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Project Summary Report 0-1405-S
Durability Design of Post-Tensioned Bridge Substructure Elements

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Durability Design of Post-Tensioned Bridge Substructure Elements: Summary

PROJECT SUMMARY REPORT

Corrosion protection for bonded internal tendons can be very effective. Within the elements, internal tendons can be well protected by the multilayer protection system— including a sound design taking away the surface water, surface treatments, high quality concrete, plastic or galvanized duct, sound cement grout, coatings and other internal barriers in the prestressing steel, and good anchorage protection measures. However, potential weak links exist when, among other conditions, the following hold true: (1) the concrete has high permeability; (2) the concrete has cracking; (3) the ducts are not adequately spliced or adequately protected by impermeable concrete; (4) the Portland cement grout has voids, bleed water, and cracks; and/or (5) the prestressing steel is not adequately protected and handled during construction.

One of the major problems that agencies face today is the difficulty of providing good monitoring and inspection techniques for bonded post-tensioned structures. Condition surveys are often limited to visual inspections for signs of cracking, spalling and rust staining, which can often overlook the deterioration of prestressing steel and fail to detect the potential for very severe and sudden collapses. Similar limitations exist when using advanced techniques to assess localized voids or active corrosion, since in these cases the analysis is limited to specific areas in selected bridge elements, overlooking grout voids or even corrosion of prestressing steel in other member locations.

What We Did...

After an extensive literature review, the project was divided into the following main components:

1. Literature Review and Survey of Existing Bridge Substructure Inspection Reports (BRINSAP),
2. Investigation of Corrosion Protection for Internal Prestressing Tendons in Precast Segmental Bridges,
3. Development of Improved Grouts for Post-Tensioning,
4. Long-Term Corrosion Tests with Large-Scale Post-Tensioned Beam and Column Elements, and
5. Development of Recommendations and Design Guidelines for Durable Bonded Post-Tensioned Bridges.

Component 1 included literature review of a substantial amount of relevant information that could be applied to the durability of post-tensioned bridge substructures and superstructures. This information allowed the scope of the experimental portion of the project to be narrowed.

Component 2 was developed and implemented under TxDOT Project 0-1264 and transferred to TxDOT Project 0-1405 for long-term testing. A total of thirty-eight macrocell specimens were used to investigate the corrosion protection of internal tendons at segmental joints. See Figure 1(a). Half of the specimens were autopsied after four and a half years of highly aggressive exposure. The second half of the specimens were autopsied with over eight years of very aggressive exposure. The variables included: joint type, duct type, grout type, and level of joint compression.

Component 3 consisted in testing numerous grouts in three phases to develop a high performance grout for corrosion protection. The testing phases included fresh property tests, accelerated corrosion tests, and a large-scale clear draped parabolic duct test that allowed observation of the grout under simulated field conditions. See Figures 1(b) and 1(c). Two grout mixes were recommended and have already become widely used in practice.

Component 4 included testing of twenty-seven large-scale beam specimens, which were constructed in two phases. See Figure 1(d). Phase I beams (16 specimens) were used to investigate the effect of prestressing levels, crack widths, and high performance grout. Phase II beams (11 specimens) were used to investigate duct splices, grout type, concrete type, strand type, duct type, and end anchorage protection. Full autopsies were performed on six Phase I beams (after four and a half years of exposure) and also on six Phase II beams (after three and a half years of exposure). Partial autopsies were performed on two Phase I beams. Full autopsies for the remaining specimens will be performed at a future date under TxDOT Project 0-4562. Component 4 also included testing of five non-prestressed and five post-tensioned column specimens to investigate corrosion mechanisms and chloride ion transport ("wicking effect") in various column connection configurations and to evaluate corrosion protection measures. See Figure 1(e). Variables included column to foundation connection, loading, concrete type, prestressing bar coatings, and post-tensioning ducts. Full autopsies were performed at the end of testing, after six and a half years.

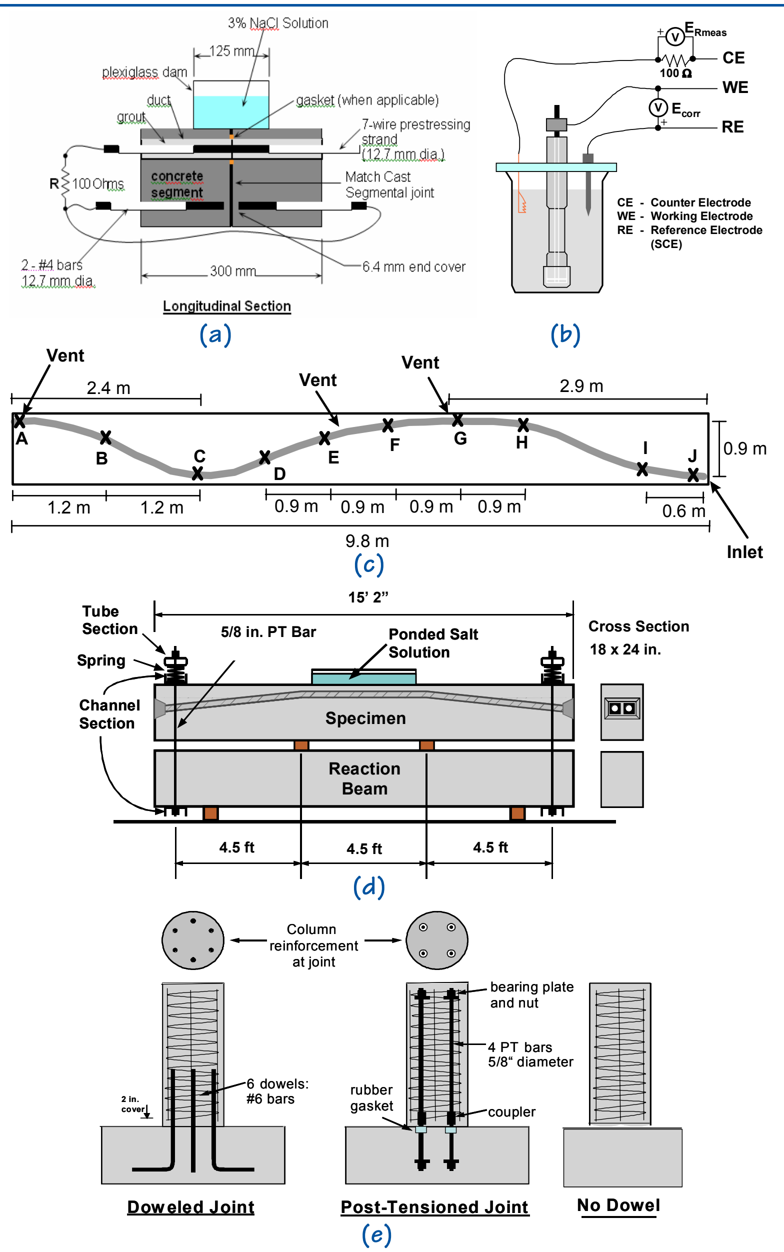

Figure 1. (a) Macrocell Specimen, (b) Schematic of ACTM Station, (c) Large-Scale Clear Draped Parabolic Duct Test, (d) Beam Test Setup, (e) Column-Foundation Joint

What We Found...

High-Performance Grouts and Grouting Procedures

- A 30% fly ash grout with a 0.35 w/c (water content) had excellent performance in horizontal applications.
- A 2% anti-bleed grout with 0.33 w/c had excellent performance in vertical applications.
- The standard TxDOT grout had below average performance.
- Grout voids, due to entrapped air, bleed water, incomplete grout filling or lack of grout fluidity were found to be detrimental not only to the prestressing strand, but also to the galvanized duct, as shown in Figure 2.
- Grout is not prestressed and grout cracks were often found under service loading.
- Calcium Nitrite corrosion inhibitor added to the grout did seem to provide some enhanced long-term strand corrosion protection.

Ducts for Internal Post-Tensioning

- Galvanized steel ducts performed poorly (see Figure 2). Plastic ducts were superior.
- The use of completely filled epoxy joints with unspliced plastic ducts showed very good protection.

Cracking and Joints

- Transverse cracking due to loading had a definite effect on corrosion damage. Larger crack widths and crack density were the cause of very severe localized and uniform reinforcement corrosion activity.

Figure 2. Bleed Water Voids and Galvanized Duct Corrosion

- Longitudinal or splitting cracks always indicated very severe corrosion within the member.
- Dry joints and incompletely filled epoxy joints in the macrocell specimens showed very poor performance.

Levels of Post-Tensioning

- As the level of post-tensioning or concrete precompression increased, the corrosion protection increased. Lower permeability due to increased precompression also provided better resistance to wicking effects.

Concrete Type

- High performance concrete appears to be effective in minimizing the chloride penetration through concrete.

Concrete Cover

- Small concrete cover was clearly shown to be detrimental to reinforcement performance.

Galvanized Duct Splices

- Neither the industry standard splice (duct taped) nor the heat-shrink splices appear to be satisfactory to prevent moisture and chloride ingress.

Gaskets for Post-Tensioning

- The use of gaskets in the joints to avoid epoxy filling of the ducts in segmental construction, or the use of rubber gaskets to seal the duct ends at column joints, were detrimental to the performance of the specimens.

Post-Tensioning Bars or Strands

- PT bar coatings showed enhanced general corrosion protection, in comparison to plain PT bars. However, under very severe localized attack, as in a crack or joint location, corrosion activity was severe.

Exposure Testing Methods

- After using half-cell potential readings, chloride content determinations and corrosion current readings, only the first two showed some degree of correlation with forensic examination results.

The Researchers Recommend...

- For PT Tendons with small rises under severe exposure conditions, the following grout should be used: 0.35 w/c, 30% fly ash (Class C) replacement and 4 ml/kg superplasticizer.
- For PT Tendons with large rises under severe exposure conditions, the following grout should be used: 0.33 w/c and 2% anti-bleed admixture.
- Plastic ducts should be used in all situations where even moderate aggressive exposure may occur.
- Epoxy joints should always be used with internal prestressing tendons.
- Stringent inspection and construction practices should be enforced to guarantee complete grouting and good epoxy filling at the joints in segmental construction.
- Duct gaskets in epoxy joints should be avoided.
- Mixed reinforcement members should be used in aggressive exposures only if special provisions are made to seal cracks and to prevent concrete exposure to chlorides.
- Fully prestressed members are recommended in aggressive environments.
- High performance concrete (w/c=0.29) is recommended in aggressive environments.
- Fly ash (Class C) concrete (w/c=0.44) may also be considered when the environment is less aggressive.
- Development of better duct splicing systems should be a high priority.
- Inspection of in-service bridges should identify potential reinforcement corrosion from any noted longitudinal or splitting crack.
- A minimum of 2-inch cover to any reinforcement should be used in any post-tensioning design.
- Fully plastic chairs to ensure proper concrete cover are recommended to eliminate corrosion damage, instead of chairs made out of steel.
- Column elements should be prestressed to improve spiral and rebar corrosion protection in very aggressive environments.
- Galvanized steel bars or epoxy coated are susceptible to severe localized corrosion.
- Bar coatings can be used when positive sealing of cracks or joints is attained.
- Half-cell potential readings and chloride content determinations could be used to assess to some degree the service condition of the specimens. Better corrosion assessment methods should be developed and evaluated.

For More Details...

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The research is documented in the following reports:

- Research Report 0-1405-1, *State of the Art Durability of Post-Tensioned Bridge Substructures*, October 1999.
- Research Report 0-1405-2, *Development of High-Performance Grouts for Bonded Post-Tensioned Structures*, October 1999.
- Research Report 0-1405-3, *Long-Term Post-Tensioned Beam and Column Exposure Test Specimens: Experimental Program*, October 1999.
- Research Report 0-1405-4, *Corrosion Protection for Bonded Internal Tendons in Precast Segmental Construction*, October 1999.
- Research Report 0-1405-5, *Interim Conclusions, Recommendations and Design Guidelines for Durability of Post-Tensioned Bridge Substructures*, October 1999.
- Research Report 0-1405-6, *Final Evaluation of Corrosion Protection for Bonded Internal Tendons in Precast Segmental Construction*, October 2002.
- Research Report 0-1405-7, *Long-Term Post-Tensioned Beam Exposure Test Specimens: Final Evaluation*, August 2003.
- Research Report 0-1405-8, *Long-Term Post-Tensioned Column Exposure Test Specimens: Final Evaluation*, August 2003.
- Research Report 0-1405-9, *Conclusions, Recommendations and Design Guidelines for Corrosion Protection of Post-Tensioned Bridges*, August 2003.

To obtain copies of the above reports, contact the Center for Transportation Research, The University of Texas at Austin, (512) 232-3126, ctrlib@uts.cc.utexas.edu.

TxDOT Implementation Status
October 2004

Results from research project 0-1405 have substantially impacted the design and construction of post-tensioned structural elements for bridges, and have been implemented both within Texas and on a national level. For example, the TxDOT specifications for grout materials were changed based on this research, and prepackaged grouts are now commercially available. A national grouting certification program has been implemented through the American Segmental Bridge Institute for construction personnel, and galvanized metal ducts are no longer specified for post-tensioning applications in corrosive environments in Texas. Epoxied segment joints are now an industry standard. Post-tensioning bar and prestressing strand coatings (epoxy, galvanized, and other) show enhanced corrosion protection and are being conclusively evaluated under ongoing TxDOT research project 0-4562.

For more information please contact Tom Yarbrough, P.E., RTI Research Engineer, at (512) 465-7403 or email at tyarbro@dot.state.tx.us.

Your Involvement Is Welcome!

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