# Structural Performance of the GSS Connection

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AKDOT - NCSU Research Workshop

1. Structural Consequences of Grout Deterioration

2. Connection Optimization

# A Review

# What was our approach?

**Phase 1**

Investigated cold climate durability of commonly available commercial grouts.

**Phase 2**

Structural tests to determine consequences of deterioration.

# So far...

## Durability of Cementitious Grouts

1. Some are good, some are bad.
2. Even good ones show inconsistency.
3. Water content per bag is important.

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# What next?

**Is grout durability important?**

Determine the structural consequences of deteriorated grout by simulating deterioration artificially in large scale test specimens.

**Simulate damage how?**

Adding EPS beads in grout mixture to reduce compressive strength and elastic modulus.

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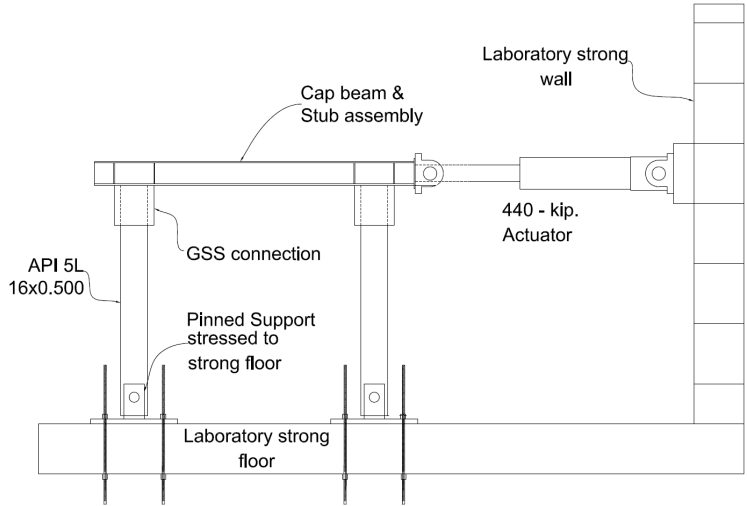
# Experimental Setup

# Research plan



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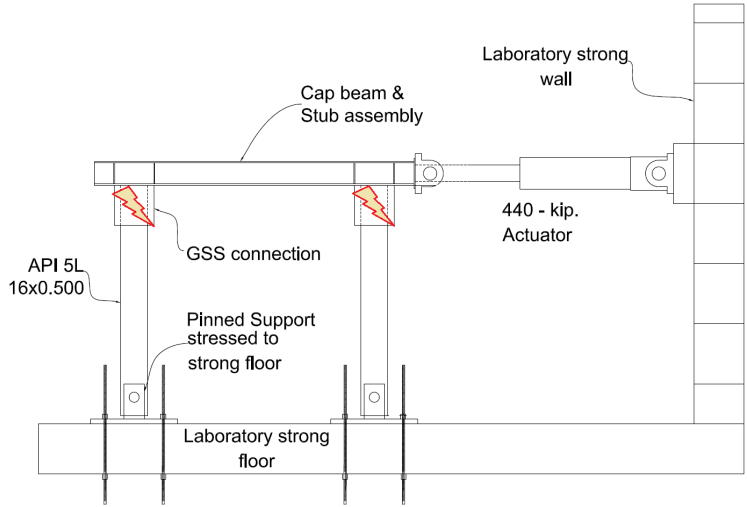

# Fulmer et al. 2015 a.k.a Test 0

**What is different?**

1. Test 0 used 96 shear studs 3/4" dia., we used 32 shear studs 1" dia.
2. Test 0 used ASTM A500 Gr.B steel, we used API 5L X52 PSL2 steel.

Test 0: Stud arrangement

# Fulmer et al. 2015 a.k.a Test 0

**Why reduce studs?**

1. Test 0 used full axial yield force of column as the pull out force.
2. Overly conservative as this will not be mobilized in reality.

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# Consequences Matrix

## Large Scale Test Matrix

| Test No. | Shear Studs | Stud dia. | Stud Area | Grout Strength | Socket length |
|---|---|---|---|---|---|
| 0 | 96 | 3/4 in. | | $0.7f'_{c0}$ | 24 in. |
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## Components

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## Steps of construction

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# Large Scale Test Matrix

## Original Plan

| Test No. | Characteristics |
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| 1 | Control test; Ideal conditions |
| 2 | Deteriorated grout ($E$ & $f_c'$) - Level 1 |
| 3 | Deteriorated grout ($E$ & $f_c'$) - Level 2 |
| 4 | Deteriorated grout ($E$ & $f_c'$) - Level 3 |

# Large Scale Test Matrix

## Revised Plan

| Test No. | Characteristics |
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| 3 | Deteriorated grout ($E$ & $f'_c$) - Level 2 |
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# Consequences of Grout Deterioration on Structural Performance of the GSS Connection

# Test Features

## Variables

**Test 1** **Test 2** **Test 3**

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## Variables

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| --- | --- | --- |
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| 32 (1" dia.) shear studs | 32 (1" dia.) shear studs | 16 (1" dia.) shear studs |

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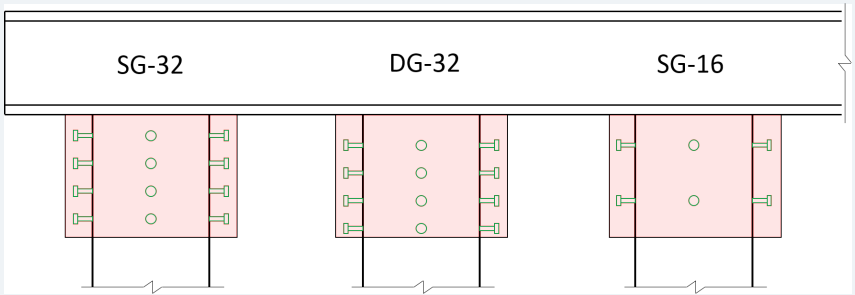
| **SG-32** | **DG-32** | **DG-16** |

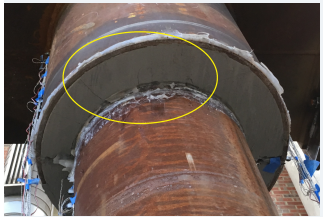
## Stud configuration



# Test Comparisons - Limit States

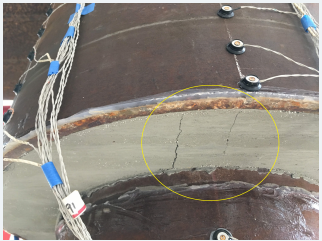
## Cracking at Neutral Axis

**SG-32**



Ductility = $\mu_{1.5}$

**DG-32**



Ductility = $\mu_1$

**DG-16**

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# Test Comparisons - Limit States

## Socket detachment - Gap

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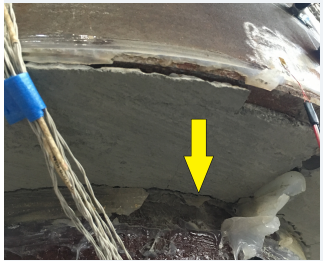

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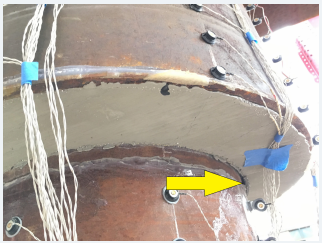

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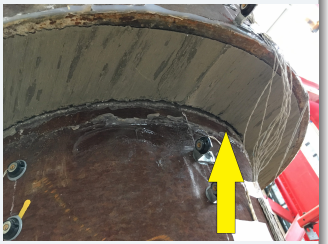

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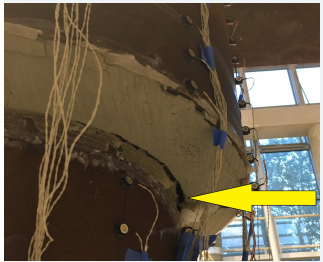
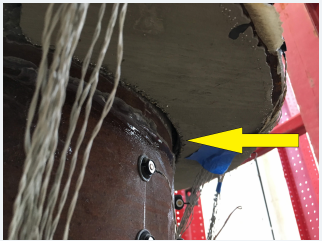


Ductility = $\mu_3$

**DG-32**



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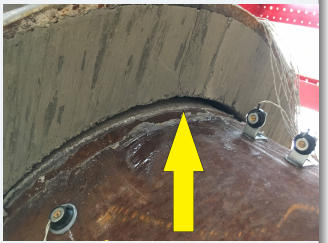

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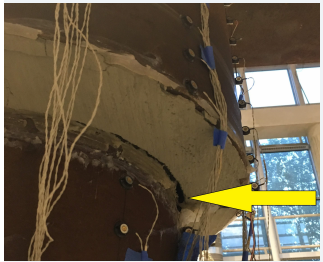

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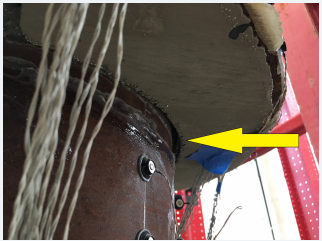

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**DG-16**

Ductility = $\mu_4$

# Test Comparisons - Limit States

## Grout spalling

**SG-32**

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**DG-16**

Ductility $= \mu_2$

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**DG-32**

Ductility = $\mu_3$

**DG-16**

Ductility = $\mu_3$

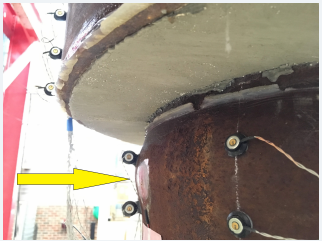
# Test Comparisons - Limit States

## Pile wall buckling

**SG-32**

Ductility = $\mu_2$

**DG-32**



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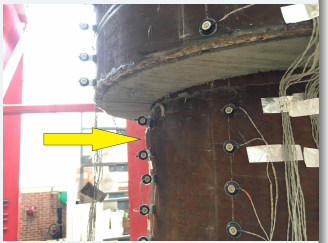

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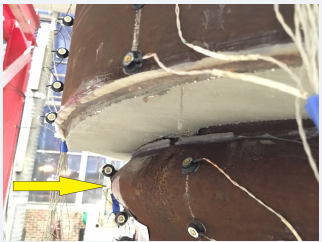

Ductility $= \mu_4$

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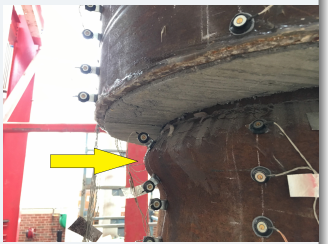

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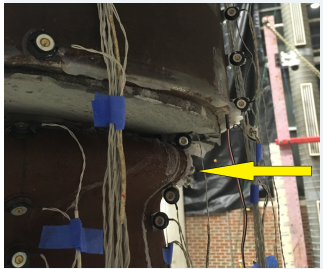


Ductility = $\mu_4$

**DG-32**

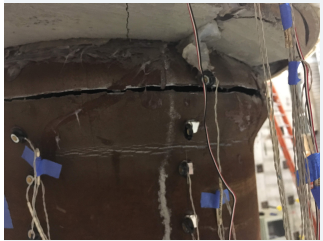
Ductility = $\mu_5$

**DG-16**

Ductility = $\mu_5$

# Test Comparisons - Limit States

## Pile wall rupture

| SG-32 | DG-32 | DG-16 |
|---|---|---|
|  |  |  |
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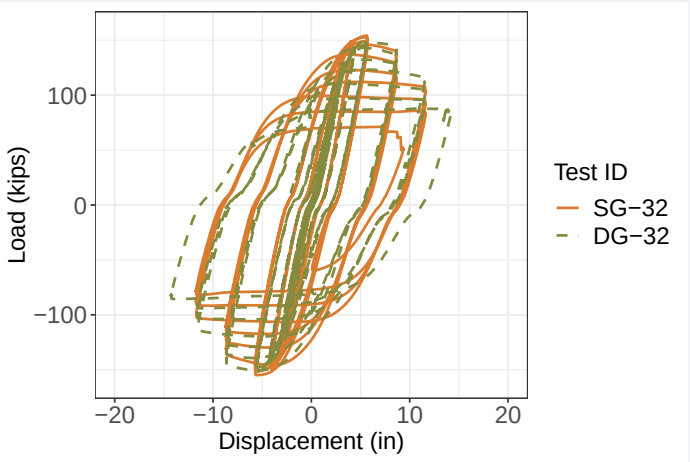
# Force Displacement Response

## SG-32 v DG-32



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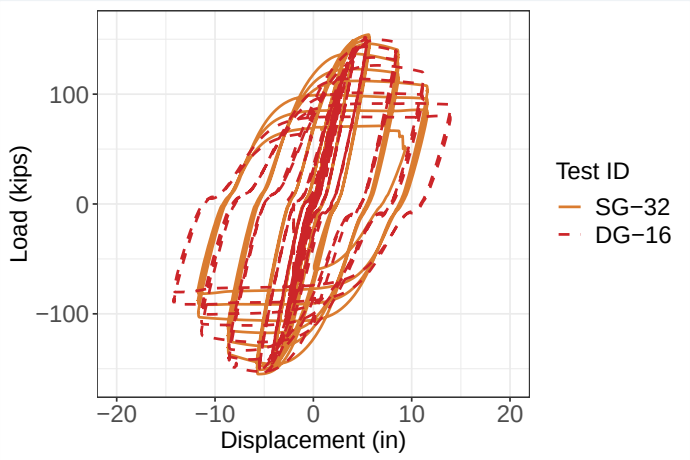

# Are there consequences of grout damage?

**Conclusion**

Experiments suggest that **grout durability** may **not** be **of** significant **concern** since the GSS connection performed adequately even when grout properties ($E$ and $f'_c$) were significantly reduced.

# GSS Connection Optimization - Force Transfer Mechanism

# Motivation

**At the end of Test 2, we...**

1. knew that durability of grout was likely insignificant, from a structural standpoint.
2. met with AKDOT engineers.
3. decided to use the last two tests to answer different questions.

**Questions**

1. Can the GSS connection be further optimized?
2. What exactly is(are) the mechanism(s) that contribute to successful plastic hinge relocation?
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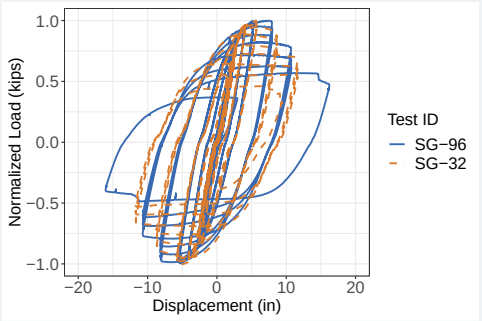
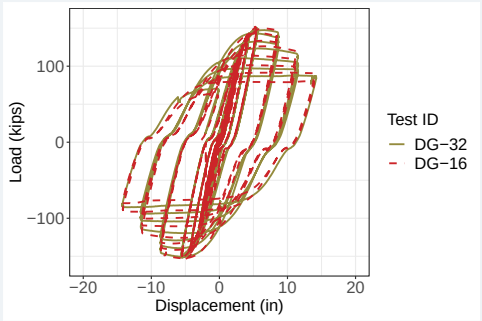
# Effect of the number of shear studs

## Comparison of global behavior



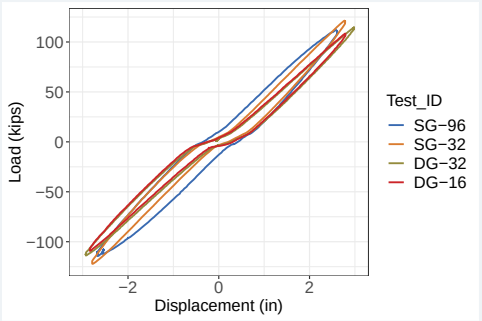

96-3/4" to 32-1"



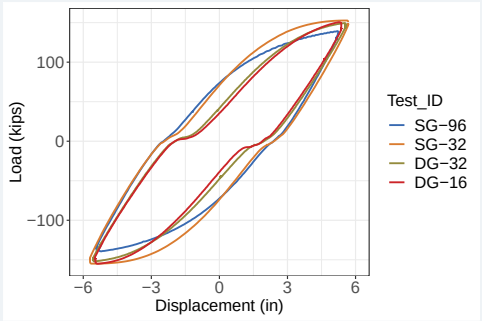

32-1" to 16-1"

# Effect of the number of shear studs

## Comparison of global hysteresis loops




$\mu_1$




$\mu_2$

# Effect of the number of shear studs

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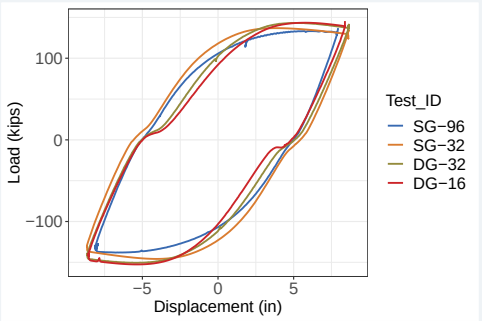
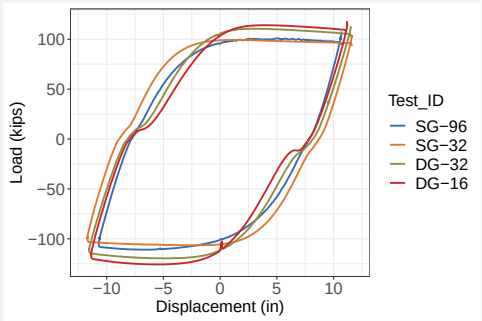


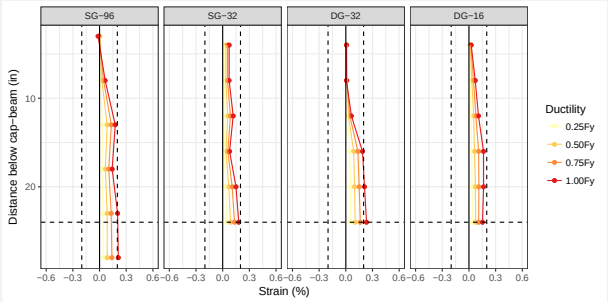

$\mu_3$




$\mu_4$

# Effect of the number of shear studs

## Strains inside the connection




Elastic cycles - North North

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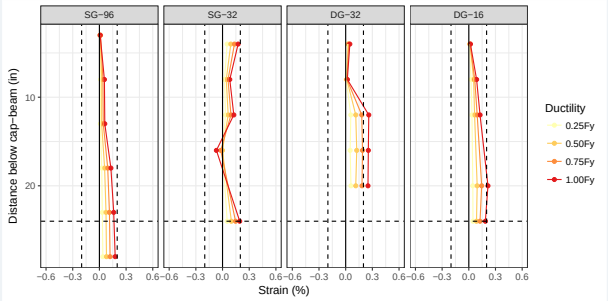


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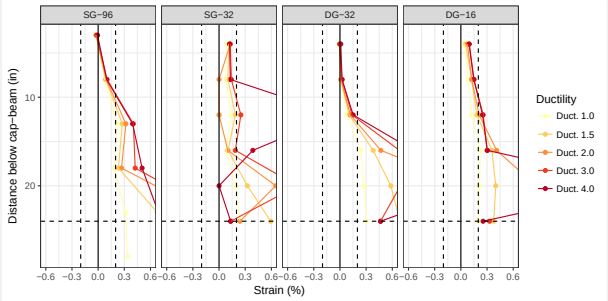


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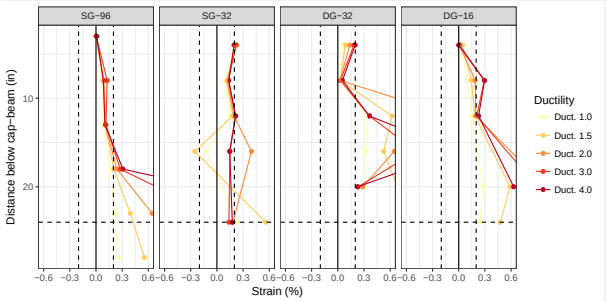



Inelastic cycles - South North

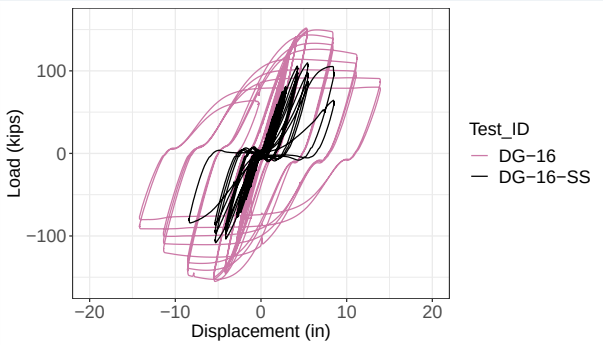
# Effect of Socket depth

## Is socket depth important?

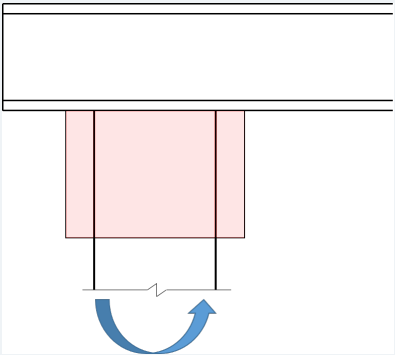
1. Final test was used to ascertain importance of socket depth.
2. Specimen used shorted stub length, **1D instead of 1.5D**
3. Premature failure was expected

# Effect of Socket depth

## DG-16 v DG-16-SS



## Socket Action



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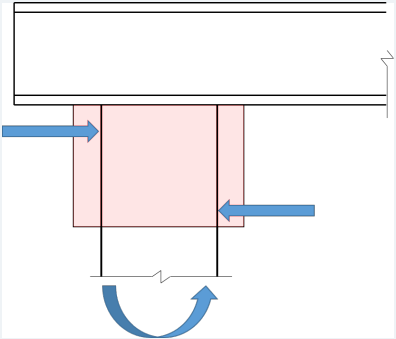

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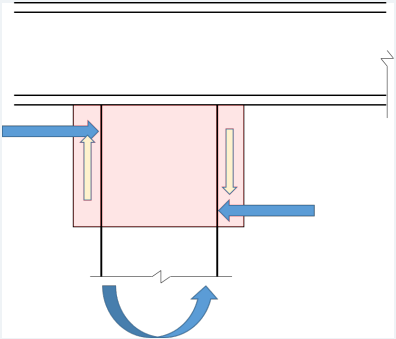

# Conclusions

## Remarks on Connection Optimization

1. The dominant force transfer mechanism seems to be the resistance couple formed by socket action.
2. The number of studs do not seem have significant impact on global response.
3. Presence/absence of shear studs result in small changes in limit state achievement.

## Need for more studies

1. Computational modeling of GSS connection may provide a better understanding of the mechanism.

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# Conclusions, Recommendations, and Open Questions

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**Does grout deterioration compromise the GSS connection performance?**

It does not, to the extend of the range of grout properties used for testing.

**What is the force transfer mechanism of the GSS connection?**

Experiments suggest that socket action is the most dominant mechanism. However, more work is required to confirm.

# Recommendations

## For good grout durability

1. Grout should meet a minimum durability factor of 95% per ASTM C666 Procedure A.
2. Keep water content per bag close to the bag labelled minimum.
3. Mix for at least 20 minutes for good air void distribution.

# Recommendations

**For satisfactory GSS performance**

1. Provide minimum number of shear studs based on engineering judgment.
2. Provide a socket length of at least 1.5 times the diameter of pile column.
3. Take action if large grout spalling is observed.

# Open Questions

## What we still do not fully understand?

1. What is the contribution of each of the following mechanisms in mobilizing force transfer:
    1. Socket action
    2. Bond/friction
    3. Strut formation between shear studs
2. Will the results hold when we vary D/t ratio of the pile?

# Review of Sections

# Acknowledgements

**I want to thank...**

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