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United States Nuclear Regulatory Commission
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Presentation to the ACRS Full Committee

Seabrook Alkali-Silica Reaction (ASR) Issue – Relevance of NIST Task 3 Study

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September 3, 2025

NIST Study – Task 3 on Cyclic Performance of ASR-Affected Shear Walls

- The National Institute of Standards and Technology (NIST) Research Task 3 Study is documented in Technical Note 2180, "Task 3: Assessing Cyclic Performance of ASR-Affected Concrete Shear Walls," publicly available at https://www.nist.gov/publications/structural-performance-nuclear-power-plant-concrete-structures-affected-alkali-silica-1 (NIST Report)
- Task 3 involved in-plane cyclic lateral loading tests under constant axial compression of three ASR-affected and one control wall specimens.
- The NIST Study was **generic ASR research** and not specific to Seabrook, whereas the Large-Scale Test Program **(LSTP)** conducted by NextEra was **Seabrook-specific**.
- Discuss relevance of the NIST Study to Seabrook ASR structural safety:
    1. Relevance of NIST Test Configuration and Results (Representativeness)
    2. Relevance of NIST Tests to In-plane Shear Capacity
    3. Relevance of NIST Tests to Past (Pre-instrument) Expansion Estimate

Seabrook Criteria for ASR-Affected Structures: Background

- Seabrook Acceptance Criteria based on ACI 318 Code and LSTP is:

  ϕ x Capacity ≥ Load Factor x Demand (including ASR) for all applicable limit states

- The LSTP forms a technical basis only for:
  - The **"Capacity"** side of the equation within the LSTP expansion limits, which is monitored by the ASR Monitoring Program; and
  - **Monitoring methods** used, including determination of through-thickness expansion-to-date (pre-instrument) at the time of extensometer installation.
- The **"Demand"** side is determined by **structure-specific structural analysis** of design loads (including ASR) and load combinations, with threshold limits allowing for future ASR expansion monitored by the Building Deformation Program.
- The distribution of force components (axial or membrane, flexure, out-of-plane (OOP) shear, in-plane shear etc.) is a result of the structural analysis and is checked against applicable acceptance criteria.

1. Relevance of NIST Test Configuration and Results

(Extract: NIST Report Fig. 2.2)

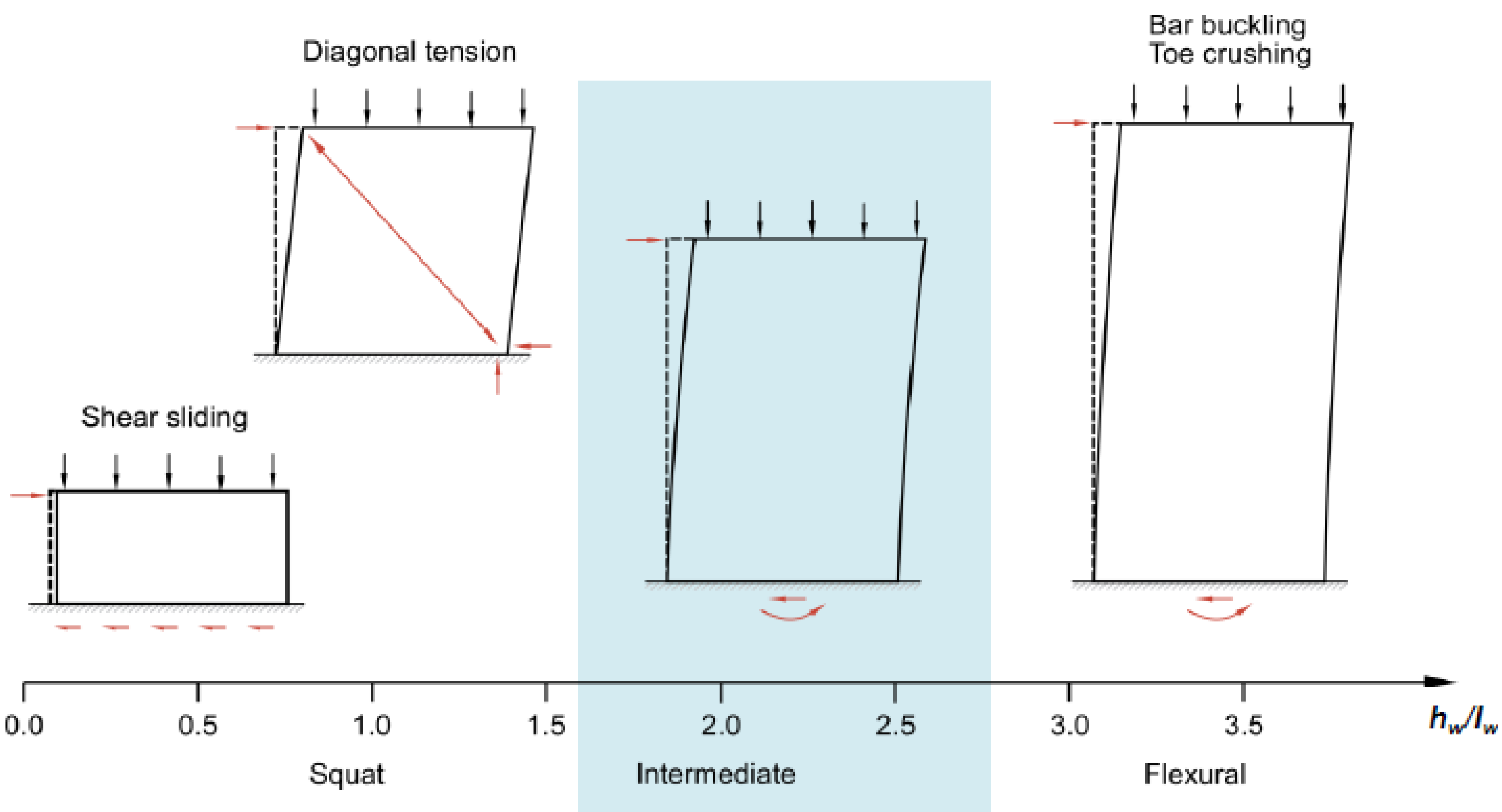

Figure 2.2: Schematic showing the effect of wall aspect ratio on predominant behavior and failure mode under lateral loading

1. Relevance of NIST Test Configuration and Results (contd...)

- NIST Task 3 shear wall test specimens had **a wall height to length (h/L) aspect ratio of 2** and therefore not “squat,” relatively low reinforcement ratio (**0.31%**, #3 @ 8.8”) and **failure mode was in flexure** (NIST Report p171) **and <u>not</u> in-plane shear**.

- Typical Nuclear Power Plant (NPP) structural walls (including Seabrook) have **low aspect ratio** (**h/L of the order 1 or less**) and larger reinforcement ratio for which the expected failure mode is **diagonal shear cracking (diagonal tension)**. Thus, NIST test specimens **were not representative of Seabrook structural walls and the test results do not apply to Seabrook**.

- Nevertheless, for the observed flexural failure mode, the measured normalized peak flexural capacity, **M'_{max}/Mn,** for all ASR-walls **are greater than 1.0** (1.132, 1.141, 1.104 for ASR vs 1.311 for non-ASR; Ref. NIST Report Table 6.1). Therefore, the tested **ASR walls reached code nominal ultimate flexural capacity, Mn, with margin** although lesser than for non-ASR wall.

- The NIST test results thus showed no reduction of maximum observed in-plane moment capacity compared to code nominal moment capacity. It poses no contradiction with LSTP out-of-plane (OOP) shear or flexural (rebar anchorage or bond) tests.

1. Relevance of NIST Test Configuration and Results (contd...)

- The LSTP test specimens were not conventional “beam” specimens. They were a slice of a representative reference location Seabrook structural wall with 2D orthogonal reinforcement on each face (providing horizontal and vertical or biaxial confinement to the wall) and no through-thickness reinforcement. For the load test, the vertical wall slice was oriented horizontally, with the 2D reinforcement layers on the top and bottom faces and loading applied normal to the top face.

- The LSTP (MPR-4273, public ML16216A242) was specific to Seabrook and as representative or bounding of typical Seabrook wall configuration as practical, and addressed the more critical limit states (flexure, out-of-plane shear, flexure and reinforcement anchorage (bond between rebar and concrete), effects on anchor bolts capacity, and instrument study) at a large scale than data available in the literature. Overall, the results of the LSTP provide the **technical basis and limitations** (e.g., expansion limits) for continued applicability of the ACI 318-71 and ASME III-2 codes-of-record to ASR-affected structures at Seabrook. The LSTP did not include in-plane shear tests.

2. Relevance of NIST Tests to In-plane Shear Capacity

- Seabrook concrete structures are subject to **design basis loads (including ASR) and load combinations** defined in the UFSAR, and physical configurations/layout that result in out-of-plane (OOP)/radial shear forces, OOP moments, in addition to membrane/axial forces and in-plane (tangential) shear forces. One or more element force components may dominate the response over the others.

- The element or sectional magnitude and distribution of these force components falls out from the structural analysis. Element or sectional design checks are made for each limit state along with applicable combined interaction. While relevant and evaluated for seismic, due to relatively larger available margin at Seabrook, in-plane shear forces typically do not control.

- Seabrook structural walls (including containment enclosure building or CEB) have **2D orthogonal reinforcement** on each face that resist in-plane shear in addition to contribution from concrete. The Containment Building (CB) has a layer of **orthogonal diagonal reinforcement** specifically designed to resist seismic tangential shear forces with zero concrete contribution.

2. Relevance of NIST tests to In-plane Shear Capacity (contd...)

- In-plane shear failure mode is expected to be relatively more ductile (due to reinforcement resisting it) versus non-ductile OOP shear failure, which is primarily resisted by concrete for the typical Seabrook configuration with no through-thickness reinforcement.

- Corroborating evidence from experimental work by Habibi et al (2018) [1] and Sawada et al (2021) [2] of lateral cyclic loading tests of ASR-affected low-aspect ratio shear walls (h/L = 0.71, web reinforcement ratio, ρ_t = 0.8%; and h/L = 0.83, ρ_t = 1%, respectively, which are more in the representative range of typical NPP structural walls) show ultimate in-plane shear capacity (strength) of the tested walls was not adversely affected by ASR. Observed failure mode was diagonal shear cracking and rebar yielding.

- There is **reasonable assurance** that Seabrook structural walls remain capable of resisting design-basis lateral seismic loads by in-plane (straight) or tangential shear (for cylindrical).

[1] Habibi et al, Effects of Alkali-Silica Rection on Concrete Squat Shear Walls, ACI Structural Journal, Sep 2018.

[2] Sawada et al, Structural Performance Evaluation and Monitoring of Reinforced Concrete Shear Walls Affected by Alkali-Silica Reactions, Journal of Advanced Concrete Technology, Volume 19, May 2021.

3. Relevance of NIST Tests to Past Expansion Estimate

- For Seabrook, the **empirical ACI code equation Ec = 57, 000 sqrt(f'c)** is used only for calculating **nominal value of concrete modulus of elasticity at time zero (Eo)** from measured compressive strength (f'c) at the time of original construction (@ 28-days, no ASR). This is used to determine value of the **normalized modulus (En = Et/Eo)** in the modulus-expansion correlation equation developed in the LSTP. This correlation is used to calculate the through-thickness expansion-to-date (pre-instrument expansion) at the time of extensometer installation. (Report MPR-4153 (public ML16279A050), p3-4)

- The elastic modulus empirical equation is **NOT used** for determining concrete modulus of elasticity (Et) **of ASR-affected concrete** at the time of extensometer installation. Et is directly measured by testing of cores removed from the location at the time of extensometer installation. There is no ASR degradation mechanism present at the time of construction; therefore, use of empirical modulus equation to determine Eo is **reasonable and justified**.

- For Seabrook, variability or uncertainty in the calculated value of the concrete elastic modulus using the empirical equation is conservatively accounted for by a **reduction factor** applied to the **normalized modulus (En = Et/Eo)** in the modulus-expansion correlation (Report MPR-4153 (public ML16279A050), p4-2)

3. Relevance of NIST Tests to Past Expansion Estimate (contd...)

- In instances where the empirical modulus equation over-predicts the original elastic modulus, use of the modulus-expansion correlation adds conservatism to the approach. In instances where the empirical equation under-predicts the original modulus, application of the normalized-modulus reduction factor adds sufficient conservatism to account for variability. (Publicly Available Report MPR-4153 (ML16279A050), p4-4)

- Regarding the empirical ACI equation for Ec, NIST Report states on page 72: ***"… This trend indicates that the compressive modulus of the reactive concrete degraded faster with ASR expansion than did the concrete's compressive strength. The non-reactive Wall 4 cylinders, on the other hand, remained within the +/- 20% range of the ACI equation."*** This is consistent with the modulus data and scatter from the LSTP (MPR-4153, p3-3, 3-6). The staff agrees that empirical modulus equation is not applicable to estimate elastic modulus in ASR-affected concrete, and it is not used for ASR-affected concrete in the LSTP methodology.

- Thus, the NIST findings **do not invalidate** the modulus-expansion correlation used at Seabrook to calculate expansion to-date at the time of extensometer installation.

Conclusion

- The NIST Task 3 wall test specimens are not representative of Seabrook structural walls (h/L, ρ_t) and thus the test results do not apply.

- The NIST Task 3 Study does not refute the overall conclusions of the Seabrook LSTP and License Amendment 159 (ML18204A291 public).

- The NRC will continue to inspect Seabrook's performance in the management of ASR under the Reactor Oversight Process.

Questions