on a positive bearing surface with the concrete (Reference 22).

Comparison to Industry Standards

The selection of anchor bolts for the MPR/FSEL test program was informed by industry standards and accepted practices for comparable evaluations.

- NUREG CR-5563 (Reference 22) is the technical basis for the NRC to establish a regulatory position on fastening to concrete. NUREG CR-5563 partitions the database of available test data on anchor depth, edge effects, and whether the anchor is functioning independently or within a group. A secondary partition separates the data by anchor type, into two groups: (1) cast-in-place and undercut anchors, and (2) expansion and sleeve anchors. This partitioning reflects the common load transfer mechanism within each grouping. The approach from the MPR/FSEL test program addresses both of these groups (i.e., the Maxi-Bolts address Group 1 and the Kwik Bolts address Group 2).

- ACI 318 (Reference 29) and ACI 349 (Reference 49) provide requirements for concrete anchors and include an equation for determining concrete breakout strength for anchors loaded in tension. This equation includes terms for basic concrete strength and projected failure area, with adjustment factors to account for edge effects and the presence of cracking. These equations do not depend on the specific type of expansion anchor or manufacturer, indicating that producing separate evaluations for such anchors is not necessary.

- ACI 318 (Reference 29) and ACI 349 (Reference 49) also provide requirements for anchor pullout strength, and refer to ACI 355.2 (Reference 51) for post-installed expansion and undercut anchors. If an anchor that has been previously tested is modified, ACI 355.2 includes a provision to forego testing of the modified anchor if the nature and significance of the modifications do not affect anchor performance. The decision to test only the KB3 expansion anchors is consistent with this approach, considering the minor design differences between the anchors and the lack of impact on the load transfer mechanism.

<u>NextEra Energy Seabrook Response to RAI-T1, Request #2</u>

Cast-in-place anchors were not specifically included in the Anchor Test Program, because they are represented by the Drillco Maxi-Bolts (Reference 21)

Undercut anchors are similar to cast-in-place anchors as they both utilize a positive bearing surface to transfer load to the concrete. As previously discussed, the primary consideration for representativeness among anchors is the path for load transfer from the anchor to the concrete. The installation process for Maxi-Bolts includes use of a special undercutting tool that creates a pocket. When the anchor is set, the expansion sleeve is deployed into the pocket creating a bearing surface between the sleeve and the undercut hole. This bearing surface is comparable to the interface between a cast-in-place anchor and the concrete that cures around the anchor, because both cases rely on a positive bearing surface rather than friction (like the Hilti Kwik Bolts).

At full embedment depth, the Maxi-Bolt anchors are limited by steel failure (i.e., the embedment depth is specified such that the concrete is stronger than the anchor itself). In fact, the design basis for Seabrook Station did not require specific qualification testing for cast-in-place or undercut anchors, because of the large margin between concrete failure and steel failure. The MPR/FSEL test programs included tests at full embedment depth, which showed that the anchors were still limited by steel failure. The MPR/FSEL test program included additional tests at reduced embedment depth, which produced concrete breakout failures. This testing provided information on the effect of ASR on the concrete breakout mode. Thus, the test results demonstrate that the test program effectively examined performance of load transfer via a positive bearing surface with the concrete, which is characteristic of undercut anchors and cast-in-place anchors. (Reference 21)

Cast-in-place anchors may also be able to transfer load through the bond between the anchor shank and the surrounding concrete (Reference 22). This extra load transfer mode is not available to post-installed undercut anchors. Accordingly, NextEra Energy Seabrook's approach of using the test results for post-installed undercut anchors to represent cast-in-place anchors is conservative. This evaluation is consistent with the equations in ACI 318 (Reference 29) and ACI 349 (Reference 49) that allow use of higher adjustment factors for cast-in-place anchors (resulting in higher calculated anchor capacities).

The discussion from the Response to Request #1 regarding comparison to industry standards also applies to the conclusion that the Maxi-Bolts satisfactorily represent cast-in-place anchors.

- Undercut anchors and cast-in-place anchors are grouped together in NUREG CR-5563 (Reference 22).

- In ACI 318 and ACI 349 (Reference 49), the magnitude of the adjustment factors depends on whether the anchor is cast-in-place or post-installed. The adjustment factors for the cast-in-place case are higher than the factors for the post-installed case, because field observations and tests show that strength of cast-in-place anchors exceeds that of post-installed anchors (Reference 29). Hence, performance of post-installed anchors bounds the performance of equivalent cast-in-place anchors. Accordingly, the MPR/FSEL test program approach of using post-installed undercut anchors to represent cast-in-place anchors is conservative.

RAI-T2

<u>Background</u>

LAR Section 3.2 states that the evaluation for impact of ASR on Seabrook structures considered data from the MPR/FSEL LSTP conducted specifically for Seabrook by MPR Associates in collaboration with FSEL at the University of Texas at Austin. It also states that the specimens that were used in testing were structurally representative of concrete used in constructing Seabrook structures. LAR Section 3.2.1 states: "[t]he LSTP included testing of specimens that reflected the characteristics of ASR-affected structures at Seabrook Station. Tests were completed at various levels of ASR cracking to assess the impact on selected limit states." The LSTP is described in MPR-4273 (LAR Enclosure 3). Section 3.1.1 of MPR-4273 notes that the concrete mix design for the fabricated specimens was specifically designed to accelerate ASR development. This allowed levels of ASR beyond that seen at Seabrook after only a short time (i.e., maximum of 2.5 years for the LSTP).

LAR Section 2.1 states that a root cause investigation into ASR at Seabrook concluded that the original concrete mix designs used a slow-reacting, coarse aggregate that was susceptible to ASR, but passed the ASTM C289-71 aggregate reactivity test during construction. This section also states that an ASTM C289-71 test was an appropriate test at the time of construction, but it is now known that the test may not accurately predict the reactivity of slow-reacting aggregates, such as the aggregate used at Seabrook.

Issue

The LAR does not discuss the potential influence, with respect to structural effects, of the use of significantly accelerated development of ASR in the large-scale test specimens versus the slow natural development of ASR over time in Seabrook structures. The development of creep effects in concrete depends on the time to loading following the concrete pour; the larger the elapsed time the smaller the creep effects will be. The development of ASR internal pre-stress load during the early age of concrete following casting of the test specimens could result in ASA-induced in-plane creep effects in the test specimens that counteract and thereby reduce the in-plane ASR expansion effects measured. This early age creep phenomenon in test specimens is potentially unconservative and is not likely to occur in the normal slow development of ASR where the internal ASR pre-stress load develops a very long time duration after concrete has set.

Request

1. Regarding structural effects, explain how it was determined that the LSTP results from test specimens with accelerated ASR are not unconservative, compared to Seabrook structures with normal slow ASR development.

2. Explain how the possible early age concrete creep effects due to accelerated ASA-induced pre-stress load were accounted for in the LSTP or in the application of the LSTP results to Seabrook structures . If early age creep effects due to ASR load in the test specimens were determined to be insignificant, provide a technical justification for this conclusion.

NextEra Energy Seabrook Response to RAI-T2, Request #1

NextEra Energy Seabrook investigated the potential effects of accelerated aging for the MPR/FSEL test program and thoroughly monitored expansion in the test specimens and at the plant. None of these efforts identified any reasons to expect that accelerated aging would produce unconservative results and necessitate a change in approach. Additionally, in the future, NextEra Energy Seabrook will perform assessments of concrete at Seabrook Station that will further investigate representativeness of expansion behavior. These assessments include:

- A periodic assessment of expansion behavior that focuses on similarity of expansion behavior between the plant and the MPR/FSEL test specimens. In particular, it looks at relative expansion in the in-plane versus through-thickness directions, and the margin relative to the expansion limits from the test programs, including volumetric expansion. (See response to RAI-M2 for details.)

- Corroboration studies of the correlation of modulus versus through-thickness expansion that use in-plant data to corroborate the correlation derived from the MPR/FSEL test programs. These studies also provide insights on the similarity of expansion behavior.

If these assessments identify expansion behavior different than what was observed in the MPR/FSEL test programs, NextEra Energy Seabrook will address the potential for application of the test results to be non-conservative.

Literature Review

Accelerated ASR development is an approach that has been used by research test programs from around the world to investigate structural performance of ASR-affected concrete (e.g., References 14, 30, 31, and 32). None of these other test programs have identified any significant adverse effect on the applicability of structural test results due to accelerated ASR development. Additionally, industry guidelines on addressing ASR are largely based on data obtained from laboratory testing of concrete with accelerated ASR development. Reputable laboratories continue to use this approach today, as evidenced by the ongoing NRC research on ASR being conducted at the National Institute of Standards and Technology (NIST) (Reference 33) and ongoing Department of Energy research at the Oak Ridge National Laboratory (Reference 34), both of which are accelerating ASR development. Leveraging the experience of other researchers, there is no reason to expect that structural test results from the MPR/FSEL test programs would be compromised due to accelerated ASR development. The Response to Request #2 addresses the specific mechanism of early-age creep effects.

Research programs identified in literature commonly used accelerated ASR development to ensure that results can be generated in a reasonable timeframe. This consideration was also applicable for NextEra Energy Seabrook. ASR has been developing at Seabrook Station for decades, so the MPR/FSEL test programs needed to accelerate ASR progression in the test specimens to obtain levels that could represent the current condition of the plant. Normal slow ASR development for the test program would not have produced results in a usable timeframe.

Expansion Monitoring and Future Assessments

Consistent with industry guidelines for monitoring ASR (References 11, 12, 13, and 14), the MPR/FSEL test programs measured expansion to characterize ASR progression. In addition to expansion measurements by embedded pins, a custom frame, and CCI, the test programs also included petrographic examination of cores. None of these methods identified any departure from "normal slow" expansion behavior that would cause structural performance to be non-representative of the plant. (Reference 9)

In addition, NextEra Energy Seabrook plans to perform in-plant corroboration studies (see response to RAI-M3 for details) and periodic expansion behavior assessments that will provide additional information confirming comparable expansion behavior between the test specimens and structures at the plant. If these studies identify expansion behavior different than what was observed in the MPR/FSEL test programs, NextEra Energy Seabrook will evaluate the implications, including the potential for application of the test results to be non-conservative.

NextEra Energy Seabrook Response to RAI-T2, Request #2

The MPR/FSEL test programs do not explicitly address early-age concrete creep effects, but the approach of monitoring ASR development by measuring expansion inherently accounts for creep. Nevertheless, NextEra Energy Seabrook performed a more detailed analysis and determined that early-age creep effects were insignificant. To the extent that such effects do exist, they would produce results in the test specimens that are comparable to the situation at Seabrook Station.

Creep Mechanism and Effect of Early-Age Loading

Creep strain is the time-dependent increase in strain under sustained load taking place after the initial strain at loading (Reference 35). Creep increases with the magnitude and duration of the applied load. Creep strain also increases with materials that are less rigid; in concrete, lower compressive strength corresponds to lower elastic modulus and less rigidity.

Early-age concrete creep effects result from the fact that concrete is less rigid soon after it is placed, when compared to concrete that has hydrated for a long period of time. As discussed in ACI 209.1R (Reference 35), "Increasing the period of moist cure before loading will decrease basic and drying creep...This reduction in creep is due to the combined effect of the reduction of permeability and increase in the overall concrete strength and modulus of elasticity with time." Therefore, all else equal, concrete with a load applied shortly after placement will exhibit greater creep effects than concrete with a load applied after a long period of time.

RAI-T2 suggests that accelerating ASR development could impact structural performance, because compressive loads resulting from ASR would be applied shortly after concrete placement, when the concrete is more susceptible to creep. This condition would be different than an actual structure, where normal ASR development occurs over a longer period of time, and the ASR loads are applied when the concrete is more rigid.

Expansion Measurements Account for Creep and Changes in Prestress

Creep effects may cause differences in the apparent expansion for a given level of ASR progression, when this progression is characterized in terms of extent of the chemical reaction. However, the MPR/FSEL test programs and NextEra Energy Seabrook characterize ASR development in terms of measured expansion rather than extent of reaction. This approach has the benefit of measuring a parameter that directly corresponds to the level of prestress – i.e., the amount of prestressing relates to the force required to stretch the rebar by a certain distance. Therefore, measurements of expansion in the MPR/FSEL test programs and at Seabrook Station both inherently include the effects of creep and any associated changes to the amount of chemical prestressing.

Even though any creep effects are accounted for in the approach for measuring ASR progression at both the laboratory and the plant, the potential impact of early-age creep effects was evaluated, as discussed below.

Observation from Petrographic Examination

For the MPR/FSEL test programs, petrographic examination of cores from the control test specimens confirmed that there were no indications of concrete distress in the test specimens at the time of concrete maturity (i.e., 28 days after placement) (Reference 6). Therefore, ASR-induced expansion did not induce a load on the concrete prior to maturity, when it was most vulnerable to creep. Concrete continues to hydrate beyond 28 days, which increases its rigidity and would make it less susceptible to creep after many years. However, continued hydration of concrete after 28 days only results in a modest increase in strength (i.e., up to about 20%; Reference 36). Therefore, the potential influence of early-age creep effects is small.

Quantitative Analysis of Potential Impact of Creep

In the shear test specimens[5], the observed in-plane expansion of approximately [redacted]% ([redacted] mm/m) produced a calculated tensile load in the rebar of approximately [redacted] kip, which is balanced by an equivalent compressive load in the concrete. For the test specimen geometry, this load corresponds to a compressive stress of approximately [redacted] psi,

[5] The prestressing load in the shear test specimens is higher than in the reinforcement anchorage specimens because the in-plane expansion was about the same, but the shear test specimens have a higher reinforcement ratio.

which is small compared to the average 28-day compressive strength of the test specimens of [redacted] psi.

The potential impact of creep was evaluated (Reference 50) using a method from Reference 37 that accounts for creep by defining a stress-strain curve using a reduced elastic modulus. The adjustment to the elastic modulus is determined with a creep coefficient that is a function of time, compressive strength, member geometry, and relative humidity. For the shear test specimens, this approach approximated a creep strain of [redacted] mm/m, which is small compared to the total in-plane expansion ([redacted] mm/m).

The inputs to this methodology can be adjusted to determine the difference in creep strain associated with non-accelerated ASR development in an actual structure, as follows: (1) increasing compressive strength and elastic modulus to account for greater hydration of concrete, (2) increasing the duration of the loading, and (3) decreasing the humidity to account for the absence of an environmental conditioning facility. Making these adjustments, the creep strain is [redacted] mm/m, which is comparable to the value calculated for the laboratory specimens and is still small compared to the total in-plane expansion. (The increased duration of sustained load actually resulted in greater creep for this case.)

RAI-D1

Background

GDC 2, "Design bases for protection against natural phenomena," of 10 CFR Part 50, Appendix A, requires structures important to safety to be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, and floods, considering appropriate combinations of the effects of normal and accident conditions with the effects of natural phenomena. GDC 4, "Environmental and dynamic effects design bases," requires these structures to be designed to accommodate the effects of environmental conditions associated with normal operation and postulated accidents, and appropriately protect against associated dynamic effects.

Section 2.2 of the LAR provides a summary of the proposed changes to the Seabrook UFSAR, and UFSAR markup pages are provided as Attachment 1, but neither includes any changes to UFSAR Section 3.8.5, "Foundations," to account for the effects of ASR. In addition, Section 3.3 of the LAR describes how structural evaluations will be performed on structures impacted by ASR; however, no discussion is provided for how ASR in building foundations will be addressed.

Issue

Since concrete foundations of the Seabrook Category 1 structures used the same reactive aggregate as the superstructure, it is unclear whether foundations were evaluated for the impacts of ASR and whether UFSAR Section 3.8.5 needs to be updated to account for ASR effects.

Request

Explain how the concrete foundations of Seabrook Category 1 structures have been or will be evaluated for ASR. If it is determined necessary to include evaluation of foundations in the UFSAR, provide a corresponding markup of UFSAR Section 3.8.5. If not, provide a technical basis for why it is determined that no UFSAR changes are necessary to address evaluation of foundations for ASR.

NextEra Energy Seabrook Response to RAI-D1

UFSAR Section 3.8.5, which provides the requirements for foundations, refers to other sections of the UFSAR for design requirements, including applicable codes, loading, acceptance criteria, and other requirements. The referenced sections, Section 3.8.1 for containment and Section 3.8.4 for Category I structures other than containment, have been revised by LAR 16-03 to address structures with concrete affected by ASR.

- Containment Structure Foundation. Foundation loads and load combinations are covered in Subsection 3.8.5.3, which refers to Subsection 3.8.1.3 for the containment structure foundation. The LAR 16-03 revises Subsection 3.8.1.3 to include ASR loads, and Table 3.8 1 shows that ASR loads are considered when calculating total demands.

- Other Category I Structure Foundations. Foundation loads and load combinations are covered in Subsection 3.8.5.3, which refers to Subsection 3.8.4.3 for Category I structures other than containment. The LAR 16-03 revises Subsection 3.8.4.3.a.1.a and 3.8.4.3.a.1.e to define creep, shrinkage, swelling, and ASR loads. LAR 16-03 revises Subsection 3.8.4.4.a to specify that ASR expansion loads are combined with other loads and the appropriate load factors from Table 3.8-16, which is revised to include ASR loads with the associated load factors for different load combinations required for calculating total demands for other Category I structures.

The UFSAR as amended by LAR 16-03 includes requirements for evaluating foundations affected by ASR. Therefore, revision of UFSAR Section 3.8.5 is not necessary.

The foundations of all Category I structures irrespective of their relative stiffness are evaluated or being evaluated to meet the UFSAR Subsections 3.8.5.2 and 3.8.5.3. The foundation evaluations have been included in the calculations summarizing the structural evaluation for each of the Category I structures that have been completed. The exception is calculation 150252-CA-02 (FP100985) for the CEB structure for which the foundation evaluation is not completely addressed, but a future revision of this calculation will address the foundation.

Appendix A
Correlating Parameters between MPR/FSEL Test Programs and Seabrook Station

This appendix provides a detailed discussion of the technical basis for correlating results from the Shear and Reinforcement Anchorage Test Programs to the condition of reinforced concrete at Seabrook Station, LLC (NextEra Energy Seabrook) that has been affected by alkali-silica reaction (ASR). In particular, this appendix discusses the rationale for establishing monitoring parameters for through-thickness expansion and volumetric expansion, and not in-plane expansion. Additionally, this appendix discusses the observation that the maximum apparent in-plane expansion at Seabrook Station is slightly greater than in-plane expansion of the MPR/FSEL test specimens.

1. Background

1.1. Test Programs

NextEra Energy Seabrook performed an interim structural assessment (Reference 38) for ASR-affected concrete structures that considered the various limit states for reinforced concrete and applied capacity reduction factors based on data in publicly available literature. This approach was limited by the representativeness of available data for ASR-affected concrete with reinforcement comparable to structures at Seabrook Station, particularly with respect to shear and reinforcement anchorage. Therefore, NextEra Energy Seabrook initiated large scale test programs to investigate shear capacity and reinforcement anchorage performance of ASR-affected concrete. The test programs were directed by MPR Associates and were performed at the Ferguson Structural Engineering Laboratory (FSEL) at the University of Texas at Austin (UT-Austin).

The test programs involved fabrication of test specimens that were designed to represent concrete structures at Seabrook Station. The test specimens were aged to develop ASR and load tested at varying levels of ASR progression. The test programs demonstrated that there was no adverse effect on shear capacity or reinforcement anchorage performance at any level of ASR progression exhibited by the test specimens, which included a maximum through-thickness expansion of [redacted]% ([redacted] mm/m) for shear tests and [redacted]% ([redacted] mm/m) for reinforcement anchorage tests (Reference 1).

The test method used in the MPR/FSEL test program for investigating reinforcement anchorage tested flexural capacity as well (Reference 1), even though flexure was not a limit state of concern in the interim structural assessment (Reference 38). Published literature identified that ASR does not have a significant effect on flexural capacity

(References 14 and 39). As noted above, the results from the reinforcement anchorage test program were consistent with the conclusions from published literature, in that there was no adverse effect on flexural capacity at any level of ASR progression exhibited by the test specimens.

1.2. Application of Test Results at Seabrook Station

NextEra Energy Seabrook is currently performing structural evaluations of ASR-affected concrete structures (Reference 40). These evaluations calculate the increased demand due to expansion and deformation of plant structures and compare the total demand against the structural capacity to confirm the presence of sufficient margin. The calculations use the results from the MPR/FSEL test programs to justify that there is no adverse effect on shear capacity or reinforcement anchorage performance, provided that expansion at the plant is comparable to the specimens from the test programs. To this end, NextEra Energy Seabrook monitors apparent expansion in structures to ensure that the condition of the plant is bounded by the ASR progression exhibited by the test specimens.

NextEra Energy Seabrook Commitments in NRC Submittals

The approach for performing a structural evaluation was submitted to the NRC in a License Amendment Request (LAR) (Reference 2). The LAR explicitly incorporates into the Updated Final Safety Analysis Report (UFSAR) the bounding through-thickness expansion from the large-scale test programs ([redacted]%) as limit on applicability of the test results. The proposed changes to the UFSAR also include a reference to the Structures Monitoring Program (SMP) (Reference 7) and a discussion of the provisions for the ASR monitoring. The detailed provisions for ASR monitoring are administratively managed within the SMP. The technical content in the SMP will reflect the Aging Management Program (AMP) that NextEra Energy Seabrook developed for the License Renewal Application (LRA). Changes to the AMP that are adopted as part of NRC review and RAI resolution will be included in the SMP.

Additional details contained in the ASR AMP include steps to check that the expansion behavior at Seabrook Station is similar to expansion behavior of the test specimens from the MPR/FSEL test programs. This expansion behavior check includes a periodic review to confirm that volumetric expansion is comparable to the specimens from the test programs. The approach for this assessment was described in MPR-4273 (Reference 6), which was transmitted with the LAR. Based on the more limiting volumetric expansion from the MPR/FSEL test programs, NextEra Energy Seabrook established an acceptance criterion of [redacted]%. Another aspect of the expansion behavior check is to track the progression of expansion measurements over time to assess margin for future expansion. NextEra Energy Seabrook will generate an item in the plant's Corrective Action Program (CAP) to investigate anomalous locations identified during these checks.

Current Expansion at Seabrook Station

NextEra Energy Seabrook has already been performing expansion monitoring at locations throughout the plant. The most recent expansion assessment (Reference 42) and a review of the latest expansion data (References 8 and 10) indicate that all locations have through-thickness expansion and volumetric expansion that are well below the acceptance criteria.

2. Expansion Mechanism

2.1. ASR Development

NRC Information Notice 2011-20 (Reference 43) provides a synopsis for the ASR mechanism:

> "ASR is one type of alkali-aggregate reaction that can degrade concrete structures. ASR is a slow chemical process in which alkalis, usually predominantly from cement, react with certain reactive types of silica (e.g., chert, quartzite, opal, and strained quartz crystals) in the aggregate, when moisture is present. This reaction produces an alkali-silica gel that can absorb water and expand to cause micro-cracking of the concrete."

This description of the ASR process, which is consistent with many published references (References 11, 12, 13, and 14) and discussion from NextEra Energy Seabrook (Reference 1), indicate that the direct effect of ASR is cracking caused by expansion of affected concrete. Cracked concrete is subject to potential changes in structural performance that may merit structural evaluation and aging management, depending on the extent of ASR progression.

2.2. Influence of Confinement on Expansion Behavior

ASR-induced cracking is an expansion effect that is mitigated by the presence of confinement.

Absent external forces, ASR gel will absorb moisture and cause expansion in all directions. The presence of reinforcement provides confinement that restrains in-situ expansion of the ASR gel and reduces the resulting cracking in concrete. In the case where confinement exists in only some directions, expansion progression will shift to primarily the unconfined directions as the restraining force accumulates in confined directions. (Reference 11, 13, 32, 44, and 45)

2.3. Expansion Observations from MPR/FSEL Test Programs

The MPR/FSEL test programs included several different methods for characterizing the level of ASR distress, including both in-plane expansion and through-thickness expansion. Through-thickness expansion was ultimately selected as the most appropriate parameter for characterizing ASR progression (Reference 1).

Observed expansion in the test specimens was much greater in the through-thickness direction than in the in-plane direction (Reference 1). In-plane expansion in all of the test specimens plateaued in the range of approximately [redacted]%-[redacted]%, whereas through-thickness expansion continued to proceed up to [redacted]%. Based on these observations, through-thickness expansion was a better indicator of ASR progression than in-plane expansion.

Another alternative would have been to characterize ASR progression by combining in-plane and through-thickness expansion into a single volumetric expansion parameter. Because in-plane expansion was a small proportion of the total expansion and in-plane expansion was essentially constant between specimens, the conversion to volumetric expansion would have produced a small offset to the characterization of ASR progression in the test specimens that would not have affected differentiation of ASR progression between test specimens. Therefore, combination of in-plane expansion with through-thickness expansion into volumetric expansion would not impact interpretation of the test results.

3. In-Plane Expansion

As noted by NextEra Energy Seabrook in the December 2016 RAI responses (Reference 1), the maximum Combined Cracking Index (CCI) at Seabrook Station slightly exceeds the in-plane expansion observed in the MPR/FSEL test specimens.

In more recent RAIs (Reference 3 and 4), the NRC has requested information on consideration of a criterion that is solely for in-plane expansion. Such a criterion is not necessary or appropriate. This section provides a detailed discussion of the rationale for this conclusion, and is summarized as follows:

- In-plane expansion is already being monitored, because it is a component of the calculated volumetric expansion. Volumetric expansion is an appropriate approach for monitoring ASR progression at Seabrook Station, since ASR-induced expansion is a volumetric effect.
- In-plane expansion will also be periodically evaluated as part of an expansion behavior assessment. Specifically, the December 2016 submittal of the AMP (Reference 1) committed to a periodic check that overall expansion behavior at Seabrook Station is comparable to the MPR/FSEL test specimens. This periodic check includes a comparison of in-plane expansion to through-thickness

expansion of all monitored points, and is expected to show that in-plane expansion curtails at low levels while through-thickness expansion continues to increase. This commitment supplements the volumetric expansion limit to assure comparable expansion behavior between the plant and the MPR/FSEL test programs.

- In-plane expansion at levels slightly greater than observed in the MPR/FSEL test programs (i.e., within the volumetric expansion criterion) will not adversely impact structural performance. ASR-induced expansion in the in-plane directions produces chemical prestressing in concrete with two-dimensional reinforcement mats, like the configuration at Seabrook Station. As described in literature and demonstrated in the MPR/FSEL test programs, chemical prestressing benefits shear capacity and does not adversely affect flexural capacity or reinforcement anchorage performance at the levels of expansion observed in the MPR/FSEL test programs. The test result trends showed no indication that this effect would be lost at slightly higher levels of ASR progression. In fact, moment-curvature calculations performed to support analysis of the test data indicate that the Code equations for moment and yield capacity would continue to be valid at in-plane expansion levels of [redacted]% (Reference 9).

- In-plane expansion at Seabrook Station is presently consistent with in-plane expansion observed in the laboratory specimens. The highest CCI value from the MPR/FSEL test programs was [redacted] mm/m (Reference 9); presently, the highest value from the plant is 2.48 mm/m (Reference 10). The average CCI value from the MPR/FSEL test specimens that reached the "plateau" was [redacted] mm/m; presently, the average CCI value for Tier 3 locations at Seabrook Station is 1.32 mm/m (Reference 10). The MPR/FSEL test programs identified that the two-dimensional reinforcement mats confined in-plane expansion to approximately [redacted]% - [redacted]% (Reference 6). Subsequent expansion was primarily in the through-thickness direction. Reinforced concrete at Seabrook Station will reach a similar "plateau" with in-plane expansion values from ASR that should be comparable to, but not necessarily bounded by, the test data. In fact, since there are more data points from the plant than from the MPR/FSEL test programs, it is reasonable to expect that the maximum CCI value from the plant may be further from the average "plateau" value than the maximum CCI value from the MPR/FSEL test specimens. Measured CCI values at the plant are consistent with expected expansion behavior.

- Measurement of in-plane expansion for some locations at Seabrook Station is not directly comparable to that from the MPR/FSEL test programs. At Seabrook Station, external loads (e.g., load applied by expansion from backfill) can initiate cracking or exacerbate (i.e., open up) existing cracks, both of which impact CCI measurement. In contrast, the MPR/FSEL test programs isolated the effect of ASR, so the in-plane cracking was predominantly from expansion of ASR gel. To this end, all expansion measurements from the MPR/FSEL test programs were prior to the application of an external load. Therefore, other factors may cause the apparent CCI at Seabrook Station to exceed the observed CCI of the test specimens. Such instances are acceptable for the following reasons:

- Load testing as part of the test programs produced cracking from the applied load that increased the apparent in-plane expansion. Although this apparent expansion could not be directly measured during load testing, it is estimated to have produced in-plane expansion levels much higher than observed at the plant.

- The acceptance criterion for volumetric expansion is conservatively based on the in-plane expansion from the test specimens before load testing, which does not include the influence of applied load on apparent expansion.

- An extensive literature review performed throughout the course of the multi-year ASR project has not identified any indication from industry documents or researchers that direction of expansion has a significant effect on applicability of Code equations for shear capacity, flexural capacity or reinforcement performance, with the exception of chemical prestressing, which benefits or has no effect on structural performance for these limit states with the range of ASR progression addressed by the MPR/FSEL test programs. (In-plane expansion can adversely affect the axial compression limit state, which NextEra Energy Seabrook is explicitly evaluating as part of building-specific structural analyses.)

3.1. In-Plane Expansion is Included in Existing Acceptance Criteria

ASR-induced expansion is a volumetric effect that results in dimensional changes in all three directions. While the test data from the MPR/FSEL test programs show that expansion was primarily in the through-thickness direction, a volumetric expansion criterion is also appropriate. Provisions for monitoring volumetric expansion were included in the December 2016 RAI response submittal (Reference 1). The provisions for volumetric expansion will also be included in the Structures Monitoring Program, which is referenced by the LAR.

Volumetric expansion is the sum of expansion in each of the principal directions, as shown in the equation below (Reference 41).

$$\varepsilon_v = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 \qquad \text{[Equation 1]}$$

Where:

ε_v = volumetric expansion
ε_1 = principal strain (e.g., in the length direction)
ε_2 = principal strain (e.g., in the height direction)
ε_3 = principal strain (e.g., in the depth direction)

Because NextEra Energy Seabrook uses combined cracking index (CCI) to characterize in-plane expansion, Equation 1 is re-written as follows (Reference 1):

$$\varepsilon_v = 2 \times (0.1 \times CCI) + \varepsilon_{TT} \qquad \text{[Equation 2]}$$

Where:

ε_v = volumetric strain, %
CCI = combined cracking index, mm/m
ε_{TT} = through-thickness expansion, %

Using Equation 2 for the bounding MPR/FSEL test specimens, and using the in-plane expansion from the embedded pins of [redacted]% instead of CCI, the criterion for the volumetric expansion check was established at [redacted]% (Reference 3).

In addition, NextEra Energy Seabrook will periodically evaluate in-plane expansion as part of an expansion behavior assessment. Specifically, the December 2016 submittal of the AMP (Reference 1) committed to a periodic check that overall expansion behavior at Seabrook Station is comparable to the MPR/FSEL test specimens. This periodic check includes a comparison of in-plane expansion to through-thickness expansion of all monitored points, and is expected to show that in-plane expansion curtails at low levels while through-thickness expansion continues to increase. This commitment supplements the volumetric expansion limit to assure comparable expansion behavior between the plant and the MPR/FSEL test programs.

3.2. In-Plane Expansion at Low Levels Has No Adverse Impact

Concrete industry guidelines and published literature on the effects of ASR commonly cite that ASR-induced expansion in the direction of reinforcement applies prestressing to the affected concrete (Reference 11, 13, 32, 44). Furthermore, this literature indicates that the prestressing effect can actually improve shear capacity (Reference 11, 44). Additionally, because ASR-affected concrete exhibits prestressed behavior, serviceability in flexure is improved by increased cracking moment. While prestressing affects the deflection at which flexural failure occurs, it does not adversely affect the magnitude of applied load associated with flexural failure.

The MPR/FSEL test programs validated that these conclusions were applicable to the reinforcement configuration of structural members at Seabrook Station.

- Results from the MPR/FSEL Shear Test Program showed that increased expansion due to ASR at the levels observed in the test specimens resulted in (1) an increase in shear capacity, defined as the load resulting in diagonal shear crack initiation, and (2) an increase in load carrying capacity beyond the initiation of diagonal cracking (Reference 9).
- Similarly, test results from the Reinforcement Anchorage Test Program indicated no loss of flexural capacity or reinforcement anchorage performance. Moment-

Similarly, test results from the Reinforcement Anchorage Test Program indicated no loss of flexural capacity or reinforcement anchorage performance. Moment-curvature analyses for in-plane expansion at greater levels than observed in the test programs (up to [redacted]%) also show no effect (Reference 9).

Therefore, ASR-related in-plane expansion at Seabrook Station that is slightly greater than observed in the MPR/FSEL test programs (i.e., within the volumetric expansion criterion) would have no adverse effect on shear capacity, flexural capacity or reinforcement anchorage.

Prestressing in the Shear Test Specimens

Shear loading in a reinforced concrete beam is carried by a set of principal compressive stresses (σ_c) accompanied by a set of perpendicular principal tensile stresses (σ_t) (Figure A-1). A diagonal (shear) crack forms when the principal tensile stress at a location within the member reaches the tensile strength of concrete.

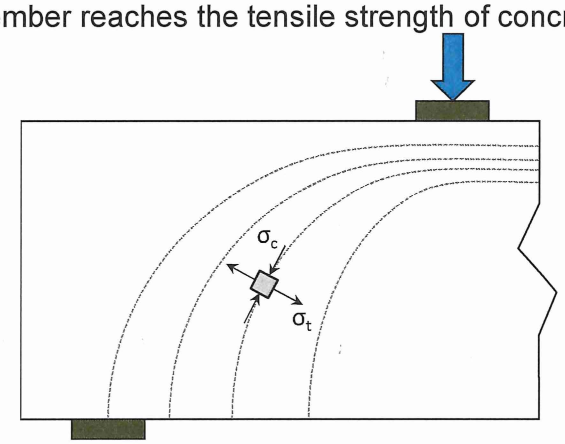

Figure A-1. Principal Stresses in Beam under Shear Loading (Reference 9)

In-plane expansion of the concrete due to ASR progression is restrained by the steel reinforcement, resulting in a tensile force in the reinforcement which is reacted by compression in the concrete to maintain structural equilibrium. This effect occurs without external loading and is typically referred to as prestress.

The presence of an axial (longitudinal) compressive stress in the concrete (such as that due to ASR-induced expansion) increases the applied shear stress in the beam necessary to produce a principal tensile stress sufficient to initiate diagonal crack formation. Therefore, the presence of axial compression (such as due to ASR-induced prestress) directly increases the shear strength of reinforced concrete members.

This mechanism for ASR-induced prestressing is identified in published literature and other laboratory test programs. NextEra Energy Seabrook performed shear testing as part of the large scale test programs to validate the effect of chemical prestressing on the shear capacity of reinforced concrete with two-dimensional reinforcement mats that represent Seabrook Station. As discussed in MPR-4273 (Reference 6), the test exhibited by the test specimens) has a beneficial effect for the shear limit state. Figure 5-5 of MPR-4273, which is reproduced below as Figure A-2, is a summary of the shear test results showing the shear capacity of test specimens with various levels of ASR progression. Test specimens with higher levels of ASR exhibited greater shear capacity.

[redacted]

Figure A-2. Normalized Shear Stress-Deflection Plots for [redacted]-inch Shear Test Specimens (Reference 6)

Prestressing in the Reinforcement Anchorage Test Specimens

Prestressing of the reinforcement anchorage test specimens occurred in the same manner as for the shear test specimens. As previously discussed, the mechanism for ASR-induced prestressing is identified in published literature and other laboratory test programs. Flexural testing was included in the MPR/FSEL test programs to validate the effect of chemical prestressing on the reinforcement anchorage performance of concrete with two-dimensional reinforcement mats that represent NextEra Energy Seabrook. As discussed in MPR-4273 (Reference 6), the test programs validated that ASR-induced expansion and the associated chemical prestressing did not have an adverse effect on reinforcement anchorage and flexural capacity. Figure 5-7 of MPR-4273, which is reproduced below as Figure A-3, compares the load-displacement plot of an ASR-affected specimen (A2) with the control specimen (A7). No adverse effect was observed on flexural capacity of the ASR-affected test specimens.

[redacted]

Figure A-3. Load-deflection Plots for Selected Reinforced Anchorage Test Specimens (Reference 6)

To consider the ASR-induced prestressing effect from an analytical perspective, FSEL performed a series of moment-curvature analyses using the material and section properties from the test specimen with the highest measured through-thickness expansion ([redacted]%). The analyses considered four cases of longitudinal (in-plane) expansion ([redacted]%). The results of these calculations, which are provided for information only, are shown in Figure A-4. Review of Figure A-4 indicates the following:

- All four levels of in-plane expansion (i.e., pre-strain) result in approximately the same moment and yield capacities. This is consistent with the observed behavior of the ASR-affected test specimens.

- The zero percent expansion (no pre-strain) case shows a significant decrease in stiffness following the onset of flexural cracking. This is typical of reinforced concrete behavior and is consistent with the observed behavior of the control test specimen.

- The [redacted]% expansion case shows that the onset of flexural cracking is delayed, which is consistent with the observed behavior of the ASR-affected test specimens.

- Each of the prestress cases shows a decreased deflection at the yield and service level loads (defined by ACI as 60% of the flexural yielding load), which is consistent with the evaluation of the service level flexural stiffness in the test specimens. This observation suggests that the ASR-induced compression limits the formation of new load-induced flexural cracking, limiting the decrease in flexural stiffness over a broad range of applied loads.

[redacted]

Figure A-4. Theoretical Moment-Curvature Behavior of Test Specimen (Reference 9)

Relevance for the Monitoring Criteria

NextEra Energy Seabrook does not credit any improvement in structural performance for the chemical prestressing that occurs due to ASR-induced expansion. For the case where in-plane expansion at Seabrook Station slightly exceeds in-plane expansion observed in the MPR/FSEL test programs, this approach introduces conservatism for shear capacity. This approach is appropriate for reinforcement anchorage and flexural capacity, for which there is no adverse effect at slightly higher in-plane expansion levels.

The opposite case, where ASR-induced expansion occurs in the through-thickness direction without prestressing by in-plane expansion, is not of concern because there is not a credible mechanism for such expansion behavior. ASR-induced cracking occurs because of expansion of gel that naturally occurs in all three directions. Preferential expansion in a particular direction only occurs as a result of accumulation of restraint forces. Therefore, for the biaxially-reinforced concrete structures at Seabrook Station, significant through-thickness expansion will not occur without chemical prestressing in the in-plane directions.

Additional Comment on Compression

As discussed in MPR-4288 (Reference 20), in-plane expansion may adversely affect capacity for the compression limit state. NextEra Energy Seabrook structural evaluations assess the effect of observed in-plane expansion on compression capacity, but do not rely on structural test data from the MPR/FSEL test programs. The MPR/FSEL test programs did not address the compression limit state, and the monitoring criteria for through-thickness expansion and volumetric expansion that are derived from the test results do not apply for the evaluation of compression.

3.3. In-Plane Expansion Behavior at Seabrook Station is Comparable to Test Specimens

The MPR/FSEL test programs concluded that the two-dimensional reinforcement mats confined in-plane expansion, such that it "plateaus" in the range of approximately [redacted]% - [redacted]%. Subsequent ASR progression caused expansion that was predominantly in the through-thickness direction. (Reference 1)

For the MPR/FSEL test specimens that were observed to have reached the in-plane expansion plateau, the embedded pins provided the most accurate data and were consistently [redacted]%. FSEL also obtained CCI data from these test specimens, which showed an average of [redacted] mm/m (i.e., [redacted]%) with a maximum value of [redacted] mm/m. (Reference 1)

Reinforced concrete at Seabrook Station is expected to reach a similar plateau for ASR-induced in-plane expansion as the MPR/FSEL test specimens. The data are expected to show a distribution about an average value that is comparable between the plant and the test specimens. For this reason, in-plane expansion measurements due to ASR at Seabrook Station should be comparable to, but not necessarily bounded by, the MPR/FSEL test data. In fact, since there are more data points from the plant than from the test programs, it is reasonable to expect that the maximum CCI value from the plant will be further from the average "plateau" value than the maximum CCI from the MPR/FSEL test specimens.

At Seabrook Station, Tier 3 locations have a CCI of at least 1 mm/m and therefore are at approximately the in-plane expansion plateau level. Of these locations, the average CCI is 1.32 mm/m (i.e., 0.132%) with a maximum value of 2.48 mm/m (Reference 10). These data are consistent with the observed in-plane expansion from the MPR/FSEL test programs.

3.4. External Loads at Seabrook Station Influence Apparent In-Plane Expansion

An important difference between the expansion behavior observed at Seabrook Station and the expansion behavior observed in the test specimens is the potential for additional loading mechanisms to influence cracking. Cracking observed in concrete can be caused by several different mechanisms. The equation below illustrates how the observed total apparent in-plane expansion can be separated into terms for different causes of cracking.

$$\varepsilon_{xy\_total} = \varepsilon_{ASR} + \varepsilon_{ext} + \varepsilon_{sh} + \varepsilon_{oth} \quad \text{[Equation 3]}$$

Where:

ε_{xy_total} = total apparent in-plane expansion
ε_{ASR} = cracking caused by in-plane expansion due to ASR
ε_{ext} = cracking caused by applied external loads (e.g., deformation from backfill)
ε_{sh} = cracking caused by shrinkage
ε_{oth} = cracking due to other causes

Measurement of in-plane expansion for some locations at Seabrook Station is not directly comparable to that from the MPR/FSEL test programs. At Seabrook Station, external loads (e.g., load applied by expansion of the backfill) can initiate cracking or exacerbate (i.e., open up) existing cracking, both of which impact CCI measurements. In contrast, the MPR/FSEL test programs isolated the effect of ASR so the in-plane cracking was predominantly from expansion of ASR gel. To this end, all expansion measurements from the MPR/FSEL test programs were prior to the application of an external load. Therefore, other factors may cause the apparent CCI at Seabrook Station to exceed the observed CCI of the test specimens.

Conservatism in the Volumetric Criterion

As part of the structural evaluation for ASR-affected structures (Reference 40), NextEra Energy Seabrook explicitly calculates additional demand due to the total expansion (including deformation, external loads from backfill, etc.), and evaluates whether structural capacity is adequate. The results from the MPR/FSEL test programs are incorporated into this analysis by considering that there is no adverse effect on shear capacity, flexural capacity, and reinforcement anchorage when observed expansion is within the criterion for through-thickness expansion. The volumetric expansion criterion ensures that expansion behavior at the plant is comparable to the test specimens, and that the conclusions from the MPR/FSEL test programs are applicable to the plant.

Observations from the load tests in the MPR/FSEL test programs support that this approach is conservative. During shear and reinforcement anchorage testing, the applied load produced additional in-plane cracking on the tension side of the test specimens. (This circumstance is analogous to external loading of structural members at Seabrook Station.) Apparent in-plane expansion values were not obtained during testing due to personnel safety considerations, but the substantial bending exhibited by the test specimens (see photograph in Figure A-5) indicates that the CCI value would have been much larger than the value determined before the load test. In all cases, shear capacity, flexural capacity, and reinforcement anchorage performance of the test specimens exceeded the design value, indicating that such total in-plane cracking is acceptable.

The volumetric expansion acceptance criterion is based on the in-plane expansion of the test specimens prior to application of the load. Because in-plane cracking that occurred during the load testing and widening of ASR cracks was not explicitly measured, these effects were not included in the volumetric expansion criterion. Therefore, this approach provides conservatism.

It would not be appropriate to apply an additional expansion criterion specifically for in-plane expansion because of the difference in whether external loads are applied at the time of the measurement. Such a criterion would be unreasonably restrictive, as in-plane cracking at the low levels exhibited by the test specimens clearly had no adverse effect on shear capacity, flexural capacity, or reinforcement anchorage performance. As discussed above, the MPR/FSEL test programs demonstrated that much more substantial in-plane cracking (i.e., from applied load) did not have an adverse effect on the tested limit states.

Furthermore, apparent in-plane expansion at the plant may be affected by additional factors (e.g., external loads) and is not directly comparable to in-plane expansion without external loading in the MPR/FSEL test specimens. A criterion that is based entirely on such a comparison would not be appropriate.

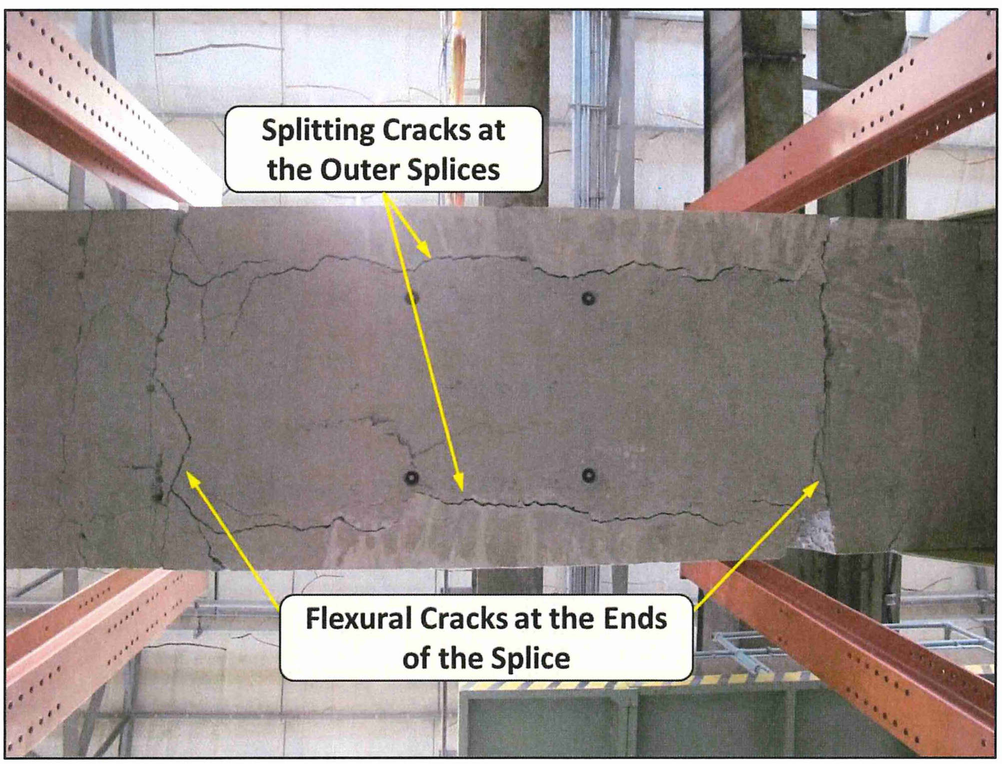

Figure A-5. Post-Failure Condition of Reinforcement Anchorage Test Specimen (Reference 9)

~~Enclosure 1 to this Letter Contains Proprietary Information~~
~~Withhold Enclosure 1 from Public Disclosure in Accordance with 10 CFR 2.390~~

Observations at Relevant Locations at Seabrook Station

In-plane expansion monitoring of all locations with extensometers (which includes all Tier 3 locations) has identified three locations at Seabrook Station where CCI (i.e., apparent in-plane expansion) exceeds the maximum CCI from the MPR/FSEL test programs of [redacted] mm/m.

As part of ongoing evaluations of ASR-affected structures at Seabrook Station, NextEra Energy Seabrook is systematically evaluating all extensometer locations to assess other influences on CCI that may affect interpretation of apparent in-plane expansion. A preliminary screening (Reference 46) has identified potential influences other than ASR in all three of the locations with CCI greater than the maximum from the MPR/FSEL test programs, as follows:

- The south wall of the Primary Auxiliary Building has a CCI of 2.48 mm/m (Reference 10). Applied load from expansion of concrete on the adjoining floor slab may be influencing the apparent in-plane expansion (Reference 46).
- The south wall of room MF105 has a CCI of 2.42 mm/m (Reference 10). Applied load from expansion of concrete fill on the opposite side of this wall may be influencing the apparent in-plane expansion (Reference 46).
- The slab below room MF303 has a CCI of 2.44 mm/m (Reference 10). Although the slab has pattern cracking, some of the cracks have relatively large widths, which is atypical of ASR at Seabrook Station and suggests that another factor may be contributing to the cracking and therefore the apparent in-plane expansion (Reference 46).

Conclusion

Application of an acceptance criterion that is based solely on in-plane expansion for shear, reinforcement anchorage, and flexure is not appropriate because apparent in-plane expansion at Seabrook Station may be influenced by factors other than in-plane ASR expansion. In particular, the apparent in-plane cracking in concrete members at Seabrook Station includes the effects of external loads—cracking initiated by the external loads and cracking exacerbated by the external loads—whereas the measured in-plane expansion of the test specimens reflects primarily ASR-related expansion. Because in-plane expansion from ASR plateaus at relatively low levels, a criterion based solely on the in-plane expansion from the MPR/FSEL test specimens would not represent the observed range of ASR progression and would not meaningfully accommodate the influence of external loads on the calculated expansion, which could not be directly represented by test program measurements.

The volumetric expansion criterion is a reasonable alternative that is appropriately conservative. The volumetric expansion criterion reflects the in-plane expansion without external loading in the MPR/FSEL test specimens, which does not include the additional apparent expansion from cracking due to external loads observed during the load test. The MPR/FSEL test program demonstrated that structural performance is acceptable with apparent expansion from ASR and external loads to levels greater than the criteria that reflect pre-test cracking.

3.5. Literature Indicates No Adverse Effects Unique to In-Plane Expansion

During the course of addressing the ASR issue at Seabrook Station, NextEra Energy Seabrook and its contractors have reviewed numerous industry guidelines for addressing ASR (including References 11, 12, and 13) and performed a detailed literature review on the state of the art in the research community (Reference 14). All of these resources acknowledge that directionality of confinement may affect expansion behavior due to chemical prestressing. None of these resources suggest that the direction of expansion has any significant adverse influence on shear capacity, flexural capacity, or reinforcement anchorage for a given level of volumetric expansion. In the absence of an aging mechanism that relates specifically to in-plane expansion, the volumetric expansion criterion is an appropriate parameter for characterizing ASR progression in a way that incorporates in-plane expansion.

In contrast to the in-plane direction, a specific limit for expansion in the through-thickness direction is appropriate. As previously discussed, published literature identifies that expansion will reorient to the unconfined directions. The MPR/FSEL test programs confirmed that, for structural members with two-dimensional reinforcement mats like those at Seabrook Station, ASR-induced expansion will occur predominantly in the through-thickness direction. Structural testing was therefore correlated to through-thickness expansion. Accordingly, ASR monitoring at Seabrook Station also uses a through-thickness.

4. Conclusion

The through-thickness expansion criterion addresses structural performance and is based directly on the maximum ASR progression observed in the MPR/FSEL test programs, as characterized by through-thickness expansion. The volumetric expansion criterion ensures that expansion behavior at Seabrook Station is comparable to the test specimens from the MPR/FSEL test program and that shear capacity, flexural capacity, and reinforcement anchorage performance are bounded by the test results.

Locations at Seabrook Station that meet the through-thickness and volumetric expansion criteria are acceptable, even if the observed in-plane expansion component of volumetric expansion exceeds the in-plane expansion of the test specimens. This conclusion is supported by published literature, the results of the MPR/FSEL test programs, and the design of the acceptance criteria.

Appendix B

Corroboration Study for Correlation of Elastic Modulus and Through-Thickness Expansion

This appendix provides a detailed procedure of the methodology for the in-plant corroboration study with graphical illustrations. In support of this objective, this Appendix also reviews the approach for developing the correlation using data from the MPR/FSEL test program and the methodology for using the correlation that was recommended in MPR-4153 (Reference 5).

1. Background on Development of Correlation

1.1. Expansion Behavior of Test Specimens

As part of its evaluation of ASR-affected structures at Seabrook Station, NextEra Energy Seabrook, LLC (NextEra Energy Seabrook) sponsored large scale test programs to investigate shear capacity and reinforcement anchorage performance of ASR-affected concrete. The test programs were directed by MPR Associates and were performed at the Ferguson Structural Engineering Laboratory (FSEL) at the University of Texas at Austin (UT-Austin).

The test specimens were concrete beams that included two-dimensional reinforcement mats on two opposite faces, which is the same reinforcement detailing used for most reinforced concrete buildings at Seabrook Station. Expansion of the test specimens initially proceeded in both the in-plane directions (i.e., on the faces of the specimens parallel to the reinforcement mats) and the through-thickness direction (i.e., perpendicular to the reinforcement mats). In-plane expansion curtailed at relatively low expansion levels (approximately [redacted]% to [redacted]% expansion), while through-thickness expansion continued to increase (Reference 6). Because of this expansion behavior, the test programs provided results correlating structural performance to expansion in the through-thickness direction.

The observed expansion behavior was consistent with discussion in industry guidelines on monitoring ASR (References 11, 12, and 13), as expansion of the test specimens occurred preferentially in the unconfined direction.

1.2. Implications for Monitoring at Seabrook Station

To facilitate application of the test results, NextEra Energy Seabrook needed to implement a methodology for measuring expansion in the through-thickness direction.

The MPR/FSEL test programs included an assessment of various commercially-available instruments for measuring through-thickness expansion (Reference 47). The test program concluded that snap ring borehole extensometers (SRBEs) are a reliable and accurate approach for monitoring through-thickness expansion. NextEra Energy Seabrook has installed extensometers in selected monitoring locations. The extensometers allow NextEra Energy Seabrook to monitor through-thickness expansion that occurs from the time that the instrument is installed through the end of plant life.

To calculate the cumulative through-thickness expansion since original construction, the extensometer measurement must be added to the expansion up to the time the instrument is installed (i.e. pre-instrument expansion). To determine pre-instrument expansion, NextEra Energy Seabrook is using a correlation between reduction in elastic modulus and ASR-induced expansion that was presented in MPR-4153 (Reference 5).

MPR-4153 defined the correlation based on a regression analysis that gives a best fit of the data from the MPR/FSEL test programs. MPR-4153 compared the correlation to literature data from various sources (References 15, 16, 17, 18, 28, 39, and 48). The literature data compare favorably with the Seabrook Station-specific correlation, and therefore validate application of the correlation at the plant (Reference 5).

To provide appropriate conservatism, the methodology described in MPR-4153 prescribes reducing the normalized elastic modulus by [redacted]%. This adjustment drives the calculated pre-instrument expansion higher, which is in the direction of conservatism. NextEra Energy Seabrook uses this adjustment for assessing concrete relative to the through-thickness expansion acceptance criterion. Figure B-1 shows the correlation and the conservative effect of applying the [redacted]% adjustment to the normalized elastic modulus.

[redacted]

Figure B-1. Correlation Between Elastic Modulus and Through-Thickness Expansion

2. PROCESS FOR DETERMINING THROUGH-THICKNESS EXPANSION

NextEra Energy Seabrook installed extensometers in 38 ASR-affected locations at Seabrook Station. For each location, NextEra Energy Seabrook obtained corresponding data for modulus of elasticity at the time the extensometer was installed. These data were used to calculate pre-instrument expansion at each location using the best-fit correlation (ε_0) and with the adjustment to the normalized elastic modulus (ε_{0_adj}). Figures B-2 and B-3 provide examples illustrating how these values were obtained for a hypothetical data point where the elastic modulus at the time of extensometer installation was [redacted] of the original elastic modulus value (i.e., normalized elastic modulus, E_n, is [redacted]).

[redacted]

Figure B-2. Determination of Best-Estimate Pre-Instrument Through-Thickness Expansion

[redacted]

Figure B-3. Determination of Adjusted Pre-Instrument Through-Thickness Expansion

3. Methodology for In-Plant Corroboration Study

To supplement the comparison of the correlation to literature data that was documented in MPR-4153 (Reference 5), NextEra Energy Seabrook also plans to conduct an in-plant corroboration study. The in-plant corroboration study was described in an RAI response from December 2016 (Reference 1) and the revised ASR aging management program (AMP), which was included with that submittal.

NextEra Energy Seabrook will obtain additional cores in the vicinity of several extensometers in the future and perform elastic modulus testing. For each location selected, NextEra Energy Seabrook will test two specimens, and average the results to determine the best-estimate elastic modulus at the time of the corroboration study[7]. Using these test results, NextEra Energy Seabrook will determine the change in through-thickness expansion since installation of the extensometers and compare it to the change determined from extensometer readings.

This section describes the detailed procedure for performing the corroboration study and includes an example with graphical illustrations of how the results will be interpreted. The corroboration study will analyze the data in two different ways (i.e., Test 1 and Test 2) to enable assessment of the data obtained at the time of the corroboration study and also the data obtained at the time the extensometer was installed.

3.1. Test 1 – Assessment of Data Obtained at Time of Study

The approach for Test 1 assumes that the through-thickness expansion determined at the time of extensometer installation is correct and evaluates the data point obtained at the time of the corroboration study.

The elastic modulus test results will be used to determine the normalized elastic modulus for a particular location at the time of the corroboration study, and the best-estimate total through-thickness expansion using the best-fit correlation (ε_{t_EM}). Figure B-4 provides an example for a normalized elastic modulus of [redacted] at the time of the corroboration study.

[7] In accordance with the methodology in MPR-4153, NextEra Energy Seabrook will also perform companion compressive strength testing.

[redacted]

Figure B-4. Determination of Best-Estimate Through-Thickness Expansion Using Elastic Modulus for Corroboration Study

NextEra Energy Seabrook will also determine through-thickness expansion using the extensometer, in accordance with the methodology for routine monitoring from the ASR AMP (Reference 1). Specifically, NextEra Energy Seabrook will measure differential expansion ($\Delta\varepsilon_{inst}$) using the extensometer and add this value to the adjusted through-thickness expansion at the time the extensometer was installed ($\varepsilon_{0\_adj} + \Delta\varepsilon_{inst} = \varepsilon_{t\_inst}$). For the ASR AMP, NextEra Energy Seabrook determines the pre-instrument expansion using the adjusted correlation from MPR-4153 to provide conservatism.

Figure B-5 provides an example illustrating the method for calculating ε_{t_inst} using the hypothetical data point of E_n = [redacted] when the extensometer was installed and assuming a measured differential expansion of [redacted]%.

[redacted]

Figure B-5. Determination of Through-Thickness Expansion Using Extensometer for Corroboration Study

NextEra Energy Seabrook will compare the through-thickness expansion determined using the extensometer (ε_{t_inst}) with the best-estimate expansion using the correlation from MPR-4153 (ε_{t_EM}). The result of Test 1 is satisfactory if $\varepsilon_{t\_EM} \leq \varepsilon_{t\_inst}$. This result indicates that the methodology from the ASR AMP is providing an appropriate level of conservatism.

Figure B-6 provides a graphical illustration of how the results are compared for Test 1.

[redacted]

Figure B-6. Example Application of Acceptance Criterion for Test 1

3.2. Test 2 – Assessment of Data from Extensometer Installation

Test 2 assumes that the through-thickness expansion determined at the time of the corroboration study is correct, and evaluates the data point obtained at the time of extensometer installation. The approach for Test 2 is essentially the reverse of Test 1.

For Test 2, NextEra Energy Seabrook will use the same data from elastic modulus testing as was used for Test 1. Different from Test 1, NextEra Energy Seabrook will use the elastic modulus to determine the <u>adjusted</u> total expansion at the time of the corroboration study using the <u>adjusted</u> correlation (ε_{t_adj}). Figure B-7 provides an example for a normalized elastic modulus of [redacted] at the time of the corroboration study.

[redacted]

Figure B-7. Determination of Adjusted Through-Thickness Expansion Using Elastic Modulus for Corroboration Study

Like Test 1, NextEra Energy Seabrook will determine differential through-thickness expansion using the extensometer ($\Delta\varepsilon_{inst}$), in accordance with the methodology for routine monitoring from the ASR AMP. However, for Test 2, NextEra Energy Seabrook will subtract this value from the adjusted through-thickness expansion determined at the time of the corroboration study ($\varepsilon_{t\_EM\_adj} - \Delta\varepsilon_{inst} = \varepsilon_{0\_inst}$).

Figure B-8 provides an example illustrating the method for calculating ε_{0_inst} using the hypothetical data point of E_n = [redacted] when the corroboration study is performed and assuming a measured differential expansion of [redacted]%.

[redacted]

Figure B-8. Determination of Initial Through-Thickness Expansion Using Extensometer and Elastic Modulus Data from Corroboration Study

NextEra Energy Seabrook will compare the calculated initial through-thickness expansion (ε_{0_inst}) with the best-estimate through-thickness expansion at the time of extensometer installation (ε_0, illustrated in Figure B-1), as shown in Figure B-8. The result of Test 2 is satisfactory if $\varepsilon_0 \leq \varepsilon_{0\_inst}$. This result indicates that the methodology from the ASR AMP is providing an appropriate level of conservatism.

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Figure B-9 provides a graphical illustration of how the results are compared for Test 2.

[redacted]

Figure B-9. Example Application of Acceptance Criterion for Test 1

3.3. Acceptable Range of Elastic Modulus Values

The corroboration study checks that the correlation from MPR-4153 is an appropriate representation of expansion behavior at Seabrook Station. Corroboration would be unsuccessful if either of the following two conditions exist:

- Through-thickness expansion determined by the correlation is **much greater** than through-thickness expansion determined using the extensometer. Test 1 confirms that this condition does not exist.

- Through-thickness expansion determined by the correlation is **much less** than through-thickness expansion determined using the extensometer. Test 2 confirms that this condition does not exist.

Example Showing Acceptable Range of Normalized Elastic Modulus

Using both tests establishes a range of acceptable elastic modulus values for the cores obtained for the corroboration study. For the example provided above, where the normalized elastic modulus at the time of initial extensometer placement is [redacted] and the measured expansion from the extensometer is [redacted]%, the acceptable bounds would be as follows:

- For Test 1, the acceptance criterion would be met if the best-estimate expansion using the correlation at the time of the corroboration study is less than [redacted]%. This result corresponds to a normalized elastic modulus of no less than [redacted] for the core taken at the time of the corroboration study. Figure B-10 illustrates a result that would satisfy this criterion with no margin.

- For Test 2, the acceptance criterion would be met if the initial expansion, calculated by subtracting the differential expansion measured by the extensometer from the adjusted expansion determined using the correlation, is greater than [redacted]%. This result corresponds to a normalized elastic modulus of no greater than [redacted] for the core taken at the time of the corroboration study. Figure B-11 illustrates a result that would satisfy this criterion with no margin.

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[redacted]

Figure B-10. Example Showing Minimum Acceptable Normalized Elastic Modulus

Figure B-11. Example Showing Maximum Acceptable Normalized Elastic Modulus

[redacted]

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