April 30, 2025
via electronic mail

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

Attn: Advisory Committee on Reactor Safeguards
℅ Lawrence Burkhart, Chief, Technical Support Branch, ACRS

Cc: Travis Daun, Senior Resident Inspector, Seabrook Station
Nik Floyd, Senior Reactor Inspector
Matt R. Young, Chief Projects Branch 2 Division of Operating Reactor Safety
Raymond Lorson, Regional Administrator, Region I
Mel Gray, Chief, Engineering Branch 1

Subject: C-10 Research & Education Foundation requests time to present during the upcoming May 7, 2025 Advisory Committee on Reactor Safeguards (ACRS) Full Committee (FC) meeting regarding Alkali-Silica Reaction (ASR) at Seabrook Station.

We are writing to respectfully request that time be made available for C-10 to present during the upcoming May 7, 2025 ACRS Full Committee meeting within the 1:00 pm - 6:00 pm agenda block which is dedicated to the Alkali-Silica Reaction issue at Seabrook Station.

Enclosed please find a white paper entitled *Assessment of NIST Shear Wall Tests and Their Relevances*, by Prof. Victor E. Saouma (Emer.), which sets forth Dr. Saouma's technical evaluation of tests conducted for the NRC at a substantial cost by the National Institute of Standards and Technology (NIST) on ASR-affected squat shear walls (Weigand, Sadek, Thonstad, et al., 2021). As you will see, Dr. Saouma has identified significant and highly concerning implications of the NIST study for the integrity of ASR-impacted safety structures at the Seabrook Station nuclear power plant.

We understand that the Advisory Committee on Reactor Safeguards is an independent body authorized by Atomic Energy Act of 1954, as amended, chartered for the following purposes:

- to review and report on safety studies and reactor facility license and license renewal applications;
- to advise the Commission on the hazards of proposed and existing production and utilization facilities and the adequacy of proposed safety standards;
- to initiate reviews of specific generic matters or nuclear facility safety-related items; and
- to provide advice in the areas of health physics and radiation protection.

C-10 respectfully submits that in order to satisfy these weighty responsibilities, the ACRS should obtain the best and most up-to-date information and technical analysis. Dr. Saouma is one of the world's foremost experts on ASR, whose views had a significant and positive effect on the terms of the ASR monitoring and assessment program approved by the NRC's Atomic Safety and Licensing Board in 2019. At that time, Dr. Saouma was not aware of the NIST study and it was not addressed in testimony by NextEra or the NRC Staff. And yet, its implications for the safety of the Seabrook reactor are profound. Therefore, we urge you to consider Dr. Saouma's significant concerns regarding the implications of the NIST study for the Seabrook reactor. This is especially important in light of the facts that (a) monitoring data has shown that ASR is progressing more quickly than estimated by NextEra's NRC-approved LSTP, (b) we understand a new testing program would be eventually required to address the observed rate of ASR expansion at Seabrook, and (c) the NIST study shows that repeating the original LSTP tests would not produce any useful result.

In addition to considering Dr. Saouma's White Paper, we respectfully request you to provide him with at least 15 minutes during the upcoming May 7, 2025 ACRS full committee meeting to provide a succinct presentation of his analysis and take questions from committee members.

Thank you for your consideration of our request and for your service on the Advisory Committee of Reactor Safeguards. We look forward to your response, and will be in attendance at the May 7, 2025 ACRS full committee meeting.

Kindly,

Sarah Abramson

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Assessment of NIST Shear Wall Tests and Their Relevances for Seabrook Station Safety

Presentation to the Advisory Committee on Reactor Safeguards
May 7, 2025

Emeritus Prof. Victor E. Saouma (CEAE)

Department of Civil Engineering
University of Colorado

C-10 Consultant

Key Findings

NIST study, (Weigand, Sadek, Thonstad, et al., 2021), independently raises two major concerns regarding Seabrook Station's structural safety:

1. While NextEra reported an increase in shear strength due to ASR, NIST observed a decrease.
2. NextEra relied on the empirical equation $E = 57{,}000\sqrt{f'_c}$ to relate compressive strength to elastic modulus. NIST found the experimental data to be widely scattered, not clustering around the proposed relation, thus rendering the equation unreliable for determining past expansion.

Related to the above:

- NextEra failed to recognize that the Containment Enclosure Building (CEB), being circular, is governed by membrane shell theory (with negligible bending) and should not be modeled as a flexural member. The dominant response involves in-plane shear, requiring testing of squat shear walls. Instead, NextEra's test specimens generated out-of-plane shear.
- The outcomes of the Large-Scale Testing Program (LSTP) were foreseeable and should have been anticipated based on prior studies, notably (Ahmed, Burley, and Rigden, 1998). The cause is the ASR induced chemical prestressing, which increases internal friction and thereby enhances shear capacity.

The findings reported by NIST are broadly consistent with the testimony I presented to the NRC's Atomic Safety and Licensing Board in 2019.

Accordingly, I continue to hold the expert opinion that Seabrook Station's safety has not been adequately demonstrated, given the presence of ASR in containment and other critical structures, and in light of the serious deficiencies in how ASR has been addressed.

I therefore join C-10 in urging the Advisory Committee on Reactor Safeguards (ACRS) to undertake a thorough, independent, and expedited technical review of the contradictions between the NIST report and NextEra's LSTP.

Should NextEra propose further ASR testing, the program must incorporate the findings of the NIST study, the conclusions of this assessment, and the results of your own independent evaluation.

Ahmed, T., E. Burley, and S. Rigden (1998). "The state and fatigue strength of reinforced concrete beams affected by alkali-silica reaction". In: *Materials Journal* 95.4, pp. 376–388.

Weigand, J., F. Sadek, T. Thonstad, S. Marcu, R. Villegas, and L. Phan (2021). *Structural Performance of Nuclear Power Plant Concrete Structures Affected by Alkali-Silica Reaction (ASR); Task 3: Assessing Cyclic Performance of ASR-Affected Concrete Shear Walls*. Tech. rep. NIST TN 2180. National Institute of Standards.

White Paper

Assessment of NIST Shear Wall Tests and Their Relevances for Seabrook Safety

Prof. Victor E. Saouma (*Emer.*)
University of Colorado, Boulder
C-10 Research and Education Foundation Consultant

Submitted to

Advisory Committee on Reactor Safeguards

April 30, 2025

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About the Author

Victor E. Saouma, with over 40 years of research experience, including nearly 15 years devoted 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, and 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 served as the editor of a RILEM report comprising over 450 pages and contributions from 30 leading researchers, underscoring his expertise.

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

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

Saouma's research on ASR has been funded by various organizations, including the Nuclear Regulatory Committee, Oak Ridge National Laboratory, and the Bureau of Reclamation. His technical reports are available 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 collaborations include 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 observed that ASR is an extraordinarily complex and nefarious reaction. Although it has been recognized since the 1940s, the emergence of structures suffering from this phenomenon has become more evident only recently (as it may take many years to manifest itself). Consequently, ASR has attracted the attention of researchers from many disciplines: chemists, mineralogists, geologists, material scientists, mechanicians, experimentalists, and, notably, structural engineers. No single discipline can independently provide a definitive answer to the questions posed by ASR. However, those who adopt a comprehensive perspective are best positioned to offer informed opinions.

In 2019, on behalf of the C-10 Research and Information Foundation (C-10), he served as an expert witness in a license amendment proceeding before the U.S. Nuclear Regulatory Commission (NRC), (NRC-ML19312B609, 2019), concerning the state of ASR at the Seabrook nuclear power plant. His testimony resulted in the implementation of stronger measures for monitoring the state of ASR over a 20-year license renewal term.

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

Executive Summary

This White Paper provides an expert technical assessment of tests conducted by the National Institute of Standards and Technology (NIST) on alkali-silica reaction (ASR)-affected squat shear walls (Weigand, Sadek, Thonstad, et al., 2021) and evaluates their implications for the structural integrity and safety of Seabrook Station.

The NIST study raises three major concerns regarding Seabrook's structural safety:

1. NextEra predicted an increase in shear strength in ASR-affected structures based on beam tests from the Large-Scale Testing Program (LSTP). Although this increase was not explicitly exploited, it influenced the license amendment request. In contrast, NIST's squat wall tests—a more appropriate configuration—showed a decrease in strength, demonstrating the inapplicability of LSTP results and raising serious concerns about the adequacy of NextEra's assessment and monitoring program.

2. This disparity between the NIST and LSTP results was foreseeable. The selection of beam flexure tests to predict Containment Enclosure Building (CEB) behavior reflected a fundamental misunderstanding: cylindrical shells resist lateral loads primarily through membrane action (in-plane shear) with minimal bending—not beam flexure, which captures out-of-plane shear.

   Tests should have been performed on specimens which capture in-plane shear failure, as consistently done by other researchers studying cylindrical shells. Given its prior research on CEB shear behavior (e.g., Cornell/MIT projects), the NRC had the knowledge and responsibility to recognize that the proposed NextEra beam test was fundamentally non-representative.

   Moreover, it appears NextEra did not conduct an adequate literature review; chemical prestressing effects, long documented (e.g., (Ahmed, Burley, and Rigden, 1998)), show that reinforced concrete beams will gain shear strength in the presence of ASR.

3. NextEra relied on the empirical equation $E = 57,000\sqrt{f'_c}$ (MPR-ML16279A050, 2017) to relate compressive strength to elastic modulus. However, NIST found the experimental data widely scattered, not clustering around the equation. This scatter highlights the need to explicitly account for uncertainties. NIST's findings thus invalidate the procedure developed in (NRC-ML18226A205, 2018) for inferring past expansion.

I continue to hold the expert opinion that Seabrook's safety has not been adequately demonstrated, given the presence of ASR in critical structures and the serious deficiencies in how ASR has been addressed.

I therefore join C-10 in urging the Advisory Committee on Reactor Safeguards (ACRS) to undertake a thorough, independent, and expedited technical review of the contradictions between the NIST report and NextEra LSTP. Should NextEra propose further ASR testing, the program must incorporate the findings of the NIST study, the conclusions of this assessment, and the results of an independent evaluation.

Background

An excellent scoping study by Snyder and Lew (2013) laid the groundwork for a comprehensive investigation into the effects of alkali-silica reaction (ASR) on concrete structures. Building on this initial effort, a 2014 Interagency Agreement between the NRC and NIST (NRC-NIST Interagency Agreement, 2014) was established to "develop a technical basis and regulatory guidance for NRC staff to evaluate ASR-affected concrete structures [and to] assess the structural performance of ASR-affected concrete structures for design basis static and dynamic loading and load combinations through its service life, including the period of extended operation for the 20-year license renewal period." The $5.6 million contract was principally motivated by the discovery of ASR at Seabrook around 2010 and led to the publication of several detailed technical reports:

1. *Structural Performance of Nuclear Power Plant Concrete Structures Affected by Alkali-Silica Reaction (ASR); Task 3: Assessing Cyclic Performance of ASR-Affected Concrete Shear Walls*
   Weigand, Sadek, Thonstad, et al., 2021
2. *Structural Performance of Nuclear Power Plant Concrete Structures Affected by Alkali-Silica Reaction (ASR); Task 1: Assessing In-Situ Mechanical Properties of ASR-Affected Concrete*
   Sadek, Thonstad, Marcu, et al., 2021
3. *Structural Performance of Nuclear Power Plant Concrete Structures Affected by Alkali-Silica Reaction (ASR); Task 2: Assessing Bond and Anchorage of Reinforcing Bars in ASR-Affected Concrete*
   Thonstad, Weigand, Sadek, et al., 2021
4. *Structural Performance of Nuclear Power Plant Concrete Structures Affected by Alkali-Silica Reaction (ASR); Task 3: Assessing Cyclic Performance of ASR-Affected Concrete Shear Walls*
   Weigand, Sadek, Thonstad, et al., 2021
5. *Material Research Support for the Structural Performance of Nuclear Power Plant Concrete Structures Affected by Alkali-Silica Reaction*
   Feldman, Eason, Bajcsy, and Snyder, 2022

A significant component of the NIST study was the conduct of shear capacity testing in shear walls containing ASR. In contrast, the LSTP tests were conducted on concrete beams containing ASR.

As discussed in more detail below, the results of the NIST study, issued in 2021, demonstrated that ASR weakens shear walls. This is a significant finding for Seabrook Station, given that the LSTP tests used to assess ASR at Seabrook showed that concrete beams were strengthened by ASR. The test data from the NIST Study were also inconsistent with the LSTP's application of ACI 318-71 to calculate capacity, thereby demonstrating that the equation is not suitable for ASR in shear walls.

Notice to Readers

This report has been prepared solely using data and information that are publicly available at the time of writing. No proprietary, confidential, or otherwise restricted sources have been accessed or utilized in the preparation of this document.

Furthermore, any figures or illustrations presented herein that do not include explicit units of measurement are not derived from actual empirical data. Such figures are intended exclusively for qualitative representation and conceptual illustration and shall not be construed as suitable for quantitative interpretation or application.

1 NIST Findings Challenge the LSTP Test Configuration

NIST conducted a series of carefully controlled tests under an Interagency Agreement (NRC-NIST Interagency Agreement, 2014).

Representativeness of Structural Testing

In structural safety evaluations, the *prototype* refers to the actual structure of concern—such as the Containment Enclosure Building (CEB)—while the *model* denotes the test specimen used to simulate its behavior. For ASR-affected concrete, reproducing only the concrete mix in the test specimen is scientifically inadequate. To generate meaningful (and regulatory-relevant) data, the test must be explicitly designed to replicate the same failure mechanism that governs the structural behavior of the prototype. Absent this, the test results cannot be extrapolated with confidence, and any safety conclusions drawn from them risk being fundamentally flawed.

Membrane Behavior in thin walled structures

Membrane action refers to the internal force distribution in *t*hin-walled structures where loads are resisted primarily through in-plane stresses (axial, hoop, and shear) without significant bending or transverse shear. It is characteristic of shells and plates subjected to smooth, distributed loading, Fig. 1.

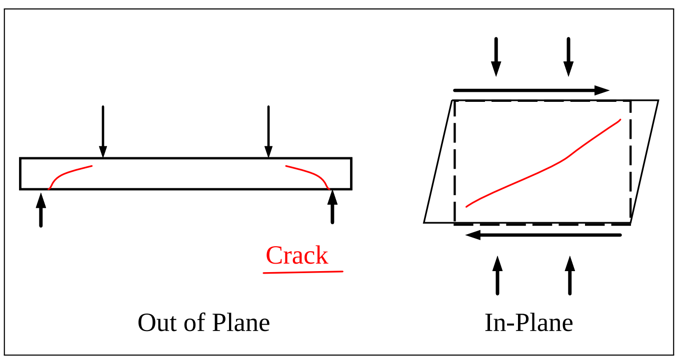


Figure 1: In-plane and out-of-plane shear

This assumption of membrane action is discussed in (Timoshenko, Woinowsky-Krieger, et al., 1959, Sec. 91) (and expanded in §B.1.

More specifically ASME III (2015) specifies procedures for calculating membrane stress resultants in cylindrical shell structures subjected to internal pressure and other loads (see Articles CC-3200 and CC-3300).

While membrane forces dominate the global behavior, the Code requires supplementary evaluation of bending moments and out-of-plane shear stresses at regions of structural discontinuity—including penetrations, changes in thickness, supports, and attachments—where flexural behavior may become significant.

Thus, the ASME Code reflects the well-established engineering principle that membrane forces govern the overall load-carrying response of cylindrical containment structures, while localized bending effects must be explicitly assessed where discontinuities introduce non-membrane actions.

In other words, the tests by NextEra are only applicable in discontinuity locations.

Characteristics of Beam and Squat Shear Wall Tests

Let us look closely at the fundamental differences of the two models.

	Beam tests	**Squat shear wall tests**
1	Out-of-plane shear	In-plane shear
2	Shear/flexure failure mode	Shear failure mode
3	Not representative of failure mode in CEB	Representative of failure mode in CEB
4	Chemical prestressing enhances the shear strength	Chemical prestressing does not significantly impact the shear strength
5	Flexure dominates	Shear dominates
6	Chemical prestressing (§C.2) will always increase shear strength	Insensitive to chemical prestressing
6	Shear strength predictably higher with ASR	Shear strength unlikely to be higher
8	Does not account for biaxial state of stress	Accounts for biaxial state of stress
9	Used only by NextEra	Used by all other researchers investigating CEB behavior
10	Applicable for localized concentrated lads	Applicable to entire CEB
11	NextEra found increased in shear strength	NIST found lower shear strength

NextEra's Argument and C-10 counterargument for beam test

LSTP argument in (NRC-ML19261A762, 2019)

> *...the LSTP did not test for the in-plane shear mode. This was because the out-of-plane shear failure mode was judged to be more critical than in-plane shear mode (note: nominal permissible out-of-plane shear stress in concrete per the ACI 318-71 code is $2\sqrt{f'_c}$ versus allowable total shear stress of $10\sqrt{f'_c}$ for in-plane shear.)*

C-10 Counterargument This justification confuses code-prescribed permissible stress levels with the actual stress states induced by seismic loading. As discussed earlier (see page 1), seismic loads acting on cylindrical containment structures such as the CEB generate predominantly in-plane membrane stresses, with negligible out-of-plane shear.

Confusing Code Imposed Stress Limits with Structural Response

Argument Interestingly the LSTP makes the distinction between "in-plane" and "out of plane".

> *...the LSTP did not test for the in-plane shear mode. This was because the out-of-plane shear failure mode was judged to be more critical than in-plane shear mode (note: nominal permissible out-of-plane shear stress in concrete per the ACI 318-71 code is $2\sqrt{f'_c}$ versus allowable total shear stress of $10\sqrt{f'_c}$ for in-plane shear.)*
>
> NRC-ML19261A762 (2019)

The LSTP justified the omission of in-plane shear testing by citing the lower allowable out-of-plane shear stress specified in ACI 318-71 ($2\sqrt{f'_c}$ versus $10\sqrt{f'_c}$ for in-plane shear).

Why it is erroneous This justification confuses code-prescribed permissible stress levels with the actual stress states induced by seismic loading. As discussed earlier (see page 1), seismic loads acting on cylindrical containment structures such as the CEB generate predominantly in-plane membrane stresses, with negligible out-of-plane shear. Thus, focusing on out-of-plane shear, regardless of its lower code limit, fundamentally misrepresents the critical response mechanisms governing the CEB's seismic behavior.

Why

The question of why Texas selected the beam configuration has not been explained.

1. I conjecture that a few years earlier, Deschenes, Bayrak, and Folliard (2009) conducted tests for the Texas Department of Transportation using the setup shown in Fig. 2. Hence, by the time the LSTP started, those tests were completed. Remarkably, the dimensions of these girders are *identical* to those later selected for NextEra.

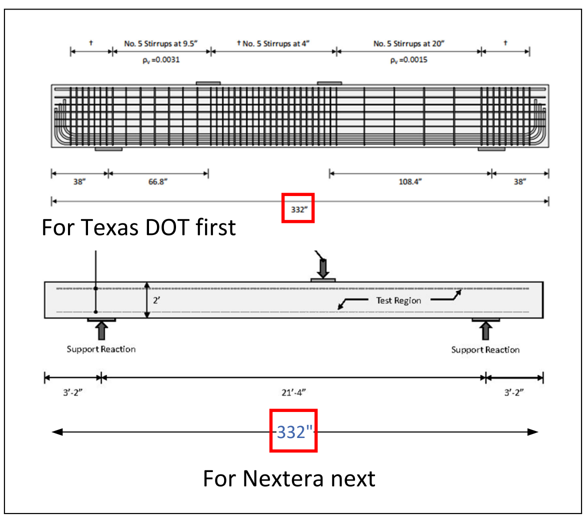


Figure 2: Identical test geometries used by Texas for TxDOT (Deschenes, Bayrak, and Folliard, 2009) and for NRC-sponsored testing (Bayrak, 2012). Both specimens are 332 inches long.

2. It is further speculated that NextEra was fully aware, based on well-established findings (Ahmed, Burley, and Rigden, 1998), that ASR *increases* the shear strength of reinforced concrete beams (§C.2). Nevertheless, it acted as if this outcome had not yet been determined. If they had conveniently selecting a beam configuration—rather

than a more representative squat shear wall test, then tests would have been structured in a way that would predictably confirm an increase in shear strength.

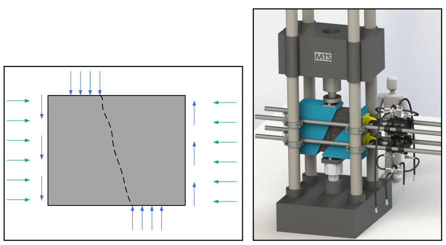
It is noteworthy that among all researchers investigating ASR, *o*nly LSTP employed a beam specimen, rather than adopting a geometry that more directly captures shear degradation and failure mechanism of cylindrical containers.

It is therefore strongly suspected that the test configuration was selected not based on its relevance to containment structures, but rather out of mere convenience — replicating a setup with which the laboratory was already familiar.

Illustrative examples of Other shear tests

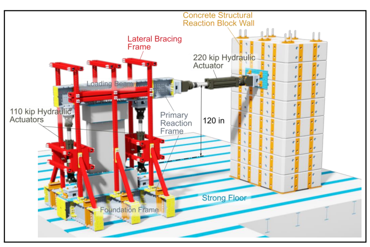
Researchers investigating the response of a CEB have all used a test which captures the in-plane shear failure mechanism, either through squat shear walls (Fig. 3(b), 3(c), 3(d)) or shear blocks (Fig. 3(a)), or in plane tests (Fig. 3(e)).

Interestingly, the NRC had funded a research study on shear in CEB. Indeed shear panels were also used, (White, Perdikaris, and Gergely, 1980), Fig. 3(e).

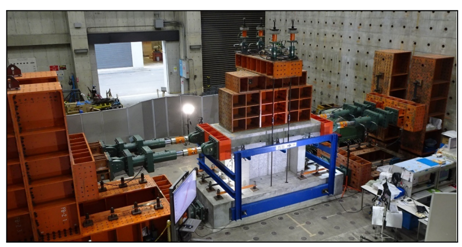


(a) Colorado

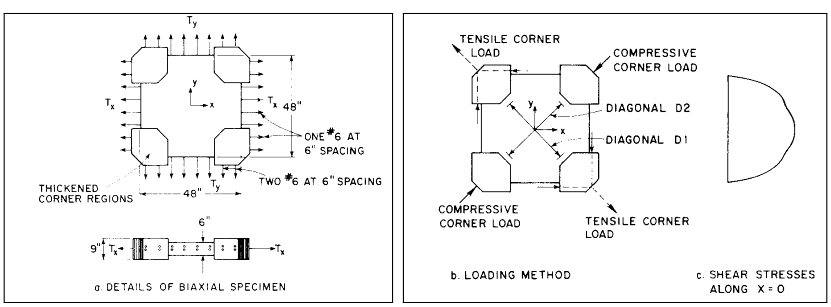
(b) Toronto



(c) NIST



(d) Kajima



(e) In-Plane shear tests funded by the NRC in the Early 80's, (White, Perdikaris, and Gergely, 1980); Cornell/MIT program

Figure 3: Various test setups used for concrete in-plane shear tests

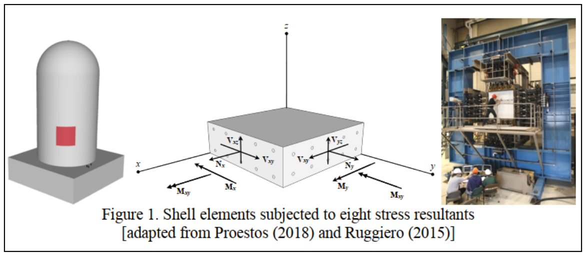


Figure 4: Configuration of (Proestos, Bentz, and Collins, 2019)

Finally, Proestos, Bentz, and Collins (2019) conducted an in-plane and out of plane test in containment walls. He used a configuration shown in Fig. 4.

Note that all of these tests accounted for the uniaxial or biaxial confinement present in structural panels subjected to in-plane shear loading.

Conclusion

Wrong test

1. NextEra explicitly acknowledges that it did not test for in-plane, rather opted for out-of-plane, configuration, thereby selecting beams instead of squat shear walls (used by all other researchers), §C.3.

2. NextEra confused code-imposed allowable stress limits with the actual stress states that govern the structural response under given loading conditions.

3. NextEra's test is not aligned with (ASME III, 2015).

4. NextEra failed to recognize that in this case, one must use *membrane theory*

5. Biaxial confinement not present in LSTP.

6. Rather than selecting a test configuration specifically tailored to containment structures, it is reasonable to conjecture that Texas' LSTP investigation simply *recycled* the geometry of previously tested beams, prioritizing convenience over representativeness.

The supporting material is provided in Appendix B

2 Relevance of NIST tests on shear strength

When confronted with two sets of experimental results that yield conflicting conclusions, the validity of each must be assessed not solely on the basis of outcome but on the fidelity of the test setup in replicating the failure mechanism of the prototype. The results derived from the test configuration that most accurately captures the governing structural behavior of the prototype should be given precedence. This principle is especially critical in safety assessments, where the representativeness of the test model directly impacts the reliability of the conclusions drawn. Disregarding this criterion risks favoring results that may be experimentally sound yet structurally irrelevant.

As mentioned above, other researchers have investigated the impact of ASR on shear strength. Some of them are described in Appendix C, and results tabulated in Table 2.

However of paramount importance for Seabrook are the contrasting results of the LSTP and NIST, shown in Table 1.

Table 1: Comparison of LSTP and NIST tests

Texas MPR-ML18141A785 (2016)	NIST
1. There is no reduction of shear capacity in ASR-affected concrete with through-thickness expansion levels up to [redacted]% or volumetric expansion levels [redacted]. 2. The [redacted] ASR-affected test were all capable of reaching their calculated shear strength per ACI 318-71.	1. The presence of ASR caused a 26 % reduction in the mean normalized yield moment capacity (M_y/M_n). 2. ASR brought the normalized yield moment capacity ratios M_y/M_n to less than 1.0(i.e. unsafe). 3. The yield moment capacity M_y being less than M_n means that ACI 318 capacity calculation procedure is unconservative and not applicable for walls affected by ASR.

Conclusion

Wrong test

1. Contrary to NextEra's findings, all other tests, Table 2 (with exception to the Toronto tests) conducted by various researchers have consistently shown a decrease, not an increase, in shear strength.
2. This outcome was essentially a forgone conclusion, as it was already well established that ASR increases the shear strength of reinforced concrete (Ahmed, Burley, and Rigden, 1998).
3. In simple terms, the results of the beam test lack credibility because the test itself was fundamentally flawed.

The supporting material is provided in Appendix C

3 Relevance of NIST tests on past expansion

An empirical equation is only valid to the extent that it reliably represents the underlying experimental data. When the observed data points exhibit significant scatter or systematically deviate from the proposed equation, the validity of that equation is fundamentally compromised. In such cases, relying on the equation for predictive or design purposes is unjustified, as it may lead to erroneous conclusions. Any use of empirical relationships must therefore be accompanied by a clear assessment of their uncertainty and applicability range, particularly when the stakes involve structural safety or regulatory compliance.

Reliable determination of past expansion is critical to assessing structural safety. The methodology used to estimate this expansion is discussed in detail in Appendix D.

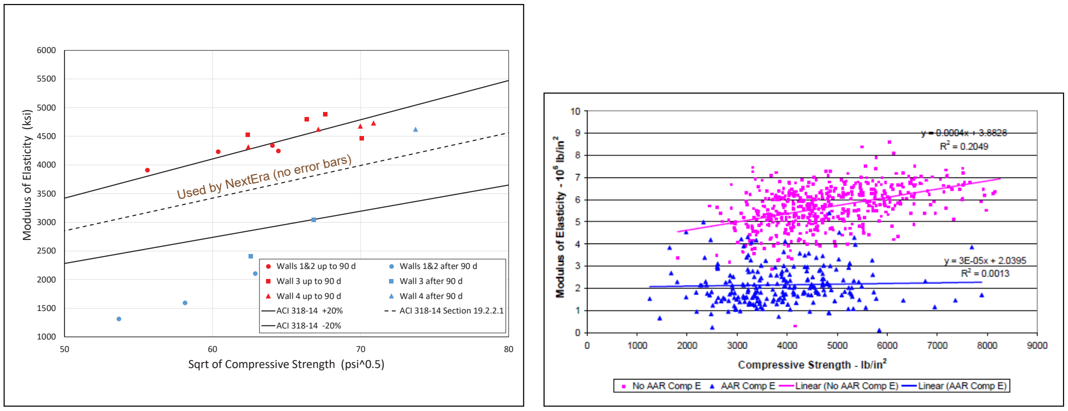
This procedure is well established and codified in ASTM C469 (2016). A concise summary is presented below:

1. **Measure the Current Elastic Modulus** E_{current} using ASTM C469:
2. ***E*stimate the Original Elastic Modulus** from compressive strength at 28 days (in psi) using ACI 318:
$$E_{\text{28-day}} = 57{,}000\sqrt{f'_c} \tag{1}$$
3. **Compute the Normalized Modulus:**
$$E_n = \frac{E_{\text{present}}}{E_{\text{28-day}}} \tag{2}$$
4. **Estimate ASR Expansion** from a pre-established empirical calibration curve:
$$\varepsilon_{\text{ASR}} = f(E_n)$$
where $E_{28-days}$ is the elastic modulus determined 28 days after casting, $E_{present}$ is the elastic modulus determined presently, f'_c is the concrete compressive strength, E_n is the normalized elastic modulus, ε_{ASR} the total volumetric expansion since casting, and $f(\cdot)$ a function determined through curve fitting of discrete experimental points.

Whereas Eq. 1 is indeed included in the ACI code, it is always presented as an empirical approximation rather than a universally valid relationship.

The NIST report clearly demonstrated the limitations of this equation, showing that it does not hold for ASR-affected concrete, as illustrated in Fig. 5.

Interestingly, the only other extensive investigation relating E to f_c was conducted by Dolen (2005), specifically for ASR-affected concrete, as shown in Fig. 5(b) (blue markers represent ASR specimens). Once again, the level of uncertainty is comparable to that observed in the NIST results, reinforcing the conclusion that the relationship between compressive strength and elastic modulus cannot be reliably captured by a single equation (Eq. 1). This is particularly relevant when applied to a task as critical as determining past



(a) NIST, (Weigand, Sadek, Thonstad, et al., 2021)

(b) Reclamation, (Dolen, 2005)

Figure 5: Experimental evidence of the variability of $E(f'_c)$ for Concrete with ASR; NIST and Bureau of Reclamation

expansion at Seabrook, the uncertainties should be explicitly accounted for—such as by including margins of error (Fig. 7).

Since the compressive strength data used for comparison correspond to specimens tested at 28 days (i.e., less than 90 days), we conclude—based on these findings—that the elastic modulus E is systematically overestimated by Eq. 1.

Relevance

- NIST found that E_{28}^{NIST} is larger than E_{28}^{NextEra}.
- This directly implies that the normalized modulus values—defined by Eq. 2, where E_{28} appears in the denominator—are also larger for NextEra:

$$E_n^{\text{NextEra}} > E_n^{\text{NIST}}.$$

- Based on the calibration curve (developed under the LSTP) that relates normalized elastic modulus to ASR expansion, this discrepancy leads to an underestimation of the actual expansion.

Does not account for Uncertainties

The procedure to determine past expansion critically hinges on two key components:

1. The estimation of the elastic modulus based on compressive strength.
2. The calibration curve that relates the drop in normalized elastic modulus to ASR-induced expansion.

Both of these components are subject to significant uncertainty[1], which must be explicitly acknowledged and incorporated into the evaluation.

The magnitude and implications of these uncertainties are illustrated in Fig. 7.

[1] During the administrative hearing (NRC-ML19312B609, 2019, pg 522) C-10 asked the judges to include Uncertainty bands. This was refused.

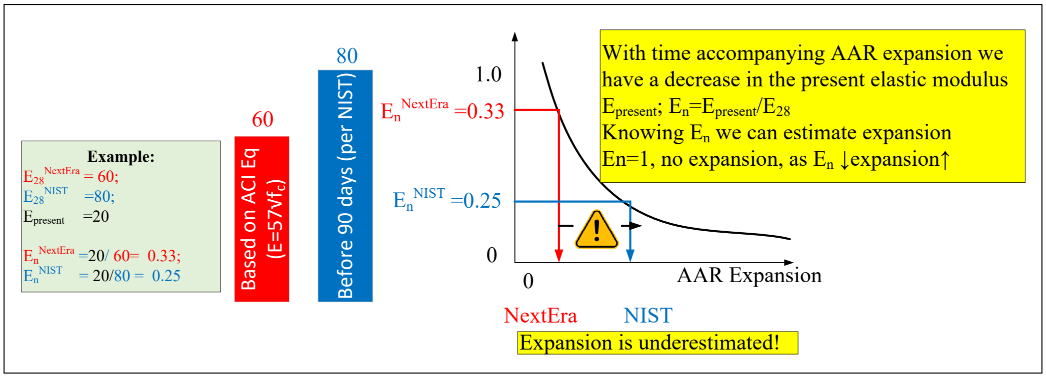


Figure 6: Why is the current monitoring procedure unconservative and dangerous according to the NIST report

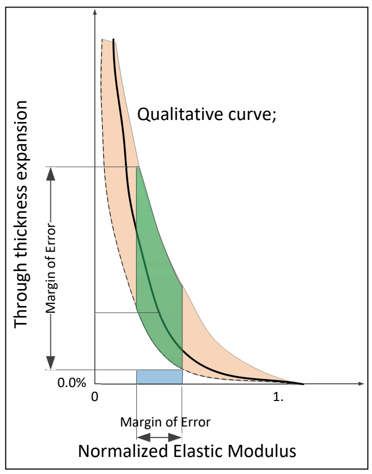


Figure 7: Impact of uncertainties associated with the determination of past expansion

Conclusion

Wrong test

1. NIST tests have demonstrated the inapplicability of the ACI Code equation relating compressive strength to elastic modulus, as the associated variabilities and uncertainties are unacceptably large.

2. Hence the procedure employed by NextEra to estimate past expansion systematically underestimates the true extent of expansion.

3. As a result, the current structural monitoring program is fundamentally flawed and presents a significant safety risk, as it fails to account for the full magnitude of ASR-induced expansion.

The supporting material is provided in Appendix D

4 Summary of Conclusions

The principal conclusions drawn throughout this white paper are summarized below for ease of reference.

LSTP erroneous test configuration

1. NextEra explicitly acknowledges that it did not test for in-plane, rather opted for out-of-plane, configuration, thereby selecting beams instead of squat shear walls (used by all other researchers), §C.3.
2. NextEra confused code-imposed allowable stress limits with the actual stress states that govern the structural response under given loading conditions.
3. NextEra's test is not aligned with (ASME III, 2015).
4. NextEra failed to recognize that in this case, one must use *membrane theory*
5. Biaxial confinement not present in LSTP.
6. Rather than selecting a test configuration specifically tailored to containment structures, it is reasonable to conjecture that Texas' LSTP investigation simply *recycled* the geometry of previously tested beams, prioritizing convenience over representativeness.

Relevance of NIST report on shear strength

1. Contrary to NextEra's findings, all other tests, Table 2 (with exception to the Toronto tests) conducted by various researchers have consistently shown a decrease, not an increase, in shear strength.
2. This outcome was essentially a forgone conclusion, as it was already well established that ASR increases the shear strength of reinforced concrete (Ahmed, Burley, and Rigden, 1998).
3. In simple terms, the results of the beam test lack credibility because the test itself was fundamentally flawed.

Relevance of NIST tests on past expansion

1. NIST tests have demonstrated the inapplicability of the ACI Code equation relating compressive strength to elastic modulus, as the associated variabilities and uncertainties are unacceptably large.
2. Hence the procedure employed by NextEra to estimate past expansion systematically underestimates the true extent of expansion.
3. As a result, the current structural monitoring program is fundamentally flawed and presents a significant safety risk, as it fails to account for the full magnitude of ASR-induced expansion.

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APPENDICES

A Glossary

AAR/ASR: Alkali aggregate reaction[2](or aggregate silica reaction).

ASLB: Atomic Safety Licensing Board.

BDAM: Building Deformation Aging Management (how NextEra monitors ASR expansion).

Compressive Strength f_c' is the maximum stress under compression that the concrete can sustain before failure.

Drift d**:** is the gradual irreversible movement or displacement over time due to external forces. In a seismic analysis, we want to structure to be resilient and accommodate as large of a drift before failure.

Ductility: is the ability of the structure to undergo large deformation (drift) before failure. Ductility enables energy absorption during seismic excitation, which is beneficial.

Free body diagram (FBD) is a simplified graphical representation of a body isolated from its surroundings, showing all external forces and moments acting upon it. It is a fundamental tool used to analyze equilibrium and internal force distributions in structures.

Elastic Modulus: "slope" of the stress strain curve for concrete. Analogous to spring stiffness of the specimen.

FSEL: Ferguson Structural Engineering Laboratory in Texas (where tests were performed).

Flexural Resistance: the maximum moment that can be resisted before failure.

Hysteretic Energy: is the energy absorbed during one cycle of push and pull. The larger the value, the more energy is absorbed during a seismic excitation.

LAR: License Amendment Request.

LSTP: Large Scale Testing Program. This encompasses all tests performed at the University of Texas through NextEra's funding.

Moment M**:** is the result of a force applied with an eccentricity thus inducing rotation about an axis.

Nominal Moment M_n**:** is the moment computed by the ACI-318 design code corresponding to operating load. It should always be smaller than the yield moment (as we do not want the structure to yield under normal service load).

[2]Alkali-Silica Reaction (ASR) is often used interchangeably with Alkali-Aggregate Reaction (AAR), although strictly speaking, AAR includes reactions with both silica and other reactive aggregate types. In most contexts, including this document, ASR and AAR are treated as equivalent.

Normalized Elastic Modulus, E_n is the present value of the elastic modulus divided by the one at time of construction (estimated from the compressive strength) typically at 28 days.

Shear wall test: involves pushing/pulling a wall from a top beam connecting to it. This causes positive (push) or negative moment (pull).

Stiffness: is the slope of the force displacement (or moment drift diagram).

Yield Moment M_y**:** is the moment at which we start having plastic or irreversible deformation. It should always be larger than the nominal moment.

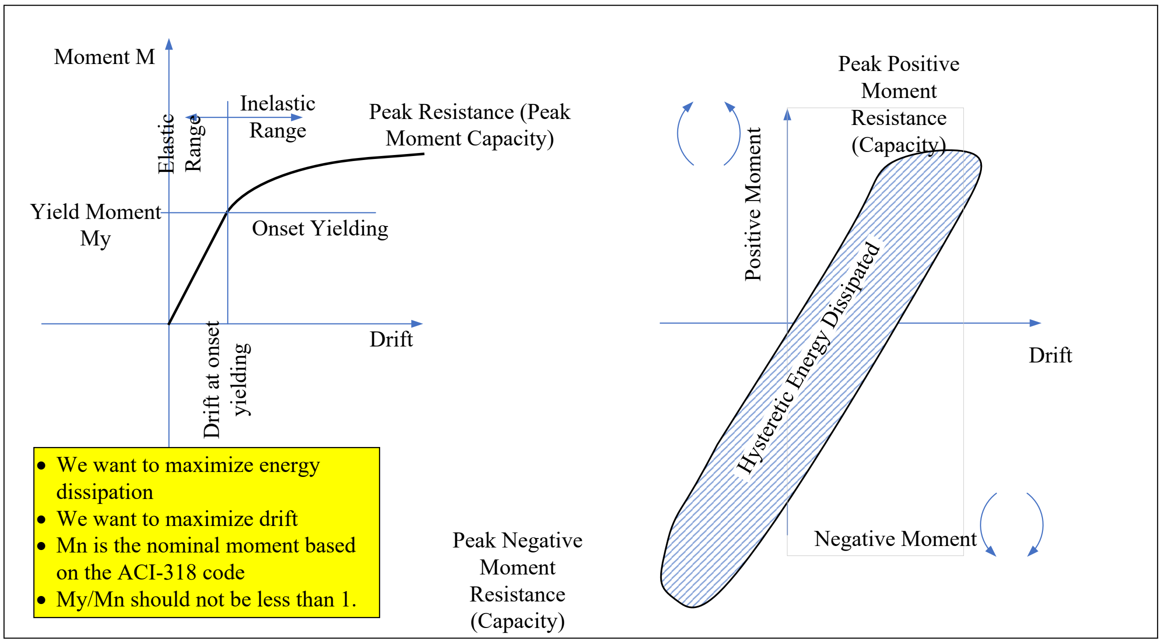


Figure 8: Graphical Illustration of Key Terms

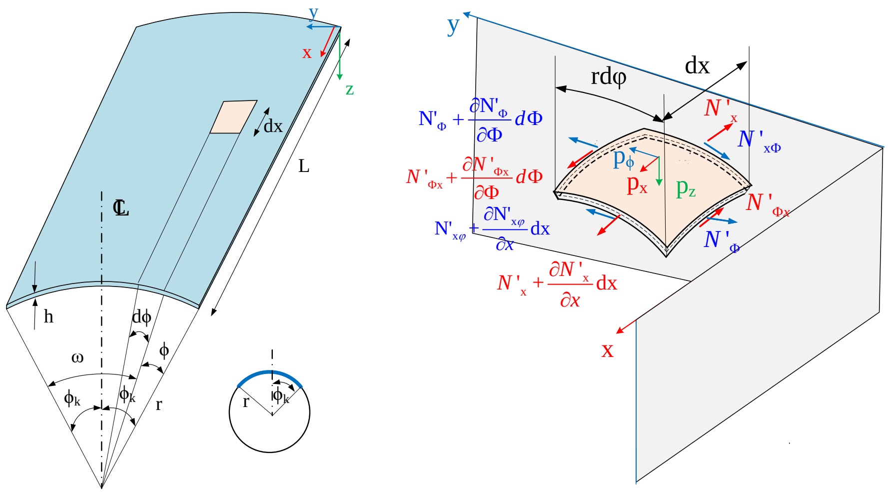
B NIST Findings Challenge the LSTP Test Configuration

B.1 Proof of validity of membrane action

To prove that membrane theory holds, we follow the classical derivations established by Timoshenko, Woinowsky-Krieger, et al. (1959, Art. 112, p. 457).

Assumptions of Membrane Theory Membrane theory of shells relies on the following assumptions:

- The shell is thin, meaning that its thickness is much smaller than its other dimensions.
- Stresses normal to the middle surface (transverse shear stresses and normal stresses) are absent (except at discontinuities).
- Deformations involve stretching of the middle surface without significant bending.



(a) Shell (b) Membrane forces

Figure 9: Free body diagram of an infinitesimal circular shell element, membrane theory (Saouma, 2025)

- External loads are sufficiently smooth and distributed so that bending effects are secondary.

For the CEB:

- The structure is a thin-walled, axisymmetric cylinder.
- The primary loads of interest are lateral inertial forces induced by seismic events.
- No significant concentrated loads or local effects are present that would induce large bending or transverse shear.

Membrane Equilibrium Equations To further reinforce the notion that membrane theory should be adopted, we consider an infinitesimal element of the shell bounded by x (longitudinal) and θ (circumferential) coordinates. Following Timoshenko, Woinowsky-Krieger, et al. (1959, Art. 112, p. 457), summing forces in each direction yields:

Force Equilibrium in the Longitudinal (x) Direction

$$\frac{\partial N'_x}{\partial x} + \frac{1}{r}\frac{\partial N'_{x\theta}}{\partial \theta} = 0 \tag{3}$$

where:

- N'_x is the membrane force per unit length in the x-direction (longitudinal force),
- $N'_{x\theta}$ is the membrane shear force per unit length acting between x and θ directions,
- r is the radius of the cylinder.

Force Equilibrium in the Circumferential: (θ) Direction

$$\frac{\partial N'_{x\theta}}{\partial x} + \frac{1}{r}\frac{\partial N'_\theta}{\partial \theta} + \frac{N'_r}{r} = p \tag{4}$$

where:

- N'_θ is the circumferential membrane force per unit length (hoop force),
- N'_r is the radial membrane force per unit length,
- p is the lateral pressure (equivalent seismic load).

Force Equilibrium in the Radial Direction:

$$\frac{\partial N'_r}{\partial r} + \frac{1}{r}(N'_r + N_\theta) = 0 \tag{5}$$

However, for thin shells subjected to lateral loading, N'_r is usually small compared to N'_x and N'_θ, and thus often neglected in first-order membrane analysis. In the derivation of the membrane equilibrium equations (Timoshenko, Woinowsky-Krieger, et al., 1959, Art. 112), no body force term appears in the x-direction equilibrium because:

- Gravity acts vertically (radially inward), not horizontally.
- Seismic loading is modeled through an equivalent lateral force (p), not as a body force in x.
- Therefore, there are no distributed body forces acting in the x-direction to be included in the membrane equilibrium equations.

In summary, based on the classical derivations provided by Timoshenko, Woinowsky-Krieger, et al. (1959, Art. 112, p. 457), and the physical characteristics of the CEB, it is fully appropriate and technically correct to use membrane theory to model the seismic response of the containment enclosure building. The dominant stress resultants are the in-plane membrane forces (N_x, N_θ, and $N_{x\theta}$), and out-of-plane bending and shear effects are negligible for the distributed seismic loads considered.

B.2 Use squat shear walls

This leads to the key question: which shear mode is more critical for the CEB? Given the substantial longitudinal and hoop reinforcement, the CEB is well-equipped to handle flexure and its associated shear demands. However, the absence of adequate shear-specific reinforcement raises serious concerns. In-plane shear, therefore, is the more critical failure mode—underscored by early NRC-funded studies that exclusively addressed it.

Even among in-plane tests, important distinctions must be made. Conventional shear walls, due to horizontal load eccentricities, tend to develop significant flexural effects. To minimize these influences and better isolate pure shear behavior, panels with small height-to-length ratios, commonly referred to as *squat shear walls*, are used (§C.3). In such configurations, flexural effects are minimized, making them more suitable for studying shear-dominated response.

C II Relevance of NIST tests on shear strength; Further details

Searching the literature we found the following (in-plane) shear tests, Table 2 for context. Some observations:

Texas Not only was the LSTP (Large Scale Test Program) conducted by the University of Texas, Fig. 10, upon which the NRC (Nuclear Regulatory Commission) heavily relied for issuing the license to operate Seabrook, the least relevant, but it was also flawed due to the presence of a large unintended pre-test crack. This factor should cast many doubts on the reliability of its results. The report concludes that shear

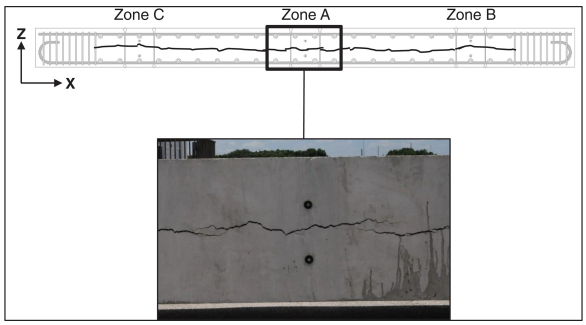


Figure 10: Texas shear tests (Wald, Martinez, and Bayrak, 2017), (note splitting crack, explained in C.2)

strength increased—without disclosing the quantitative data supporting this claim.

> ***6.2.2 Shear Performance***
>
> Results from the Shear Test Program indicate that there is no reduction of shear capacity in ASR-affected concrete with through-thickness expansion levels up to [redacted]%, which is the maximum expansion level exhibited by the test specimens. The [redacted] ASR-affected test specimens (total of [redacted] tests) were all capable of reaching their calculated shear strength per ACI 318-71. The test results indicated a repeatable trend that higher levels of ASR resulted in higher shear capacity due to ASR-induced prestress. For conservatism, MPR does not recommend taking credit for this prestressing as part of structural evaluations.
>
> While ASR-related expansion is a volumetric effect, the Shear Test Program used through-thickness expansion as the monitored parameter representing ASR degradation because in-plane expansion plateaued at relatively low levels (approximately [redacted]%).

Toronto Following the completion of the tests by Habibi, Sheikh, Orbovic, Panesar, and Vecchio (2015), shown in Fig. 11, a workshop was organized under the auspices of the Organisation for Economic Cooperation and Development (OECD), specifically through the Assessment of Structures subject to Concrete Pathologies (ASCET) initiative. One of the workshop's key objectives was to launch a blind simulation benchmark aimed at predicting the behavior of structural elements affected by ASR.

The University of Colorado was among the participants.[3] To the best of the author's knowledge, the University of Colorado was the only participant to subsequently publish a peer-reviewed analysis of this benchmark exercise (Hariri-Ardebili and Saouma,

[3]Interestingly, the NRC—represented by Jacob Philip—was a co-organizer, and NIST (through Fahim Sadek) was nominally present but did not submit an analysis.

2018), thereby contributing to the academic rigor and technical transparency of the program.

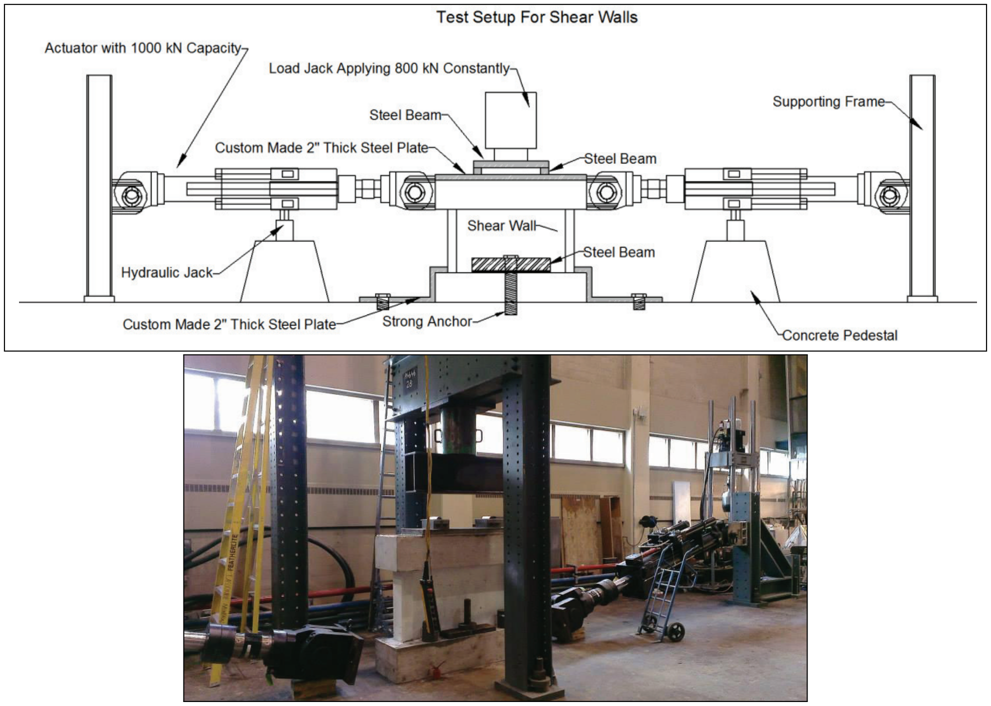


Figure 11: Toronto shear test (Habibi, Sheikh, Orbovic, Panesar, and Vecchio, 2015)

Colorado has conducted an original test which was as close as pure shear as possible, Fig. 12. The Report submitted to the NRC can be found here.

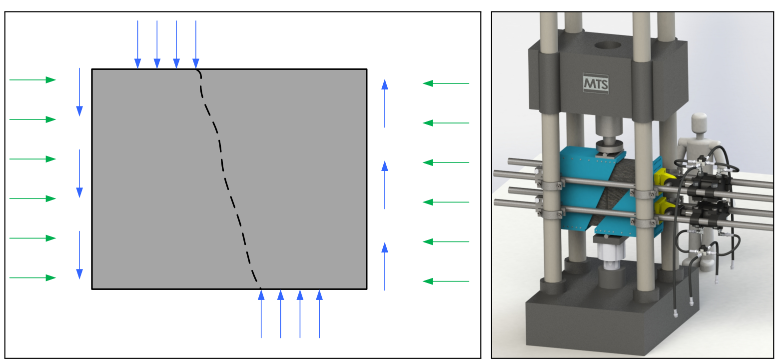


Figure 12: Colorado shear tests (Saouma, 2017)

NIST These tests, Fig. 13, will be discussed below in relation to each other, including the one listed above, and most importantly, in relation to the issued license by the NRC. Final comments, quoting from the NIST report Weigand, Sadek, Thonstad, et al. (2021) write:

> *The study by Habibi et al. (2018) was performed at the University of Toronto under the sponsorship of the Canadian Nuclear Safety Commission and is, to the authors'*

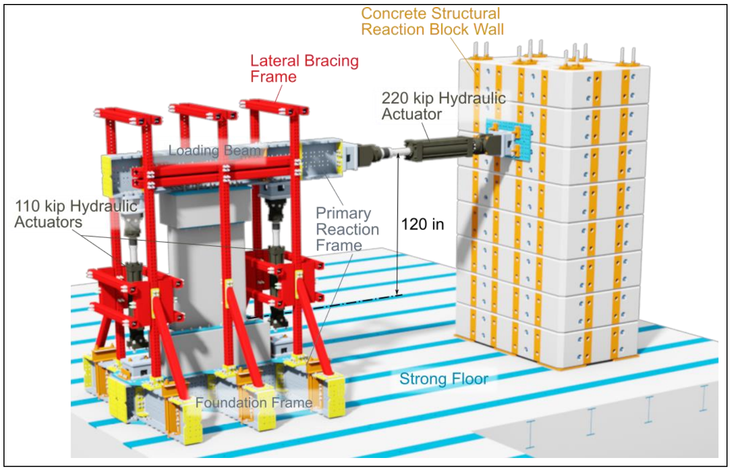


Figure 13: NIST shear tests

knowledge, the only test data available in the literature on seismic performance of structural walls affected by ASR.

Kajima The most comprehensive test involving shear walls with AAR (Alkali-Aggregate Reaction) was conducted in Japan by the Kajima Corporation (Sawada, Takaine, Okayasu, Nimura, and Shimamoto, 2021). The funding sources of this research underscores the seriousness and depth of investigation involved.

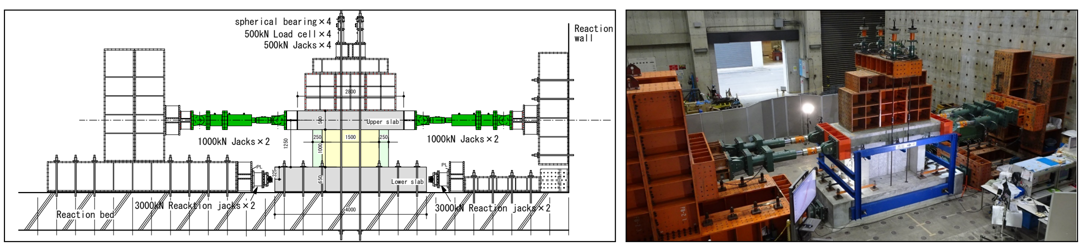


Figure 14: Kajima tests (Sawada, Takaine, Okayasu, Nimura, and Shimamoto, 2021)

Again, note that all of these tests capture in-plane shear failure mechanism (except the LSTP).

Summary of results

Table 2 summarizes the results of some of the shear tests.

Both projects funded by the NRC (Colorado and NIST) clearly identified a reduction in shear strength.

Table 2: Shear tests on specimens with ASR

Research Organization	Funding Agency	Type	# of tests	Shear Strength
Texas/MPR	NextEra	Out-of Plane beam	?	Higher† (redacted)
U. of Colorado	NRC	in-plane panel	16	≃ 22 % Lower
NIST	NRC	In plane shear wall	4	≃ 20% Lower**
U. of Toronto	CNCS*	In-plane shear wall	6	≃ 14% Higher
Kajima	Many‡	In-Plane shear wall	5	No impact

*CNSC: Canadian Nuclear Safety Commission
** The report omits the term shear resistance, and used "flexural resistance".
† Data redacted in (MPR-ML16216A242, 2016).
‡ Chubu Electric Power Co., Inc., Hokkaido Electric Power Co., Inc., Tohoku Electric Power Co., Inc., Tokyo Electric Power Company Holdings, Inc., Hokuriku Electric Power Co., Inc., Kansai Electric Power Co., Inc., Chugoku Electric Power Co., Inc., Shikoku Electric Power Co., Inc., Kyushu Electric Power Co., Inc., The Japan Atomic Power Company, Electric Power Development Co., Ltd. and Japan Nuclear Fuel Limited.

C.1 Highlights of LSTP and NIST Shear Wall Test Results

LSTP

The LSTP concluded:

> Results from the Shear Test Program indicate that there is no reduction of shear capacity in ASR-affected concrete with through-thickness expansion levels up to [redacted]% or volumetric expansion levels [redacted]%, which are the maximum expansion levels exhibited by the test specimens. The [redacted] ASR-affected test specimens (total of [redacted] tests) were all capable of reaching their calculated shear strength per ACI 318-71. The test results indicated a repeatable trend that higher levels of ASR resulted in higher shear capacity due to ASR-induced prestress. For conservatism, MPR does not recommend taking credit for this prestressing as part of structural evaluations.
>
> *MPR-ML18141A785 (2016)*

NIST

> 1. The presence of ASR and its associated effects on concrete material properties and cracking were found to cause statistically significant degradation in the structural capacities of shear walls. Specifically, within the bounds of the experimental parameters examined, the presence of ASR caused a reduction of 11 % in the mean normalized peak moment capacity M_{max}/M_n) and of 26 % in the mean normalized yield moment capacity (M_y/M_n) of the shear walls tested in this program.
> 2. More importantly, the structural capacity degradation resulted from the presence of ASR brought the normalized yield moment capacity ratios M_y/M_n for all ASR-affected walls in this test program to less than 1.0[a] . As the nominal wall's moment capacity M_n is computed using ACI 318 calculation procedure based on yielding of the longitudinal bars in the wall, the measured yield moment capacity M_y being less than M_n means that ACI 318 capacity calculation procedure is unconservative and not applicable for walls affected by ASR.
>
> *(Weigand, Sadek, Thonstad, et al., 2021)*
>
> [a] If it is less than one, it is unsafe.

C.2 What is Chemical prestressing

Indeed, there is strong evidence that AAR will increase the shear strength of reinforced concrete structures due to the "prestressing" effect of the reinforcement which will *reduce shear crack opening and increase resistance*. Sequentially, this is what happens, Fig. 15 :

1. The concrete experiences volumetric expansion as a result of Alkali-Silica Reaction (ASR).
2. This expansion is restrained by the longitudinal reinforcement[4].
3. The imposed restraint leads to an increase in tensile stresses within the reinforcement and a corresponding increase in compressive stresses within the uncracked concrete.
4. Consequently, shear-induced cracks are inhibited from widening as much as they would in the absence of tensile restraint provided by the reinforcement (i.e., prestressing).
5. Due to the reduced crack widths, the opposing faces of the cracks remain in closer proximity, resulting in increased interfacial friction.
6. The enhanced frictional resistance contributes to an increase in the beam's overall shear capacity, thereby enabling it to sustain greater loads than would be possible without the effects of ASR-induced expansion.

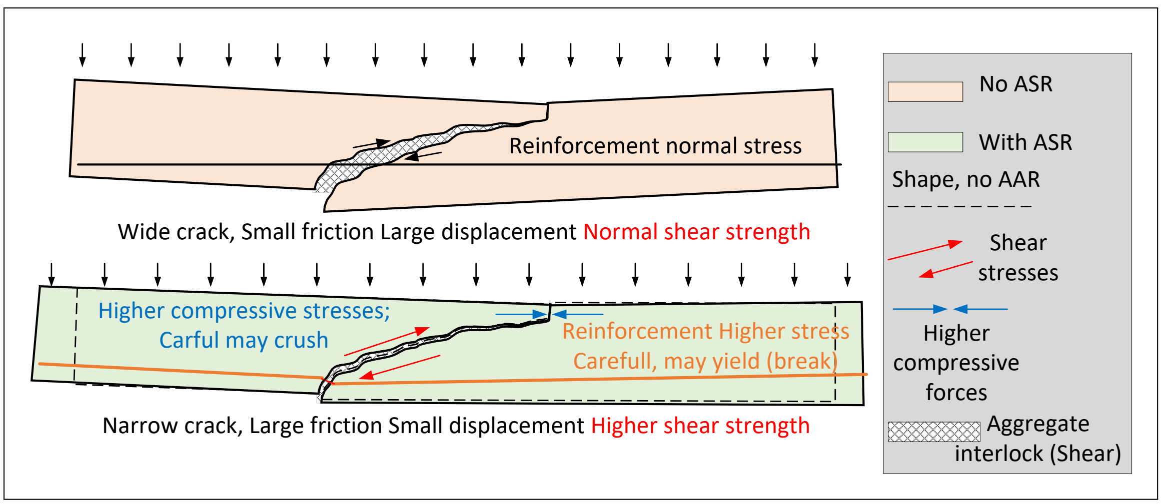


Figure 15: Chemical prestressing explained; Structural response

We now reconsider the problem from a mechanics-based perspective — an approach that is rarely, if ever, thoroughly examined. This mechanism is further clarified in Fig. 16, which presents an extension of a widely accepted model for shear transfer. The associated free-body diagram of the cracked section is also provided in Fig. 16.

$$V_{ext} = \alpha V_c + \beta V_y^{agg} + V_d + \sum_n A_v f_v \tag{6}$$

[4]Except in the vertical direction if there are no shear reinforcement (stirrups), in which case the concrete beam will split in the midddle. This is what happened in the LSTP test, Fig. 10.

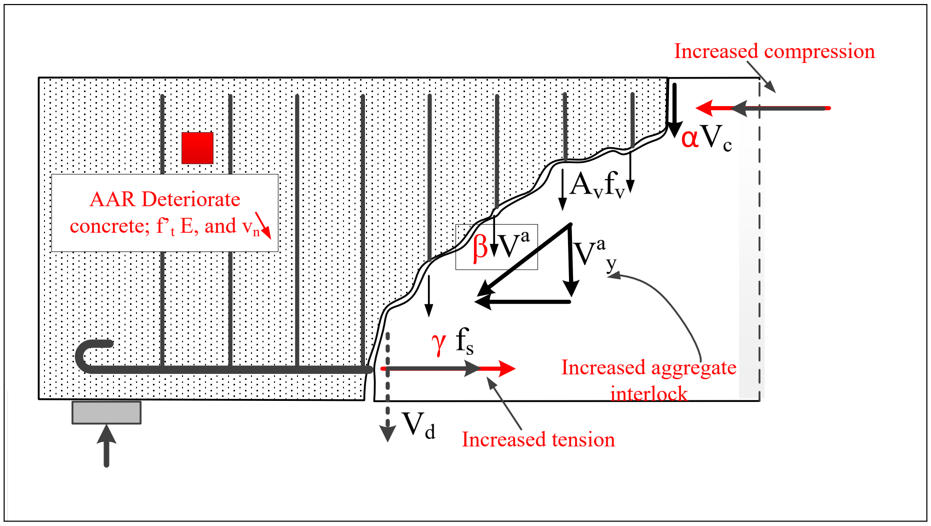


Figure 16: Chemical prestressing explained; Local response

Where V_{ext} is the external shear that must be equal to the sum of the internal forces; αV_c is the shear force in the uncracked section, βV^{agg} is the contribution of the aggregate interlock, V_d shear due to dowel effect, and $\sigma_n A_v f_v$ is the shear in the (n) vertical stirrups. $\alpha > 1$, $\beta > 1$ and $\gamma > 1$ are caused by the presence of ASR.

When the longitudinal steel yields V_d can be neglected. ACI 318 (2019)[5] lumps the effects of the first three terms as

$$\alpha V_c + \beta V_y^{agg} + V_d = 2\sqrt{f_c'} bd(\text{psi}) \tag{7}$$

(using the simplified equation).

In summary, the shear resistance of a reinforced concrete beam affected by ASR will *always* be higher than that of regular concrete. A simple free-body diagram supports this conclusion, confirming its validity from a fundamental mechanics perspective. There is therefore no need to perform additional tests (such as the LSTP) to experimentally confirm what has been well established since 1998 (Ahmed, Burley, and Rigden, 1998), as illustrated in Fig. 17. This finding has been consistently confirmed by numerous subsequent studies.

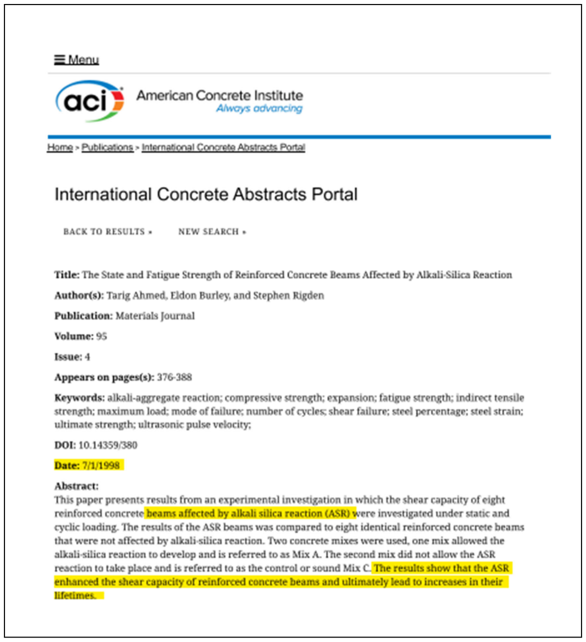
Finally, it should be emphasized that the *reinforcement stress under service loads is now increased*, bringing it closer to the yield stress limit and thereby potentially reducing the margin of safety in flexure.

C.3 What are Squat Shear Walls

Squat shear wall is a reinforced concrete wall with a low height-to-length ratio, typically less than 2.0. Due to this geometry, lateral loads applied to the wall are primarily resisted through shear forces rather than flexural (bending) action.

This makes squat walls the preferred configuration for shear testing, as their dimensions maximize shear stresses and minimize flexural contributions, allowing researchers to isolate and study shear-related behavior — such as cracking, stiffness degradation, and strength loss — especially in materials affected by deterioration mechanisms like Alkali-Aggregate Reaction (AAR). The corresponding failure mechanism is the same as the one in a CEB.

[5] Recent versions do not differ from the 74 version of the code for this equation.



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Title: The State and Fatigue Strength of Reinforced Concrete Beams Affected by Alkali-Silica Reaction

Author(s): Tarig Ahmed, Eldon Burley, and Stephen Rigden

Publication: Materials Journal

Volume: 95

Issue: 4

Appears on pages(s): 376-388

Keywords: alkali-aggregate reaction; compressive strength; expansion; fatigue strength; indirect tensile strength; maximum load; mode of failure; number of cycles; shear failure; steel percentage; steel strain; ultimate strength; ultrasonic pulse velocity;

DOI: 10.14359/380

Date: 7/1/1998

Abstract:
This paper presents results from an experimental investigation in which the shear capacity of eight reinforced concrete beams affected by alkali silica reaction (ASR) were investigated under static and cyclic loading. The results of the ASR beams was compared to eight identical reinforced concrete beams that were not affected by alkali-silica reaction. Two concrete mixes were used, one mix allowed the alkali-silica reaction to develop and is referred to as Mix A. The second mix did not allow the ASR reaction to take place and is referred to as the control or sound Mix C. The results show that the ASR enhanced the shear capacity of reinforced concrete beams and ultimately lead to increases in their lifetimes.

Figure 17: First paper proving increase in shear resistance in beams with ASR, (Ahmed, Burley, and Rigden, 1998)

In contrast to the free body diagram of the cracked beam shown in Fig. 16, the free body diagram illustrating the internal and external forces acting on a cracked squat shear wall is presented in Fig. 18.

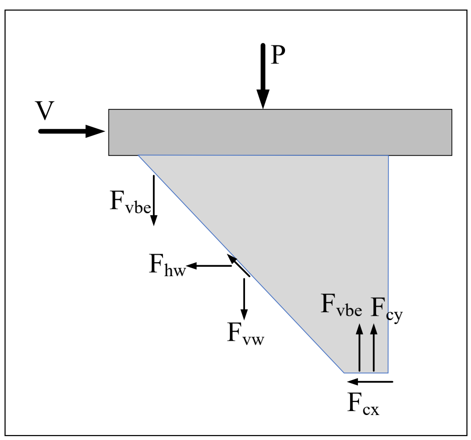

Figure 18: First paper proving increase in shear resistance in beams with ASR, (Gulec and Whittaker, 2009)

where V is the lateral force; P is the axial force (providing confinement); F_{vbe} is the force carried by the vertical boundary element reinforcement; F_{vw} is the total force carried by the vertical web reinforcement; F_{hw} is the total force carried by the horizontal web reinforcement; F_{fri} is the friction force associated with aggregate interlock between the two surfaces of the cracks; F_{cx} and F_{cy} are the components of the compression strut force.

Clearly The internal and external force mechanisms in a squat shear wall differ fundamentally from those in a reinforced concrete beam.

D Relevance of NIST tests on past expansion; Further details

A key component of the LAR is the estimate[6] of past expansion. This is performed as follows Fig. 19:

1. Once the location of the measuring point is determined, retrieve the concrete compressive strength f'_c from the archives of the closest point[7].

2. The corresponding elastic modulus E is not available (only compressive strength are measured, and saved).

3. Utilize the observation/relation that:

   (a) The elastic modulus decreases with an increase in AAR expansion (Institution of Structural Engineers, 1992) and (Thomas, Fournier, and Folliard, 2013). This change can be expressed as a normalized quantity:

   $$E_n = \frac{E_{\text{present}}}{E_{28 \text{ days}}} \qquad < 1 \tag{8}$$

   where E_{present} is the current elastic modulus (say 2024), and $E_{28 \text{ days}}$ is the value measured during construction (around 1984).

   Note that this relationship is not universally applicable; it is specific to the type of concrete used. In the case of NextEra, the calibration curves were developed in Texas using a concrete mix that, while similar, is not identical to the one used at Seabrook.

   (b) There exists an *approximate* empirical equation in the ACI code that relates the compressive strength to the elastic modulus for 28-day concrete tests:

   $$E_{28 \text{ days}} = 57000\sqrt{f'_{c,28days}} \tag{9}$$

   Although widely used, this equation is empirical and must be applied with caution, especially in the presence of degradation mechanisms such as ASR.

4. Determine the 28 days elastic modulus, Fig. 19 from Equation 9.

5. Determine the current elastic modulus E_{present} from standard tests.

6. Compute the normalized elastic modulus E_n from Eq. 8

7. Using the calibration curve from Fig. 19 determine the expansion.

[6]This can not be directly measured.

[7]This raises questions as to whether NextEra maintains a sufficiently fine-grained archive to identify past data close enough to the location of the extracted core, to perform a credible corroboration study.

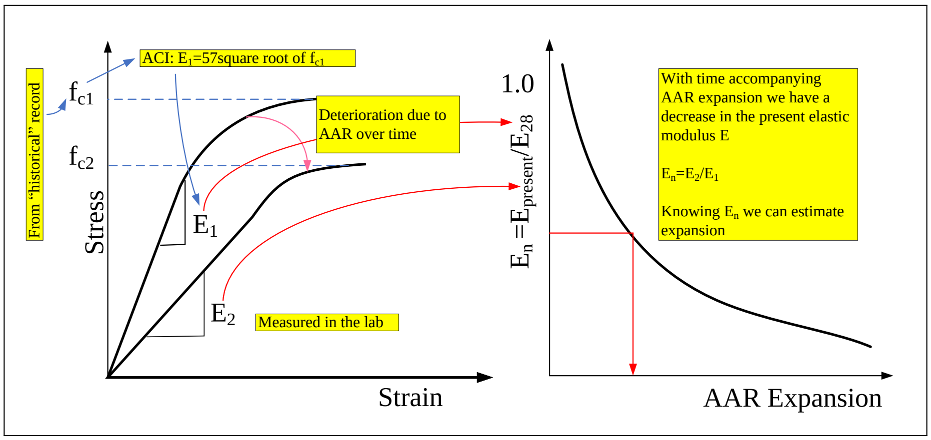

Figure 19: Out of plane expansion explained