NEXTera ENERGY SEABROOK

IMPACT OF ALKALI SILICA REACTION ON SEABROOK CONCRETE STRUCTURES

APRIL 23, 2012

NextEra Energy Seabrook Team

- Paul O. Freeman – Site Vice President
- Richard Noble – Director of Engineering
- Michael Collins – Design Engineering Manager
- Michael O'Keefe – Licensing Manager
- Richard Cliché - License Renewal Project Manager
- Brian Brown – Design Engineering Supervisor
- Theodore Vassallo – Design Engineering
- Allan Griffith – Communications
- Steve Hamrick - Legal

- John Simons – MPR Associates
- Thomas Roberts – MPR Associates
- Dr. Oguzhan Bayrak – University of Texas at Austin

NEXTera ENERGY SEABROOK

Overview

- Alkali Silica reaction (ASR) was self identified by NextEra Energy
- Alkali Silica reaction has very limited impact on the performance of Seabrook and impacts a small localized percentage of Seabrook plant structures
- A comprehensive walk down inspection of Seabrook structures identified indications less than the industry standards for concern
- Ongoing full scale testing is expected to validate assumptions and identify additional margin
- A formal monitoring plan is in place to identify any change in performance

Seabrook Station

- Seabrook Station is 4-loop pressurized water reactor
- 3648 MWt Thermal Power; ~ 1,300 net MWe
- Commercial operation 1990
- Located in the Town of Seabrook, New Hampshire, two miles west of the Atlantic Ocean. Two miles north of Massachusetts and 15 miles south of Maine

NEXTera ENERGY SEABROOK

License Renewal

- License Renewal is a rigorous well-defined NRC process involving average of 125,000 of preparation and 20,000 man-hours of review
- The NextEra License Renewal staff questioned visual indications and conditions of concrete. Based on concrete condition and presence of ground water, NextEra Seabrook initiated a comprehensive review of possible effects to concrete structures
- In May 2010, NextEra License Renewal submitted License Renewal application
- In September 2010, NextEra identified concrete walls in “B” Electrical Tunnel were experiencing ASR

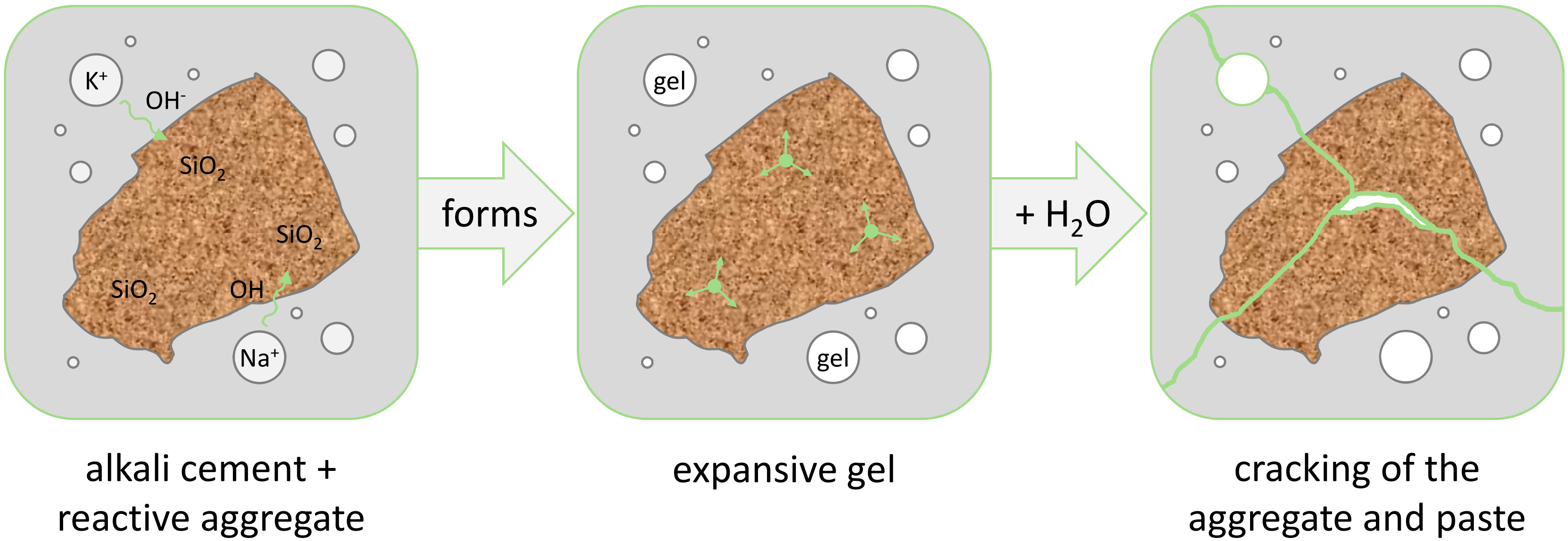
NEXTera® ENERGY SEABROOK

ASR

- ASR was first identified in late 1930's
- Common in transportation industry – bridge structures, roads and airport runways
- **ASR**: A reaction that occurs over time in concrete between alkaline cement paste and reactive, non-crystalline silica in aggregates. An expansive gel is formed within aggregates resulting in micro cracks in aggregates and adjacent cement paste. This mechanism requires presence of water thus, has been predominately detected in ground water impacted portions of below grade structures, with limited impact to exterior surfaces of above grade structures.

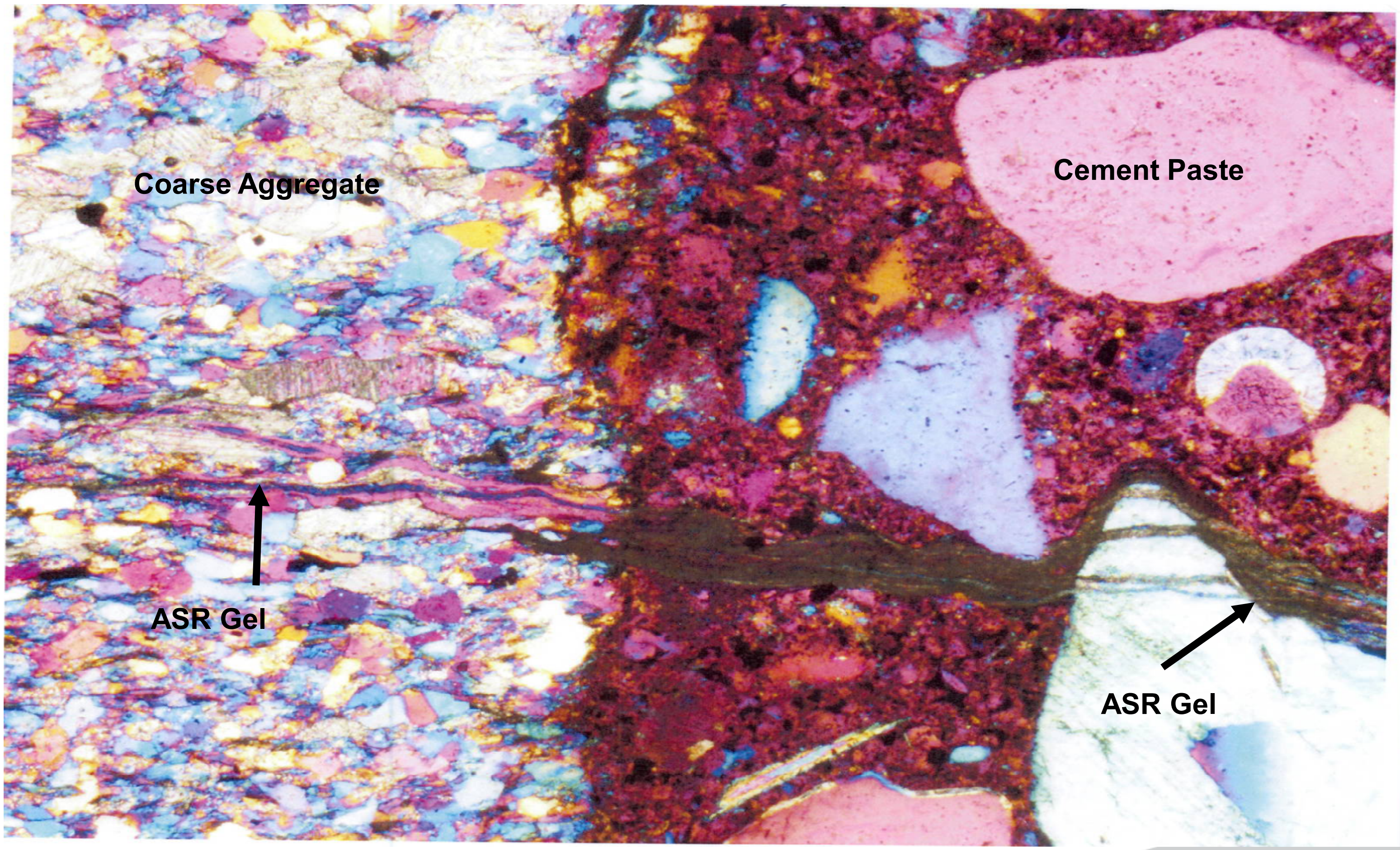
NEXTera ENERGY SEABROOK

ASR Reaction



PETROGRAPHIC EXAMINATION

Microscopic View of ASR Affected Concrete



Seabrook Concrete Construction

- Design of concrete structures at Seabrook complies with American Concrete Institute design code, ACI 318-71
- Original concrete placements occurred late 1970’s to mid 1980’s
- Concrete mixes designed to prevent Alkali-Silica Reaction (ASR)
  - Low alkali Portland cement was used
  - Aggregates routinely passed ASTM reactivity and expansion tests per C227 and C289 the standards in place at that time
  - These test methods were subsequently determined not to be effective for slow reactive aggregates
  - Petrographic examinations of aggregates per C295 were performed but did not detect presence of reactive aggregates

NEXTera ENERGY SEABROOK

ASR Impact on Concrete Structures

- ACI 318 code equations used to establish required strength of structures to resist dead weight, live loads, seismic and other external events

- ASR can potentially effect following concrete properties and performance characteristics:
  - Compressive Strength
  - Modulus of Elasticity
  - Flexural Stiffness
  - Shear Strength
  - Tensile Strength

- ASR impacts material properties but structural performance of concrete elements depend if concrete is unconfined or confined within reinforcing bars

NEXTera ENERGY SEABROOK

Concrete Core Testing "B" Electrical Tunnel

- In April 2010, 12 concrete cores removed from "B" Electrical Tunnel and tested to determine compressive strength and modulus of elasticity

  Average compressive strength   4790 psi

  Average modulus of elasticity   2080 ksi

- In October 2011, 20 additional concrete cores removed from "B" Electrical Tunnel and tested for compressive strength. This testing was performed to validate compressive strength of the concrete

  Testing observed by the NRC

  Average compressive strength   5140 psi

NEXTera ENERGY SEABROOK

Concrete Core Testing "B" Electrical Tunnel

- The initial, 2010 compression test results from 12 cores from "B" Electrical Tunnel indicated a 21.7 percent reduction in compressive strength when compared to concrete cylinders tested in 1979 when "B" Electrical Tunnel was constructed

- The differences in 1979 cylinder test results and 2010 core test results is attributed to rate of applied loading during testing and accuracy of testing equipment used in 1979

- In November 2011, subsequent compression testing of additional cores from areas in "B" Electrical Tunnel affected by ASR were compared to core removed from an area of the same concrete but not affected by ASR.

- ***Test results confirmed no reduction in compressive strength due to ASR***

NEXTera ENERGY SEABROOK

Extent of Condition Concrete Core Testing

In February 2011, based on test results from "B" Electrical Tunnel, 20 extent of condition cores removed from Containment Enclosure Building, RHR Equipment Vault, EFW Pump House, EDG Fuel Oil Tank Room, RCA Walkway and tested to determine compressive strength and modulus of elasticity

Range of compressive strength	5030 psi to 6855 psi
Range of modulus of elasticity	2700 ksi to 4050 ksi

NEXTera ENERGY SEABROOK

Petrographic Examinations Results

BUILDING	PETROGRAPHIC EXAMINATION RESULTS
B Electrical Tunnel	ASR Confirmed
CEB	ASR Confirmed
DGB	ASR Confirmed
EFW	ASR Confirmed
Equipment Vaults	ASR Confirmed
RCA Walkway	ASR Not Confirmed

NEXTera ENERGY SEABROOK

Confirmation of ASR

- Confirmation of ASR in 5 structures based on Petrographic Examinations and visual inspections

- Confirmation of ASR in 14 additional structures based on visual features:
  - Pattern cracking
  - Secondary deposits
  - Staining and discoloration
  - Deposits of alkali silica gel

Assessment by Professional Petrographer

Similar concrete materials of construction

NEXTera ENERGY SEABROOK

Affected Structures

- “B” Electrical Tunnel, CEB, DGB, EFW Pumphouse, RHR Equipment Vaults
- CST Enclosure, CBA Air Intake, SWCT, “A” Electrical Tunnel
- Fuel Storage Bldg., East & West Pipe Chase, Pre-Action Valve Room, PAB
- Mechanical Penetration Area, WPB, Intake & Discharge Structures, Switchyard foundations

NEXTera ENERGY SEABROOK

NextEra Actions to Date

- Engaged Industry Experts
- Assessed Extent of Condition
- Assessed Impact of Reduced Modulus
- Performed Petrographic Examinations
- Evaluated of Structural Anchors
- Evaluated the Affect of ASR on Concrete Structures

NEXTera ENERGY SEABROOK

Industry Experts Engaged

- MPR Associates Inc. commissioned to assist Seabrook's assessment of concrete structures impacted by ASR.
- Engaged Subject Matter Experts regarding ASR and impact on concrete structures:
  - University of New Hampshire
  - University of Texas at Austin
  - Electric Power Research Institute (EPRI)
  - Simpson, Gumpertz, and Heger (SG&H)
  - Wiss, Janney, Elstner (WJE)

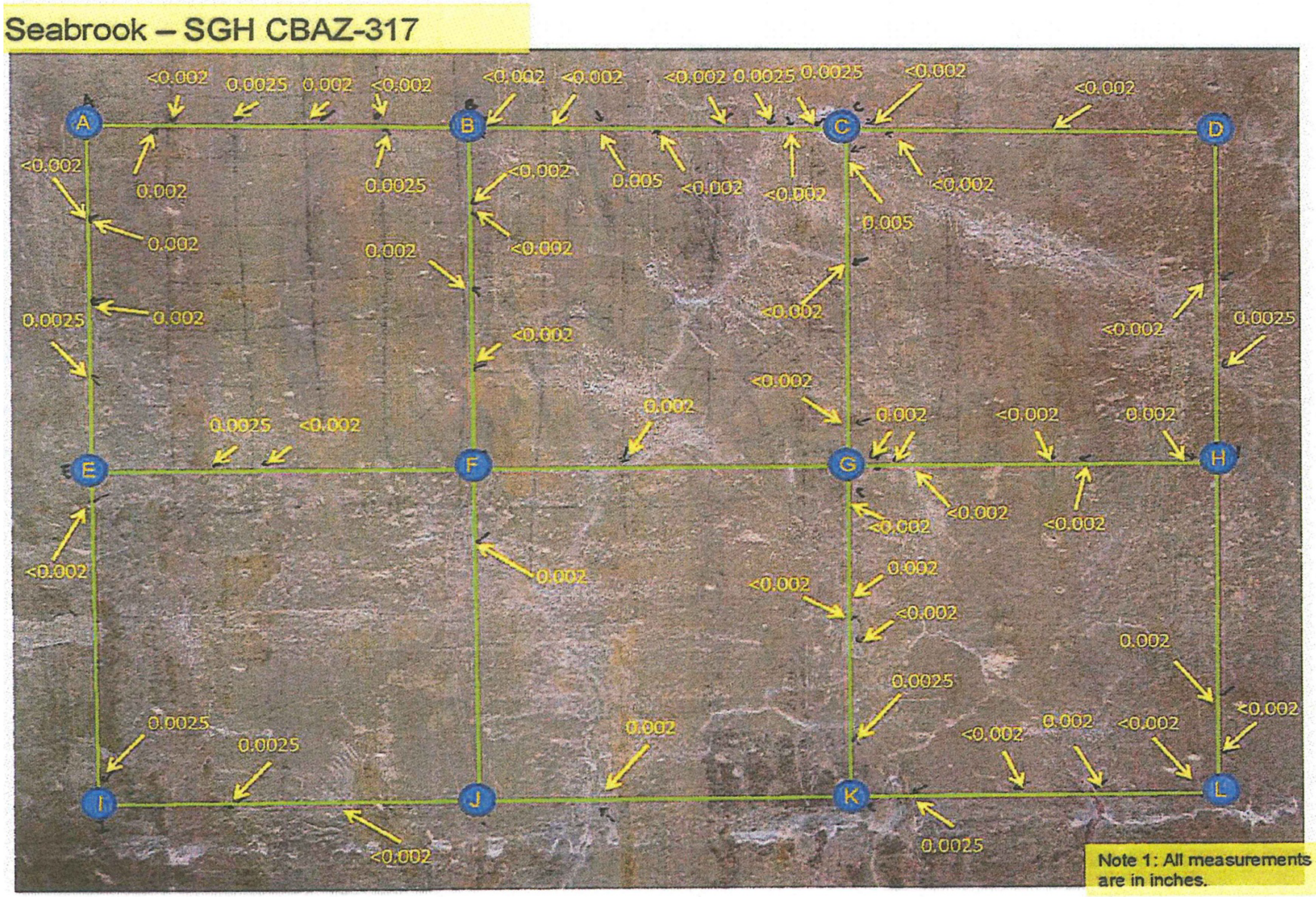
NEXTera ENERGY SEABROOK

Extent of Condition Assessment

- Completed comprehensive, Extent of Condition (EOC) inspections of 131 locations
- The EOC team included a Structural Engineer and certified, Professional Petrographer
- The inspections included baseline, ASR crack measurements and crack indexing
- The results of these walkdown inspections were documented in a Walkdown Summary Report which concludes; **the cracking indices are low and extent of ASR is minor**
- The EOC also documented locations of concrete embedments and attachments adjacent to indications of ASR

NEXTera ENERGY SEABROOK

Extent of Condition Assessment



- Maximum crack width less than 0.005"
- Lower than threshold requiring evaluation (0.040")

Impact of Reduced Modulus on ASR Affected Structures

Containment Enclosure Building (CEB)

- CEB was selected as it conservatively bounds other structures. Applied mechanical properties from other ASR affected structures
- Developed 3D Finite Element Analysis Model to replicate original seismic response and design loadings of CEB
- Performed parametric analyses with and without ASR

Finite Element Model Results:

- Maximum acceleration profiles and In Structure Response Spectrum **not** significantly impacted by ASR affected properties
- Distribution of forces and moments are **not** significantly impacted by ASR affected properties

Conclusion: Load distribution and seismic response is negligibly impacted by ASR

NEXTera ENERGY SEABROOK

Petrographic Examination

- Completed petrographic examination of a ASR affected wall cross section
- Established cracking patterns in cover concrete and structural core
- Results validated assumptions ASR cracking is less in interior confined section of a wall compared to ASR cracking in unconfined, observable cover concrete

Conclusion - ASR cracking visible on observable, exposed interior surfaces of Seabrook walls is a conservative representation of the condition of entire wall cross section

NEXTera ENERGY SEABROOK

Evaluation of Structural Anchors

- Anchor Test program at University of Texas at Austin initiated to establish structural capability of anchors in ASR-affected concrete specimens readily available
  - Expansion anchors and Undercut anchors were tested
  - Testing included pullout testing and breakout testing

- Anchor testing in concrete samples with ASR degradation greater than at Seabrook

- Anchor testing concluded:
  - The range of ASR induced cracking at Seabrook does not adversely impact the capacity of concrete anchors inservice
  - The observed crack indices at Seabrook essentially produced no reduction in pullout capacity of the anchors
  - A small decrease in concrete breakout capacity is accounted for in conservative anchor design factors applied by Seabrook

NEXTera ENERGY SEABROOK

Implications of ASR on Reinforced Concrete Structures

- Confinement acts to restrain expansion of concrete similar to pre-stressing, thus improving performance of structural element
- No direct correlation between mechanical properties of concrete cores and in situ properties of concrete
- Removed cores are tested in an unrestrained condition
- Testing full scale structural elements provides more accurate concrete performance parameters
- Testing unconfined cores for Splitting Tensile Strength and Stiffness Damage is not representative of the structural context

Industry Expert

It has to be realized that any strength test conducted on a specimen quantifies the performance of the material in relation to that method of test only and does not necessarily reflect the performance of the material in its structural context. The significance of this for the assessment of structures [subject to ASR] is that no reliance should be placed on the values obtained from any one test and that commonly accepted procedures, such as the cube crushing test, may not indicate the value to be used in a normal design check.

Clayton et al., 1990

NEXTera ENERGY SEABROOK

Restrained vs. Unrestrained Expansion

NEXTera ENERGY SEABROOK

Operability of Structures

Operability Determinations based on

- Dynamic response of the structure
- Seismic qualification of the equipment housed within the structure
- Structural capacity of the concrete structure
- Anchorage of equipment supports in concrete
- Periodic monitoring; i.e., crack measurement and crack indexing
- CEB Finite Element Analysis – bounding condition for other affected structures
- Interim Structural Assessment

"Operable but degraded" - testing is anticipated to show that the performance of ASR-affected concrete structures is not compromised

Once testing is successfully completed, Operability Determinations will be closed documenting compliance with ACI 318-71

NEXTera® ENERGY SEABROOK

Operability of Structures Structural Evaluation

- Developed estimation of ASR affect on element strength
  - Used published test data from small-scale testing for advanced (severe) ASR degradation
  - Seabrook ASR is not in advanced state
- Documented design margin in Design Basis calculations
- Screened impact of ASR on margins for Shear and Reinforcing bar anchorage considering
  - Impact of severe ASR from small-scale tests
  - Margins available between mean values and lower bound values used in ACI 318-71
  - Potential margin recovery where necessary

NEXTera ENERGY SEABROOK

Screening for ASR

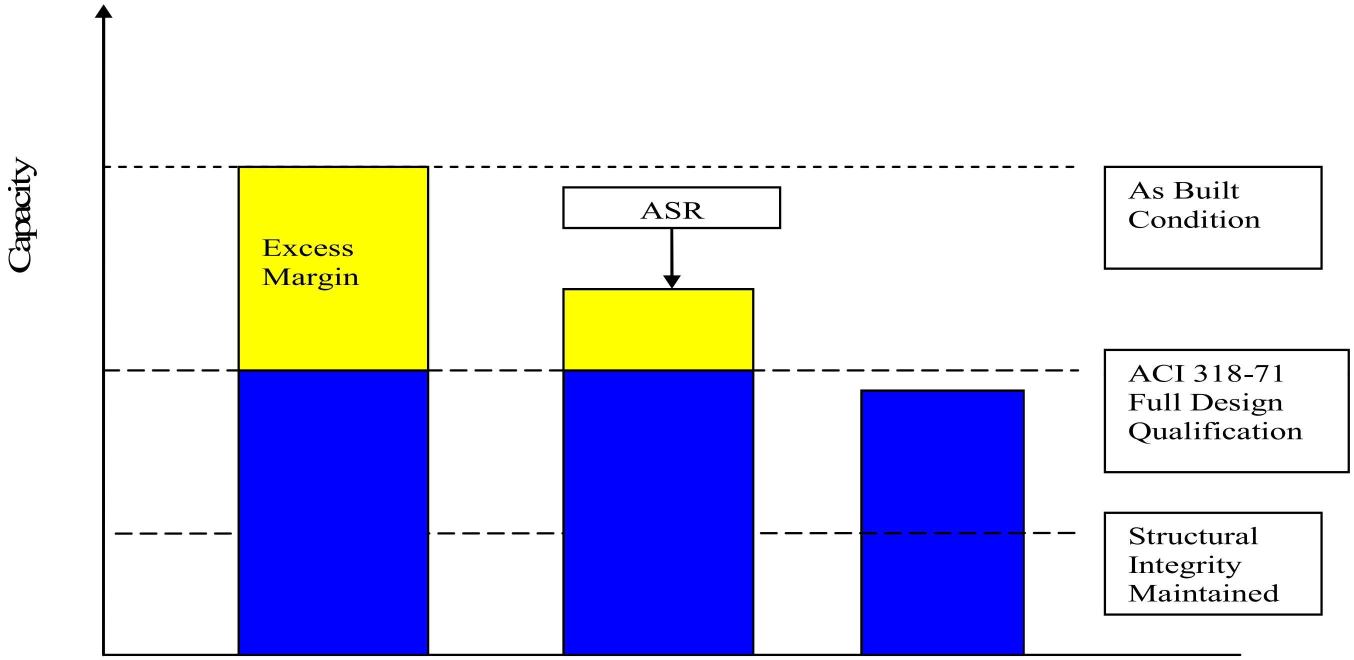
- Reviewed 143 evaluations in calculations for a biased sample of 11 areas

- Found 15 evaluations (in 5 areas) in which margin in original design basis calculation were not sufficient for the conservatively assumed ASR impact

- Additional analyses were conducted by NextEra for these areas. Considering the actual demands on the structural capacity and conservatism in load demand, these areas are operable.

NEXTera® ENERGY SEABROOK

Margin Summary



Root Cause Evaluation

NextEra has completed a comprehensive Root Cause Evaluation and identified the following:

- The ASR developed because concrete mix designs unknowingly utilized an aggregate susceptible to ASR. Although testing was conducted per ASTM standards, those testing standards were subsequently identified as limited in their ability to predict long-term ASR.

- The Health Monitoring Program for systems and structures does not contain a process for periodic reassessment of failure modes excluded from the monitoring criteria to ensure monitoring/mitigating strategies remain applicable and effective.

NEXTera ENERGY SEABROOK

Root Cause Corrective Actions

- Revise design requirements to specify the use of ASR inhibiting materials in future concrete mixes and the use of current ASTM standards for aggregate testing
- Develop a process for system/structure monitoring plans focusing on vital failure modes and utilizing the evaluation of specific Operating Experience for each failure mode
- Add requirements to the Structural Monitoring Program for condition assessments for ASR degradation

NEXTera ENERGY SEABROOK

ASR Plans and Schedule Going Forward

Shear and Lap Splice Test Programs:

University of Texas at Austin, conduct series of full-scale, concrete beam tests to provide representative test data of in-situ strength of restrained concrete elements.

- Test beams will be fabricated to represent Seabrook structural elements. Beams will have varying levels of ASR and control beams with no ASR.
- Beams instrumented to measure load and deflection at incremental steps up to failure.
- Test data used to derive ASR impact on concrete design parameters for varying levels of ASR
- Design parameters derived from ASR affected and control beams include:

  Shear strength (V_c) — Reinforcing steel anchorage (l_d)

  Modulus of Elasticity (E) — Flexural stiffness (EI)
- Design parameters for ASR affected concrete will be compared to ACI Design Code requirements and reconciled with Seabrook design basis calculations.

NEXTera ENERGY SEABROOK

ASR Plans and Schedule Going Forward

Anchor Test Program:

Anchor pullout and breakout testing program at University of Texas at Austin

Aggregate Expansion Testing:

Expansion testing of coarse aggregates to establish extent that aggregate has reacted to date and what additional reactivity/expansion is expected going forward. Testing per ASTM standards:

- ASTM C 1260 - Mortar Bar Expansion Test
- ASTM C 1293 - Concrete Prism Test

Monitoring:

- NextEra will inspect 20 previously crack indexed locations at six months intervals until a rate is established.
- Changes in crack size and crack indices will be trended and re-evaluated per the Structural Monitoring Program.
- Long term management of condition via established thresholds of crack indices at which point action will be taken.

ASR Plans and Schedule Going Forward

- Aging Management Program (AMP) for License Renewal will initially reflect criteria to be used for periodic inspection of the 20 previously crack indexed locations, at 6 month intervals.

- AMP criteria and frequency will be revised as the full-scale concrete beam test program develops

NEXTera ENERGY SEABROOK

In Conclusion

- ASR has limited impact on the structural performance of reinforced concrete elements
- ASR impacts Seabrook's concrete structures in small, localized areas
- A comprehensive walk down inspection of Seabrook structures established ASR is minor and crack indices are low
- Ongoing testing programs are expected to identify additional structural margin
- Assuming conservative losses, in concrete structural performance, Seabrook's structures remain fully operable

NEXTera® ENERGY SEABROOK