Durability of Cementitious Grouts in Cold Climates

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AKDOT - NCSU Research Workshop

Introduction

What is the Grouted Shear Stud (GSS) Connection?

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Why GSS connection?

Suitable for seismic design

It eliminates brittle failure modes and provide full strength and ductility capacity.

Accelerated bridge construction

It eliminates almost all field welding resulting in faster construction.

Possible retrofitting option

It employs plastic hinge mechanism to move damage away from critical areas.

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Is it ready for widespread use?

Grout Durability

We need to better understand how durable the grout material in the connection is in cold climate.

Consequences of deteriorated GSS connection

We need to better understand the consequences of grout deterioration on structural performance

Force transfer mechanism

We need to better understand how the connection resists bending.

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What was our approach?

Phase 1

Investigated durability of commercially available grouts in cold climate.

Phase 2

Structural tests to determine the consequences of grout deterioration.

What did we find?

Conclusion

Out of the commercial grouts we tested, some are durable and some are not. However, grout deterioration, within the range of our tests, does not compromise structural integrity of the lateral load resisting system.

Cementitious Grouts

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Features

1. Portland cement based mixtures that harden when mixed with water
2. Pre-packaged
3. Typically used in crack injection, anchorage sealing, post-tensioning applications etc.

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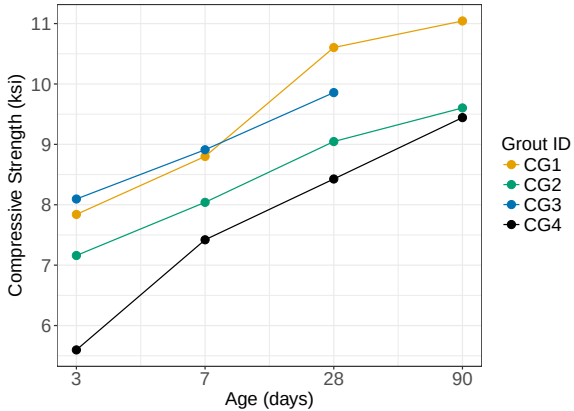
Grouts used for our study

Four commercially available high strength grouts, that meet AKDOT specifications, were chosen.



Mechanisms of Grout Deterioration in Cold Climates

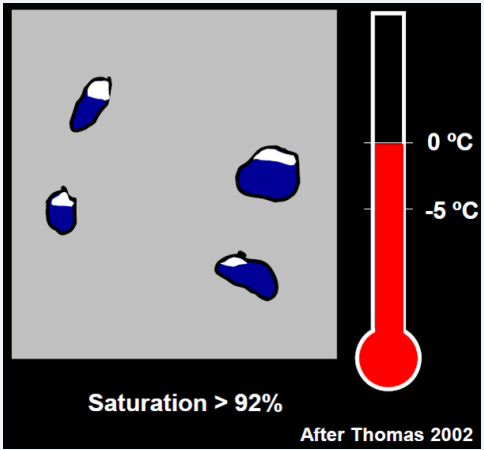
What affects durability?

Durability concerns in this study

1. Freeze and Thaw Cracking
2. Early Age Shrinkage Cracking

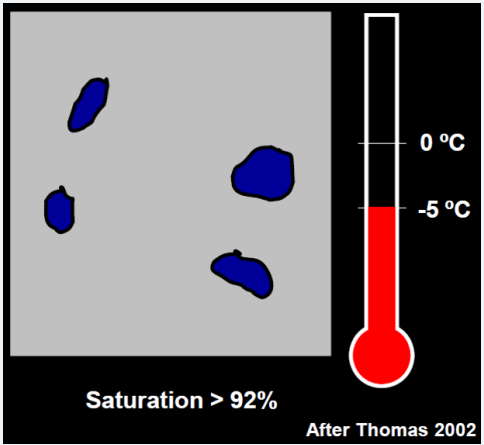
Freeze and Thaw (FT) cracking

At freezing point



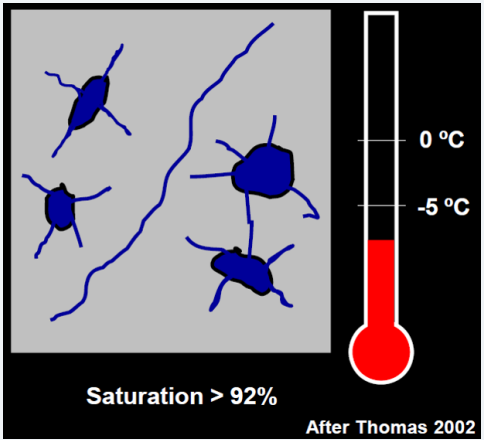
Freeze and Thaw (FT) cracking

Expansion of ice



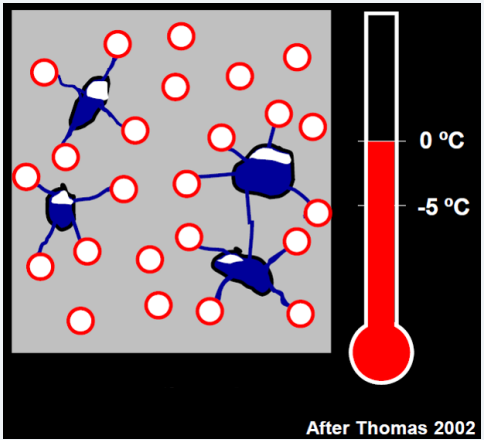
Freeze and Thaw (FT) cracking

Crack initiation



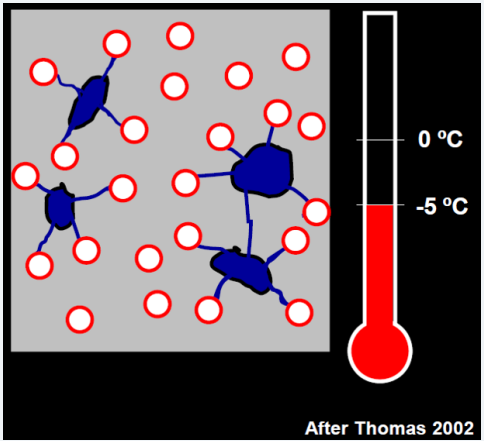
Freeze and Thaw (FT) cracking

The role of air



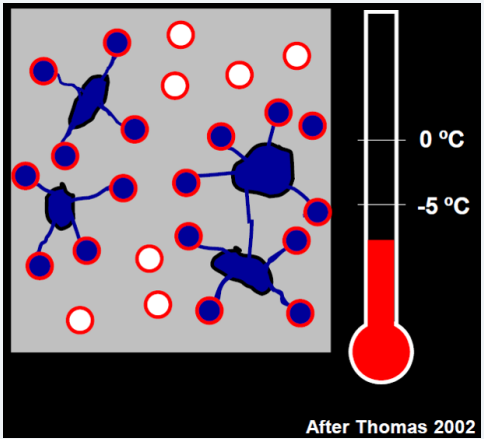
Freeze and Thaw (FT) cracking

Freezing in the presence of air pockets



Freeze and Thaw (FT) cracking

Space for water to flow into



Freeze and Thaw (FT) cracking

Requirements for FT cracking

1. Freezing and thawing temperature cycles
2. Critical degree of saturation
3. No air entrainment or poor air void distribution

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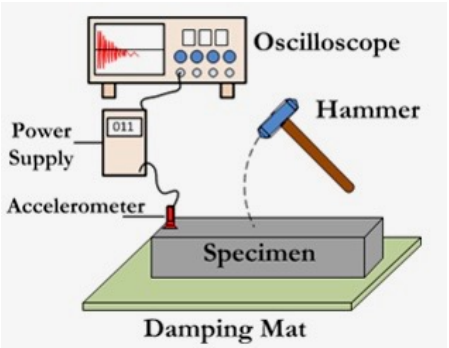
Testing FT resistance of grouts

Mechanism

Water expands inside grout upon freezing causing cracking.



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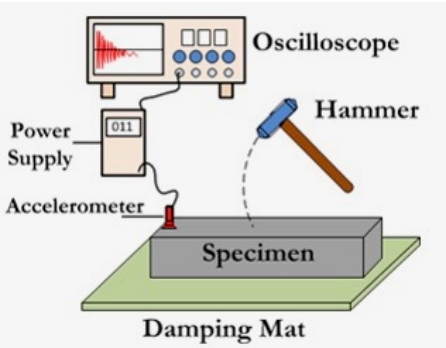
1. 4 different commercial grouts were tested.
   1. CG1, CG2, CG3, CG4
2. Testing Standard
   1. ASTM C666
   2. 300 F-T Cycles
   3. Relative Dynamic Elastic Modulus (RDME) to assess damage
   4. Durability Factor (DF)



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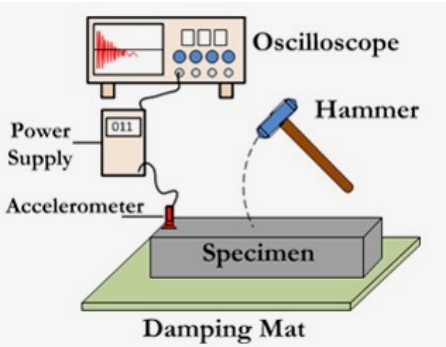

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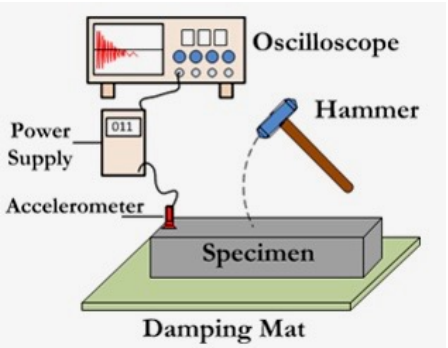

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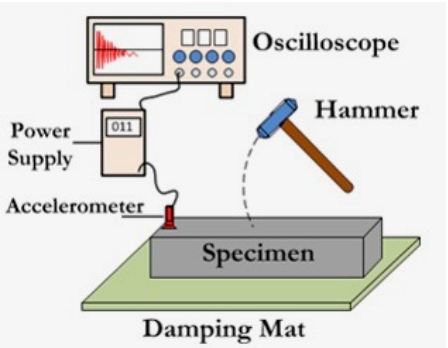

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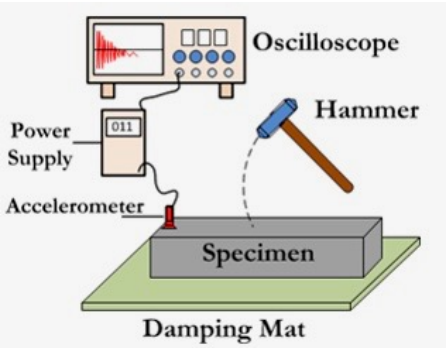

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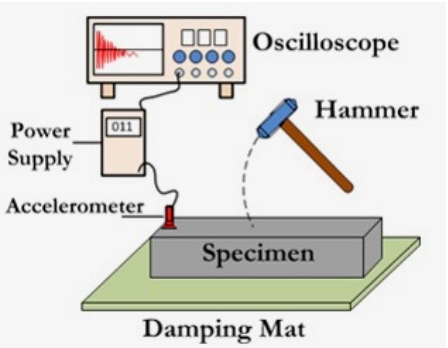

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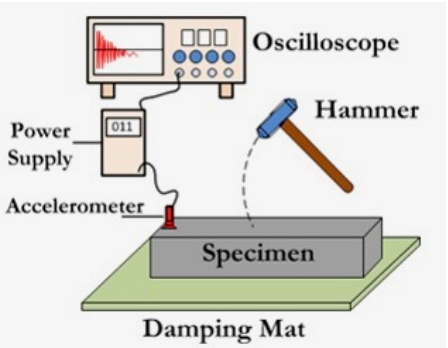
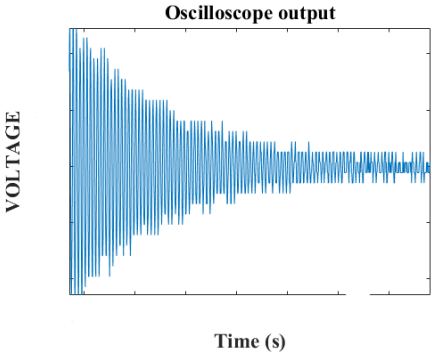
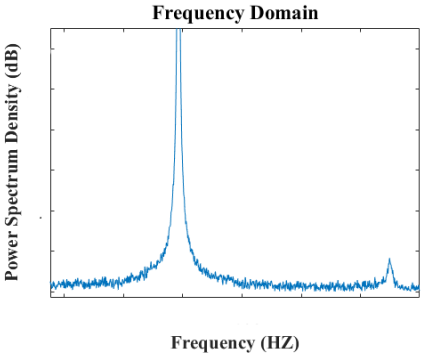


How to calculate RDME?

Impact gives time history response



Convert to frequency domain



$$P = \frac{f^2}{f_0^2} = \frac{E}{E_0}$$

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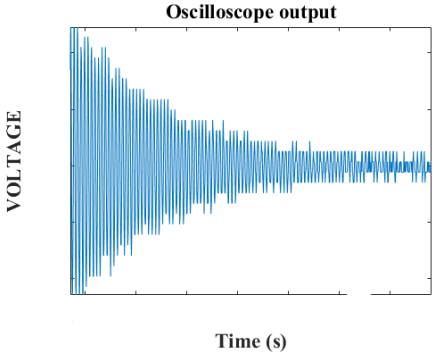

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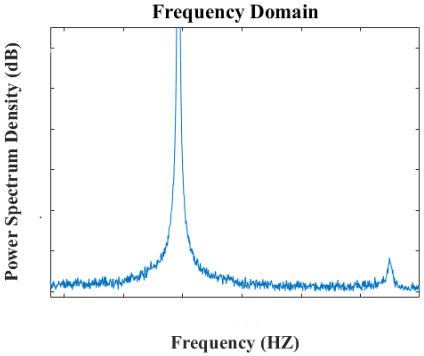
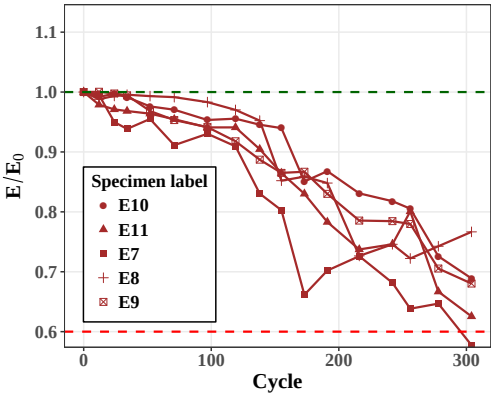


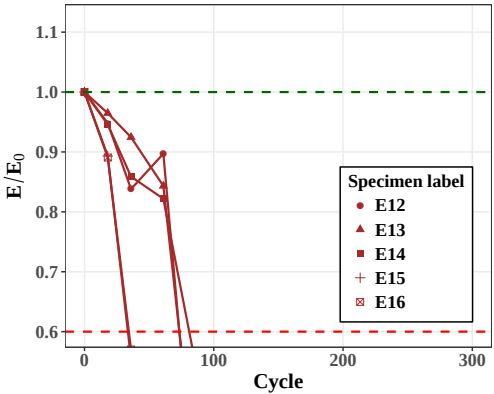
$$DF = \frac{P \times N}{M}$$

Exploratory study

Cured under water for 14 days



Sealed cured for 14 days



FT test on multiple grouts

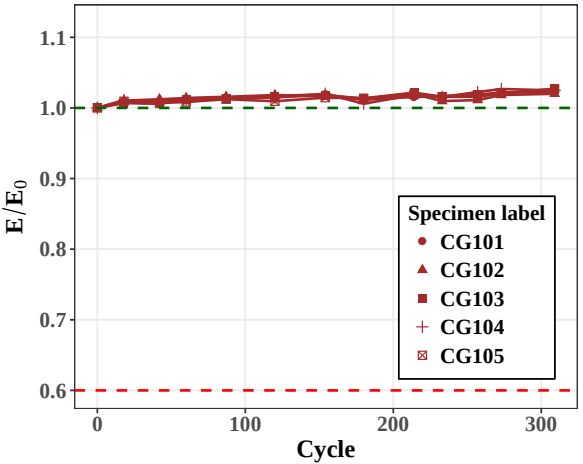
Good Grouts

1. CG1
2. CG2
3. CG3

Bad Grouts

1. CG4
2. PG1

Typical "Good" grout result



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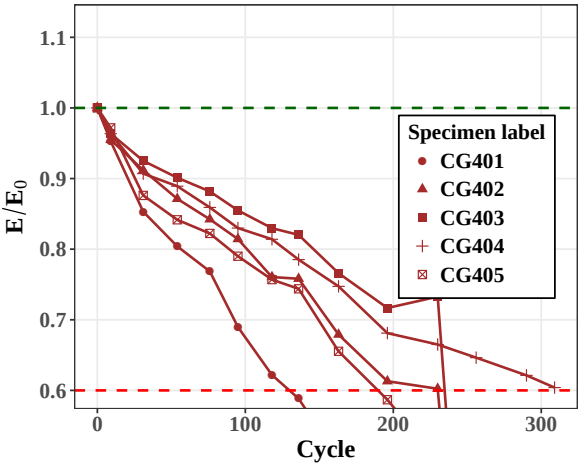

What was the problem earlier?

For the same material:

9 lbs. water lead to average FT resistance

Does 0.5 lbs. of water make such a difference?

Sealed curing lead to poor FT resistance

Is this always the case?

What was the problem earlier?

Repeated mixture with 9 lbs. water.

Exploratory Batch

Repeated Batch

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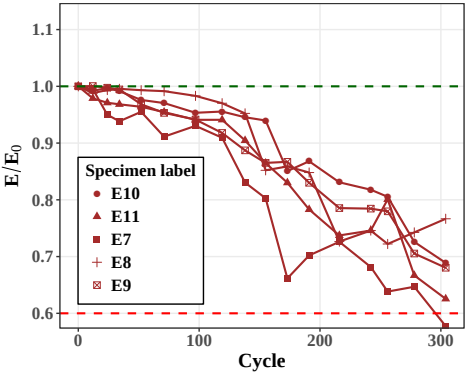
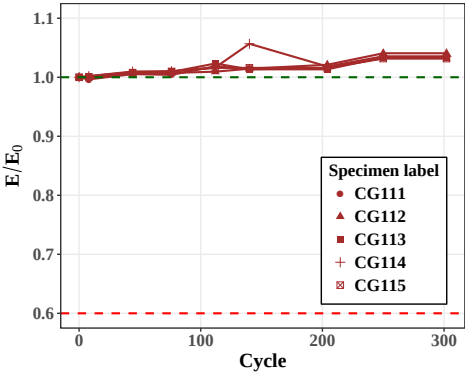


Repeated Batch



What was the problem earlier?

Repeated sealed curing with 8.5 lbs. water.

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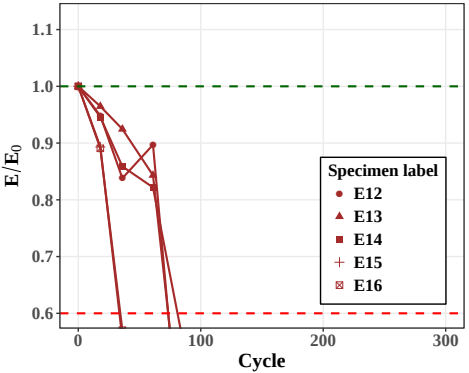

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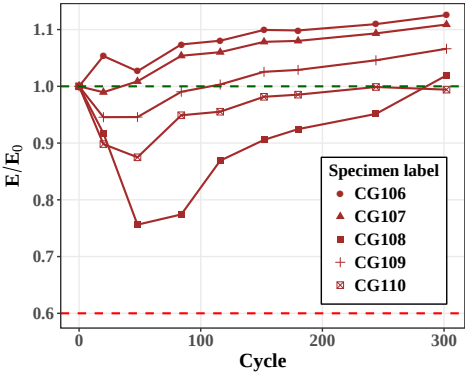

Are cementitious grouts durable then?

Conclusions on FT resistance

1. Some grouts are durable and some are not.
2. Material inconsistency was observed, even in the best grout.
3. Sealed curing delayed hydration - material specific observation.
4. Good air distribution is important.

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We recommend...

Use grouts that specify a durability factor (DF) greater than 95% on their data sheet.

Shrinkage in cementitious materials

Note that:

Contrary to popular wisdom, shrinkage of concrete cannot be fully expressed by a single quantity such as shrinkage strain (ϵ_{SH}).

Different types of shrinkage

1. Chemical shrinkage
2. Autogenous shrinkage
3. Drying shrinkage

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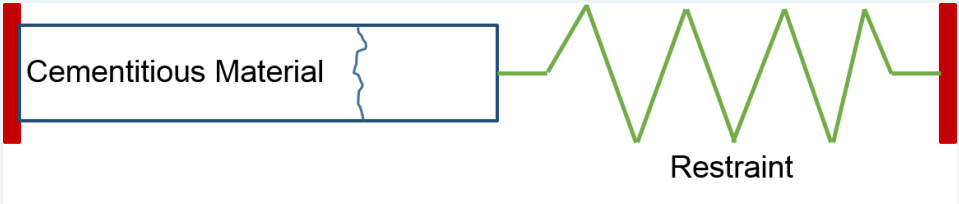
Restrained shrinkage cracking

Mechanism

Free shrinkage, if not allowed, may induce stresses high enough to cause cracking.

Illustration of Restrained Shrinkage cracking

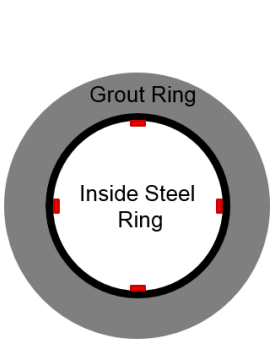


How do we test the grouts?

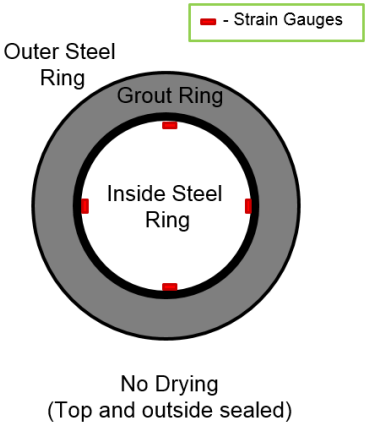
Ring Tests

1. Standard for testing - ASTM C1581.
2. Grout rings allowed to shrink onto
3. Shrinkage produces stress in steel and can be measured.
4. Cracking of ring detected by release of strain.

How do we test the grouts?



Circumferential Drying
(Only top sealed)

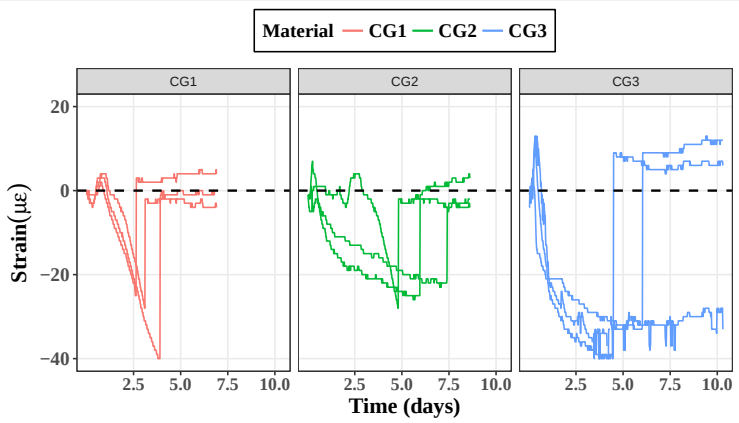


No Drying
(Top and outside sealed)

How do we test the grouts?

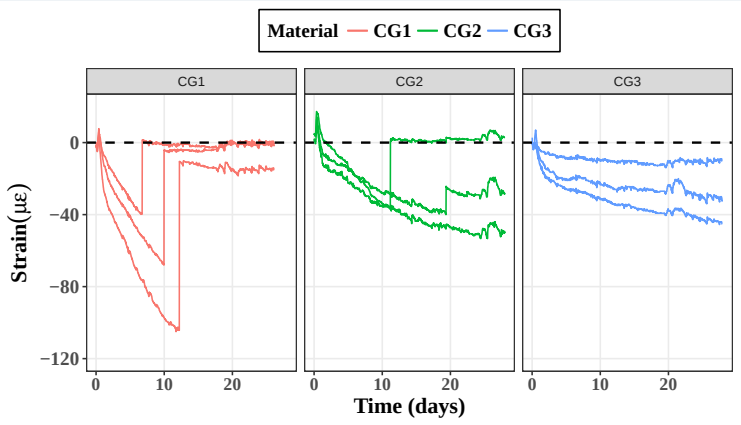
Comparison of grouts

Circumferential drying



Comparison of grouts

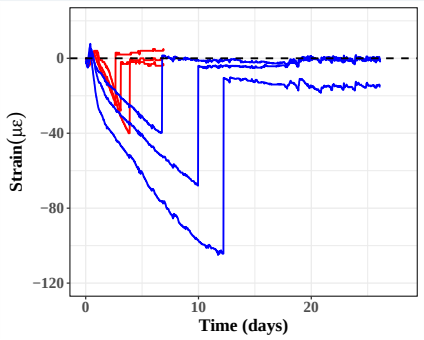
No drying



Comparison of drying conditions

CG1

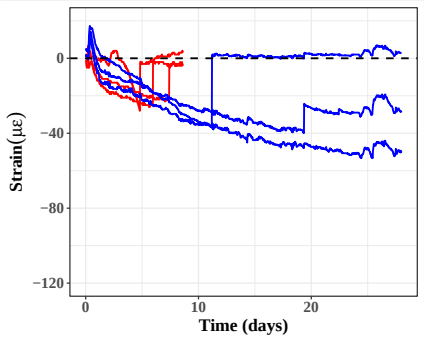
Circumferential vs No Drying



Comparison of drying conditions

CG2

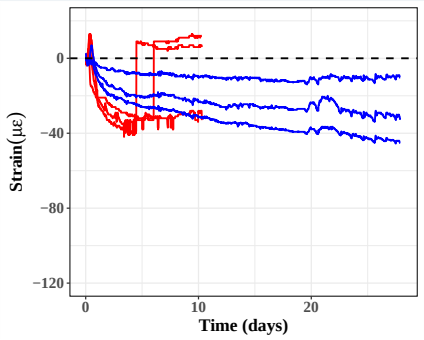
Circumferential vs No Drying



Comparison of drying conditions

CG3

Circumferential vs No Drying

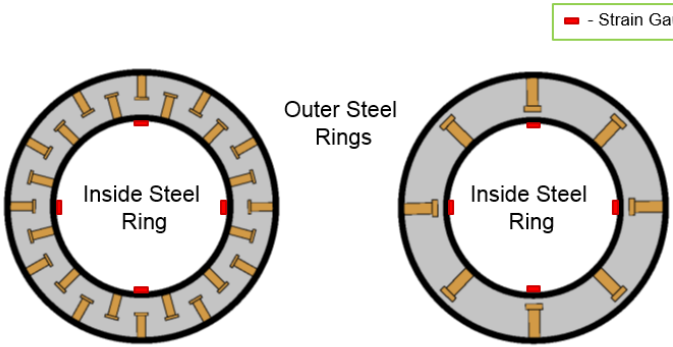


Effect of complex GSS geometry

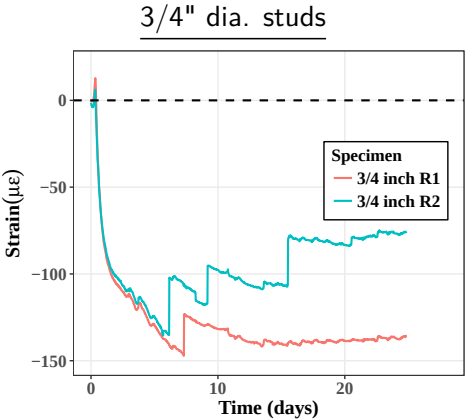
So far...

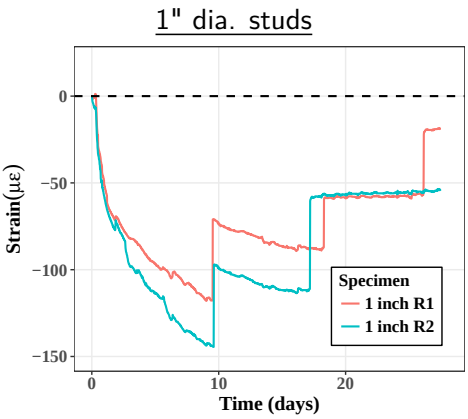
1. Cementitious grout shrinks and cracks when restrained.
2. Cracking occurs earlier in circumferential drying with larger crack widths.

Effect of complex GSS geometry



Effect of shear studs





Ring Test Matrix

Material	Drying	Shear Studs	Cracking age	Crack Width	Cracking Strain ()
CG1	CD	No	3.2 d	1.70	28 $\mu\epsilon$
CG2	CD	No	6 d	1.00	23 $\mu\epsilon$
CG3	CD	No	5.9 d	1.08	38 $\mu\epsilon$
CG1	ND	No	9.5 d	0.40	68 $\mu\epsilon$
CG2	ND	No	15.3 d	0.30	40 $\mu\epsilon$
CG3	ND	No	N/A	N/A	N/A
CG1	ND	24-3/4" dia.	7.5 d	0.10	139 $\mu\epsilon$
CG1	ND	8-1" dia.	9.9 d	0.10	134 $\mu\epsilon$

What did we learn from ring tests?

Conclusions on ring tests

1. The grout within the GSS connection is likely to experience early age cracking.
2. Shear studs are helpful to distribute cracks thereby reducing crack widths.
3. Smaller crack widths less of a concern (Low ingress, easily repaired etc.)

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What next?

Remember our motivation

To determine if the GSS connection is durable in cold climates.

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Are cementitious grouts durable?

It depends.

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What happens if grout deteriorates?

To determine if the GSS connection structural performance is affected by grout deterioration.

How to find out?

Step 1

A control large scale test with standard GSS connection.

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Step 2

Large scale tests with GSS connections simulating grout deterioration.

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Step 1

A control large scale test with standard GSS connection.

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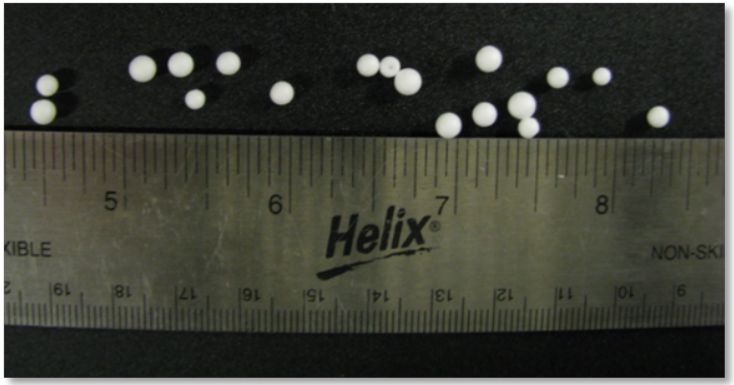
Large scale tests with GSS connections simulating grout deterioration.

Step 3

Compare results to check for consequences of grout deterioration.

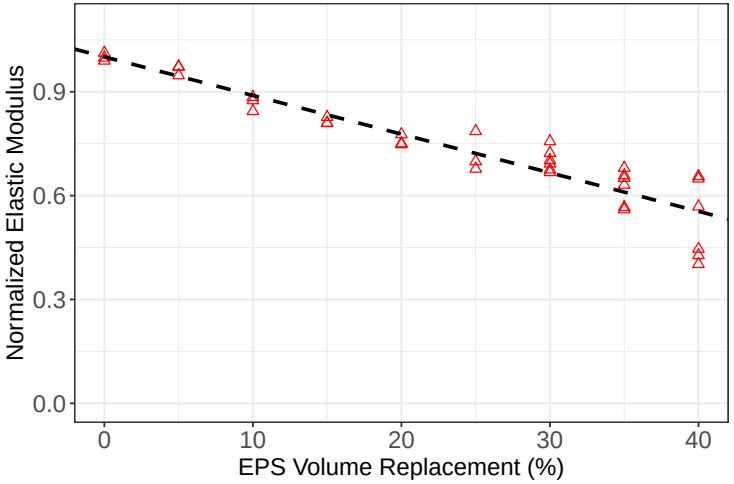
Physical Damage Simulation

Simulating deterioration



Expanded Polystyrene (EPS) beads. (After Bucher 2009)

How much EPS?



Elastic modulus versus volume of EPS

However, EPS migration...

The light beads migrate to the top

However, EPS migration...

Standard casting

However, EPS migration...

2 inch layered casting

However, EPS migration...

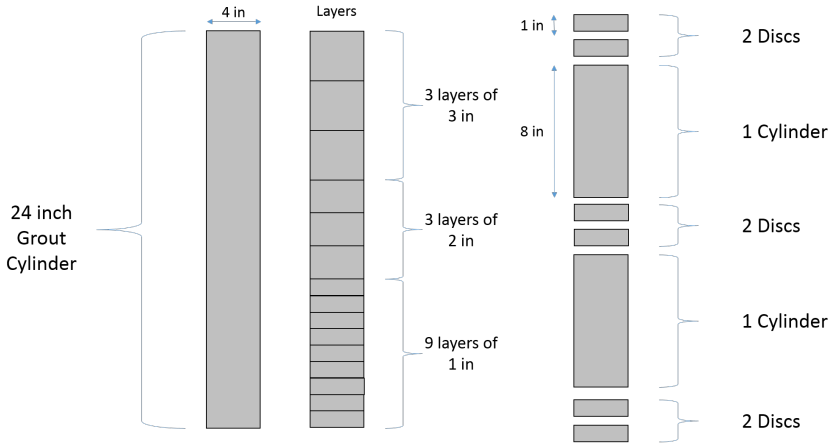
1 inch layered casting



Getting some more practice: Mock GSS connection

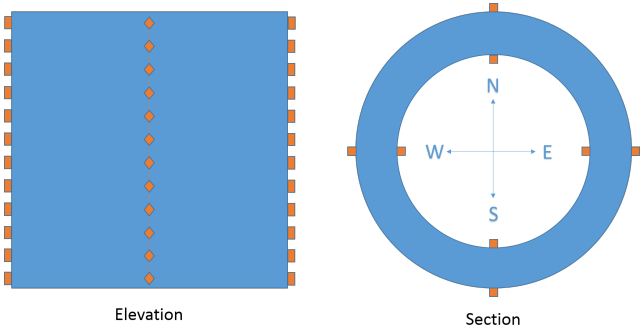
Formwork for mock connection

Getting some more practice: Mock GSS connection

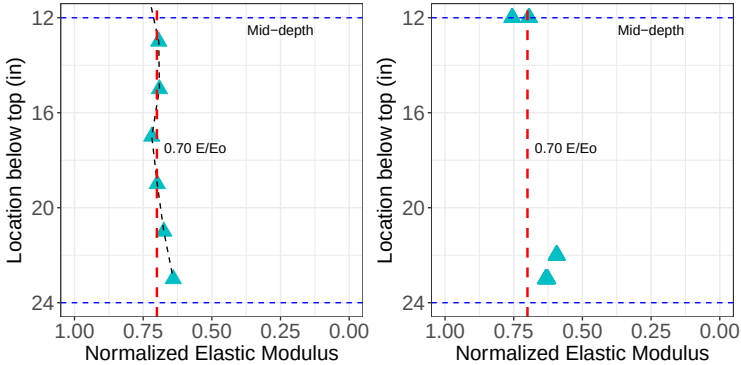


Casting Schematic

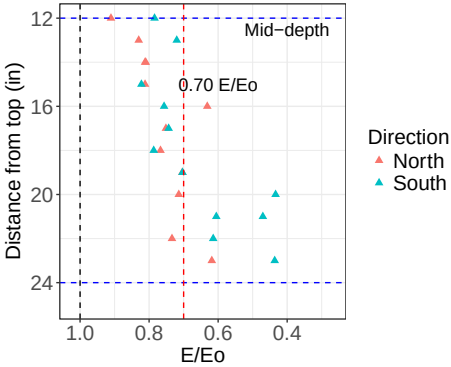
Getting some more practice: Mock GSS connection



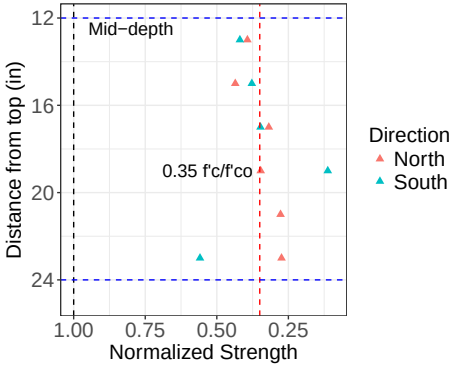
Getting some more practice: Mock GSS connection



State of grout in Large Scale Tests



Elastic modulus along height



Compressive strength along height

Preview of Part 2

Structural consequences of grout deterioration

Three large scale tests, their results, and conclusions.

GSS connection optimization

Use of large scale test data to determine the force transfer mechanism within the GSS connection.

Stay tuned...