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Project Summary Report 0-4562-S1
Project 0-4562: Corrosion Resistance of Grouted Post-Tensioning Systems
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# Summary: Factors Affecting Bond and Friction Losses in Multi-Strand Post-Tensioning Tendons Including the Effect of Emulsifiable Oils

Engineered structures must be not only safe and serviceable but also durable. Inadequate attention to durability in either the design or construction phases of a project can result in costly repairs or, in some cases, failure. Although the vast majority of post-tensioned bridges in the U.S. have performed satisfactorily, corrosion problems in a number of bridges in Florida have raised concerns about durability in these types of structures.

These problems have highlighted the importance of controlling corrosion in post-tensioned concrete, including the use of new construction methods. One recently used method is the application of emulsifiable oils to tendons as temporary corrosion protection during the period between stressing and grouting.

However, this practice has caused other problems. Tendons coated with emulsifiable oils were typically flushed with water before grouting to remove the oil. Disposal of the oil-contaminated water posed environmental problems. In addition, compressed air was used to remove water from the post-tensioning ducts. Inspections of the grouted tendons often revealed significant voids and corrosion damage, presumably due to the water not being completely removed from the duct. Since flushing the tendons has proved problematic, this practice is not likely to continue. The effects of oils on the behavior of post-tensioned systems must therefore be determined.

The main objectives of the first phase (2005-2006) of Project 0-4562 were to assess the corrosion-inhibiting performance of emulsifiable oils, to investigate how the oils affect friction losses during post-tensioning, and to determine the impact of the oils on bond strength in multi-strand tendons. The second, ongoing phase is evaluating a variety of new materials that could improve durability in post-tensioned concrete systems. This document summarizes the first phase only.

## What We Did...

Corrosion tests and preliminary bond tests were performed at Pennsylvania State University before large-scale tests began at The University of Texas at Austin. Nineteen emulsifiable oils currently available on the market were chosen for corrosion tests. Sections of strand were coated with oil and exposed for six months to three different environments: the outdoors, a controlled temperature and humidity chamber, and a 5% NaCl solution. Single-strand pullout tests were also performed as a preliminary indication of the oils' effect on bond. Based on the results of these tests, two oils were chosen for large-scale bond and friction testing: Trukut NC205, produced by Citgo, and NoxRust 703D, produced by Daubert VCI.

Twelve-strand tendons of grade 270, nominal 1/2-in. diameter strands were chosen for all large-scale tests because they are the smallest tendon that would typically be used in segmental construction. Bond and friction test specimens were constructed with one of three duct types: smooth, rigid steel pipe, often used in deviator blocks; corrugated, semi-rigid galvanized duct; and corrugated high-density polyethylene (HDPE) duct.

Monotonic pullout tests were performed on grouted tendons to investigate the oils' effect on bond. The specimens were post-tensioned beams with a 44-in. bonded length, which allowed large forces to be developed without fully developing the tendon. Tendons were either unoiled, oiled and grouted after 2 days, or oiled and grouted after 10 days.

Friction tests were performed with ungrouted tendons in curved beams. Tests were performed using two radii of curvature: 10 ft and 30 ft. Load was measured at both the live and dead ends of the specimen. The difference between the two forces corresponds to the friction losses along the length of the duct. Tests were conducted with tendons either unoiled, freshly oiled, or one day after oiling.

## What We Found...

Both oils used in the large-scale testing program provide adequate temporary corrosion protection for post-tensioning tendons. NoxRust

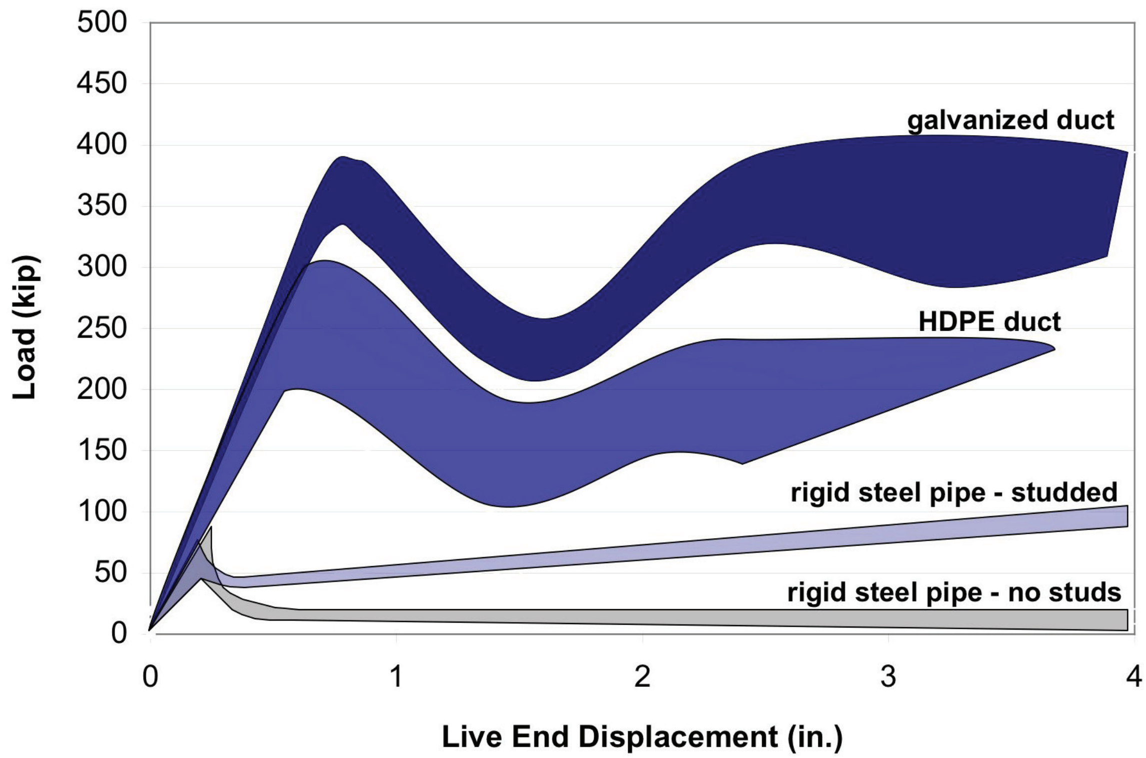


*Figure 1 – Live End Load-Displacement Behavior, Unoiled Tendons*

703D performed slightly better in all three environments than Trukut NC205.

Bond test conclusions are based primarily on a strength criterion and a serviceability criterion. The strength criterion is peak load. The serviceability criterion is a limiting value of dead end slip, which in this test program was set at 0.02 in. High levels of dead end slip at low loads indicate poor bond between the tendon and grout. Because good bond is required for effective crack width control, high levels of slip could lead to serviceability problems if a member is already cracked.

Peak loads for specimens with galvanized ducts were 20% to 40% higher than peak loads for specimens with HDPE ducts, as shown in Figure 1. Galvanized ducts therefore allow bonded tendons to be developed in shorter lengths than HDPE ducts.

Peak loads for specimens with rigid steel pipes were 70% to 90% lower than peak loads for specimens with galvanized or HDPE ducts, as shown in Figure 1. This poor behavior was due to failure at the interface of the concrete and the smooth steel pipe. Shear studs welded to the outside of the pipes prevented this type of failure, but peak loads were still low due to failure at the grout-duct interface.

For specimens with corrugated galvanized or HDPE ducts, peak loads were typically 15% to 30% higher for specimens with oiled tendons than specimens with unoiled tendons. One possible explanation for this increase is that the oil allowed the tendon to slip relative to the grout at low loads. This slippage may have initially helped relieve some of the splitting pressure which eventually caused the specimens to crack and the load to drop.

While peak load behavior was unchanged or improved for specimens with oiled tendons, these specimens tended to exhibit high levels of dead end slip at low loads. For specimens with unoiled tendons, failure based on slip was typically 10% to 20% lower than the peak loads. For specimens with oiled tendons, the average failure load based on slip was 45% to 95% lower than the average peak loads.

Giving the oil 10 days to dry instead of the typical 2 days did not change peak loads significantly. The additional drying time did increase failure loads based on slip, but these loads were still 35% to 60% lower than the value for unoiled specimens.

Measured friction coefficients for unoiled tendons in rigid steel pipes and corrugated galvanized ducts generally agreed with design values suggested by AASTHO, ACI, and PTI. However, the measured friction coefficient for unoiled tendons in HDPE ducts was 0.12, almost 50% lower than the AASHTO-recommended value of 0.23.

Tendons which were lubricated with oil and stressed immediately after oiling experienced lower friction losses than unoiled tendons, as shown in Figure 2. Oiling caused the greatest reductions in the friction coefficient for steel pipe specimens, on the order of 20% to 30%. Reductions for HDPE duct specimens were smaller but still significant, on the order of 20%. Reductions for galvanized ducts specimens were the least significant, on the order of 10%.

For tendons stressed one day after oiling, the data was highly scattered. The results indicate that dried oil is less effective in reducing friction losses than fresh oil, as shown in Figure 2, but detailed conclusions about the effect of time on these oils cannot be drawn based on these tests.

Inspection of the galvanized ducts and HDPE ducts after testing revealed minimal damage to the inside walls of the ducts, even for specimens with a tight, 10-ft radius of curvature.

## The Researchers Recommend...

Bond stresses in HDPE duct specimens were 20% to 40% lower than in galvanized duct specimens for unoiled and oiled tendons, respectively. The research team therefore recommends that designers using HDPE ducts in place of galvanized ducts, account for lower bond stresses, and provide bonded lengths sufficient to develop the tendons.

If smooth, rigid steel pipes are used, shear connectors or shear studs should be used for anchorage purposes on the outside of the pipes.

Emulsifiable oils used as temporary corrosion protection in grouted post-tensioned construction do not need to be flushed with water. In cases where cracking might occur under service loads, the oil may cause cracks to widen, but the strength of the member will not be affected. Such cracking would not be expected in segmental construction and could easily be controlled in cast-in-place construction with supplementary mild reinforcement.

Post-tensioning tendons may be grouted when the oil is still fresh. Allowing the oil to dry will improve slip behavior, but has no effect on strength.

Additional data on friction losses in HDPE ducts should be compiled from field measurements. The current AASHTO-recommended friction coefficient of 0.23 is overly conservative compared to the value of 0.12 found in this program.

A 15% reduction in the friction coefficient can be used with steel pipes or HDPE ducts and approved oils if the tendon is stressed immediately after oiling. Both emulsifiable oils used in this test program, Trukut NC205 and NoxRust 703D, are approved for this application.

No significant damage to HDPE ducts was observed, even with a 10-ft radius of curvature. AASHTO currently limits the radius of curvature for HDPE ducts to 30 ft or greater. A reduction of the limiting radius of curvature for HDPE ducts is possible based on damage to the inside of the duct. However, other factors should be considered before changing this limit.

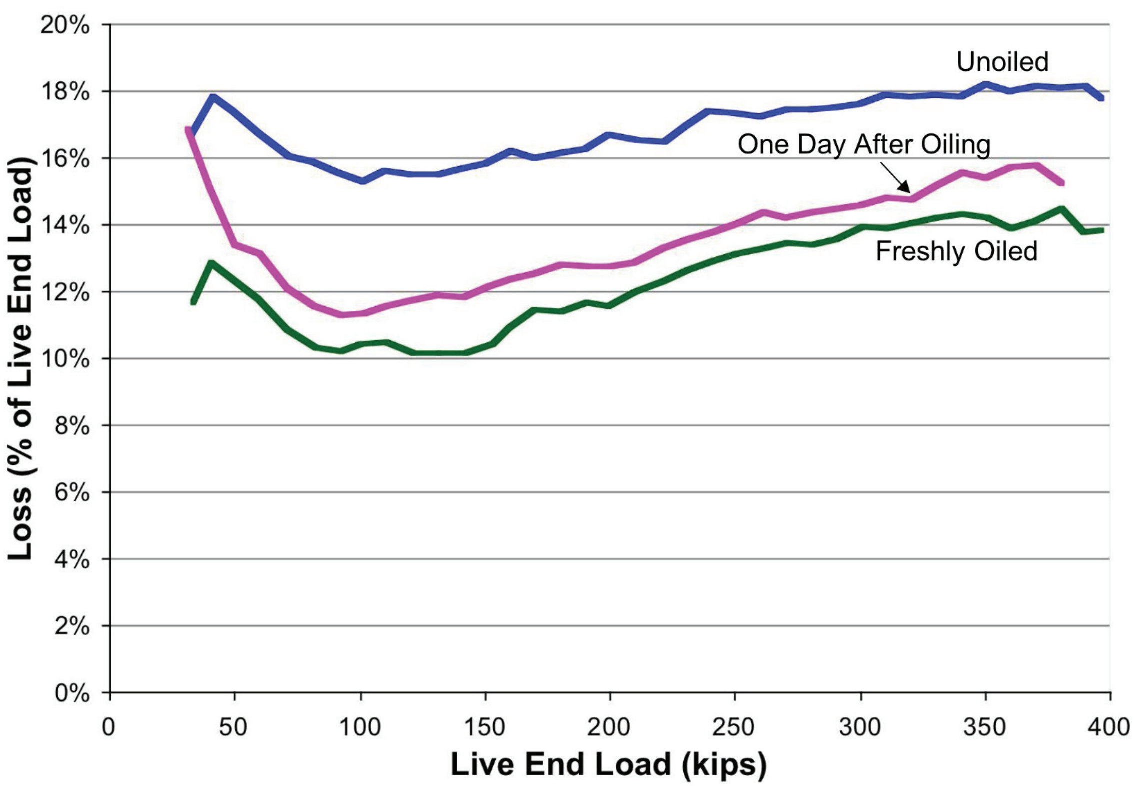


*Figure 2 – Average Friction Losses, HDPE Duct, 10 ft Radius, Oil NC205*

## For More Details...

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The research is documented in the following reports:

4562-1 *Factors Affecting Bond and Friction Losses in Multi-Strand Post-Tensioning Tendons Including the Effects of Emulsifiable Oils* June 2005

To obtain copies of a report: CTR Library, Center for Transportation Research, (512) 232-3126, email: ctrlib@uts.cc.utexas.edu

## Your Involvement Is Welcome!

## Disclaimer

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