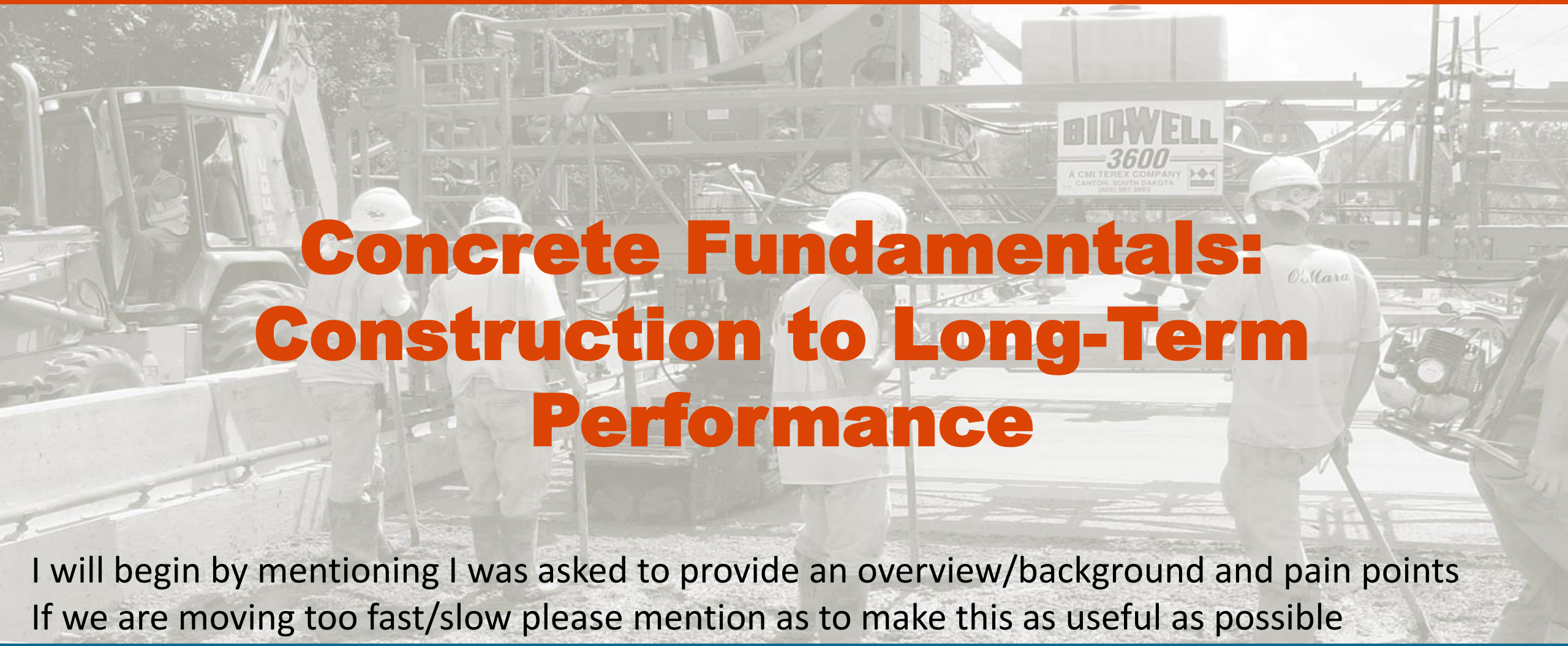
Concrete Fundamentals: Construction to Long-Term Performance

Jason Weiss, Edwards Distinguished Professor, Oregon State University



Concrete Fundamentals: Construction to Long-Term Performance

I will begin by mentioning I was asked to provide an overview/background and pain points
If we are moving too fast/slow please mention as to make this as useful as possible

Jason Weiss, Edwards Distinguished Professor, Oregon State University

Background

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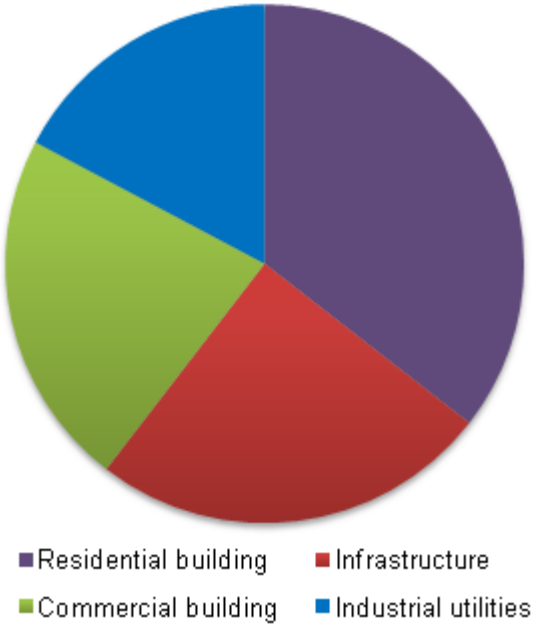
- Concrete widely used
- Wide range of applications, and needs, important each can differ
- ASCE Estimate need to be $3.6 T by 2020



Durability in Service

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Corrosion of Reinforcing Steel in Decks/Structures

Joint Damage in the Presence of Salts

Cracks spaced at 2.5 ft on the approaches to a bridge deck

Observations of the Concrete Industry

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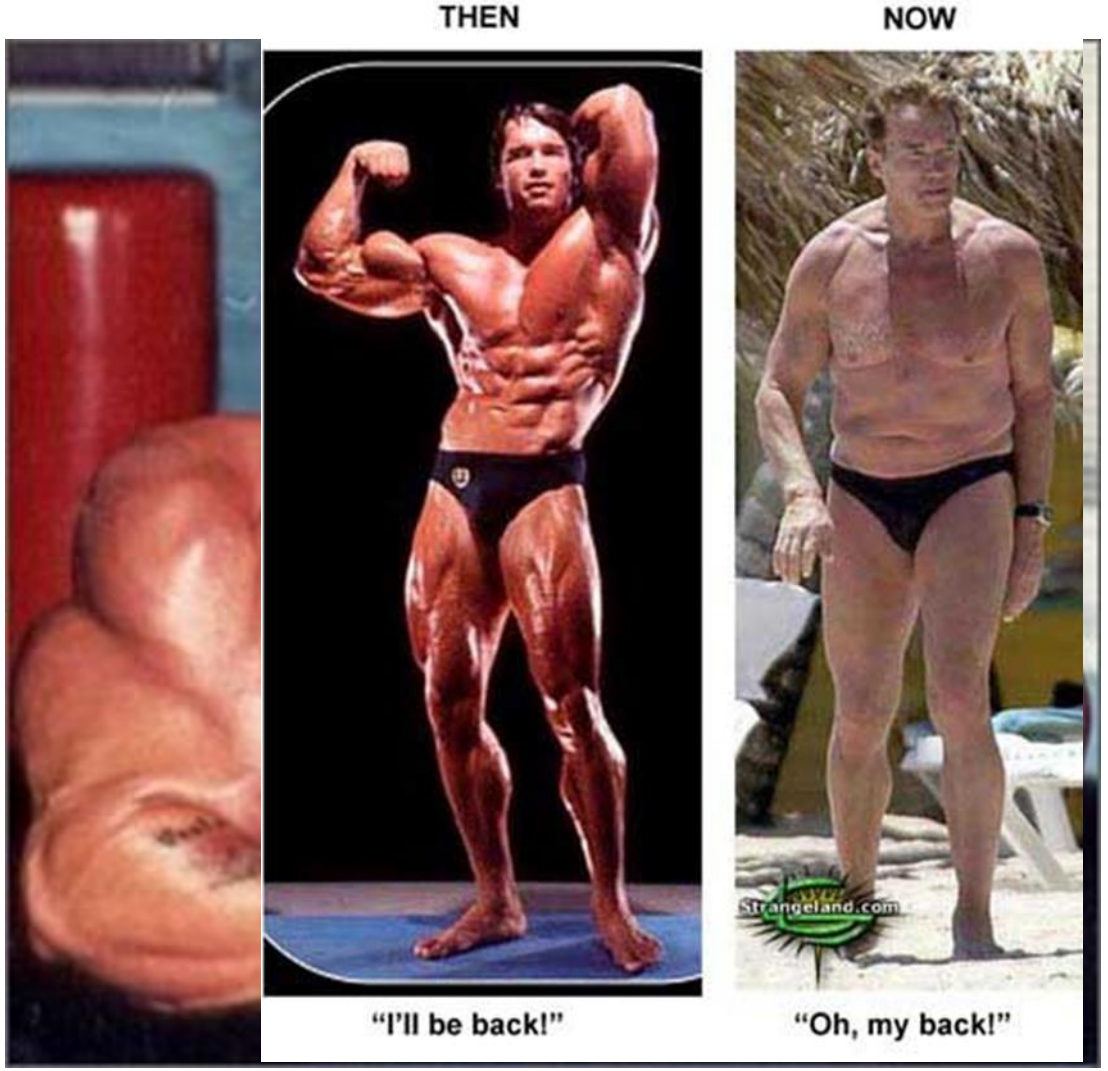
- Obsessed with strength
  - Codes/specifications – f'c
  - Often a surrogate test, but lost
- Durability is key; however
  - Durable to what
  - Poorly defined exposure
  - Lack of attention
- Reliability/robustness
  - Rather overdesign than risk



Built in the Environment Not a Controlled Factory

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- Concrete is prepared on site frequently using locally available materials & labor
- ‘processing’ is often poorly specified (prescriptively)
- ‘curing’ is often poorly specified and implemented
- Here a great strength can also often be a limitation

Concrete Often Treated as a Commodity Item

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- Many applications view concrete as a ‘low bid’, commodity item
- For many applications durability is easily achieved due to
- Building code - “only the minimum requirements necessary to provide for public health and safety.”
- Concern over liability and litigation
- Contracts focus on time, f’c, cost

"I'm Dr. Nick Riviera, and I will perform any major operation for just $129.95!"

Overall Approach

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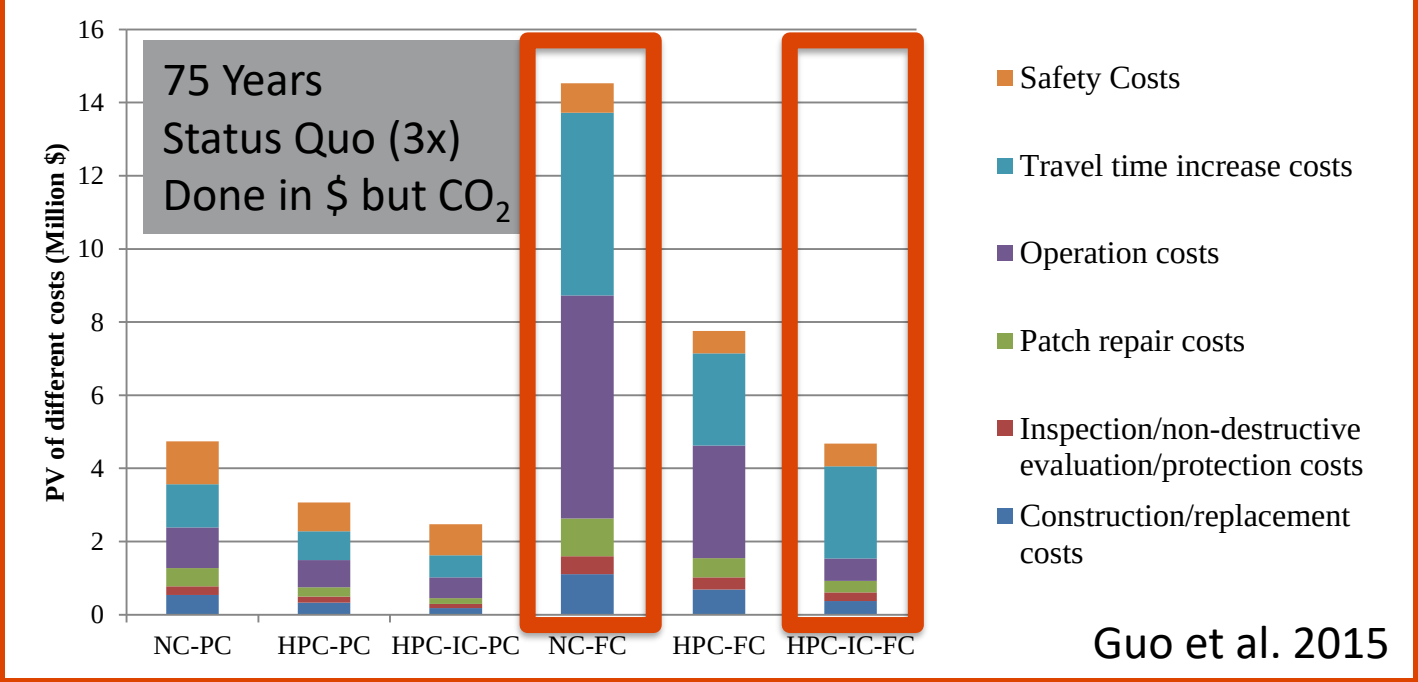
- Many interesting niche materials are being developed; however volumes we are discussing are enormous
- Can we use current materials to expand the life span and reduce material/ energy use over time
- By doing so, can we reduce the number of times we need to repair



Guo et al. 2015

Example 1a: Pavement Joints and Deicing Salts

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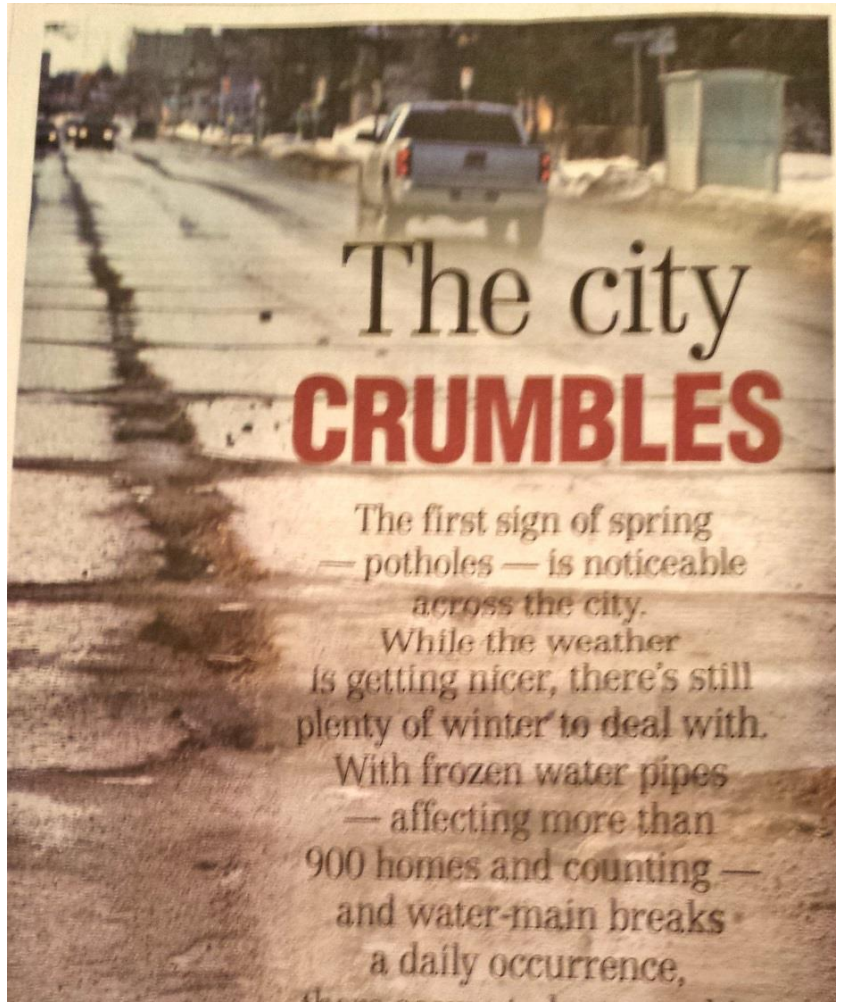
- Pavement joints have been experiencing premature damage
- This damage is largely due to changes in ‘exposure’ as the salts used have changed



Example 1b: Pavement Joints and Deicing Salts

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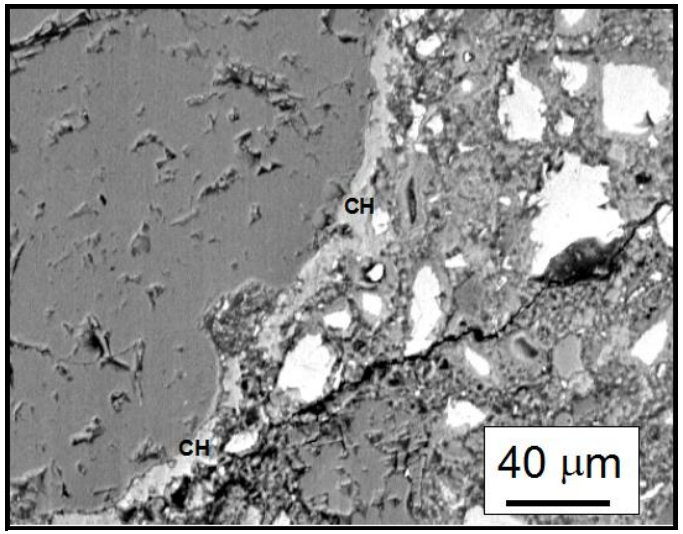
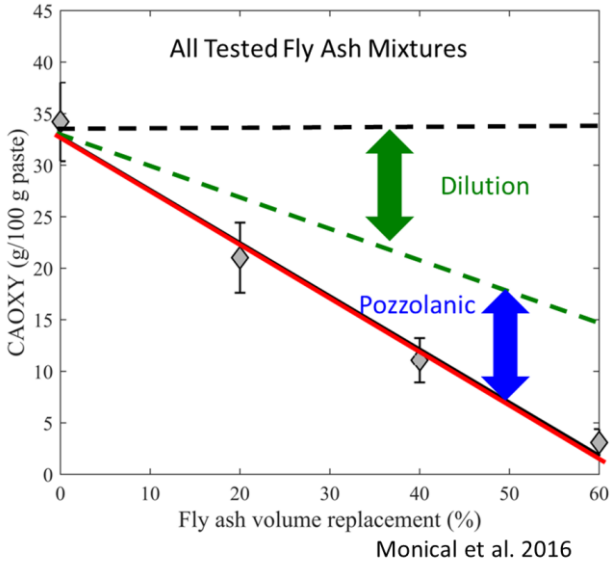
- Pavement joints have been experiencing premature damage
- This damage is largely due to changes in ‘exposure’ as the salts used have changed
- “Requires new design criteria”
- Service life can be improved with little impact to initial cost but the service life implications ($, RM, CO_2) huge





Monical et al. 2016

Example 2: IC Bridges

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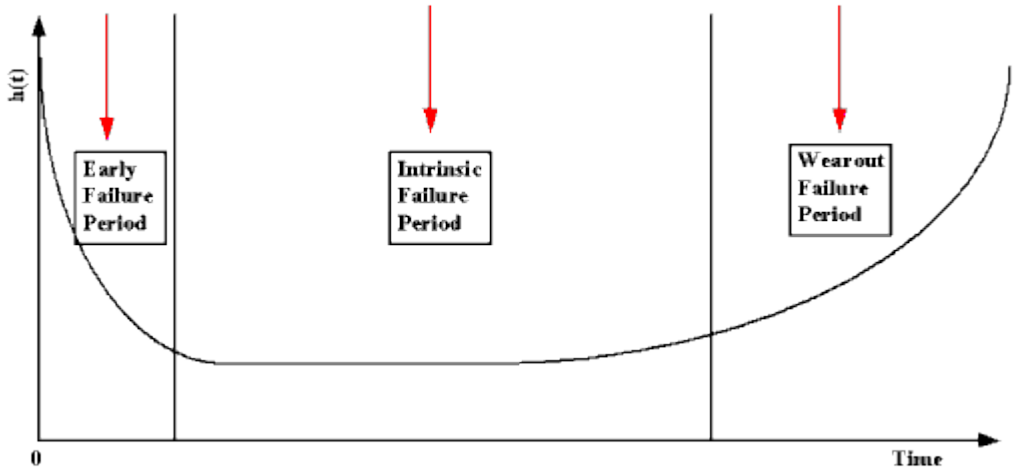
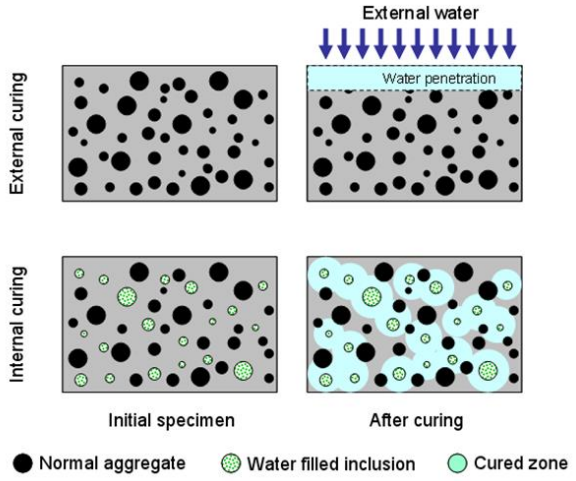
- Internal Curing (IC) has been developed to address two main issues
- Reduction in cracking at early ages
- Improving ‘curing’ in the field
- 3x service life of IN bridges ($, RM, CO_2)

Streeter et al. 2012

DiBella et al. 2010





Example 3: MIC

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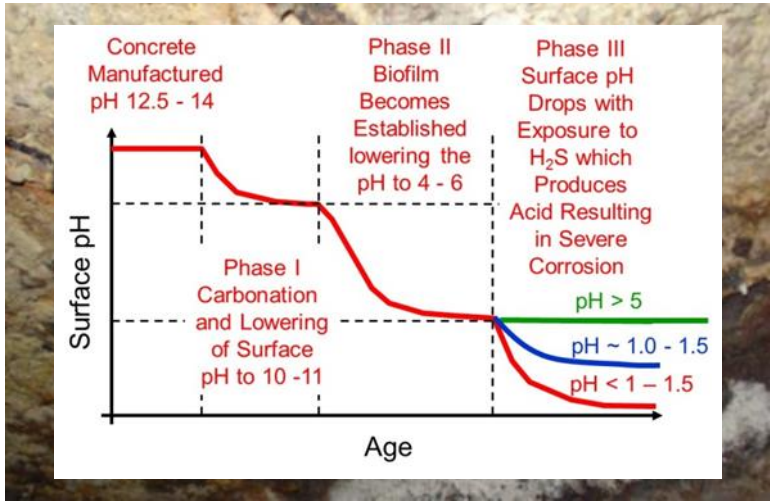
- Microbially Induced Corrosion
- Acid produced by bacteria
- Can lead to rapid degradation
- Currently poorly understood, exposure poorly defined, appropriate standards do not exist
- Innovative solutions may exist but need to be verified/quantified
- Combined sewers 7.1 billion (Atlanta)



Fundamentals

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Frequently We Think About Concrete at the Macro Scale

Composite Material

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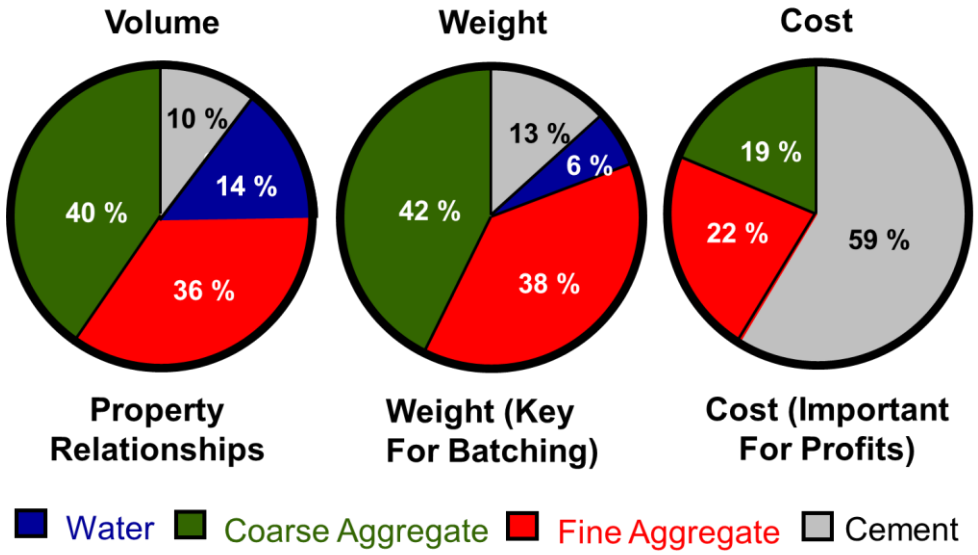
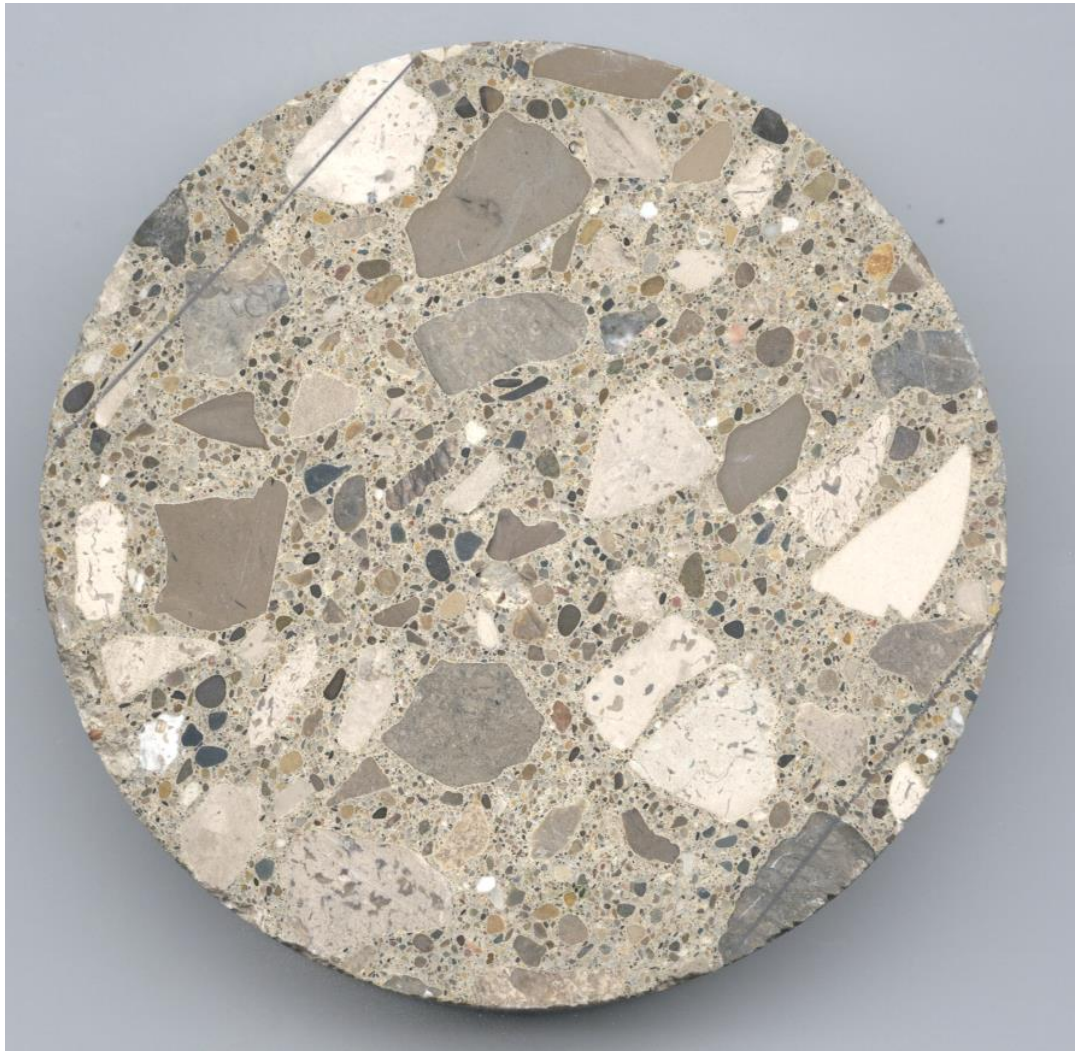
- Coarse Aggregate
- Fine Aggregate
- Binder (Cement, SCM, Water)





A Look Before Hydration

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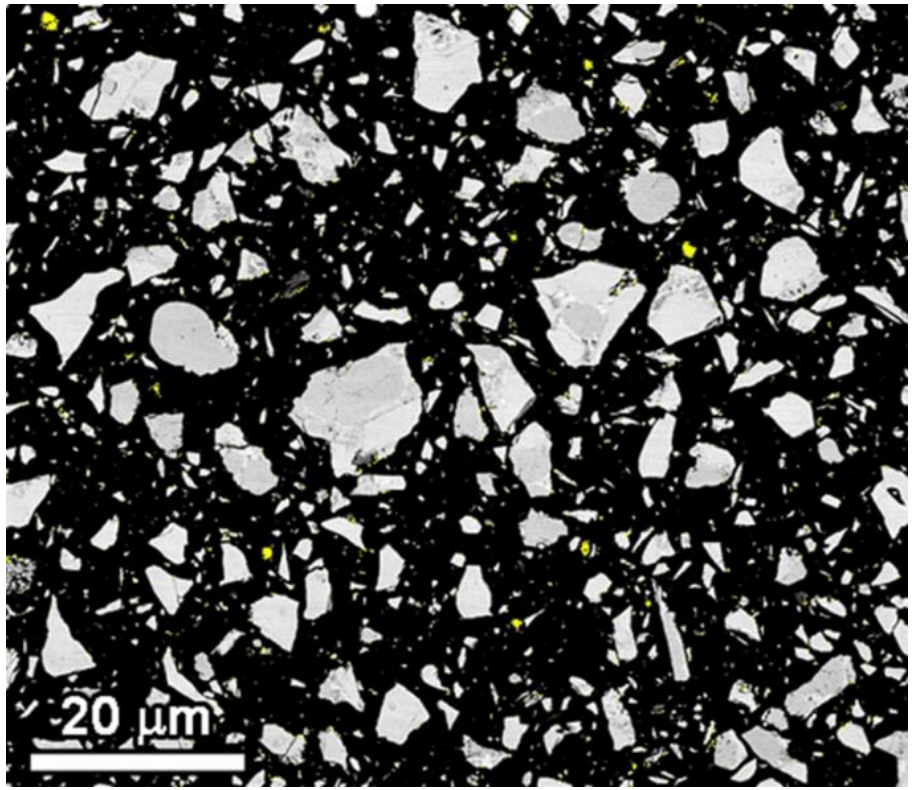

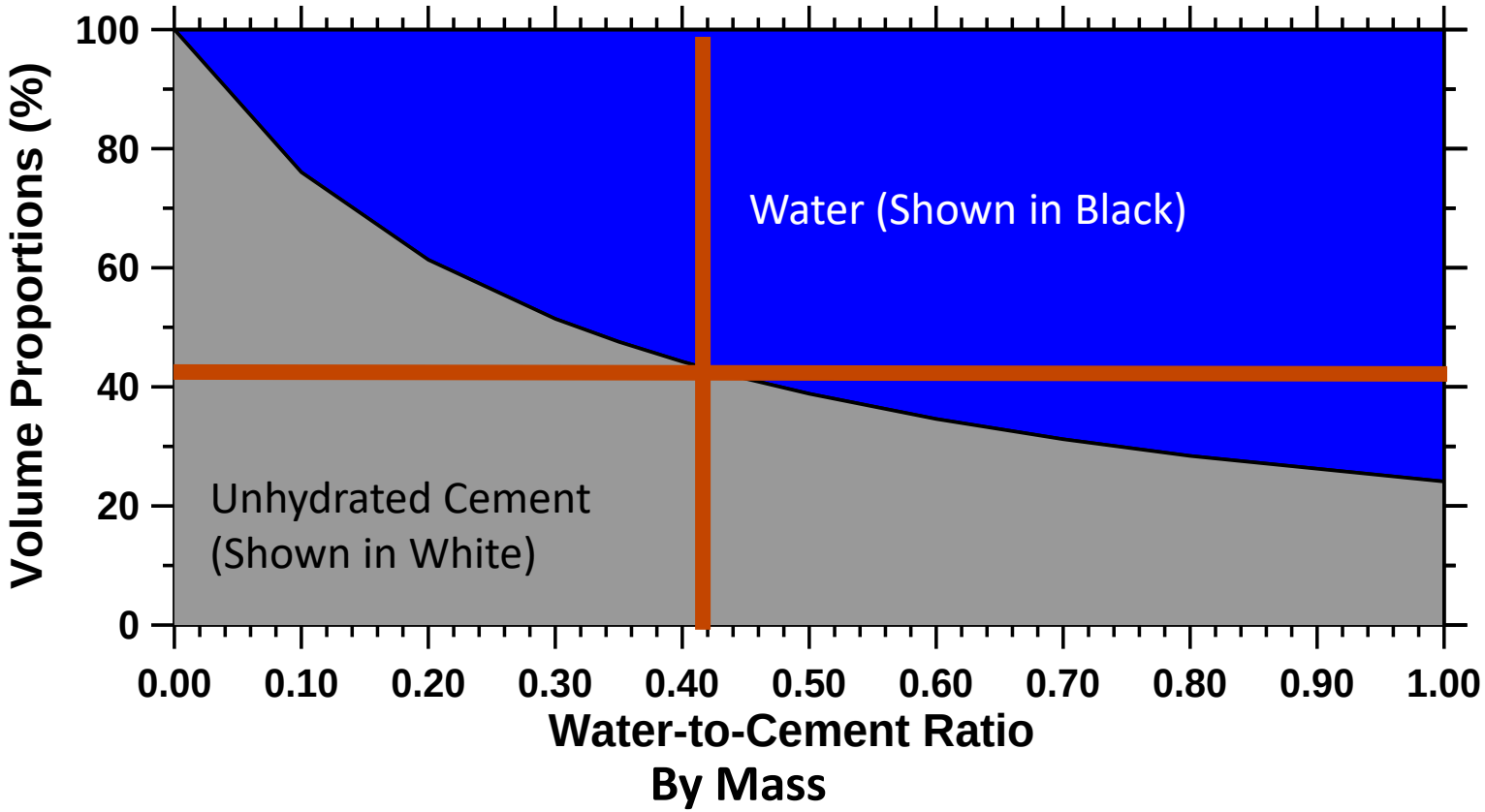

During Hydration

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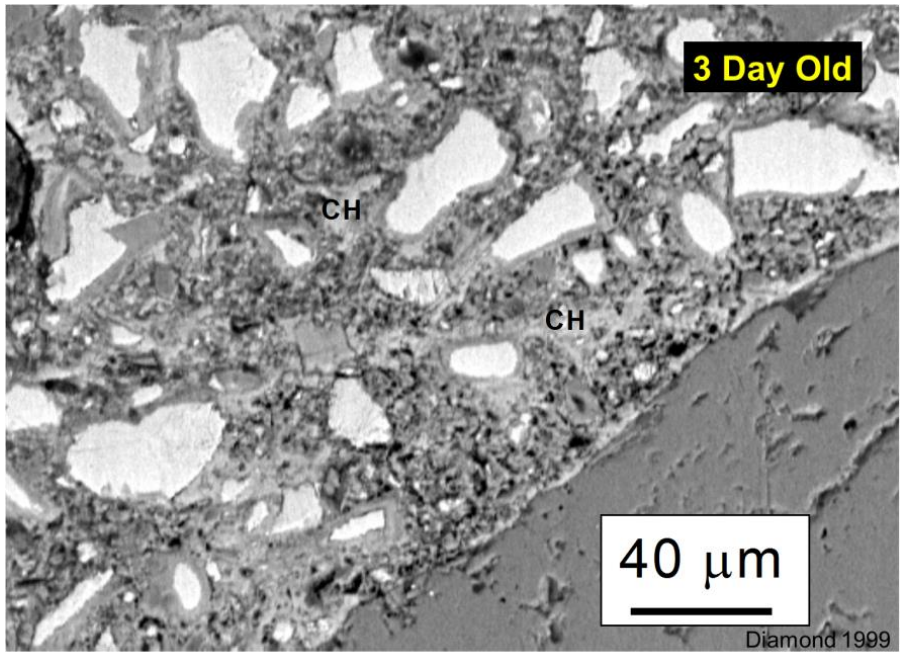

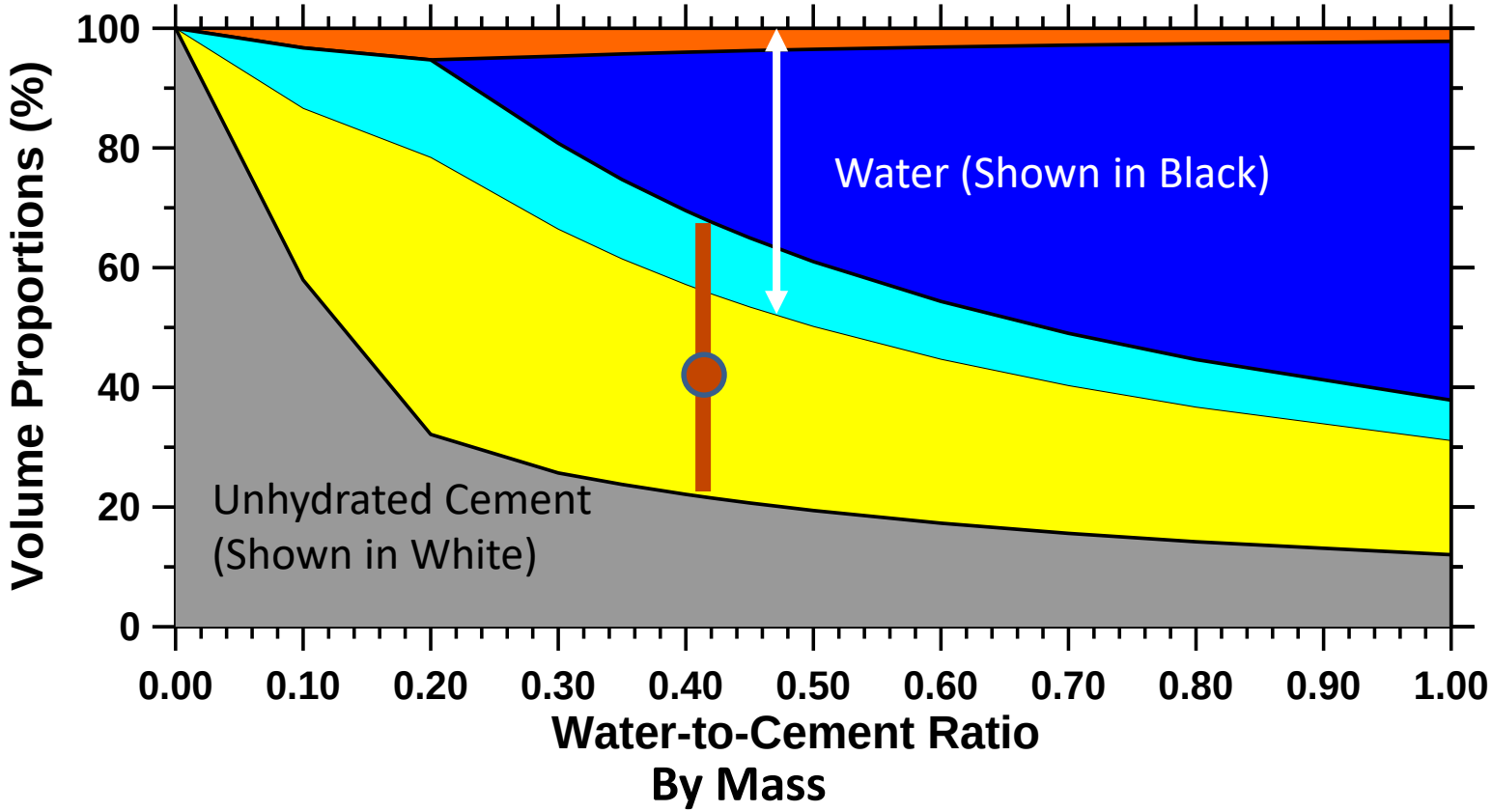

A Look at Pores

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Entrained/Entrapped Air

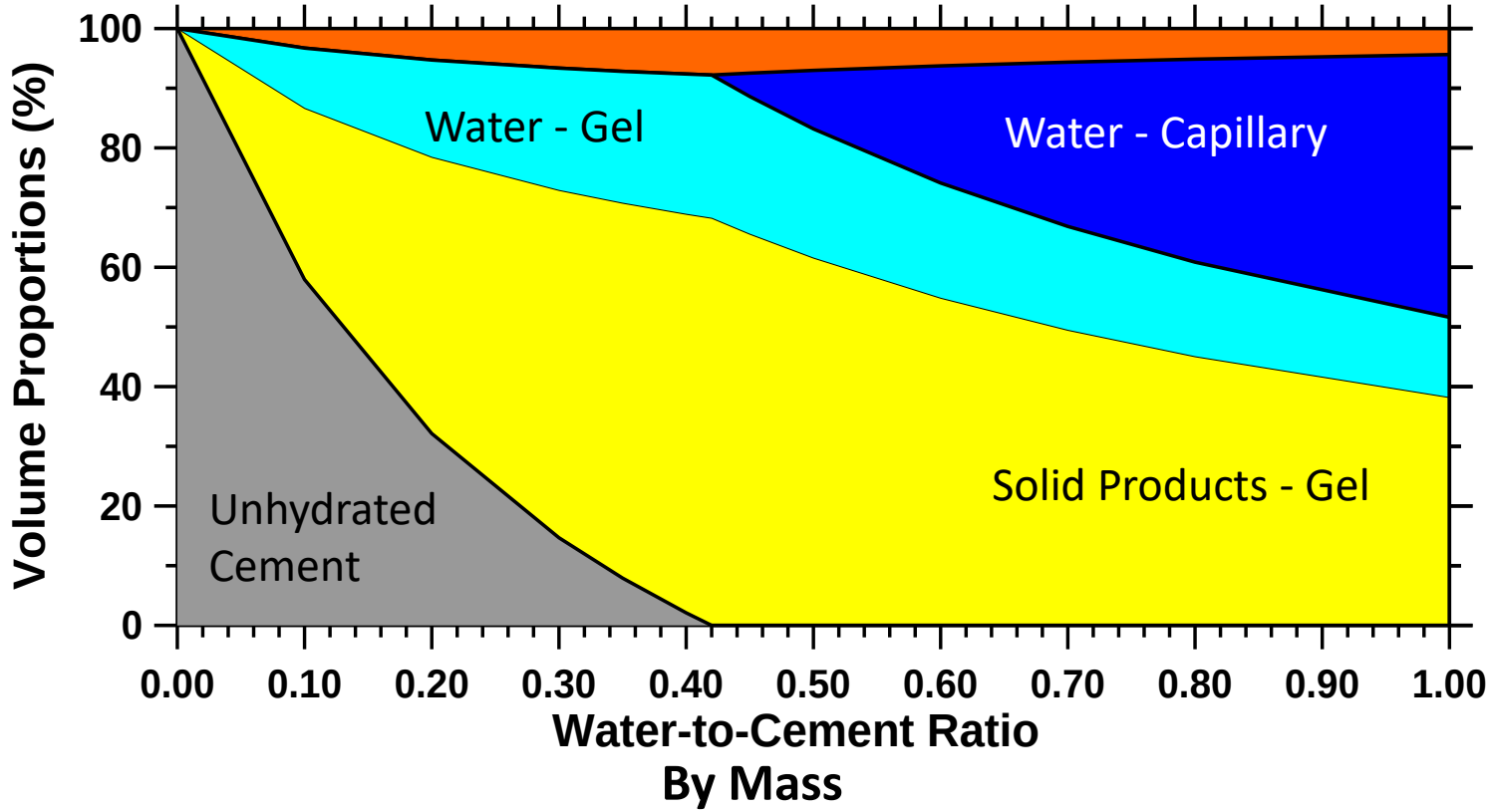
- Not Shown
- BFP, Freeze-Thaw

Capillary Pores (5nm-10 mm)

- control by water, w/c
- Important for Transport

Gel Pores (2-5 nm)

- Part of the structure
- important for shrinkage



Variety of Binder Compositions

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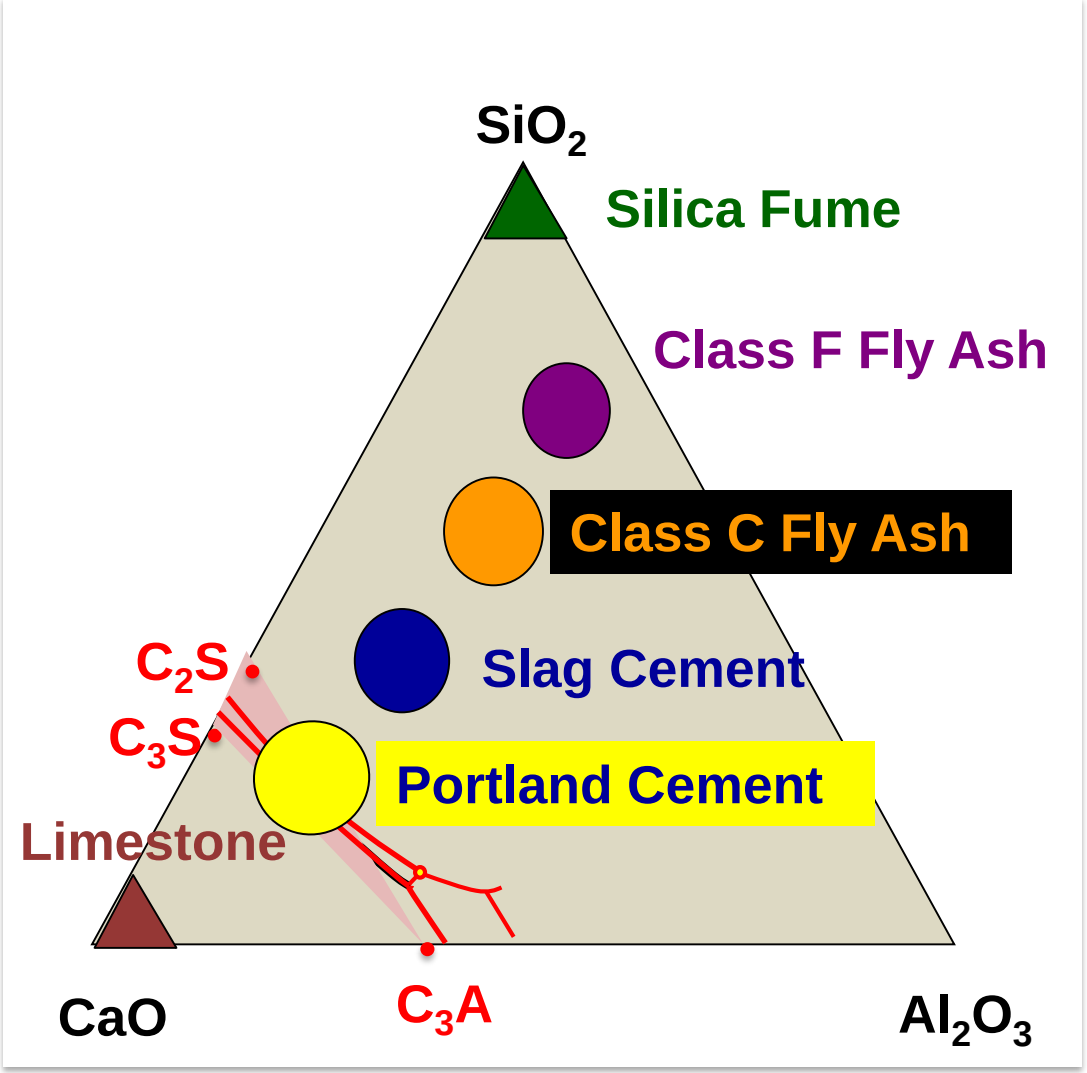
- Many are excited about using alternative SCMs
- These can have a great deal of benefits but they do alter the system
- Historically considered “ waste or dilution” and as such they are a ‘filler’ not a vital lever in design



Reactive Transport Modeling and GEMS

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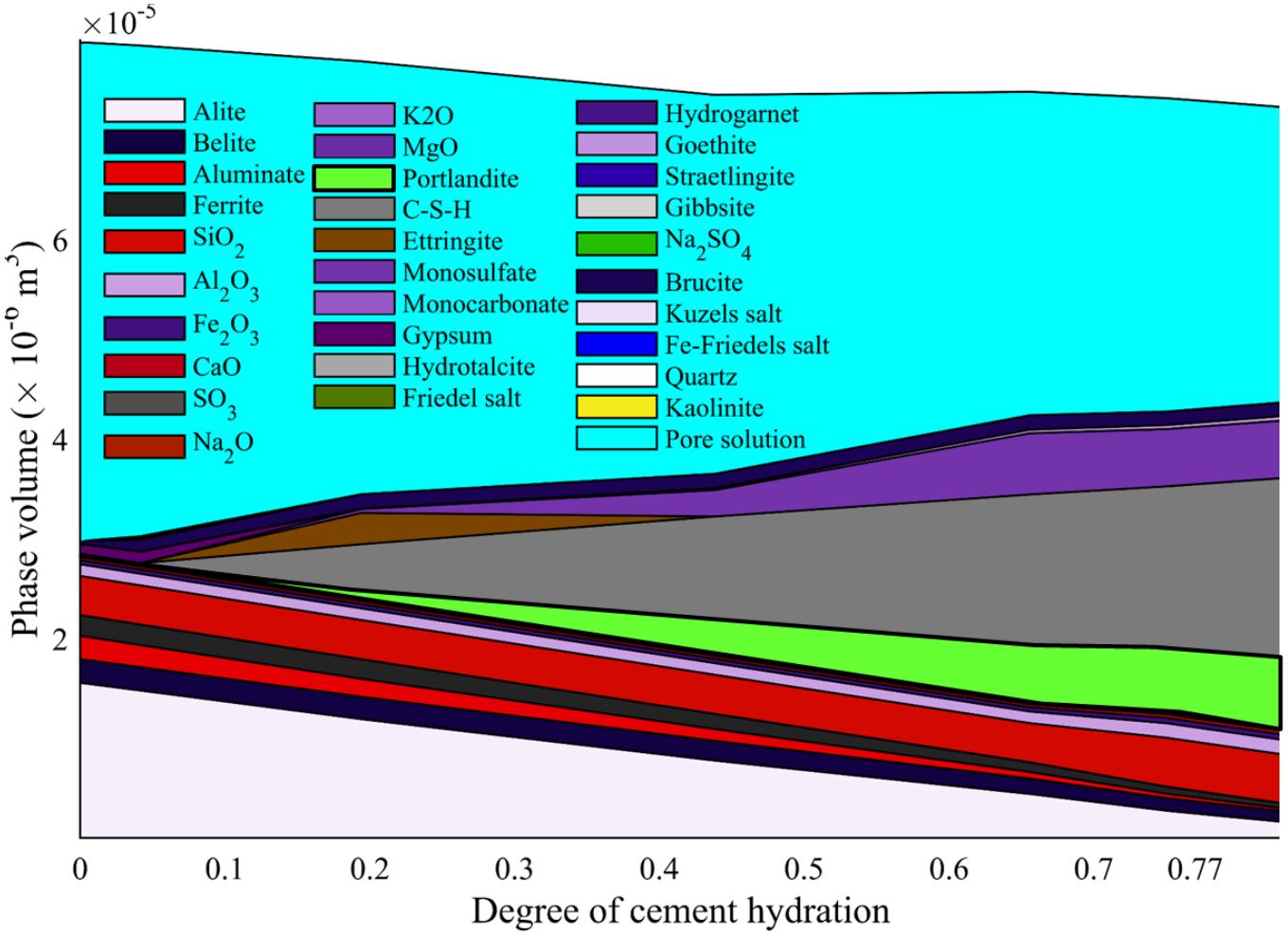
- Powers approach has been updated to consider other binders
- Crucial to move forward



Azad et al. 2016

Chemical Admixtures Abound

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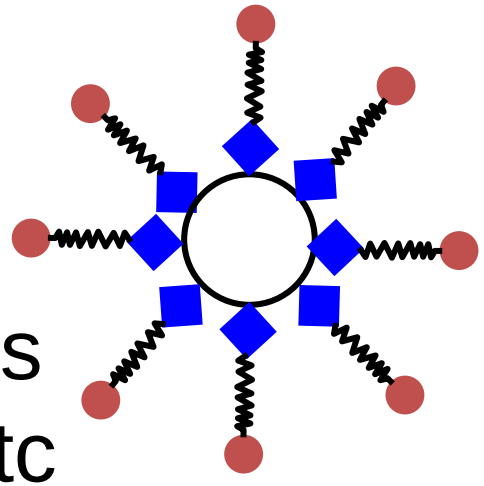
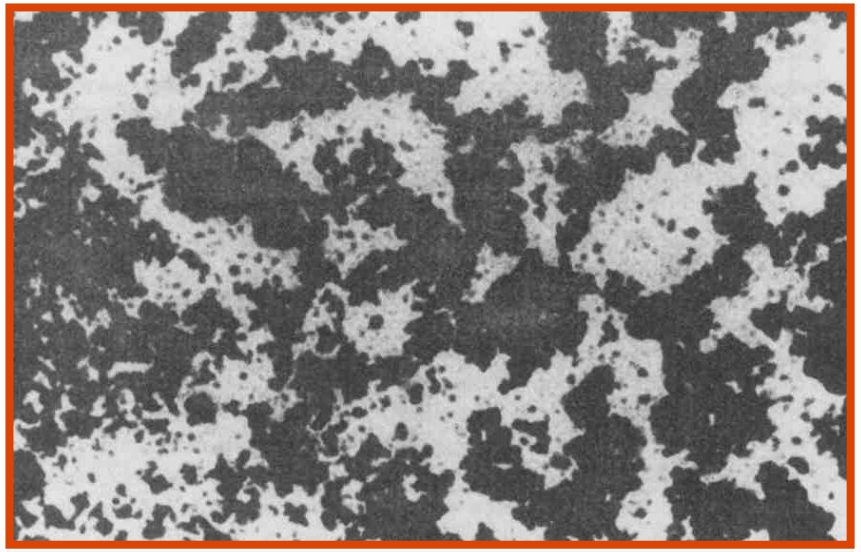
- Dispersants (Water Reducers, Plasticizers) – Fluidity
- 5 to 30% water reduction

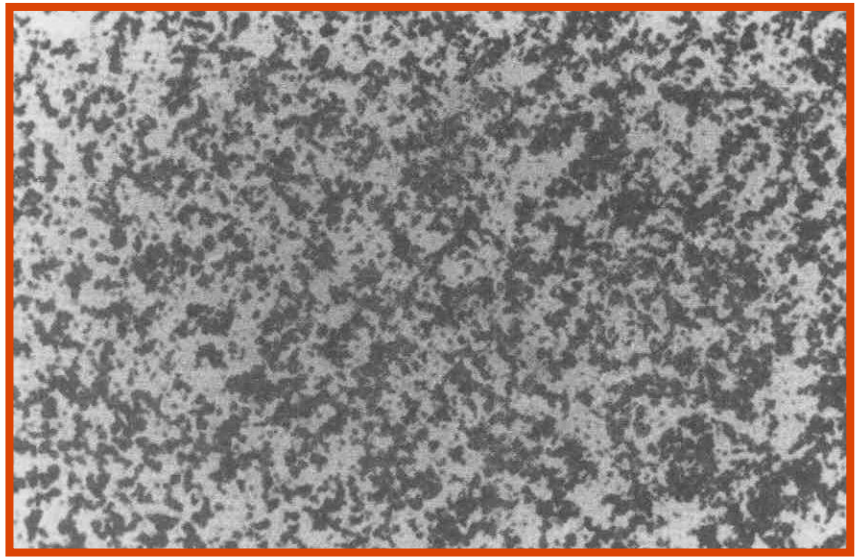
- Surfactants
- (Air Entrainers)

Hydrophillic Hydrophobic



- Accelerators, Retarders Shrinkage Reducers etc





Change in Rheology & Construction Process

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- Extrusion technologies, self consolidating concrete and 3d printing are all potential impacting technologies
- Despite some being ‘mature’ they are still niche technologies
- Vertical Integration/Costing
- Construction, Inspection, Reinforcement and Code Issues
- Durability remains/increases as an issue

Perceived Gaps

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- Field tests and long term durability
- Understanding and definition of exposure conditions
- Modeling/Experimental Test Beds
- State of the art, state of the practice and practice
- Technology Transfer and Education

Field Tests and Durability

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- Many of the tests used are historically based and do not represent modern materials or the focus on durability
- Some change with AASHTO's PEM program however there are questions on costs, training, what makes a test better, etc.
- Need for rapid, low cost, accurate

Four Step Approach Toward Performance

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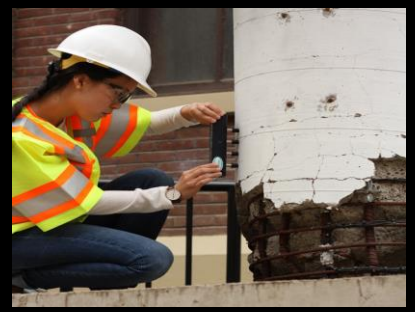


Assess Performance w/ Standard Tests

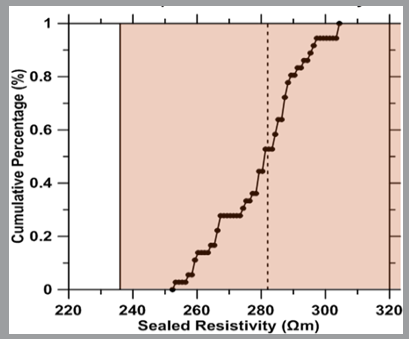
Tests should be:
- easy to perform
- economical
- repeatable

Convert Test Results to Fundamental Properties

Example:
- Measure ρ
- Account for Pore Solution
- Determine F- Factor

Relate Properties w/ Exposure Conditions

Use Exposure, Material Properties, and Models to Estimate Performance



Establish Performance Grade and Measure

Set Performance Limits and Use Tests to Measure to Insure That You Received What you Specified

Barde et al. 2007

Two Types of Tests

Qualification Testing

- Performed for Approval
- Relatively Fast
- Assess “Mixture/Materials”

Production Tests

- Performed During Production
- Must be Fast and Robust
- Assess Variables in Production

Exposure Conditions

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- US lags behind others in defining exposure conditions
- Even after a ‘major advancement’ in the building codes - still far from defined

- Now the exposure is based in concept and is not linked with performance models
- Improving exposure conditions/durability expert requirement would advance ‘getting the right mixture’

Look at Life Cycle Cost

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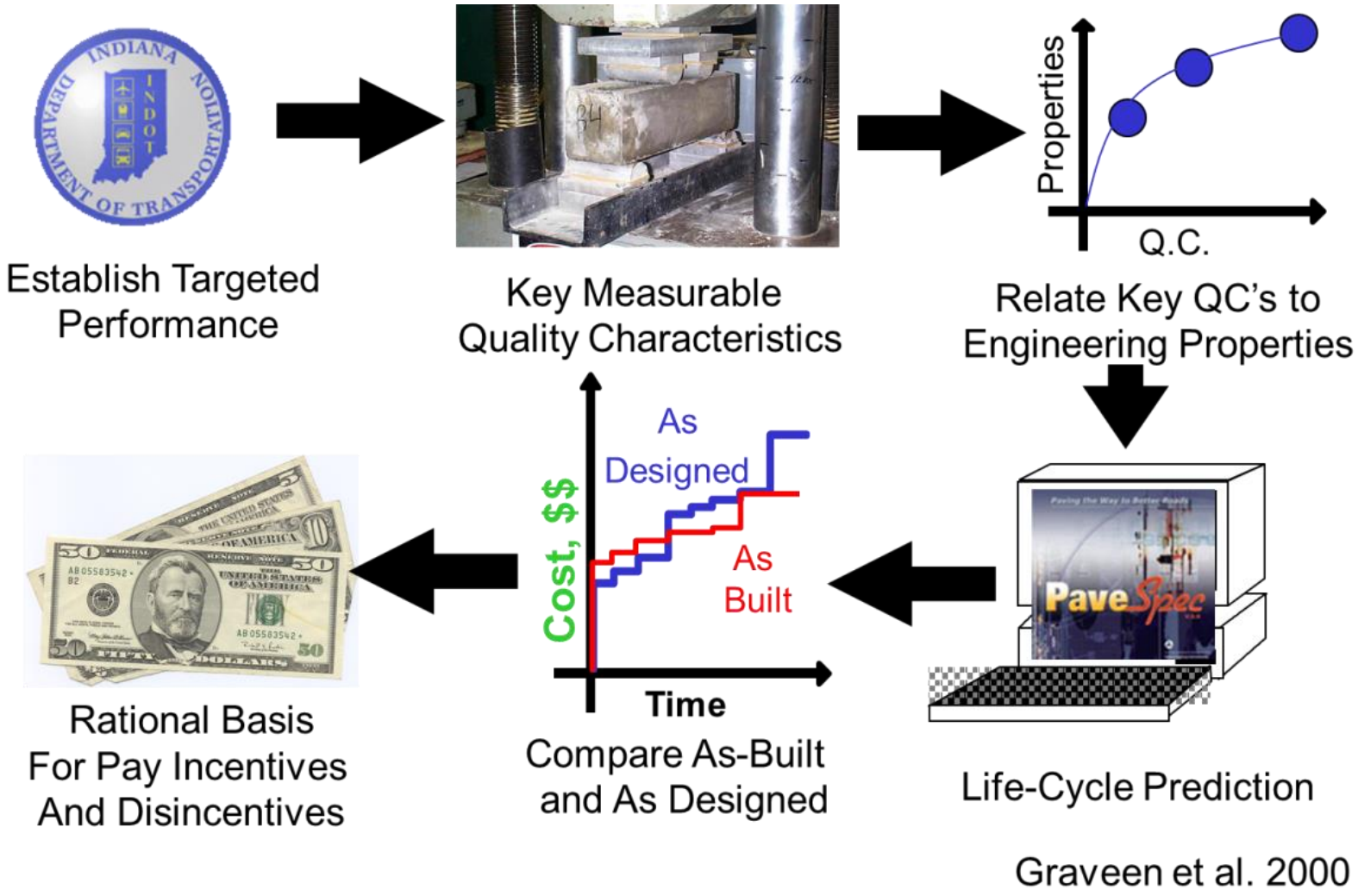
- PRS/PBS/PEM approaches are often discussed; however we need data to improve models
- Pavements built in 1999-2002 but data missing



Graveen et al. 2000

Test Beds, Independent, and System Evaluation

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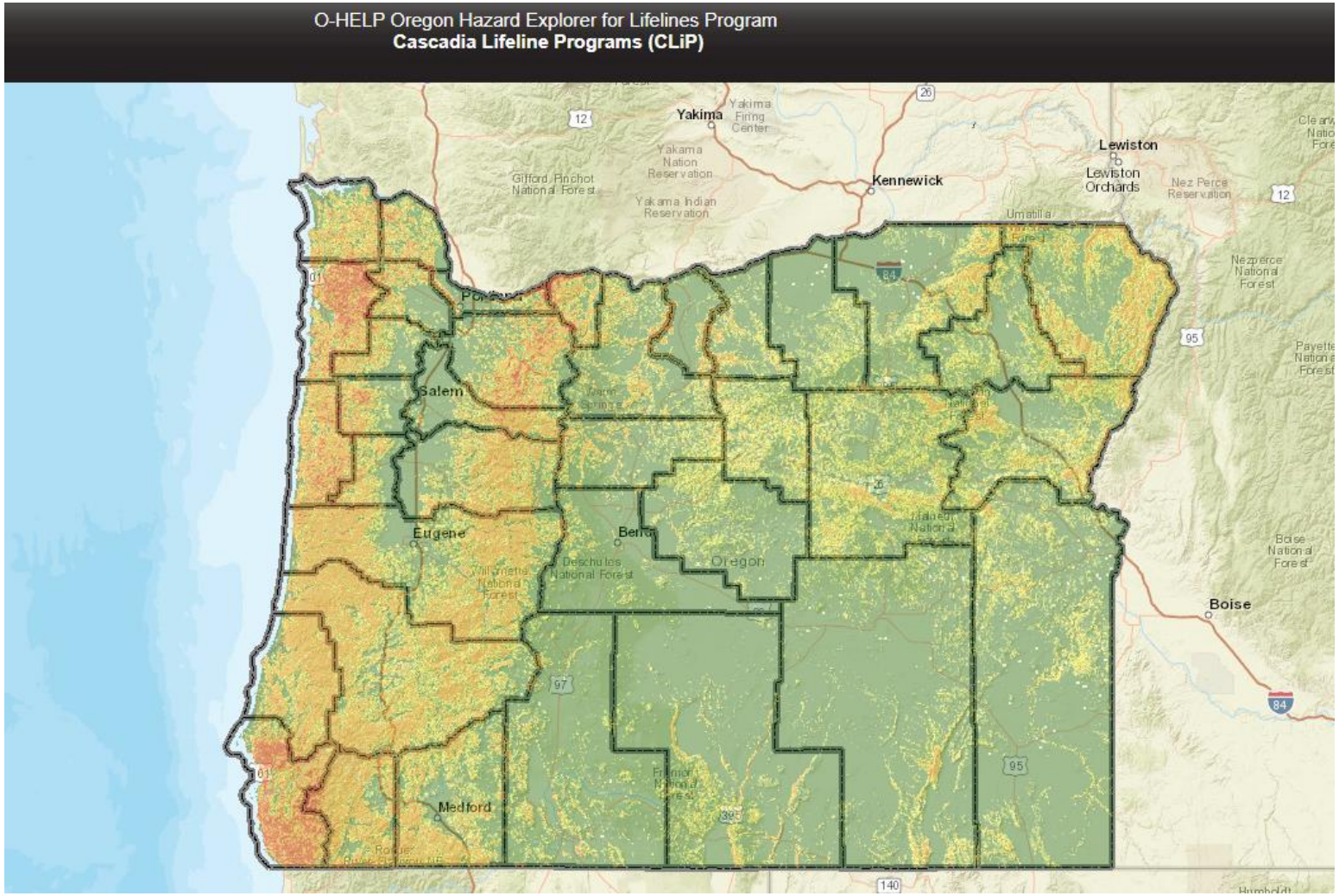
- Despite widespread impact, widespread evaluation is done
- Can we develop test beds for evaluation



Think about Models

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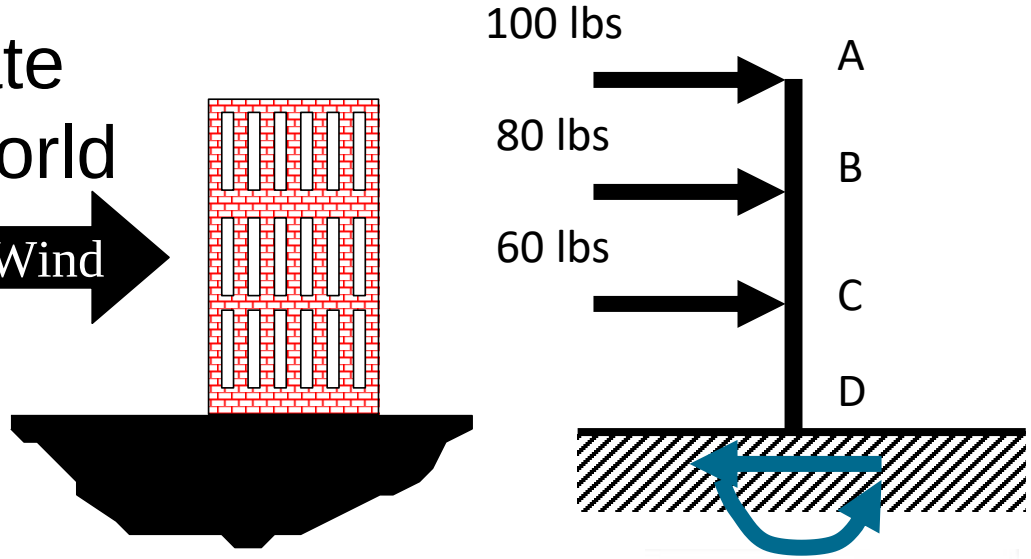
- **Idealization -** Creating an Approximate Mathematical Model to Assess the World
- **Example** - How Forces Act on A Structure and Cause Deformations
- **Not Exact** – Engineers Must Understand Approximations etc...



- **All models are wrong, but some models are useful**. (G. Box)
- Can models push us in the correct direction, these will improve with time if we have 'good form and inputs'

Weiss et al. 2001

Toward FT SLM

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Develop the Sorption Based Modeling Concept

Relating the saturation level in concrete to a theoretical critical limit of saturation

Develop Testing Procedures to Evaluate Concrete Mixtures

Developed Testing for Critical Saturation, Absorption, and Degree of Saturation

Evaluate Properties of Typical Paving Mixtures

Measuring typical values of the properties of typical pavements

Work with SHA's on Shadowing Field Projects for PEM/PRS

Implementing Shadow Specifications in 17/18

Add in Statistical Variation To Assess Reliability

Using Monte Carlo Simulation of Measured Properties to Relate Variability to Life

Weiss et al. 2017


Research
Practice

Research and Adoption

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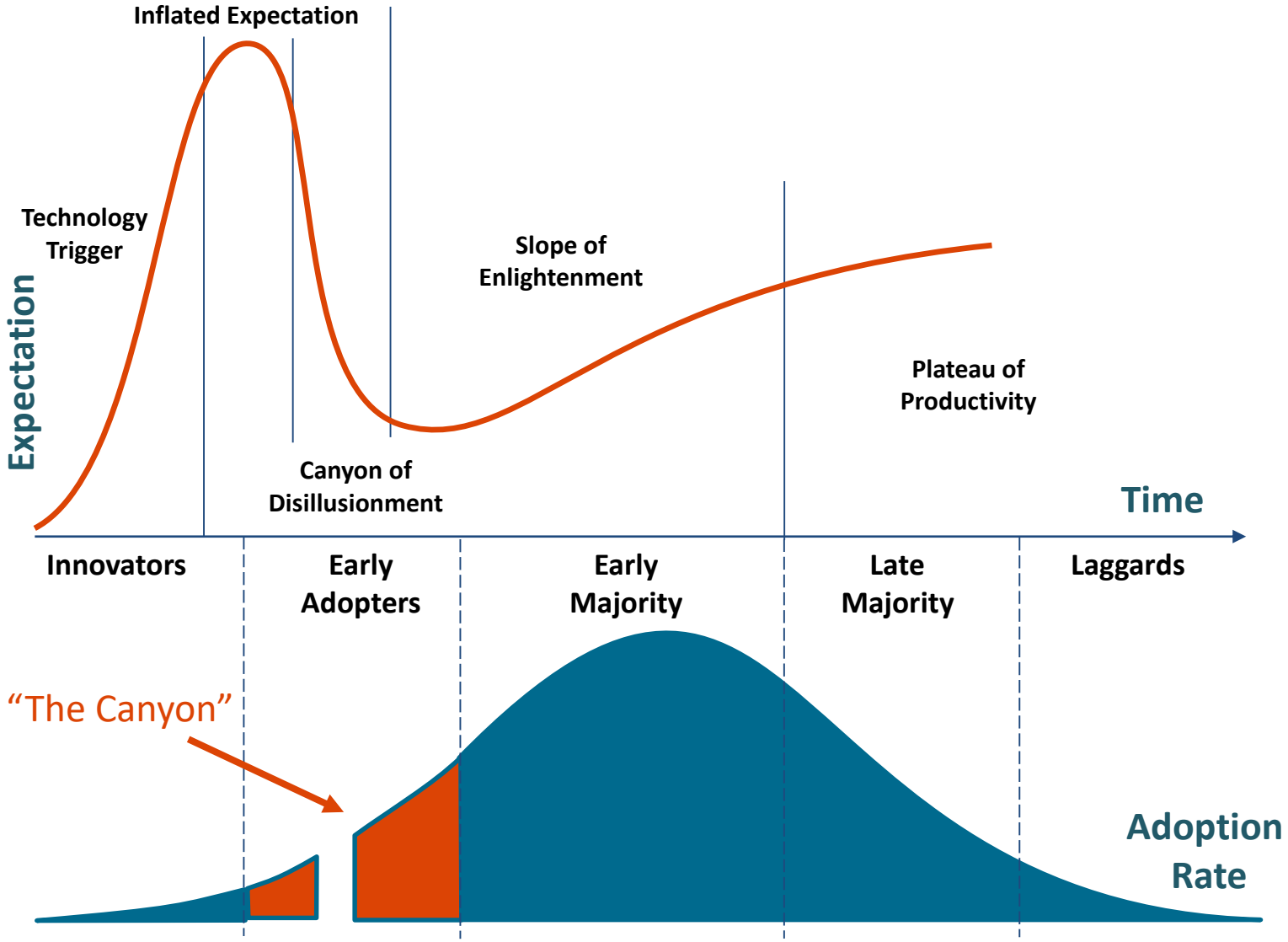

- Hype Cycle
- Many times innovative research occurs but stalls at the 'canyon'
- How do we make it past this gap or minimize this gap

Potential Technologies (But … consider size)

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- Portland Limestone Cement + Supplementary Cements
- Self Consolidating Concrete
- Extrusion and Printing
- Internal Curing
- Nano Materials
- UHPC
- Geopolymers
- Carbonated Silicates

Change is not Easy

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Challenges

- New Tests to learn and possibly revise
- Data to collect
- May have to abandon some existing rules of thumb
- This will take time
- Education is key.

Opportunity

- Enormous potential exists to make the product more durable & quantifiable
- Potential to reward innovation and increase smart use ($, RM, CO_2)

Summary

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- Many desire developing ‘new materials’ however we need to carefully consider volumes and adoption
- Great strides in $, RM, Energy, CO_2 savings can be made by improving how we account for durability
- Fitness for exposure and removing early failures
- Field durability tests; levels of complexity
- Improving exposure and linking with models
- Need for service life test beds and ‘validation standards’

Concrete Chivalry ?

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Photo Weiss 2011