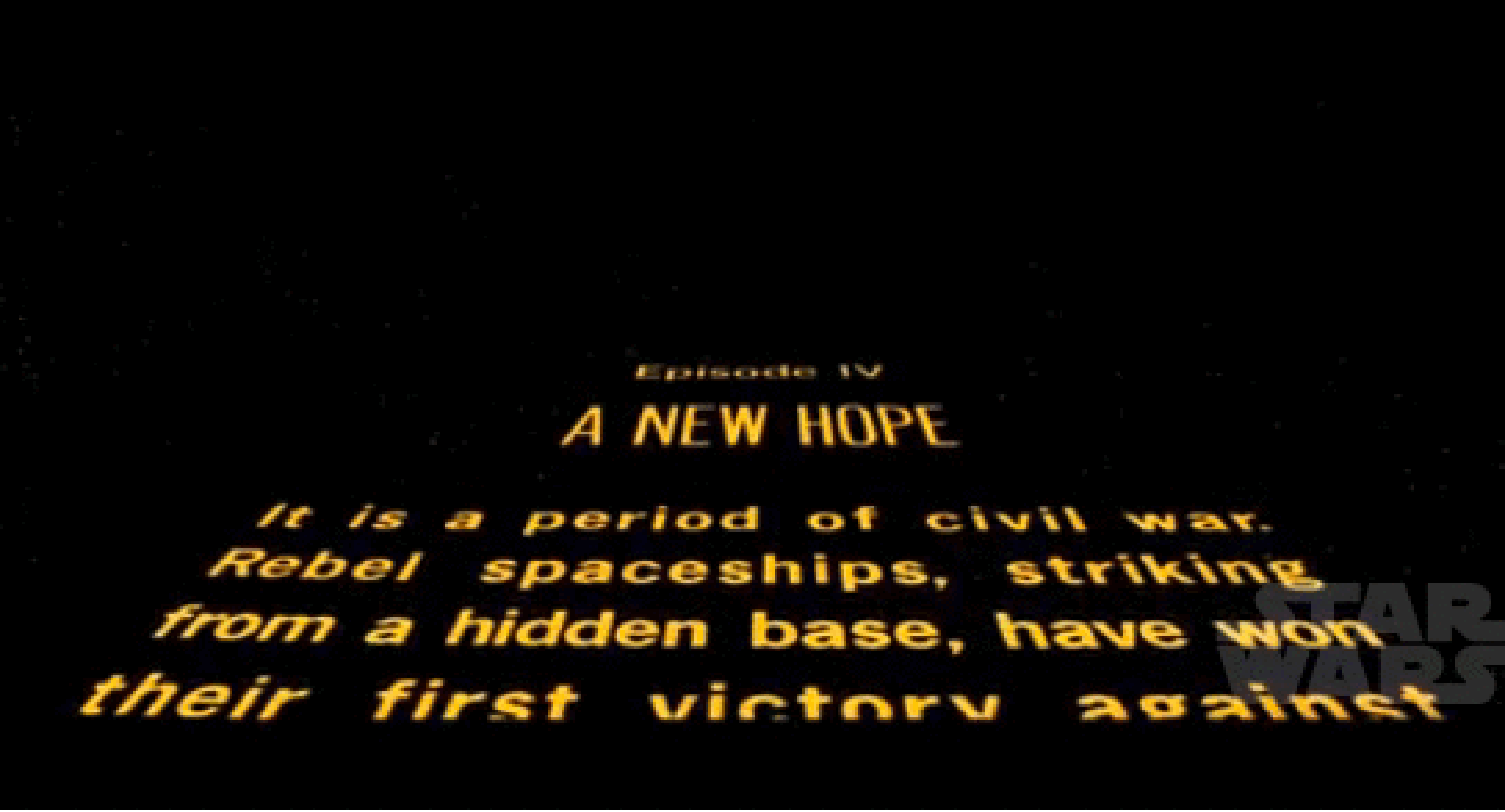
The Formation Factor

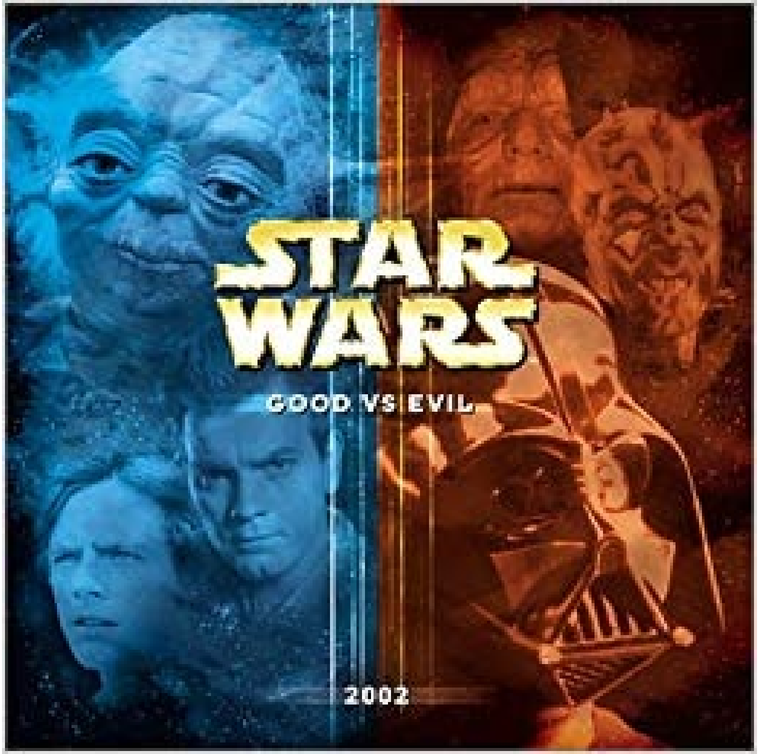
Jason Weiss
Oregon State University

April 2nd 2019


Episode IV
A NEW HOPE
It is a period of civil war.
Rebel spaceships, striking
from a hidden base, have won
their first victory against

A Challenge at Hand

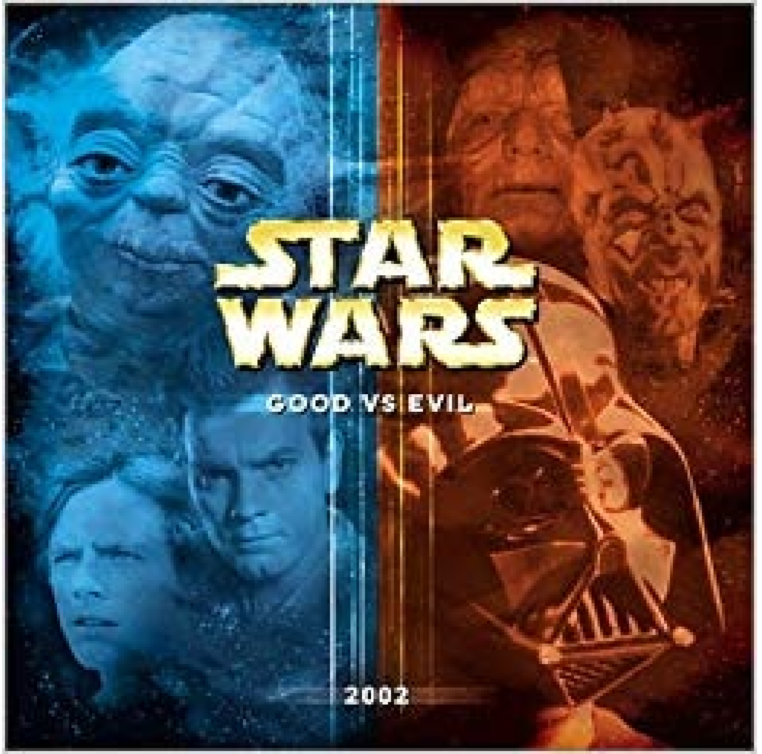
Oregon State University
College of Engineering



The Challenge

A Challenge at Hand

Oregon State University
College of Engineering

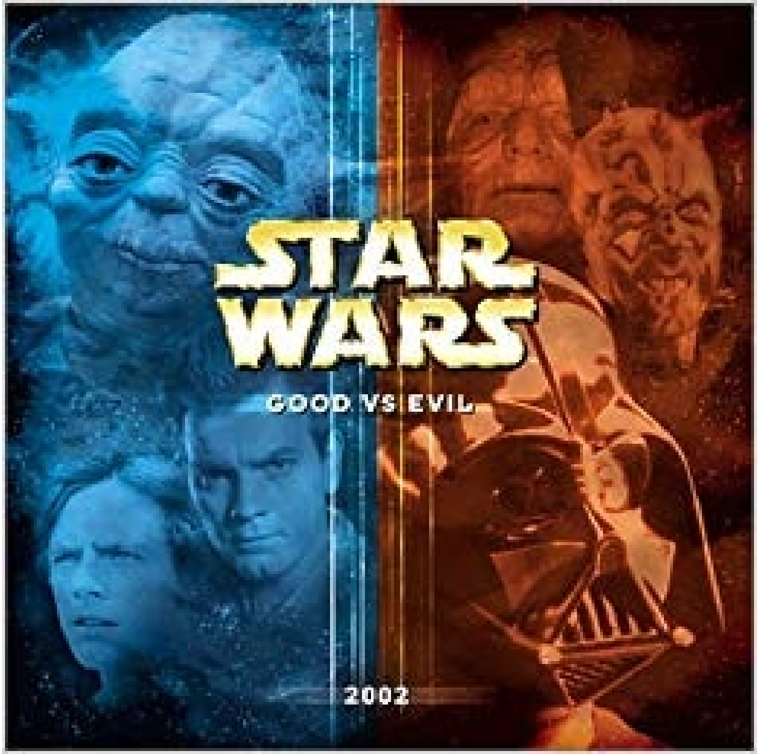


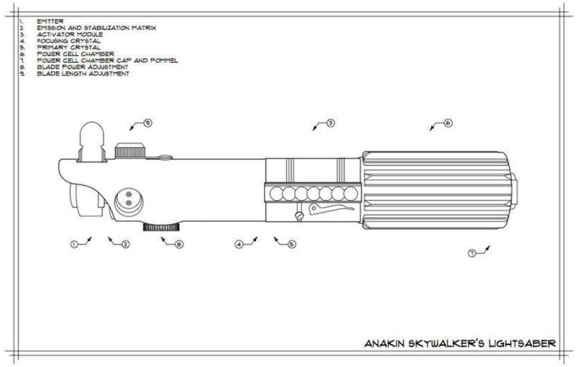
The Hero

The Challenge

A Challenge at Hand

Oregon State University College of Engineering





The Hero

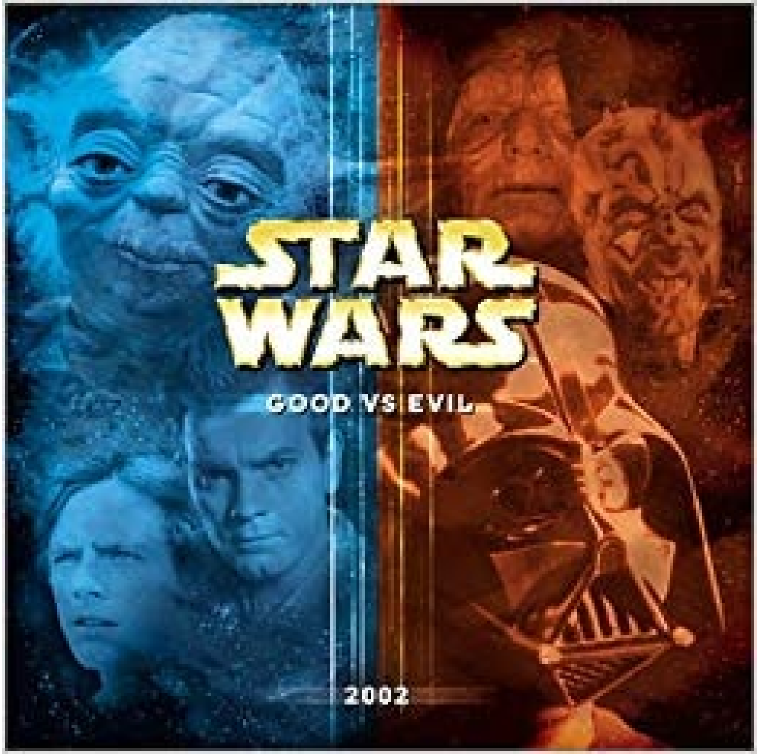
The Challenge

The Tools

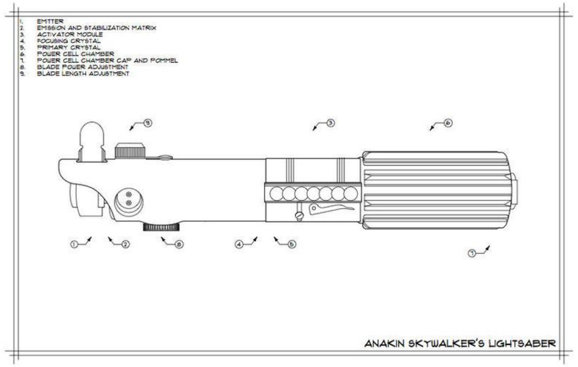
A Challenge at Hand

Oregon State University
College of Engineering

The Hero



The Challenge



Use The Force
You Must

Our Challenge at Hand

Our Challenge

Our Challenge at Hand

Our Heros

Our Challenge

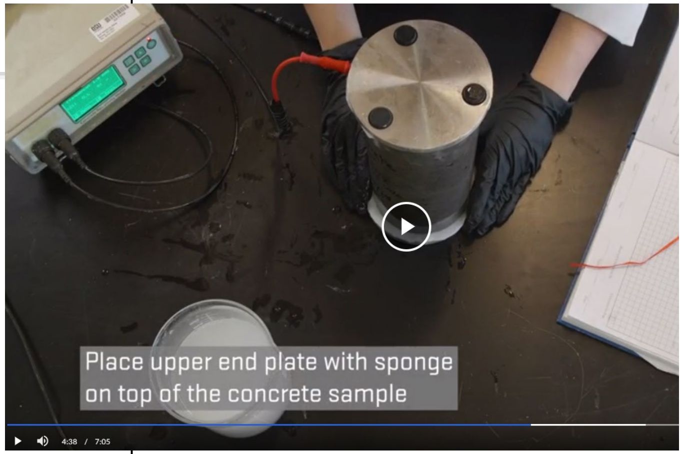
Our Challenge at Hand

Oregon State University
College of Engineering


Standard Practice for

Developing Performance Engineered Concrete Pavement Mixtures

AASHTO



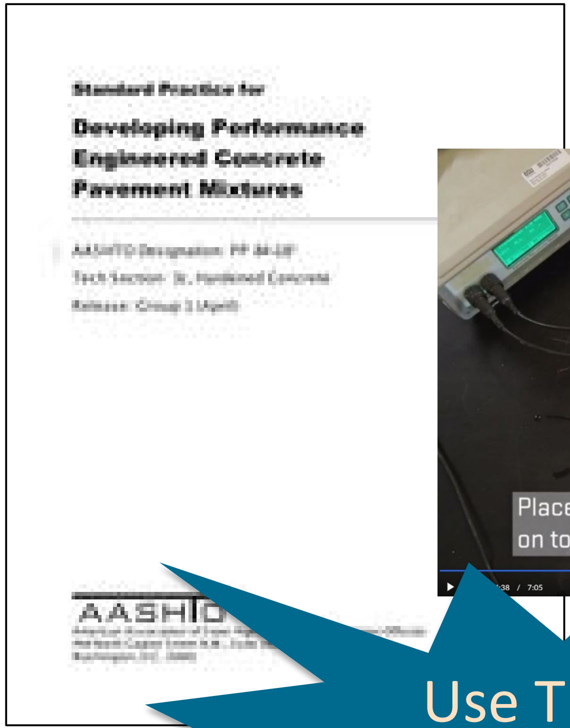
Our Heros

Our Challenge

Our Tools

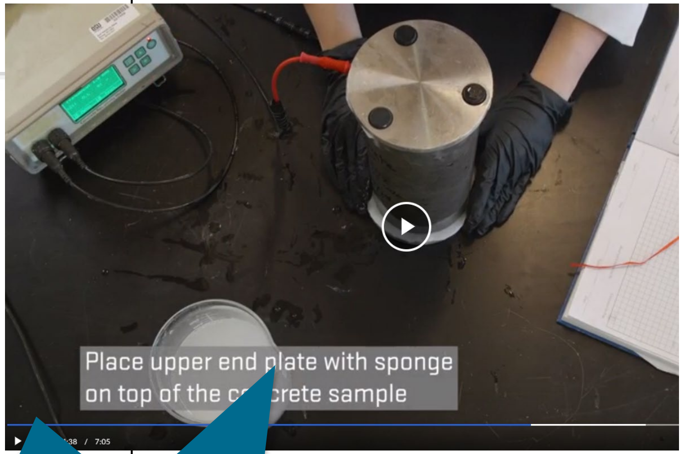
Our Challenge at Hand

Oregon State University
College of Engineering


Standard Practice for

Developing Performance Engineered Concrete Pavement Mixtures

AASHTO



Use The F-Factor You Can

Our Heros

Our Challenge

Before We Can Make Use New Specifications

Oregon State University
College of Engineering

Before We Can Make Use New Specifications

Oregon State University
College of Engineering

Before implementing new specifications

Oregon State University College of Engineering

- Learning how to obtain the Formation Factor
- Lets start with resistivity
- The test is ‘easy’ but details are important
- Sample conditioning is key
- Identified 4 methods and discussed in Idaho (listed in proposed TP119 revisions)

I - Geometry is key

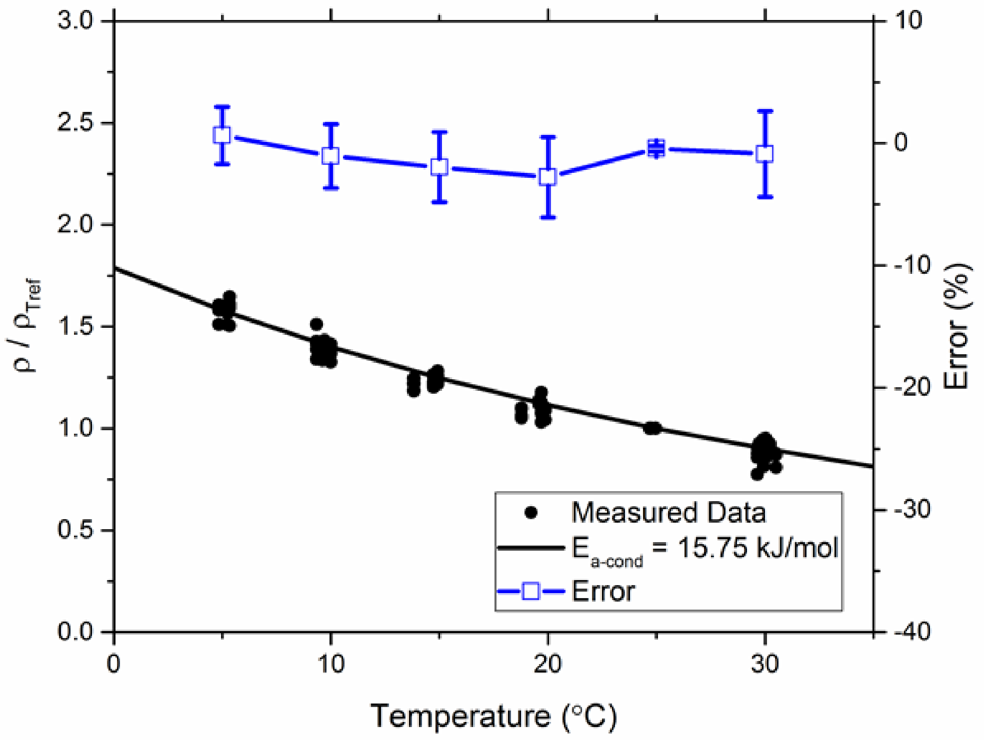
Oregon State University College of Engineering

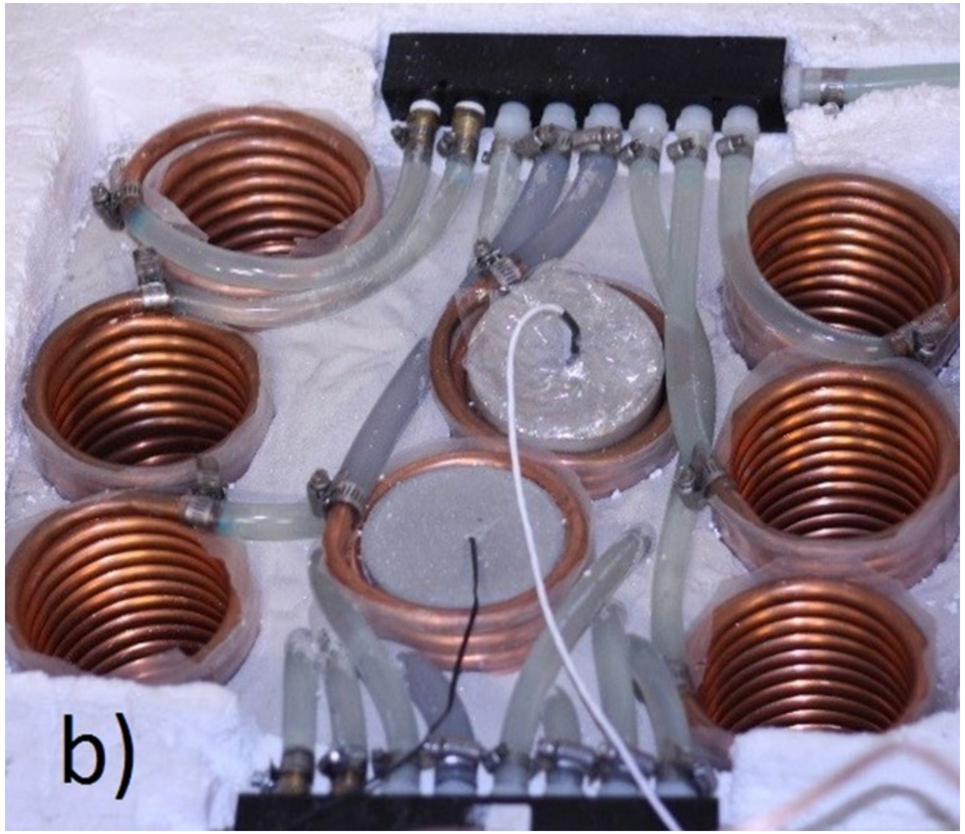
- There are ‘three geometries’ frequently used
- With proper geometry conditioning, all are similar

- There are two AASHTO test standards; the primary issue in repeatability is related to conditioning
- Temperature, Moisture, Leaching, Degree of Saturation

II – Temperature is Important

Oregon State University
College of Engineering





$$\rho_{Tref} = \rho_T \, exp\left[\frac{-E_{a-cond}}{R}\left(\frac{1}{T+273} - \frac{1}{T_{ref}+273}\right)\right]$$

III – Curing and Conditioning

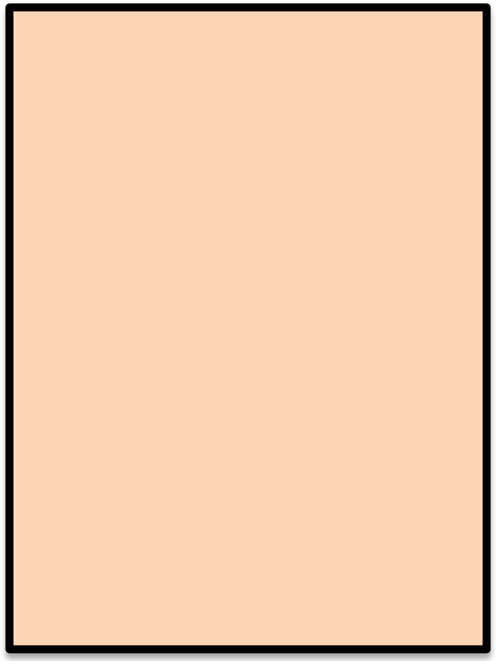
Oregon State University
College of Engineering

- Option 1 - "The Bucket Test"
- ~~Option 2 - Sealed Samples (Not Today)~~
- ~~Option 3 – Vacuum Saturation~~
- ~~Option 4 – Moist Curing Room~~

- We will start by describing how to perform the tests using simplified procedures

Option A "Bucket Test"

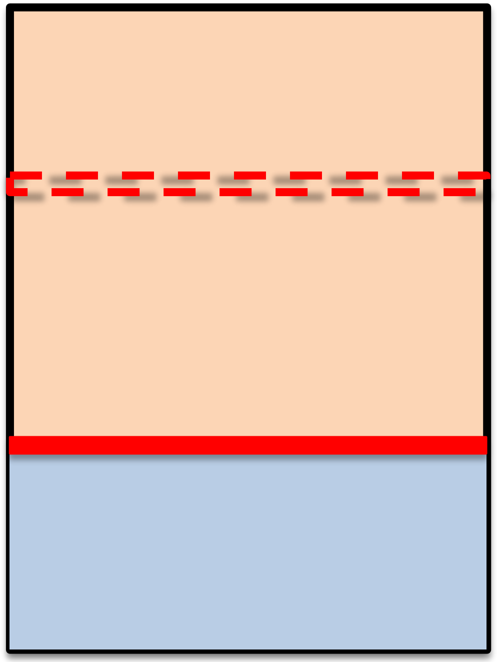
- Begin with a 5 gallon bucket



Option A "Bucket Test"

Oregon State University
College of Engineering

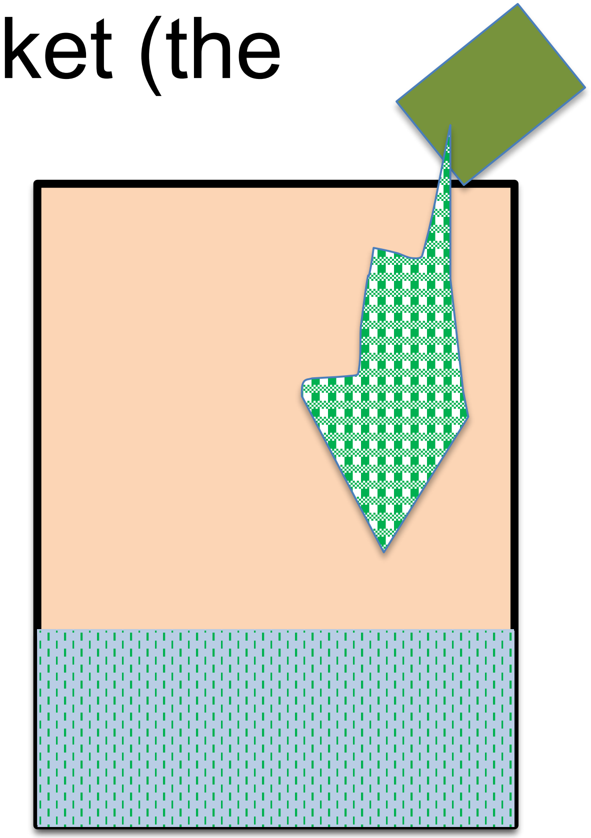
- Begin with a 5 gallon bucket
- Place a specific volume of fluid into the bucket (the solution to sample ratio is important, place a line on the bucket)



Option A "Bucket Test"

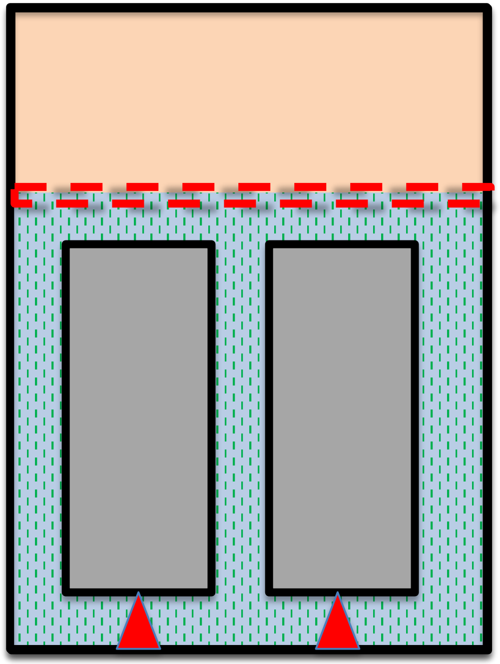
Oregon State University College of Engineering

- Begin with a 5 gallon bucket
- Place a specific volume of fluid into the bucket (the solution to sample ratio is important, place a line on the bucket)
- Place a specified "CH-salt" into the solution (some adjust to the mixture, we suggest selecting a standard value)



Option A "Bucket Test"

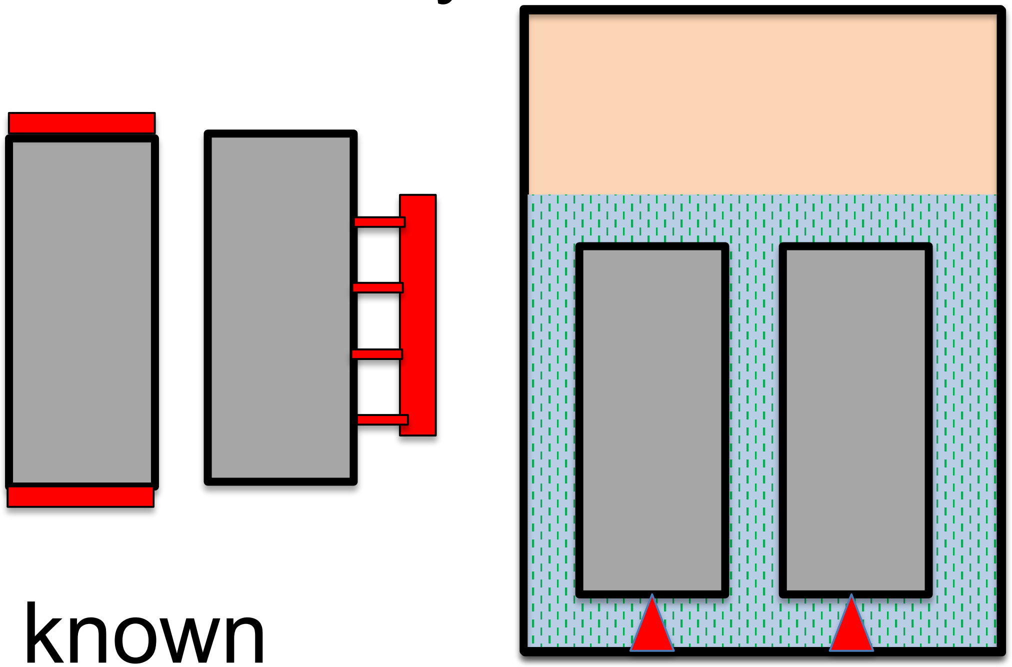
- Begin with a 5 gallon bucket
- Place a specific volume of fluid into the bucket (the solution to sample ratio is important, place a line on the bucket)
- Place a specified "CH-salt" into the solution (some adjust to the mixture, we suggest selecting a standard value)
- Place samples into the solution to allow the solution to reach the entire sample



Option A "Bucket Test"

Oregon State University
College of Engineering

- At select ages remove sample from the bucket, towel/ wash off the surface and perform either the surface resistivity test or the uniaxial bulk resistivity test
- After 5 days in solution the sample is assumed to be in matrix saturation
- This can provide a measure of $\rho_{measured}$ or F_{matrix}
- Conditioning solution $\rho_{solution}$ is known



This is outlined in the AASHTO TP 119 revision

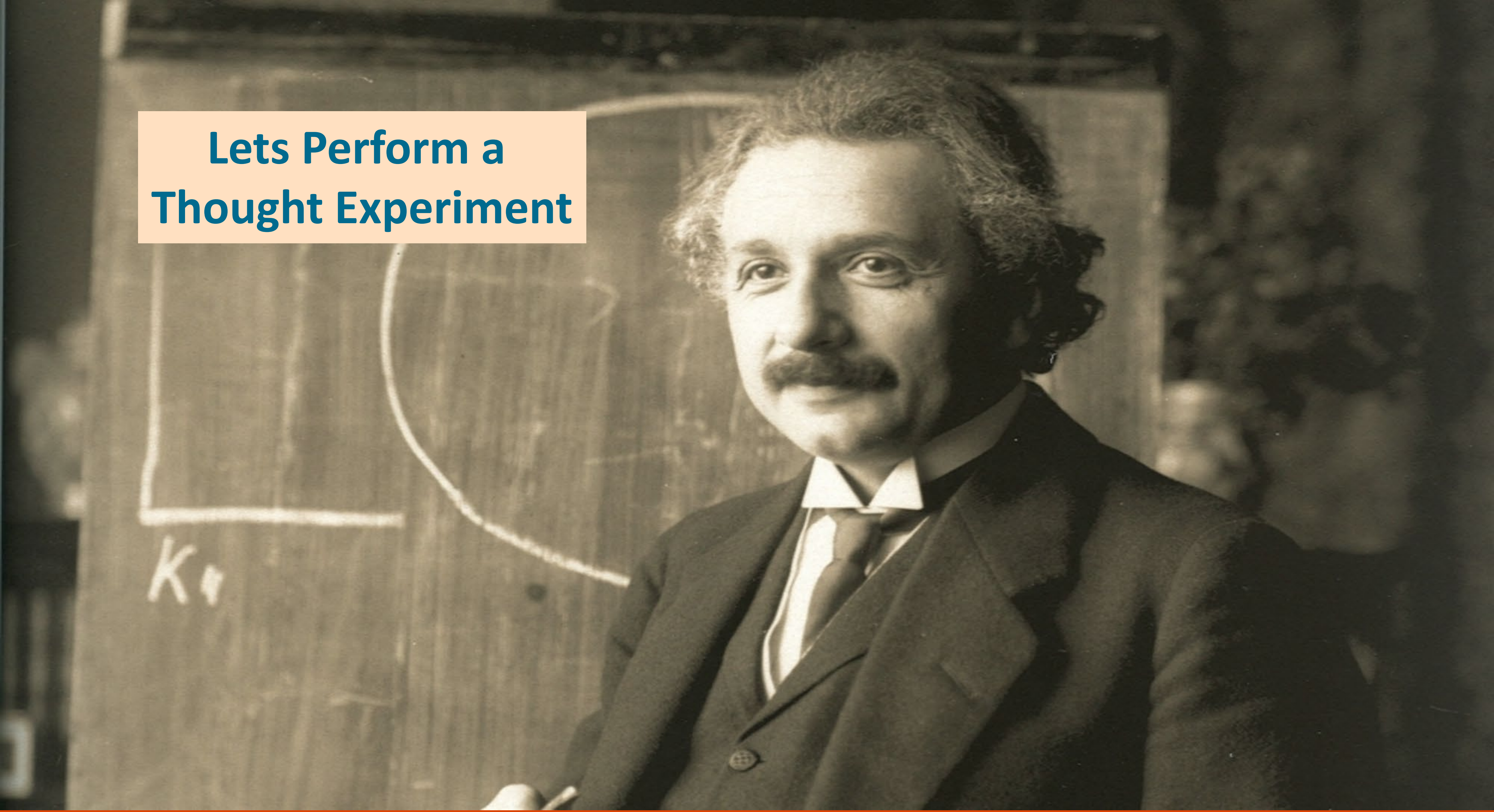
Oregon State University College of Engineering

Things to keep in mind

Oregon State University
College of Engineering

- The bucket with one solution is a compromise that has been made to make this easy to implement as many in the field are struggling to make pore solutions
- The approaches used several years ago matched the solution in the bucket to the concrete
- This is the best way but has been difficult to implement
- The bucket solution is designed as a 40:1 (approx.) solution exchange
- This is an approximation and is documented in reports

Lets Perform a Thought Experiment



Imagine a Chunk of Concrete

Oregon State University
College of Engineering

Lets Compute the RCPT of this concrete

Cl^-

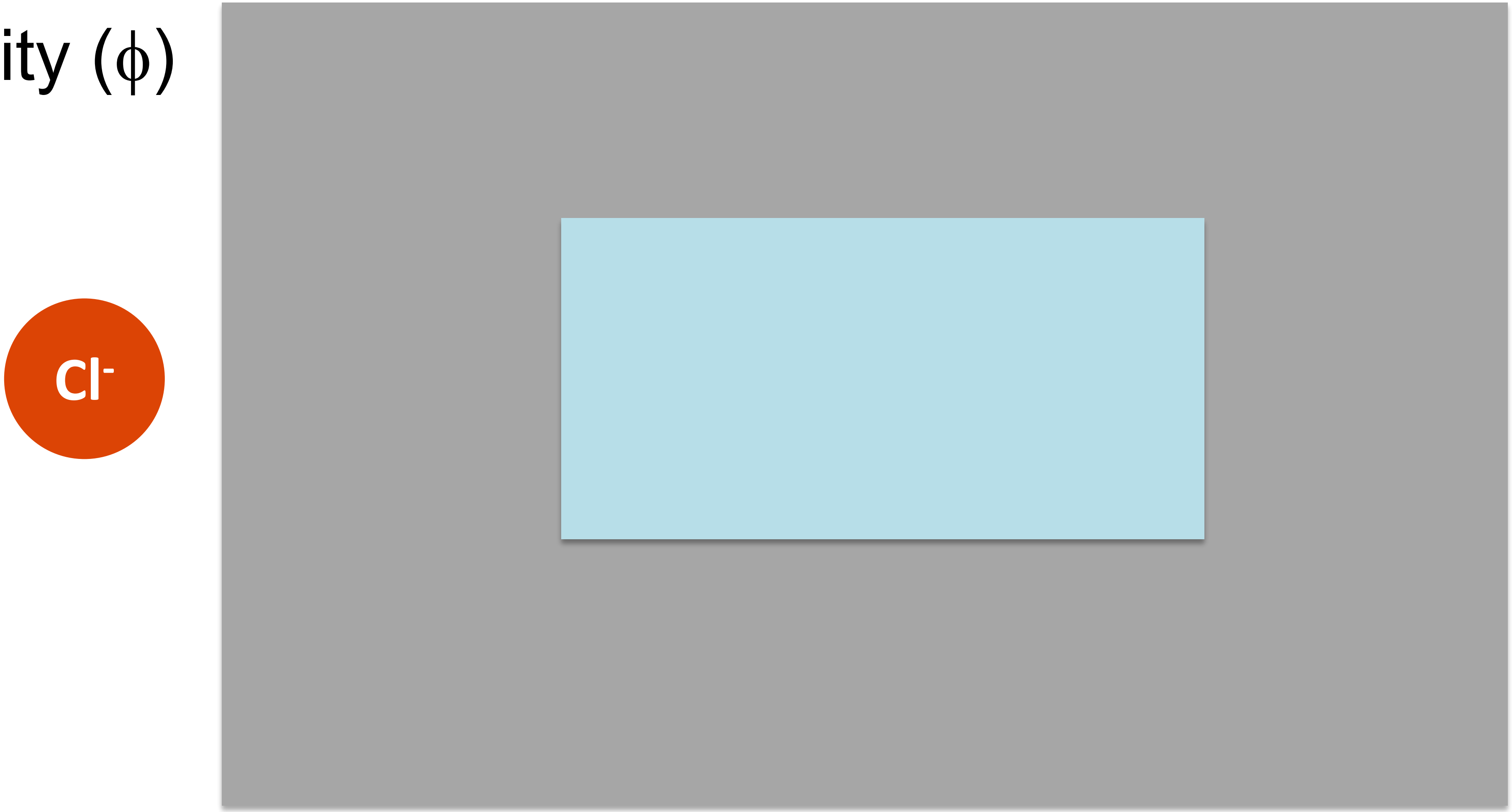
Lets have an ion to conduct

Gray is a non-conductive solid

Imagine a Chunk of Concrete

Oregon State University
College of Engineering

- 20% Porosity (ϕ)

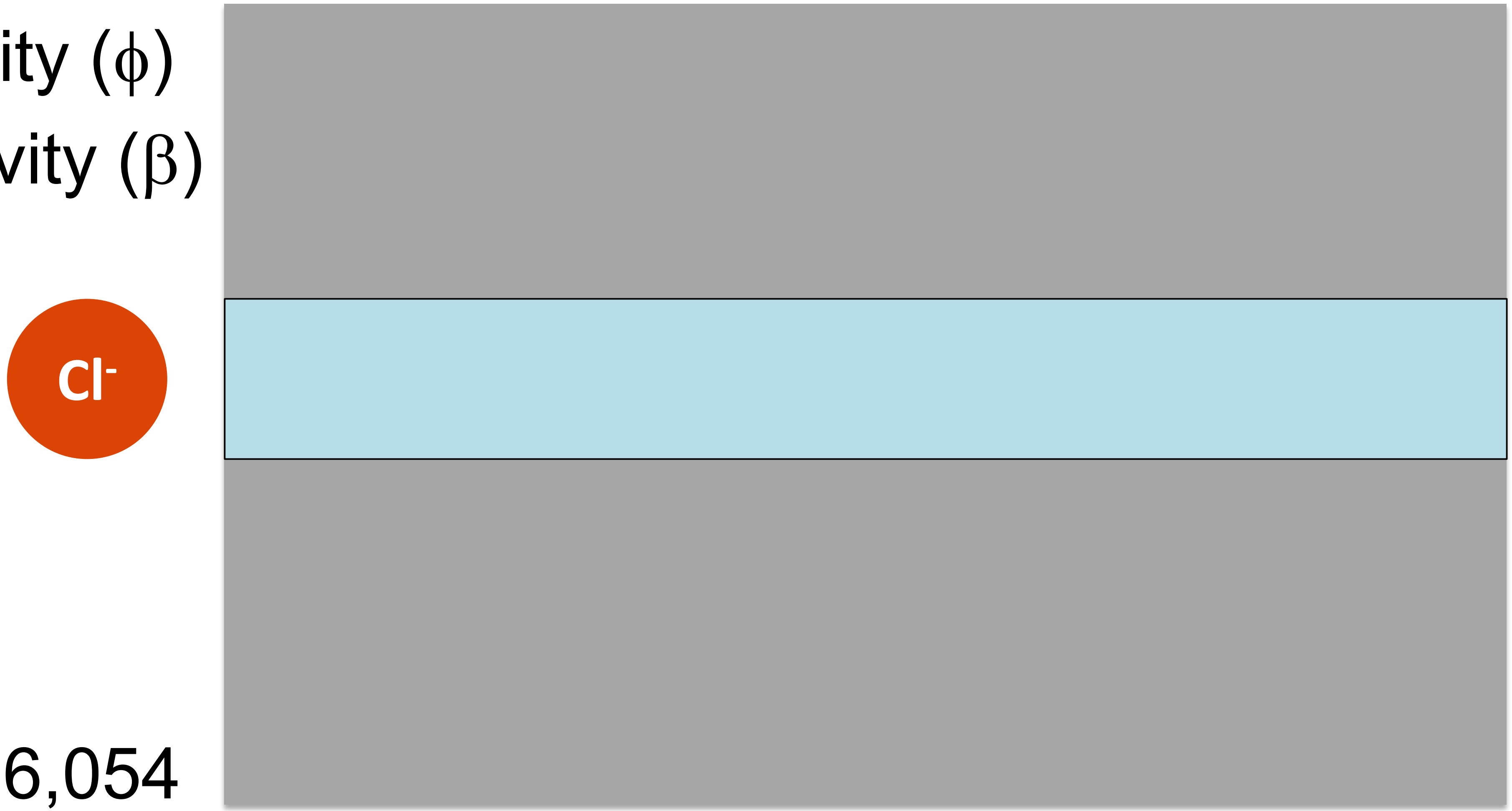


- RCPT = 0

Imagine a Chunk of Concrete

Oregon State University College of Engineering

- 20% Porosity (ϕ)
- 1 Connectivity (β)

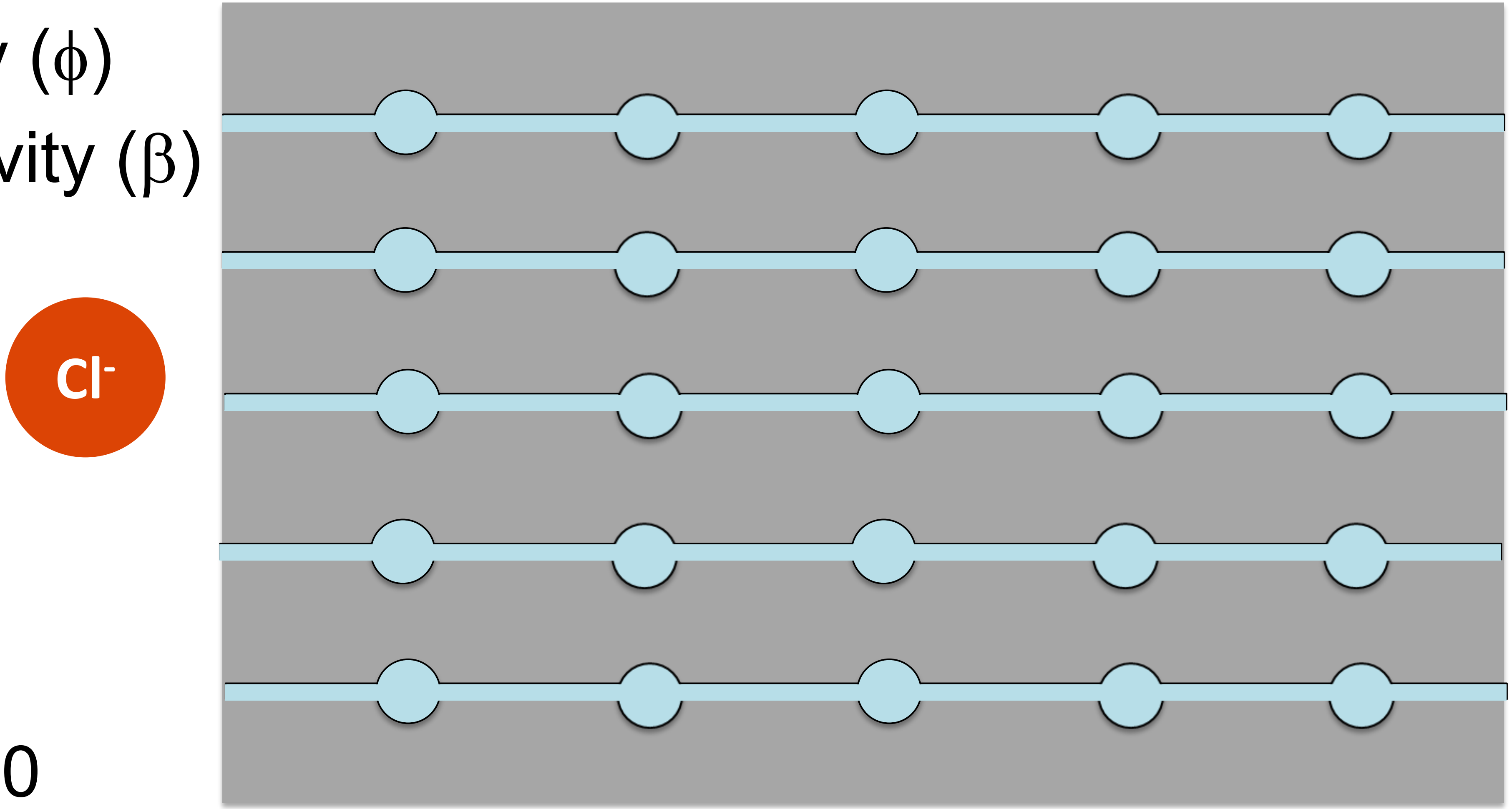


- RCPT = 376,054

Imagine a Chunk of Concrete

Oregon State University College of Engineering

- 20% Porosity (ϕ)
- 0.1 Connectivity (β)

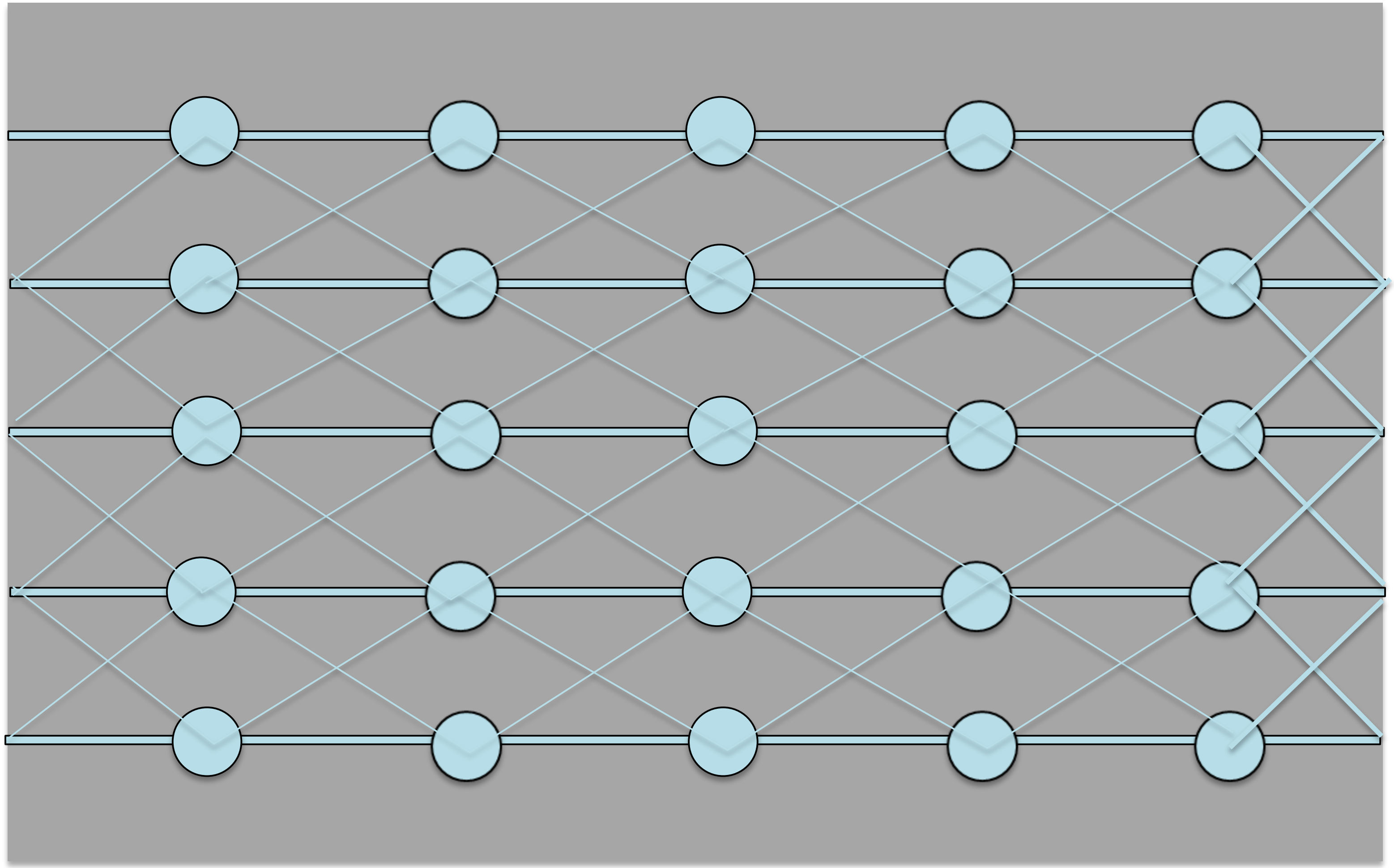


- RCPT = 3,760

Imagine a Chunk of Concrete

- 20% Porosity (ϕ)
- 0.004 for a value of Connectivity (β)

Cl^-



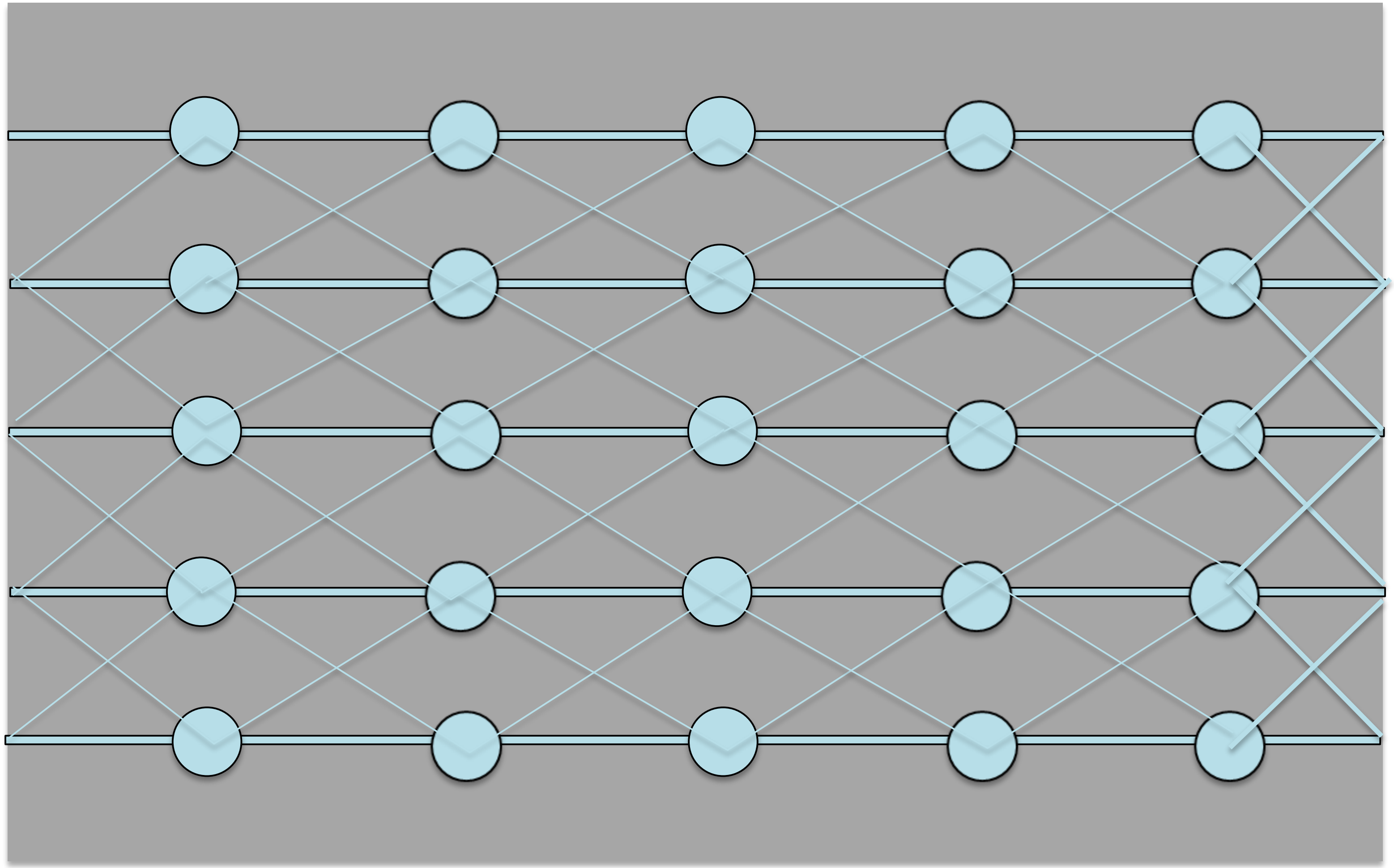
- RCPT = 1500

Change Alkali Content

Oregon State University College of Engineering

- 20% Porosity (ϕ)
- 0.004 for a value of Connectivity (β)
- Double the alkali content of the cement

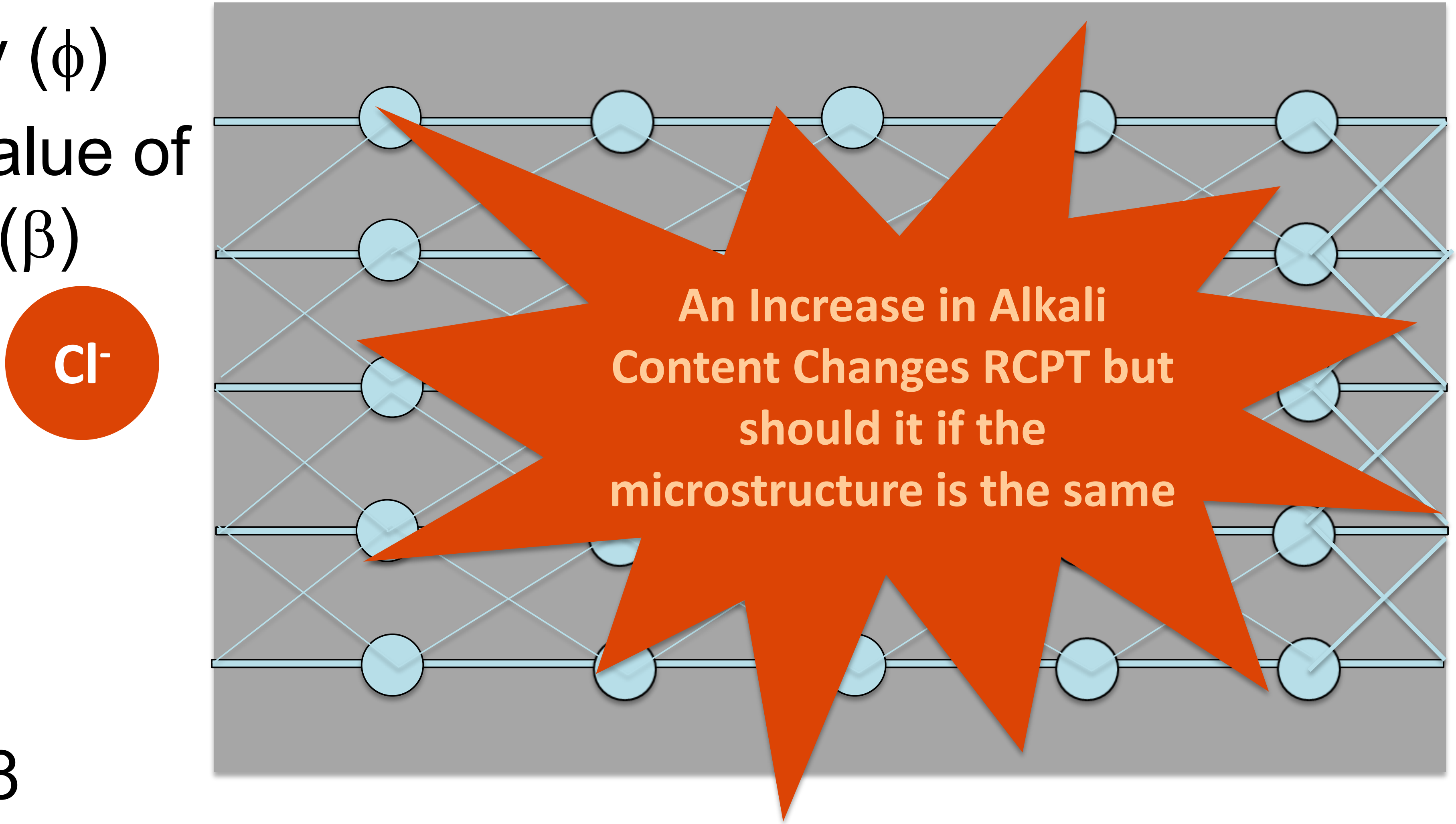
Cl^-



- RCPT = 3008

Change Alkali Content

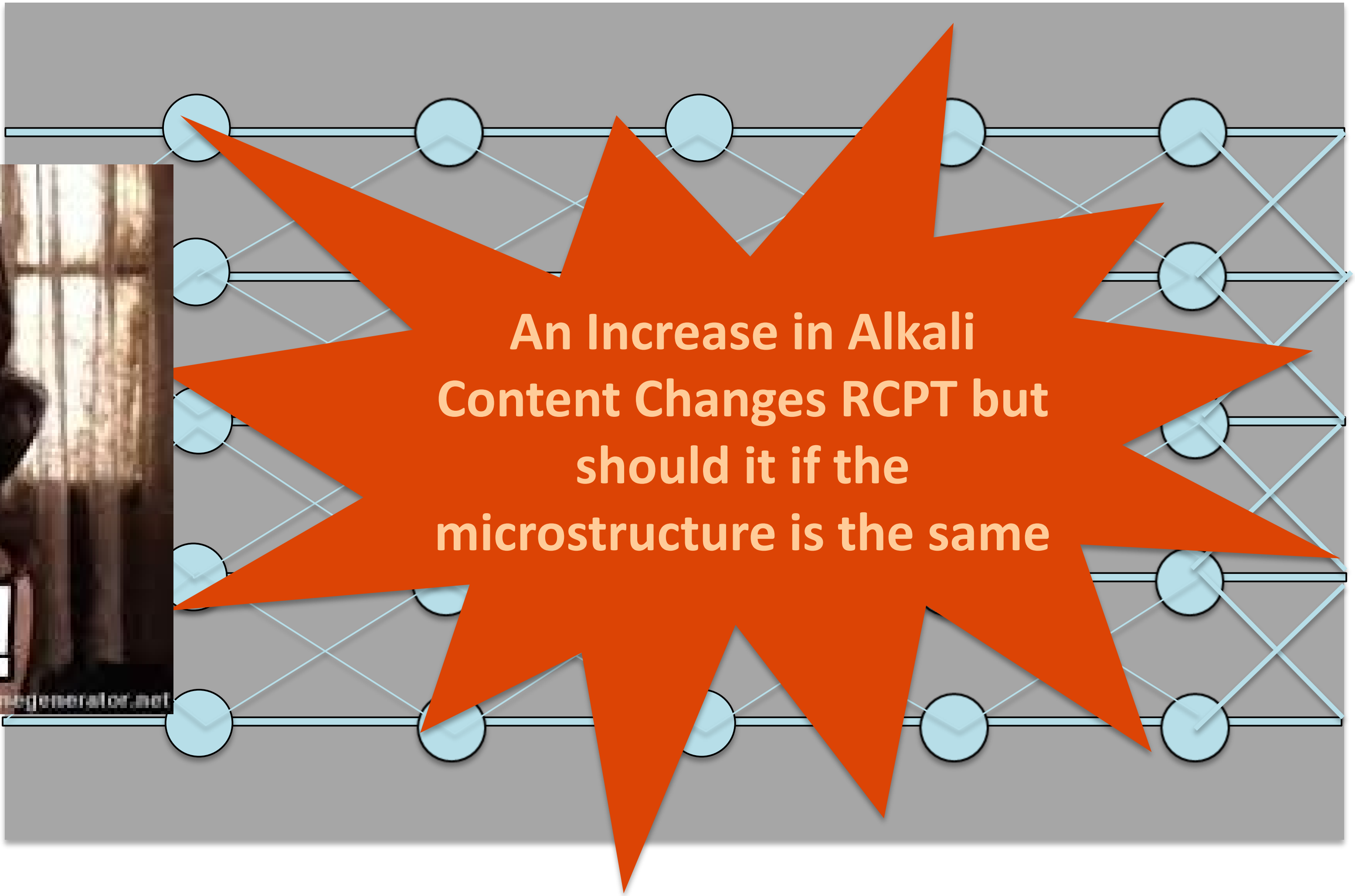
- 20% Porosity (ϕ)
- 0.004 for a value of Connectivity (β)
- Double the alkali content of the cement
- RCPT = 3008



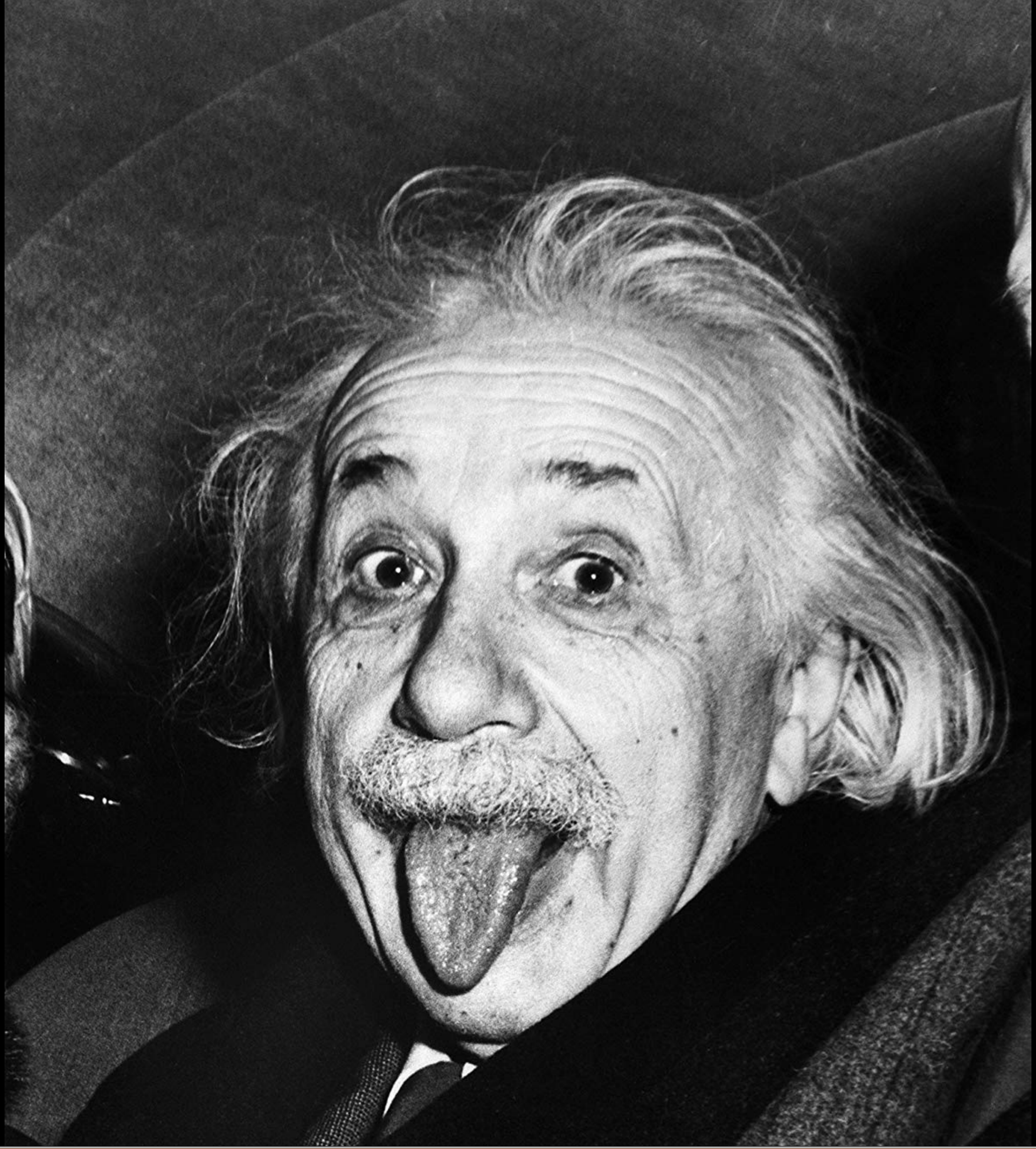
Change Alkali Content

Oregon State University
College of Engineering

- 20% Porosity (ϕ)
- 0.004 for a value of



- RCPT = 3008

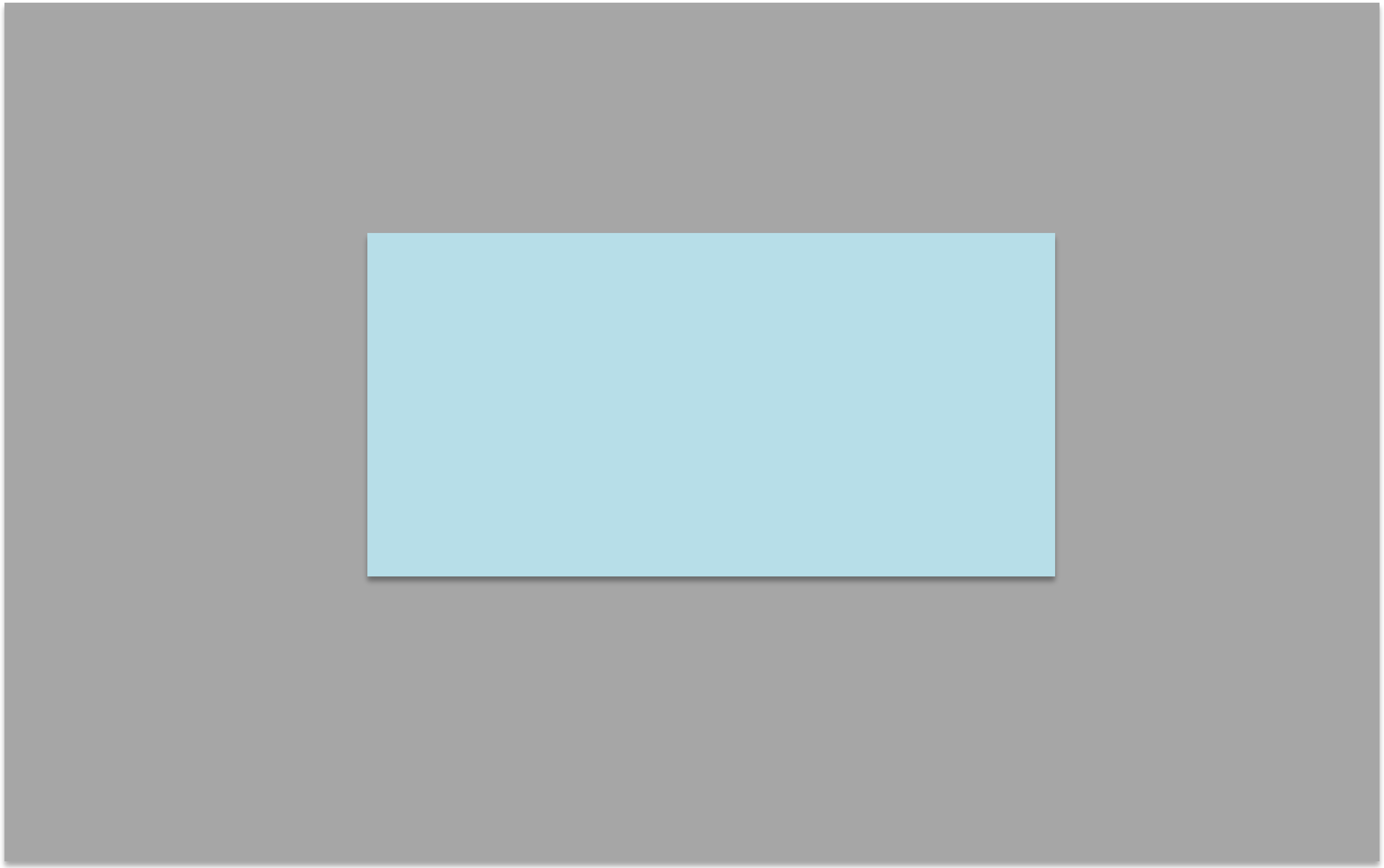


Lets Perform a Thought Experiment But Lets Use the Formation Factor This Time

Imagine a Chunk of Concrete

Oregon State University
College of Engineering

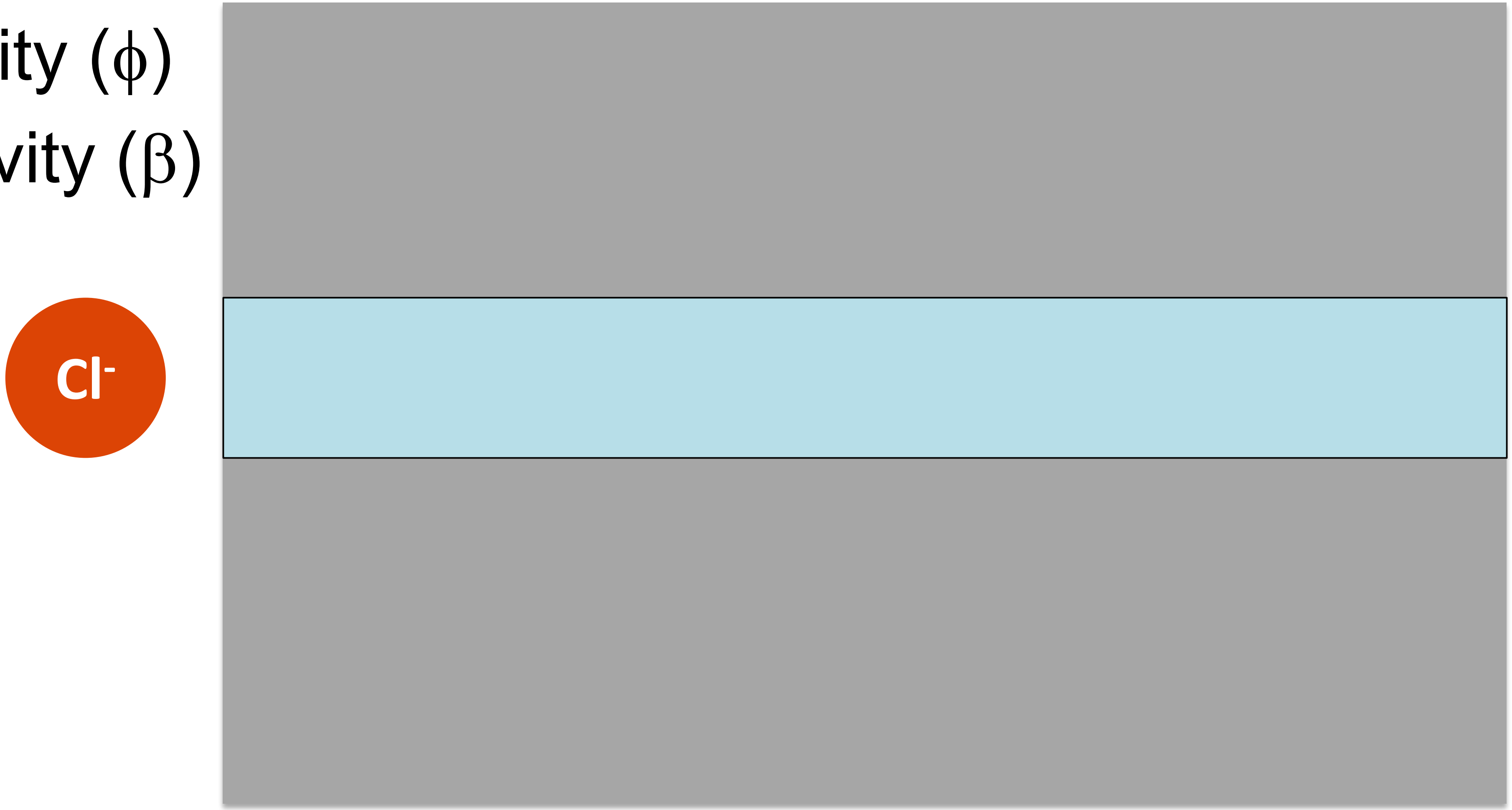
- 20% Porosity (ϕ)



- $F = \infty$

Imagine a Chunk of Concrete

- 20% Porosity (ϕ)
- 1 Connectivity (β)

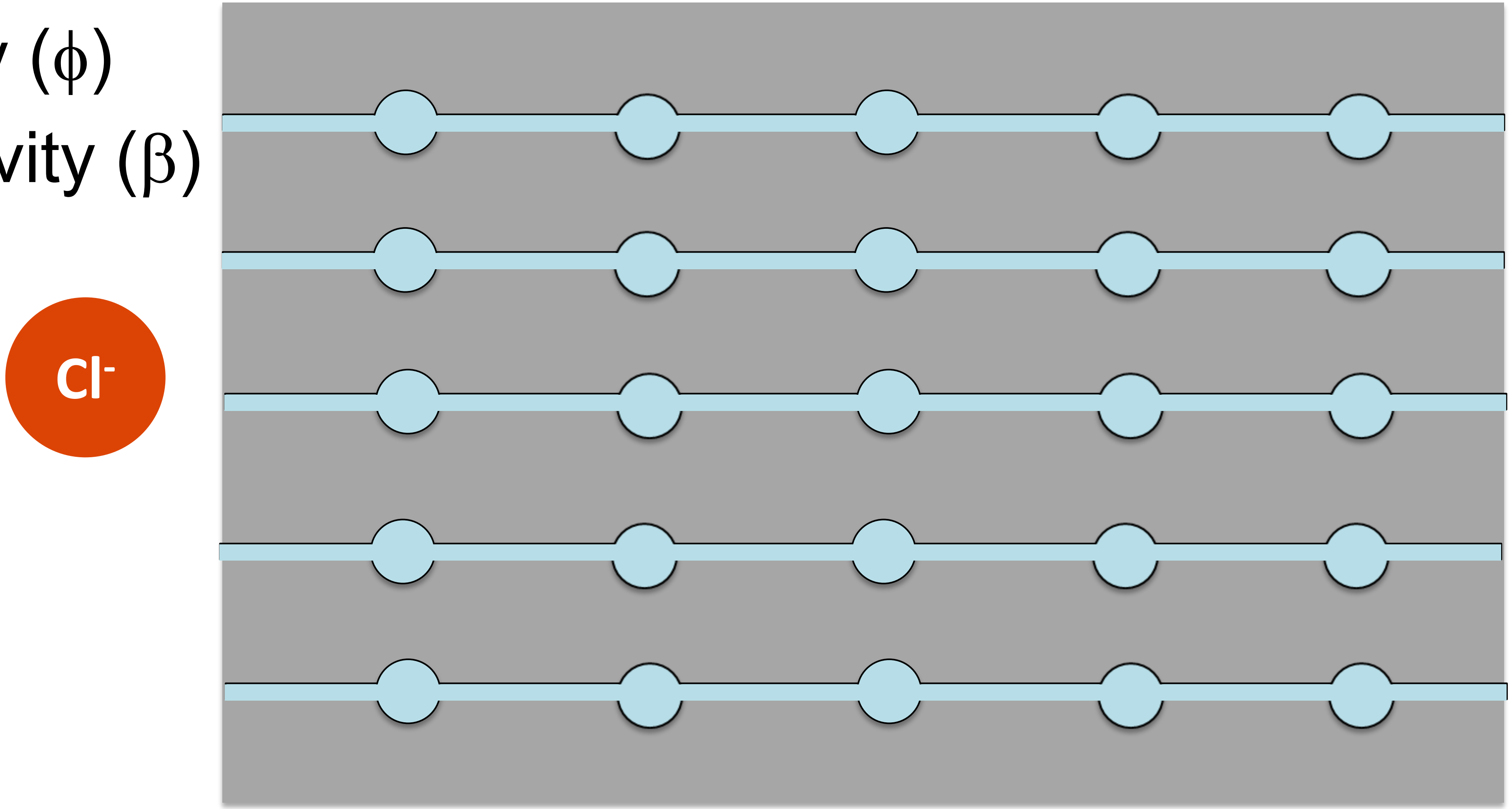


- F = 5

Imagine a Chunk of Concrete

Oregon State University
College of Engineering

- 20% Porosity (ϕ)
- 0.1 Connectivity (β)



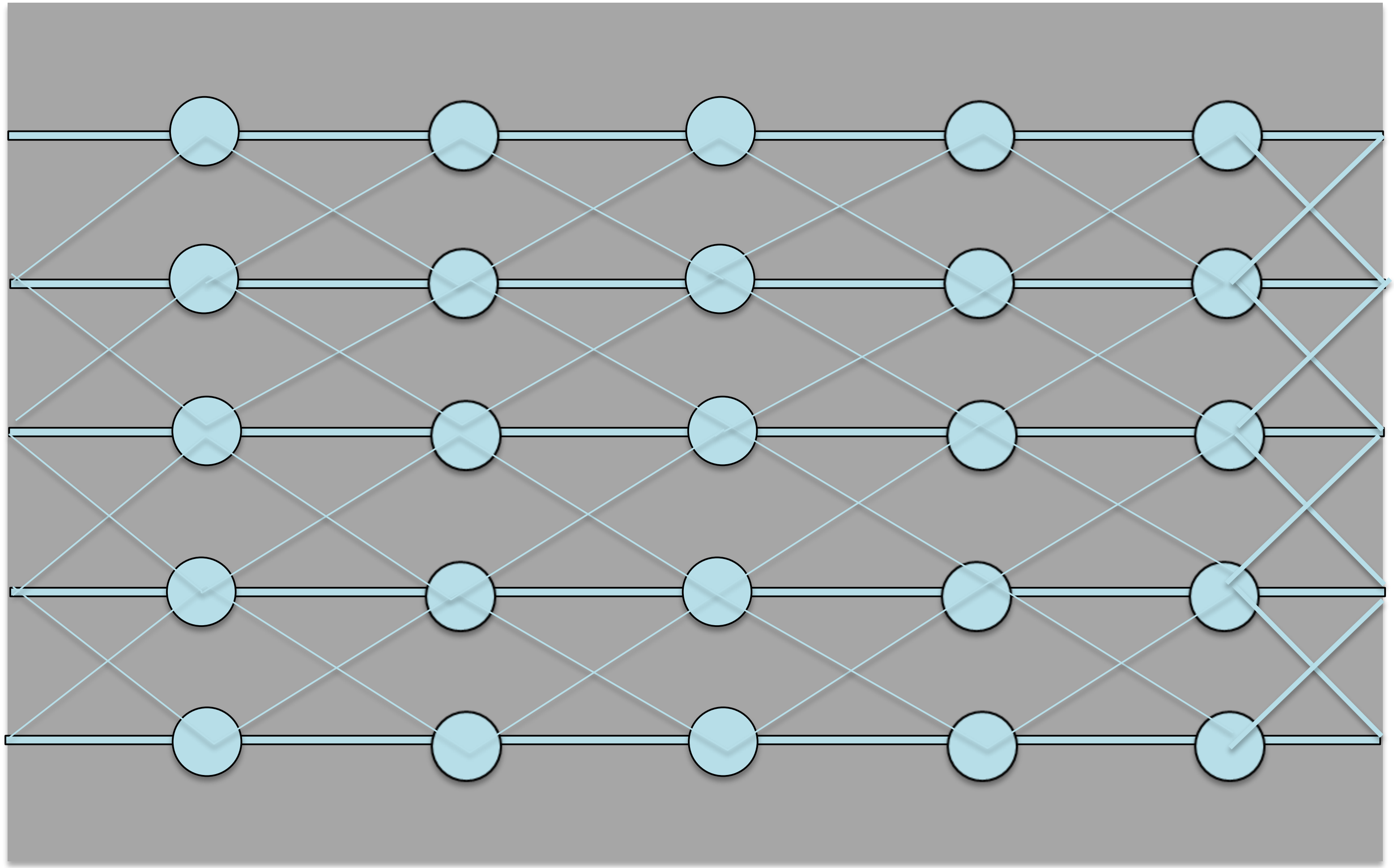
- F = 50

Imagine a Chunk of Concrete

Oregon State University
College of Engineering

- 20% Porosity (ϕ)
- 0.004 for a value of Connectivity (β)

Cl^-

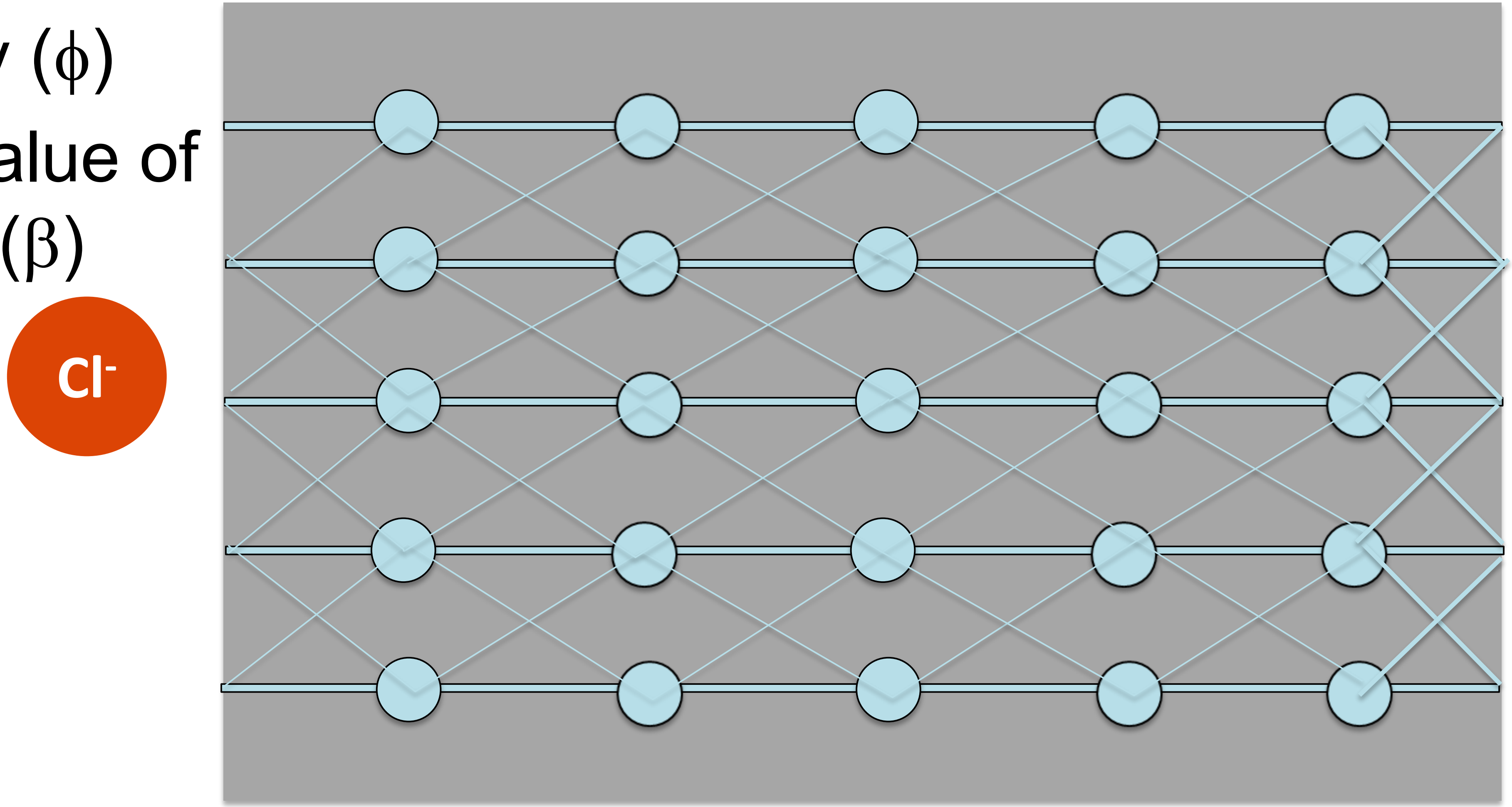


- F = 1250

Change Alkali Content

Oregon State University
College of Engineering

- 20% Porosity (ϕ)
- 0.004 for a value of Connectivity (β)
- Double the alkali content of the cement
- F = 1250

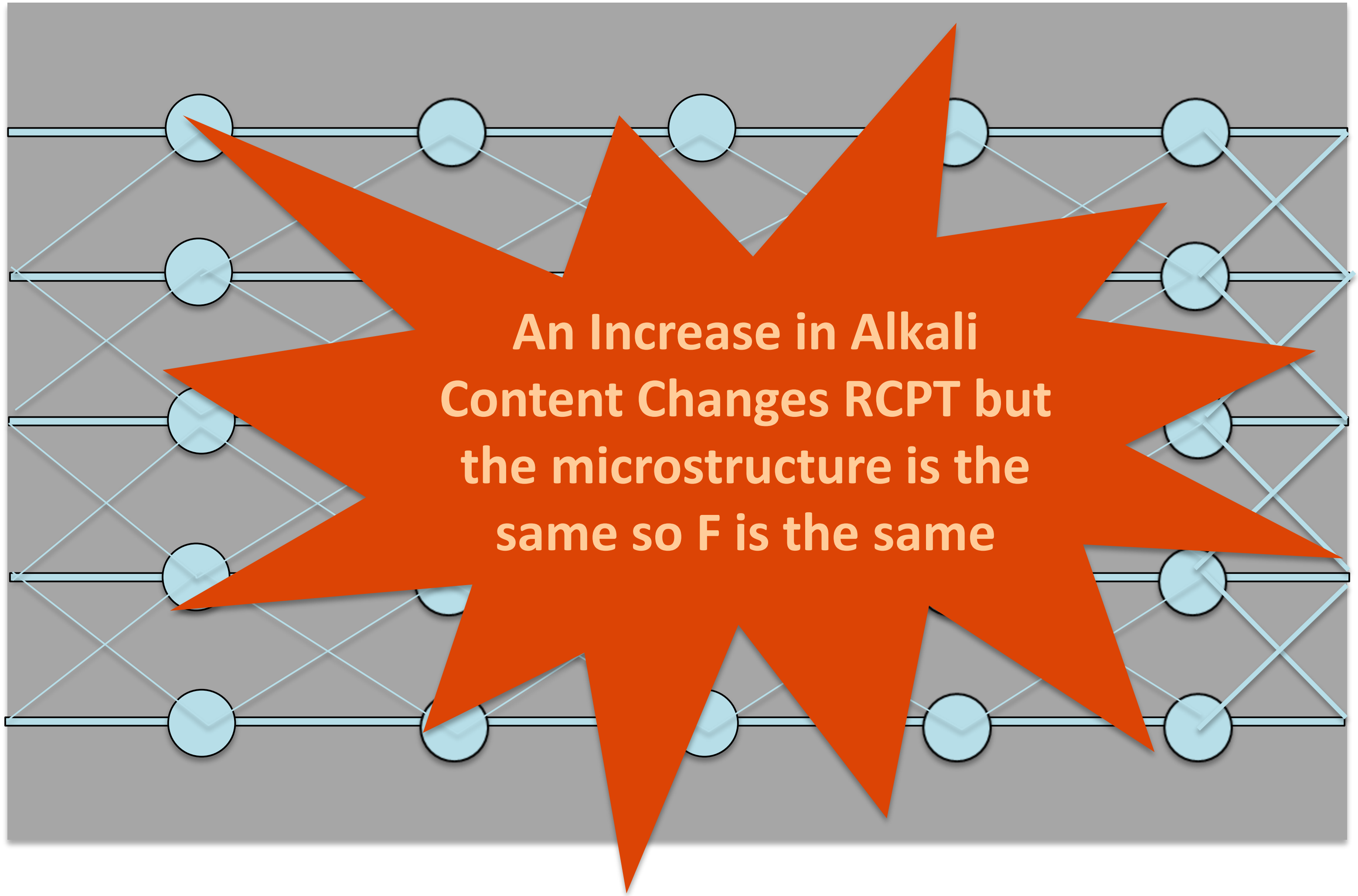


Change Alkali Content

Oregon State University
College of Engineering

- 20% Porosity (ϕ)
- 0.004 for a value of Connectivity (β)
- Double the alkali content of the cement

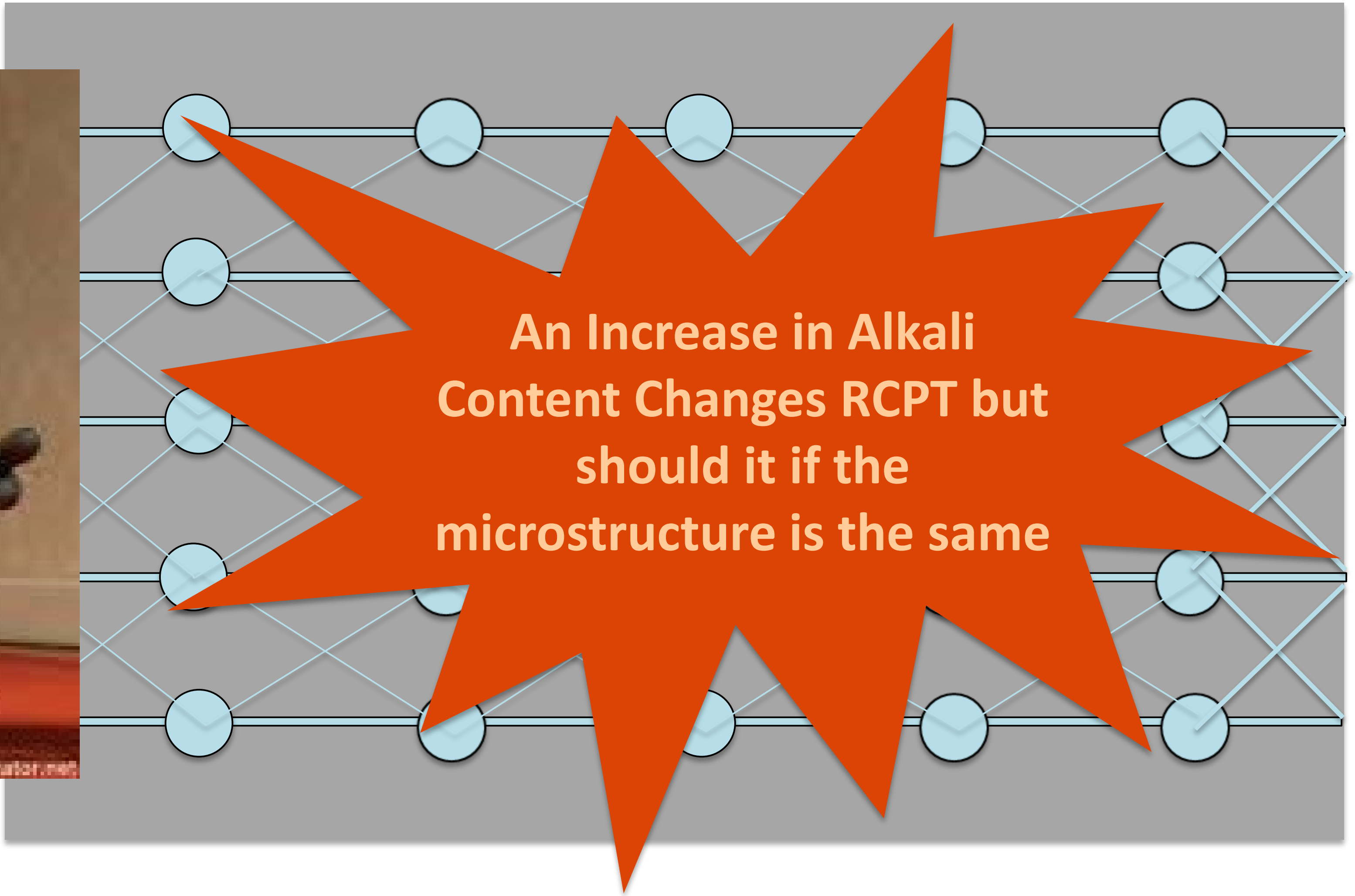
- RCPT = 1250



Change Alkali Content

Oregon State University
College of Engineering

- 20% Porosity (ϕ)



- RCPT = 3008

Summary Slide

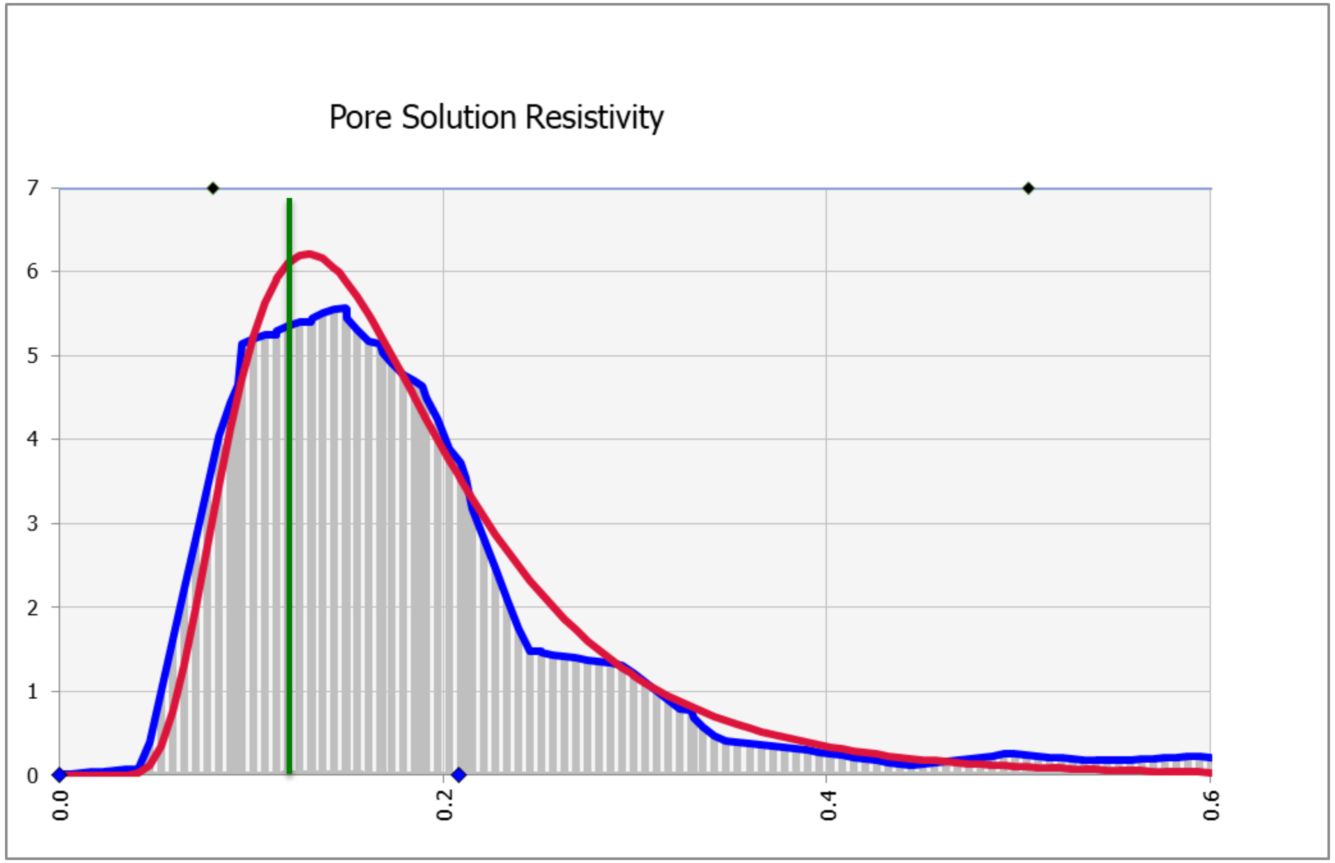
Oregon State University
College of Engineering

Case	RCPT	F Factor
Pure Non Conductive Solid	0	Infinite
20% Disconnected Porosity (ϕ)	0	Infinite
20% Connected Porosity; Beta = 1	3760545	5
20% Con. Porosity; Beta = 0.1	3760	50
20% Con. Porosity; Beta = 0.004	1500	1250
20% Con. Porosity; Beta = 0.004 Double Alkali Content	3000	1250

If we don’t know anything about p. soln

Oregon State University
College of Engineering

- A survey was done by L. Montanari about the pore solutions that have been reported in the literature (blue)
- Fitted data is shown in red (log normal)



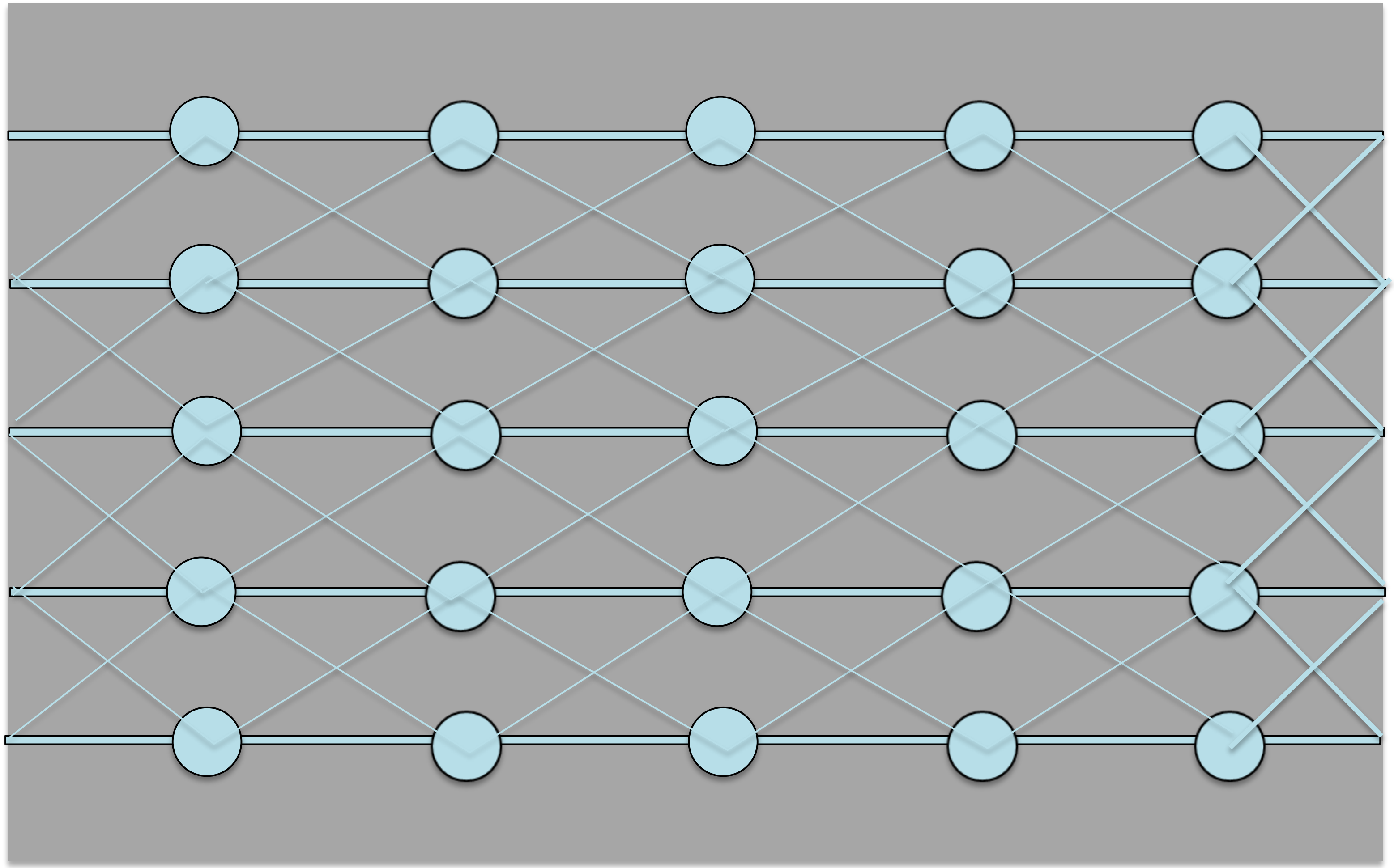
- The typical resistivity we discuss as ‘guessed’ is 0.11 and is shown in green (its been an ‘average value’)

Change Alkali Content

Oregon State University College of Engineering

- 20% Porosity (ϕ)
- 0.004 for a value of Connectivity (β)
- Lets use the pore solutions that we collected from the literature

Cl^-

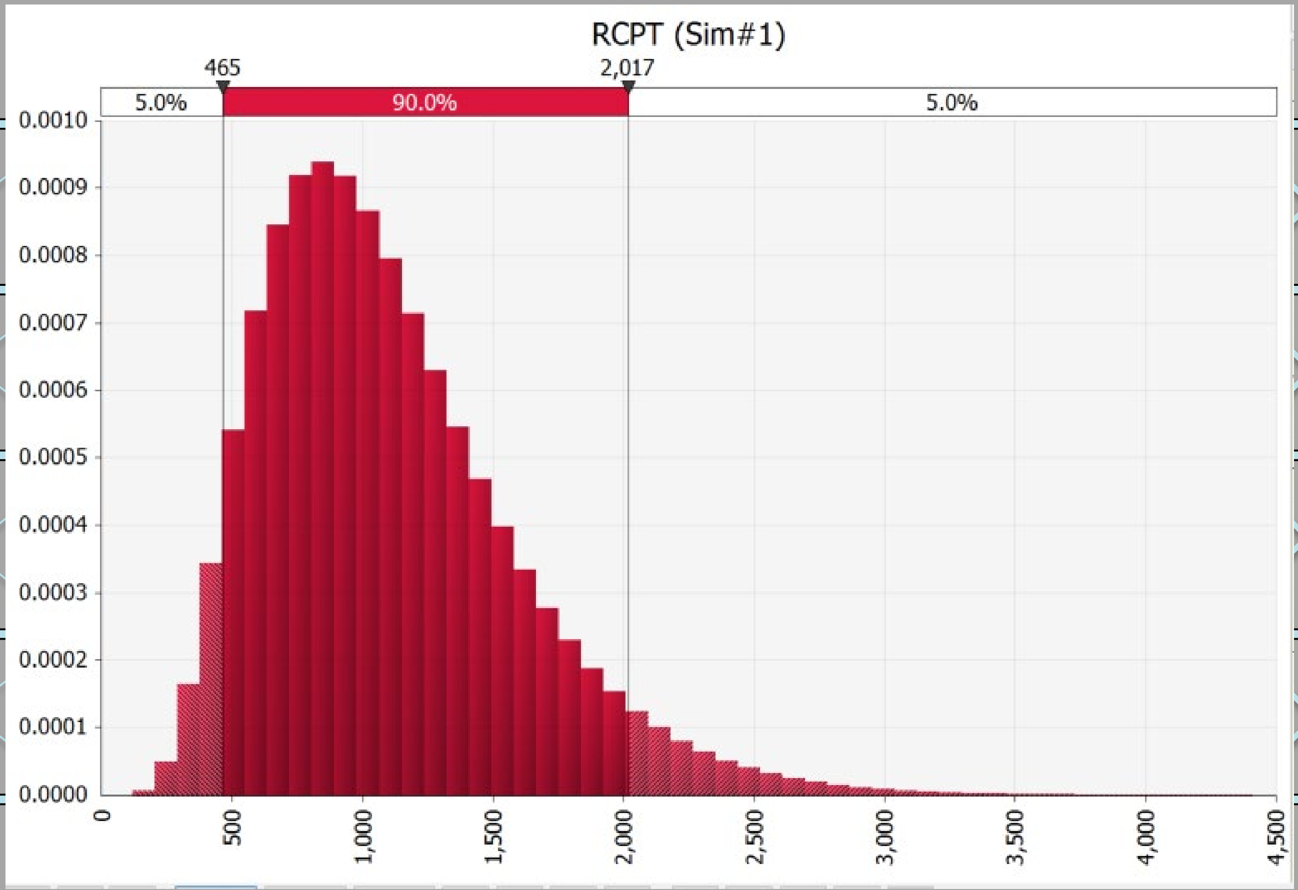


- RCPT = ?

Change Alkali Content

- 20% Porosity (ϕ)
- 0.004 for a value of Connectivity (β)
- Lets use the pore solutions that we collected
- RCPT has a mean of 1100 w/ 90% CI limits 465 to 2017

Cl^-

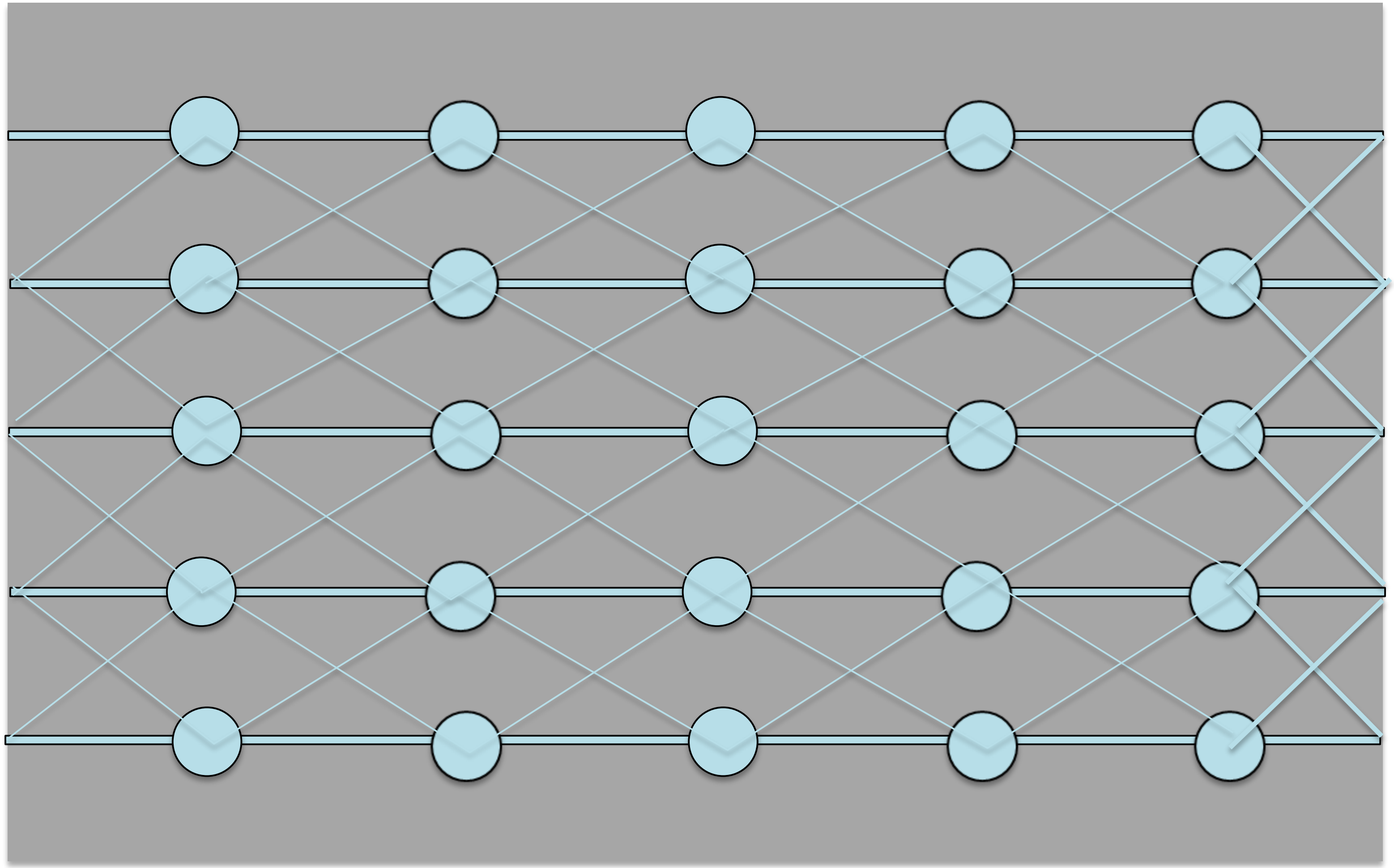


Change Alkali Content

Oregon State University
College of Engineering

- 20% Porosity (ϕ)
- 0.004 for a value of Connectivity (β)
- Lets use the pore solutions that we collected from the literature

Cl^-



- F = 1250

Summary Slide

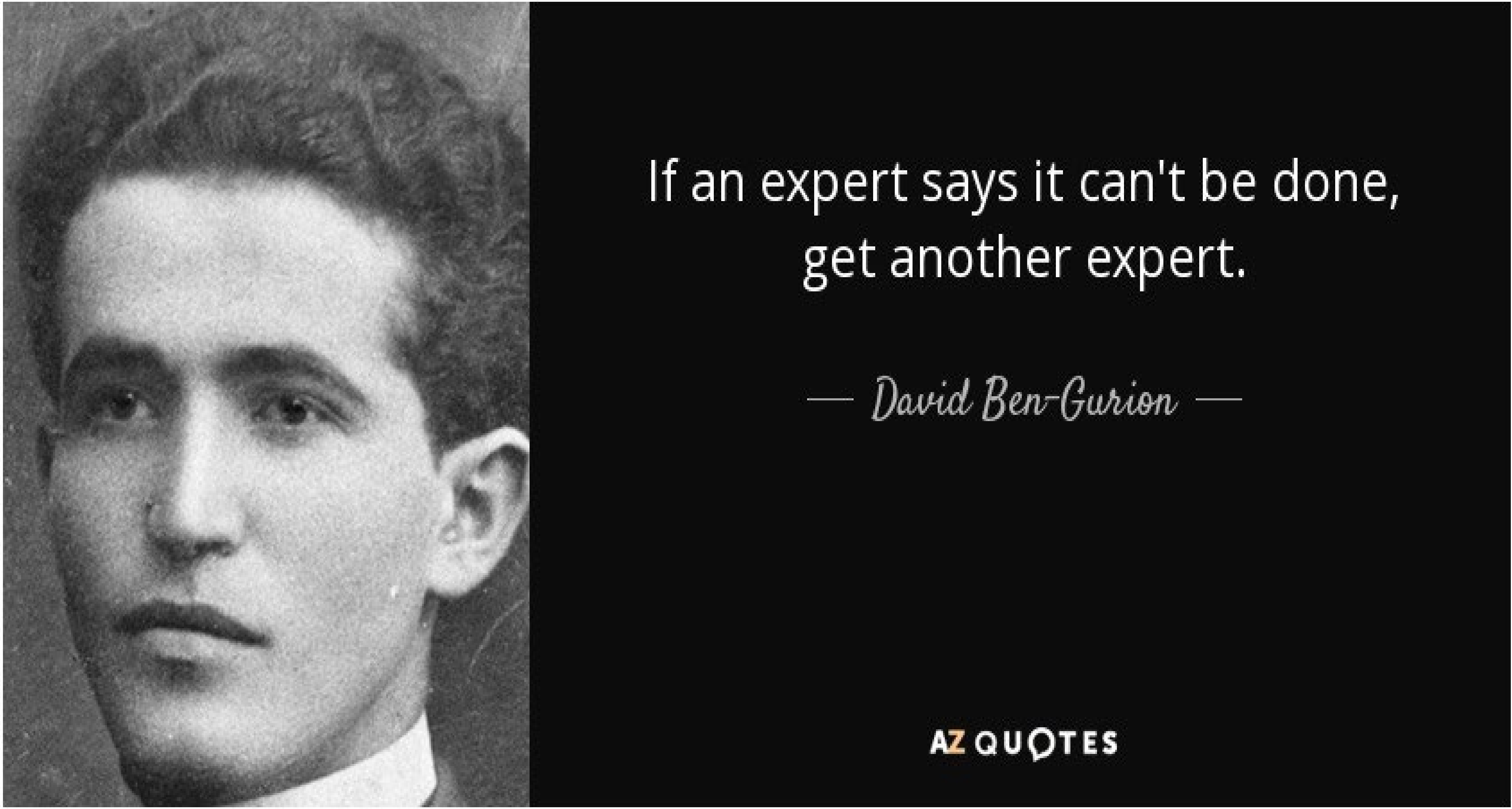
Oregon State University College of Engineering

Case	RCPT	F Factor
Pure Non Conductive Solid	0	Infinite
20% Disconnected Porosity (ϕ)	0	Infinite
20% Connected Porosity; Beta = 1	3760545	5
20% Con. Porosity; Beta = 0.1	3760	50
20% Con. Porosity; Beta = 0.004	1500	1250
20% Con. Porosity; Beta = 0.004 Double Alkali Content	3000	1250
0% Con. Porosity; Beta = 0.004 Pore Solution Distribution	Varied	

Predicting Pore Solution

Oregon State University
College of Engineering

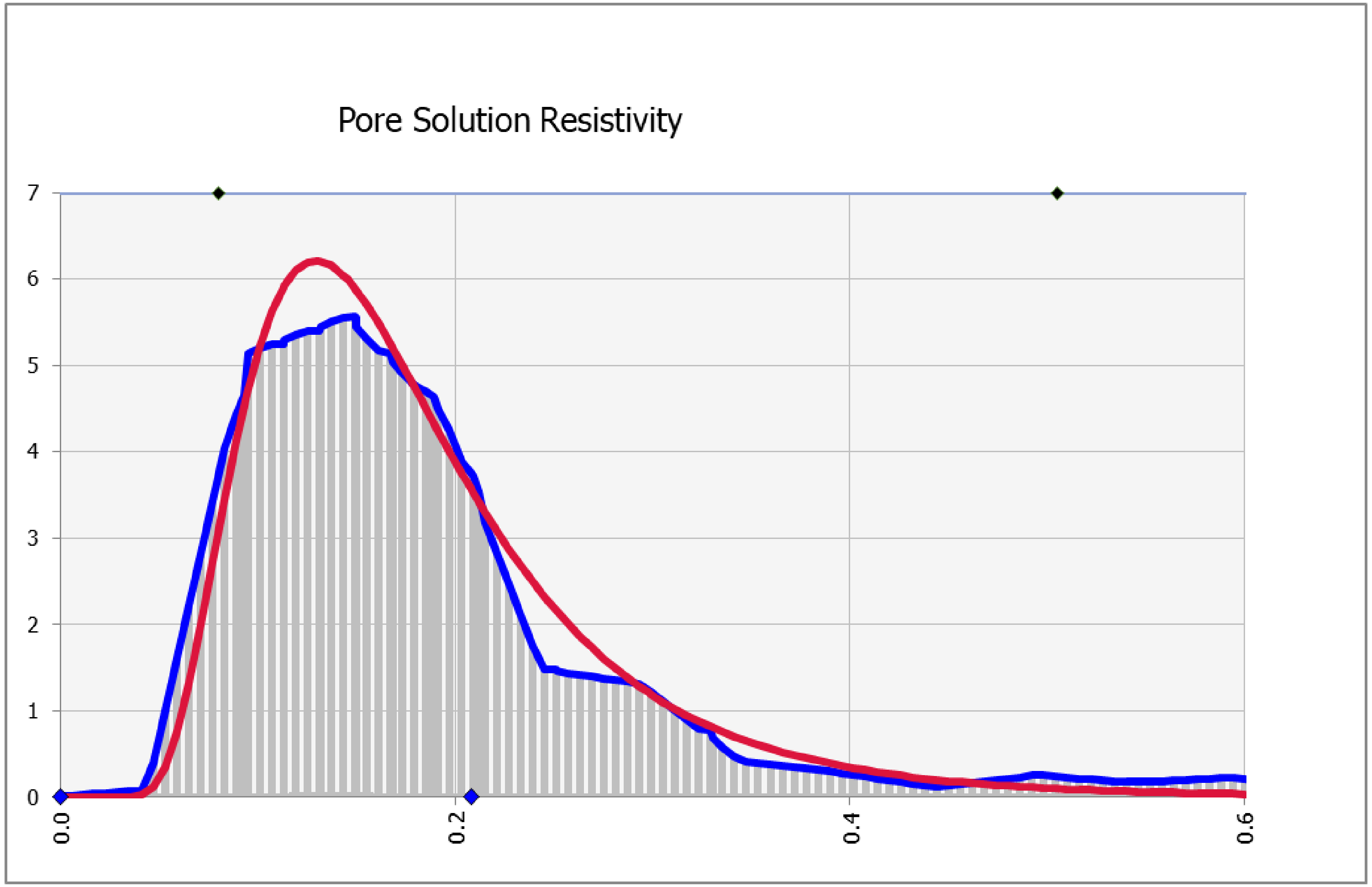
- There are models that can be used to predict the ions in pore solution (these exist but depend on assumed solubility functions etc..)
- Once we know the composition we have a very strong algorithm to predict the resistitivity
- Some have questioned the accuracy that we can expect to have with knowing the pore solution and speculated that this just cant be done


If an expert says it can't be done,
get another expert.
— David Ben-Gurion —
AZ QUOTES

How Accurate Do We Need to Be with P Soln

Oregon State University
College of Engineering

- If we know nothing about the pore solution and just make a guess (0.11 ohm m)



Monte Carlo Simulation

Oregon State University College of Engineering

- We can utilize the distributions for the pore solution and determine relative error
- Each case is simulated 10,000,000

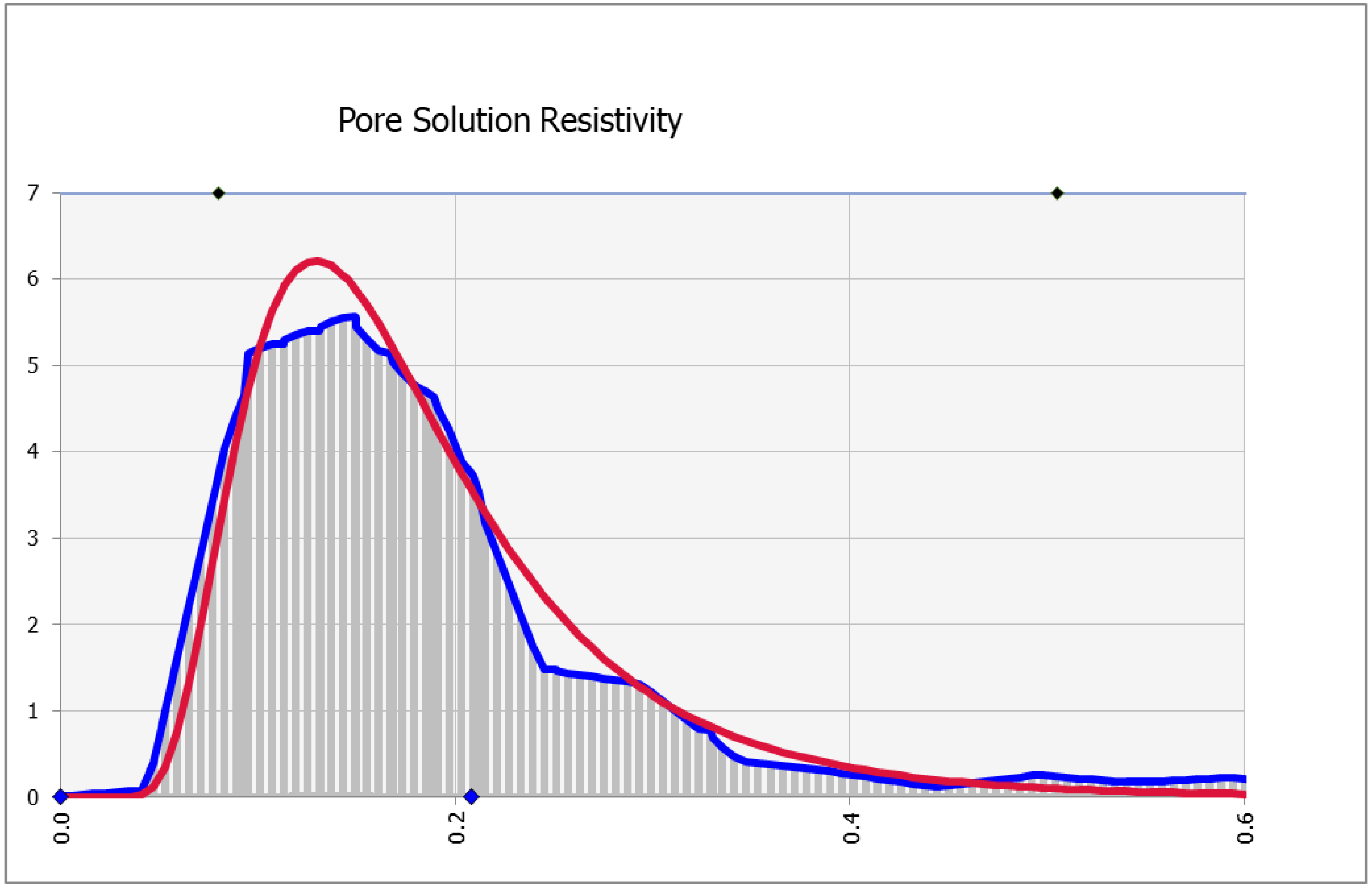
How Accurate Do We Need to Be with P Soln

Oregon State University
College of Engineering

- If we know nothing about the pore solution and just make a guess (0.11 ohm m)

$$Estimate = \frac{F_{est} - F_{act}}{F_{est}}$$

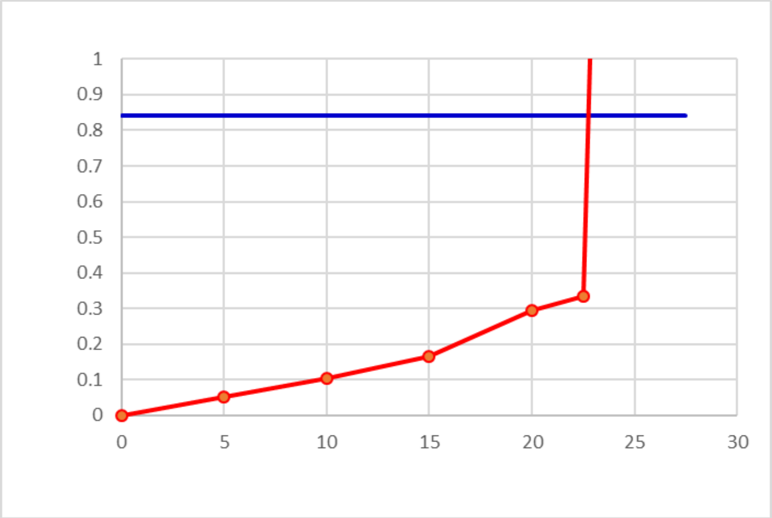
- Estimate 0.84 (std dev)



How Accurate Do We Need to Be with P Soln

Oregon State University College of Engineering

- Standard deviation of prediction knowing nothing about pore solution (shown in blue)
- We can estimate the pore solution using some algorithm with a known COV (error, shown on the x axis)
- It is only when the known COV (error) exceeds 22.5% that we are better off to just use a constant value
- As an example (+/- 2 SD)
- 0.11 would be 0.06 to 0.16

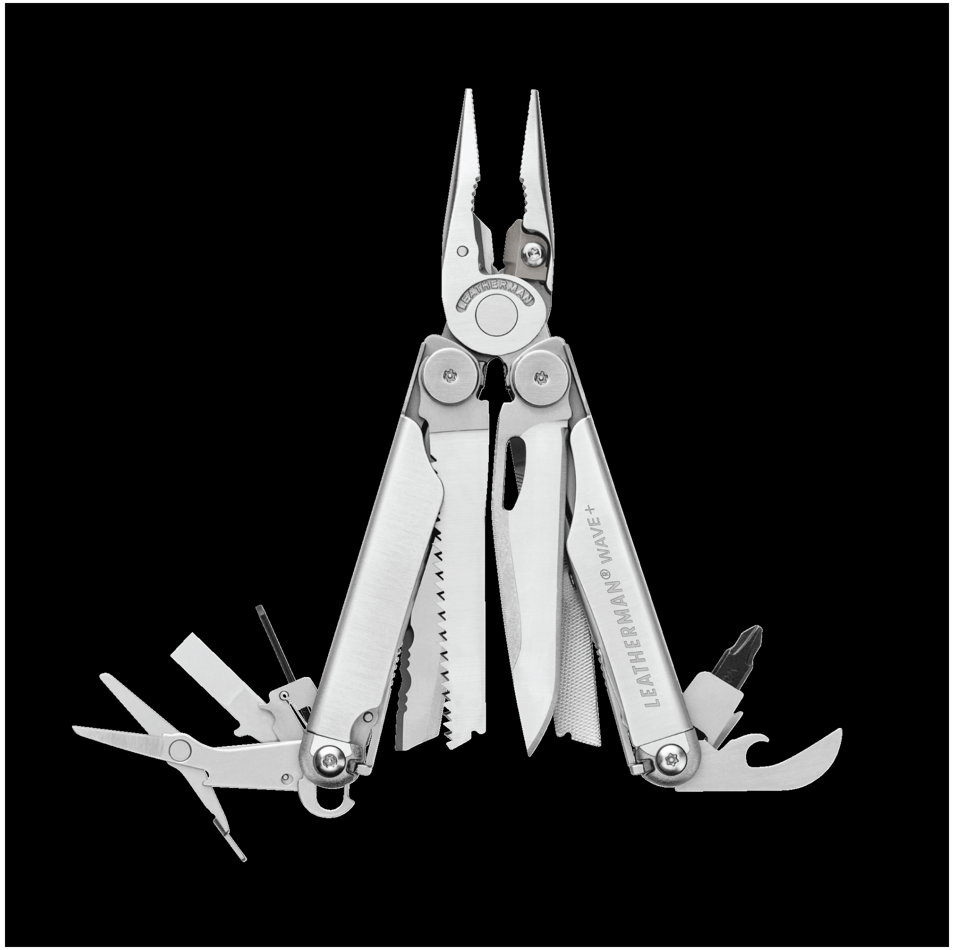


RCPT is a solid tool

Oregon State University
College of Engineering

Is this Versatile?

Is this Versatile?



Formation Factor is the Leatherman of Transport

Oregon State University
College of Engineering

- RCPT tells you RCPT and people feel comfortable

- The formation factor provides information that is directly related to several transport properties (Derivations available)
- Quality Control (water content; water to cement ratio)
- Ionic Diffusion (Effective Diffusion)
- Diffusion with Binding (Apparent Diffusion)
- Fluid Absorption (Sorptivity)
- Water/Hydraulic Permeability

Shadow Projects

Oregon State University
College of Engineering

- It is important that as we do the shadow projects we perform the tests carefully

- We also need to carefully think about the work that needs to be done to advance the topic in a coordinated way as opposed to just repeating previous work

Peer Reviewed Findings

Oregon State University
College of Engineering

- In academic publishing, the goal of peer review is to assess the quality of articles submitted for publication in a scholarly journal.
- Many times there is speculation on what may or may not happen
- It would be good for us as a profession to document questions/concerns and then we can prove or disprove

Summary

Oregon State University
College of Engineering

- We discussed how to perform the test (revised version of the test is with the AASHTO COMP committee
- Option A – Bucket is an approach that is a compromise to have an easy approach and consistent pore solution
- We discussed thought experiments and showed how porosity, connectivity, and pore solution are related
- We have shown 'accuracy needed' for pore soln estimates
- We also know that formation factor describes a wide number of QC/QA and transport properties

Use the Force

Oregon State University College of Engineering

The F Factor and Bucket Test are in You SHA's

Oregon State University
College of Engineering