Structural Consequences of Grout Deterioration in the Grouted Shear Stud Connection

Arjun Jayaprakash, James Nau, Mohammad Pour-Ghaz, and Mervyn Kowalsky

March 1st, 2019
Structural Engineering and Mechanics Symposium

Structural Consequences of Grout Deterioration in the Grouted Shear Stud Connection
Arjun Jayaprakash, James Nau, Mohammad Pour-Ghaz, and Mervyn Kowalsky
March 1st, 2019
Structural Engineering and Mechanics Symposium

Good morning everyone, my name is Arjun Jayaprakash and today I would like to present a part of my PhD project. The title of this presentation is as you see here. However, it all boils down to figuring out whether this bridge connection I'm working on would still carry out its function after multiple years of extreme cold climate exposure.

Background and Motivation

First, I would like to give you some background information to get you all upto speed.

What is the Grouted Shear Stud (GSS) Connection?

What is the Grouted Shear Stud (GSS) Connection?

What is the Grouted Shear Stud (GSS) Connection?

What is the Grouted Shear Stud (GSS) Connection?




What is the Grouted Shear Stud (GSS) Connection?

If you pay attention to the photograph on the left, the yellow ring shows the conventional detail to connect steel piles to steel cap beams, which, essentially is directly welding them together. This type of a connection has been recently found to be unsatisfactory for seismic design.

The grouted shear stud connection or the GSS connection, which you see on the photograph to the right, is an alternate detail that serves the same purpose, however with better features compared to the directly welded connection.

The GSS connection is a socket type connection where columns or piles go into a socket formed by a larger diameter pipe stub shop welded to the cap beam. The annular region thus created is then filled with grout. You may also notice shear studs welded within this grouted region. These help to mobilize the composite action within the connection and also provide some reinforcement to the grout.

Why GSS connection?

Suitable for seismic design

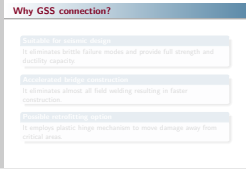
It eliminates brittle failure modes and provide full strength and ductility capacity.

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.



Why GSS connection?

Suitable for seismic design

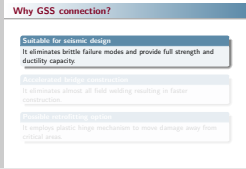
It eliminates brittle failure modes and provide full strength and ductility capacity.

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.



Why GSS connection?

Suitable for seismic design

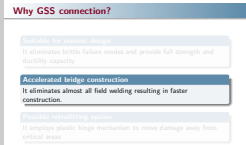
It eliminates brittle failure modes and provide full strength and ductility capacity.

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.



Why GSS connection?

Suitable for seismic design

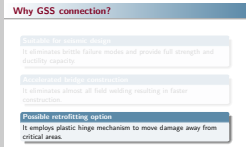
It eliminates brittle failure modes and provide full strength and ductility capacity.

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.



At the risk of sounding like an infomercial, I have compiled some advantages of using the GSS connection.
First, the GSS connection is ideal for seismic design as it eliminates any brittle failure around the weld region, and provides full strength and ductility capacity.
Second, the GSS connection can be incorporated in accelerated bridge construction as the fabrication requires no field welding.
And finally, with some modifications, the GSS connection can also be tailored for retrofitting applications as one of its main functionalities is moving damage away from critical regions through plastic hinge relocation.

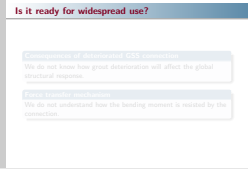
Is it ready for widespread use?

Consequences of deteriorated GSS connection

We do not know how grout deterioration will affect the global structural response.

Force transfer mechanism

We do not understand how the bending moment is resisted by the connection.



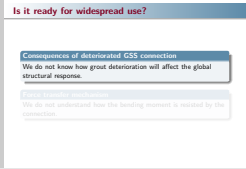
Is it ready for widespread use?

Consequences of deteriorated GSS connection

We do not know how grout deterioration will affect the global structural response.

Force transfer mechanism

We do not understand how the bending moment is resisted by the connection.



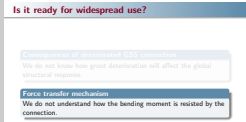
Is it ready for widespread use?

Consequences of deteriorated GSS connection

We do not know how grout deterioration will affect the global structural response.

Force transfer mechanism

We do not understand how the bending moment is resisted by the connection.



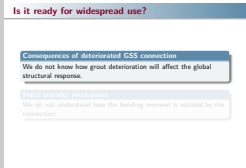
Is it ready for widespread use?

Consequences of deteriorated GSS connection

We do not know how grout deterioration will affect the global structural response.

Force transfer mechanism

We do not understand how the bending moment is resisted by the connection.



Well, if it has all these good features, can we recommend this for widespread use?

Alaska DOT already has a detour bridge that employs this connection. However, they wanted some more issues to be sorted out to fully switch.

First, we do not know the performance of this connection over a long time. The grout is a new variable and is vulnerable to environmental deterioration, especially in extreme cold climate such as Alaska.

Second, we still do not fully understand the force transfer mechanism in this connection. It is definitely a useful information to have while designing this connection.

My presentation today will focus on the first issue, which is consequences of grout deterioration.

Research Approach

So, how did we go about solving this problem?

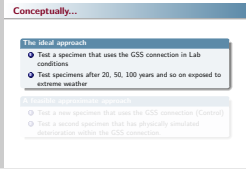
Conceptually...

The ideal approach

1. Test a specimen that uses the GSS connection in Lab conditions
2. Test specimens after 20, 50, 100 years and so on exposed to extreme weather

A feasible approximate approach

1. Test a new specimen that uses the GSS connection (Control)
2. Test a second specimen that has physically simulated deterioration within the GSS connection.



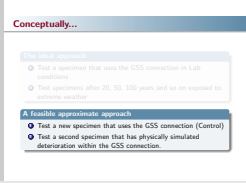
Conceptually...

The ideal approach

1. Test a specimen that uses the GSS connection in Lab conditions
2. Test specimens after 20, 50, 100 years and so on exposed to extreme weather

A feasible approximate approach

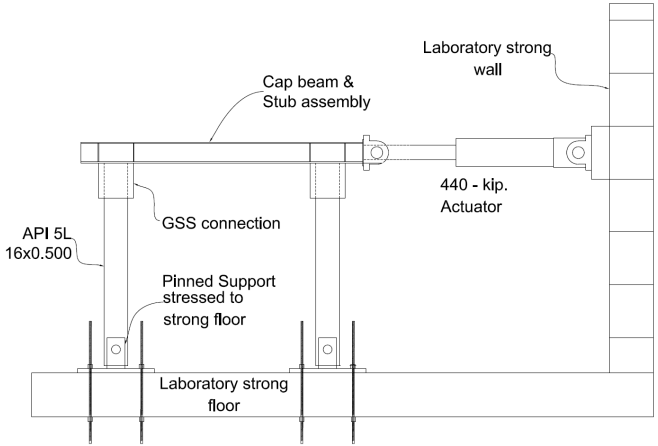
1. Test a new specimen that uses the GSS connection (Control)
2. Test a second specimen that has physically simulated deterioration within the GSS connection.

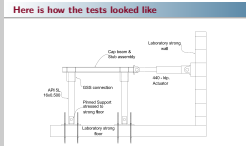


The ideal approach would have been to first test a structural specimen, that uses the GSS connection, in laboratory conditions. Then, subject 1 or more such specimens to extreme weather for say 20, 50, or a 100 years and test them at these times, and observe and quantify differences in structural response. Needless to say, this is impractical.

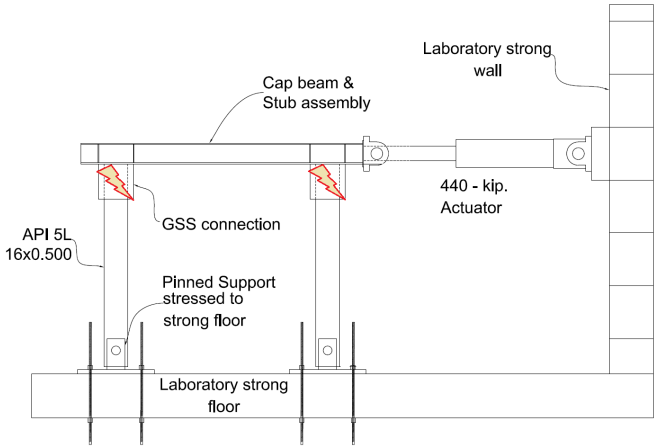
A more feasible approach was the following. The first step was to test a control specimen in laboratory conditions. The second step was to test a second specimen with some sort of simulated grout deterioration. And, the idea was to compare the structural response of the these two tests and draw meaningful conclusions.

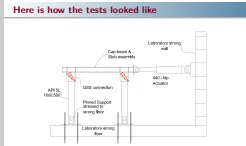
Here is how the tests looked like





Here is how the tests looked like

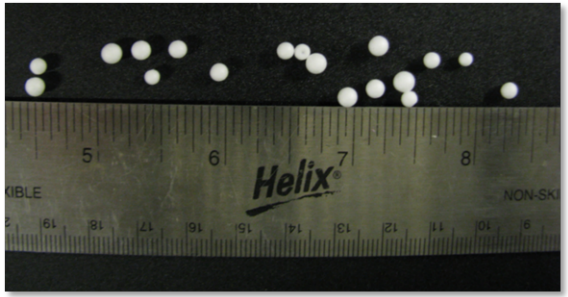




So, here is what we did.
We had two columns supported by pins attached to a cap beam at the top using the GSS connection. This two column specimen represented a typical steel bridge bent. This specimen was loaded laterally under cyclic quasi static loading using an actuator mounted on the strong wall.
Now, imagine this as the first test. For the second test, we simulated grout deterioration within both the GSS connections in the specimen and compared the results. By deterioration, what I specifically mean is that the grout in these connections had reduced elastic modulus and strength compared to that in the first test.

The question now becomes, how did we simulate deterioration?

Simulating deterioration



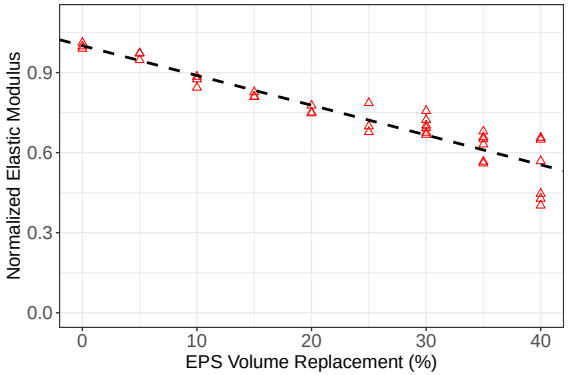
Expanded Polystyrene (EPS) beads

Simulating deterioration

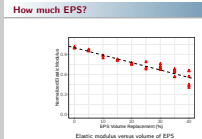
Expanded Polystyrene (EPS) beads

There are studies in the literature where they have used a material called expanded polystyrene or EPS in short to reduce the weight of concrete. EPS is an extremely light material. They also observed that EPS reduced the elastic modulus as well as the compressive strength of concrete. We decided to give this material a try to get the same effect.

How much EPS?



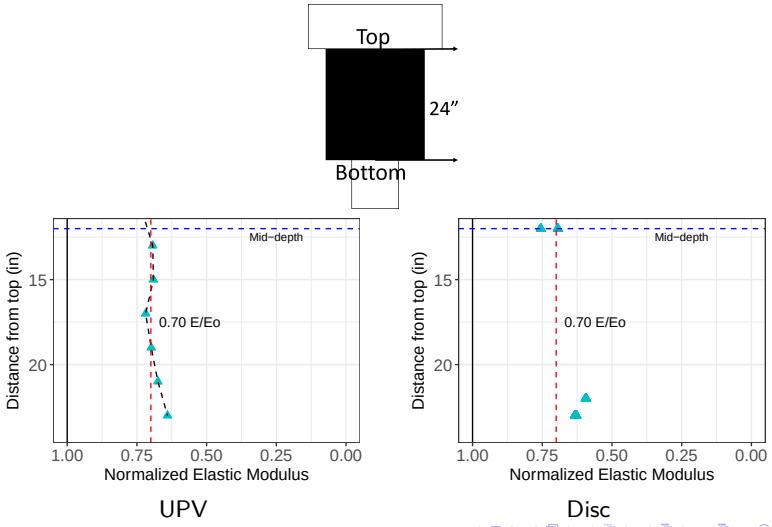
Elastic modulus versus volume of EPS

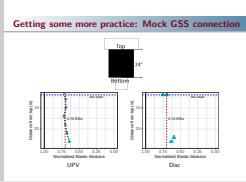


Our requirement necessitated a controlled drop in properties like the elastic modulus. So, a trial procedure was used to get an approximate idea of the amount of EPS required.

In this graph, you see the amount of EPS by volume on the x-axis and the value of elastic modulus on the y-axis. Please note that the elastic modulus is normalized to the value when we had zero percent EPS. We observed a more or less linear trend with a negative slope which gave us an idea of the required amount of EPS to be added in our grout.

Getting some more practice: Mock GSS connection



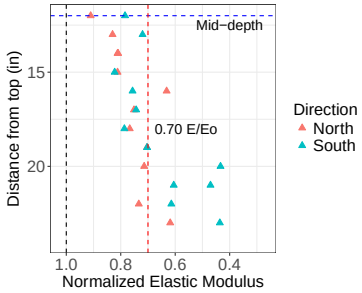


Now, we had an understanding of the required amount of EPS to be used in out Test 2. However, before we proceeded to Test 2, we wanted to make sure that we are getting what we set out to achieve. So, we cast a mock GSS connection. It is nothing but a same scale replica of the grout ring in the GSS connection. The mixture had around 20% EPS by volume. We then measured the elastic modulus of this mock connection at different points along its height.

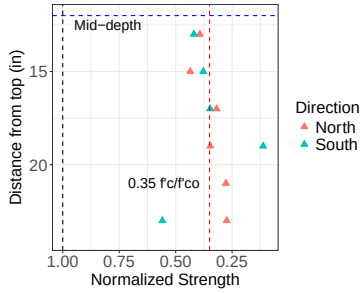
On the left, you see results of ultra sonic pulse velocity tests. On the x-axis you see the normalized elastic modulus and on the y-axis you see the distance from the top of the connection. You can see that the values are distributed at or around 70% of initial elastic modulus or in other words a 30% reduction.

On the right, you see a similar graph. However, the measurement technique used here is different. We used disc samples obtained from these heights and used them to measure elastic modulus. But, what is interesting is that with two different measurement techniques, we more or

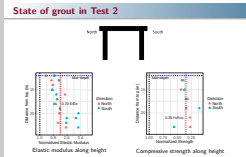
State of grout in Test 2



Elastic modulus along height



Compressive strength along height



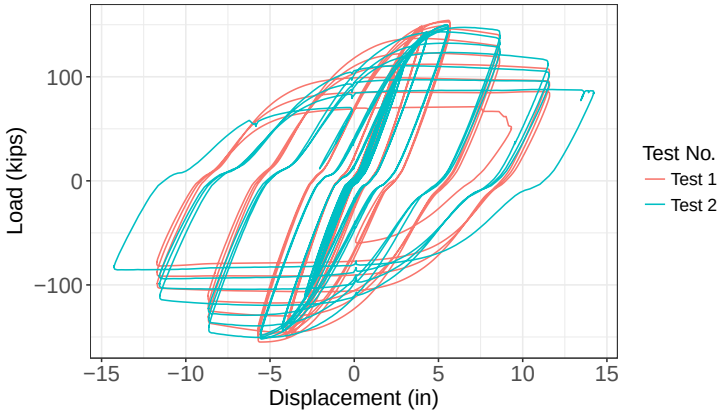
The success of the mock test motivated us to use the same mixture for Test 2. Remember, Test 1 was the control test and Test 2 was the one with simulated deterioration. The state of the grout in Test 2 is as shown here. On the left, you have the elastic modulus measurements along height. there is much more scatter here compared to the mock test. However, on average, the values fall around 70% of initial.

We also measured the compressive strength of the grout along the height of the connection. The results are on the right. On average, we had around 65% reduction in compressive strength compared to the grout in Test 1.

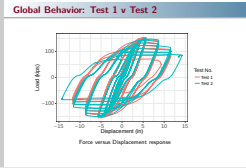
So, does grout deterioration matter?

Okay. So now to the main question at hand. Does grout deterioration in the GSS connection really matter among larger scheme of things.

Global Behavior: Test 1 v Test 2

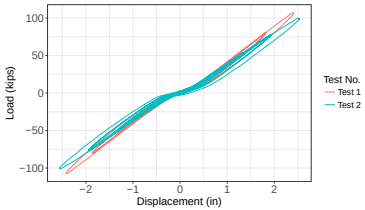


Force versus Displacement response

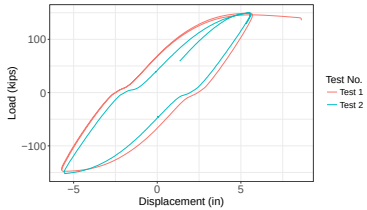


Here, we have the comparison of results from the two tests. This is the force versus displacement response of the two systems. Test 1 is red and Test 2 is blue. Test 1 was the control and Test 2 was the one with deteriorated connections. What is easily seen is that both curves more or less lie on top of each other. If there was an impact of grout deterioration, it doesn't show up here. In fact, Test two reached a larger ductility compared to Test 1.

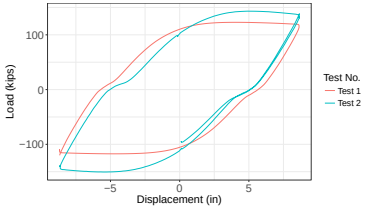
A closer look



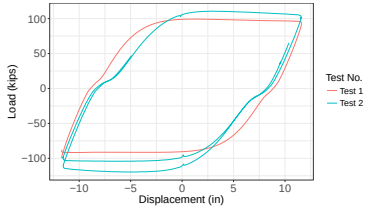
First yield



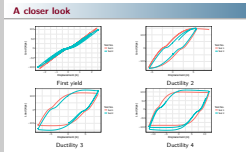
Ductility 2



Ductility 3



Ductility 4



Lets take a closer look on the results for clarity. Here, I have picked up cycles at different ductility levels. In each of these figures, the behavior of both tests are pretty much the same. Although in the case of the first yield cycles, you can may be notice a reduced stiffness, basically the slope, for Test 2. This matches expectation because the grout in Test 2 was less stiff.

What about the failure modes?

Failure Mode: Test 1 v Test 2

Test 1 (Control Specimen)

Test 2 ("Deteriorated" Specimen)

Failure Mode: Test 1 v Test 2

Test 1 (Control Specimen)

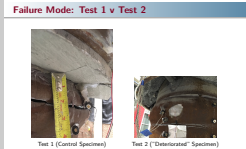
Test 2 ("Deteriorated" Specimen)

Failure Mode: Test 1 v Test 2

Test 1 (Control Specimen)

1. Yielding
2. Local buckling
3. Plastic hinging
4. Wall rupture or instability

Test 2 ("Deteriorated" Specimen)



Test 1 failed by pile wall rupture just under the connection while Test 2 did not have any wall rupture. Test 2 on the other hand reached a large enough drift that it was terminated due to stability concerns. Nevertheless, both tests showed similar progression of limit states. The columns yielded first which was followed by minor local buckling. The plastic hinge then forms just below the connection where it eventually ruptures.

Drift: Test 1 v Test 2

Test 1 (9% drift)

Test 2 (11% drift)

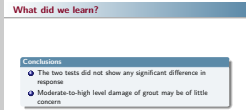
Drift: Test 1 v Test 2

Here is a comparison of the maximum drifts that were obtained for each test. Test 2 had a higher drift of 11% compared to 9% for Test 1.

What did we learn?

Conclusions

1. The two tests did not show any significant difference in response
2. Moderate-to-high level damage of grout may be of little concern



So, all in all, what did we learn?
Well, we did not observe significant difference in global structural performance between specimens with damaged and undamaged connection. So one conclusion was that a moderate to high level of durability damage is of little concern when using the GSS connection.

What we did not know about the GSS connection

Consequences of deteriorated GSS connection

We do not know how grout deterioration will affect the global structural response.

Force transfer mechanism

We do not understand how the bending moment is resisted by the connection.

What we did not know about the GSS connection
Consequences of deteriorated GSS connection
We do not know how grout deterioration will affect the global structural response.
Force transfer mechanism
We do not understand how the bending moment is resisted by the connection.

What we did not know about the GSS connection

Consequences of deteriorated GSS connection

Grout deterioration within the GSS connection is likely to be structurally insignificant.

Force transfer mechanism

We do not understand how the bending moment is resisted by the connection.

Going back to our motivation slide, we have went on to conclude that consequences of grout damage in the GSS connection are minor.

Now, as part of future work, we are planning two more large scale tests that we will use to answer the second issue of the force transfer mechanism in the GSS connection.

Future Work

Consequences of deteriorated GSS connection

Grout deterioration within the GSS connection is likely to be structurally insignificant.

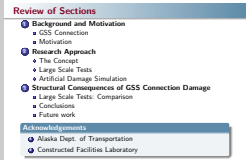
Force transfer mechanism

Two large scale tests to reveal more information on force transfer mechanism.

Review of Sections

Acknowledgements

1. Alaska Dept. of Transportation
2. Constructed Facilities Laboratory



With that I come to the end of my presentation. Here is a list of things that I talked about. Before I close, I would like to acknowledge AKDOT for sponsoring this project. Also, CFL and the staff at CFL for helping me do my tests.