October 17, 2017

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Docket No. 50-443
SBK-L-17169

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

Seabrook Station

Supplement 58 – Non-Proprietary Enclosure 1 to SBK-L-17155

References:

1. NextEra Energy Seabrook LLC, letter SBK-L-10077, "Seabrook Station Application for Renewed Operating License," May 25, 2010 (Accession Number ML101590099).

2. NRC, "Request for Additional Information for the Review of the Seabrook Station License Renewal Application (CAC NO. ME4028)," March 29, 2017 (Accession Number ML17088A614).

3. NextEra Energy Seabrook LLC, letter SBK-L-17155, "Supplement 58 - Response to Request for Additional Information for the Review of the Seabrook Station License Renewal Application – Building Deformation Analyses Related To Concrete Alkali-Silica Reaction," October 3, 2017.

In Reference 1, NextEra Energy Seabrook, LLC (NextEra Energy Seabrook) submitted an application for a renewed facility operating license for Seabrook Station Unit 1 in accordance with the Code of Federal Regulations, Title 10, Parts 50, 51, and 54.

In Reference 2, the NRC requested additional information to complete the review of the application related to Alkali-Silica Reaction (ASR) and Building Deformation Monitoring Programs.

In Reference 3, NextEra Energy Seabrook submitted letter SBK-L-17155, responding to the Request for Additional Information (RAI) in Reference 2. Enclosure 1 of SBK-L-1755 is proprietary.

The Enclosure provides a non-proprietary version of Enclosure 1 from SBK-L-17155 (Reference 3).

This letter contains no new or revised Commitments.

If there are any questions or additional information is needed, please contact Mr. Edward J. Carley, Engineering Supervisor - License Renewal, at (603) 773-7957.

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-17155, Response to Request for Additional Information for the Review of the Seabrook Station License Renewal Application –Building Deformation Analyses Related To Concrete Alkali-Silica Reaction

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Enclosure 1 to SBK-L-17169

Non-Proprietary Version of Enclosure 1 to SBK -L-17155
Response to Request for Additional Information for the
Review of the Seabrook Station License Renewal Application –
Building Deformation Analyses Related To Concrete Alkali-Silica Reaction

(NON-PROPRIETARY)

RAI B.2.1.31A-A1-1 – ASRMP: Consideration of In-plane and Through-Thickness Expansion in Acceptance Criteria for Effect on Structural Limit States

Background:

In RAI B.2.1.31A-A1, the staff discussed concerns that the Alkali-Silica Reaction (ASR) Monitoring Program (ASRMP) was monitoring strain (cracking, expansion) in the in-plane and out-of-plane directions separately, using the basis that in-plane cracking (CCI) plateaus at a certain expansion, and then through-wall expansion continues, and therefore the program would use only the through-wall expansion measurement as the monitoring parameter for Tier 3 locations (CCI greater than 1 mm/m). In its December 23, 2016, response to RAI B.2.1.31A-A1 the applicant clarified that as part of routine expansion monitoring as detailed in the "detection of aging effects" program element of the ASRMP, it will monitor, on a 6-month interval, both inplane (via CCI monitoring) and through-thickness expansion (using snap-ring borehole extensometers) of all Tier 3 locations. The applicant also revised the "acceptance criteria" program element and the updated final Safety Analysis Report (UFSAR) Supplement for the ASRMP to state the above and revised the Table titled "Effect of ASR on Structural Limit States" to indicate that the expansion limit criteria for flexure/reinforcement anchorage and shear is for through-thickness expansion. The "parameters monitored or inspected" program element states the following with regards to effects on structural capacity for flexure/reinforcement anchorage and shear:

> Based on the MPR/FSEL [University of Texas] large-scale test program results, structural evaluations should consider that there has been no adverse impact on flexure capacity and reinforcement anchorage (development) length performance [and shear capacity], *provided that through-thickness expansion is at or below bounding conditions of the large-scale testing and expansion behavior is comparable to the test specimens* [emphasis added].

Also, the "monitoring and trending" program element states "[f]or anchor capacity, shear capacity, and reinforcement anchorage, use in-plane expansion (CCI) and out-of-plane expansion (modulus + SRBE measurements) to compare with the test results from the Large Scale Testing Program."

The applicant's December 23, 2016, response to RAI B.2.1.31A-A1 also stated that in-plane and through-thickness measurements will be used to determine volumetric expansion. The applicant 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 testing program, and to account for this difference, the applicant will monitor volumetric expansion and confirm that ASR expansion is within the volumetric expansion criterion determined from the test programs.

Issue:

The staff determined that it is reasonable for the applicant to assess the quantitative expansion parameters monitored (i.e., CCI, through-thickness) for impact on structural capacity in flexure/reinforcement anchorage and shear as indicated above in the "parameters monitored or inspected" and "monitoring and trending" program elements, provided that (1) through-thickness expansion is at or below bounding conditions of the large-scale testing and (2) expansion (including in-plane expansion) is comparable to that observed in the test specimens. However, the "acceptance criteria" program element of ASRMP, which addresses the effect of ASR on structural limit states in the Table titled "Effect of ASR on Structural Limit States" on Page 21 of Enclosure 3, only includes the criteria for through-thickness expansion for flexure/reinforcement anchorage, and shear, and does not provide acceptance criteria to assess measured in-plane expansion (CCI) compared to the large-scale testing. Further, for cases in which in-plane expansion measured on Seabrook structures exceeds the "plateau" levels seen in the testing, there is no technical basis for the applicant's stated volumetric expansion criterion to support the conclusion that the large-scale testing results can be considered bounding (with regard to impact on structural limit states) because the proposed comparison of volumetric expansion of testing specimens versus Seabrook structures does not consider the directionality effects of expansion and cracking on structural limit states.

Request:

Clarify how the "acceptance criteria" program element of the ASRMP incorporates consideration of measured in-plane expansion during each monitoring interval, in addition to the measured through-thickness expansion, in the criteria for assessing effect on structural capacity in flexure and reinforcement anchorage and shear to ensure that expansion in all directions is also bounded or comparable to that observed in the large-scale test specimens that forms the basis.

Update applicable program elements and UFSAR supplement accordingly.

NextEra Energy Seabrook Response to RAI B.2.1.31A-A1-1:

NextEra Energy Seabrook will enhance the Alkali-Silica Reaction Aging Management Program (ASR AMP) to incorporate volumetric expansion (which includes a term for in-plane expansion) in Element 6 (Acceptance Criteria). The rationale for this enhancement and the associated changes to the ASR AMP are provided below.

Volumetric Expansion

As discussed in the ASR AMP submitted in December 2016 (Reference 1) and in MPR-4273 (Reference 6), NextEra Energy Seabrook is monitoring volumetric expansion,

which is the sum of expansion in all three dimensions (i.e., the equation for volumetric expansion includes terms for both in-plane and through-thickness expansion). In the ASR AMP submitted in December 2016 (Reference 1), NextEra Energy Seabrook incorporated the volumetric expansion check in Element 10 (Operating Experience).

To address the request from RAI B.2.31A-A1-1, NextEra Energy Seabrook will enhance the ASR AMP to incorporate volumetric expansion as a new monitoring parameter in Elements 3, 4, and 5, and provide the acceptance criterion (i.e., [redacted]%; Reference 6) in Element 6. The volumetric expansion review will be removed from Element 10, as it would be redundant. Additionally, to address the NRC concern regarding monitoring during each interval, the volumetric expansion check will be performed concurrently with in-plane and through-thickness expansion measurements, which are the input parameters. For Tier 3 locations, the ASR AMP specifies that such monitoring will occur at least every six months.

In addition to the volumetric criterion, NextEra Energy Seabrook will maintain the existing acceptance criteria for through-thickness expansion for shear capacity, flexural capacity, and reinforcement anchorage performance. The through-thickness expansion criterion is more conservative than the volumetric expansion criteria when in-plane expansion is very low.

In-Plane Expansion

An alternative approach for considering in-plane expansion would be to implement a monitoring criterion that is specific for in-plane expansion. NextEra Energy Seabrook concluded that such a criterion is not necessary or appropriate. Appendix A 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, 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 [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]%, 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 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.

- 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.)

RAI B.2.1.31A-A4-2 – ASRMP: Corroboration of Modulus – Expansion Correlation from FSEL Testing

<u>Background:</u>

The proposed ASR Monitoring Program states that Seabrook will install extensometers in Tier 3 (CCI > 1 mm/m) and other selected locations to measure expansion in the through-thickness direction. The LRA states that this approach will enable measuring expansion for a given concrete structural member from the time the extensometer is installed and going forward. To calculate total expansion, the applicant stated that it will determine expansion from original construction until the time the extensometers are installed using a correlation developed from the large-scale testing program. The methodology is described in Report MPR 4153, which was submitted to the NRC, and uses a normalized reduction in modulus of elasticity to calculate through-thickness expansion-to-date for Seabrook structures. In the December 23, 2016, response to RAI B.2.1.31A-A4, the “operating experience” program element of the revised ASR Monitoring Program was revised to state that the applicant will corroborate the correlation of normalized modulus versus through-thickness expansion derived from the MPR/FSEL testing against Seabrook plant data at least 2 years prior to the period of extended operation (PEO) by comparing expansion determined from elastic modulus testing of core bores and extensometer readings from three Tier 3 Seabrook monitoring locations.

Issue:

While the staff agrees that the methodology used to correlate the MPR/FSEL-derived modulus of elasticity to through-wall expansion should be corroborated, the staff is concerned about the adequacy of using cores at three locations at only one point in time to provide a meaningful validation of a correlation curve that is a function of expansion over time versus normalized reduced modulus of elasticity. In addition, despite the applicant's claim that literature data [also from laboratory testing] follow a trend consistent with the FSEL test data, the use of this methodology is first-of-a-kind for estimating through-wall ASR expansion to-date for in situ structures, and it may need to be validated in the field for higher levels of expansion by reevaluating the methodology during the PEO. Also, 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. Provide technical basis for the adequacy of taking only 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.

2. Considering the need to validate that the curve applies to ASR expansion over time, state whether the corroboration activity of the modulus-expansion correlation will reoccur during the period of extended operation. Provide a technical basis for the number of times the corroboration activity will be performed that would demonstrate validity for the period of extended operation.

3. State how the evaluation will determine whether the data taken for Seabrook structures correlates to the curve derived from large-scale test specimens.

NextEra Energy Seabrook Response to RAI B.2.1.31A-A4-2

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.

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 (see response to Request #2 and Request #3), NextEra Energy Seabrook will perform the corroboration study by obtaining new cores from the vicinity of 20% of

the extensometers[1], 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 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.

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:

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[1] 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.

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.[2]

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.

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 study twice: once prior to PEO and once thereafter, as discussed below. This approach will corroborate that the MPR-4153 correlation is independent of the rate of ASR progression.

Initial Corroboration Study before PEO

NextEra Energy Seabrook plans to perform the initial corroboration study prior to PEO 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 PEO or that these locations do not sufficiently cover the applicable range of the correlation. If the set of

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

extensometer data do not support meeting the location selection criteria, NextEra Energy Seabrook will still perform the corroboration study at least five years prior to PEO using the best available data, per the commitment stated in Reference 1.

Subsequent Corroboration Study during PEO

NextEra Energy Seabrook will repeat the corroboration study during PEO to confirm that expansion behavior 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 still have not been satisfied at the time of the repeat corroboration study, NextEra Energy Seabrook will evaluate the need to perform a third corroboration study.

To reflect the changes discussed above Commitments 45 and 66 are revised as follows:

45	Alkali-Silica Reaction (ASR) Monitoring Program	NextEra will obtain additional cores in the vicinity of ~~three~~ ***20% of the*** extensometers and perform modulus testing. Using these test results, NextEra will determine the change in through-thickness expansion since installation of the extensometers and compare it to change determined from extensometer readings. Consistency between these results will provide additional corroboration of the methodology in MPR-4153.	A.2.1.31.A	At least ~~2~~ 5 years prior to the period of extended operation ***(initial study) and 10 years thereafter (followup study)***.

66	Alkali-Silica Reaction (ASR) Monitoring Program	NextEra will perform an integrated review of expansion trends at Seabrook Station by conducting a periodic assessment of ASR expansion behavior to confirm that the MPR/FSEL large-scale test programs remain applicable to plant structures. This review will include the following specific considerations: • Review of all cores removed to date for trends of any indications of mid-plane cracking. • Comparison of in-plane expansion to through-thickness expansion of all monitored points by plotting these data on a graph of ~~CCI~~ ***in-plane expansion*** versus through-thickness expansion. • Comparison of in-plane expansions, volumetric expansions, and through-thickness expansions recorded to date to the limits from the MPR/FSEL large-scale test programs and check of margin for future expansion. ~~Also, the calculated volumetric expansion will be compared to the range observed in the beam test programs and margin for future expansion will be checked.~~	A.2.1.31.A	At least 5 years prior to the period of extended operation and every 10 years thereafter.

RAI B.2.1.31B-B2-1 – "Parameters Monitored or Inspected" for Building Deformation Monitoring Program

Background:

During its onsite audit October 25-27, 2016, the staff reviewed implementing documentation for the Building Deformation Monitoring Program and interviewed cognizant Seabrook personnel and contractors. The staff noted that the program does not have one set of parameters monitored or acceptance criteria, but that the applicant establishes a set of threshold parameters to monitor and corresponding acceptance criteria (threshold parameter limits) for each structure using a proposed 3-stage evaluation process. The staff also noted that the baseline structural evaluations to establish the criteria for each structure's individual building deformation monitoring were not complete for all structures in the scope of the program, and therefore the applicant could not provide the parameters monitored and monitoring methods for all structures.

Therefore, by RAI B.2.1.31B-B2 dated December 12, 2016, the staff requested that the applicant either (1) provide a list of parameters for each structure when the evaluations are complete; or (2) provide a comprehensive discussion of the processes and procedures for determining the parameters to monitor and monitoring methods for structures in the scope of the program in a manner that would demonstrate repeatability of the process.

By letter dated December 23, 2016, the applicant responded to RAI B.2.1.31B-B2 and provided an overview of its evaluation process, a list of field observations and measurements for deformation evaluations to determine potential threshold parameters to monitor, and examples of the types of decisions that are made during the evaluation. The applicant also supplemented Commitment 91 by stating it will "[d]evelop a design standard to implement Aging Management Program B.2.1.31B Building Deformation, Program Element 3 – Parameters Monitored/Inspected. The design standard will clarify the deformation evaluation process and provide an auditable format to assess it. The design standard will include steps for each of the three evaluation states that include parameters monitored, basis for why the parameter is monitored, and conditions that prompt action for the subsequent step."

The "Parameters Monitored or Inspected" program element on pages 40-42 of Enclosure 3 of the December 23, 2016, submittal includes statements such as "[i]t should be noted that the values in the table are presented in the table as an *example and are not intended to be applicable to actual locations* [emphasis added]," and incomplete references in the Table appear to indicate that the evaluation process (including threshold parameters, monitoring methods and acceptance criteria) may not have been completed for any structure.

10 CFR 54.13(a) requires that information provided to the Commission by an applicant for a renewed license or by the Commission's regulations must be complete and accurate in all material respects. 10 CFR 54.21(a)(3) requires, for each structure and component subject to aging management review (AMR), the applicant demonstrate that the effects of aging will be adequately managed so that the intended function(s) will be maintained consistent with the current licensing basis (CLB) for the period of extended operation. The staff's guidance for generic aging management review is provided in Branch Technical Position for Aging Management Program Elements (Section A.1.2.3 of the [standard review plan] SRP-LR, Revision 2).

<u>Issue:</u>

The staff determined that the response and description of the evaluation process that leads to parameters monitored and acceptance criteria was a general overview on how NextEra may perform an evaluation and lacked specificity on how engineering decisions are made that lead to development of parameters monitored or acceptance criteria. The staff needs to review specifics of the evaluation process that clearly demonstrate that it is repeatable and consistent between structures. It appears that the design standard

referenced in Commitment 91 may provide those details, but the applicant's implementation deadline for this Commitment is March 15, 2020, which implies this will be completed in the future.

At this time, the staff is unable to complete its review of the section B.2.1.31B, "parameters monitored or inspected" and related "detection of aging effects," "monitoring and trending," and "acceptance criteria" program elements and make a safety determination given that, contrary to the regulations in 10 CFR 54.13(a) and 54.21(a)(3) and the Branch Technical Position for Aging Management Program (AMP) elements in SRP-LR, aspects of program elements of the Building Deformation Monitoring Program AMP that are important to a safety determination of adequate aging management are incomplete and are currently in development.

Request:

For each structure in the scope of the Building Deformation Monitoring Program, provide the [threshold] parameters monitored, demonstrate capability of these parameters for detecting the presence and extent of aging effects, and establish the link between the parameter(s) monitored and how monitoring of these parameters will ensure adequate aging management.

Update the applicable and inter-related program elements of the AMP, FSAR supplement, and/or other aspects of the license renewal application (LRA), as applicable, consistent with the response above.

NextEra Energy Seabrook Response to RAI B.2.1.31B-B2-1:

As discussed during the Public Meeting on August 24, NextEra Energy Seabrook has developed a comprehensive criteria document for the selection of parameters to be evaluated for input into deformation models. Based on discussion with the staff NextEra Energy Seabrook will be enhancing this document to include modeling methodology and establishment of threshold monitoring resulting from building specific analysis. NextEra Energy Seabrook will submit this revised document to the staff by December 15, 2017.

RAI 3.5-A1-1: AMR

Background:

10 CFR 54.21(a)(3) states that for each structure and component (SC) subject to an aging management review (AMR) as identified in an applicant's integrated plant assessment, the applicant must demonstrate that the effects of aging will be adequately

managed so that the intended function(s) will be maintained consistent with the CLB for the period of extended operation.

LRA Section B.2.1.31B (letter dated August 9, 2016, and amended by letter dated December 23, 2016) states in the "Scope of Program" program element that the Building Deformation Monitoring Program "provides for management of the effect of building deformation on Seismic Category 1 structures and associated components within the scope of license renewal. Program scope includes components within the scope of license renewal contained in concrete structures within the scope of the Structures Monitoring Program." In RAI 3.5-A1, the staff noted that the applicant's submittal did not include Table 2 AMR line items for SCs that may be subject to aging effects of building deformation, including supported SCs. The staff requested that the applicant provide the results of their aging management review for structures and components that are affected by structures in the scope of the Building Deformation Monitoring program in accordance with 10 CFR 54.21(a).

Issue:

In its December 23, 2016, response to RAI 3.5-A1, the applicant stated that "baseline inspection of buildings susceptible to Building Deformation has identified various categories of equipment affected by deformation as listed in Element 3 – Parameters Monitored/Inspected" but did not include any Table 2 line items for BDMP. To be consistent with regulation for aging management review (AMR) in 10 CFR 54.21(a)(3) and license renewal guidance found in [Nuclear Energy Institute] NEI 95-10, NUREG-1800 and NUREG-1801, the applicant should indicate AMR Table 2 line items and any associated Table 1 line items (e.g., one for concrete components, others for components and commodities affected by ASR Building Deformation) that call out the appropriate program(s) (e.g., [building deformation monitoring program] BDMP, [ASR monitoring program] ASRMP, [structure monitoring program] SMP) for managing aging effects of building deformation due to ASR.

Request:

Provide AMR results that identify the structures and components, materials and environments that will be affected by building deformation and indicate the applicable aging management program, in accordance with 10 CFR 54.21(a).

NextEra Energy Seabrook Response to RAI 3.5-A1-1: AMR:

As discussed in the response to RAI 3.5-A1 on December 23, 2016 (Reference 1), the application of plant specific application of Aging Management Program(s) (AMP) B.2.1.31A for Alkali Silica Reaction (ASR) and B.2.1.31B for Building Deformation are initially established by the Structures Monitoring AMP B.2.1.31. As contained in Enclosure 2, AMR Tables contained in License Renewal Application Section 3.5 have

been revised to include the additional line items of interest and annotated with one of three specific plant notes to clearly delineate when these plant specific programs apply to the specific line items in as follows:

517 After initial identification and determination of the presence of alkali-silica reactivity by the Structures Monitoring Program, Seabrook Station will age manage this condition through the Alkali-Silica Reaction (ASR) Monitoring Program.

519 After initial identification of alkali-silica reaction (ASR) induced building deformation by the Structures Monitoring Program, Seabrook Station will age manage this condition through the Alkali-Silica Reaction (ASR) Monitoring Program and the Building Deformation Monitoring Program.

520 After initial identification of alkali-silica reaction (ASR) induced building deformation affecting plant equipment and components by the Structures Monitoring Program, Seabrook Station will age manage this condition through the Building Deformation Monitoring Program.

The AMR Tables within Enclosure 2 will supersede the revised AMR tables that were previously submitted under letter SBK-L-12101 (Accession Number ML12142A323).

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 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, LLC (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]%, 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 8). 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 1.46 mm/m (Reference 8). 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) and were updated in the response to RAI B.2.31A-A1-1. 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 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-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.

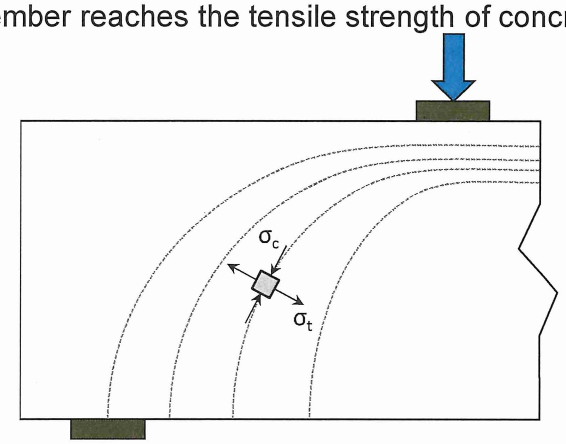

Figure A-1. Principal Stresses in Beam under Shear Loading (Reference 9)

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

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

programs validated that chemical prestressing (within the levels of ASR progression 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 Seabrook Station. 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 NextEra Energy Seabrook 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 NextEra Energy Seabrook 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.

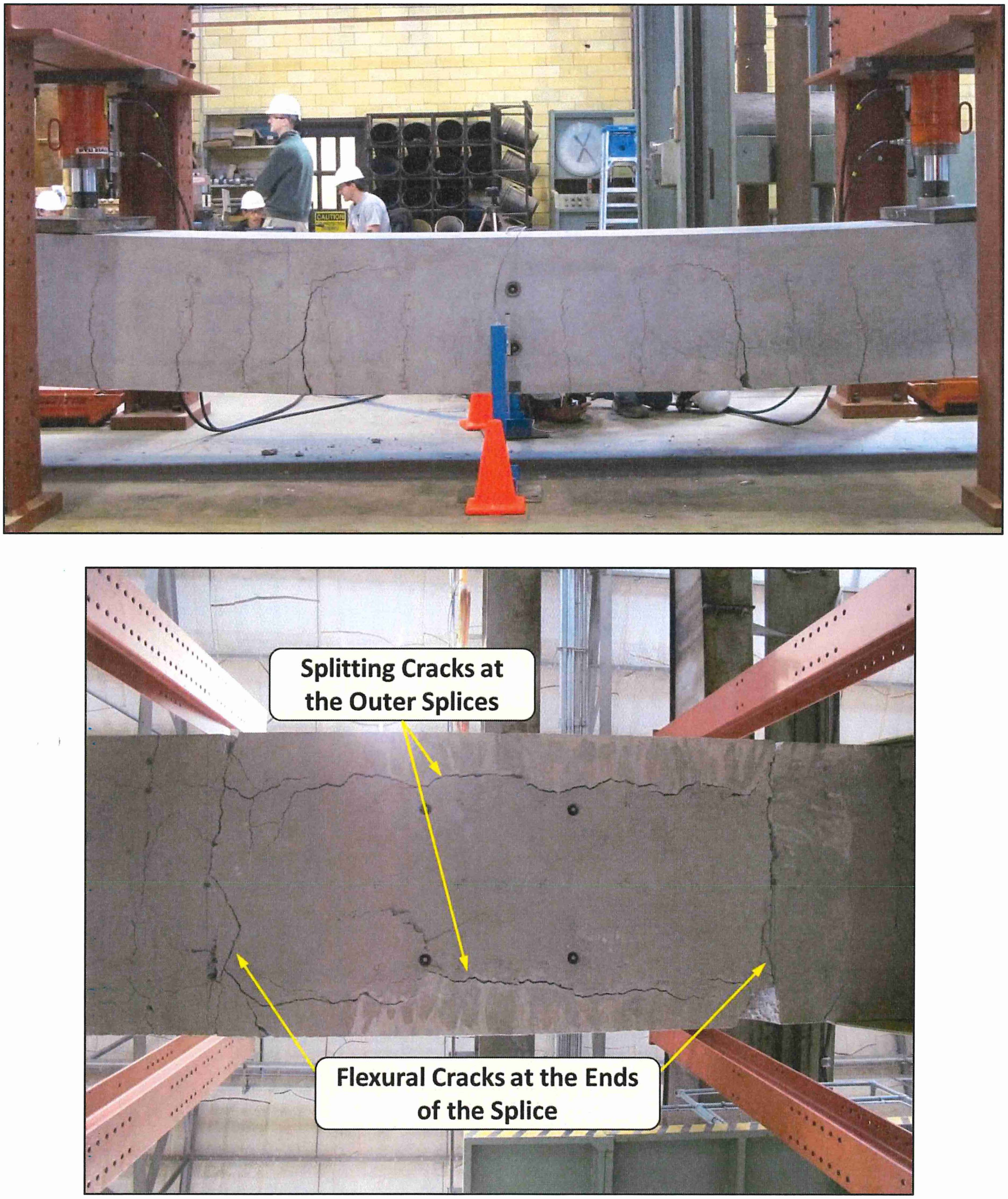

Figure A-5. Post-Failure Condition of Reinforcement Anchorage Test Specimen (Reference 9)

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 NextEra Energy Seabrook 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) 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. Seabrook Station 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-11 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]).

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[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[3]. 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.

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[3] In accordance with the methodology in MPR-4153, NextEra 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.

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[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 adjusted total expansion at the time of the corroboration study using the adjusted 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 ($\varepsilon_{t\_EM\_adj}$ - $\Delta\varepsilon_{inst}$ = ε_{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.

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

[redacted]

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

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