William W. Hay Railroad Engineering Seminar

"Freeze-Thaw Durability of Concrete Crossties"

David Lange

Professor

University of Illinois at Urbana-Champaign

Date: Friday, March 04, 2016

Time: Seminar Begins 12:20 pm

Location: Newmark Lab, Yeh Center, Room 2311
University of Illinois at Urbana-Champaign

Sponsored by

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

NURail Center

UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

Freeze-Thaw Durability of Concrete Crossties

Prof. David A. Lange

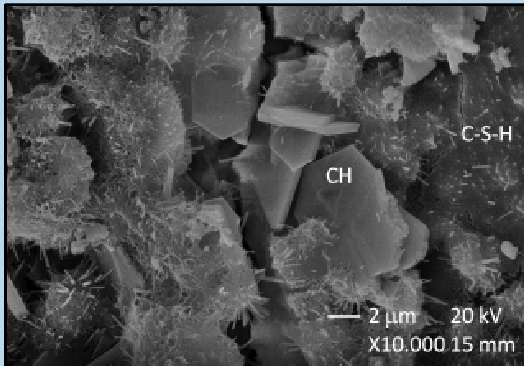
William W. Hay Railroad Engineering Seminar

March 4, 2016

FRA BAA Project
Prof. Kyle Riding, Kansas State
Prof. David Lange, UIUC
and Prof. Randy Ewoldt, UIUC
2012-2015

Final Project Presentation was on Jan 28, 2016

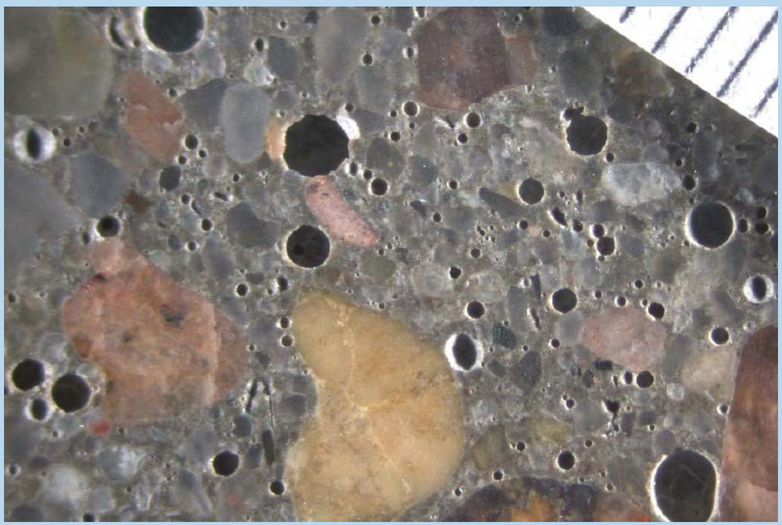
Freeze-thaw durability

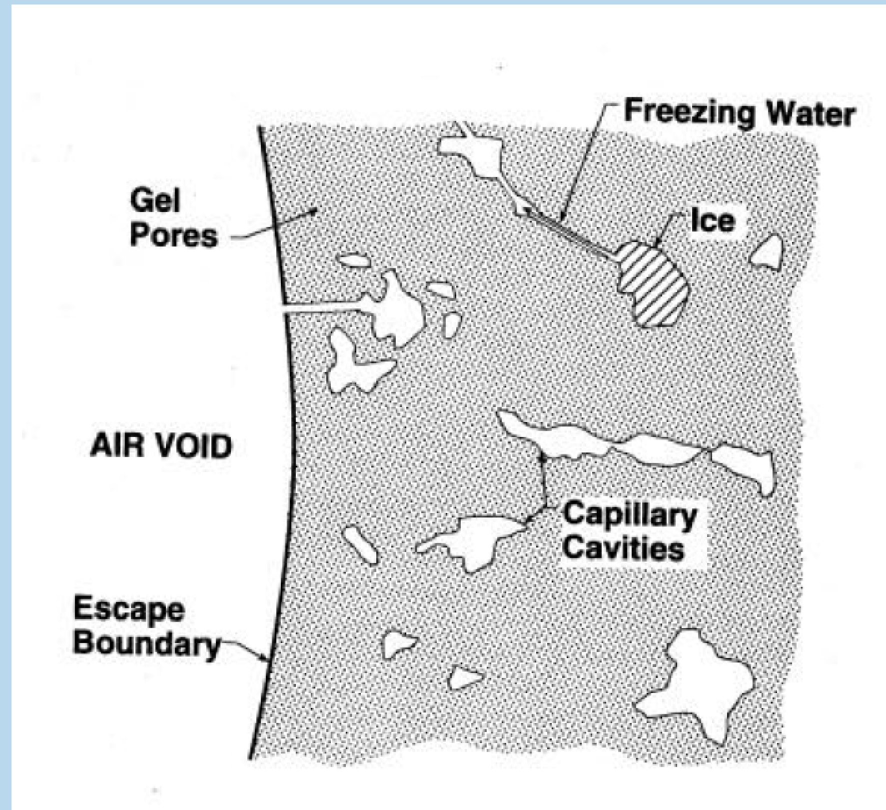


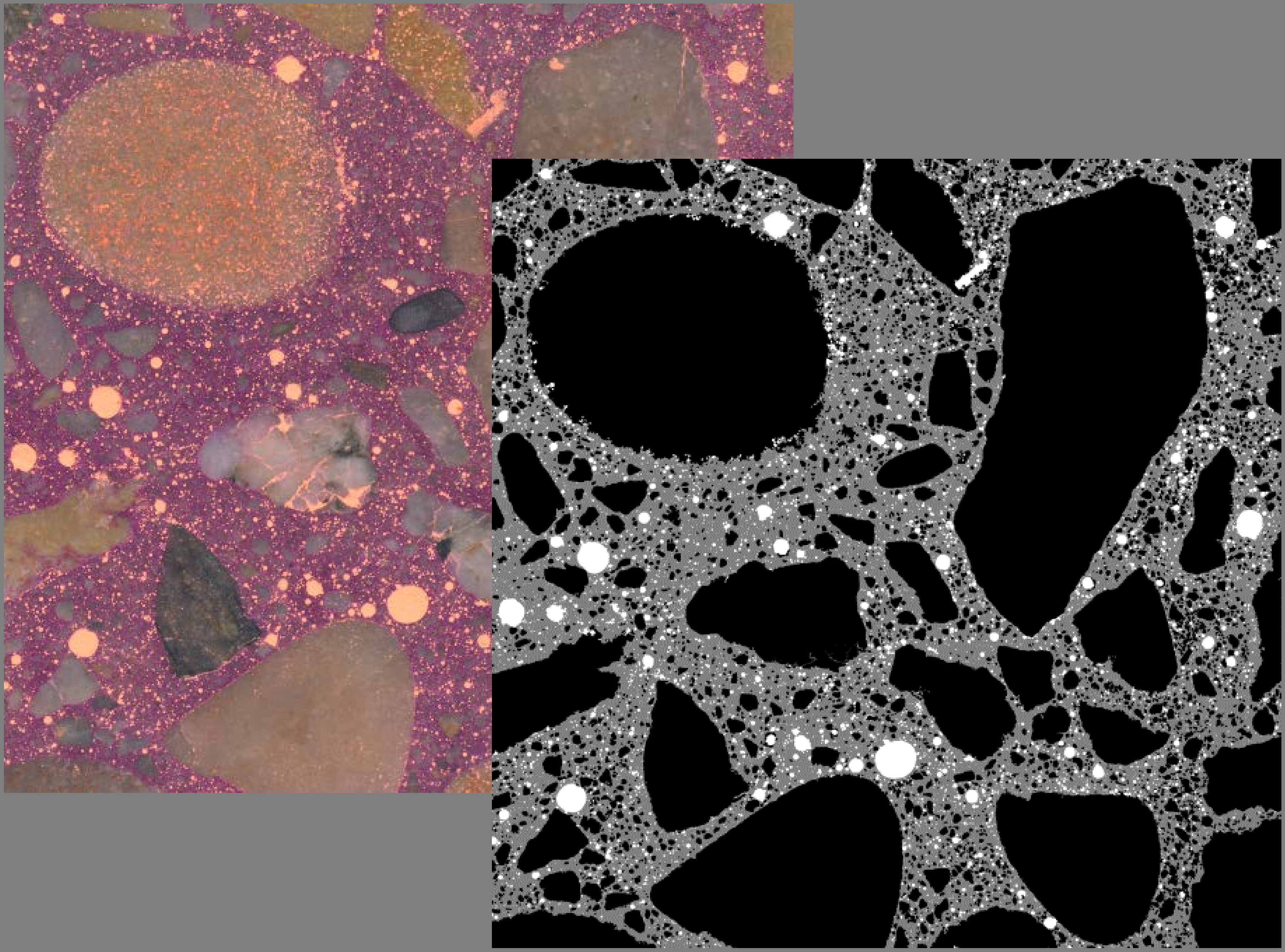
- Damage requires near-saturated conditions
  - Can a crosstie be critically saturated in well draining ballast?
- Damage requires many freeze-thaw cycles
  - Midwest climate is more severe than the arctic!

What about air entrainment?

- Air entraining admixtures







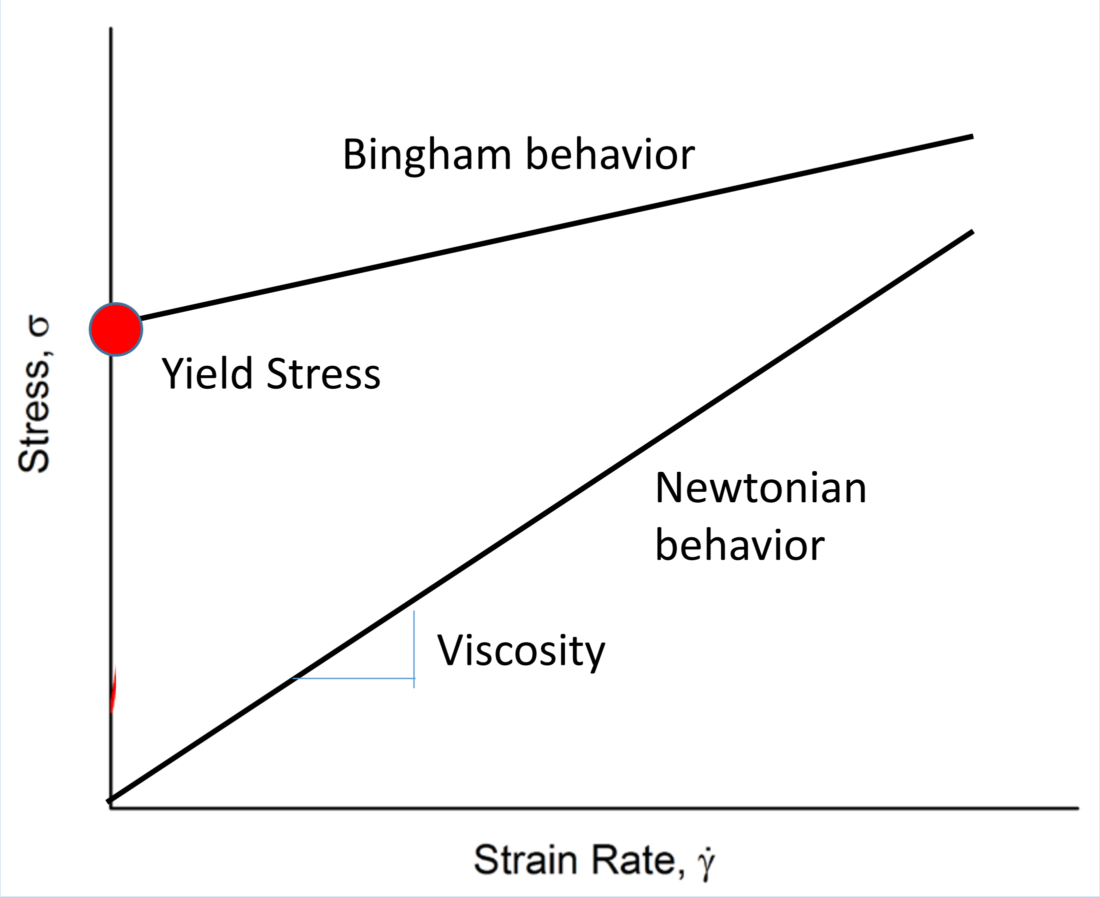
Goals: Improve understanding of…

- How air bubbles respond to vibration.
- Actual conditions of crossties in track.
- How to produce ties with better freeze-thaw resistance.
- New testing methods to assess freeze-thaw performance.

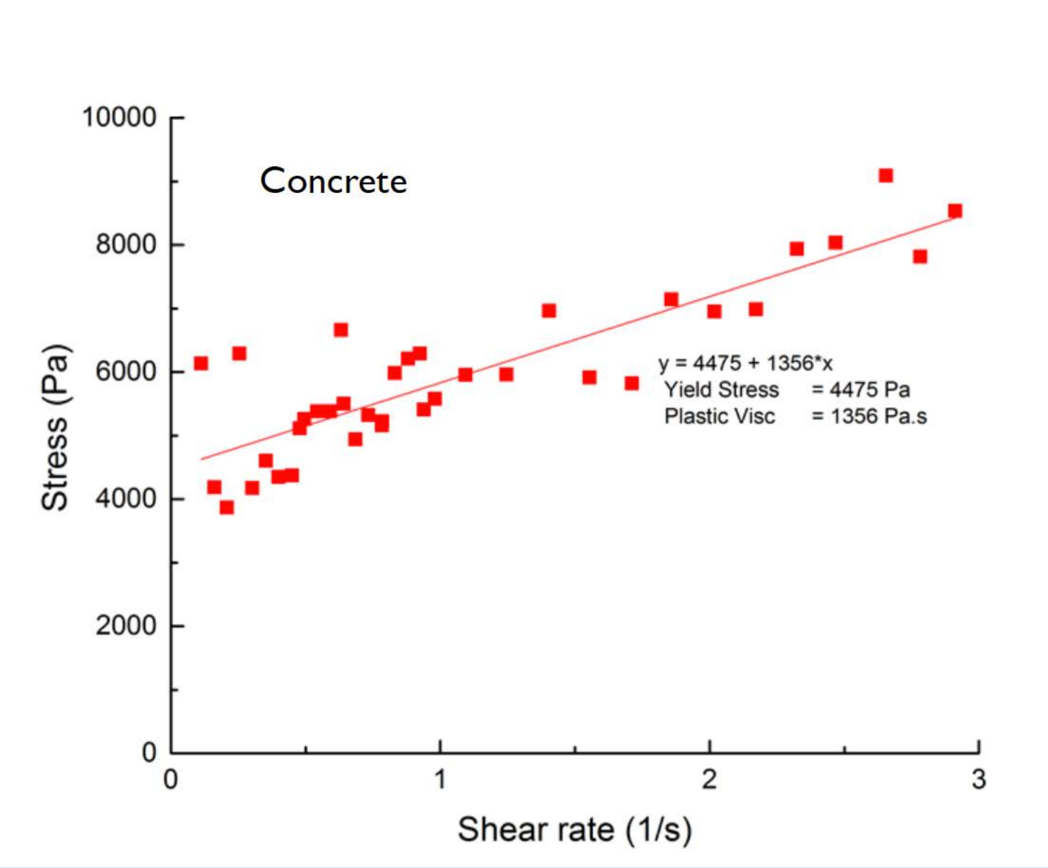
Report contents

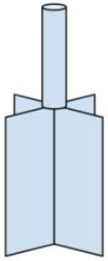
Rheology of Concrete

- Concrete exhibits a yield stress at rest
- Vibration defeats yield stress



Rheology of Concrete





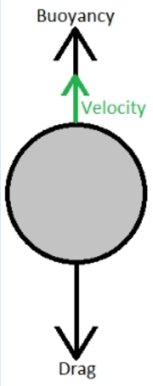
Theory for bubble rise

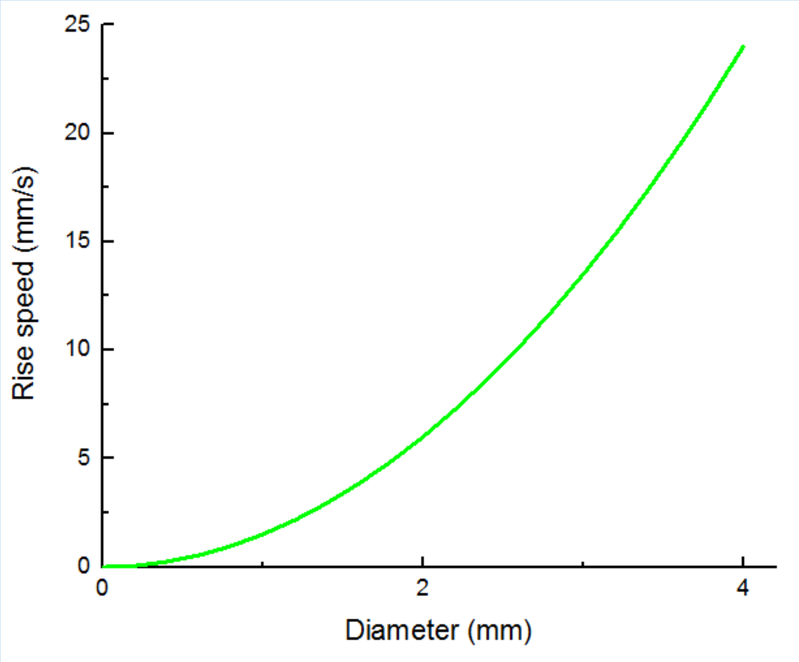
- All bubbles are stable when concrete has yield stress is at rest
- Bubbles rise under buoyant forces in a viscous fluid with no yield stress
- Vibration defeats yield stress
- Terminal velocity of a hard sphere:

Buoyant Force vs. Stokes' Drag Force

$$\frac{1}{6}\pi\Delta\rho g D^3 = 3\pi\mu U D$$

$$U = \frac{1}{12}\frac{\Delta\rho g D^2}{\mu}$$





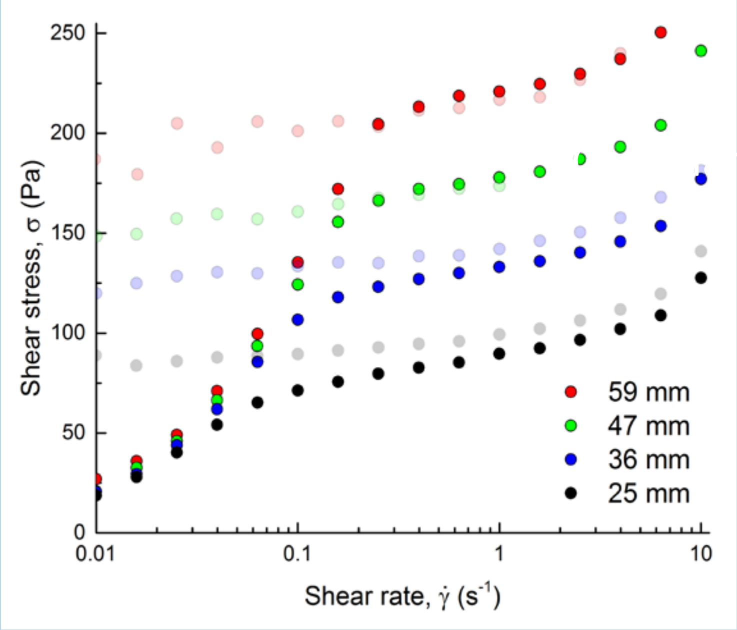
So, very small bubbles are relatively stable

Vibration with air entrainment

- Vibrate fresh materials and measure fresh air content
- Air loss is prominent when aggregates are present

Rheology during vibration

- Simple yield stress fluids (Bingham) with aggregates
- Shows influence of vibration



Dim symbols: No vibration
Solid symbols: Sample is vibrated

Granular Physics

- Roscoe's Equation predicts the viscosity increase when particles are added to a fluid. From paste to concrete:

$$\mu_{mortar} = \mu_{paste}\left(1 - \frac{1}{r}V_{sand}\right)^{0.89m-9.31} \qquad \mu_{conc} = \mu_{mortar}\left(1 - \frac{1}{\tilde{r}}V_{coarse}\right)^{0.57\tilde{m}-3.40}$$

- Vibrated granular constitutive model predictions:

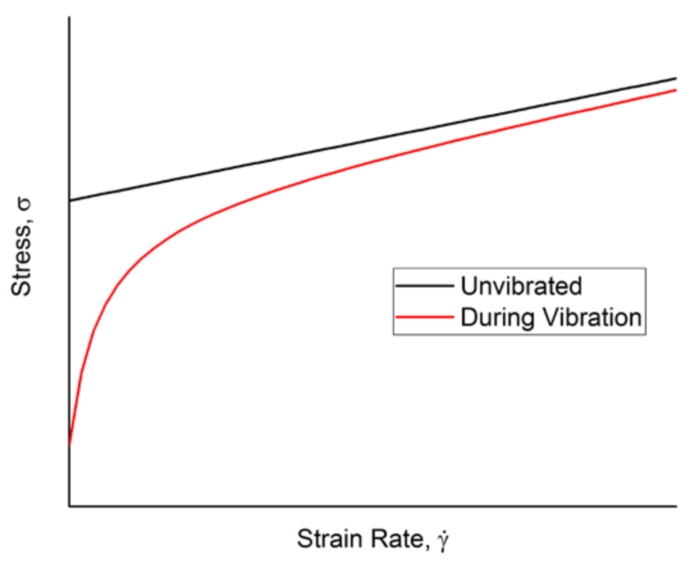
without vibration: $\sigma = G\gamma_c + \eta_H\dot{\gamma}$

with vibration:

High strain rate: $\sigma = G\gamma_c + \eta_H\dot{\gamma}$

} Bingham

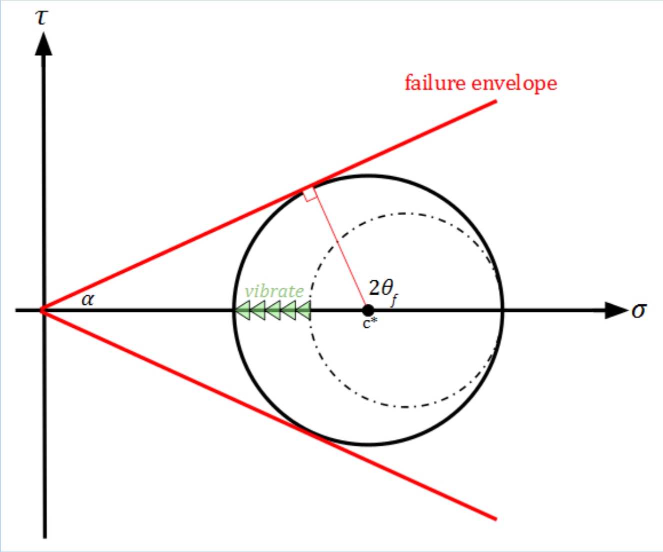
Low strain rate: $\sigma = \left[\frac{G}{f_b} + \eta_H\right]\dot{\gamma}$ Newtonian!

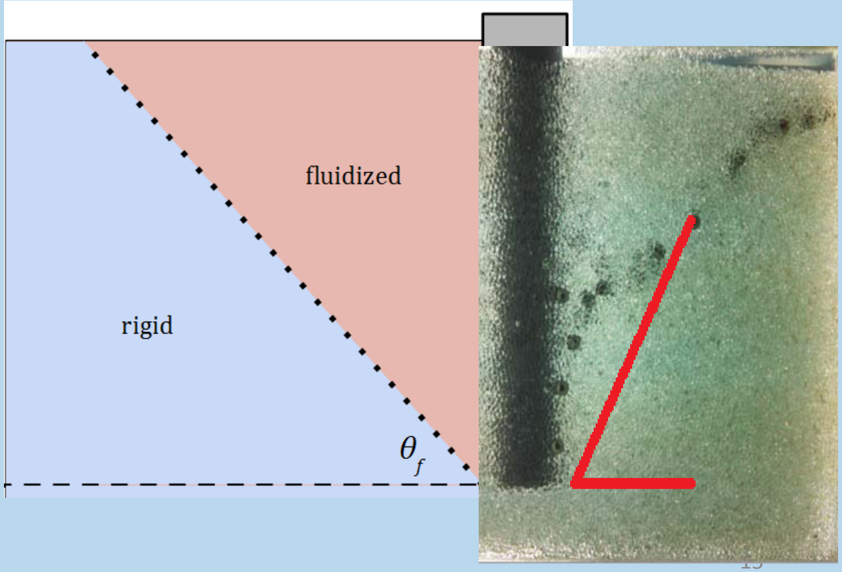


Hanotin, C., et al. "Viscoelasticity of vibrated granular suspensions." *Journal of Rheology* 59.1 (2015): 253-273.

Practical Implication: "Cone of Action"

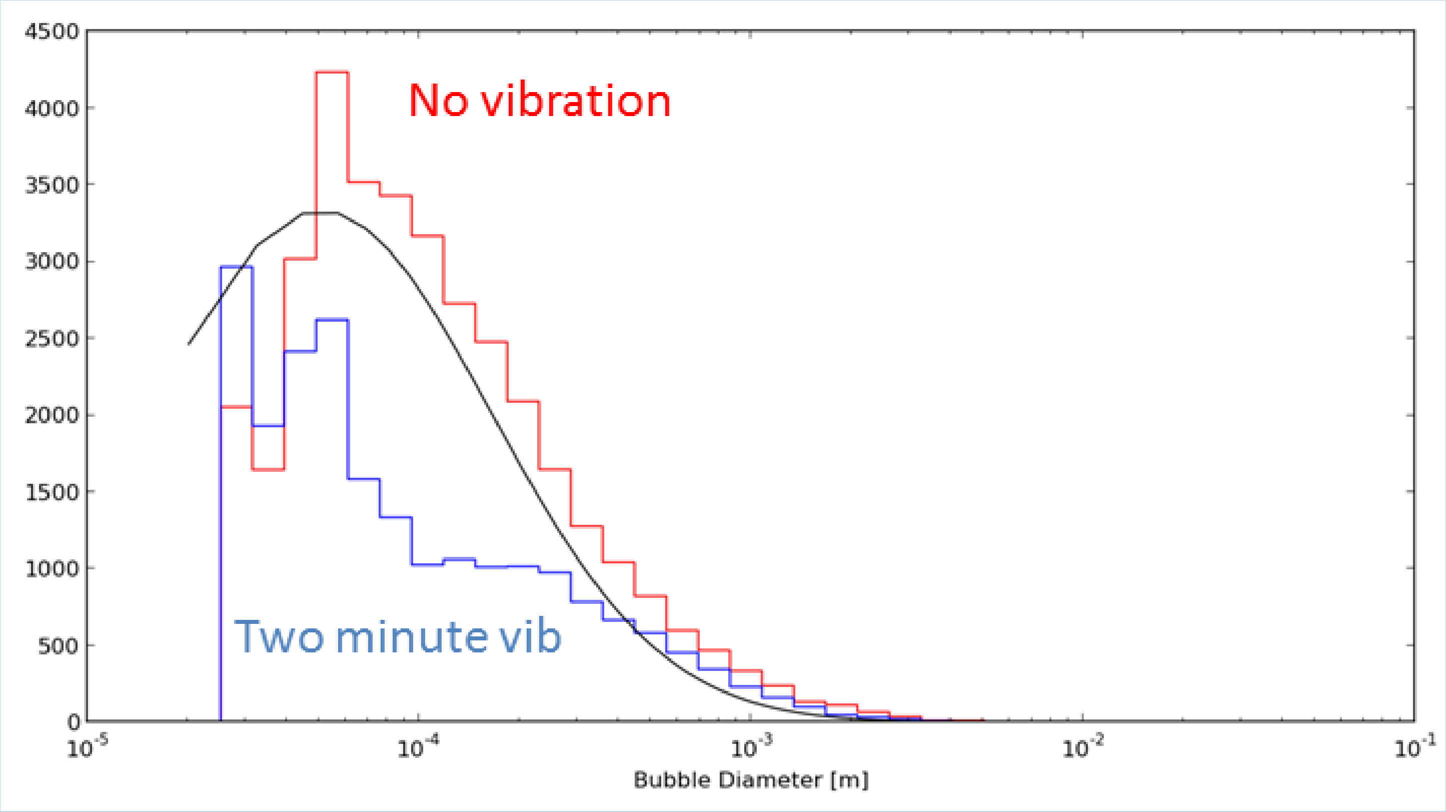
- A consequence of depth-dependent rheology: failure angle
- Theoretical prediction: $$\theta_f = \frac{\pi}{4} + \frac{\alpha}{2}$$ α = angle of repose
- Consequence: effect of vibration is not uniform, leading to inhomogeneous air distribution





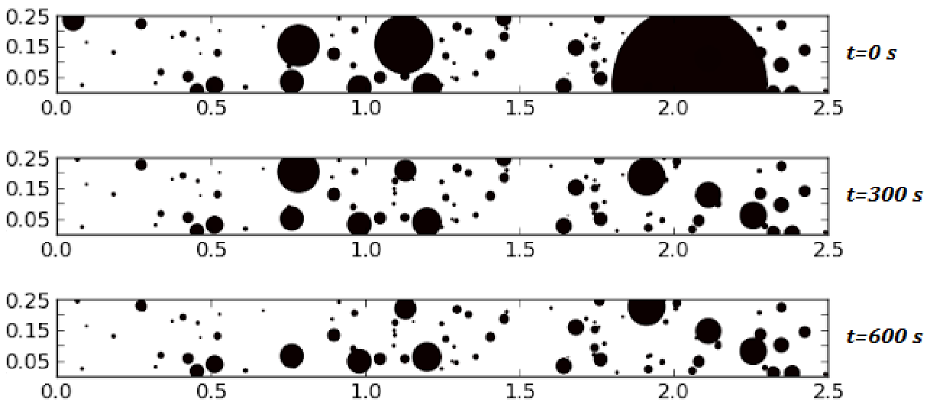
Air Content under Vibration

- Vibrated concrete is quasi-Newtonian
- Model explains experimental observations
- We can predict air bubble size distribution:

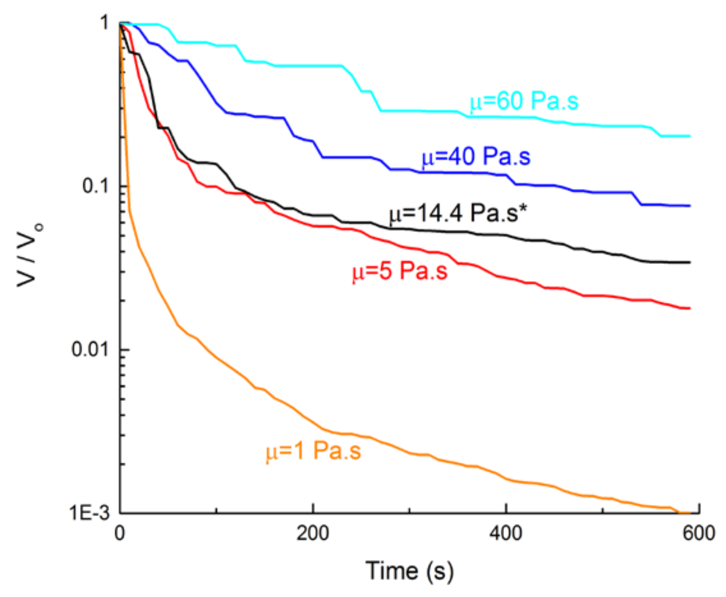


Bubble Rise simulations

- Large bubbles rise and leave quickly
- Small bubbles endure due to D^2 law

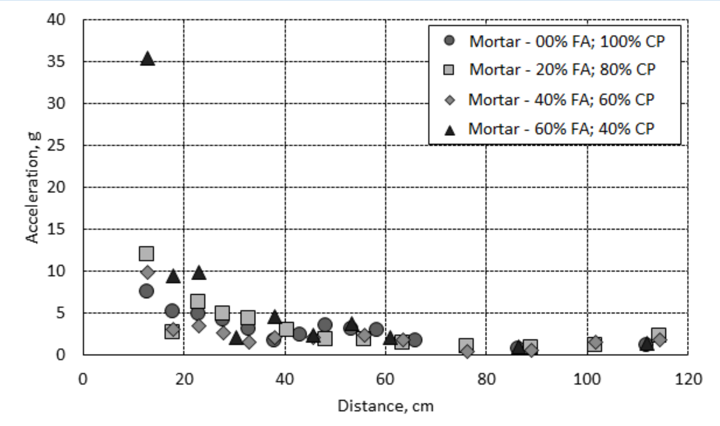


- Model explains how VISCOSITY under VIBRATION controls AIR LOSS
- DURATION of vibration is key
- Suggests: There exists an ideal viscosity for maintaining air distribution
- And we control viscosity via concrete mix design



How is vibration damped?

- Vibration of beam samples
- Accelerometers measure vibration energy



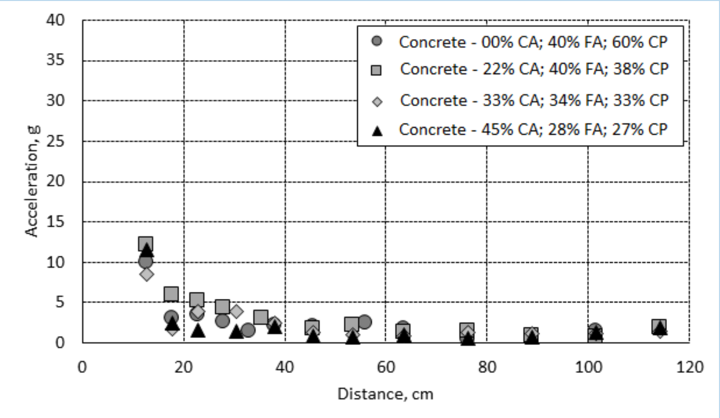
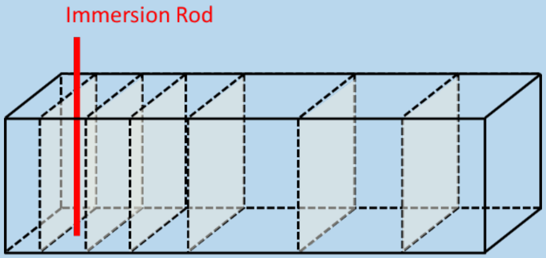


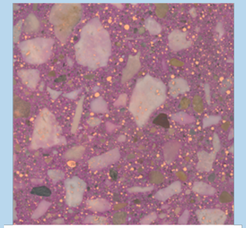
Table 4.5 Bingham parameters of fresh concrete, mortar, and paste with varying aggregate content

Sample Name	Yield Stress (Pa)	Plastic Viscosity (Pa.s)
Mortar – 0% FA; 100% CP	164.2	31.8
Mortar – 20% FA; 80% CP	114.2	49.1
Mortar – 40% FA; 60% CP	90.1	68.3
Mortar – 60% FA; 40% CP	276.6	423.7
Concrete – 00% CA; 40% FA; 60 % CP	207.3	10.5
Concrete – 22% CA; 40% FA; 38 % CP	130.1	22.8
Concrete – 33% CA; 34% FA; 33 % CP	208.5	33.5
Concrete – 45% CA; 28% FA; 27 % CP	467.3	101.1

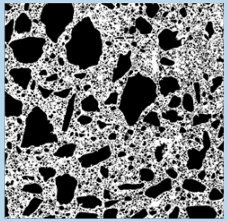
Loss of Air due to Vibration

- Paste shows no air loss
- Concrete has high air loss

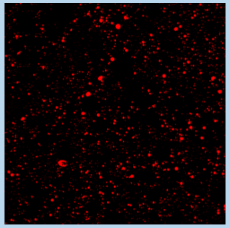




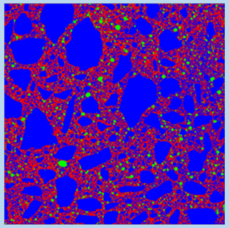
1) Original scan with phenolphthalein stain



2) Identify all paste (white)



3) Identify all air (red)

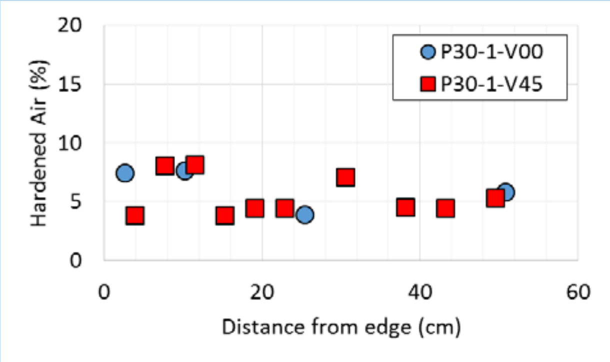


4) Reconstruct all 3 phases

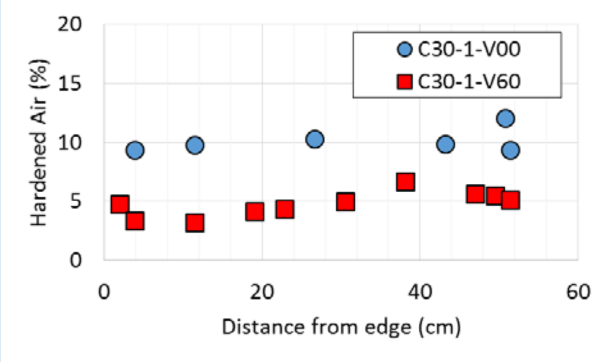
Blue dot – no vibration

Red square – after vibration

Paste samples



Concrete samples



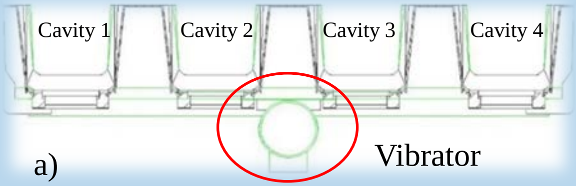
Plant Testing

- Three plants visits. (1 month stays for 2 plants; 4 days for 3rd plant)
- Testing in these plants included:
  - Slump
  - Fresh and hardened air content
  - Unit weight
  - Temperature
  - Rheology
  - Vibration

Plants Vibration

- Three plants visits. (1 month stays for 2 plants; 4 days for 3rd plant)
- Testing in these plants included rheology and vibration

Plant A
vibration rods attached to the casting machine.

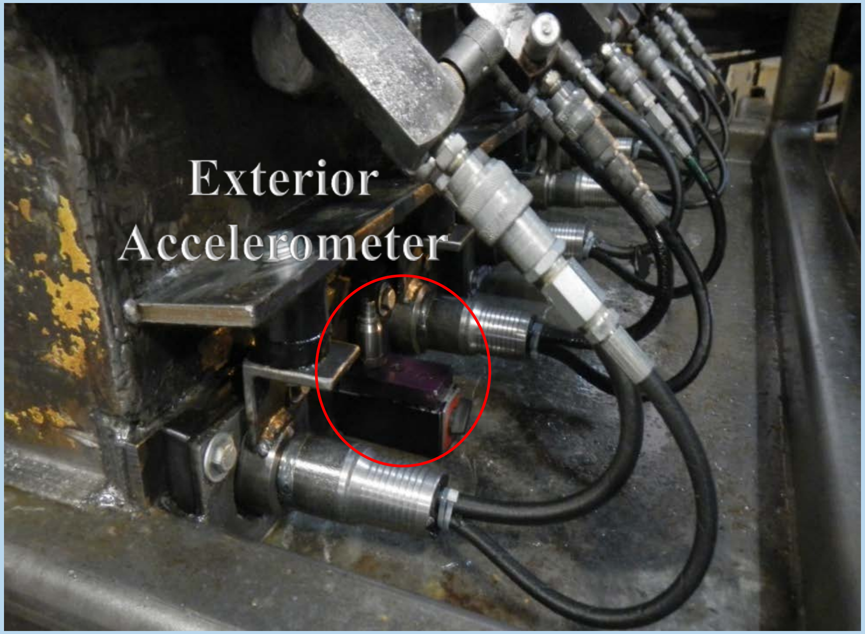


Plant B
vibrator under forms

Plant C
used handheld vibrator

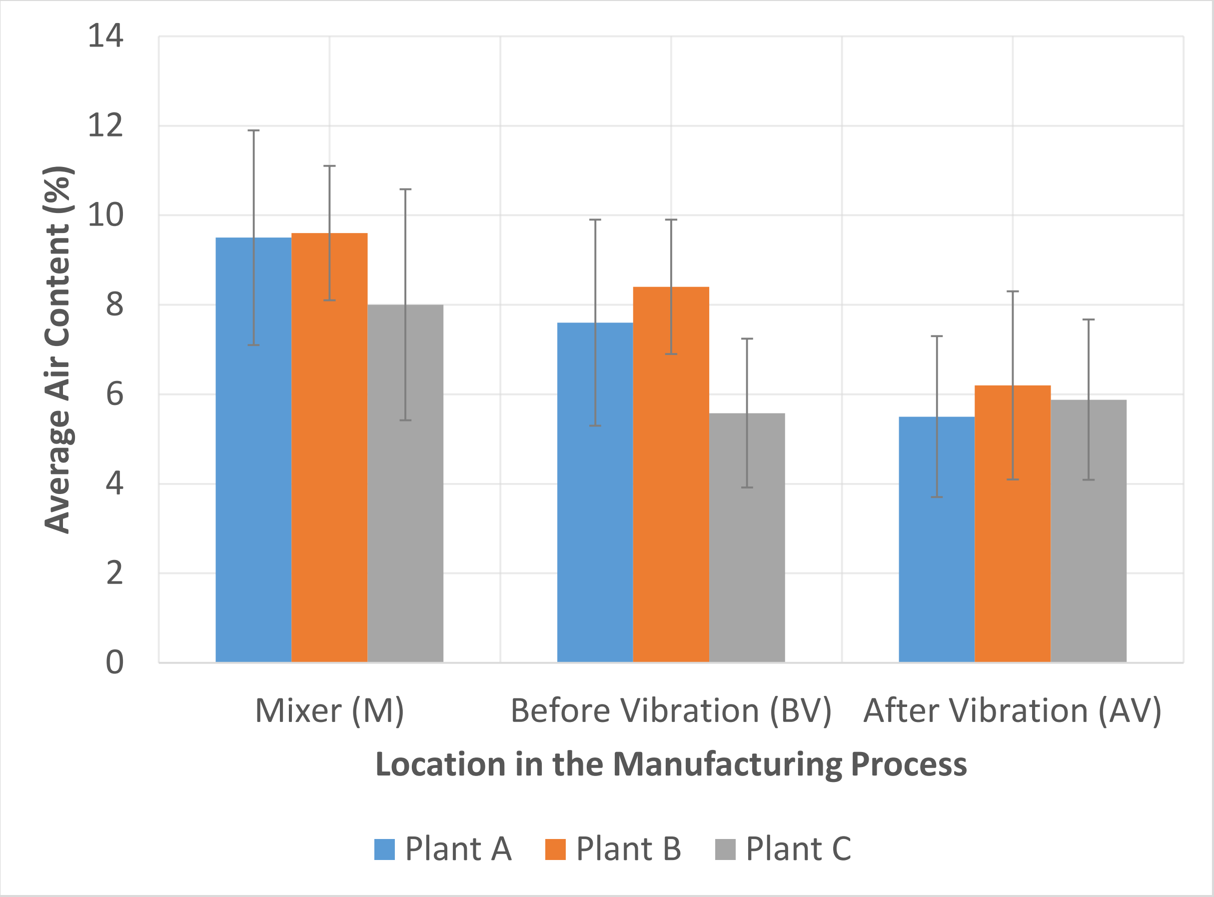
Plants Vibration

- The accelerometers used to measure vibrations.



Confirmed:
Handling & vibration drives air from concrete

- Average hardened air content:



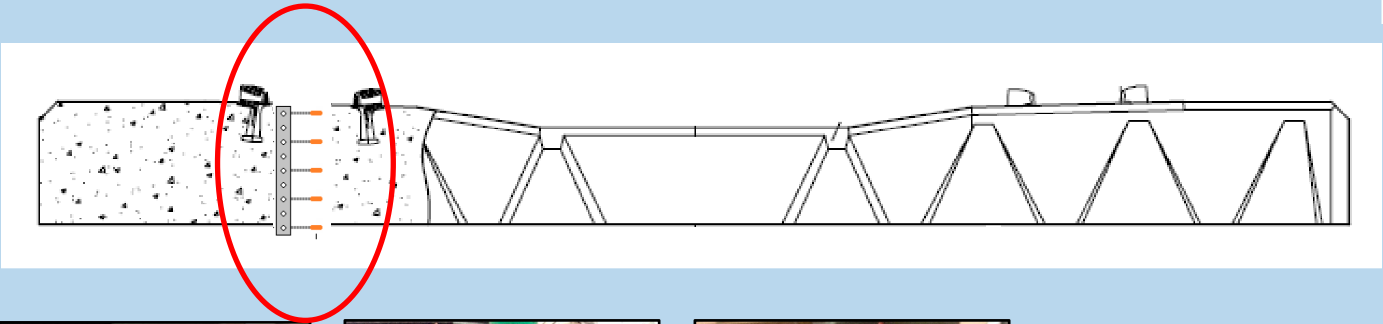
What are field conditions of concrete crossties?

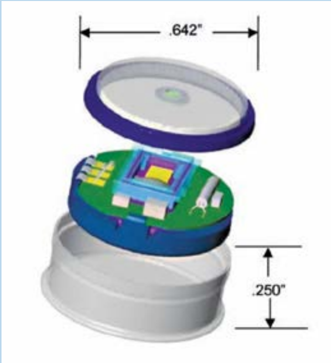
Field testing

- ***Locations:***
  - ***Lytton, British Columbia***
  - ***Rantoul, IL***
- ***Parameters***
  - ***Temperature***
  - ***Internal relative humidity***

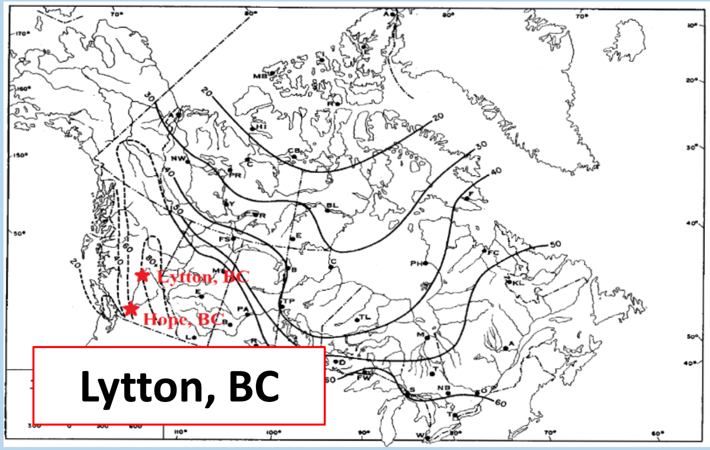
Instrumentation

- Install **<u>humidity & temperature</u>** sensors inside crosstie at rail seat area during manufacturing

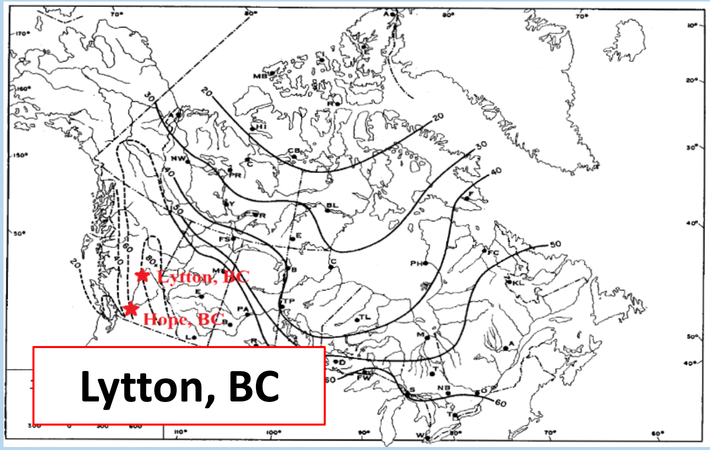


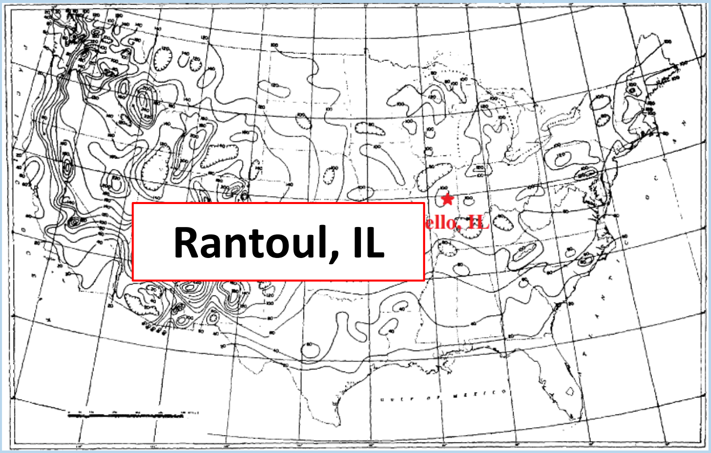


Installing instrumented crossties

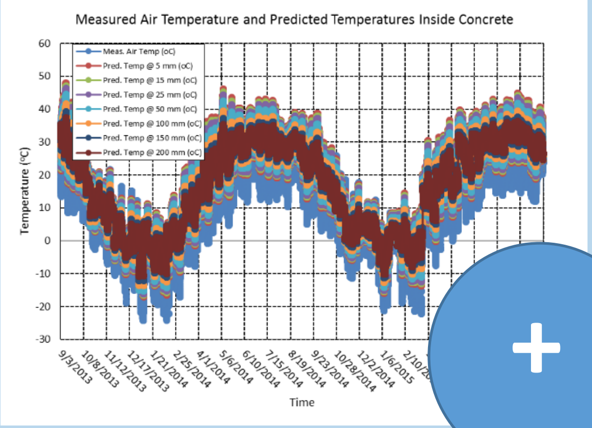


Installing instrumented crossties

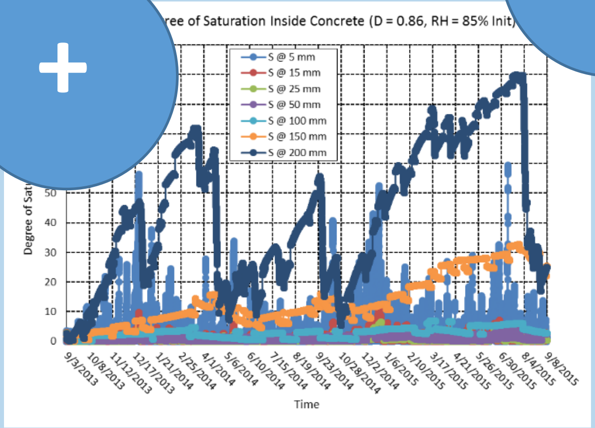




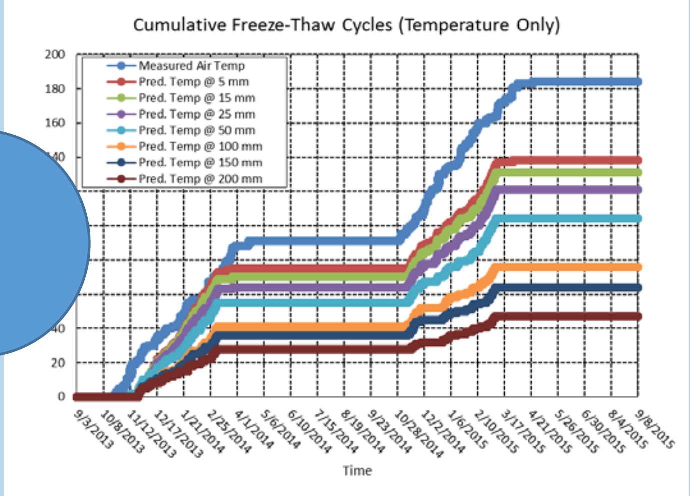
Model to predict temp/RH history on basis of local weather station data



+

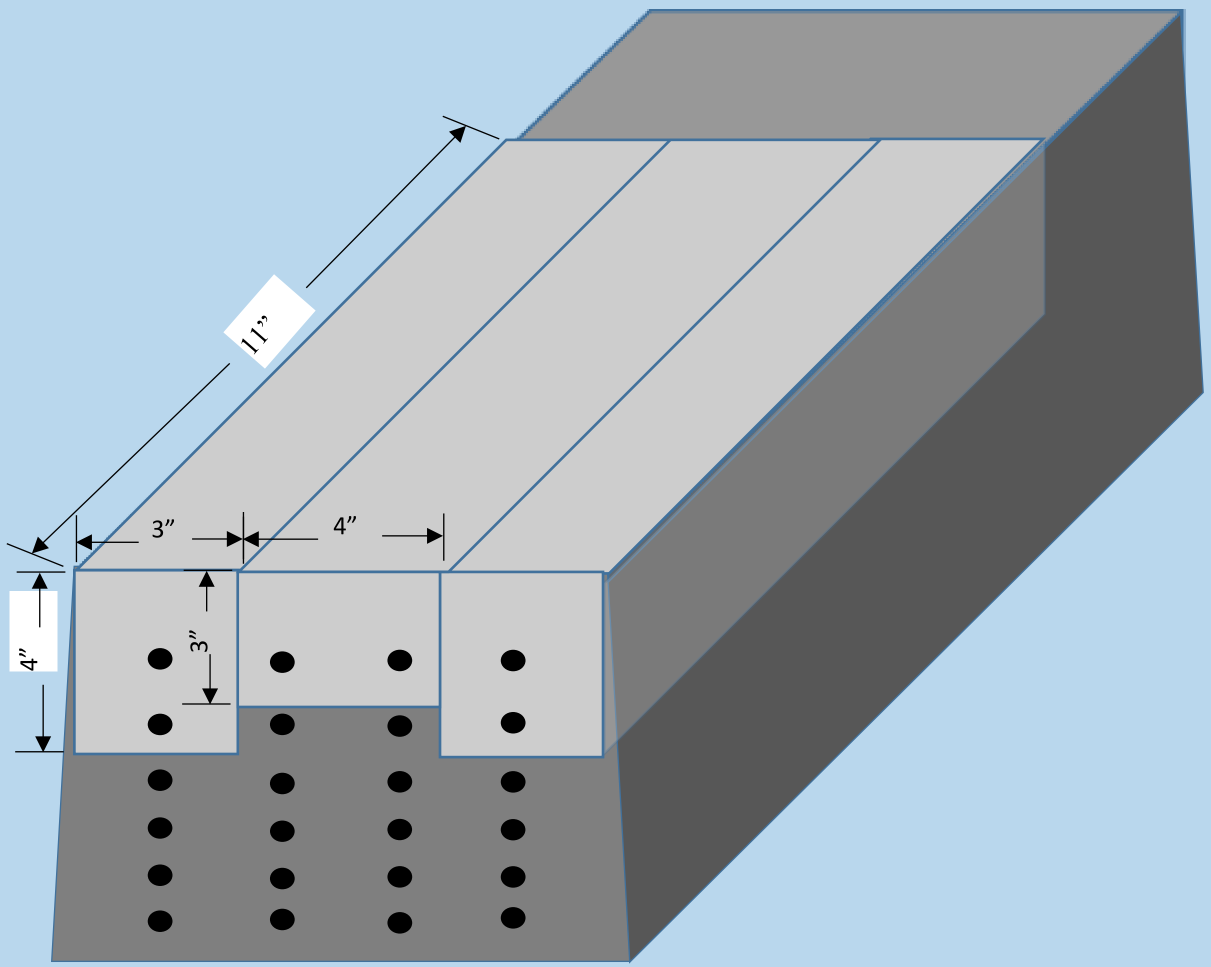


=



- Key findings:
  - Concrete is persistently high moisture in winter
  - Concrete temps DO experience significant cycling
  - Concrete FT cycles ~ 0.7X ambient weather
  - Crossties received 70 FT cycles/yr

How should we test crossties? How should samples be taken?



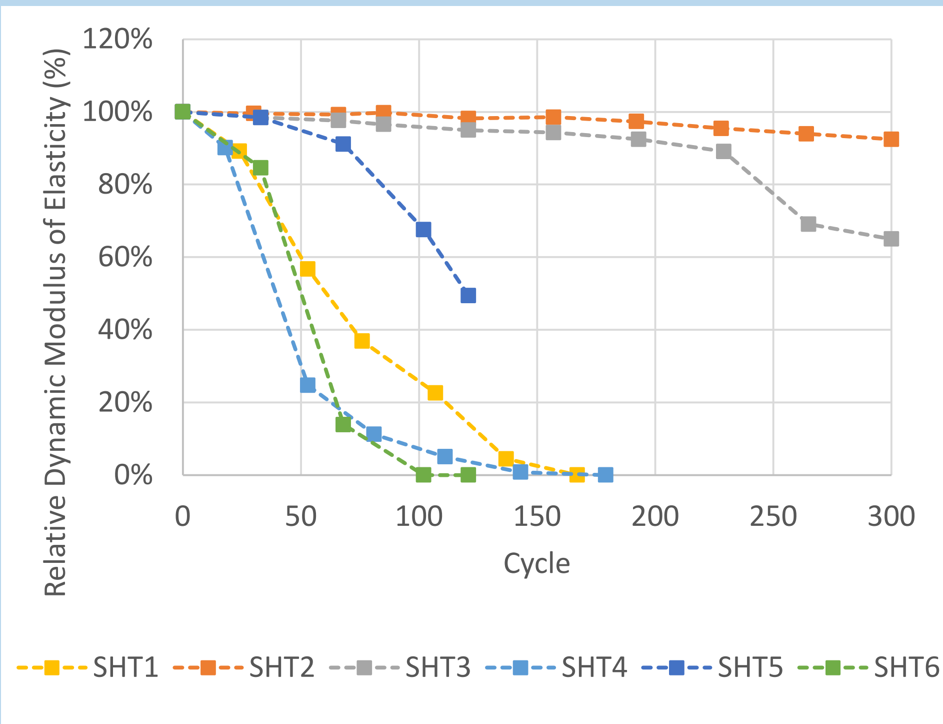
Extensive FT testing

Full ties
FT tests
Half ties
Excised prisms
Cast prisms

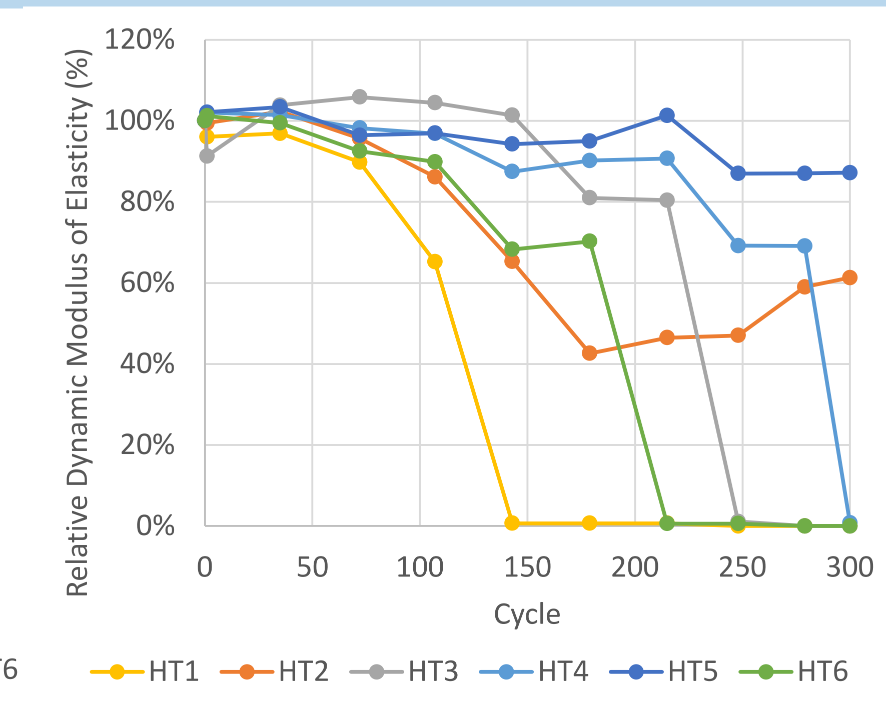
Sawcut ties perform poorly

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

Saw-cut samples



Half-tie samples



Summary

- We developed new models for vibration and air
- We documented true field conditions of crossties
- We proposed new guidelines for making durable concrete
- We proposed new approaches for production specification language
- We recommended quality control approaches

- Better understanding of distress mechanisms leads us to improve product performance!