Testing Precast Piles with Carbon Fiber Reinforced Polymer Mesh

FDOT

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Overview

The FDOT M. H. Ansley Structures Research Center performed testing to evaluate the use of carbon fiber reinforced polymer (CFRP) mesh in lieu of spiral ties or conventional reinforcement stirrups for a 24 inch square prestressed concrete pile. The testing, which was conducted on September 13, 2010, involved measuring and recording strain, displacement and load values at a sample rate of 10 Hz. The CFRP pile was cast with (20) 1/2” special diameter low-relaxation strands in a circular pattern, and then wrapped with the carbon mesh, allowing an eight inch overlap. The control pile was also a 24 inch square prestressed concrete pile, however it had (16) 0.6 inch diameter low-relaxation strands in a square pattern with W3.4 spiral ties. Note the control pile was tested at an earlier date and will be used to compare the ratio of actual capacity to theoretical capacity. Details of both pile sections are shown in Figure 1 below.

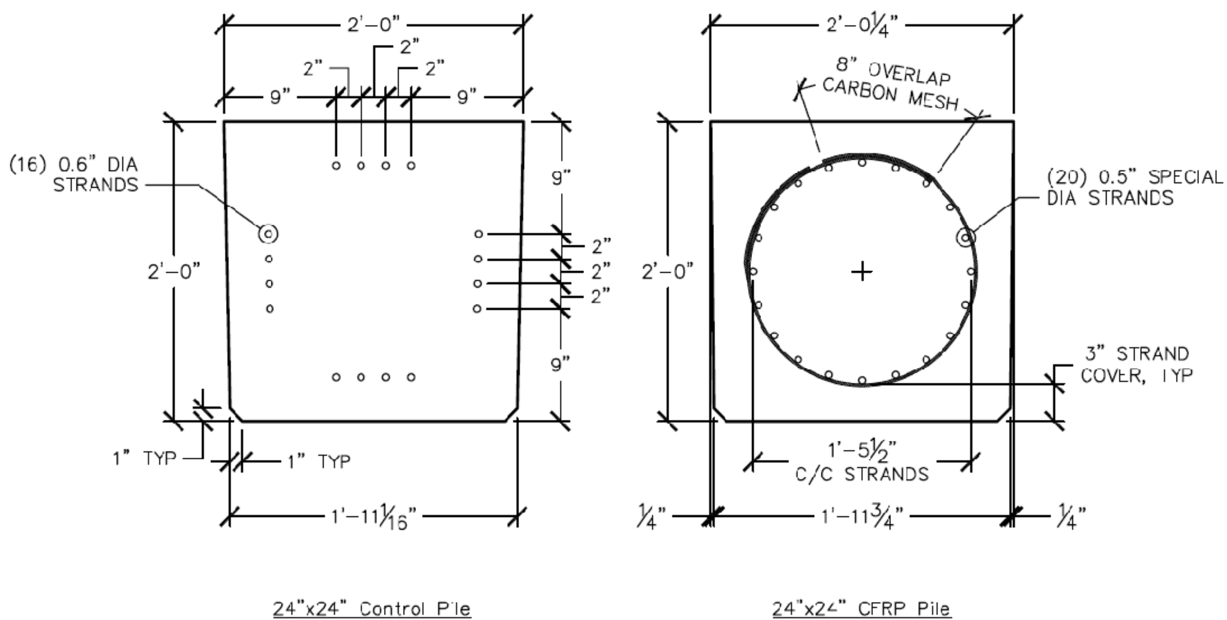


Figure 1 – Pile Sections

Carbon Fiber Reinforced Polymer

Several concerns arose with the introduction of CFRP reinforcement prior to testing. The first concern was whether the concrete would segregate during casting due to the size of the openings within the CFRP mesh. The second concern involved proper overlapping of the mesh. Per details provided by Gate Concrete Products, the CFRP mesh overlaps 8 inches in the transverse direction, and in the longitudinal direction there is a butt joint where ties connect one sheet to another (yellow ties where used to facilitate inspections). The final concern was whether the carbon fiber and the prestressing steel would create a galvanic couple and accelerate corrosion.

The first concern mentioned above was relieved by simply cutting a section of the pile after testing to confirm the concrete was homogeneous throughout the section. Slight signs of segregation were observed, however, it did not warrant concern. The second issue, regarding proper lapping, will be heavily dependent on proper inspection prior to pouring.

The final concern, which is the most critical concerning this type of reinforcement is the galvanic corrosion caused by the interaction between steel (strands) and carbon (CFRP mesh). It is a very basic concept that if the steel and the carbon are in direct contact, galvanic corrosion will occur, more so in an aggressive environment. The specimen for this particular test had a thin layer of epoxy to bind the carbon fibers. Referencing the article in the *Journal of Composites for Construction* "Galvanic Corrosion of Carbon and Steel in Aggressive Environments" a "typical layer" or 0.25 millimeter layer resulted in a more significant decrease in corrosion rate (approximately 4 times) than a thin layer or 0.1 millimeter layer. Although the thin layer in our specimen may not be of equal thickness to that of the article, it would be considered a thin layer because the carbon appears to be exposed. A "typical layer" as described in the article would have enough epoxy such that the carbon would not be exposed, preventing contact with the strands.

Figure 2 – CFRP mesh in casting bed at butt joint (Left). CFRP Mesh during concrete pour (Middle). Pile section (Right).

Test Setup

A 24"x24"x40'-0" pile was cast, later instrumented and then tested. The centerline of the supports was one foot from each end, resulting in a 38'-0" clear span. Six strain gages were placed on the top of the pile towards the center of the span as shown in the detail sheet provided in the Appendix labeled Test Setup, Carbon Reinforced Pile. Ten displacement gages were placed along the length of the pile as shown in that same detail sheet. In addition to the gages mentioned above, four additional displacement gages were placed at the pile ends to measure strand slip. At the top of the detail sheet, how the load was applied and distributed is illustrated. A single point load was applied to a spreader beam consisting of two steel I-beams that provide the two point loads applied to the pile. The picture below demonstrates the load setup.

The control pile, also 24"x24"x40'-0", had a similar test setup. The only difference was the number of strain gages instrumented on this pile. As shown in detail sheet provided in the

Appendix labeled Control Specimen Test Setup, there were only two strain gages located at the mid span of the pile.

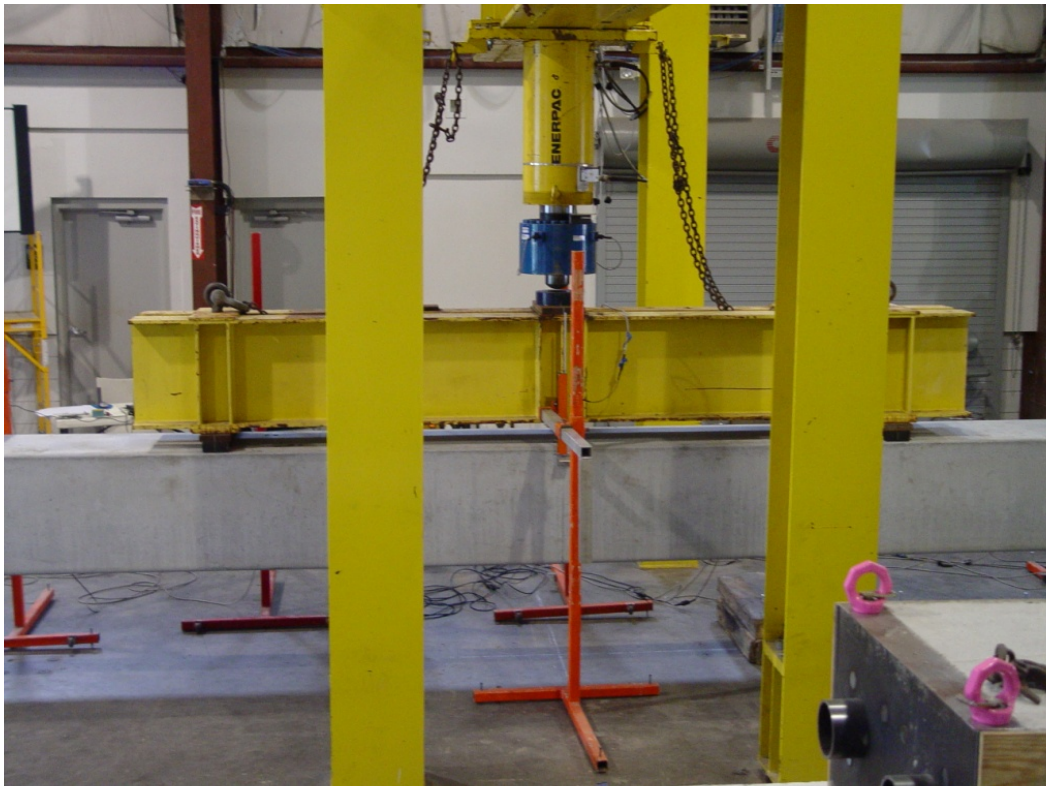


Figure 3 – Load Testing Setup

Test Results

Concrete cylinders of the piles' concrete mixes were tested for both the control pile and the CFRP pile resulting in a concrete compressive strength of 10 ksi and 11 ksi, respectively. These values were the average of (4) 4"x8" cylinders tested for each pile type.

The initial moment before loading was 125 kip-ft for both piles due to self weight of the pile (580 plf) and the spreader beam weight (approximately 3000 lbs). In Figure 5, Moment/Load versus Displacement Diagram, the dead load moment is not included resulting in a zero moment/load at zero displacement. The results used to plot Figure 5 were taken as the average of displacement gages D5 and D6 located at the center of the span (see Test Setup Sheets in the Appendix). Also, note the displacement values from D1 and D10 (support displacement) were neglected because they were reasonably small (.04 and .02 inches, respectively). Strand slip was also ignored, because the displacement values were negligible.

Once the instrumentation was complete and the piles were ready for testing, the load was applied until failure. The CFRP pile experienced a compressive failure (crushing the top of the pile) offset about 3.5 feet from the midspan (or about 2 feet away from the point the load was applied), as the concrete approached a maximum strain of approximately 3000 micro-strain recorded from strain gage S3. The CFRP pile failed at a load of 97.7 kips, resulting in a moment of 9312 kip-in (776 kip-ft). The control pile reached failure at a load of 94.8 kips, resulting in a moment of 9108 kip-in (759 kip-ft). Both these moments include the dead load moment as well as the moment due to the applied load. The theoretical moment capacity for both pile configurations were calculated using the FDOT Biaxial Column Program. According to this program the maximum moment in pure bending for the CFRP pile configuration is about 7350 kip-in (612.5 kip-ft). See Table 1 below.

Table 1

	CFRP Pile	Control Pile
Theoretical Moment Capacity	612.5 kip-ft	625 kip-ft
Actual Moment Capacity	776 kip-ft	759 kip-ft
Ratio (Actual/Theoretical)	1.27	1.21

As shown in Table 1, the performance ratio for the CFRP pile is slightly higher than that of the control pile. This is in part due to the longitudinal portion of the CFRP grid, adding to the capacity of the pile, as well as experimental variability.

As a result of the testing the following graphs were created from the data collected, load versus strain and both moment and load versus displacement (mentioned previously). Figure 4, load versus strain for the CFRP pile, shows the load peaking or leveling off as the strain approaches 3000 micro-strain. The strain values were averaged for strain gages S1 and S2, S3 and S4, and S5 and S6. Figure 5 compares the deflected behavior of the CFRP pile and the control pile. The curve(s) indicate that the control pile did experience a larger displacement than the CFRP pile with less force. However as the curve(s) approach the failure load(s), the difference in displacement is less than an inch.

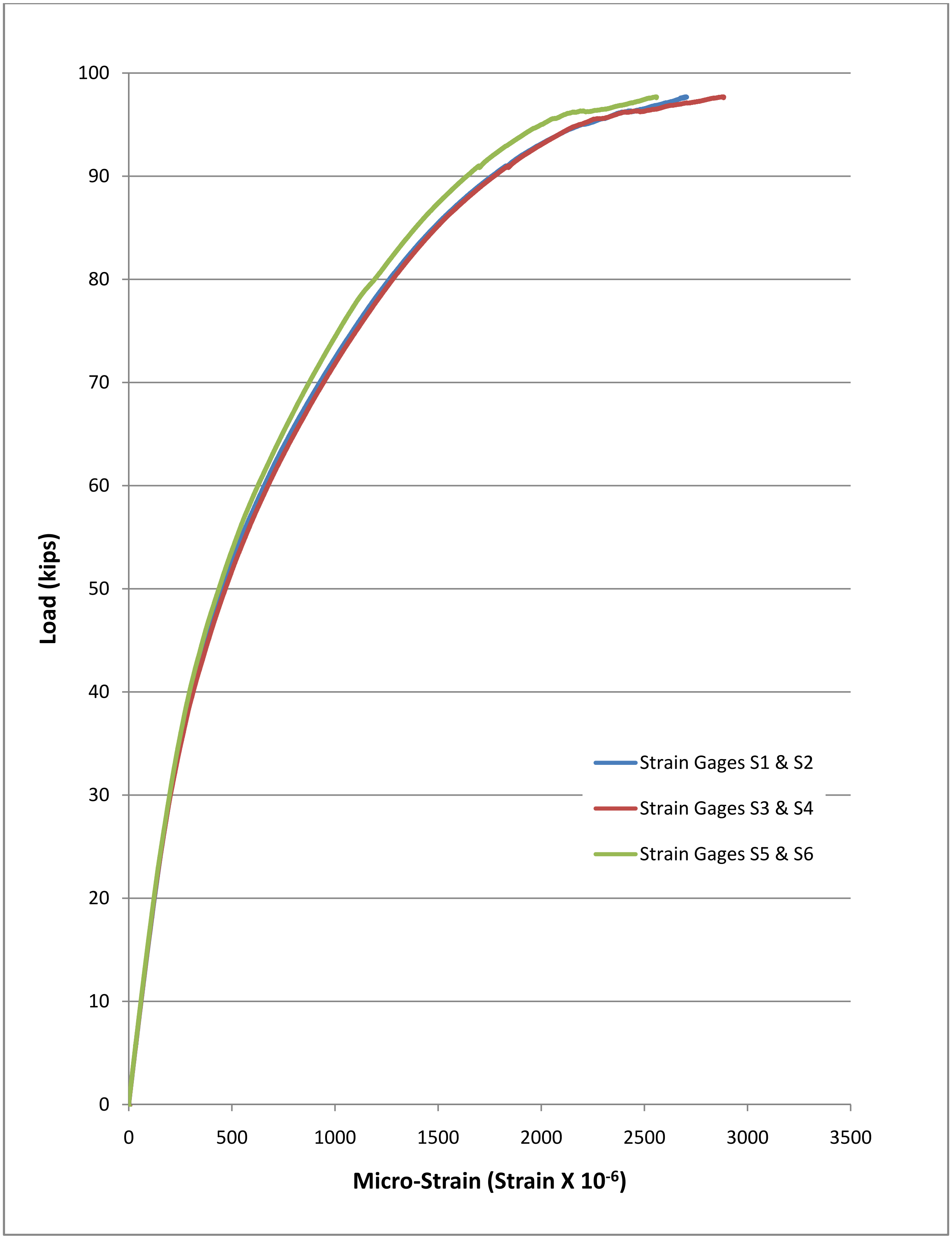


Figure 4 – Load versus Strain Diagram (CFRP Pile)

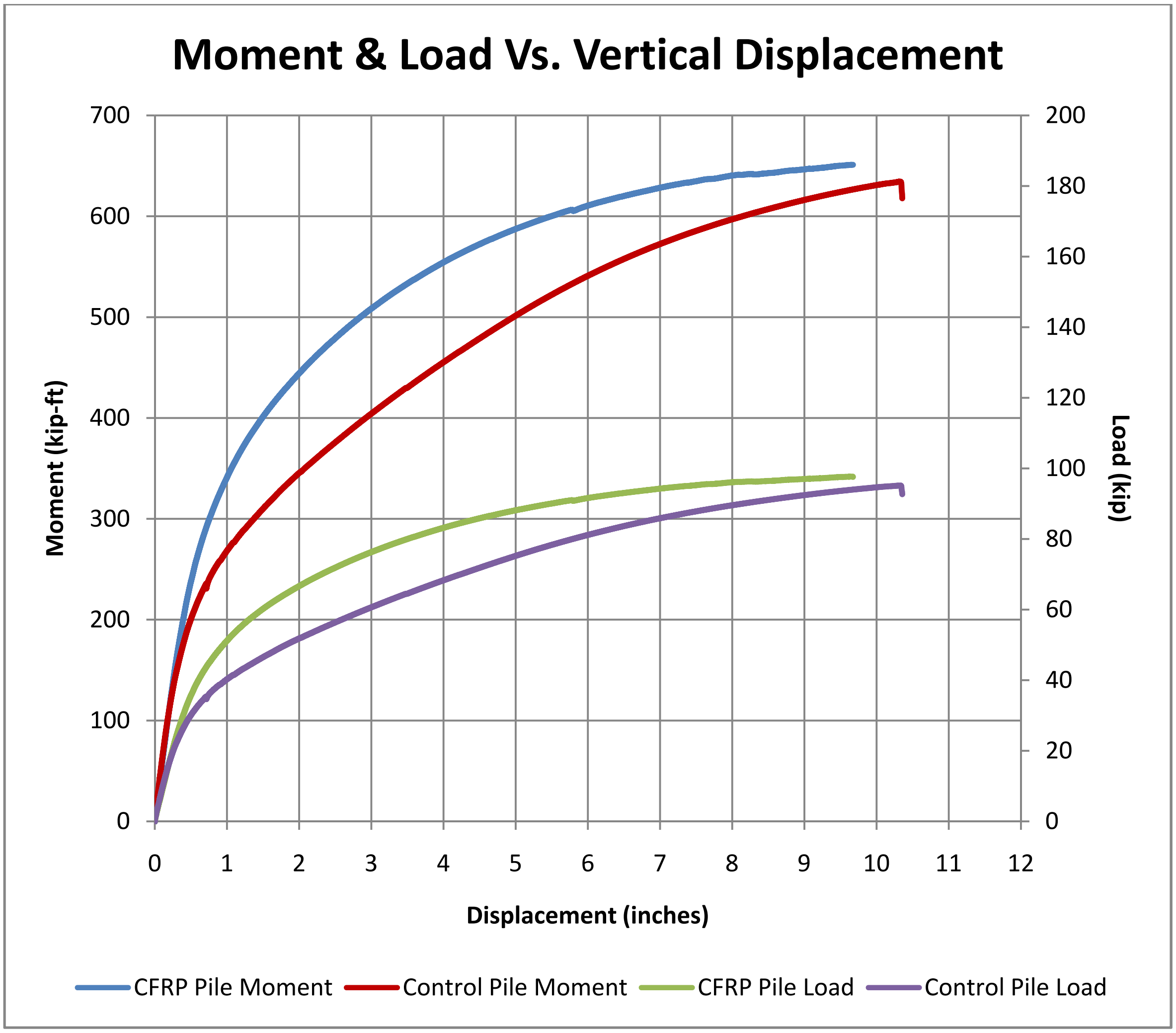


Figure 5 – Moment/Load versus Vertical Displacement Diagram

Conclusions

The test results indicate that the use of CFRP mesh in lieu of spiral ties as specified in the FDOT Design Standards did not reduce the moment capacity of the pile. The pile resulted in a moment capacity 1.27 times what was predicted from the analytical results. It also resulted in a slightly greater ratio, actual capacity to theoretical capacity, than that of the control pile tested earlier with a square strand pattern.

It is highly recommended that if this mesh reinforcement be used, that additional inspection be performed focusing primarily on proper installation and lapping of the mesh. In addition, as mentioned earlier, an acceptable epoxy layer must be used in the carbon fibers, to avoid contact between the carbon and the prestressing steel. This acceptable layer referred to as the "typical layer" previously may need further investigation to assure that galvanic corrosion will be prevented.

References

Gate Concrete Products.

Tavakkolizadeh, Mohammadreza. "Galvanic Corrosion of Carbon and Steel in Aggressive Environments." *Journal of Composites for Construction*, August 2001.

- Appendix -

Calculations for CFRP Pile Testing

Concrete Unit Weight	$\gamma_c := .145\frac{kip}{ft^3}$
Pile Size	$b := 24in$
Total Pile Length	$L := 40ft$
Unsupported Length	$L_{clear} := 38ft$
Distance from edge of pile to point load	$a := 13.33ft$
	$K_1 := 0.9$
Weight of steel spreader beam (assumed)	$P_{steel} := 3000lbf$
Section modulus of pile	$S := \frac{1}{6}\cdot b^3 = 2304 \cdot in^3$
Pile self weight	$w_{sw} := \gamma_c \cdot b^2 = 0.58 \cdot klf$
Moment before loading	$M_{before\_loading} := \frac{w_{sw} \cdot L_{clear}^2}{8} ... + \frac{P_{steel}}{2}\cdot a = 1496.22 \cdot kip \cdot in$

CFRP Specimen

Concrete compressive strength (from cylinders)	$f'_c := 11.073ksi$
Modulus of elasticity	$E := 33000 \cdot K_1 \cdot \left(\gamma_c \cdot \frac{ft^3}{kip}\right)^{1.5} \cdot \sqrt{f'_c \cdot ksi} = 5456.84 \cdot ksi$

Control Specimen

Concrete compressive strength (from cylinders)	$f'_c := 10ksi$
Modulus of elasticity	$E := 33000 K_1 \cdot \left(\gamma_c \cdot \frac{ft^3}{kip}\right)^{1.5} \cdot \sqrt{f'_c \cdot ksi} = 5185.71 ksi$

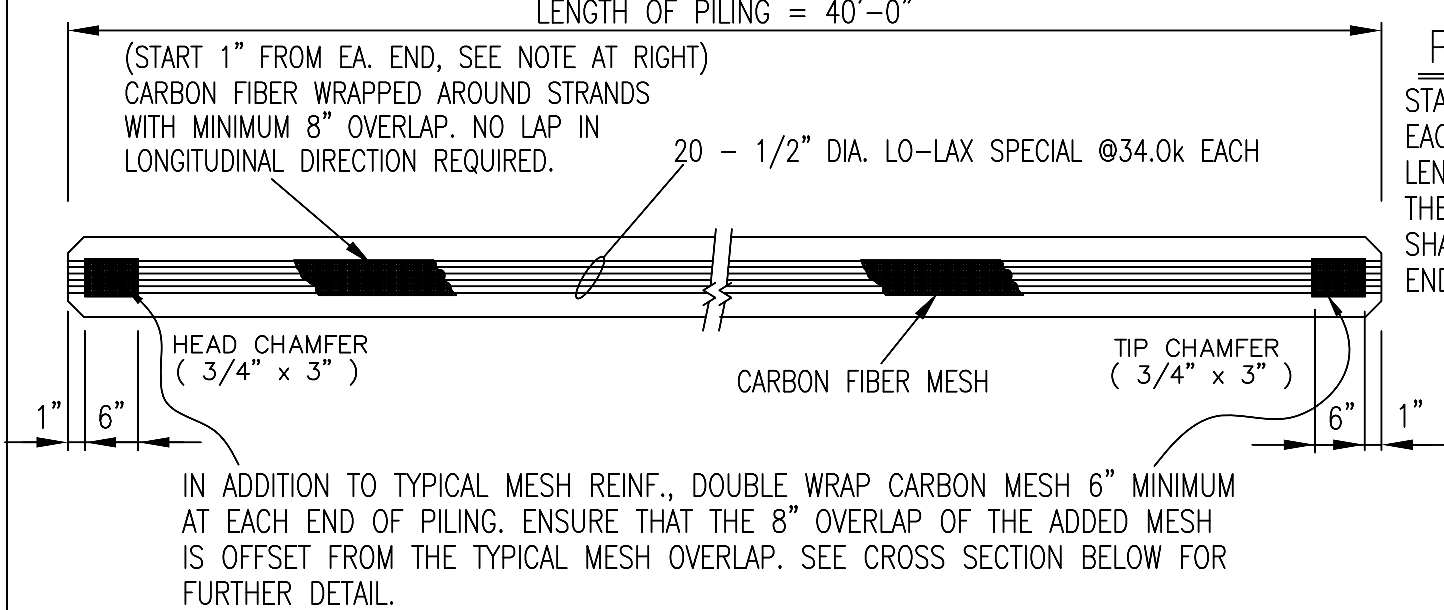
Applicable equations

Equation for moment after load (P) is applied	$M_{total} = M_{before\_loading} + \frac{P}{2}\cdot a$
where	$a = 159.96 in$

GATE
CONCRETE PRODUCTS
402 Zoo Parkway Jacksonville, Florida 32226 (904) 757-0860

JOB NO.
TEST PILING

SHT. NO.
1 OF 1

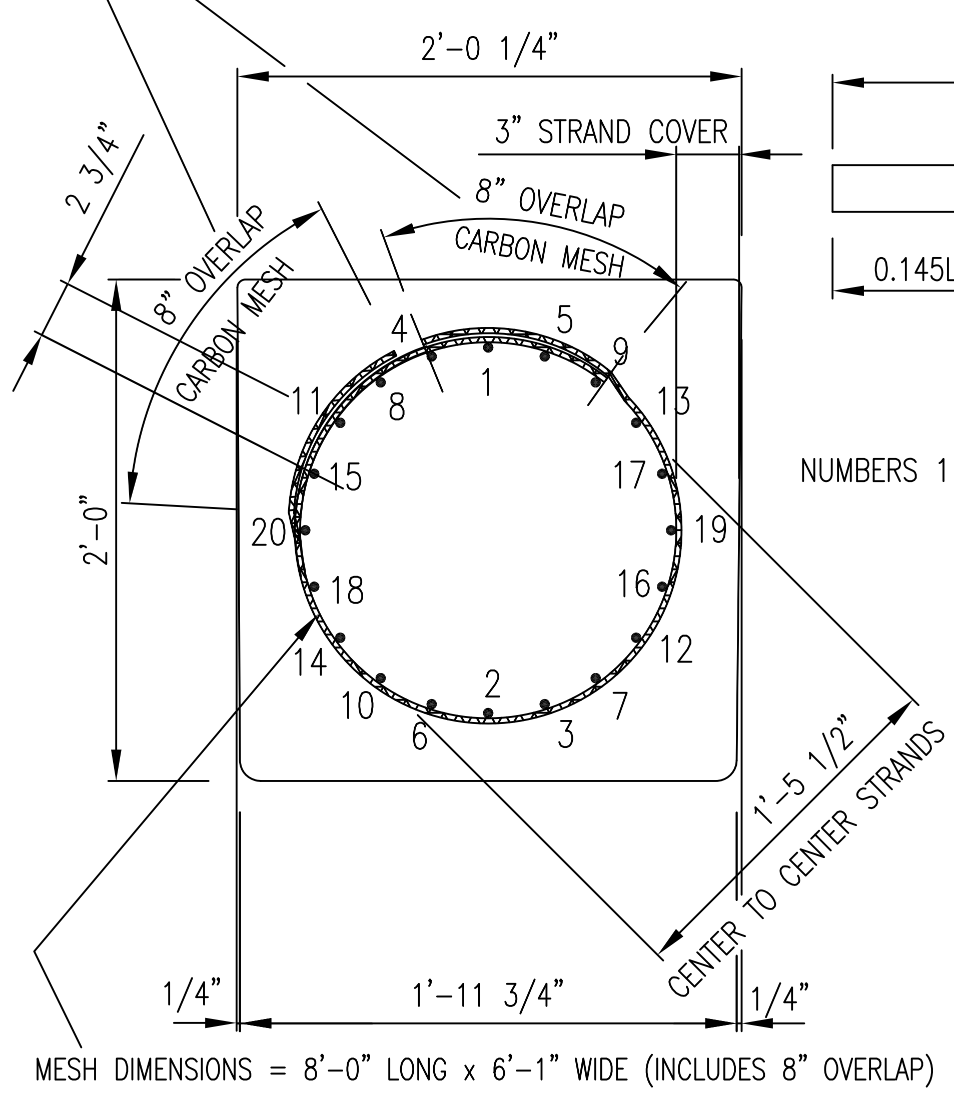


PRODUCTION NOTE

START CARBON MESH 1" FROM EACH END OF PILE. IF PILE LENGTH REQUIRES MESH CUTBACK, THEN 'FINISHED' END OF MESH SHALL BE PLACED TOWARDS END OF PILE.

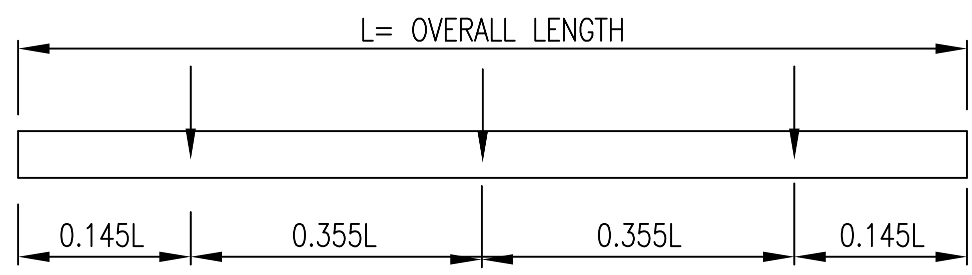
NOTE A

ANY PRESTRESSING STRANDS PROTRUDING BEYOND THE ENDS OF THE PILE, SHALL BE CUT FLUSH OR SLIGHTLY BELOW THE SURFACE OF THE CONCRETE, BEFORE TRANSPORTED FROM PLANT. LIFTING LOOPS TO BE CUT BACK 1"± INTO CONCRETE AND PATCHED W/APPROVED EPOXY MORTAR, BEFORE TRANSPORTED FROM PLANT.



MESH DIMENSIONS = 8'-0" LONG x 6'-1" WIDE (INCLUDES 8" OVERLAP)

✓ 20 ~ 1/2" ø (SPEC.) L.R.S. – A_S = 0.167 $IN.^2$ –270K AT 34,000# EA. SPACED @ 2 3/4" CTRS.



PICK-UP POINTS

NUMBERS 1 THRU 20, INDICATE DETENSIONING SEQUENCE

CONCRETE: F'C = 6000 PSI @ 28 DAYS
F'CI = 4000 PSI @ RELEASE
CLASS V (SPECIAL)

REINF: CARBON FIBER MESH TIED TO STAND AT BOTH SIDES OF 8" OVERLAP AND ADDITIONAL STRAND LOCATIONS AS REQUIRED TO SECURE MATERIAL

FINISH: SIDES & BOTTOM – STEELFORM
TOP – STEEL TROWEL
ENDS – NO FINISH (SEE NOTE A)

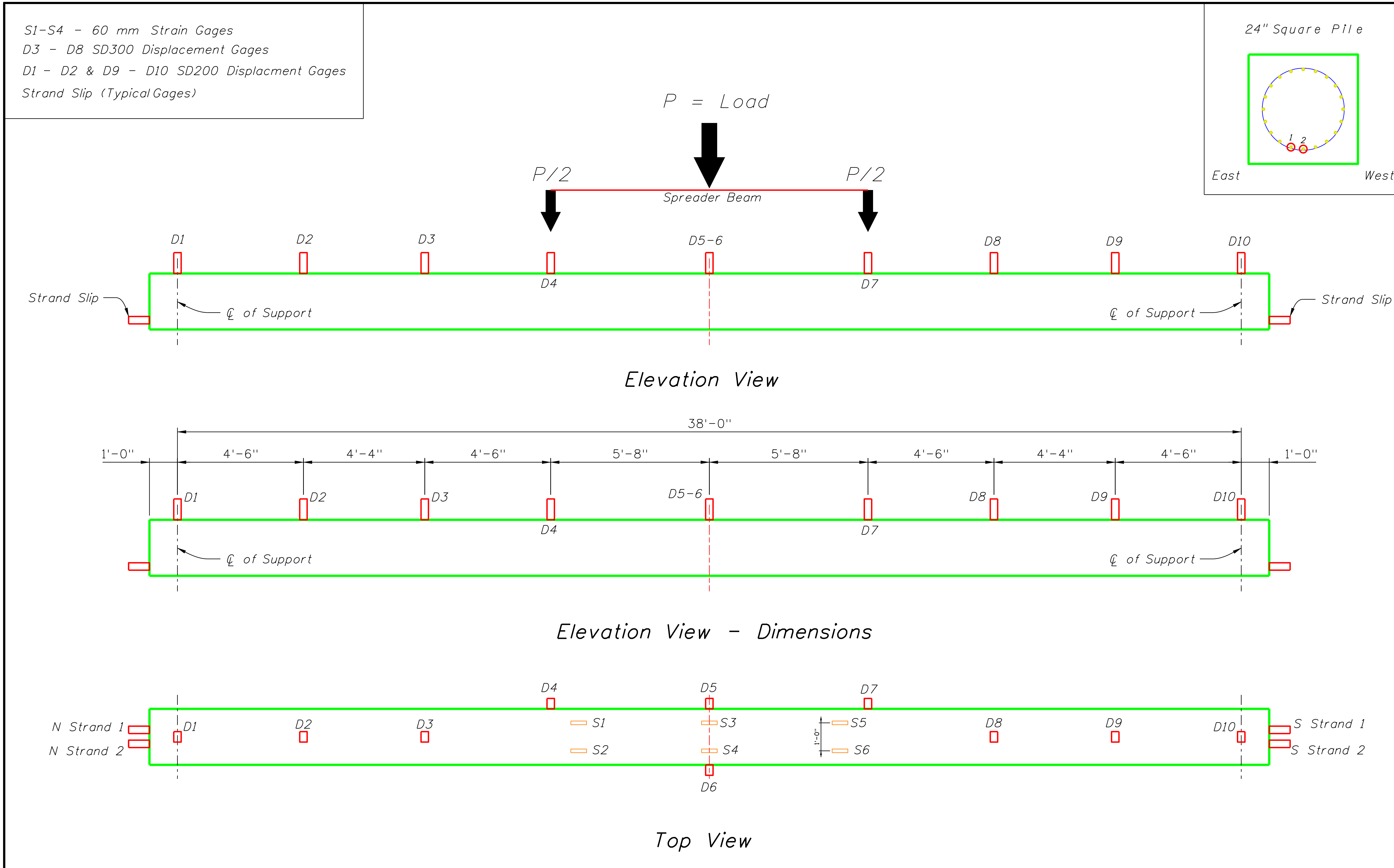
ENVIROMENT: – AGGRESSIVE

PRINTED
Thu, Jun 17, 2010, 3:49pm
JACKSONVILLE FLORIDA

24" SQUARE PILING SCHEDULE				
MK	UNIT	# REQ'D	LENGTH	REMARKS

JOB TITLE: – **CIRCULAR PRECAST PRESTRESSED PILE W/ CARBON FIBER**

24" SQUARE PILING	DWN. BY MS	DATE 6/15/10
STANDARD PCI SPECIFICATIONS	GEN. CONTR.	



REVISIONS					
DATE	BY	DESCRIPTION	DATE	BY	DESCRIPTION

DRAWN BY:
CHECKED BY:
DESIGNED BY:
CHECKED BY:

STATE OF FLORIDA
DEPARTMENT OF TRANSPORTATION

ROAD NO.	COUNTY	FINANCIAL PROJECT ID

SHEET TITLE: Test Setup

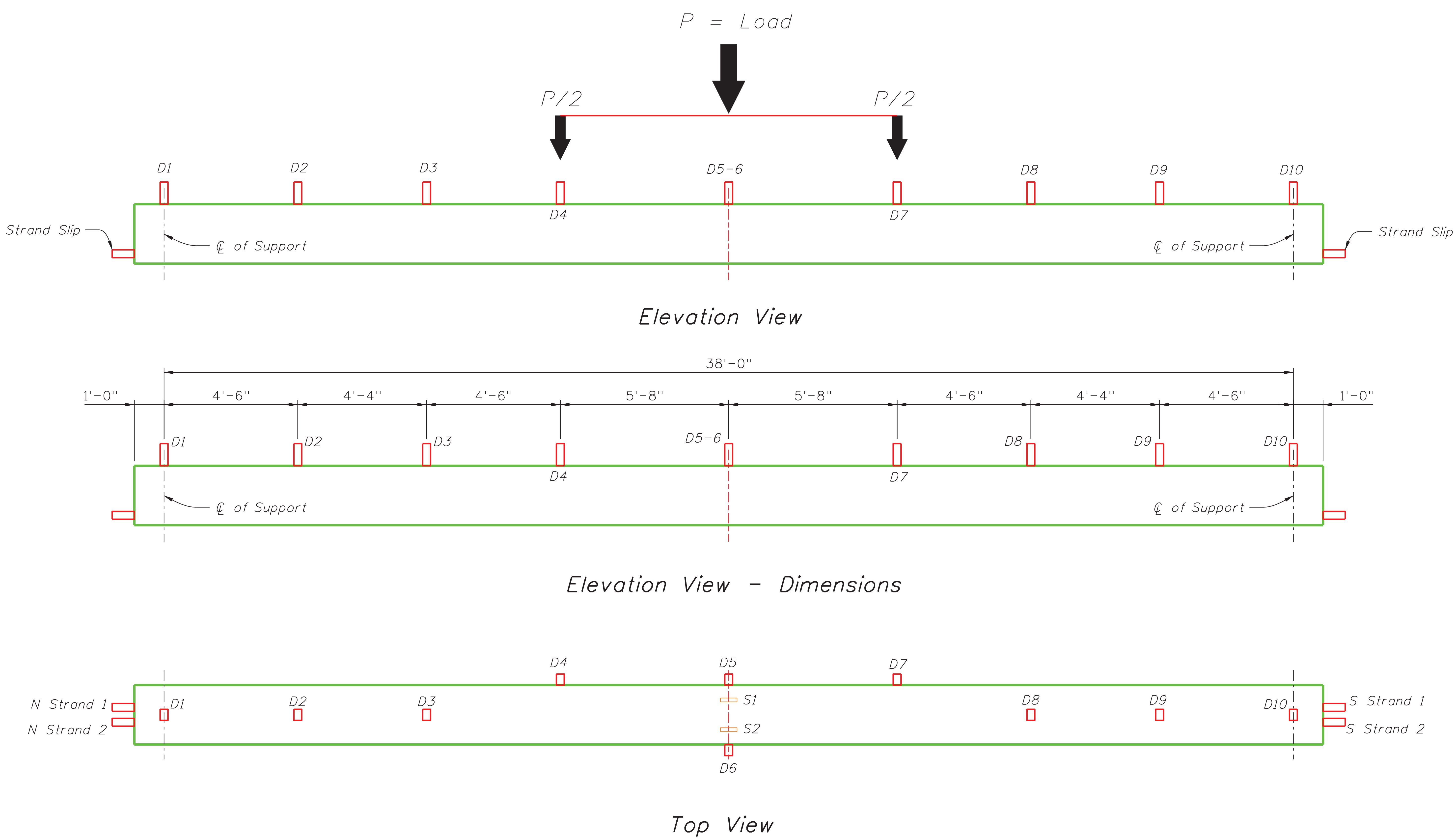
PROJECT NAME: Carbon Reinforced Pile (Gate)

REF. DWG. NO.

SHEET NO. 1

S1-2 - 60 mm Strain Gages

24" Square Pile



REVISIONS

DATE	BY	DESCRIPTION	DATE	BY	DESCRIPTION

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CHECKED BY:

STATE OF FLORIDA
DEPARTMENT OF TRANSPORTATION

ROAD NO.	COUNTY	FINANCIAL PROJECT ID

SHEET TITLE:
Control Specimen
Test Setup

PROJECT NAME:
Carbon Reinforced Pile (Gate)

REF. DWG. NO.

SHEET NO.
1