Effects of Freeze-Thaw Testing Procedures on Prestressed Concrete Railroad Ties

2016 Concrete Tie Symposium

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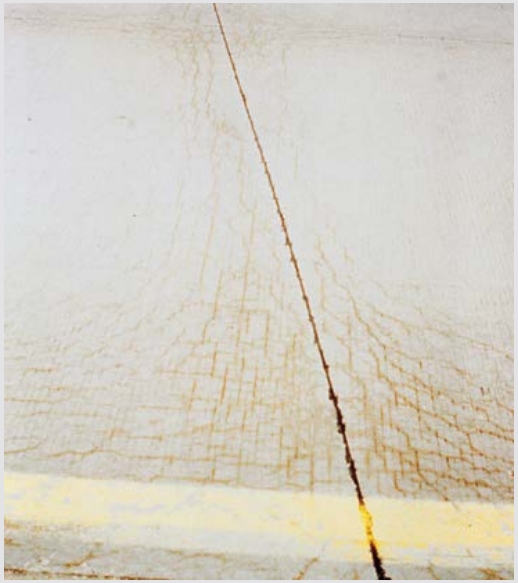
Research Questions

Guidance needed for concrete vibrated with high workability, high admixture dosage

- Fresh air required for durability
- Hardened air required for durability
- How do you test freeze-thaw durability of vibrated, prestressed concrete railroad ties?

Concrete Deterioration

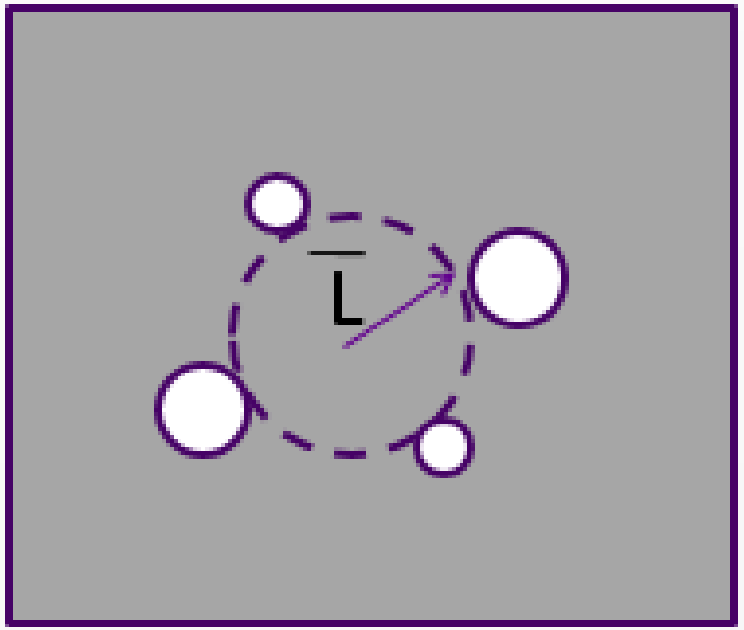
- Bulk Freeze-Thaw
- Deicer Salt Scaling



Figures from PCA

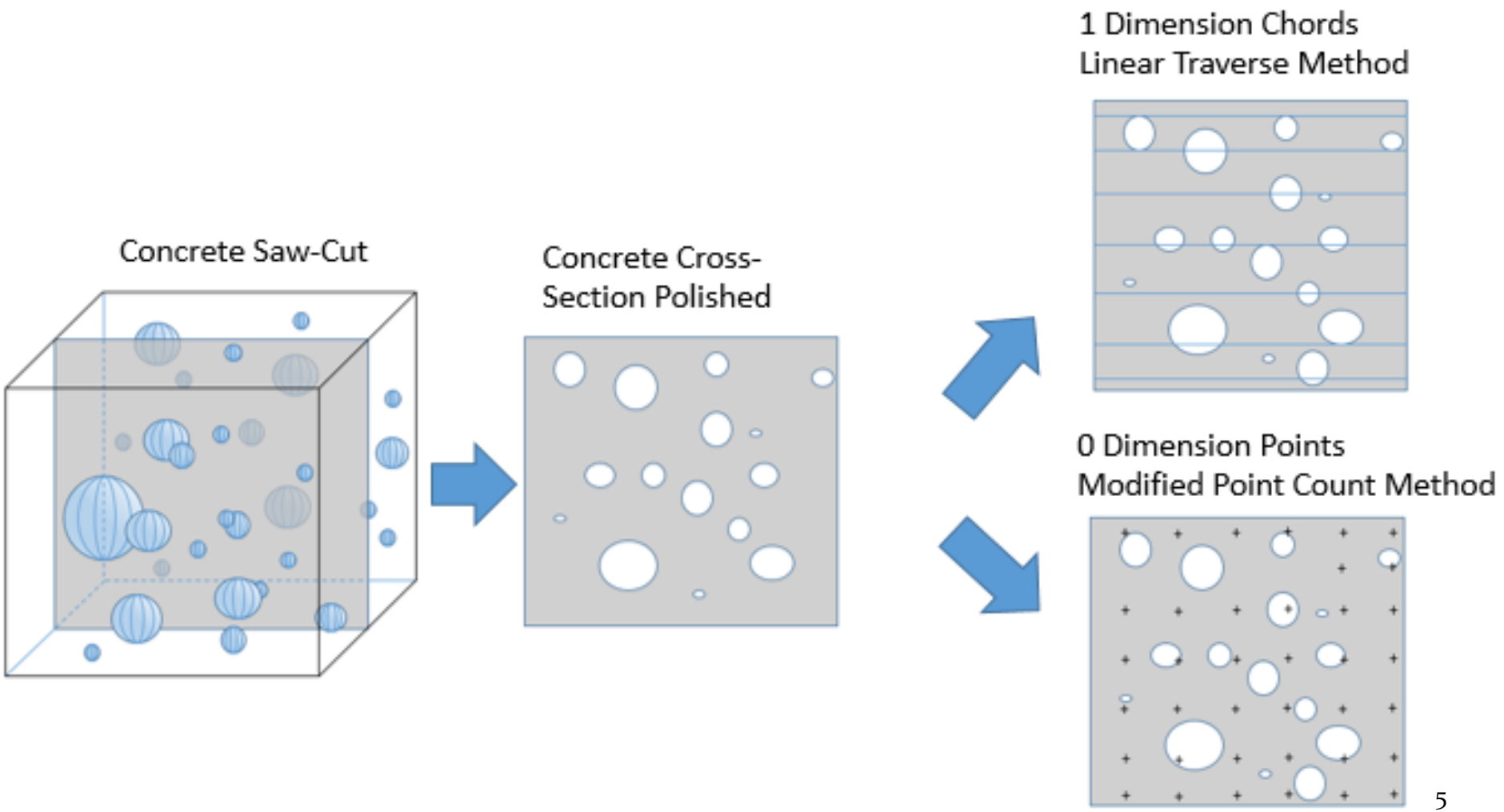
Air Entrainment

- The spacing factor, L is the maximum distance any point in the paste is away from the edge of the nearest air bubble.
- Specific surface is the surface area of a quantity of air voids that has a volume of 1 mm3 (1 in3)



- Based on work of Paul Klieger, 1951
- Many railroads have adopted the requirement of 4.5% air in fresh concrete, 3.5% air in hardened concrete
- Require spacing factor <0.008 in. (0.200 mm)

ASTM C457 – Hardened Air Void System Analysis

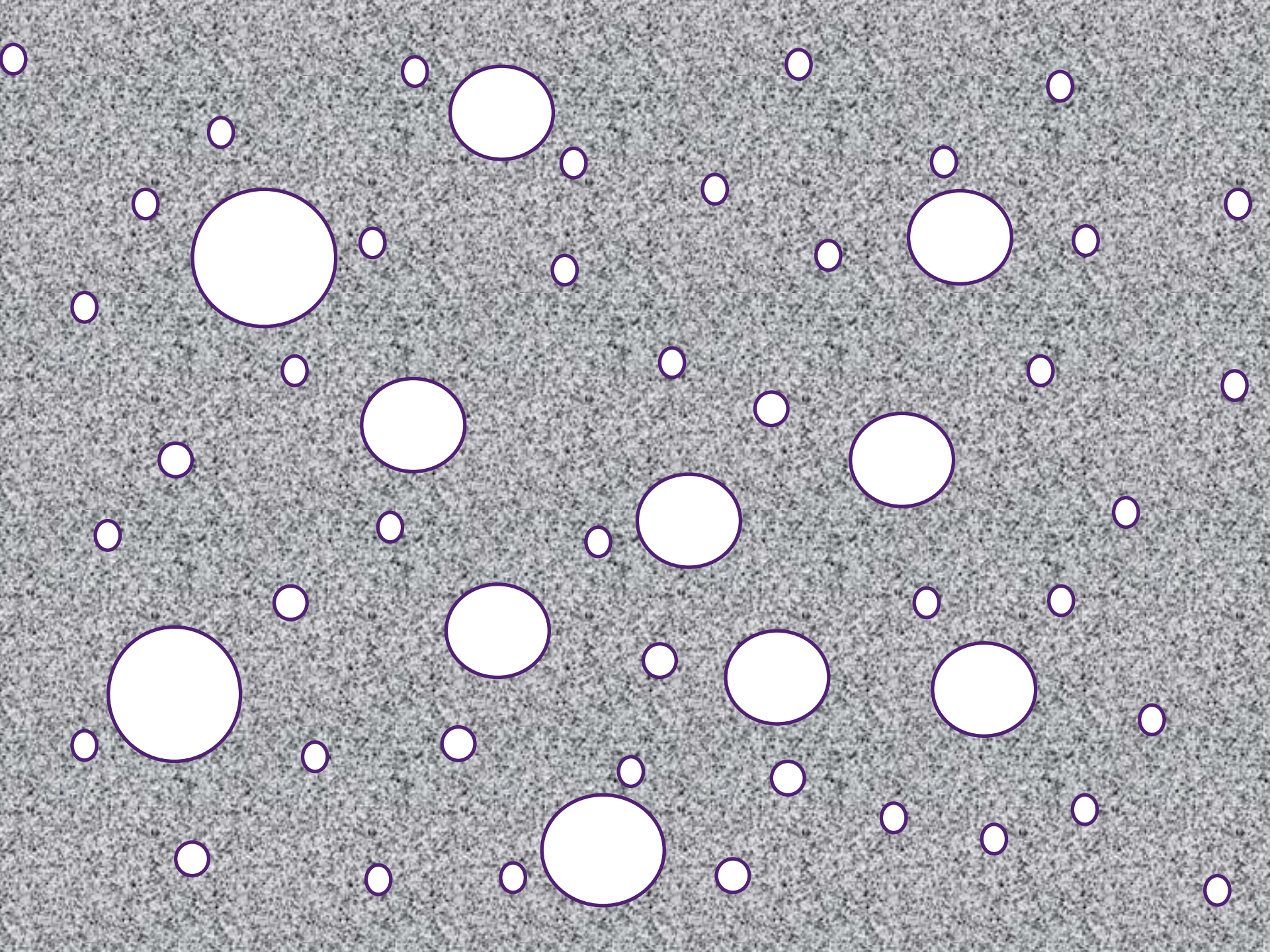


Poor Consolidation

Honeycombing

Bug holes

Fear of poor consolidation can lead to over-vibration

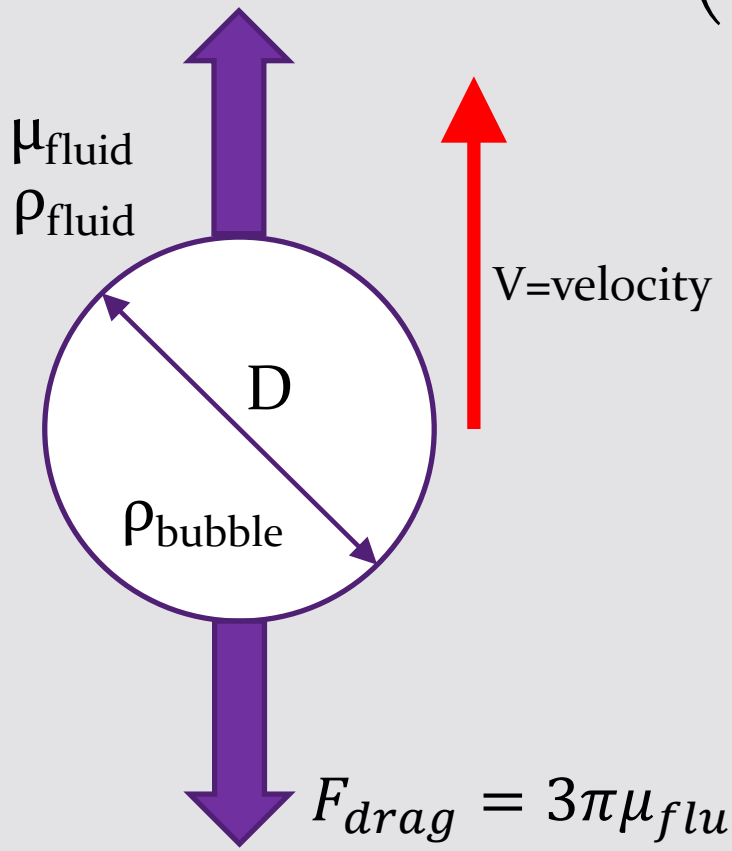


Air Bubble Rise in Concrete

Stoke's law says that air bubble rise is a function of the fluid density, viscosity, and bubble diameter

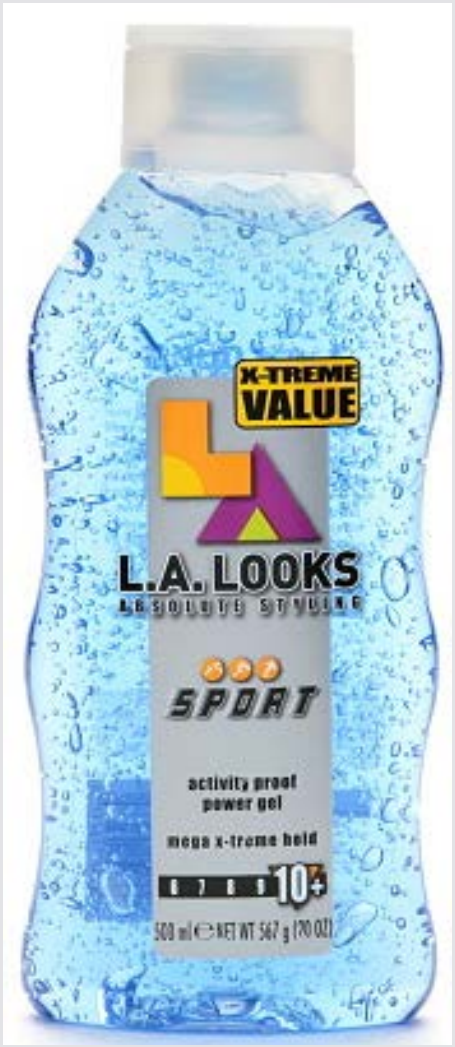
$$V = \frac{1}{18}\frac{\Delta\rho g D^2}{\mu_{fluid}}$$

$$F_{bouyancy} = (\rho_{fluid} - \rho_{bubble})\left(\frac{\pi g D^3}{6}\right)$$



$$F_{drag} = 3\pi\mu_{fluid} DV$$

How Does Vibration Affect Concrete?



Methods: Freeze-Thaw Machine

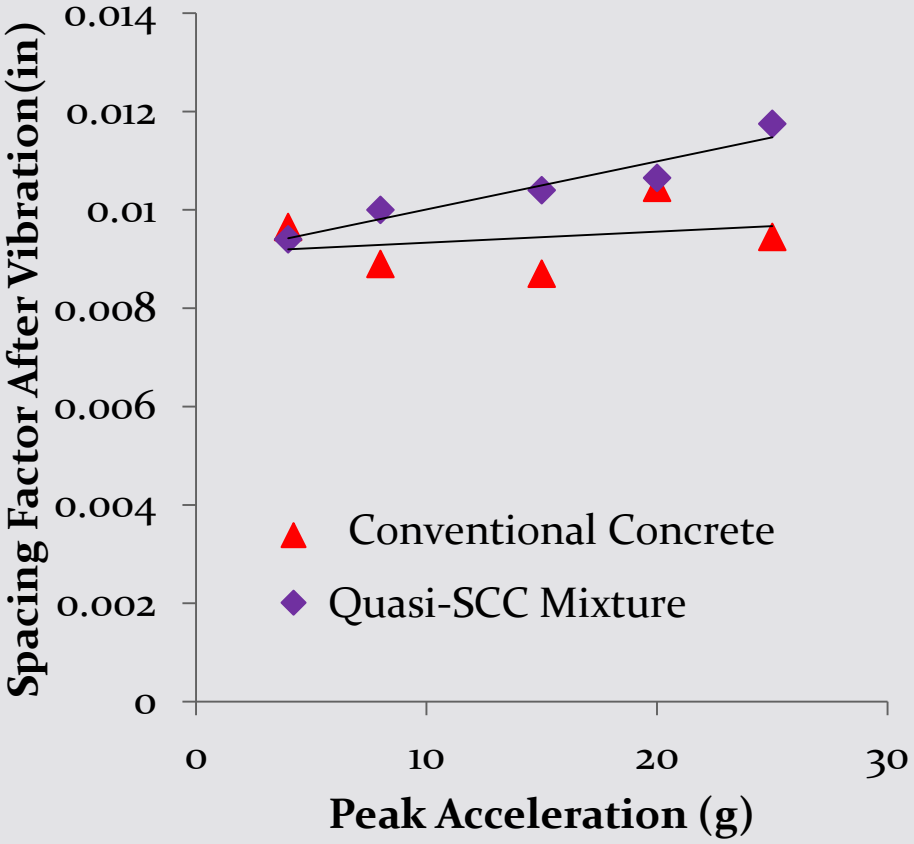
- Freeze-thaw test according to ASTM C666 Method A
- Concrete fluid properties measured using ICAR rheometer

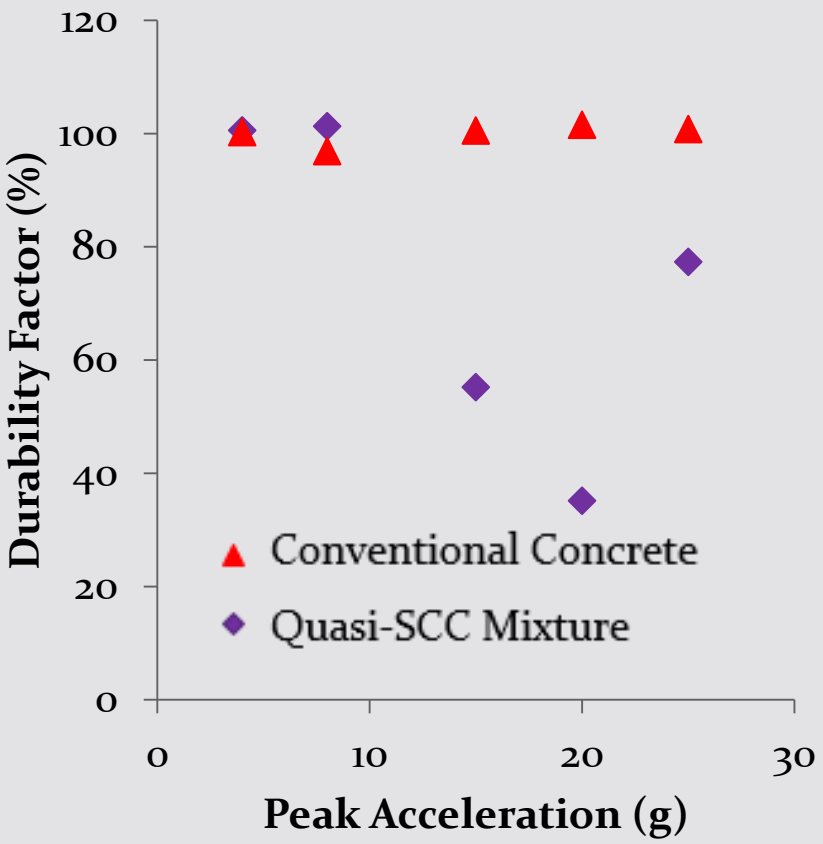
Methods: Vibration

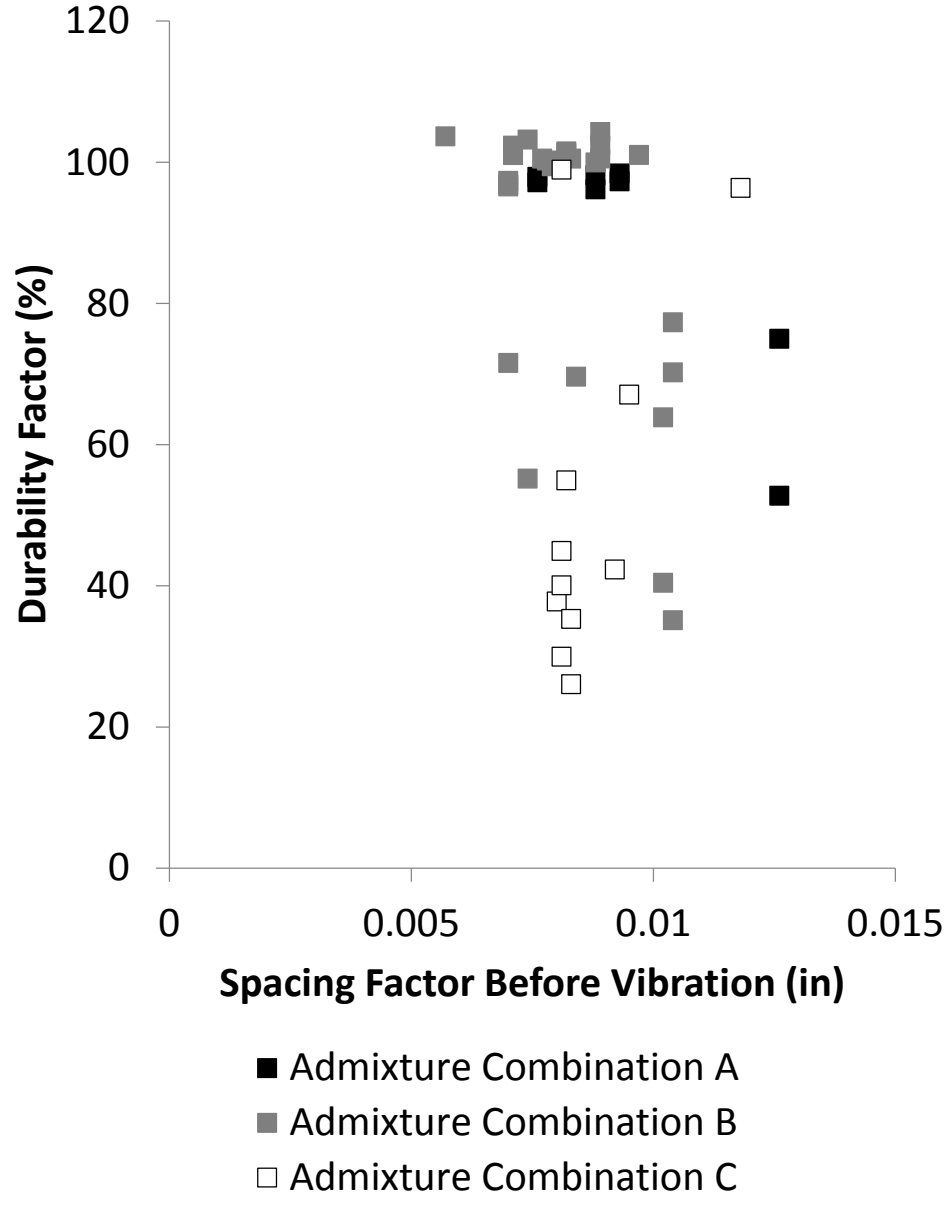
- Vibration frequency = 33 Hz to 160 Hz
- Vibration duration = 0.5 or 4 minutes
- Vibration peak acceleration = 4 g to 25 g

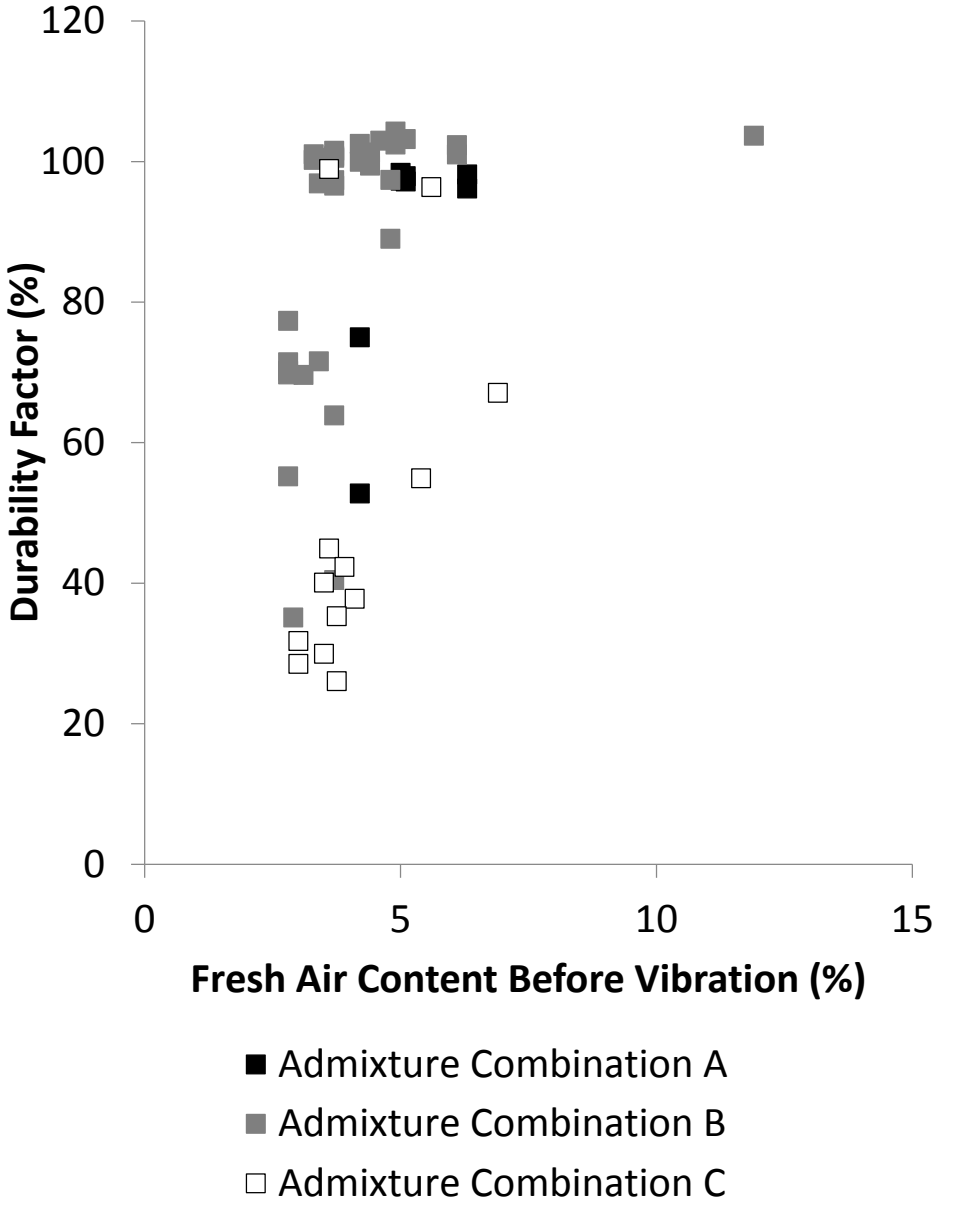
Vibration Acceleration

Vibration frequency = 75 Hz
Vibration duration = 4 minutes
Target 3-4% fresh air before vibration

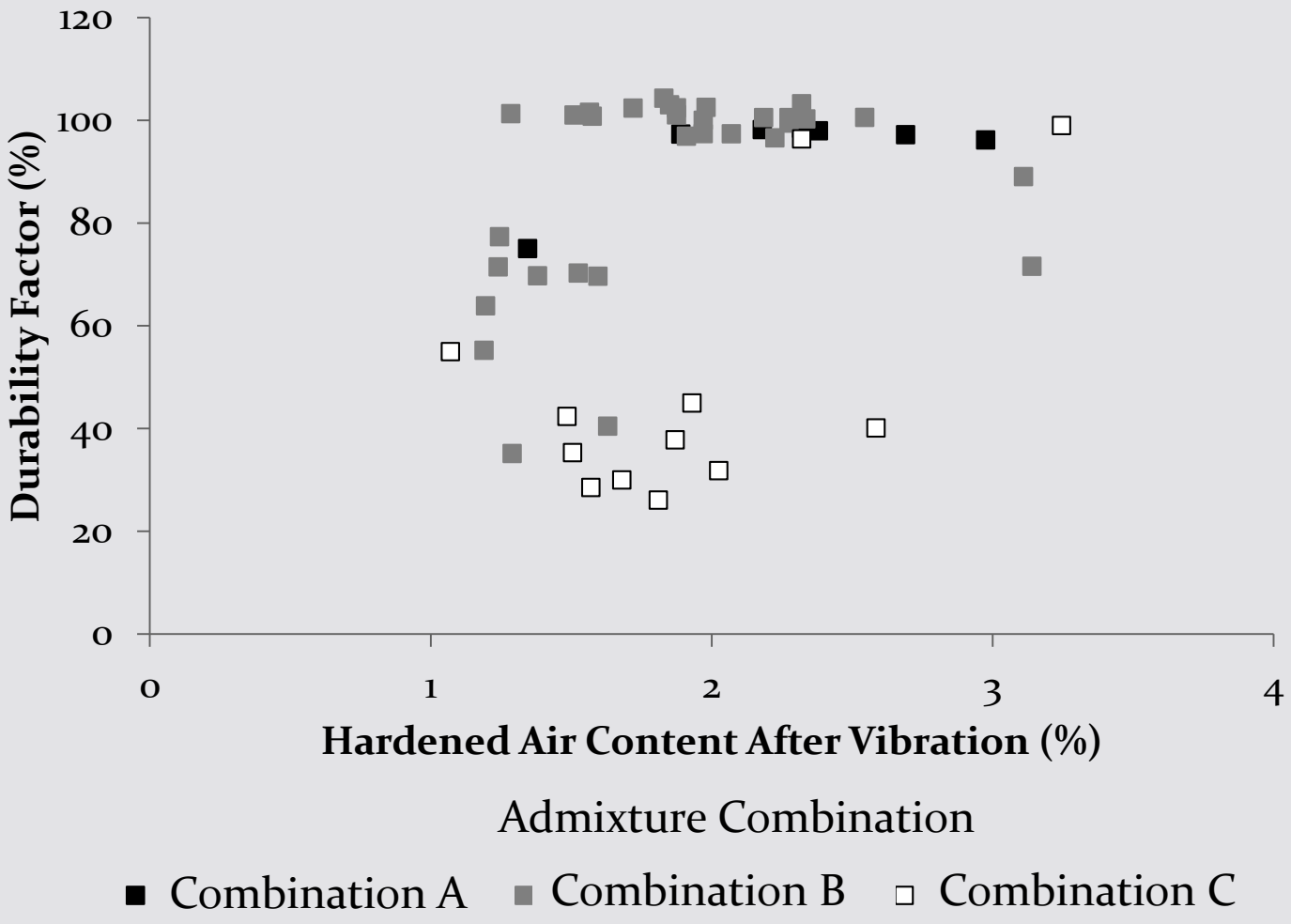


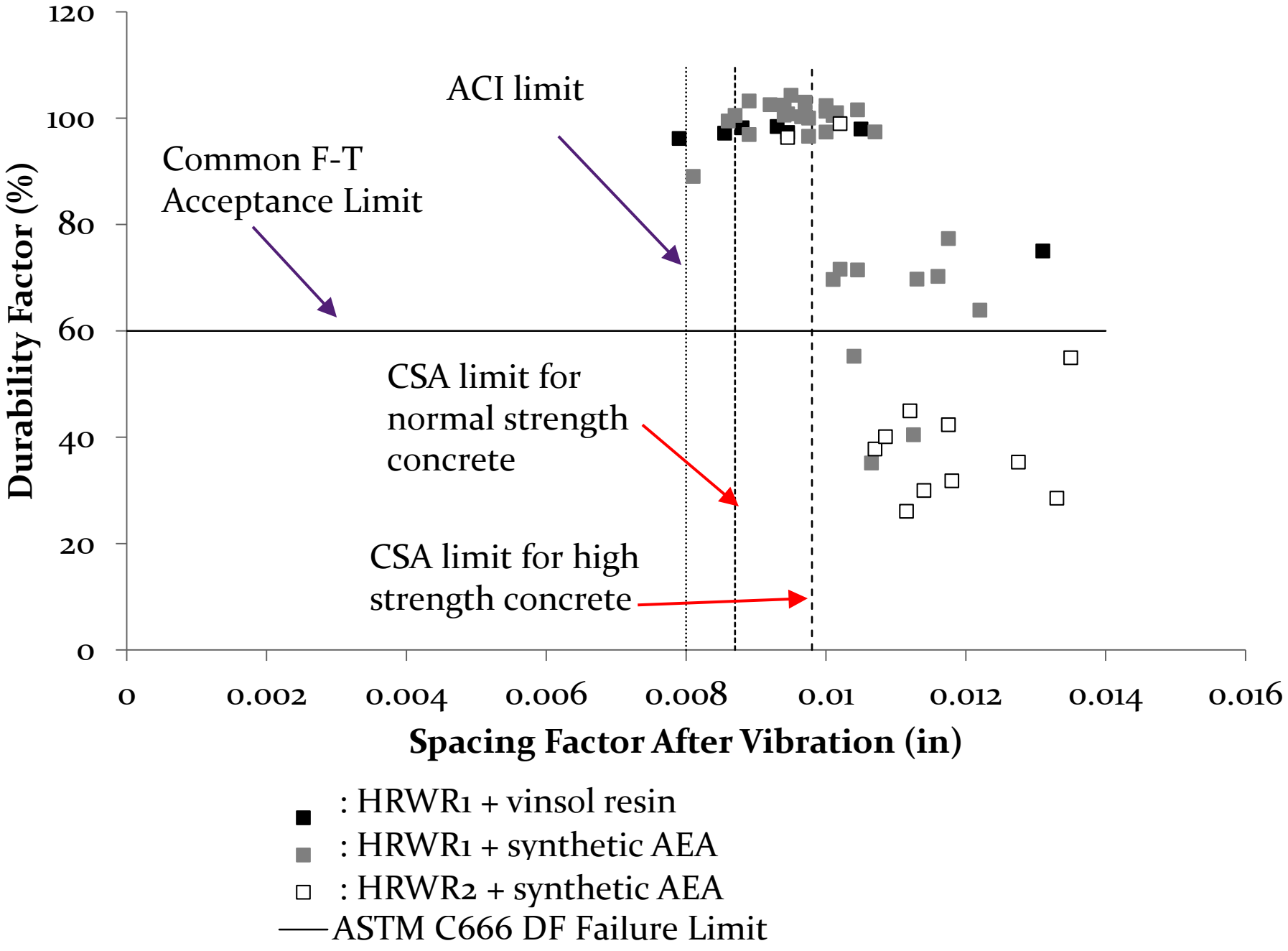



120
100
80
60
40
20
0
Durability Factor (%)
0
0.005
0.01
0.015
Spacing Factor Before Vibration (in)
Admixture Combination A
Admixture Combination B
Admixture Combination C


120
100
80
60
40
20
0
Durability Factor (%)
0
5
10
15
Fresh Air Content Before Vibration (%)
Admixture Combination A
Admixture Combination B
Admixture Combination C

Hardened Air Content After Vibration




120
100
80
60
40
20
0
Durability Factor (%)
ACI limit
Common F-T
Acceptance Limit
CSA limit for
normal strength
concrete
CSA limit for high
strength concrete
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
Spacing Factor After Vibration (in)
: HRWR1 + vinsol resin
: HRWR1 + synthetic AEA
: HRWR2 + synthetic AEA
ASTM C666 DF Failure Limit

Research Questions

- Guidance needed for concrete vibrated with high workability, high admixture dosage
  - Fresh air required for durability
  - Hardened air required for durability
  - How do you test freeze-thaw durability of vibrated, prestressed concrete?

Research Questions

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    Mix specific – must be determined for your mixture and vibration
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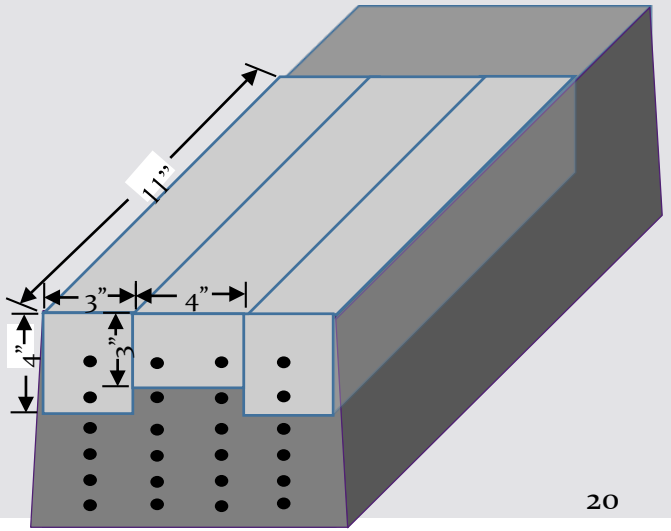
    Spacing Factor < 0.0087 in.- normal strength / 0.0098 in.- high strength
  - How do you test freeze-thaw durability of vibrated, prestressed concrete?

Product Freeze-Thaw Testing

- Most North American concrete railroad ties are prestressed
- Concrete freeze-thaw samples have been traditionally made by excising samples out of produced ties
- Does saw-cutting affect the concrete specimens and give misleading freeze-thaw test results?

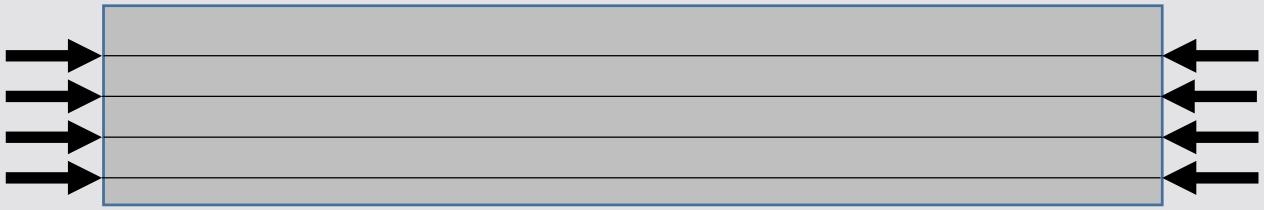
Sample Extraction

- ASTM C666 allows samples to be cast or sawn extracted from larger elements.
- Tie Sample Extraction Producer Concerns:
  - For some ties, it is not possible to extract a sample without wires.
  - Damage can occur from saw-cutting
  - Damage from relieving prestress forces during saw-cutting causing micro-cracking
  - Inclusion of wires may change durability

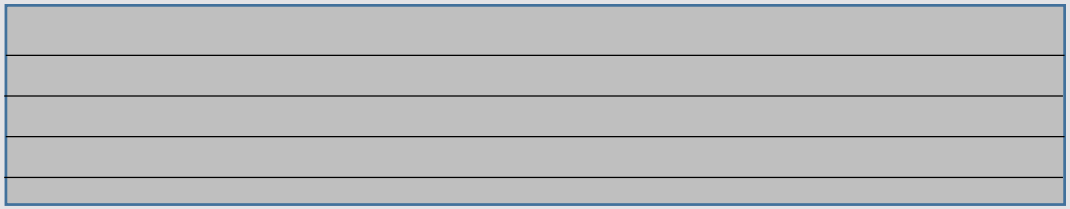


Concrete Ties Made for Comparison between Saw-cut and Cast Prisms

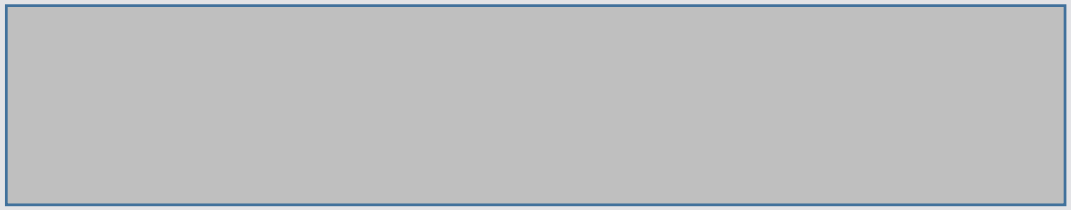
Prestressed Concrete Tie



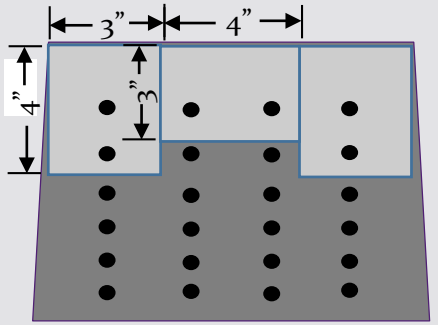
Concrete Tie with Wires, No Prestressing

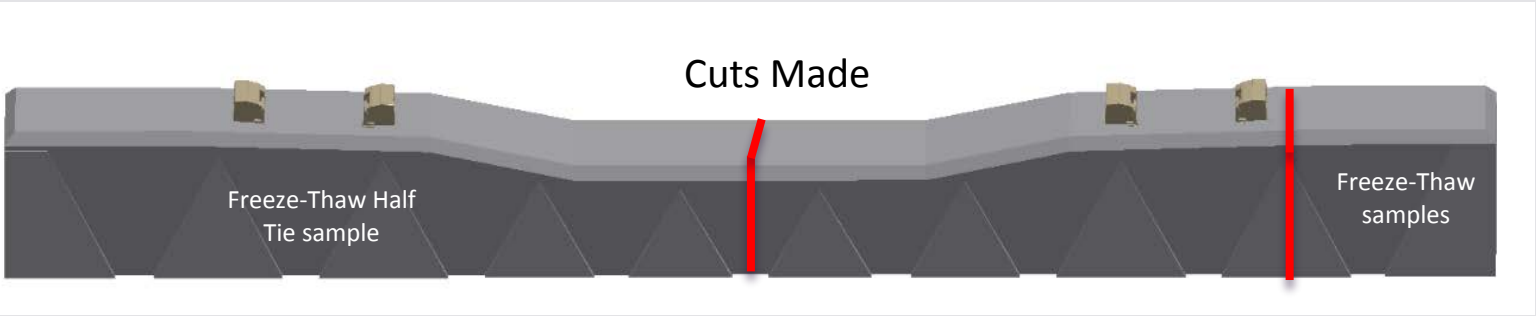


Concrete Tie without Wires



Samples| Saw-cutting

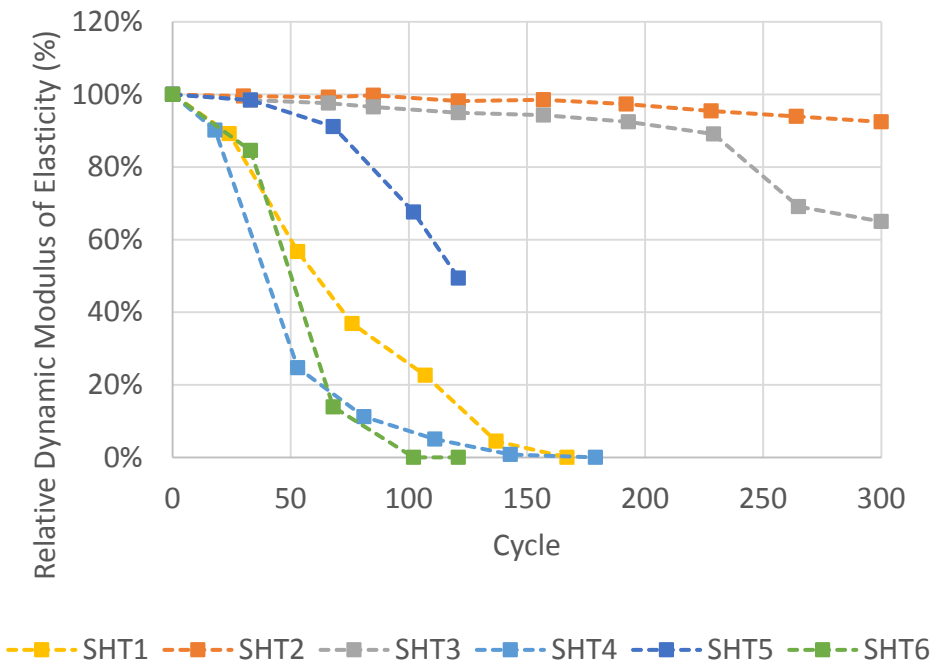




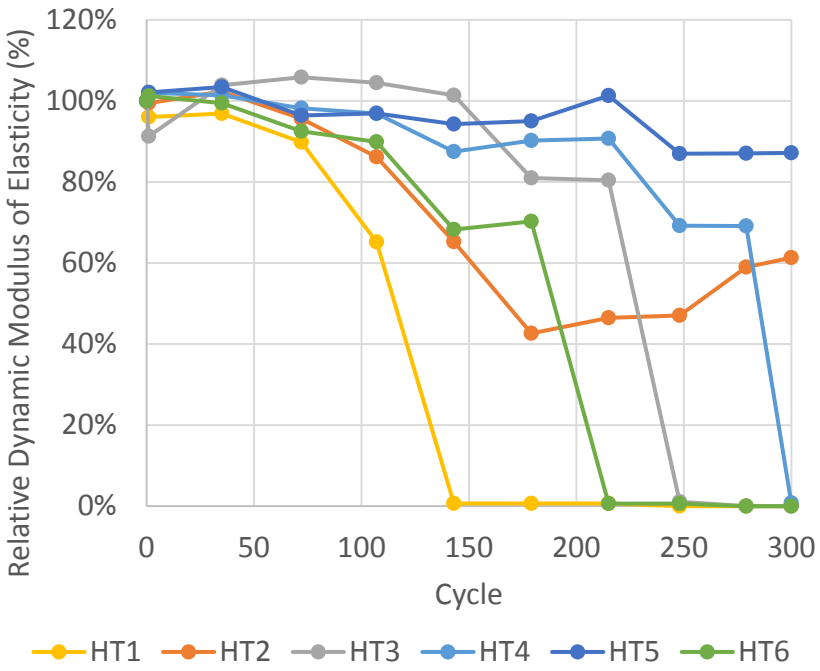
Results

- Large samples (half-ties) vs. excised samples from the same ties

Saw-cut samples

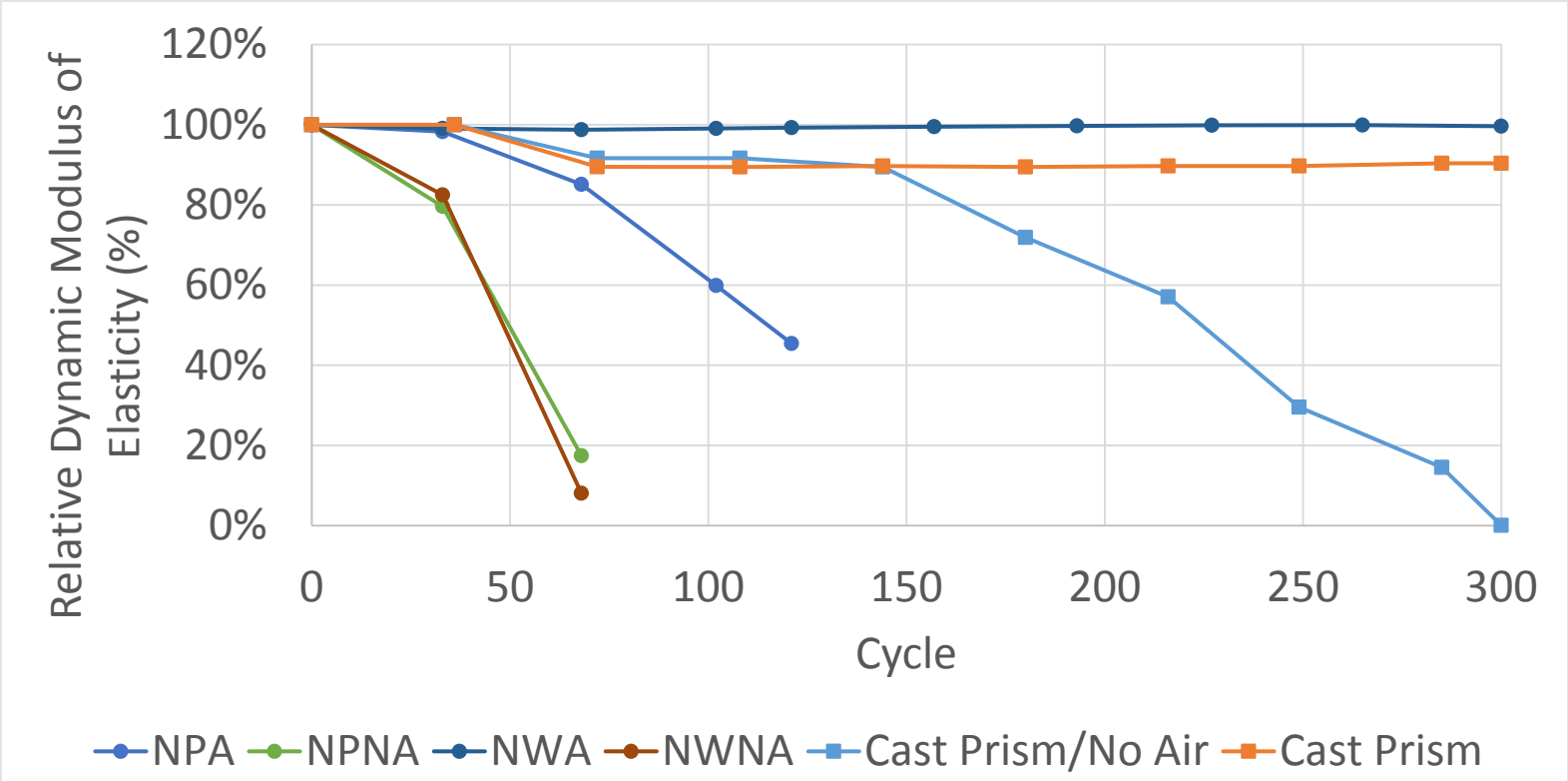


Half-tie samples

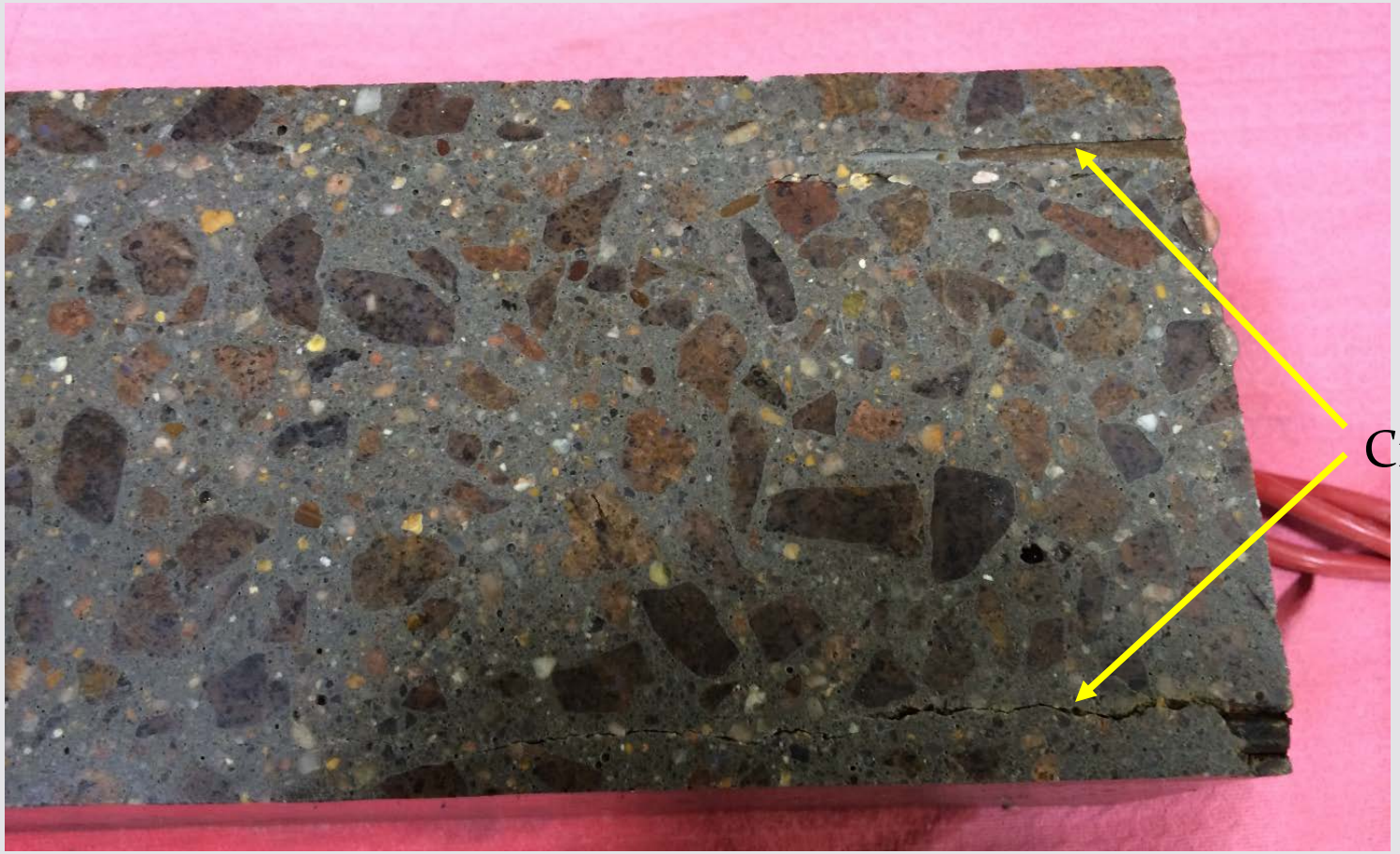


Results

- Saw-cut Prestressed vs. Saw-cut Not Prestressed vs. Saw-cut Plain vs. Non-Saw-cut prisms



Prestressed with Air Entrainment



Excised ASTM C666 Sample

- *Before freeze-thaw cycles*

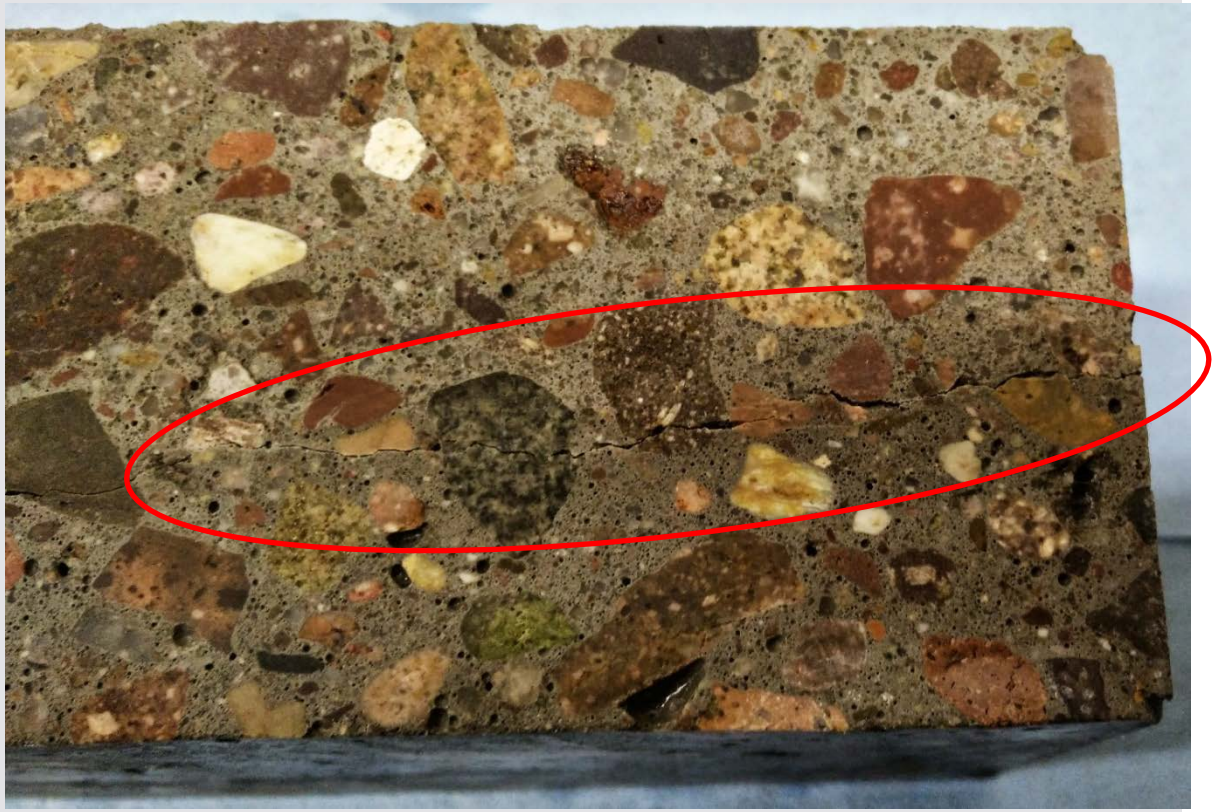
After 193 freeze-

Ties Freeze-Thaw Testing | HT2-M4

- *After 300 freeze-thaw cycles*

Ties Freeze-Thaw Testing | HT3-T1

- *After 300 freeze-thaw cycles*



Ties Freeze-Thaw Testing | HT3-B1

- *After 300 freeze-thaw cycles*

Ties Freeze-Thaw Testing | HT4-M1

- *Before freeze-thaw*

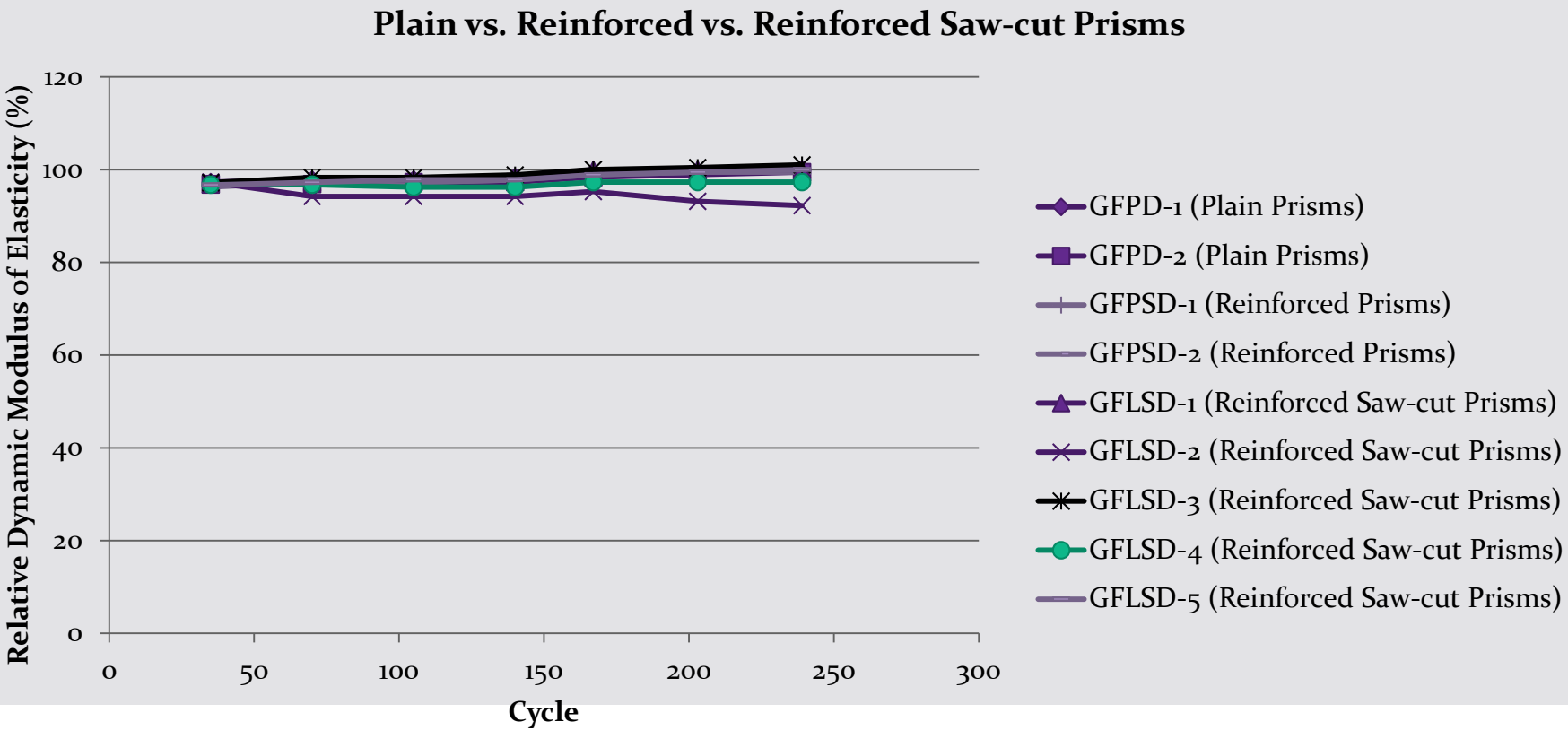
- *After 193 freeze-thaw cycles*

Ties Freeze-Thaw Testing | HT4-B2

- *After 193 freeze-thaw cycles*

F-T Experiments

- Plain vs. Reinforced vs. Reinforced Saw-cut Prisms
- Air content = 5.1%
- Synthetic AEA and a good HRWR
- Fluid mixture, no vibration



Pictures of one of the reinforced Saw-Cut Prisms

Cycle 0

Cycle 70

Pictures of one of the reinforced Saw-Cut Prisms

Cycle 0

Cycle 70

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    Mix specific – must be determined for your mixture and vibration
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    Spacing Factor < 0.0087 in.- normal strength / 0.0098 - high strength
  - How do you test freeze-thaw durability of vibrated, prestressed concrete?

    Excising samples from prestressed ties for freeze-thaw testing should be avoided

    Use match-vibration test method

How to make durable concrete

- Know your plant processes and impact on air. Focus on post-vibration air properties.
- Understand your mixtures and resiliency under vibration. Certain admixtures can help.
- Do not vibrate to remove all bugholes – that may be more vibration than you want for durability.
- Qualify all new materials and admixtures in light of FT durability. Test aggregate sources to avoid popouts.

Specification Provisions

- ASTM C457 air parameters
  - Use Max Spacing Factor = 0.22 mm to ensure FT durability of normal concrete.
  - Max Spacing Factor could be 0.25 mm for some HP concretes.
- Total Air Content
  - Spec levels need to be calibrated to plant processes
- ASTM C666
  - Still the “gold standard” to demonstrate frost durability
- Guide specification needs to be incorporated into AREMA Committee 30

Acknowledgements

- Federal Railroad Administration for funding this work
  - Cameron Stuart
  - Hailing Yu
  - David Jeong
- CSX Concrete Ties, Nortrak Voestalpine, CN