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The Effects of Aggregates Containing Iron-Sulfides on Concrete

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NESMEA

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Pyrrhotite

- Highly reactive mineral in the presence of water and oxygen
- Rapid oxidation of pyrrhotite (and other iron sulfides) can cause spontaneous combustion in coal mines
- Pyrrhotite oxidation is one of big contributors to acid mine drainage

What is the Concern?

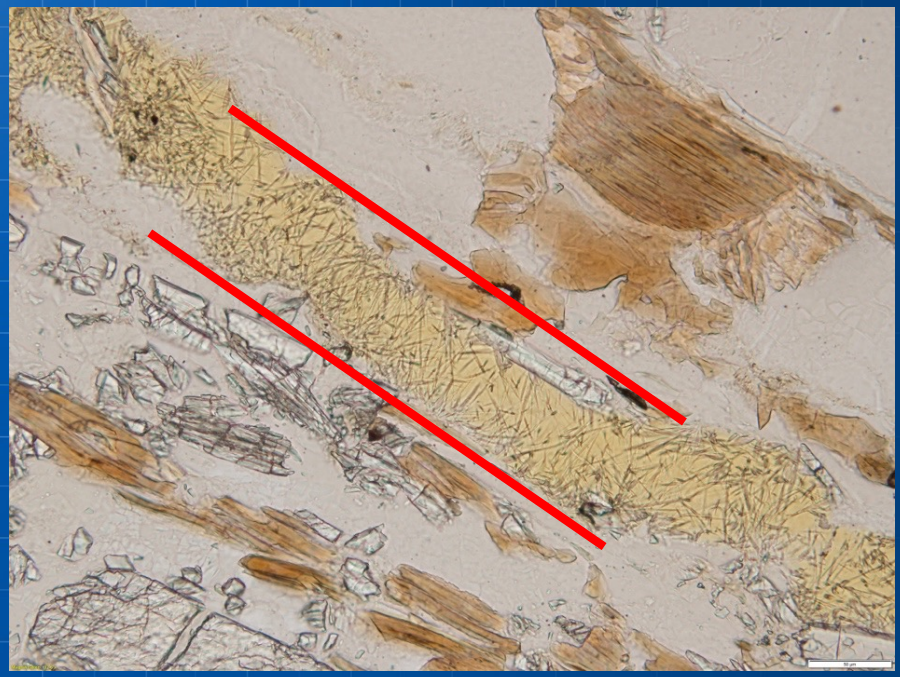
Pyrrhotite Oxidation Causes the Concrete to Expand

Pyrrhotite – What is Affected

- Residential foundations
- Commercial buildings
- Municipal buildings
- To date, no US transportation structures have been documented with pyrrhotite damage
- Damage looks a lot like ASR, but mechanism is different

Iron-Sulfide Mineral Oxidation

- When iron-sulfides oxidize, they release sulfuric acid as well as form expandable minerals such as ettringite in the voids (needle like structures in image between red lines)



Iron-Sulfide Minerals

- Pyrite
- Pyrrhotite (slightly magnetic)
- Marcasite
- Troilite
- Pentandite
- Chalcopyrite (copper iron-sulfide)

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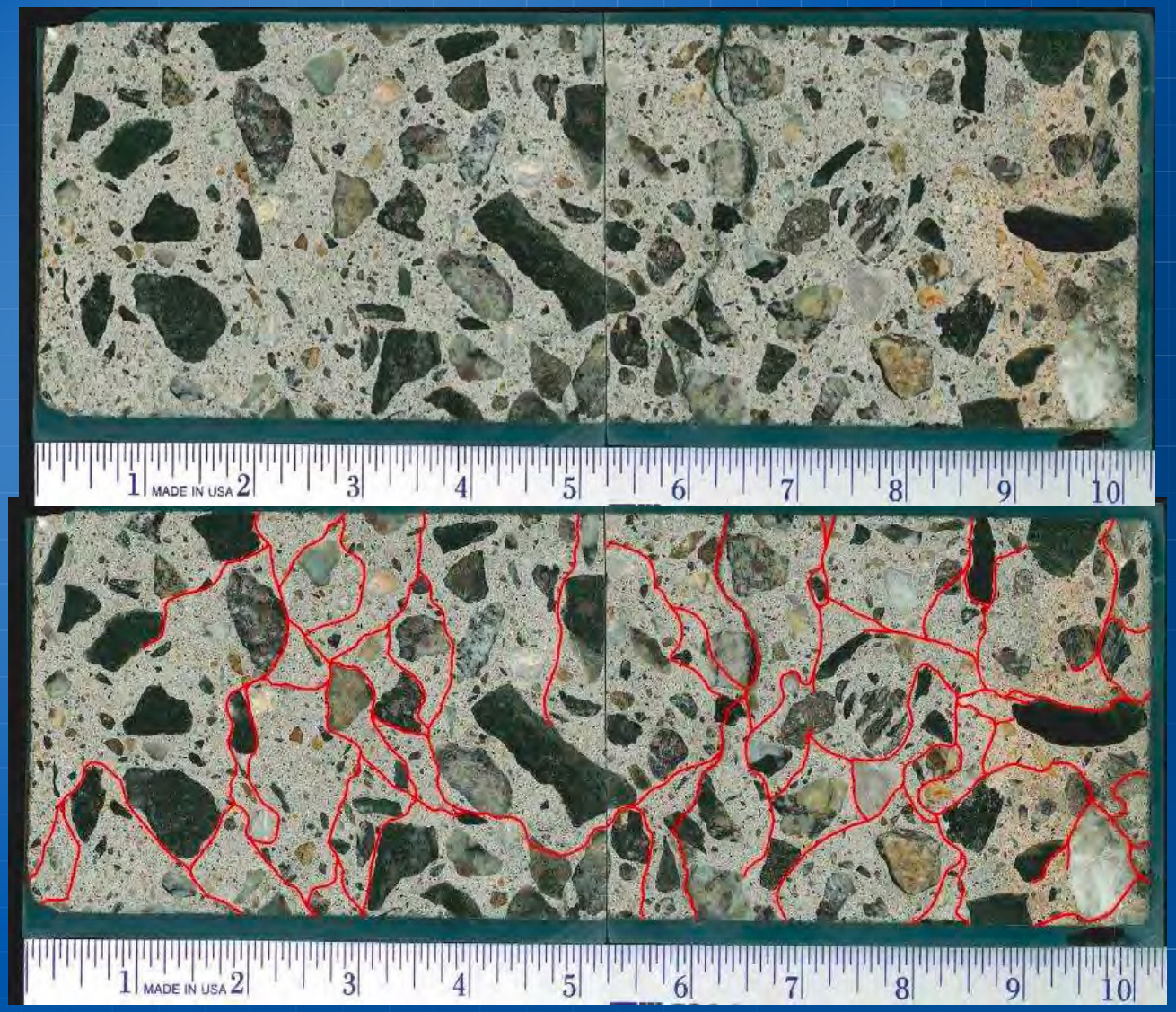
Cracking Mapped in Petrographic Analysis of Core Sample



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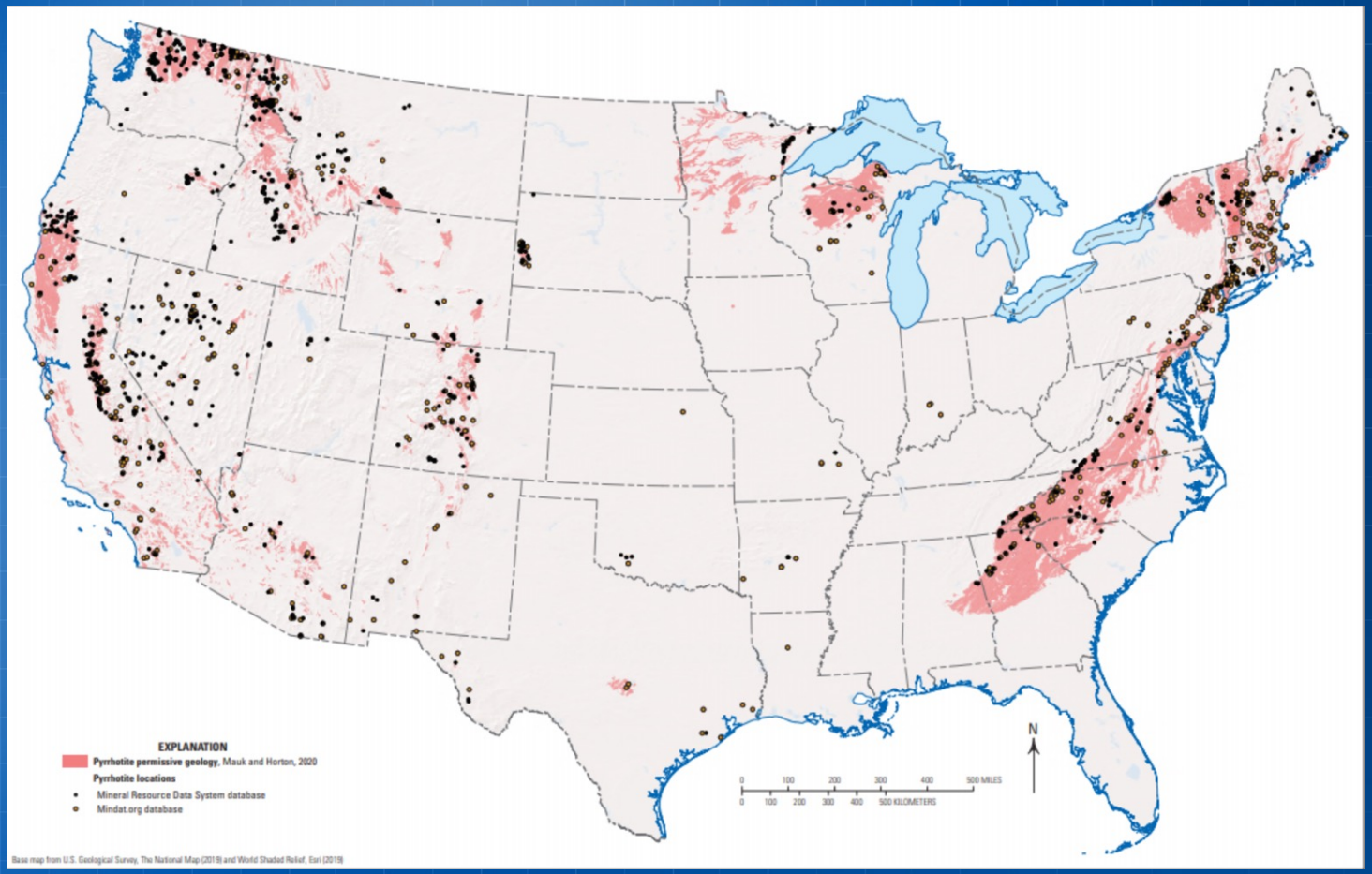
Pyrrhotite Damage Timeframe

- It takes time to for the damage to show up – this what makes it so challenging
  - Used in an estimated 30,000+ foundations
- Connecticut and Massachusetts, 20-30 years to show damage
- Canada, 5-7 years to see damage
- Not a photogenic disaster

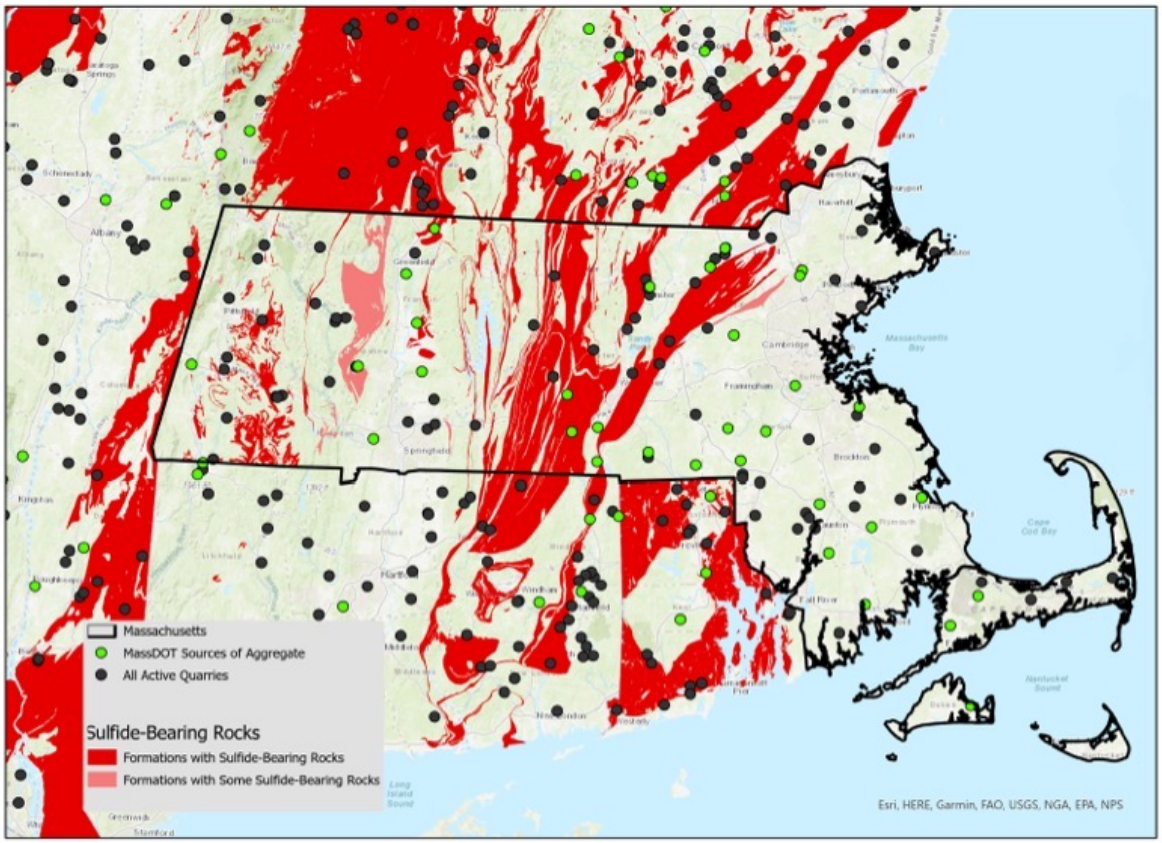
How Prevalent are Iron-Sulfide Issues?

- Connecticut and Massachusetts are experiencing problems
- Three Rivers area, north of Montreal
- Ireland (originally believed it was mica)
- Cornwall, England area (Mundic Blocks – concrete blocks made from spoils of tin mine)
- US Navy
- Many more

USGS Map of Potential Pyrrhotite Locations

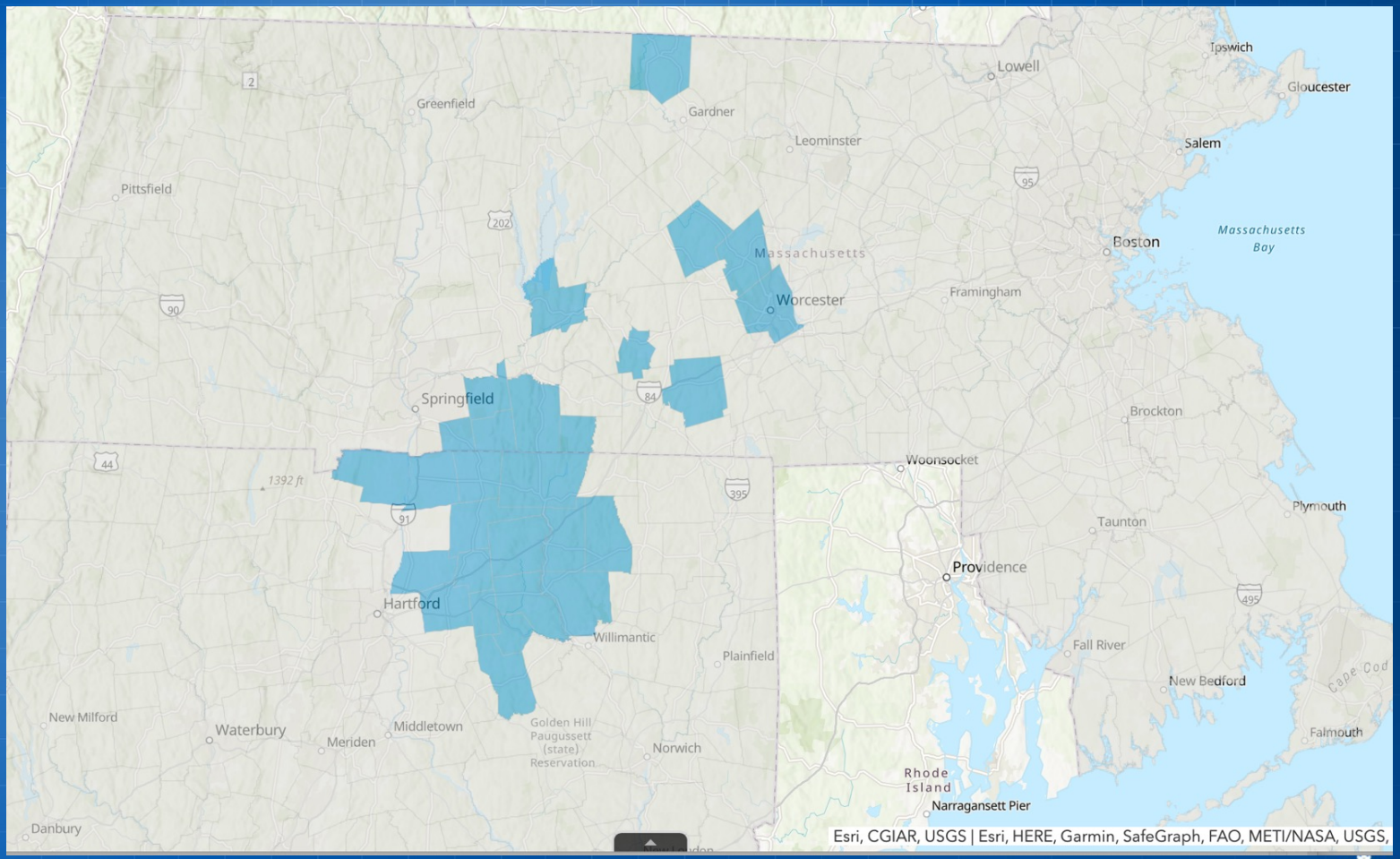


Pyrrhotite Bearing Bed Rock in Southern New England



Courtesy of MassDOT

Locations With Pyrrhotite Positive UConn Tests of Foundations



Hypothesis as to Why is this Problem Becoming More Common?

- As natural sand and gravel deposits are being used up – the shift to manufactured aggregates (coarse and fine) is becoming more common
- Natural sand and gravel has had thousands of years to oxidize the iron-sulfides and they are no longer present

Current Problem

- Currently there is no established safe level of pyrrhotite in concrete
- Homeowners selling their homes are stuck if the foundation comes back positive for pyrrhotite – even with no visible damage
- CT has a program to help homeowners with failing foundations
  - Does not cover all of the costs and disruption
- MA is working on a program

Scale of the Problem

- The scale of the problem is unknown
- Many property owners don't want to know if they have the problem (plausible deniability)
- Knowing you have the problem destroys property value and selling of the property very difficult

Remediation Options

- Full foundation replacement is currently the only recognized means to remedy the problem
- Reinforcing the existing foundation has not worked
- Can we find ways to prevent foundations with pyrrhotite, but no visible damage, be saved?

Research Funding

- UConn provided seed funding of more than $300k to develop a test method
- UConn has received approximately $7 million from the National Institute of Standards and Technology to develop a risk assessment framework
  - Goal is to establish risk of failure based on pyrrhotite content of foundations

NIST Research Project

- Conducting sampling and testing of homeowners foundations at no cost
  - Not limited to residential properties
- Using elemental analyzer to determine total sulfur
- WD-XRF to differentiate sulfates from sulfides
- Assume excess sulfur comes from aggregates

NIST Research Continued

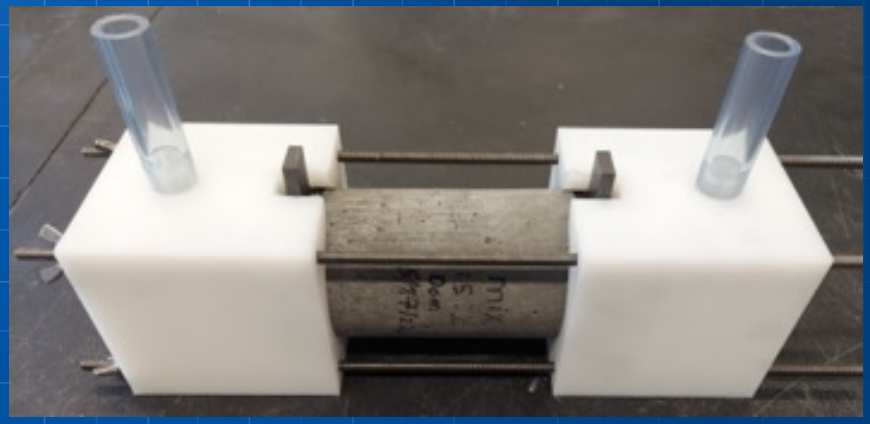
- Working on developing an accelerated test method to establish likelihood of concrete failure
- Conducting laboratory testing to understand rate of oxidation
- Expansion testing
- Laboratory synthesis of pyrrhotite

Have to Think of Problem Differently

- Compressive strength plays a huge role in most concrete
- Don't have any idea what the original strength of the concrete was
- Areas with cracking – compressive strength is essentially zero

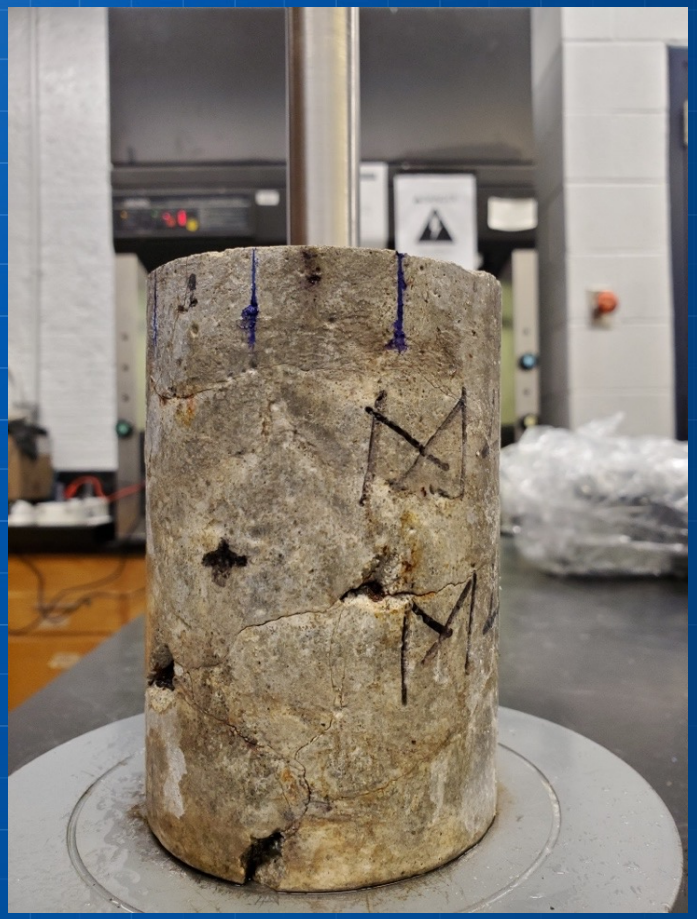
Looking at Accelerated Testing

- Looking at accelerated testing of concrete cored from houses showing distress
- Trying to accelerate the oxidation of pyrrhotite present but not alter concrete

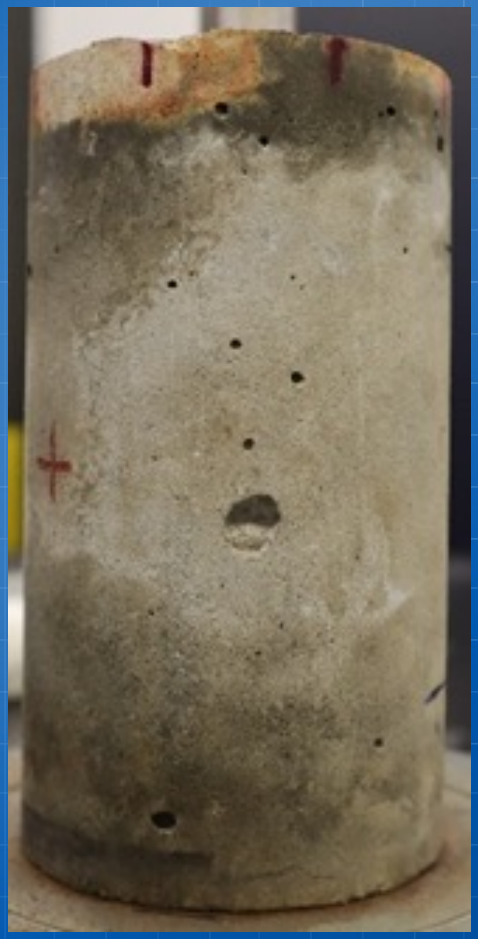


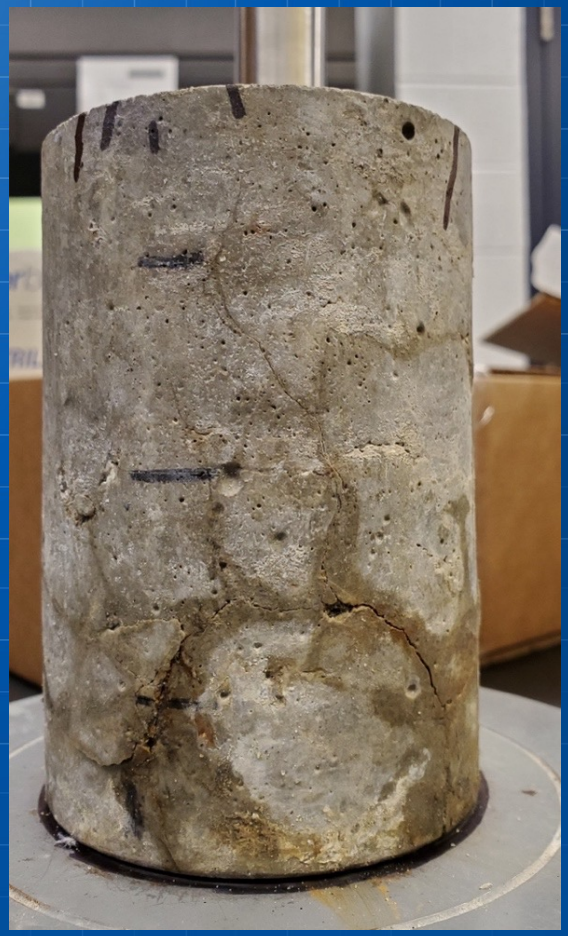
Accelerated Testing

- Uses electrolytes at both ends of the cylinder, passing electrical current through the specimen
- So far, results have been very promising, seems to only affect concrete containing pyrrhotite



35 Days of Current Applied Same Mix – One on Right Spiked with Pyrrhotite





Laboratory Fabricated Cylinders

What Has Connecticut Done?

- Committed over $100 million to provide assistance to homeowners for foundation replacements
  - Does not cover all of the costs for replacement
- $12 surcharge on homeowner's insurance policies to help fund replacements
- The source of the iron-sulfide aggregate has agreed to stop selling aggregate for concrete production

Connecticut Quarry Requirements

- Enacted requirements for quarries to test their aggregates being used for concrete
- Less than 0.1% total sulfur – no issues
- 0.1-1.0% total sulfur – further examination required
- More than 1.0% total sulfur – can not be used for concrete
- Administered through the state Geologist

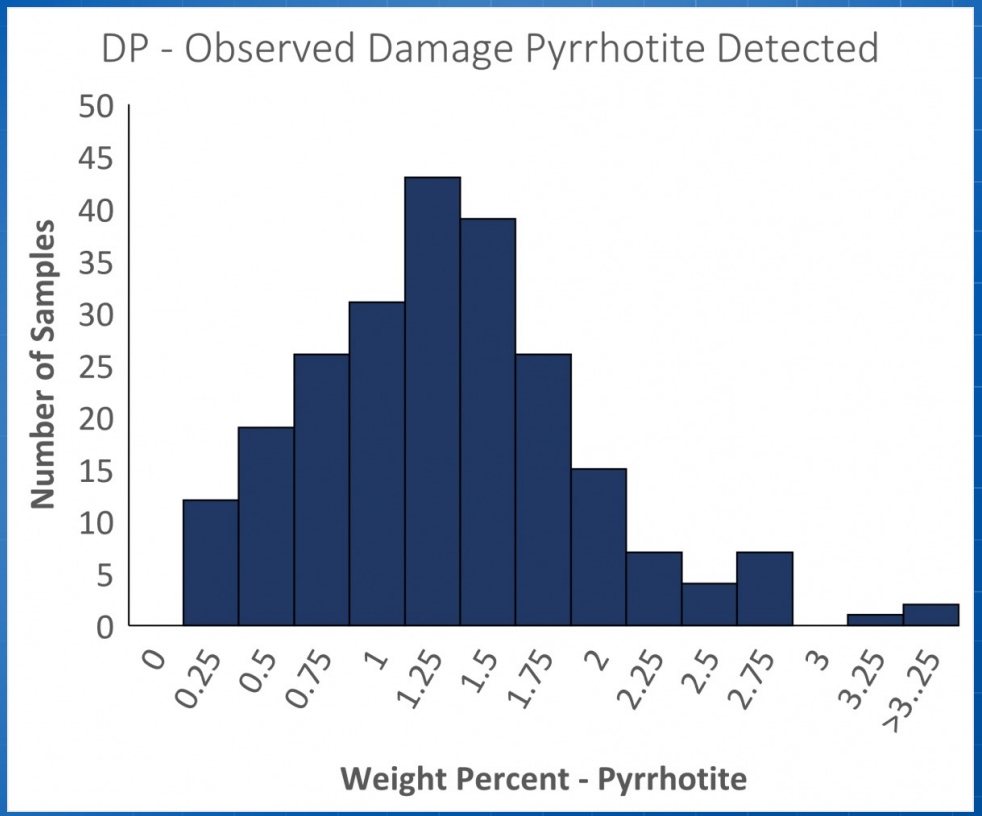
Takeaways

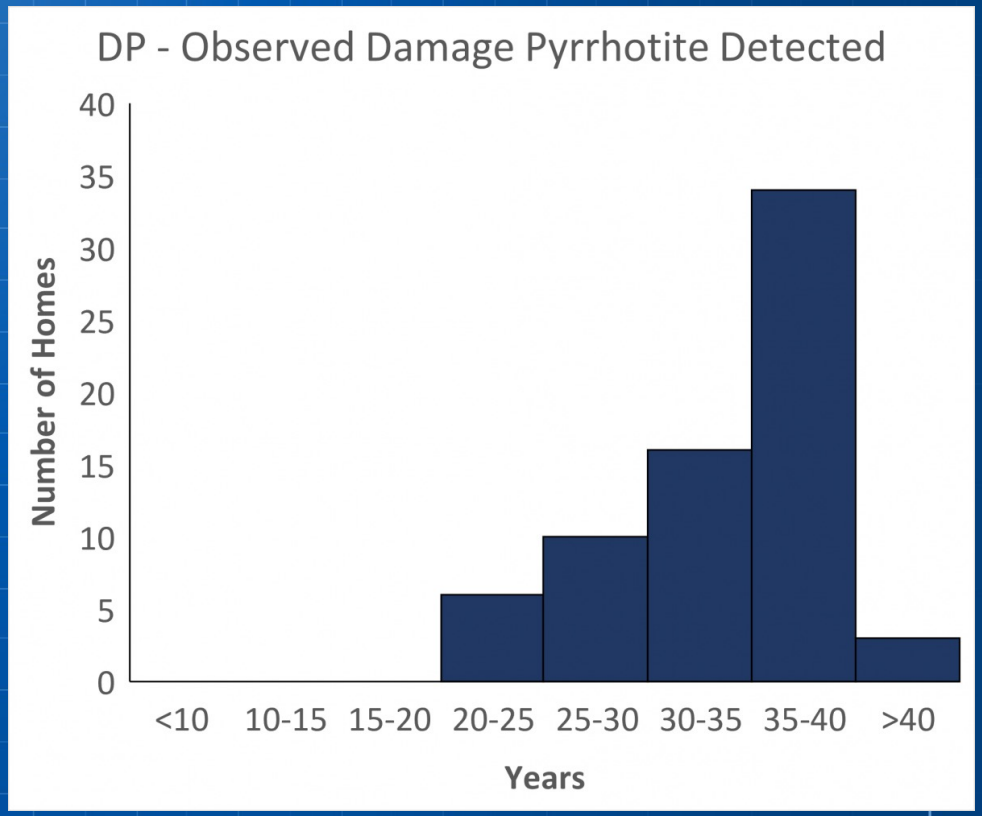
- Transportation agencies are generally the largest purchasers of concrete in their states
- Consider enacting specifications to limit sulfur contents of aggregates for concrete
- When problems do occur – this becomes a political issue and science takes a backseat
- People will push (unique) ideas that are in the own best interest without technical merit
- This is problem is much different than what we are used to dealing with

Where Do We Go From Here

- It took many years (1983 – 2015 in CT) to get here, it will take time to solve
- We have several years of funding to build this risk assessment
- Better to avoid the problem up-front
- Can't pretend this is not a problem
  - There were chances to limit the problem in CT, but many opportunities were missed

Two Observations





On a Personal Note

- I owned a house that was affected by this problem
- Lost approximately $250k on the sale of our house
- This problem is life altering for those affected

Questions

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