Florida Department of Transportation

Galvanic Testing of Stressed Strands Inside Carbon Steel Pipe

Final Report

Specimen Fabrication by:	**State Structures Research Laboratory**
Corrosion Tests by:	**State Materials Office** **Corrosion Research Laboratory**
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Galvanic Testing of Stressed Strands Inside Carbon Steel Pipe

Objective: To test the corrosion behavior of stressed strands when galvanically coupled to a carbon steel pipe similar in metallurgical composition to the pipe used in the column foundations in the Sunshine Skyway Bridge.

Materials: Pipe: Steel tubing meeting the requirements of ASTM A-513 Type 5, grade 1020 comparable to pipe used in original construction ASTM A53, Grade 5. Table 1 compares the chemical requirements of both ASTM's, the mill certificate and the chemical analysis performed by FDOT on pipe used in the experiment.

Table 1 Chemical Analysis of pipe (%)

Element	ASTM A53 Type B[1]	ASTM A-513 Type 5[2]	Mill Certificate[3]	FDOT Testing[4]
Carbon	0.30 (Max)	0.17 - 0.23	0.200	0.205
Manganese	1.20 (Max)	0.30 - 0.60	0.410	0.357
Phosphorus	0.05 (Max)	0.035 (Max)	0.014	0.018
Sulfur	0.045 (Max)	0.035 (Max)	0.003	0.004
Copper	0.40 (Max)			0.02
Nickel	0.40 (Max)			0.005
Chromium	0.40 (Max)			0.044
Molybdenum	0.15 (Max)			< 0.001
Vanadium	0.08 (Max)			0.002

[1]Material specified for Skyway column foundations.
[2]Specification for ASTM A-513 Type 5 pipe used in experiment.
[3]Mill certificate for ASTM A-513 pipe used in experiment.
[4]FDOT check test on A-513 pipe used in experiment.

Strand: High tensile strength, 7-wire strand meeting the requirements of ASTM A 416 (AASHTO M 203), Grade 270.

Procedure: One seven-wire strand was inserted into one piece of carbon steel pipe having similar metallurgical composition to the pipe used in the Sunshine Skyway Bridge. The strand was stressed to between 15.5 kips and 21.6 kips (Figure 1) and then the bottom of the pipe and joint between pipe and strand was sealed to form a watertight container. The metals were connected together to form a galvanic couple and the pipe was filled to 18" depth with Tampa Bay water with a chloride content of 18,000 ppm. There were a total of 11 samples, 9 were divided into 3 sets of 3 samples each, to be exposed for 4, 10, and 35 days; with 2 extra samples. The macro-cell current was read at 0, 4, 10 and 35 days to characterize the corrosion behavior of the cell. The common lead of the current meter was connected to the pipe in all the current measurements. In this manner a positive current would indicate the pipe is anodic to the strand. Upon termination of the test, the test specimens were dismantled and the pipe was cut in half lengthwise. The pipes and strands were then immersed in a 20% Hydrochloric acid bath for one minute and rinsed with water to remove about 90% of the ferrous oxides; the rest of the oxides were removed by wire brushing. The samples were visually inspected for corrosion. Pictures were taken to document all the samples, and then the type, degree and location of corrosion were determined, as well as average and maximum pit dimensions.

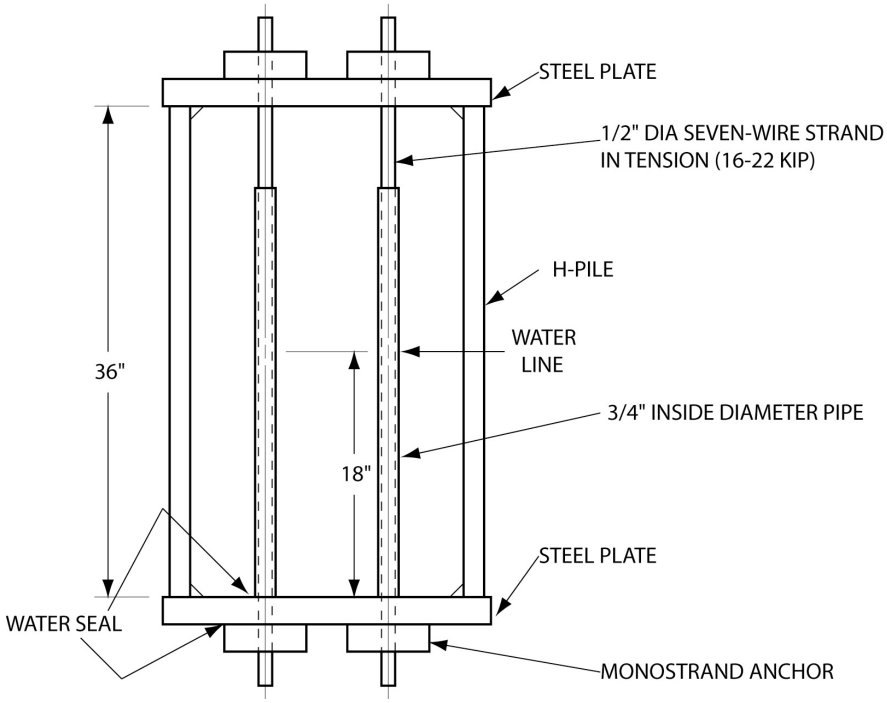

Figure 1- Test Specimen Schematic

Figure 2- Photo of Test Specimen

Discussion:

The primary objective of the test was to determine if the strand would be anodic to the pipe, and, at what rate the strand would corrode. The impetus for this test was to address the question of whether there might have been aggravated corrosion conditions (for the strands) in the Skyway column foundations resulting from saltwater intrusion prior to grouting. The stressing of the strands was primarily to determine whether the strand (or wires) would fail as a result of corrosion while the strands were in a stressed state. The corrosion rates of unstressed strands under the same exposure conditions would not be expected to be any different. This is because the relatively low stresses in the strand do not introduce any appreciable elastic deformation or grain boundary changes in the metal.

As shown in Table 2, the 10-day and 35-day exposures showed significant corrosion rates on the pipe. Corrosion pitting on the strands was significant but markedly less. As shown in Table 3, the pipe was predominantly anodic to the strands based on the macro-cell current readings. These readings, along with the much higher corrosion rates measured on the pipes, clearly show that the galvanic couple was unfavorable for the pipe. The exceptionally heavy pitting (0.61mm@35 days) on the pipe was the only surprise in the experiment. Pitting rate: [0.61/(35/365)]=6.4mm/year.

In earlier experiments with prestressed strands grouted and coupled in a PT anchor, it was found that the strands were predominantly anodic in the presence of recharge water even without the addition of chlorides. In these conditions, the strands developed a potential typically ~100mV more negative than the ductile iron anchor. This, of course meant that the strands were anodic to the anchor. In the pipe/strand experiments, we observed that the mild steel pipe and the strand were of almost identical potential (~-575mV) when measured in synthetic seawater, indicating that, under static conditions, no galvanic cell should be expected. In a galvanic couple the role of anode and cathode will be largely dependent on such things as solution chemistry and the ability of each of the metals to support the reduction of oxygen. In some galvanic couples, it is possible for the components to reverse their anodic/cathodic roles. Note in Table 3, that 7 out of 11 specimens showed the strand to be anodic at time zero and that this trend completely reversed by day 10. Although the pipe was predominantly anodic to the strands, the strand still showed significant corrosion. Since both metals experienced significant corrosion, it is obvious that the predominantly anodic pipe did not provide sufficient current to prevent corrosion on the strands. The deepest pit observed on the strands (0.10mm) translates to an annual pitting rate of >1mm. This is significant because its depth is ~23% of the wire diameter. In the grouted trumpet tests, the maximum pitting rate on the strands was ~0.70mm/year while the average pitting rate of 18 wires was 0.53mm/year or >10% of the individual wire diameter. These are very significant corrosion rates that underscore the extreme importance of avoiding any grout voids and significant amounts of water (including fresh-water) coming into contact with any portion of the PT system.

The corrosion observed on the strands in both experiments comes as no surprise. Comparable results have been observed by others. The combination of metals commonly used in PT systems does not necessarily represent bad choices. They are all ferrous metals, each selected to provide a very specific function. If these metals and their surroundings remain dry, it would be very unlikely for a galvanic cell to develop. Where conditions are conducive to dissimilar metals corrosion, the strands would be almost as likely to corrode without being coupled to a dissimilar metal. It is becoming very clear that our main problem is the presence of voids and water-not dissimilar metals.

In this regard, the Department is definitely on the right track by first addressing the issues associated with grouting materials and grouting procedures. The measures that are being implemented, (including the moratorium on PT systems in the splash zone) if properly adhered to should all but completely eliminate the majority of the types of problems that we have encountered.

In hindsight, the tendons in the column foundations at Skyway probably would not have problems today if the upper terminus of the metal duct and foundation concrete had been brought sufficiently above the splash zone and the duct interior kept clean and dry. Moreover, the findings in the field and laboratory should be viewed as being instructive in how we use metal ducts in PT systems and this might very well be the key to resuming use of PT in the splash zone.

And finally, and more importantly, enough cannot be said with regard to, "never letting our guard down" when it comes to design, materials selection, technical specifications, construction techniques, contractor quality control, inspection, remediation and re-inspection.

Conclusions: (1) Based on the macro-cell current readings and visual examination of the pipes and strands, we conclude that the carbon steel pipe is predominantly anodic to the strands.

(2) Significant corrosion developed on both the pipe and strands.

(3) Although the pipe was predominantly anodic to the strand, the galvanic current from the pipe was insufficient to prevent the strands from corroding.

Table 2 Pit Dimensional Measurements.

Age	Material	Corrosion		Location from Water Line		Average Pit		Deepest Pit		
		Type	Degree	Start (Low End)	Length	Diameter	Depth	Diameter	Depth	Location
4 Day	Pipe	Generalized	Light	1.25cm Above	29cm	Nil	Nil			
	Strand	Generalized	Light	0.64cm Above	30cm	Nil	Nil			
10 Day	Pipe	Pitting	Medium	18cm Below	37cm	1.5mm	0.20mm	0.76mm	0.28mm	3.0cm Below
	Strand	Generalized	Light	Varies		Nil	Nil			
35 Day	Pipe	Pitting	Heavy	5cm Below	36cm	5.0mm	0.45mm	2.5mm	0.61mm	9.5cm Above
	Strand	Pitting	Light	0cm	11cm	2.5mm	0.10mm	1.5mm	0.10mm	21cm Above

Table 3- Macro Cell Currents-micro-amps*

Group	Sample #	0 Day	4 Day	10 Day	35 Day
4 Days Exposure	10	-365	305		
	11	-362	325		
	2	-32.1	235		
10 Days Exposure	7	-1540		194	
	5	-632		155	
	8	699		197	
	9	-4300		83	
	1	2250		145	
35 Days Exposure	4	-131		260	109
	6	7280		25	-192
	3	1120		220	280
	Average	**362**	**288**	**160**	**66**

*** Positive value indicates pipe is anodic.**

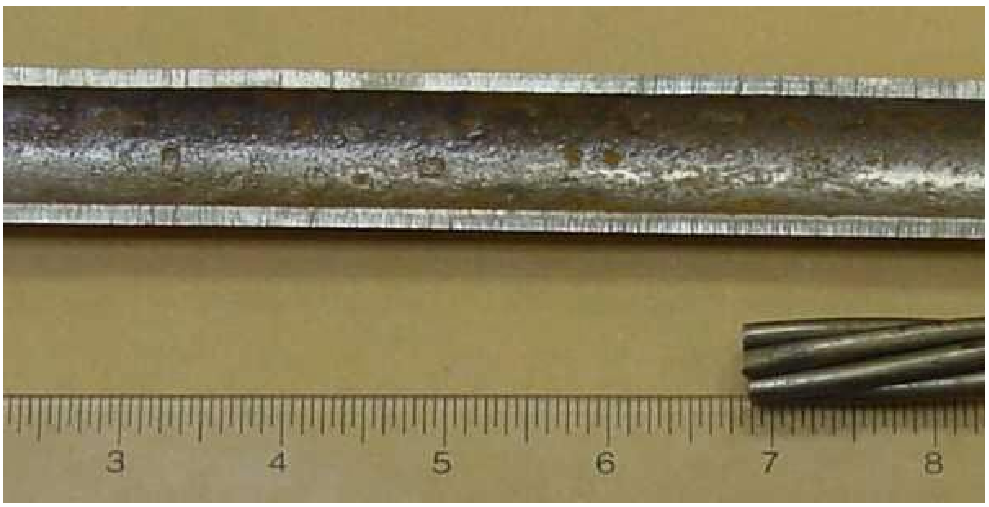

Figure 3 Condition of Pipe- 35 days

Figure 4 Condition of Strand- 35 days