White Paper

Technical Response to NRC's Rebuttal of My Analysis of NIST ASR Findings for Seabrook Safety

By

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About the Author

Victor E. Saouma with over 40 years of research experience, including nearly 15 years dedicated to Alkali Silica Reaction (ASR) has made significant contributions to the field. His ASR research encompasses 11 major funded projects, two books (Saouma and Hariri-Ardebili, 2021), (Saouma, V.E., 2013), 9 major reports, 9 short courses, 13 peer-reviewed papers.

He chaired an international committee through RILEM (International Meeting of Laboratories and Experts of Materials, Construction Systems, and Structures), focusing on the diagnosis and prognosis of structures affected by ASR. He was the editor of a RILEM report with over 450 pages and 30 top researchers contributing, his expertise is evident.

He is a past President and Fellow of the International Association of Fracture Mechanics for Concrete and Concrete Structures, and is thus well-versed in concrete cracking issues. He has advised the Tokyo Electric Power Company (TEPCO) on nonlinear dynamic analysis of large arch dams and on ASR-related problems for massive reinforced concrete structures. He conducted shear tests for them (and for EPRI).

He was a key contributor to EPRI's report *Structural Modeling of Nuclear Containment Structures*.

Saouma's research on AAR (Alkali-Aggregate Reaction) has been funded by various organizations including the Nuclear Regulatory Committee, Oak Ridge National Laboratory, and the Bureau of Reclamation. His technical reports are accessible online.

His research interests extend to theoretical, numerical, and experimental fracture mechanics, chloride diffusion in concrete, real-time hybrid simulation, and centrifuge testing of dams.

His international collaboration includes France, Spain, Switzerland, Italy and Japan.

In addition to his scientific expertise, Saouma is a trained civil engineer. He has taught linear and nonlinear structural analyses as well as reinforced and advanced reinforced concrete design, providing him with a broad perspective on engineering challenges.

In studying ASR over fifteen years, he has found that ASR is an extraordinarily complex and nefarious reaction. While it has been known since the 1940's, only recently have we witnessed an emergence of structures suffering from this problem (as it may take many years to manifest it- self). As a result, ASR has attracted the attention of researchers from many disciplines: chemists, mineralogists, geologists, material scientists, mechanicians, experimentalists, and yes structural engineers. Not a single one of those disciplines can provide a definite answer to questions posed by ASR. However, those who have taken a comprehensive view to the problem are best positioned to opinionate.

Given his diverse research background encompassing theoretical, experimental, numerical, and field work, as well as his leadership in addressing ASR globally, he is well-positioned to evaluate the adequacy of the work conducted at Seabrook Nuclear Power Plant.

Contents

Executive Summary

I have reviewed the NRC's 22-point rebuttal to my earlier analysis of the implications of the NIST report for the structural safety of the Seabrook Nuclear Power Plant. I approached this review with the same rigorous standards I would apply to a peer-review assignment: demanding credibility, accuracy, and completeness in technical arguments.

The NRC's response fails to meet basic scholarly standards. Of the twenty-two points presented, only one cites supporting peer-reviewed literature. More troubling, the rebuttal contains demonstrable technical errors, including a fundamental misunderstanding of how elastic modulus predictions affect expansion calculations—claiming that over-prediction "adds conservatism" when the physics dictates the opposite.

Two critical deficiencies render the NRC's safety assessment unreliable:

1. **Inappropriate testing methodology:** The Large-Scale Test Program (LSTP) relies on out-of-plane shear testing, which is scientifically inappropriate for cylindrical containment analysis where in-plane membrane forces govern structural response.

2. **Flawed expansion reconstruction:** The methodology for determining historical ASR expansion depends on empirical equations with well-documented statistical inadequacies, compounded by undisclosed "reduction factors" that cannot be independently verified.

Rather than addressing these fundamental technical concerns, the NRC deflects with irrelevant discussions and unsubstantiated assertions. The response reads more like advocacy than technical analysis, relying on professional judgment rather than documented evidence.

Based on my expertise in ASR research spanning nearly fifteen years and documented qualifications (page i), **I conclude that the current approach compromises Seabrook's ability to safely resist seismic loading.** The NRC has not demonstrated that their methodology can reliably assess structural integrity under ASR degradation.

Given the magnitude of these technical deficiencies and their implications for public safety, I strongly recommend that the ACRS submit both this analysis and the NRC's response for independent review by a panel of recognized experts in structural engineering, seismic analysis, and ASR effects on nuclear containment structures.

1 Introduction

> Because what is ultimately at stake is the structural safety of Seabrook under seismic excitation, I strongly recommend that the ACRS subject this document—like the one submitted by C-10—to external independent review by a panel of recognized structural engineering scholars

In this review I will examine, one by one, the 22 points raised by the NRC (presented in grey boxes). My approach is that of a scholar, applying a rigorous standard in which each argument must be substantiated, documented, and evaluated against accepted principles and peer-reviewed evidence. This stands in clear contrast to the engineering approach taken by the NRC, which relies heavily on professional judgment and unsubstantiated assertions.

This difference in method gives rise to a fundamental clash: on the one hand, an engineering response rooted in intuition and selective references to the American Concrete Institute (ACI) design code[1], even though the code does not address AAR and at times is invoked with a permissive interpretation; on the other, a scholarly review that insists on documented support. I encourage the reader to keep this distinction in mind when reading what follows, as my analysis necessarily employs a fine-comb approach that may appear exacting but is essential when the structural safety of Seabrook under seismic excitation is at stake."

With this framework established, I now turn to a detailed examination of each of the 22 NRC points, evaluating them individually for credibility, rigor, and relevance.

2 Test configuration

> 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.

- Both the NIST study and my contract with the University of Colorado were necessarily generic in scope. The NRC commissioned them precisely to improve its understanding of ASR in reinforced concrete, not to provide site-specific case studies.
- It is difficult to see why the NRC would have invested millions of dollars in ASR research unless the intent was to address gaps in its technical knowledge relevant to plant safety.
- The NRC itself described my Colorado contract as "confirmatory." Had either the Colorado or NIST studies produced outcomes consistent with the NRC's earlier (and poorly conceived) Texas tests, those results would have been treated as valid and directly applicable to Seabrook.
- In any event, even if these studies had been framed as Seabrook-specific, the essential findings and implications would not have differed materially.

[1] The ACI code is a prescriptive design standard developed for conventional reinforced concrete structures. It does not address material degradation from Alkali–Aggregate Reaction (AAR), nor does it provide a research framework for evaluating such deterioration.

SLIDE 3

The discussion of this (questionable) approach to safety assessment is entirely irrelevant in this context.

SLIDE 4-8

> **Slide 5; Squat**
>
> NIST Task 3 shear wall test specimens had a wall height-to-length (h/L) aspect ratio of 2 and therefore were not "squat," had a relatively low reinforcement ratio (0.31%, #3 @ 8.8"), and failed in flexure (NIST Report p.171) rather than in-plane shear.

I agree with the NRC that the aspect ratio of the NIST shear wall tests (2.0) places them in the "intermediate" category (between squat and slender), but this does not in itself disqualify them.

> Shear walls (or wall segments) shall be considered slender if their aspect ratio (height/length) is >3.0, and shall be considered short or squat if their aspect ratio is <1.5. Slender shear walls are normally controlled by flexural behavior; short walls are normally controlled by shear behavior. The response of walls with intermediate aspect ratios is influenced by both flexure and shear.
>
> Elwood, Matamoros, Wallace, et al. (2007) *"Update to ASCE/SEI 41 concrete provisions"*

Turning to the LSTP tests, two distinct failures are evident:

Unintended: The absence of vertical reinforcement in the center of the beam allowed vertical expansion, producing a large delamination crack *before the test even started*. This flaw rendered all subsequent results highly questionable (Fig. 1).

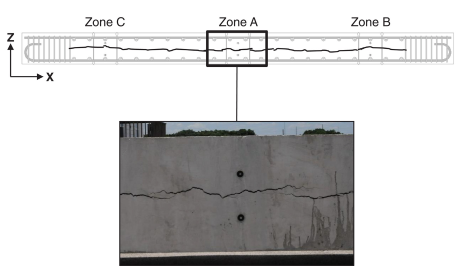


Figure 1: Unanticipated pre-test delamination

Intended: Since the purpose of the LSTP was to investigate the impact of AAR on shear strength degradation, the specimen should have been designed to maximize shear and minimize flexure. The NRC itself recognizes this necessity (see slide 4). However, even setting aside the pre-test delamination, the governing mode was not pure shear but rather *flexure-shear*[2]. In the critical zone, significant shear was accompanied by a non-negligible moment—precisely the situation for shear walls with larger aspect ratios that the NRC criticizes in the NIST tests (Fig. 2).

[2]A flexure-shear crack is a flexural crack that, under significant shear, rotates into a diagonal crack and propagates from the tension zone toward a support or load point across the web.

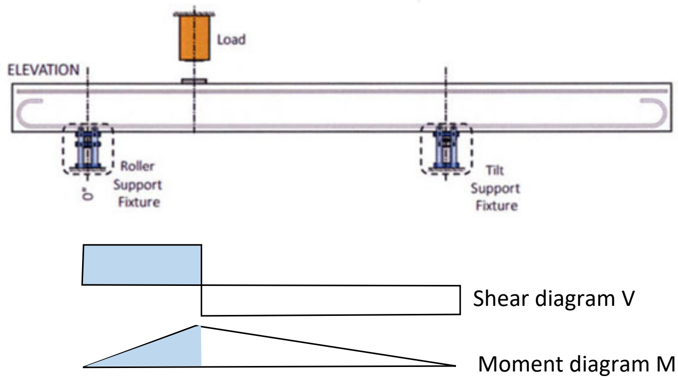


Figure 2: LSTP specimen with shear and moment (flexure) diagrams

> **Slide 5; Aspect ratio not applicable to an NPP**
>
> 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.

To claim that an NPP has a *low aspect ratio* is **conceptually flawed**. The containment is a **thin cylindrical reinforced-concrete shell**, not a planar shear wall. For such a structure, the definitions of h and L used for wall aspect ratios are not meaningful, and applying them to the Seabrook containment is therefore **inappropriate**.

> **Slide 5; Nominal moment M_n**
>
> Nevertheless, for the observed flexural failure mode, the measured normalized peak flexural capacity, M'_{max}/M_n, for all ASR walls was greater than 1.0 (1.132, 1.141, 1.104 for ASR vs. 1.311 for non-ASR; see NIST Report Table 6.1). Therefore, the tested ASR walls reached code nominal ultimate flexural capacity, M_n, with margin, although the margin was smaller than for the non-ASR wall.
> The NIST test results thus showed no reduction of maximum observed in-plane moment capacity compared to the code nominal moment capacity. This poses no contradiction with LSTP out-of-plane (OOP) shear or flexural (rebar anchorage or bond) tests.

This segment of the NRC review is essentially irrelevant, since in the NPP containment we are dealing with membrane action; bending moments develop only locally at the juncture between the cylindrical and spherical shells.

1. It is correct that Table 6.1 shows $M'_{max}/M_n > 1.0$ for the NIST tests. However, Swamy and AlL-Asali (1989) report that *ASR can create large irreversible concrete and steel strains that affect the overall serviceability, strength, and stability of reinforced concrete beams. The maximum recorded loss in flexural capacity due to ASR was about 25%.*

2. The NIST report itself (p. 184) notes several important reductions:

   - The presence of ASR decreased normalized peak flexural capacity, M_{max}/M_n, by about 10–11%.
   - The presence of ASR decreased normalized yield moment, M_y/M_n, by about 26%. For seismic analysis, this indicator is more relevant than maximum moment, as it reflects the ductility[3] required to dissipate energy without brittle, sudden cracking.
   - When the four NIST measurements of M_{max}/M_n were combined with three additional measurements from Oh, Han, and Lee (2002)[4], the presence of ASR was found to reduce the mean M_{max}/M_n by about 7%.

In light of this evidence, the NRC's assertion that the NIST tests show "no reduction" is **misleading**: while ultimate flexural strength may have met code values, ductility—**critical under seismic loading**—was demonstrably compromised by ASR. The NIST results (Table 6.1) clearly show that the ASR-affected walls exhibited reduced ductility, with normalized yield moment M_y/M_n decreased by approximately **26%** compared to the non-ASR wall. **Ignoring such reductions in ductility is unacceptable for any credible seismic safety evaluation of Seabrook.**[5]

> Slide 6; Design of the LSTP beam
>
> 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.

I agree that the configuration is indeed **unconventional** and **unrepresentative** of the shear resisted in a cylindrical containment subjected to lateral load. It is universally accepted that in this case, the lateral load is resisted by *membrane in-plane* shear,[6] not by out-of-plane shear.

In fact, the NRC itself acknowledges that the LSTP does not capture in-plane shear and does not treat the specimen as representative of membrane action.

- The LSTP setup is illustrated in Fig. 3(a). Note that pre-test delamination occurred in the center segment of the specimen. What is actually modeled is a narrow vertical strip

[3] In structural engineering, *ductility* is the ability of a material or structural element to undergo significant plastic deformation before failure. In seismic design, ductility is essential because it allows a structure to dissipate earthquake energy through controlled inelastic deformations rather than collapsing in a brittle manner (Paulay and Priestley, 1992).

[4] The geometry and reinforcement ratios of the NIST wall specimens were selected to match non-reactive walls previously tested by Oh et al. (2002) to facilitate independent comparisons.

[5] In structural engineering, *ductility* is the ability of a material or structural element to undergo significant plastic deformation before failure. In seismic design, ductility is essential because it allows a structure to dissipate earthquake energy through controlled inelastic deformations rather than collapsing in a brittle manner (Paulay and Priestley, 1992).

[6] Global response is membrane-dominated; in-plane resultants $N_\theta, N_\phi, N_{\theta\phi}$ govern. Transverse (out-of-plane) shear Q_θ, Q_ϕ is generally small and localized near supports, junctions, penetrations, and under non-axisymmetric actions; it is not zero.

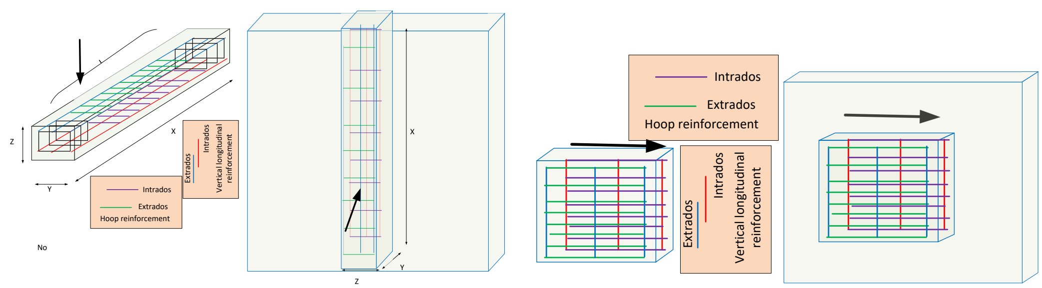
of the wall by "punching" through it. This strip is artificially **laterally constrained** by adjacent concrete; such edge effects could have been reduced had the LSTP tested a plate rather than a beam. Key differences are:

  - **Dimensionality:** Beam theory is 1-D; plates are 2-D with coupled curvatures (κ_x, κ_y) and twisting M_{xy}. Beam tests cannot capture M_y or M_{xy}.
  - **Shear field:** Beams develop primarily Q_x (τ_{xz}), whereas plates carry bidirectional shear Q_x, Q_y (τ_{xz}, τ_{yz}). Beam tests miss through-width shear flow.
  - **Crack mechanics:** Beams transition flexure → flexure–shear. Plates develop **two-way crack fields** (diagonal + transverse) governed by biaxial bending and in-plane shear.
  - **Torsion/biaxial coupling:** Plates experience twisting moments and Poisson coupling; beams omit these effects.
  - **Size (width) effects:** Plate response reflects finite-width phenomena (shear-lag, stress redistribution). Beams lack a mechanism to capture this.

  Thus, while I strongly disagree with the design philosophy of relying on out-of-plane shear, the handicap would have been at least partially mitigated had a plate been tested instead of a beam.

- By contrast, an **in-plane shear test** configuration, Fig. 3(b), would be far more representative of the structural response of an NPP containment under lateral seismic load. By limiting the height, flexural effects are minimized and shear clearly dominates.

Bottom line: to the best of my knowledge, the LSTP is the **only test program in the world** that relies on **out-of-plane shear** (Fig. 3(a)), in stark contrast to other researchers who correctly test **in-plane shear**.



(a) LSTP (b) Other researchers

Figure 3: LSTP vs. in-plane shear tests by others

This acceptance of LSTP by the NRC stands in direct contradiction to established principles of structural mechanics and to the testing practices followed worldwide.

Slide 6; Test configuration trying to satisfy multiple demands

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-ofrecord to ASR-affected structures at Seabrook. The LSTP did not include in-plane shear tests.

- The test configuration indeed does **not explicitly refer to Seabrook in particular**; it represents a generic NPP. At the very least, the test should have attempted to satisfy the requirements of the Buckingham Pi theorem (Buckingham, 1914)[7], and clarified how the **reinforcement of the test specimen correlates with that of an actual NPP containment structure** as I have attempted to elucidate in Fig. 3(a).
- The single test configuration attempts to cover **too many limit states simultaneously**:

  1. flexure
  2. out-of-plane shear
  3. flexure and reinforcement anchorage
  4. anchor bolts capacity
  5. instrument study

  I agree that the beam test may have been adequate for the last three objectives. However, in an NPP **flexure is not predominant**, and with respect to out-of-plane shear—**which is not the relevant shear mode for containment**—a plate should have been tested instead of a beam.
- The assertion that the LSTP results "provide the technical basis and limitations (e.g., expansion limits) for continued applicability of the ACI 318-71 and ASME III-2" is **irrelevant**: **bad data can also be forced into a good model**. What is needed is an **in-plane shear test**, which would have provided reliable and representative shear data.

Slide 7; Mixing correct but irrelevant with erroneous details

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-ofplane (OOP)/radial shear forces, OOP moments, in addition to membrane/axial forces and inplane (tangential) shear forces. One or more element force components may dominate the response over the others.
Seabrook structural walls (including containment enclosure building or CEB) have 2D orthogonal reinforcement on each face that resist in-plane shear in addition to

[7] Buckingham Pi (scaling) rule, in plain terms: many physical problems can be described by a few key *ratios* with no units (for example, height/length or load/strength). A small model represents the real structure only if those ratios are the same in both. If the ratios are not matched, the model's results cannot be trusted for the full-size case. Think of it like a recipe: halving every ingredient works; changing only some does not.

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.

- This discussion is **completely irrelevant** in the context of responding to criticism of the LSTP test configuration.
- The NRC claims—without clarification or substantiation—that the configuration results in membrane/axial forces. A simple free body diagram[8] demonstrates that there are **no such forces**.
- The statement that "one or more element force components may dominate the response over the others" is a **gratuitous claim**, offered without identifying which force component dominates (I maintain it is the out-of-plane response) or providing any scientific substantiation.
- In short, much of this passage combines **true but irrelevant assertions with erroneous ones**, a ploy often used when substantive arguments are lacking. The reader should be on guard against such tactics so as not to be **misled or obscured**.

Slide 8; Irrelevant detail given delamination compromise

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.

*This statement shifts the discussion away from the real failure mechanisms relevant to a cylindrical containment shell, where global response is **membrane-dominated** rather than governed by through-thickness shear.*

I agree that the in-plane response is **more ductile** than the out-of-plane response, where shear is resisted directly by the concrete (since there are no stirrups). **However, the assertion that Seabrook containment is governed by a "non-ductile" out-of-plane shear mode is questionable: as a cylindrical shell, its global response is membrane-dominated, and through-thickness shear is not the critical failure mechanism.**

Let us also not forget that the LSTP test specimens cracked along their length *prior to testing*. At that point, the LSTP was no longer testing one beam of depth h, but effectively two beams of depth $h/2$ stacked on top of each other. **This is summarized quantitatively in Table 1**, which highlights the differences.

Bottom line: once delamination occurred, the experimentalist had no way of knowing whether the behavior corresponded to Case 2 or Case 3. **One cannot credibly assess the safety of an NPP subjected to AAR on the basis of such clumsy and compromised results.**

[8] A free body diagram is a schematic representation of a body or structure isolated from its surroundings, showing all external forces and moments acting upon it.

Table 1: Comparison of original deep beam with two-beam arrangements: well-connected (ideal) versus delaminated (weakened). The delaminated case (Case 3) **invalidates the LSTP results as a basis for any credible safety assessment of Seabrook**.

Configuration	Deflection	Bending Stress	Shear Stress
1. Original beam (depth h)	small (stiff section)	low (spread over deep section)	low (spread over deep section)
2. Two beams, fully connected (acting as one)	essentially the same as original	essentially the same as original	essentially the same as original
3. After delamination (two beams, depth $h/2$ each, unconnected)	about **4× larger**	about **4× higher**	about **2× higher**

> Slide 8; Conclusions
>
> 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).

Ideally, the qualifier **"reasonable"** should have been omitted altogether. This assertion can be **easily challenged**, because:

In-plane: The specimen was already **damaged prior to testing**, rendering all subsequent results highly questionable.

Tangential: If by this the NRC means "in-plane shear," then the claim is **unsupported by the test data**. The LSTP provides no credible basis for such a conclusion.

Bottom line: this statement is part of the NRC's rebuttal of my previously submitted analysis—and as shown above, it is **fundamentally unfounded and scientifically indefensible**.

3 Relevance of NIST Tests to Past Expansion Estimate

> Slide 9; Applicability of the equation
>
> For Seabrook, the empirical ACI code equation $E_c = 57,000\sqrt{f'_c}$ is used only for calculating the nominal value of concrete modulus of elasticity at time zero (E_0) from measured compressive strength (f'_c) at the time of original construction (@ 28 days, no ASR). This is used to determine the value of the normalized modulus ($E_n = E_t/E_0$) 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), p. 3–4)
> The elastic modulus empirical equation is NOT used for determining the concrete modulus of elasticity (E_t) of ASR-affected concrete at the time of extensometer in-

stallation. E_t 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 the empirical modulus equation to determine E_0 is reasonable and justified.

- I agree that the equation is applied only to concrete at an early age. However, reliance on the ACI expression is **problematic**, as it is purely empirical.
- The NRC does not address my central concern: the NIST data (not disputed) **unequivocally show that reliance on this equation is not only incorrect but also unconservative**.
- The absence of an alternative method does not make the current approach correct by elimination. At a minimum, one should provide **error bars or uncertainty bounds** to delimit its range of applicability.
- ASR is highly heterogeneous: expansion may occur at point A and be entirely different (or absent) a few feet away. Reliable reconstruction of past expansion would require **fine-grained historical data**, but only a very limited number of cores were tested at construction. It is therefore highly probable that the assumed expansion history is **poorly correlated with the actual local behavior**.
- **Historical context matters:** Based on Pauw's (1960) foundational research, which forms the basis for the current ACI 318 equation, the statistical relationship between compressive strength and elastic modulus is inherently poor. Pauw observed "a poor statistical relationship between compressive strength and the elastic modulus" and recommended "a future reassessment of the role of compressive strength in estimating the elastic modulus." Puttbach, Prinz, and Murray (2023) note that despite six decades since Pauw's recommendation, this fundamental weakness persists. The equation essentially conflates two mechanistically different properties: elastic modulus is primarily governed by aggregate properties and the aggregate-paste interface, while compressive strength is controlled by paste strength. Therefore, the assertion of high variability in predicting elastic modulus from compressive strength for normal weight concrete remains valid

In short: the NRC's position does not resolve the fundamental problem—**past expansion cannot be credibly reconstructed using empirical equations with substantial scatter in the underlying data**.

Slide 9 Applicability of the equation

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 ($E_n = E_t/E_0$) in the modulus-expansion correlation (Report MPR-4153 (public ML16279A050), p4-2)

Indeed, ML16279A050 states that "*a normalized modulus reduction factor of XXX is applied so that the final calculated through-thickness expansion is conservative*". However, **this approach raises fundamental concerns about transparency and adequacy**:

- **Why is the reduction factor redacted?** Transparency in safety calculations is essential for public confidence and technical review.
- **A reduction factor cannot remedy a fundamentally inadequate baseline calculation.** If the original value X is unconservative (as established by NIST and not challenged by the NRC), applying an undisclosed reduction factor provides no assurance of safety. For example, if X = 100 but NIST demonstrates the correct value should be 70, **how can we verify that the NRC's reduction factor is sufficient?** If only a 20% reduction is applied, yielding 80, this remains 14% higher than the NIST-established value of 70.
- **The logic is circular**: The NRC acknowledges uncertainty exists (hence the need for a reduction factor) but simultaneously claims the result is "conservative" without demonstrating that the reduction adequately addresses the identified uncertainty.

> Slide 10 Under/over estimate of the modulus
>
> 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)

The NRC's statement contains a fundamental error that undermines their entire safety analysis:

- **The NRC's first claim is categorically wrong.** The NRC states: *"In instances where the empirical modulus equation over-predicts the original elastic modulus, use of the modulus-expansion correlation adds conservatism to the approach."* This is the exact opposite of reality[9]. As clearly shown in Figure 4, when the initial modulus is over-predicted ($E_0 \nearrow$), the normalized modulus decreases ($E_n \searrow$), which leads to **increased predicted expansion** ($\varepsilon^{AAR} \nearrow$). This is **non-conservative**, not conservative.
- **The NRC's second claim is equally flawed.** They state: *"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."* Again, the physics is backwards: when E_0 is under-predicted ($E_0 \searrow$), the normalized modulus increases ($E_n \nearrow$), leading to **decreased predicted expansion** ($\varepsilon^{AAR} \searrow$). The system naturally becomes more conservative in this case, **without any reduction factor**.
- **No scientific justification exists for the adequacy of the reduction factor.** As previously discussed, there is no evidence that the (redacted) reduction factor is sufficient to compensate for the systematic errors in the empirical equation. The NRC

[9] Such a fundamental error from the NRC is incomprehensible and suggests inadequate technical review. This type of error should not occur at an agency entrusted with safeguarding public safety from nuclear accidents.

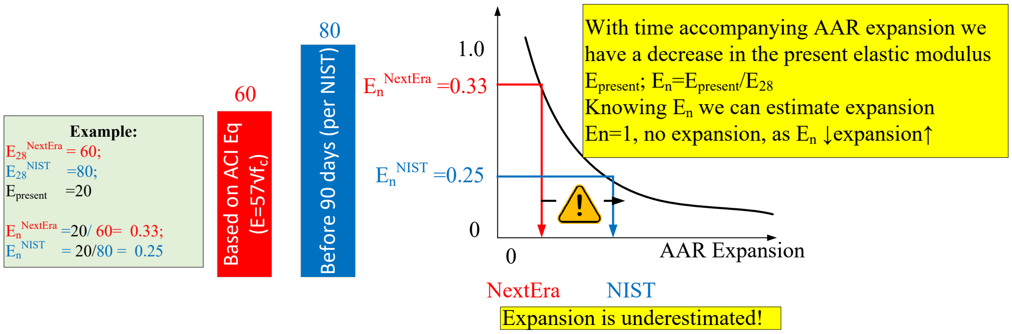


Figure 4: Effect of underestimation of E_0 in expansion prediction

provides no quantitative analysis demonstrating that their adjustment addresses the magnitude of uncertainty identified by NIST.

Slide 10 Applicability of the ACI equation

Regarding the empirical ACI equation for E_c, 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.

This statement appears to be addressing a non-existent issue and creates unnecessary confusion:

- **No one has claimed the ACI equation applies to ASR-affected concrete.** The fundamental issue is not whether the ACI equation works for degraded concrete—of course it doesn't. The issue is whether the ACI equation can **accurately estimate the original, undamaged elastic modulus** (E_0) needed for the LSTP methodology.
- **The NRC is conflating two different applications.** There is a critical distinction between:
  - Using the ACI equation to estimate current modulus of ASR-degraded concrete (inappropriate and never proposed)
  - Using the ACI equation to estimate the original modulus of concrete before ASR degradation (the actual concern raised by NIST)
- **The statement deflects from the real problem.** By focusing on the obvious fact that the ACI equation doesn't work for damaged concrete, the NRC avoids addressing the core issue: **the high variability and poor statistical correlation between compressive strength and elastic modulus in normal concrete**, as identified by (Pauw, 1960) and confirmed by the NIST report.

- **The reference to LSTP data scatter actually supports the critics' position.** The NRC mentions "modulus data and scatter from the LSTP" as if this validates their approach, but scatter in the data actually demonstrates the unreliability of empirical predictions—exactly the concern being raised.

Slide 10 Applicability of the ACI equation
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.

This conclusion is fundamentally flawed and contradicted by the NRC's own analysis. The NRC's dismissal of the NIST findings is particularly troubling given the multiple technical errors and omissions in their presentation:

- **The NRC made a blatant error in analyzing the impact of elastic modulus under-prediction.** Their claim that over-predicting the original elastic modulus "adds conservatism" is physically incorrect—it actually leads to non-conservative (higher) expansion estimates, as demonstrated in Figure 4.
- **The NRC ignores fundamental statistical limitations.** They fail to acknowledge that the substantial randomness and scatter in the empirical data warrant the inclusion of uncertainty bounds and error bars in any safety analysis. The high variability identified by Pauw (1960) and confirmed by subsequent data from the NIST report, as well as scatter reported in my original analysis of Bureau of Reclamation data (Dolen, 2005), demonstrates that single-point estimates from empirical equations are insufficient for safety-critical applications without proper uncertainty quantification.
- **None of the NRC's six arguments refute the core technical concerns.** Rather than addressing the fundamental statistical inadequacy of using compressive strength to predict elastic modulus—the central issue raised by NIST—the NRC deflects to tangential issues and mischaracterizes the problem.
- **The NRC relies on an unquantified "reduction factor" to compensate for unquantified errors.** This approach provides no scientific basis for confidence in safety margins. Without transparency regarding both the magnitude of the error in E_0 determination and the adequacy of the correction factor, the public and technical community cannot evaluate the safety implications.
- **The burden of proof remains unmet.** The NRC has not demonstrated that their methodology can reliably reconstruct historical expansion values with sufficient accuracy for safety-critical applications, particularly given the empirical equation's inherent limitations and the consequential nature of potential underestimates.

In short: the NRC's position does not resolve the fundamental problem—**past expansion cannot be credibly reconstructed using empirical equations with substantial scatter in the underlying data**.

4 Conclusion

This detailed examination of the NRC's 22-point rebuttal reveals fundamental flaws in both their technical analysis and regulatory approach to ASR-affected structures at Seabrook Nuclear Power Plant.

Critical Technical Deficiencies The NRC's response contains several **egregious technical errors** that call into question the competency of their safety assessment:

- **Physics misconceptions:** The NRC incorrectly claims that over-predicting the original elastic modulus "adds conservatism" when the opposite is true—it leads to non-conservative expansion estimates. This represents a fundamental misunderstanding of the modulus-expansion correlation.
- **Inappropriate test methodology:** The LSTP's reliance on out-of-plane shear testing contradicts established structural mechanics principles for cylindrical containment analysis, where membrane-dominated in-plane shear governs. The NRC's acceptance of this approach is scientifically indefensible.
- **Compromised experimental data:** The pre-test delamination that compromised the LSTP specimens fundamentally altered the structural behavior being measured, yet the NRC continues to rely on these flawed results for safety-critical decisions.

Methodological Inadequacies Beyond specific technical errors, the NRC's approach suffers from systemic methodological problems:

- **Empirical equation limitations:** The NRC dismisses well-documented concerns about the ACI elastic modulus equation's statistical inadequacy, first identified by Pauw (1960) and confirmed by NIST data. The equation's high variability and poor correlation between compressive strength and elastic modulus make it unsuitable for safety-critical historical reconstructions.
- **Lack of transparency:** Critical safety factors are redacted without justification, preventing independent verification of their adequacy. The use of an undisclosed "reduction factor" to compensate for known systematic errors provides no scientific basis for confidence.
- **Circular reasoning:** The NRC simultaneously acknowledges uncertainty in their calculations (hence the need for reduction factors) while claiming the results are "conservative" without demonstrating that their adjustments adequately address the identified uncertainties.

Regulatory and Scientific Standards The contrast between approaches is stark and concerning. Where rigorous scientific analysis demands:

- Documented evidence and peer-reviewed support
- Proper uncertainty quantification with error bounds
- Transparent methodologies subject to independent review

- Conservative assumptions when dealing with public safety

The NRC instead relies on:

- Unsubstantiated engineering assertions and professional judgment
- Single-point estimates without uncertainty bounds
- Redacted safety factors that cannot be independently verified
- Claims of conservatism that are demonstrably incorrect

Safety Implications The documented technical errors and methodological inadequacies raise serious questions about the NRC's ability to ensure public safety at Seabrook. Specifically:

- **Unreliable expansion estimates:** The methodology cannot credibly reconstruct historical ASR expansion with sufficient accuracy for seismic safety assessment.
- **Non-conservative assumptions:** Key aspects of the analysis underestimate potential structural degradation, contrary to standard nuclear safety practice.
- **Inadequate structural testing:** The reliance on inappropriate test configurations fails to capture the actual failure mechanisms relevant to containment structures under seismic loading.

Recommendations Given the magnitude of technical deficiencies identified and the stakes involved, I make the following recommendations:

1. **Independent expert review:** Both this analysis and the NRC's response should be submitted to a panel of recognized structural engineering experts with expertise in ASR, seismic analysis, and nuclear containment design for independent evaluation.
2. **Comprehensive testing program:** A properly designed testing program focusing on in-plane shear behavior of ASR-affected concrete specimens representative of containment wall configurations should be conducted.
3. **Transparent methodology:** All safety factors, reduction coefficients, and calculation procedures must be disclosed and subjected to peer review to enable independent verification of adequacy.
4. **Conservative interim measures:** Until these fundamental technical issues are resolved through credible scientific analysis, additional monitoring and potentially enhanced seismic restrictions should be considered to ensure public safety.

Final Assessment

The NRC's 22-point rebuttal fails to address the core technical concerns raised about Seabrook's structural integrity under ASR degradation. Indeed, the response reveals additional technical errors and methodological flaws that further undermine confidence in the current safety assessment.

Two fundamental deficiencies remain unresolved:

1. **The testing program is inadequate:** The LSTP's focus on out-of-plane shear is scientifically inappropriate for cylindrical containment analysis. A proper shear wall test examining in-plane shear behavior—the actual failure mechanism relevant to seismic loading of containment structures—should have been conducted.

2. **The methodology to determine past expansion is fundamentally flawed:** Historical expansion cannot be credibly reconstructed using empirical equations with substantial scatter in the underlying data, particularly given the systematic errors and lack of uncertainty quantification identified in this analysis.

The NRC has failed to properly address my earlier technical contentions, instead deflecting with irrelevant discussions and demonstrably incorrect assertions about the physics of structural behavior. As documented in my credentials and expertise (outlined on page i) **it is my professional opinion that if the current approach remains unchanged, the safety of Seabrook to resist even small seismic events is compromised**.

Public safety in nuclear facilities demands the highest standards of technical rigor and transparency. The documented deficiencies in the NRC's approach fall far short of these standards, necessitating immediate independent review and corrective action before any conclusions about Seabrook's continued safe operation can be drawn.

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