PRE-XVII CONGRESO ARGENTINO de Vialidad y Tránsito

8º EXPOVIAL ARGENTINA

3 AL 6 DE NOVIEMBRE 2014

HOTEL PANAMERICANO - Buenos Aires, Argentina

Mixture Design for Durability

Dr. Peter Taylor

National Concrete Pavement Technology Center

Tech Center

IOWA STATE UNIVERSITY

Institute for Transportation

X CONGRESO INTERNACIONAL ITS

X SIMPOSIO DEL ASFALTO

II SEMINARIO INTERNACIONAL DE PAVIMENTOS DE HORMIGÓN

www.congresodevialidad.org.ar

An Emphasis on Durability

Ability of the concrete to survive the environment to which it is exposed

- What can go wrong?
- How do we prevent it?
- What's new?

But I have been doing it this way for 30 years…

How Does Concrete Fail?

- Mechanical overload
- Internal expansion
- Cold
- External attack

For each one…

- Mechanism
- Prevention
- Testing

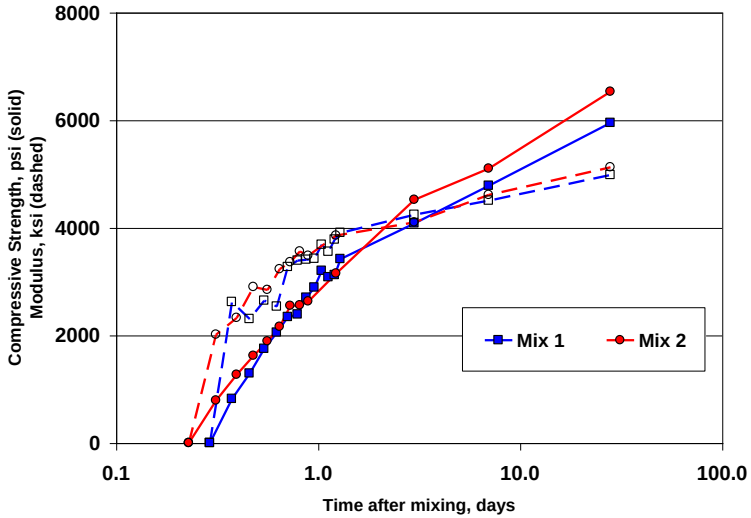
How Does Concrete Fail

- Overload / Fatigue. Not enough:
  - Strength
  - Thickness
  - Support
  - Drainage

- Early age Cracking

Strength

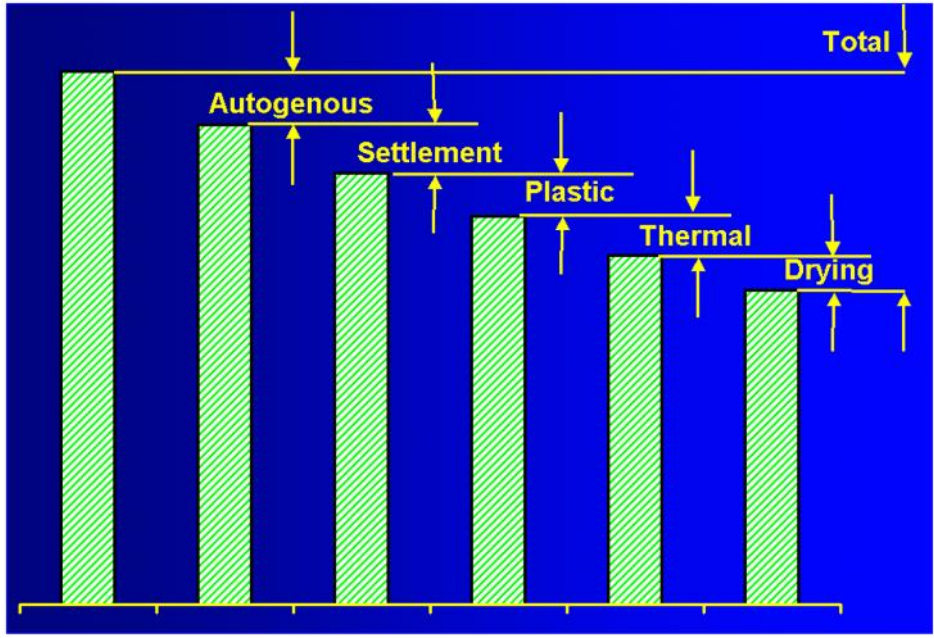
- Strong enough
  - Controlled by w/cm
- Stiffness?
  - High stiffness = small deflections
  - Low stiffness = high cracking risk



Cracking

- Concrete always cracks
  - Control size and spacing

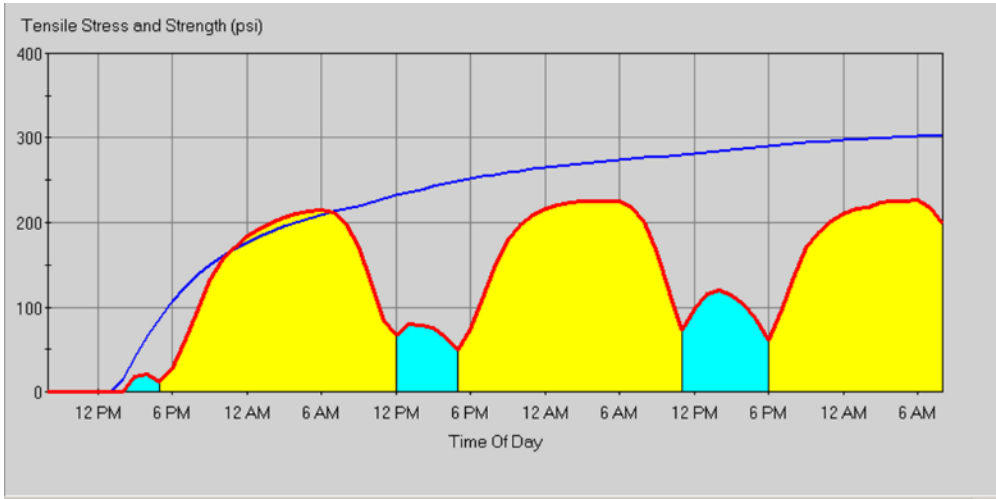
- Concrete moves over time:
  - Chemical changes
  - Moisture changes
  - Temperature changes
  - Loading



Cracking

- Stress depends on
  - Contraction
  - Stiffness
  - Creep
  - Load

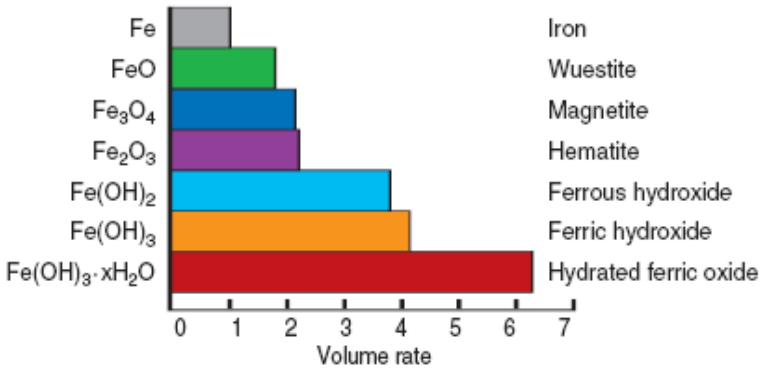
- Cracking depends on
  - Stress
  - Strength



How Does Concrete Fail

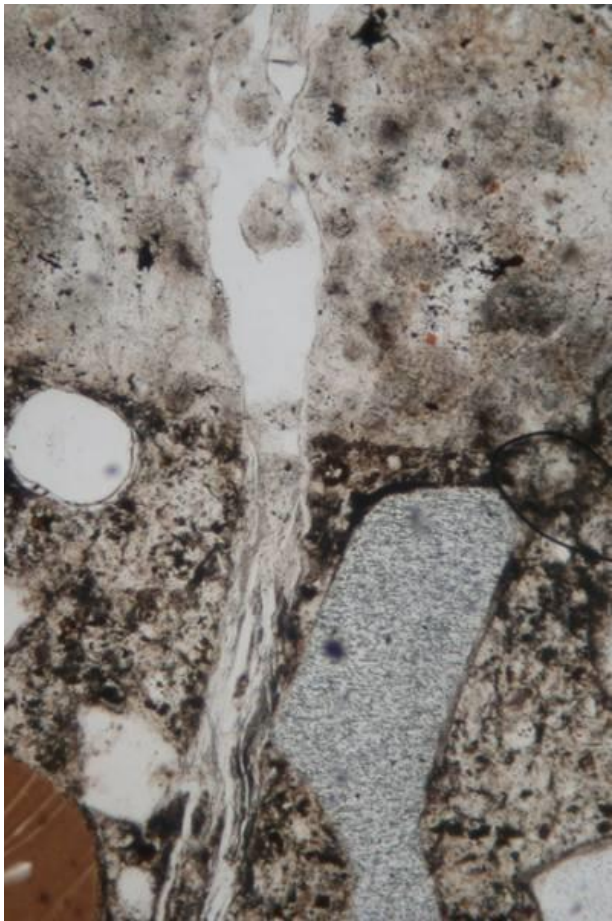
- Internal Expansion
  - AAR
  - D-Cracking
  - Steel Corrosion

  - Choose aggregates
  - Reduce permeability
  - Use SCMs



Alkali Aggregate Reaction

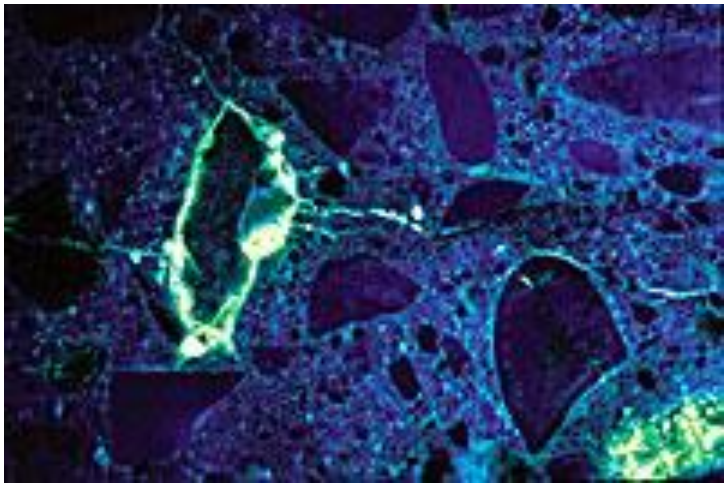
- Chemical reaction with
  - Reactive aggregates
  - Alkali hydroxides
  - Water



Alkali Aggregate Reaction

- Prevention
  - SCM's at the right dosage
  - Amount of SCM depends on Calcium content
  - Lithium compounds
  - Limit alkalis

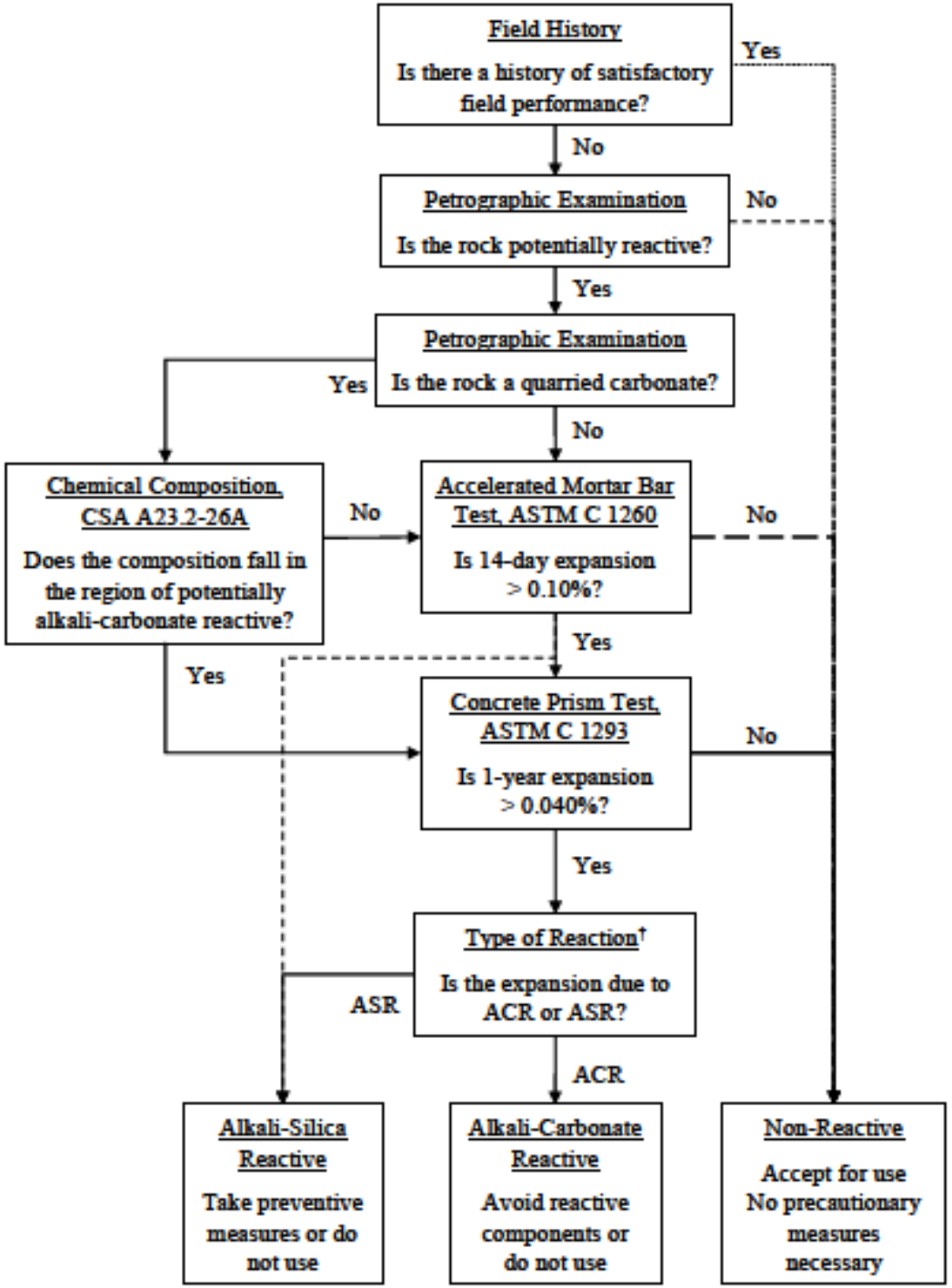
- Testing / Specification
  - AASHTO PP65



Alkali Aggregate Reaction

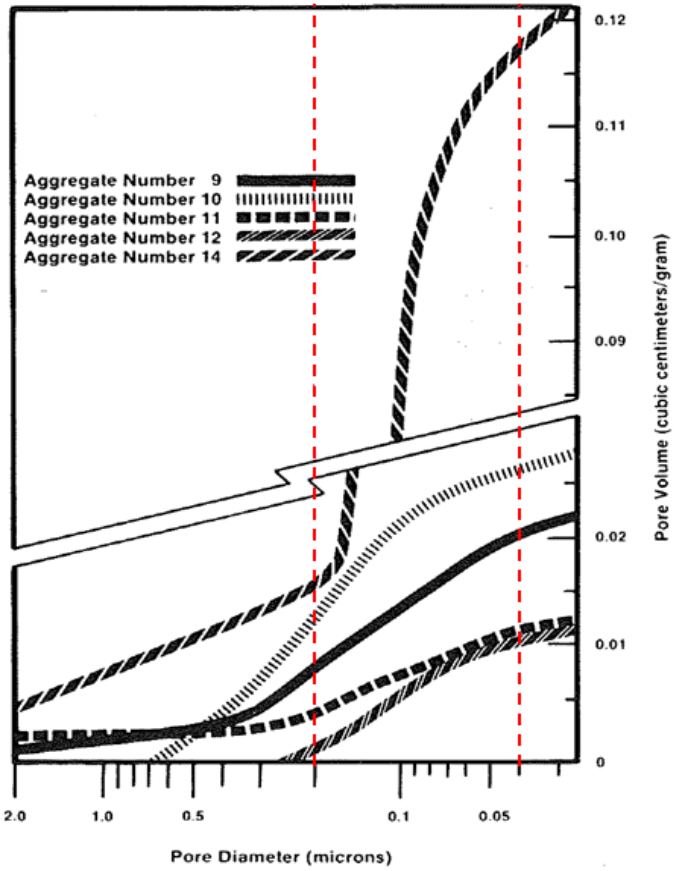
Report on Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction

U.S.Department of Transportation
Federal Highway Administration



D-Cracking

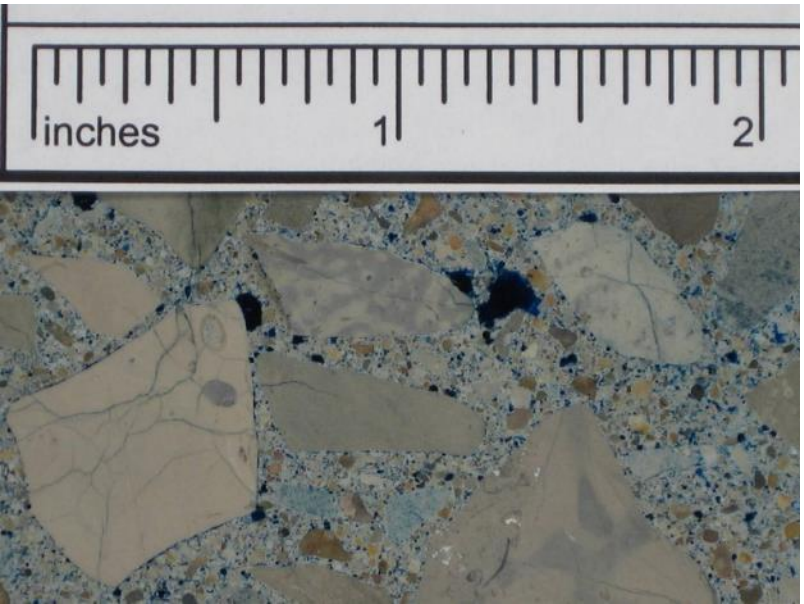
- Mechanism
  - Some limestone aggregates
  - Cold weather
  - Pores absorb water and hold it
  - Some chemical effects



Marks and Dubberke 1982

D-Cracking

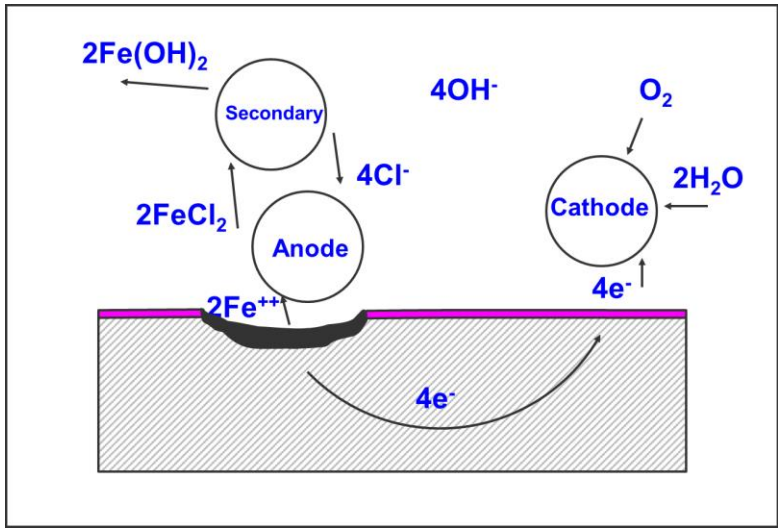
- Prevention
  - Limit risky aggregate use
  - Smaller sizes buy time
- Testing
  - Local practice



Corrosion

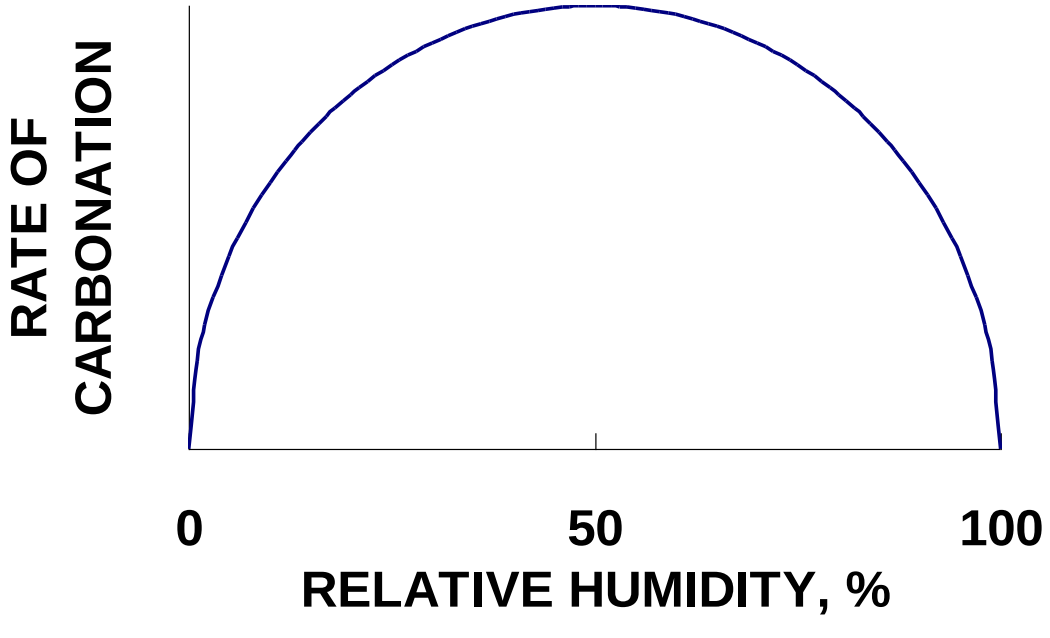
- Steel expands 700% when fully oxidized
- Normally protected by paste except:
  - pH <~9
  - Chlorides present

- Keep chlorides out
- Prevent carbonation
- Keep water out
- Provide cover



Carbonation

- Sensitive to moisture state
- Reduces pH



How Does Concrete Fail

- Cold Weather
  - Freeze Thaw Cycling
  - Salt Crystallization

  - Good Air
  - Low Permeability

Freeze Thaw Cycling

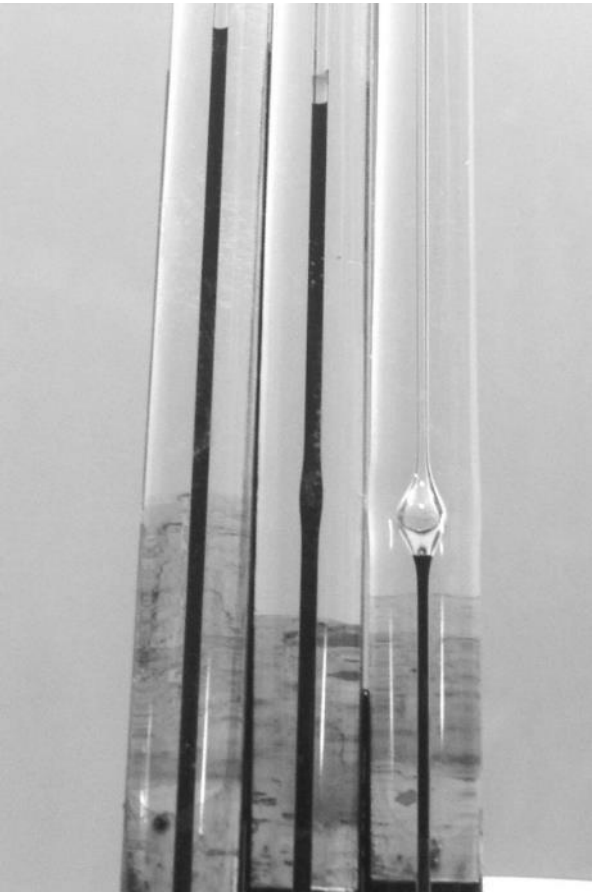
- Mechanisms
  - Saturated system
  - Water freezes and expands
  - Normally cracks parallel to
  - Depth depends on water movement and temperature range

Freeze Thaw Cycling

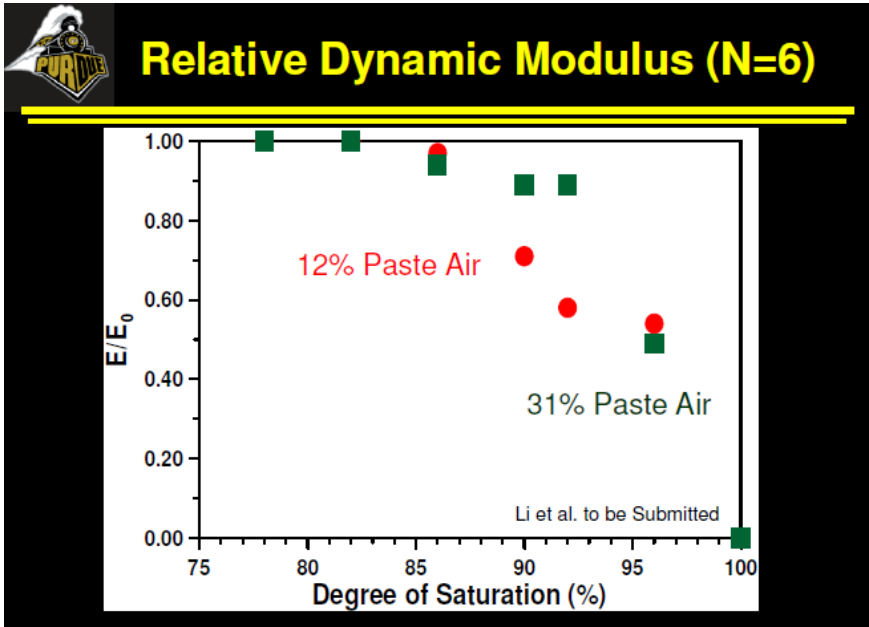
- Prevention
  - Air void system
  - Prevent saturation (<85%)
    - Let it dry regularly
    - Reduce permeability

Freeze Thaw Cycling

- Prevention
  - Air helps slow saturation

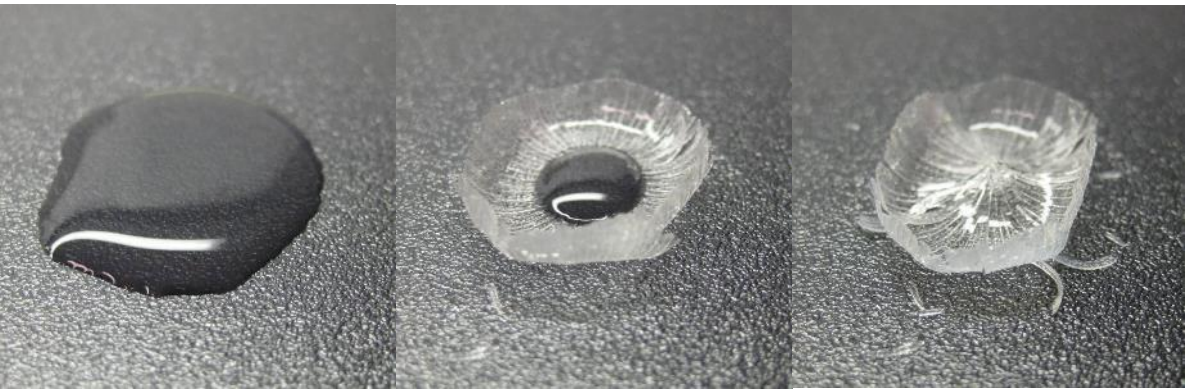


Jason Weiss



Salt Scaling

- Mechanisms
  - Salts in solution crystallize
  - Osmosis
  - Not necessarily cold related



Salt Scaling

- Prevention
  - Reduce permeability
  - Good air
  - System chemistry
  - Finishing

How Does Concrete Fail

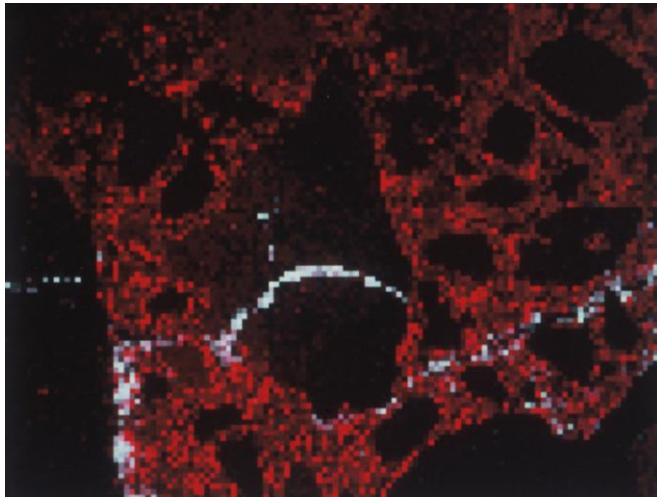
- Chemical Attack
  - Soft Water / Acid
  - Sulfates
  - De-icing Salts

  - Permeability

Sulfates

- Needs
  - Sulfates
  - Water
  - C_3A
- Complex reactions to form ettringite then gypsum
- Makes paste soft

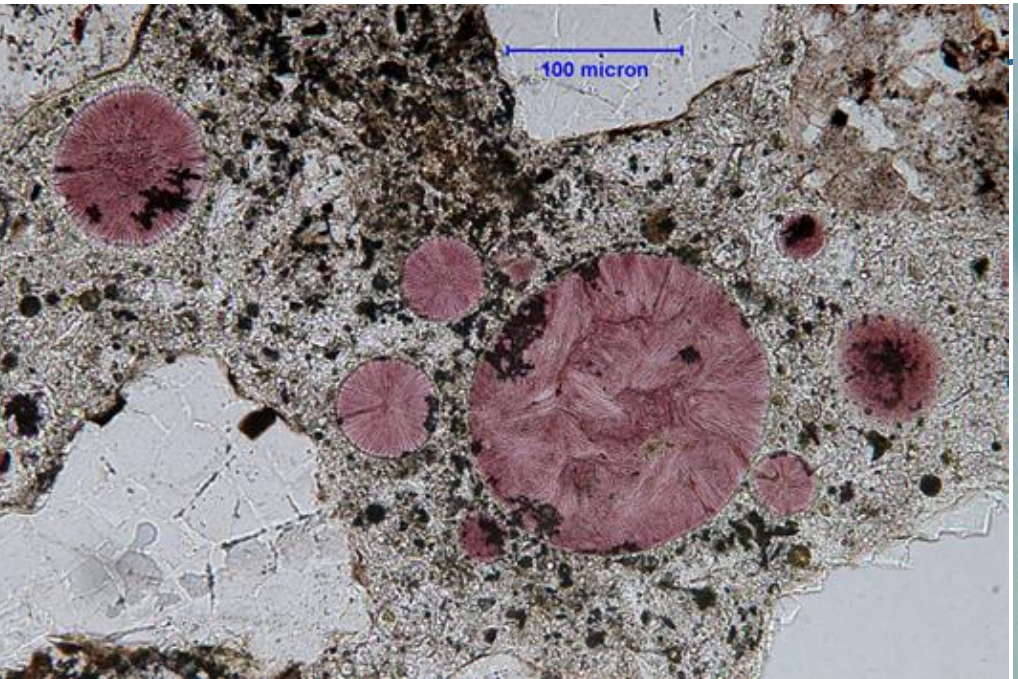
- Reduce C_3A
- Prevent access of sulfates
- Use low calcium SCMs



Salts can cause chemical attack

- Calcium oxychloride
- Friedel's Salt – Calcium-chloro-aluminate
- Ettringite
- Saturation

Moulzolf



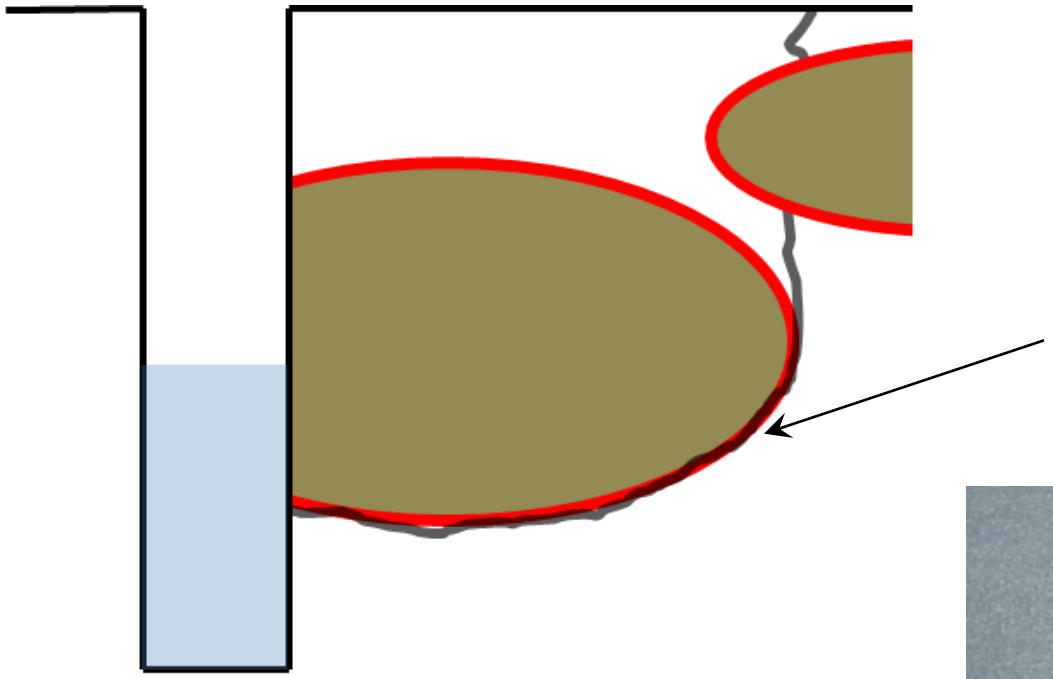
Sutter

Incremental Cracking

The Symptoms

- Not typical freezing and thawing
  - No thin flakes

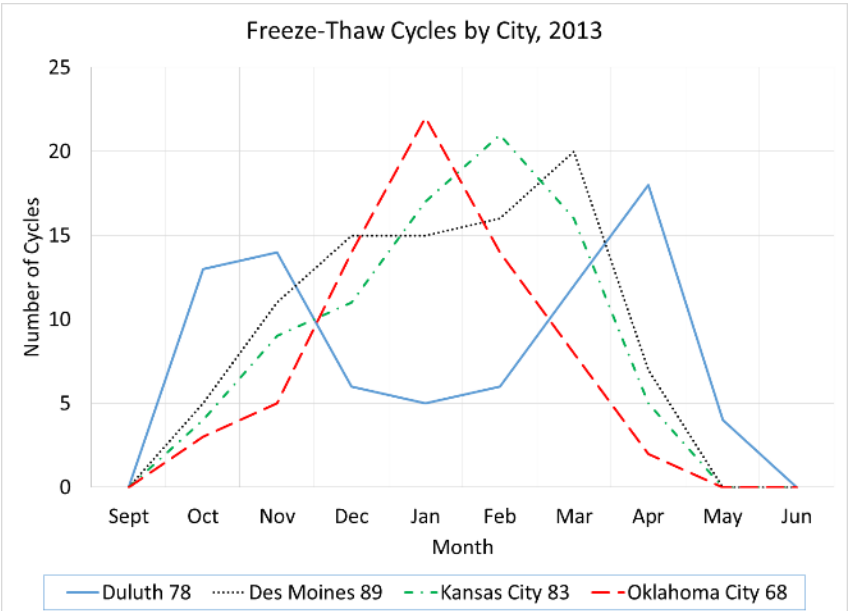
Interfacial Zone



IFZ likely dissolved in salt solutions at low temperatures

What do we do now?

- The game has changed
  - Materials are different
  - Environment is tougher
  - Demands are higher



What do we do now?

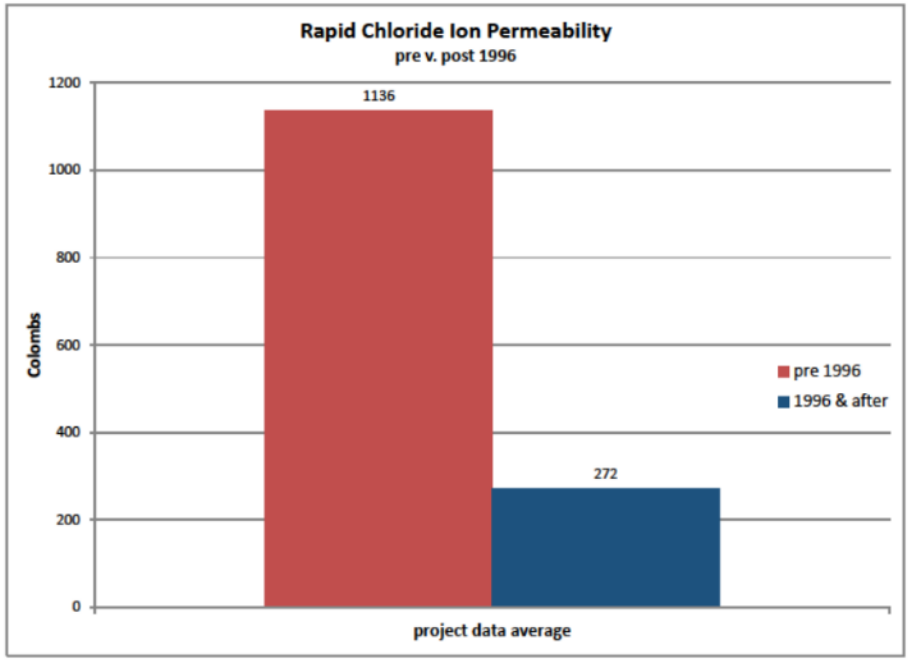
- We have to
  - Keep water away from the concrete
  - Permeability of the concrete should be as low as practical
  - The air void system in the in-place concrete must be appropriate
  - Choose materials wisely

Drainage

- Avoid bathtubs and swimming pools
- Make sure water can get away
- Where is the water table?
- Local effects

Permeability

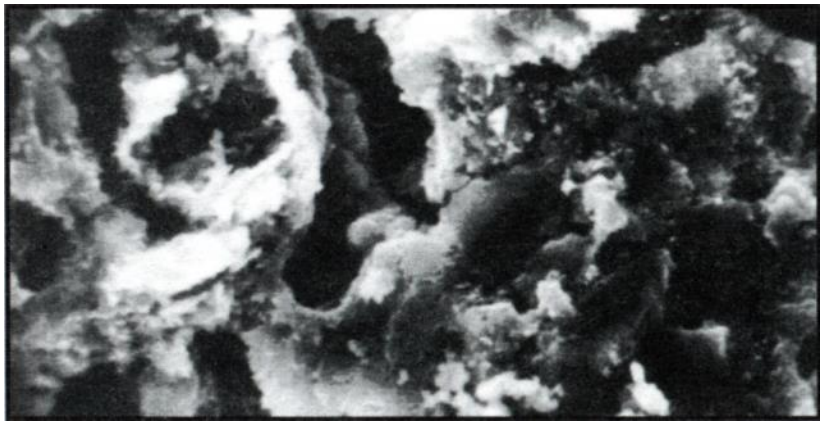
- Stop fluids from penetrating
  - ~0.40 to 0.42 max w/cm
  - Use appropriate SCMs



Moulzolf

Less Water = Lower Permeability

- w/c 0.43

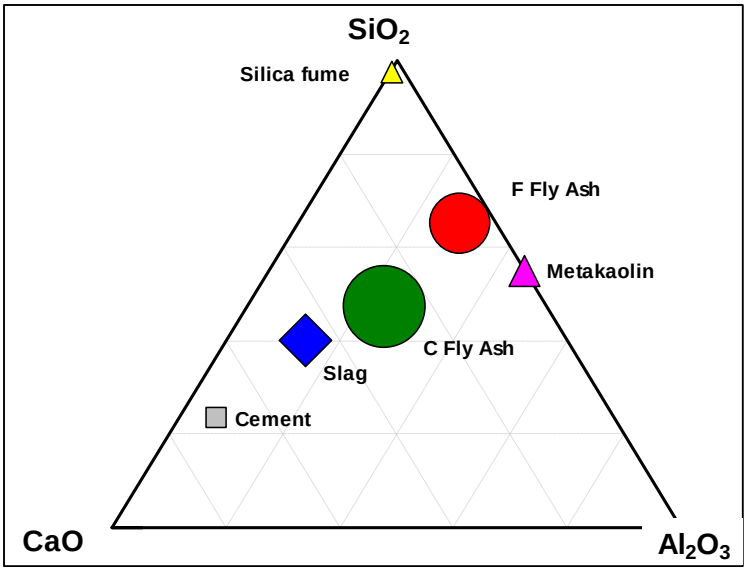


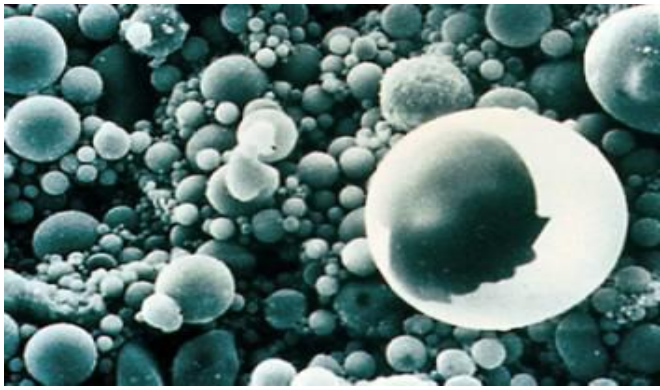
- w/c 0.60 – dark voids where water once occupied space

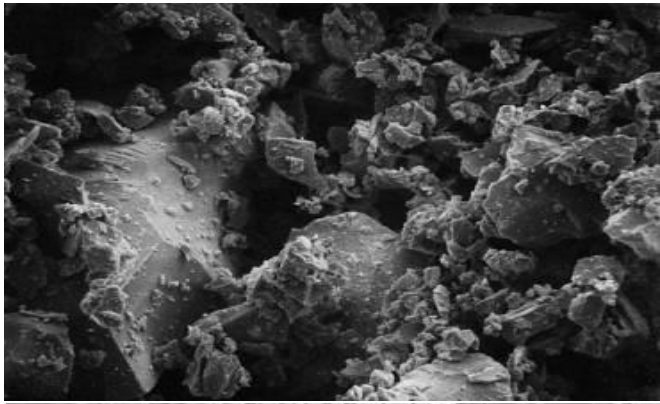
Supplementary Cementitious Materials

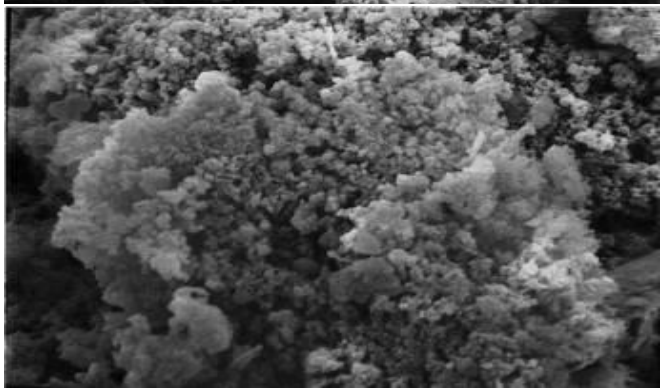
- Fly ash
- Slag Cement
- Silica fume

- Consider using ternaries



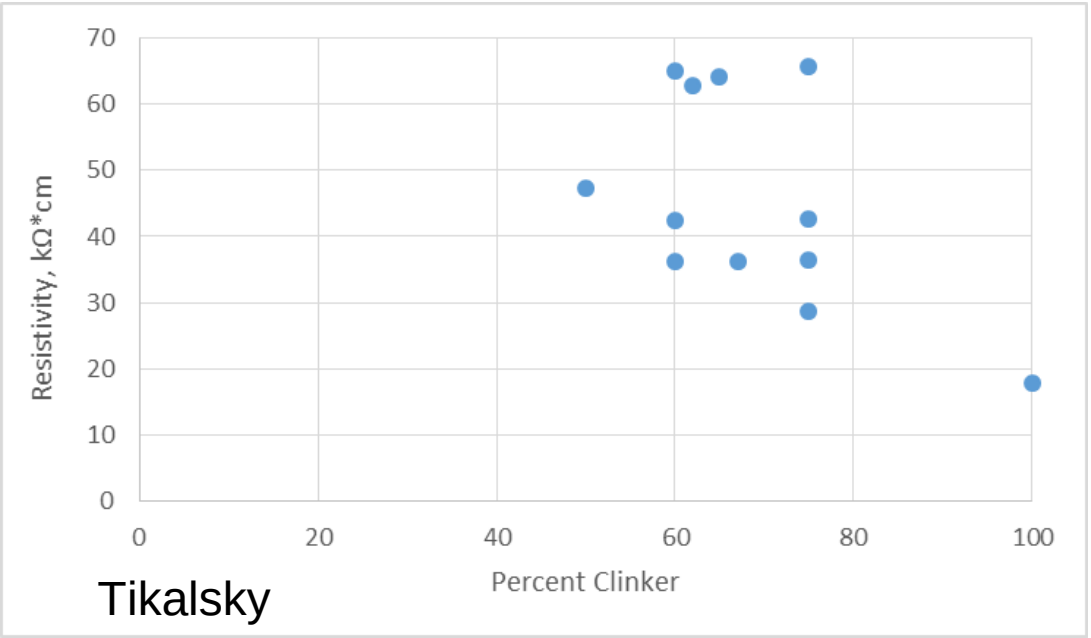




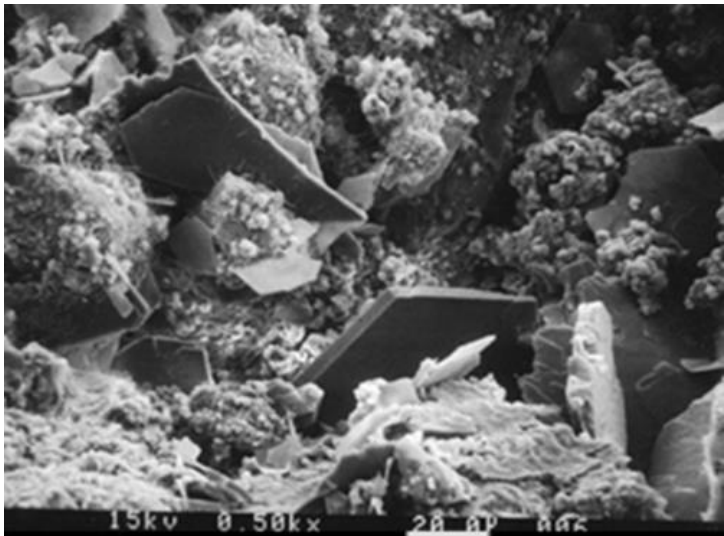


Supplementary Cementitious Materials

- Convert CH to CSH
- Densify the system
- Slow ASR and sulfate attack
- Change cracking risk
- Need better curing



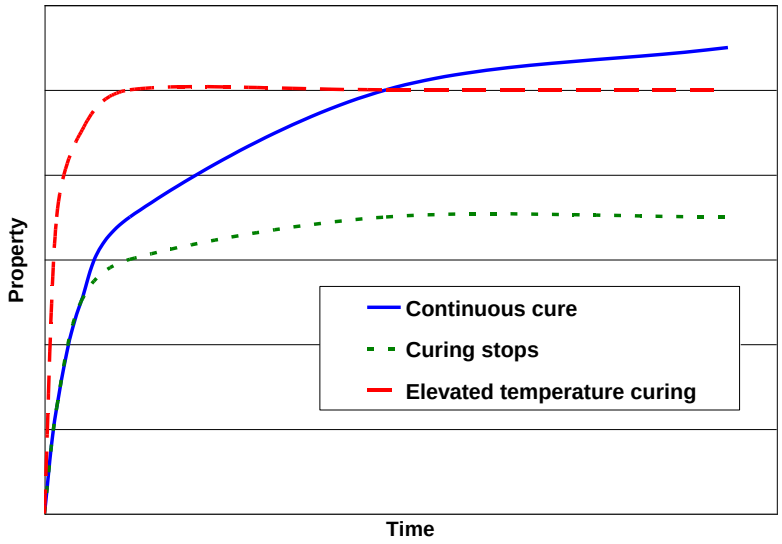
Tikalsky



Curing

Provide an environment that promotes hydration

- Start early vote often
- Keep it wet and warm
- 7 Days would be nice
- Does it affect strength?



How?

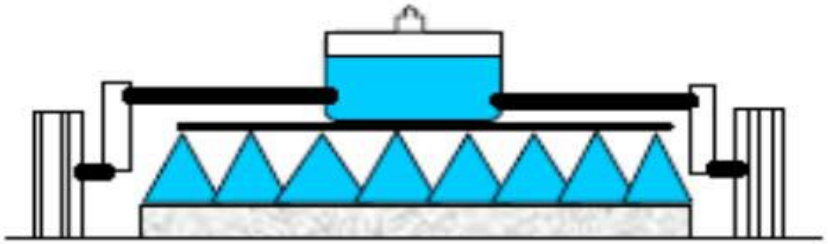
- Keep it wet
  - Flood
  - Fog
  - Cover

How?

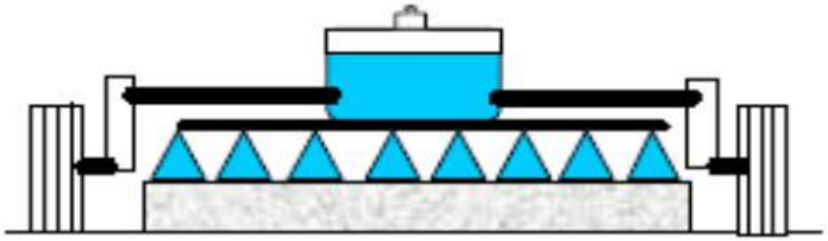
- Keep it wet
  - Curing compound
    - Poly-alpha-methylstyrene
    - ASTM C 309 (0.55 kg/m^2)
    - Or local requirements (e.g. 0.3 kg/m^2)
    - White

How?

- Must
  - Be applied to moist surface
  - Be applied by machine



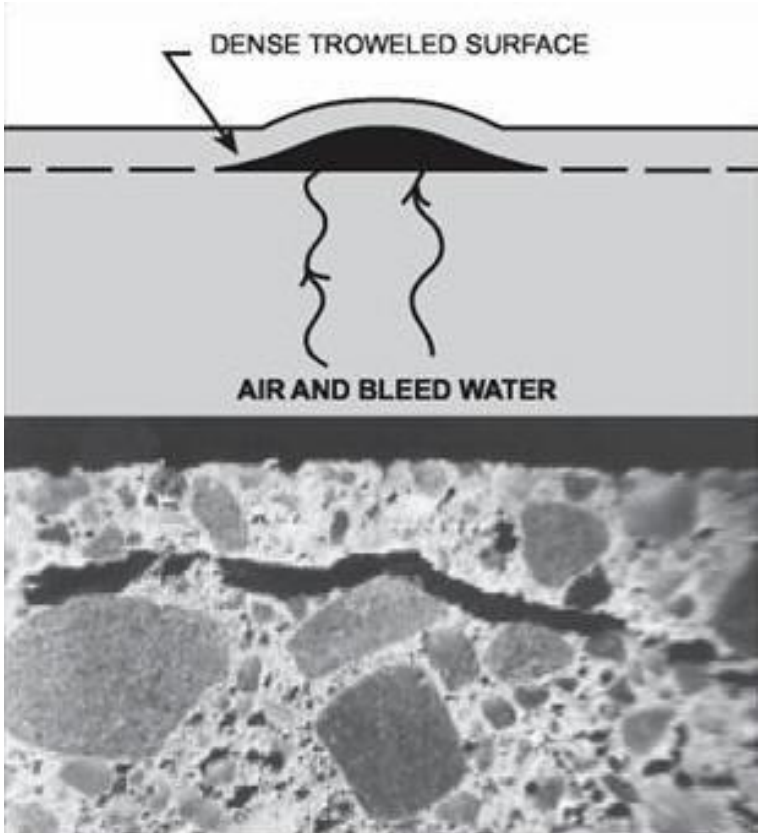
a.) Nozzle heights adjusted to obtain 30% overlap of adjacent spray patterns.



b.) Nozzles must be raised to retain 30% overlap for the 250-mm PCCP.

When?

- Too early
  - Bleed water is trapped → flakey surface
- Too late
  - Why bother

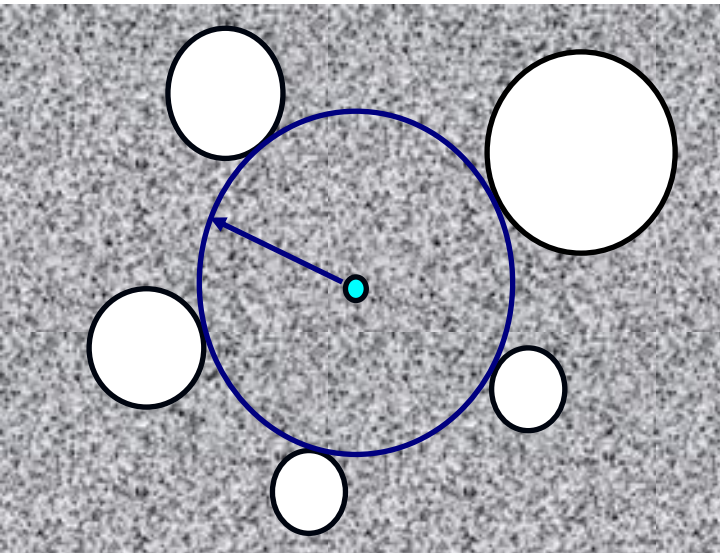


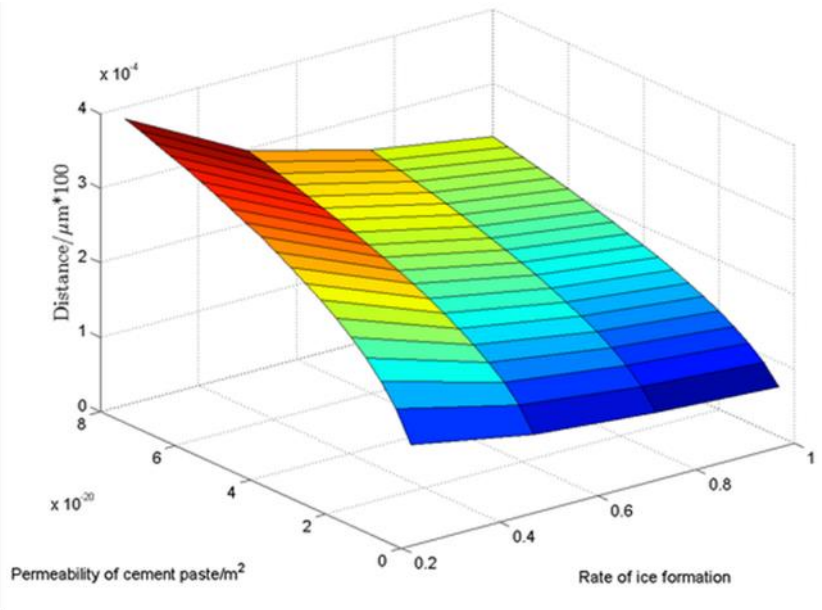
Penetrating Sealants

- Linseed, silane, soy-methyl ester, lithium silicate
  - When do we put them on?
  - Where?
  - Which ones are good?
  - How do we know?
- More work needed

Air-Void System

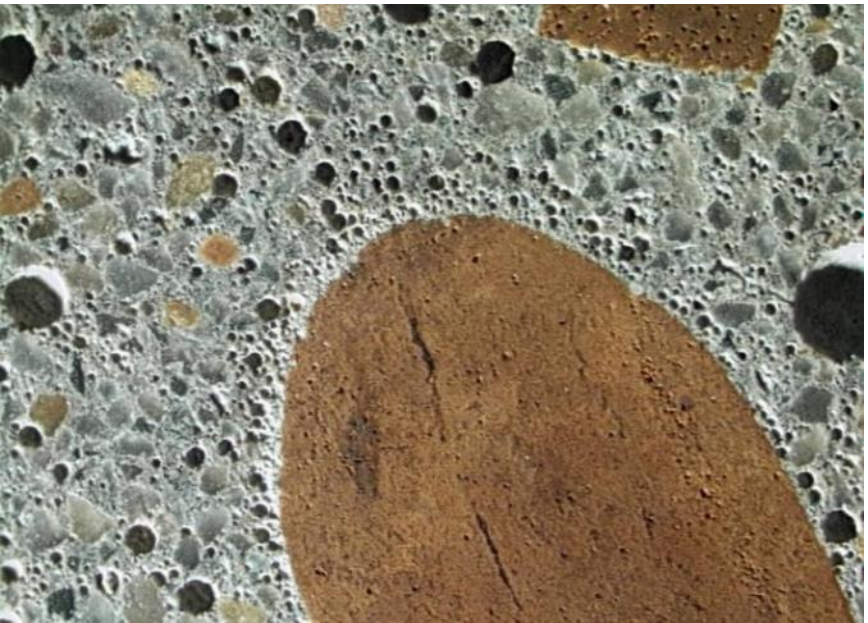
- Why?
  - Frost resistance
- What are we looking for?
  - 9% expansion
  - Air void system is more important than total air content

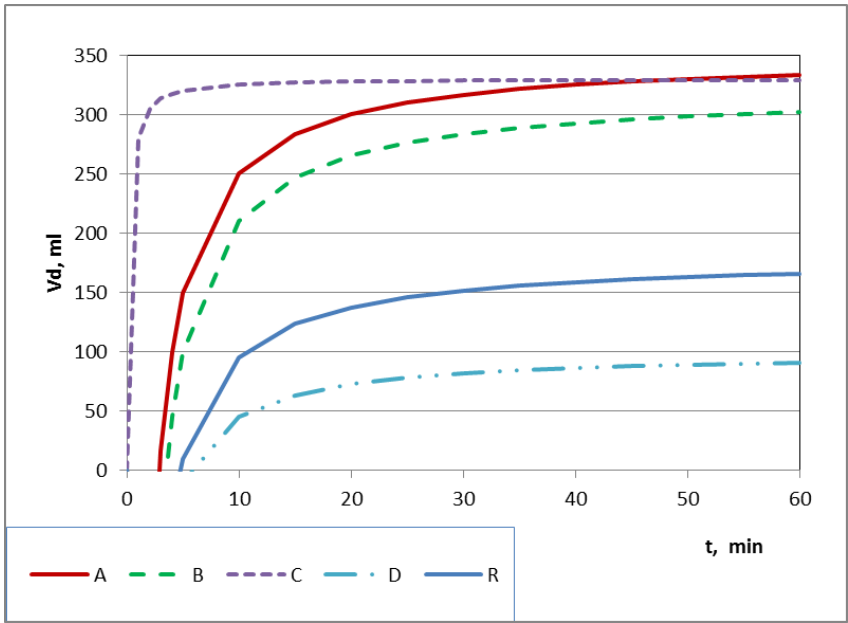




Air Entrainers

- Vinsol / Rosin / Tall Oil / Synthetics
- Affect
  - Bubble size
  - Stability
  - Effects of WRA
  - Clustering





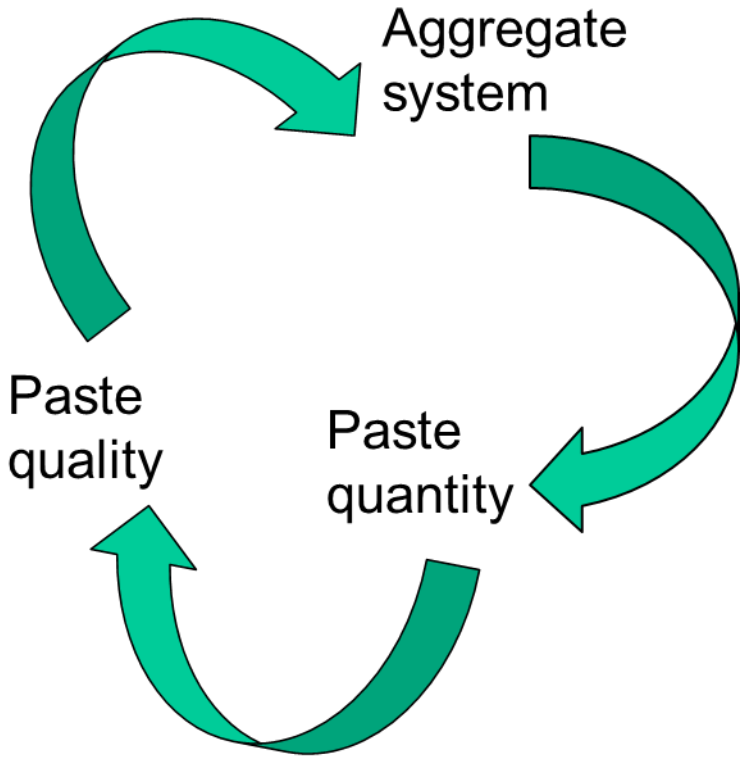
Air Void System

- Suggested 5% minimum behind paver – or 0.2 SAM number

Current Proportioning Technologies

- Developed
  - Before water reducers
  - Before supplementary cementitious materials
- Primarily focused on structural concrete
  - 100 mm (4”) slump
  - 30 MPa (~4000 psi)
- ACI 211 last revised in 1991

Proposed Mixture Proportioning Procedure

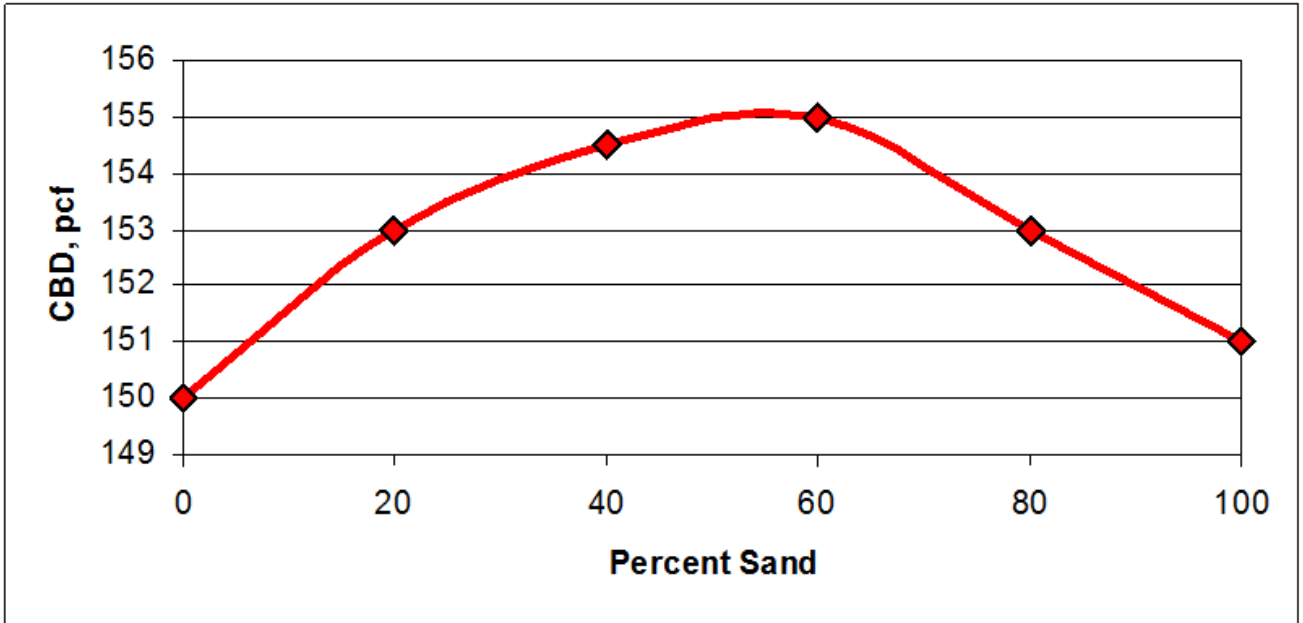


Koehler

Proposed Mixture Proportioning Procedure

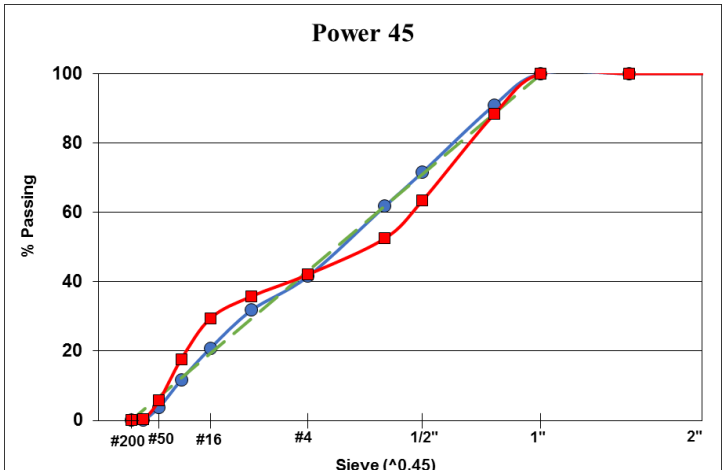
Choose the Aggregate System

- Combined gradation
- Determine void ratio



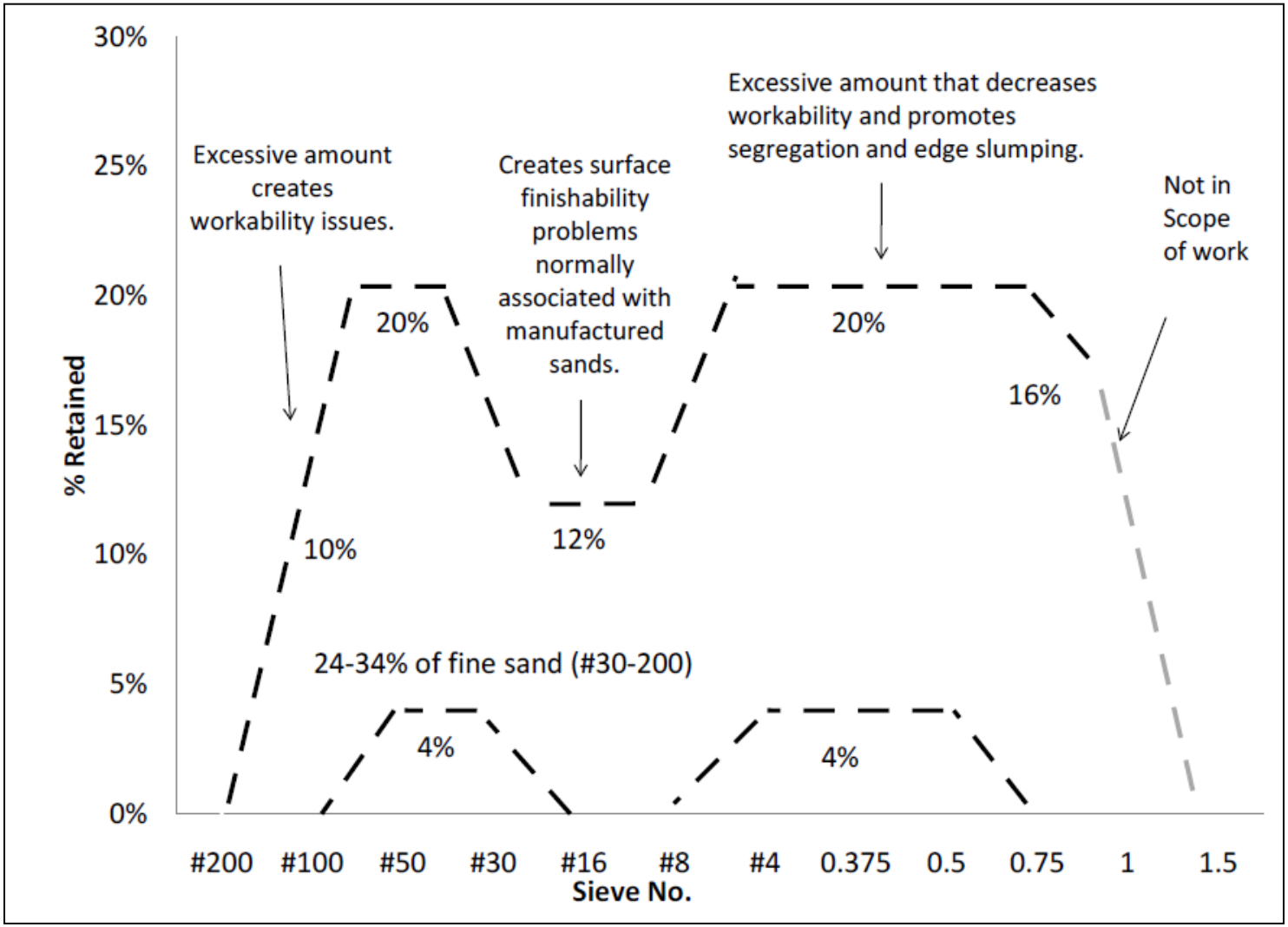
Aggregate System

- Control combined grading to increase amount of aggregate in the mix
- Maximum aggregate size
  - Bigger NMS means
    - Less paste and lower water requirement
    - Increased risk of segregation
  - Limited by section thickness
  - ¾” to 1½” is typical



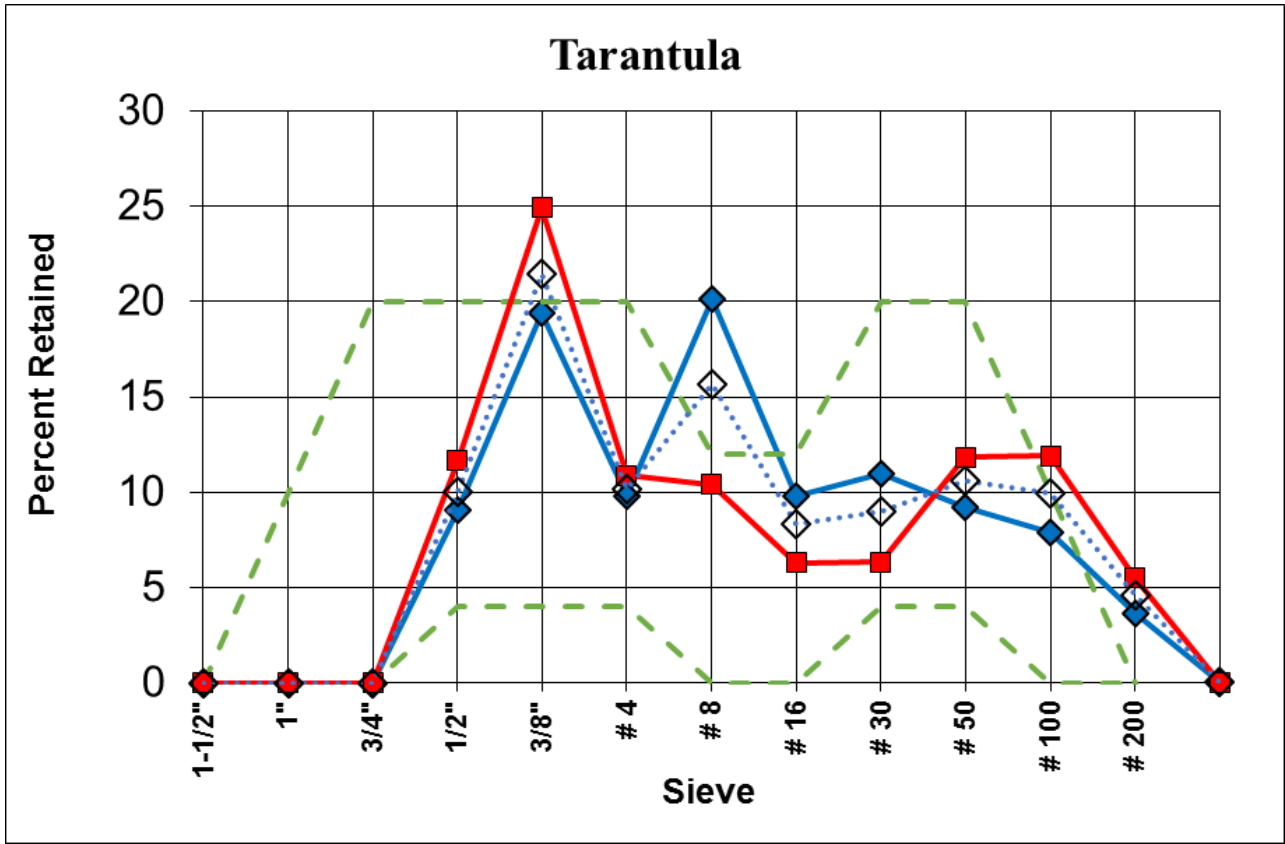
Aggregate System

- Tarantula Curve (Ley)



Aggregate System

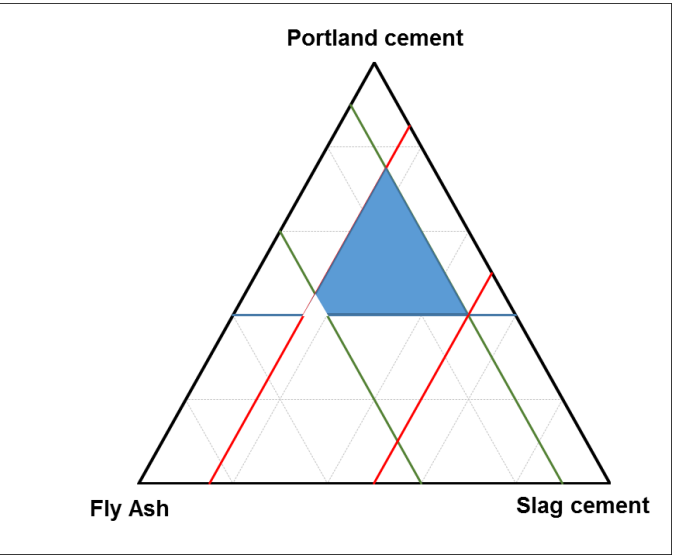
- 2 aggs – void ratio 23.2%
- 3 aggs – void ratio 19.8%
- 3 aggs (T) – void ratio 20.4%



Proposed Mixture Proportioning Procedure

Choose a Paste System for Performance

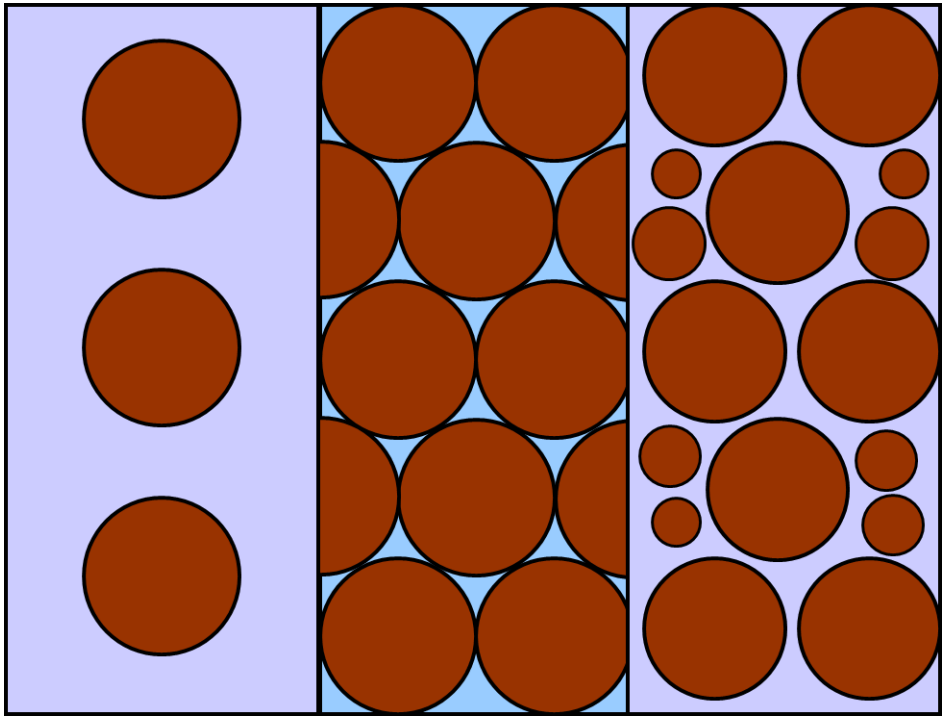
- Cementitious blend
- W/Cm
- Air content
- Chemical admixtures



Proposed Mixture Proportioning Procedure

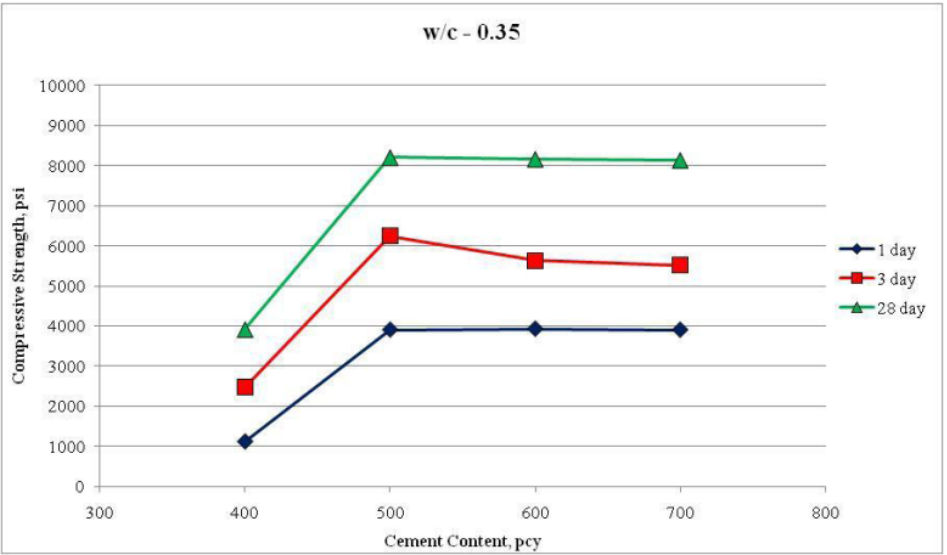
Choose Paste Volume

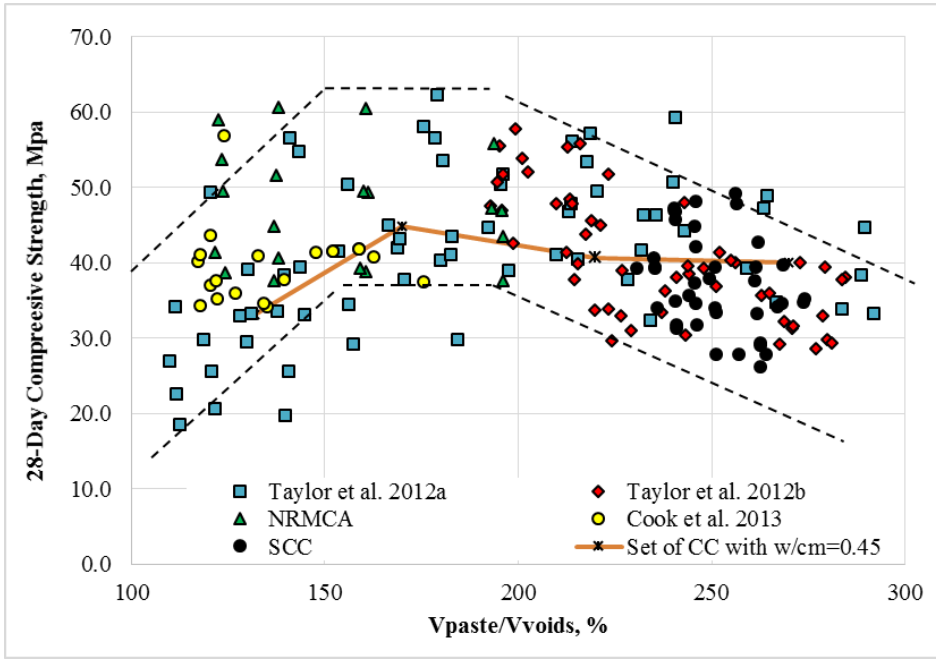
- All voids must be filled with paste
- And a bit more to coat the particles for workability



Proposed Mixture Proportioning Procedure

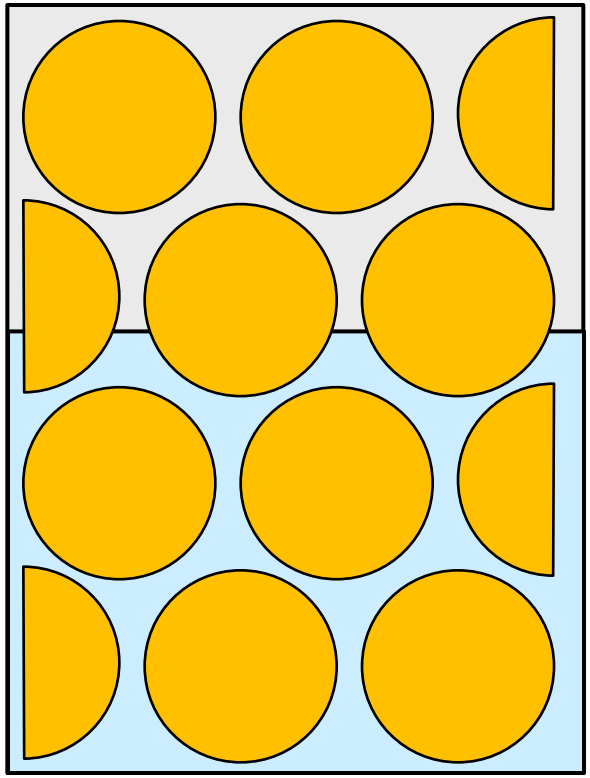
- Need enough paste for mechanical properties ~175% of voids
- And not much more

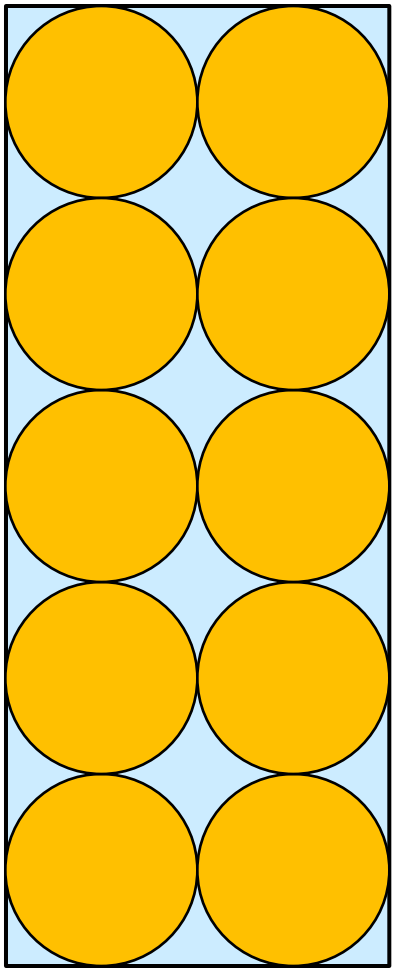




Definitions…

- Blue = Vvoids (C29)
- Grey + Blue = Vpaste
- Void ratio = Vpaste/Vvoids





What do we want to specify?

- Aggregate Stability
  - ASR – PP65
    - Mortar bar
    - Concrete prism
    - Block
  - D-Crack – local
    - Iowa Pore Index
    - Chemistry
    - Ledge analysis

What do we want to specify?

- Air void system
  - After placement
  - Spacing factor or SAM number

- Freeze-thaw resistance
  - C666
  - C672 / Toronto test

What do we want to specify?

- Mixture Permeability
  - Fluids
  - Ions

Purdue University
Purdue e-Pubs

Joint Transportation Research Program Technical Report Series

Joint Transportation Research Program

2010

Portland Cement Concrete Pavement Permeability Performance

Javier Castro
Purdue University

Robert Spragg
Purdue University

Phil Kompare
Purdue University

William Jason Weiss
Purdue University

Recommended Citation
Castro, J., R. Spragg, P. Kompare, and W. J. Weiss. *Portland Cement Concrete Pavement Permeability Performance*. Publication FHWA/IN/JTRP-2010/29. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2010. doi: 10.5703/1288284314244

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.

What do we want to specify?

- Curing
  - How?
- Shrinkage?
- Consolidation (?)

When do we measure?

- Mixture design
  - Most critical properties
  - Accept mixture(s)
- Field trials
  - Workability and uniformity
- Acceptance
  - Is the mixture the same?
- QC
  - Are we going to get there?

Closing

- Did you get what you thought you paid for?
- Did you measure what you really want?
- Concrete can last a long time…

Chicago Sun Times

Discussion…