ASR & Seabrook Station: 20 Questions and Answers

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A bit about my credentials

- Professor, Department of Civil Engineering, University of Colorado in Boulder
- New project funded by the US Bureau of Reclamation on alkali aggregate reaction
- Chairman of an international committee on impacts on structures affected by alkali-silica reactions
- $700K study for US NRC on Alkali-Silica Reaction on nuclear containment vessel structures
- Past President of the International Association of Fracture Mechanics for Concrete and Concrete Structures
- Past member of the NRC's Expanded Proactive Materials Degradation Analysis Expert Panel for concrete in nuclear reactors, 2010-2014
- Study on Alkali-Silica Reaction in Nuclear Power Plants (2014-2015) funded by the Oak Ridge National Laboratory, US Dept. of Energy.
- Published extensively. https://ceae.colorado.edu/~saouma/index.php/alkali-aggregate-reactions/

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How I came to work with C-10

Safety for Citizens

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Our Discussion in 20 Questions

ASR BASICS:

Q1: What is ASR?
Q2: How does ASR manifest itself?
Q3: How does ASR impact concrete?
Q4: Are all aggregates created equal?
Q5: How does concrete expand?
Q6: Can we estimate past expansion?
Q7: Can we estimate future expansion?
Q8: How does ASR increase with time?
Q9: How should ASR be addressed?
Q10: Do major structures have ASR?
Q11: How does ASR affect nuclear plants?

SEABROOK TESTING AND ANALYSIS

Q12: Was FSEL testing representative?
Q13: Were assumptions valid?
Q14: Were ASR tests performed?
Q15: Was the analysis of data adequate?
Q16: Is proposed monitoring adequate?
Q17: Was the work peer reviewed?

CONCLUSIONS: SEABROOK SAFETY

Q18: Is Seabrook operating safely now?
Q19: Will Seabrook be safe to operate for a 20-year license renewal term?
Q20: What is your recommendation?

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Q1: What is ASR?

A nefarious chemical reaction between:

- alkali in the cement paste
- silica in the aggregates.

Q2: How does ASR manifest itself?

- Formation of “map” cracks or cracks.
- Cracks align with rebar behind the concrete surface.

Q3: How does ASR impact concrete?

- Swelling.
- Reduced tensile and shear strengths.
- Reduced “elastic modulus” (larger deformation, more cracks than otherwise).
- No substantial reduction in compressive strength).

Q4: Are all aggregates created equal?

- Some aggregates are “early expansion,” others are “late-expansion.”
- Sand reacts more quickly than aggregates, but ultimate expansion is smaller.

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Q5: How does concrete expand?

- Expansion is volumetric (equal expansion ɫ in all three directions).
- High expansions are about 0.1%
- If constraints in one direction (*i.e.,* rebar) expansion will increase in other directions.

Q6: Can we estimate past expansion?

- Yes, by performing a “Damage Rating Index (DRI)” microscopic petrographic study.
- DRI requires a highly qualified petrographer.

Q7: Can we estimate future expansion?

- Yes, by performing “accelerated expansion tests” (concrete core tests).
- Accelerated expansion tests require a specialized facility.

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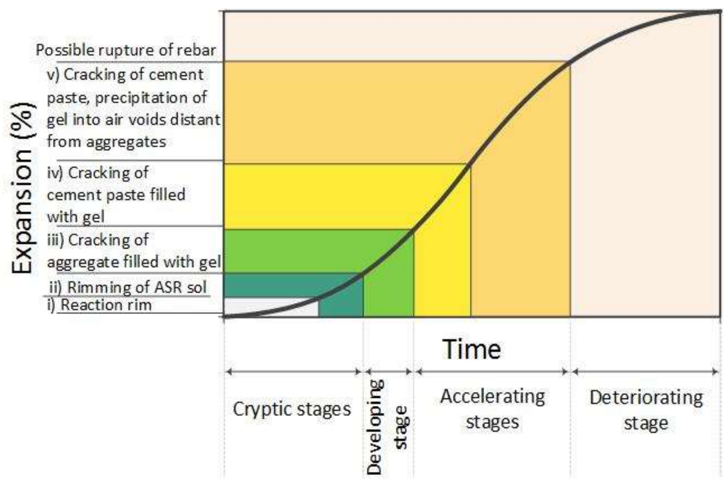
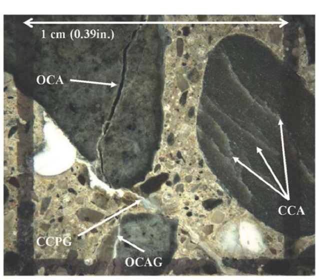
Q8: How does ASR increase with time?

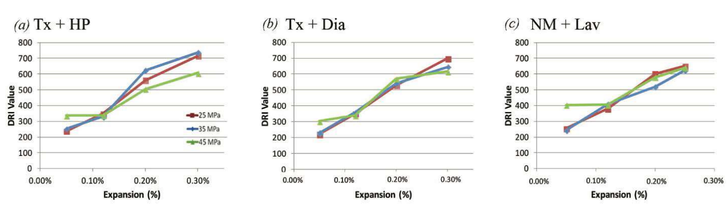
- ASR follows a sigmoid curve: slow, fast, slow.
- ASR typically takes many years to show visible signs.
- ASR requires high relative humidity of the concrete.
- Increased temperature makes ASR increase faster.



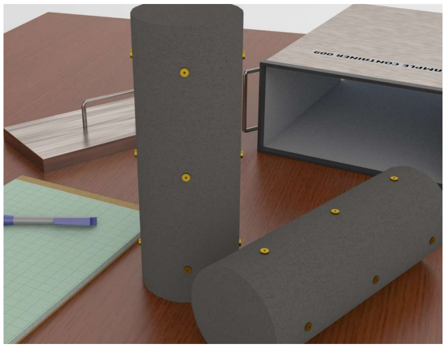
Q9: How should ASR be addressed?

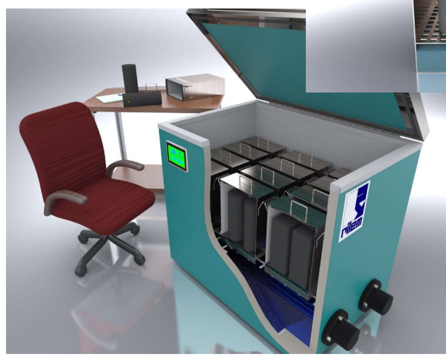
1. Damage Rating Index (DRI) microscopic petrographic analysis of damage in polished concrete sections, with goal of quantifying concrete deterioration.
2. Accelerated expansion tests.
3. Finite element analysis
4. Monitoring





Accelerated expansion





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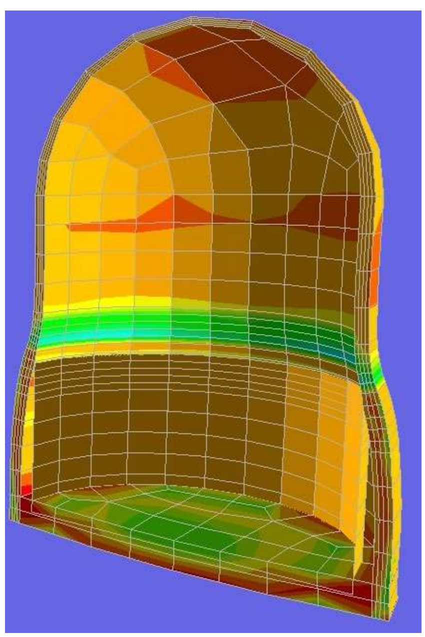
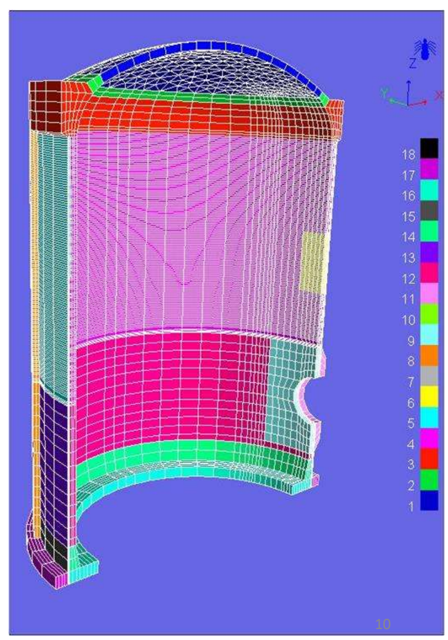
Finite element simulation:

static
vs.
dynamic

deterministic
vs.
probabilistic





Q10: Are there many other major structures suffering from ASR?

- Yes, many dams and bridges.
- Mactacuaq dam in New Brunswick and Beauharnois dam in Quebec have severe ASR.
- They are operational.
- Replacement costs over $1B each.
- Are investigated and monitored by very highly skilled engineers.
- Strong interactions with academia and research community.

Q11: How does ASR affect nuclear plants?

- Biggest concern is the reduction in shear strength of the concrete.
- Nuclear plants have no shear reinforcements.
- An earthquake will cause large shear stresses at the base (where most of the ASR occurs)
- Thus, concern is that ASR will greatly reduce the capacity of the containment structure to adequately resist a seismic excitation.

- **Note:** Cannot rely on so-called “chemical prestressing” (due to ASR) and assume that the shear strength is increased.
- Assumption of shear strength increase is <u>wrong:</u>
  - Does not take into account in-situ state of stresses;
  - Is not applicable to in plane shear.

Q12: Was FSEL testing representative?

- Concrete mix in FSEL test was not identical, similar, or representative.
- Concrete is like bread: same ingredients (flour, yeast, water and salt) but with different dosage/source could result in French bread or pita bread.
- FSEL did not use same aggregates and sand.
- Having reactive concrete is not enough.

Q13: Were assumptions valid?

- No.
- Scaling from prototype to model not performed.
- Boundary conditions incorrect.
- No evidence (picture, force displacement diagram) of shear failure.
- Specimen severely damaged before test even started.

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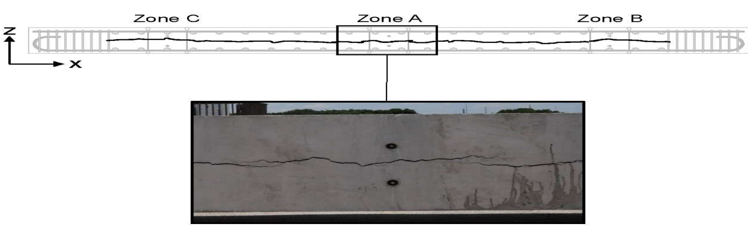

Figure 3-8: Mid-depth surface crack on X-Z specimen face

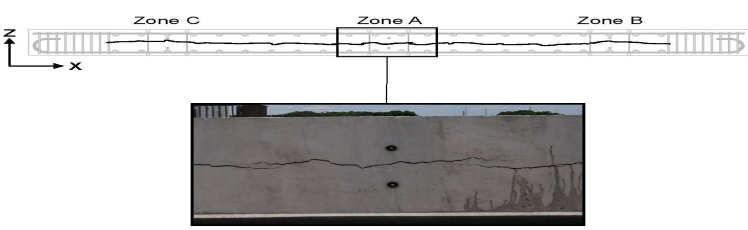

Figure 3-8: Mid-depth surface crack on X-Z specimen face

"This highlights the precautions that must be taken when interpreting data from ASR-affected elements."

David Michael Wald, Ph.D Dissertation: ASR Expansion Behavior in Reinforced Concrete – Experimentation and Numerical Modeling for Practical Application (U of TX at Austin, Aug. 2017)

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Q14: Were ASR tests performed?

- No. Essential tests were omitted.
  - No DRI petrographic tests to assess past damage.
  - No accelerated expansion tests to assess future expansion (how much expansion, and roughly when would it occur).
- Result: benefit of 8 years of data was missed.

Q.15: Was the finite element analysis adequate?

- No. Very simplistic approach:
- ASR treated as demand load when it should be a capacity reduction.
- Heavy reliance on laboratory tests.
- Ignored temperature and stress dependence.
- Simple "stick" model for dynamic analysis, no soil structure interaction
- No one would perform as simplistic an analysis for even a moderately important structure as what was performed for Seabrook.
- Fully deterministic, not a hint of risk based assessment.

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Q16: Is proposed monitoring adequate?

- No. Too heavy a reliance on crack index measurement on the surface:
  - On the surface, concrete is dry – shows little expansion.
  - By the time interior expansion daylights sufficiently on the surface, too much expansion will have taken place inside.

Q17: Was the work peer reviewed?

- No independent peer review by a panel of experts.
- Seabrook = first ASR case presented to NRC, yet NRC allowed NextEra to write the procedure for safety assessment and monitoring supporting license renewal.
- While NRC had funded over $8M of research on ASR, no indication that they took any of that into account

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Q18: Is Seabrook operating safely now?

- We really do not know.
- Tests and analyses conducted by NextEra's contractors are fundamentally inadequate.
- Heavy reliance on inadequate crack index for monitoring.
- Monitoring, analysis, and testing are very tightly coupled and intertwined.
- Each one of them was shown to be independently inadequate.

Q19: Do you think NRC had an adequate basis to re-license Seabrook for an additional 20 years past 2030?

Based on the documents filed, the short answer is NO.

Q20: What further steps do you recommend?

- Take a deep breath. There is no “Band-Aid” remedy.
- Perform adequate:
  - DRI (petrography)
  - Accelerated Expansion tests
  - Finite element studies.
- Talk to HydroQuebec. They are facing very similar problems.
- Catch up with the scientific literature.
- Perform peer review.

Key Takeaways:

- Extraordinarily complex problems require complex solutions at a minimum.
- Too much is at stake to take shortcuts and jeopardize the safety of the public.
- Unless/until NRC takes steps to rectify, decision to re-license Seabrook with a substandard program for addressing ASR this LAR may become a major stain on the reliability and credibility of the agency.

Questions?