

Compressive Strength Failures

- Causes
- Evaluation
- Resolution

Wednesday, August 3, 2022
12:00 PM – 1:00 PM

Minnesota Concrete Council
A CHAPTER OF 

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Presenters

Alf Gardiner and Dan Vruno are Principal Engineers at the two largest concrete testing companies in the area

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Goals

Three goals for this presentation:

1. Provide you with reasons for the low strengths
2. Discuss how low strength is typically evaluated
3. Discuss what can be done to resolve the issue

3

FAILED COMPRESSIVE STRENGTHS

Now what do I do?

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Why do we test?

- Health and Safety of the public



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Who is responsible of testing?

- Minnesota Building Code
- An *approved agency* shall be objective, competent and independent from the contractor responsible for the work being inspected.
- An *approved agency* shall test a representative sample of the product or material being *labeled* to the relevant standard or standards. The *approved agency* shall maintain a record of the tests performed. The record shall provide sufficient detail to verify compliance with the test standard.

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Again why are we testing

Quality Assurance

NOT

Quality Control

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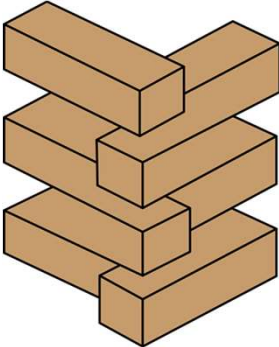
Specification not Mix Design

- Testing lab needs to focus on the specification requirement not the performance of the mix
 - Batch ticket often indications the testing parameters
 - Specification are King

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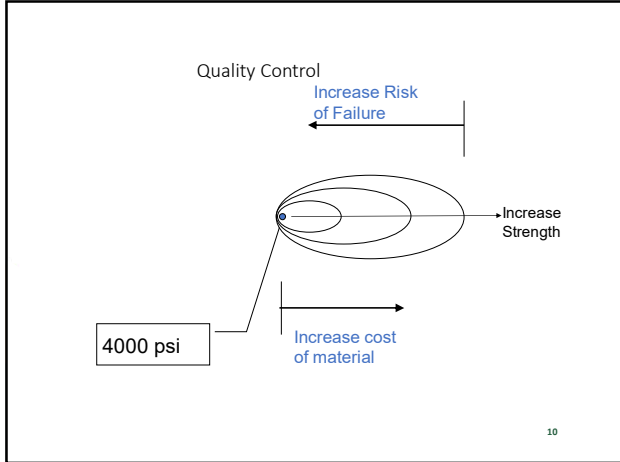
Proportion or Design ?



- Proportioning
 - to adjust in proper proportion or relation, as to size, quantity, etc
 - to balance or harmonize the proportions of
- Designing
 - showing or using forethought
 - the act of making [designs](#)
 - Putting the pieces of the puzzle together to create a successful concrete project

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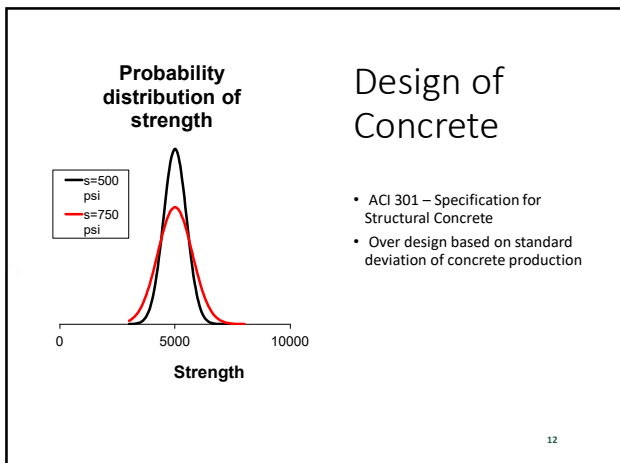
How do we Design Concrete

- We Design concrete to **Fail**.

Well at least 1 out of every 100 test

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ACI 301 Calculations

Test Results 1		Test Results 2	
5500	4750	5500	4750
4520	4680	4520	4680
4120	4580	3200	4580
4680	5200	4680	5200
4710	4710	4710	4710
4850	4820	4850	4820
4620	4870	4620	4870
4910	4520	4910	4520
4750	4680	4750	4680
4780	4430	4780	4430
4520	4510	4520	4510
4680	4620	4680	4620
4350	4950	4350	4950
4850	4210	4850	4210
5320	4740	7900	4740

Average	4714	4756
Stand Dev	288	635
Design Strength	4386	4851
Increase in Design strength	464	

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What to do When Cylinders Fail

- Stay Calm

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What to do When Cylinders Fail

- Are you Calm?
- Yes -- Great now what?
- Review the data ---- All the DATA!
- First example
 - Call came in with cylinder needing to meeting 5000 psi
 - What happened.

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ACI 318
26.12.3.1

- ...satisfactory if both the following requirements are met
 - (a) Every arithmetic average of **any** three consecutive strength tests equals or exceeds f'_c
 - (b) No strength test falls below f'_c by more than 500 psi when f'_c is 5,000 psi or less; or by more than $0.10f'_c$ when f'_c is more than 5,000 psi

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What is a test?

- A test result is define as the average of two 6 by 12 inch cylinders or the average of three 4 by 8 inch cylinders.

Age at time of Test	Specimen Size	Specimen	Compressive Strength (psi)
7	4 by 8	A	2800
28	4 by 8	B	4230
28	4 by 8	C	4490
28	4 by 8	D	4370
Average Compressive Strength			4360

Test Result

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Are all things Equal

Age at time of Test	Specimen Size	Specimen	Compressive Strength (psi)
7	4 by 8	A	2800
28	4 by 8	B	3500
28	4 by 8	C	4490
28	4 by 8	D	4370
Average Compressive Strength			4120 4430

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Example analysis

- Test result = Average of the cylinder in a set at a specific age

Set No.	Test Results (psi)	Running average of 3 Tests (psi)
1	4500	
2	4740	4300
3	3670	
4	4690	4450
5	4980	

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Example Analysis

Remember the word "any"

Set No.	Test Results (psi)	Running average of 3 Test (psi)
1	4500	
2	4740	4300
3	3670	

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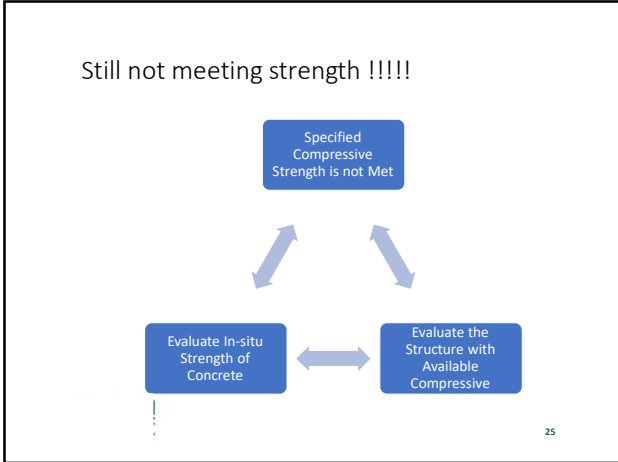
What's Next?

Specified Strength = 5000 psi

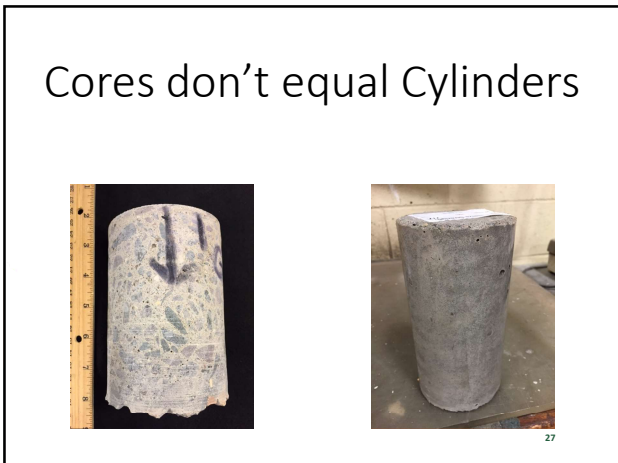
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Average Compressive Strength			4360

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- Concrete in an area represented by core tests shall be considered structurally adequate if (1) and (2) are satisfied:
 - The average of three cores is equal to at least 85 percent of f_c' .
 - No single core is less than 75 percent of f_c' .
- 26



Strength of Cores

f'c (psi)	3000	4000	5000	6000
85%	2550	3400	4250	5100
75%	2250	3000	3750	4500

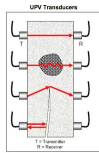
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Investigate the Structure

- Non-Destructive Testing
- In commentary



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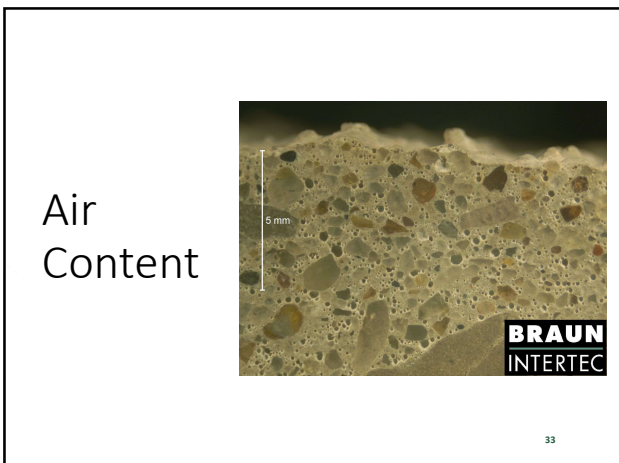
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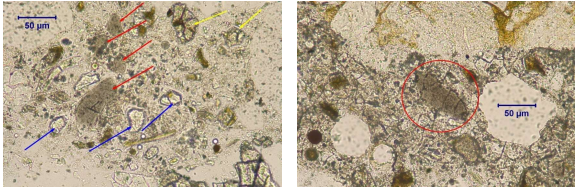
Batching
issues

High performance
concrete



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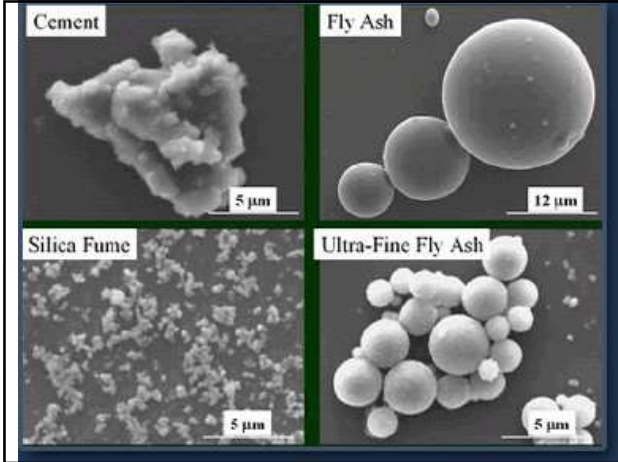


Silica Fume
Clumping

- Silica fume was specified for a parking ramp.
- Poor performance was measured
- Many clumps were observed a few up to 150 micrometers.

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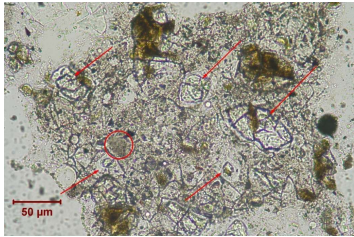
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Silica Fume Clumping

- Suggestions:
 1. Change the batching sequence
 2. Extend mixing time
- Results:
 - Improved dispersion of the silica fume
 - Improved Performance



The micrograph shows a cross-section of a material with a 50 µm scale bar. Red dashed lines and circles highlight areas where silica fume particles are clumped together, while blue dashed lines and circles highlight areas where the particles are more uniformly dispersed.

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TESTING ISSUE

Maybe

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We see all sort of items


In 2018 Braun Intertec tested over 300,000 cylinders



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Check the Testing

The cylinders don't always represent the concrete on site



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Quality of the Test



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Column Breaks



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Abrams Water-Cement Ratio "Law"

"For given materials the strength of concrete (so long as we have a plastic mix) depends solely on the relative quantity of water as compared with the cement regardless of mix or size and grading of aggregate."

Duff A. Abrams, 1918

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Concrete Design Strengths

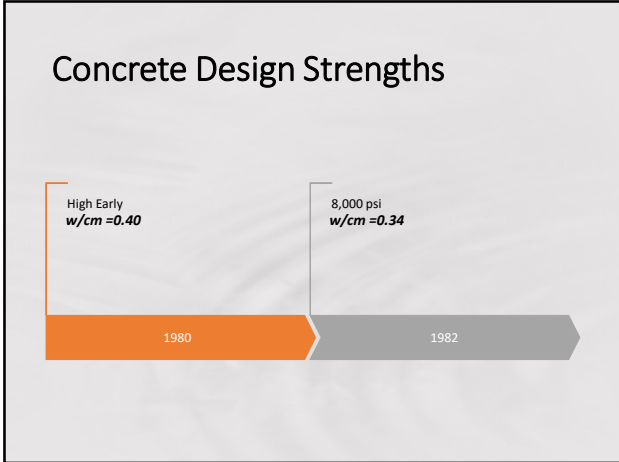
High Early
 $w/cm = 0.40$

1980

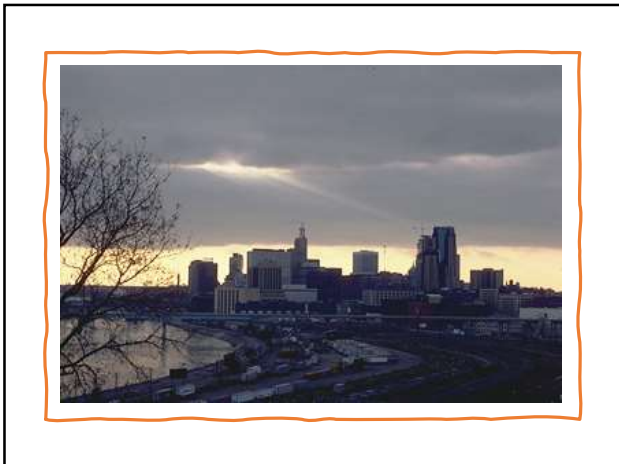
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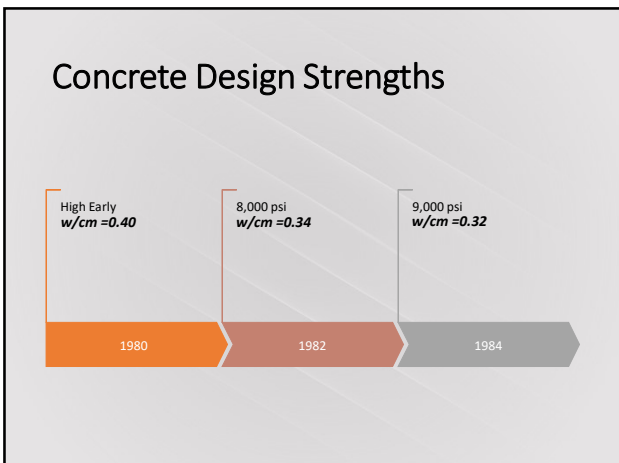
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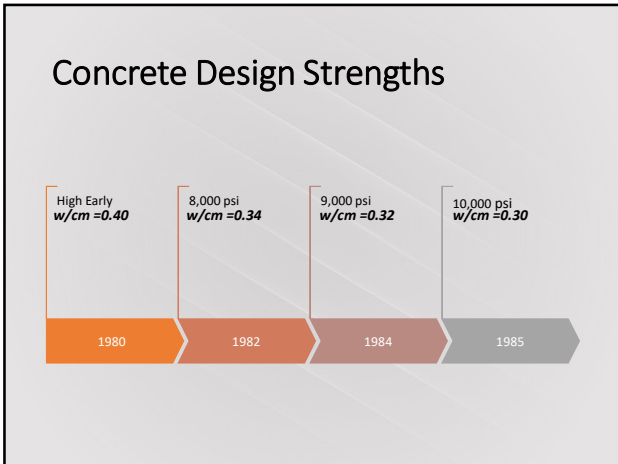
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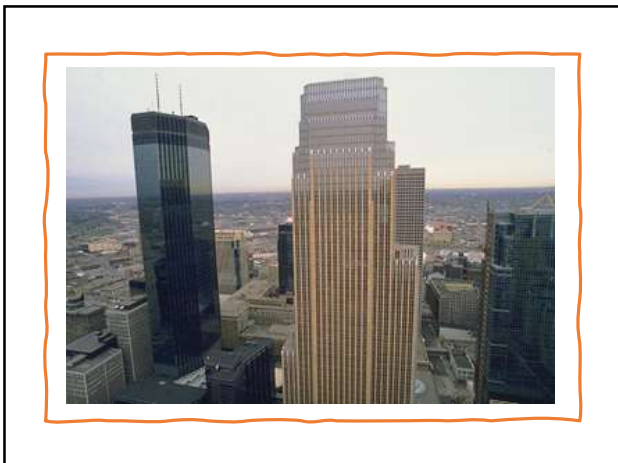
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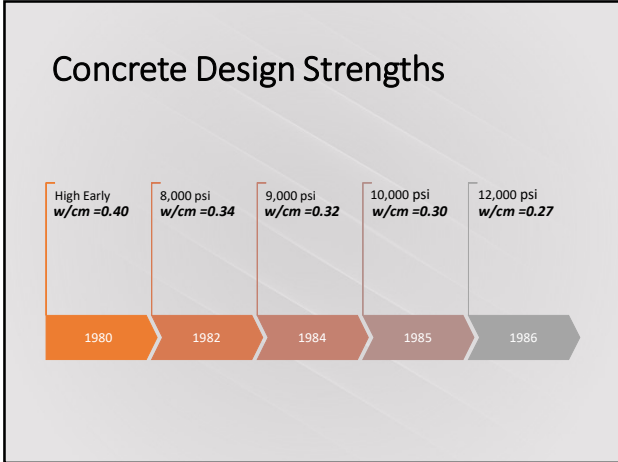
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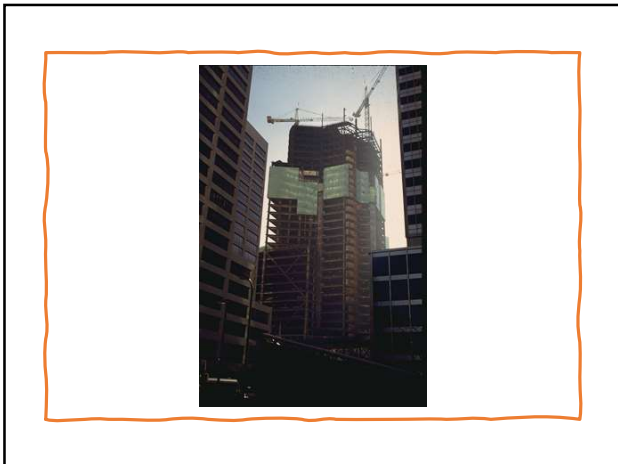
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Hydraulic Reaction (Cementing Reaction)

Cementing Material + Water \longrightarrow *C-S-H + CH*

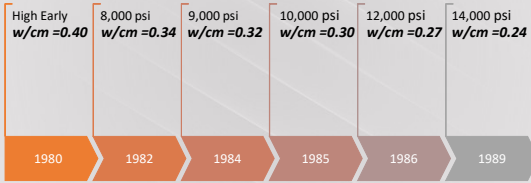
Pozzolanic Reaction

Pozzolanic Material + CH + Water \longrightarrow *C-S-H*

C-S-H = Calcium Silicate Hydrate
CH = Calcium Hydroxide

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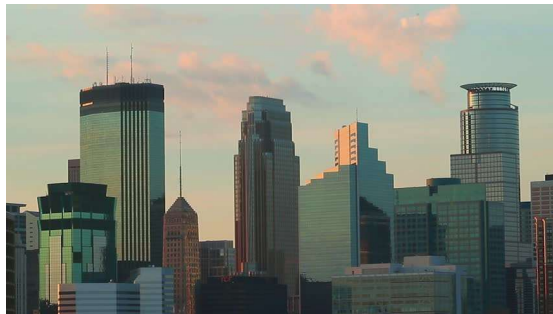
Concrete Design Strengths



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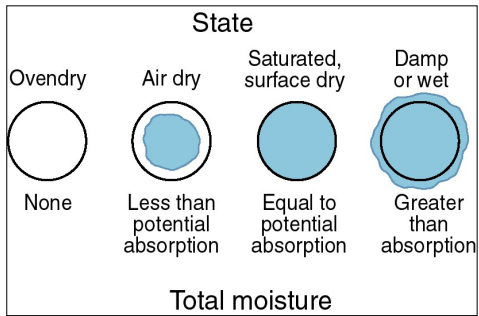


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Moisture Conditions



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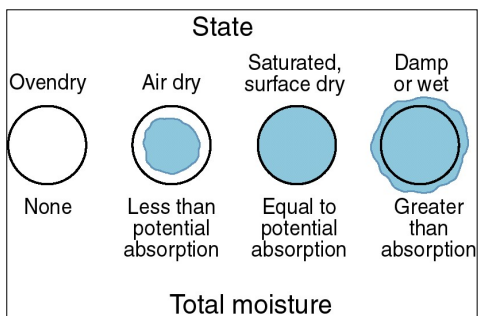
MnDOT
Oven Dry
Mix
Design

CEMENT	564
ROCK	1,800
SAND	1,300
WATER	236.9

$$236.9 \div 564 = 0.42$$

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Moisture Conditions



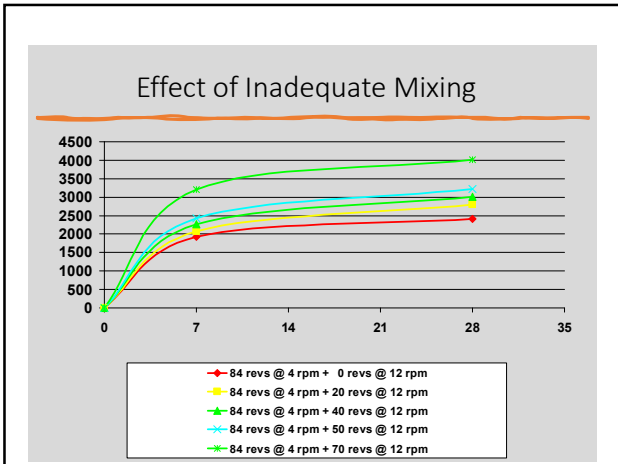
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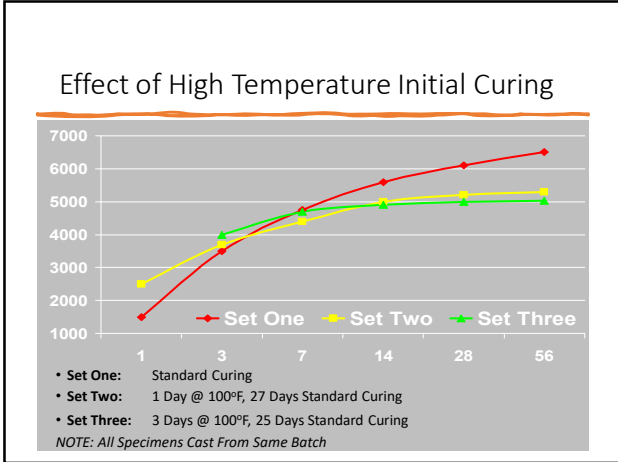


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Testing
Effects

1. Specimen End Conditions
2. Specimen Size
3. Diameter – Aggregate Size Ratio
4. Length – Diameter Ratio
5. Specimen Moisture
6. Loading Rate

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ACI 318 26.12.3.1

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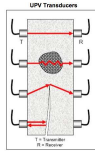
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Average Rebound Hammer Readings		
	Lab Cylinders	In-Situ
Footing	23.4	35.1
Column	23.2	34.1
Existing Columns	N/A	39.0

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Conclusions

- There are a variety reasons which cause compressive strength failure
- Evaluation – ACI 318 26.12.3.1 gives us guidelines for evaluating compressive strength failures
- Resolution – Once the evaluation is presented to the owner and design team, the final resolution is determined

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