Durability of the Grouted Shear Stud (GSS) Connection in Cold Climate

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Background and Scope

Steel Bridge Substructures:

- Prevalent connection detail – Directly welded column to cap-beam connection (DWC)
- DWC prone to brittle failure of weld/heat affected zone (Fulmer et al. – 2010 [1])
- DWC result in strength and ductility capacity lower than that predicted
- Grouted Shear Stud (GSS) Connection developed to mitigate issues (Fulmer et al. – 2015 [2])

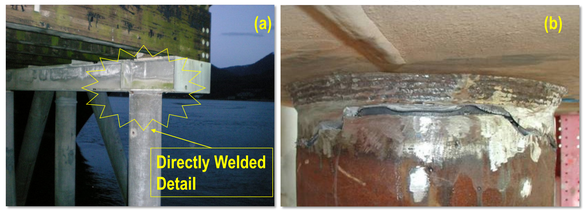


Figure 1. a) A typical steel bridge substructure with directly welded connection (DWC) (b) Failure mode for DWC – Brittle cracking.

Grouted Shear Stud (GSS) Connection:

- Developed with the following objectives:
  - Protection of welded region of steel pipe column to cap beam connections
  - Plastic hinge relocation
  - Increased strength and ductility capacity
  - Potential application in accelerated bridge construction (ABC) and structural retrofitting.

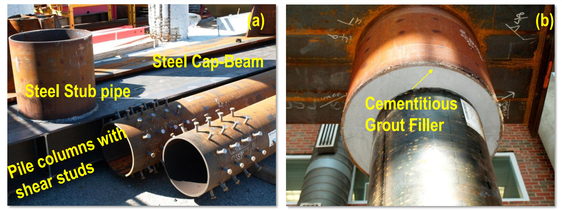


Figure 2. a) GSS cap-beam and piles welded with shear studs (b) GSS connection with offset socket.

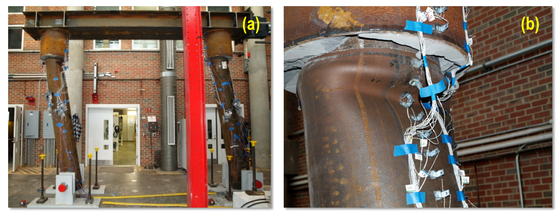


Figure 3. a) Tested steel bridge bent with the GSS connection (b) Failure mode for GSS connection – Ductile plastic hinge formation.

Important questions being addressed:

- Can GSS connection be used in cold climate?
  - Is the grout filler durable under repeated Freeze – Thaw (FT) cycles and Restrained Shrinkage?
  - Does durability damage compromise structural integrity of the lateral load resisting system?

Durability I - Freeze and Thaw

Testing FT resistance of grouts:

- ASTM C666 Procedure A [3]
- 3 x 3 x 12 in. prismatic grout specimens
- Freeze and thaw in water (Range - 4°C to -18°C)
- Damage leads to reduction in the elastic modulus
- Damage assessed by measuring relative dynamic elastic modulus (RDME), i.e. the ratio of Elastic modulus (E) at any cycle to the value at 0 cycles.
- Classify grouts by performance into "Good" and "Poor" categories

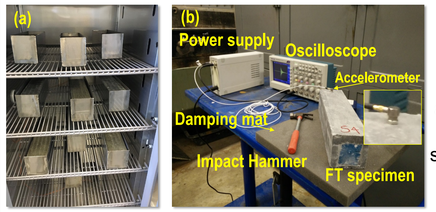
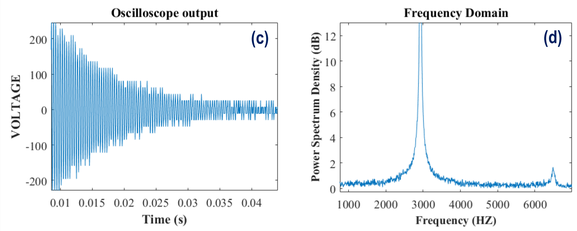


Figure 4. (a) Specimens in chamber (b) Damage assessment setup (c) Typical specimen response (d) Response in freq. domain



Durability Factor

$$DF = E/E_0 \cdot \frac{N_{cycles}}{300}$$

RDME

$$E/E_0 = \frac{n^2}{n_0^2}$$

Material	ASTM C666(A) Durability Factor (DF)	FT Resistance
CG1	100%	Good
CG2	100%	Good
CG3	100%	Good
CG4	46%	Poor
PG1	<10%	Very Poor

Table 1. Results of ASTM C666 test on commercial grouts.
Equations 1 & 2. DF = Durability factor; E/E_0 = Relative Dynamic Elastic Modulus (RDME); N_{Cycles} = Number of FT cycles until termination; n = Fundamental specimen frequency.

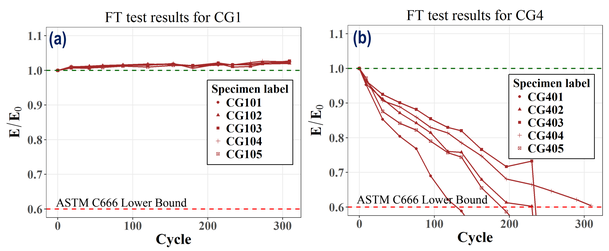


Figure 5. Typical results from FT resistance tests: (a) "Good" grout (b) "Bad" grout

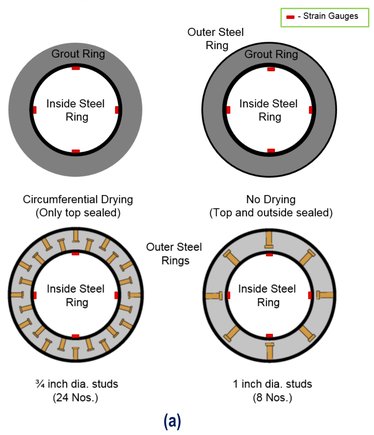
Conclusions:

- CG1, CG2, and CG3 proceed for further durability tests.
- Not all commercially available cementitious grouts have good FT resistance.

Durability II - Restrained Ring Test

Testing shrinkage cracking potential of grouts:

- Test based on ASTM 1581-09a [4]
- Strain gages installed on inner side of 16" dia. steel rings.
- Grout material cast around the steel ring
- Specimens left to shrink under restraint (provided by steel ring) at 23°C and 50% relative humidity
- Steel ring strains monitored until cracking
- Cracking indicated by a rapid drop in compressive strain denoting stress release
- Average strain ($\mu\varepsilon$) versus time curves plot



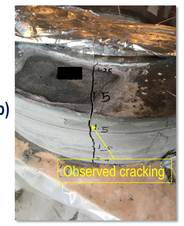


Figure 6. (a) Schematic showing 4 different ring tests performed with variable drying (Circumferential & Sealed) and geometric (with and without studs) conditions (b) Typical cracking observed on specimen with no studs

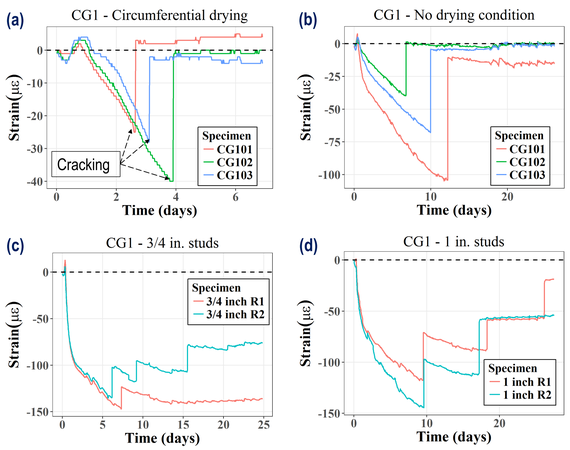


Figure 7. Typical results from ring tests: (a) Early cracking under circumferential drying (b) Delayed cracking under no drying (c) & (d) Early but minimal and distributed cracking with presence of ¾ in. studs and 1 in. studs.

Conclusions:

- All the tested grouts cracked and are prone to shrinkage.
- Shrinkage cracking occurs within the first few days.
- Presence of shear studs in GSS connection distributes cracks resulting in minimal crack widths.

Does Durability Damage Compromise Structural Integrity? (Ongoing)

Research Approach:

- Simulate damaged GSS connections in large scale two-column bent specimens
- Test specimens under cyclic quasi-static lateral loading and compare with a control (no damage)
- Investigate difference in performance

Figure 8. Expanded Polystyrene (EPS) beads will be added to grout filler to simulate damage, i.e., reduced strength and elastic modulus

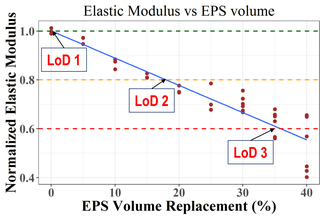


Figure 9. Results of elastic modulus measurement of grout with different volume replacements (%) of EPS beads.

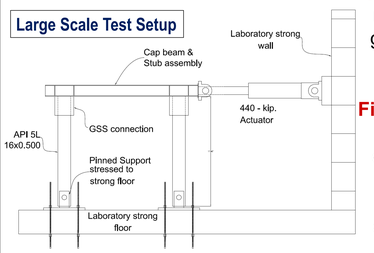


Figure 10. GSS Connections with different levels of deterioration (LoD) will be used in two-column bent specimens as shown to assess performance drop under lateral loading.

References

1. Fulmer, S. J., Kowalsky, M. J., Nau, J. M., Hassan, T., "*Ductility of welded steel pile to steel cap beam connections*", ASCE/SEI Structures Congress, vol. I.; 2010. pp. 216–27.
2. Fulmer, S. J., Kowalsky, M. J., Nau, J. M., "*Grouted shear stud connection for steel bridge substructures*", Journal of Constructional Steel Research, 109, 2015, pp. 72-86.
3. *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*, ASTM C666-15.
4. *Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage*, ASTM C1581-09a.

Acknowledgements

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