CORROSION DEVELOPMENT OF POST-TENSIONED TENDONS WITH DEFICIENT GROUT

Kingsley Lau and Mario Paredes

Florida Department of Transportation, State Materials Office
5007 NE 39th Ave. Gainesville, FL 32609

Durability of Post-Tensioned Infrastructure
INTRODUCTION: Post-Tensioned Strand Corrosion

• Several Documented Cases of Corrosion-Related Failures of Post-Tensioned (PT) Strand in FL.

• Corrosion identified in early 2000’s attributed to grout void formation due to bleed water formation and chloride presence.

• Subsequent specifications in FL include low bleed grout requirements.

• However, corrosion problems persist.

✓ Investigation of recent PT corrosion and repair issues are on-going. This presentation overviews current findings from field and laboratory explorations of deficient grout in tendons.
BACKGROUND:
PT Bridge in Florida built in 2002

- PT segmental bridge with int. and ext. tendons.
- Among first FL bridges to use low bleed grouts.
- Ext. Tendons placed to reduce tensile stresses in web. Anchor caps at low elevation.
- Severe corrosion in multiple ext. tendons. Failure occurred after ~8 years service.
- Severe corrosion accompanied by wet plastic grout.
Grout segregation characterized as:
- A. Wet plastic
- B. Sedimented Silica
- C. White chalky

 ✓ Corrosion attributed to wet plastic grout but not necessarily to void presence.
 ✓ Grout segregation created environment with dissimilar pore water chemistry and physical properties.
Segregated Grout Properties: Moisture Content

High moisture content associated with segregated grout.
• ~50% moisture in white chalky grout; ~70% moisture in wet plastic grout
Segregated Grout Properties: Pore Water pH

- Pore water of segregated grout typically retains high pH.
- No indication of processes to decrease pH such as carbonation.
- Regions with accumulation of corrosion products may contain localized low pH environments.

Regions with severe corrosion

† Prepared by Ex-situ Leaching Method
Segregated Grout Properties: Chloride Content

- Assuming threshold ratio $[\text{Cl}^-]/[\text{OH}^-] = 0.3$, and an upper measured free Cl concentration $\sim 50$ to $100$ ppm, threshold pore water pH ($<11.5$-$12$) $< \text{observed pH values (typ. }>12$).

- Assuming 67% cement content in grout, upper range 0.3mg/g Cl would correspond to 0.05% cement which is $<<C_T$.

☑ Low chloride content associated with segregated grout. Below conventional chloride corrosion threshold concentrations.

• Accumulated chloride content in moist grout may be due to ionic transport.

• However, total chloride test preparation methods may over-sample size of segregated grout thus higher reported chloride concentrations.
Segregated Grout Properties: Grout Content

- Apparent enhanced presence of sulfurous compounds in segregated grout.
- Gypsum and ettringite identified as sulfur bearing crystalline compounds.
- Ettringite-filled voids visually predominant in segregated grout; however, identified in grout in vicinity of segregated grout as well.

✓ Possible indicator of enhanced sulfate presence segregated grout free water.
Segregated Grout Properties: Pore Water Content

- Sulfate concentrations as high as 9700 ppm measured in pore water.
- Apparent lower concentrations of Na\(^+\), K\(^+\), and OH\(^-\) and the higher Ca\(^{2+}\) concentration in the segregated grout than elsewhere.
Corrosion and similar deficient grout characteristics observed at low elevations, too.
CORROSION CONDITIONS IN SEGREGATED GROUT

Variation in open-circuit potential characterizing local anodes in wet plastic grout and passive steel elsewhere.

- Differences in OCP develop macrocell corrosion.
Macrocell Corrosion

- Corrosion activity in wet plastic grout.
- Anodic polarization of active steel due to coupling with passive steel enhances corrosion rates.
✔ Large anodic macrocell currents developed in lab tests of field samples.
✓ High sulfate concentrations appear to have negative impact on steel passivation.
Corrosion activity measured in lab samples with high concentration of sulfates.

20,000 ppm Na$_2$SO$_4$
✓ Corrosion activity measured in lab samples with high concentration of sulfates.  
• Research is in progress to resolve the role of sulfates.
TENTATIVE PROPOSED CORROSION MECHANISM

- High water content was present in the grout.
- High water content carried higher concentrations of ionic species including sulfates and chloride ions. High concentrations of sulfurous compounds (sulfates in solution) were present in the grout.
- Segregated grout material provided poor corrosion protection for embedded strand that did not attain uniform stable passivity.
- Differential aeration condition present due to easy access to oxygen, vastly different moisture contents in localized regions, and strand interstitial spaces creating crevices.
- Accelerated corrosion was caused by macrocell coupling of local anodes in the strand embedded in segregated grout and extended cathode throughout the tendon.

WORK IN PROGRESS

- Identifying physical parameters of grout segregation mechanism.
- Resolving role of chloride, sulfates, and pH on steel depassivation in deficient grout.
- Identifying possible corrosion after repairs of deficient tendons.
CONCLUSIONS

- Segregated grout material was observed in localized portions of the tendons, characterized as: wet plastic, white chalky, and sedimented grout.
- High water content (up to 70 wt%) was measured in grout from localized portions of the tendons where corrosion occurred.
- Chloride accumulation was apparent in grout with high water content but concentrations were lower than conventional critical chloride threshold concentrations.
- No significant drop in pore water pH was observed in limited amount of sampling. However, slight depression of pore water (pH>11) from the wet plastic grout was apparent.
- Sulfate concentrations in the grout pore water were as high as 9700 ppm.
- Corrosion in segregated grout (signified by high moisture content, high porosity, and high sulfate concentrations) was likely accelerated due to macrocell coupling with extended cathode throughout the tendon.
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QUESTIONS???