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NON-DESTRUCTIVE AND DESTRUCTIVE INVESTIGATION OF AGED-IN-THE FIELD CARBON FRP-WRAPPED COLUMNS

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16. Abstract

The common practice of applying deicing salts on highway bridges increases the potential of reinforcing steel in these structures to experience extensive corrosion in the decks as well as the substructure. A new rehabilitation method which is believed to arrest the corrosion, restore structural integrity, extend the life, and provide interim safety until replacement at a later time is FRP jacketing. In line with this concept, all the columns of the Highland Drive Bridge at I-80 in Salt Lake City were rehabilitated with carbon FRP composites in June 2000. The present project will evaluate the performance of the carbon FRP composite for two of these columns and its ability to maintain a good bond to the concrete, thus restoring and maintaining the column's capacity after exposure to field conditions for 8 years. In addition, the use of a GFRP spiral as a non-corroding column tie will be examined.

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EXECUTIVE SUMMARY

Many bridges in the Unites States are aging such that they are in need of repair or strengthening. Due to its high strength to weight ratio, corrosion resistance, and increasingly competitive cost, one popular material that is used for bridge repair is fiber reinforced polymer (FRP) composite. The purpose of this research is to evaluate the effectiveness of externally wrapped carbon FRP composite jackets to arrest the corrosion of the column steel reinforcement, and the soundness of the bond of the carbon FRP composite to the columns after exposure to field conditions for 8 years. In addition, the use of internal FRP reinforcement in the form of a GFRP spiral as a non-corroding column tie will be examined.

This quarterly report presents the milestones that have been achieved. According to the schedule, the following tasks are to be performed for completion of this project:

Task 1. Review existing experimental results and analytical models for corrosion arrest of steel reinforcement using external CFRP jackets.

Task 2. Evaluate corrosion progression, concrete quality and chloride penetration from field samples.

Task 3. Perform concentric axial and eccentric axial load tests of two full-scale columns aged in the field with external CFRP composite jackets.

Task 4. Perform axial load tests of small-scale columns with and without external CFRP jackets.

Task 5. Perform concentric axial load tests of small-scale columns with GFRP spirals as internal column ties.

In the third quarter, we have completed Tasks 1 and 2, and have focused most of our effort on Task 3. In the third quarter, the following activities were initiated or completed:

1. Corrosion Tests of Small-scale Columns with Steel Reinforcement (Stage 2)

Small-scale columns #7 and #8 are both reinforced with steel reinforcement. These columns were placed in the corrosion environment on Sept. 17, 2009 to carry out a preliminary investigation of corrosion. One of the two preliminary corrosion specimens (column #7) was removed from the corrosion environment on Oct. 23, 2009 (after five weeks) and is shown in Figure 1(a). Column #8 was removed on Nov. 27, 2009 (after 10 weeks) and is shown in Figure 1(b). Cracks were measured and documented as shown in Tables 1 and 2. It is important to note that these cracks developed while the specimen was cycled in the corrosive environment at room temperature and that no freeze thaw cycles were applied.

(a) (b)

Figure 1. Small-scale column corrosion tests: (a) Column #7; (b) Column #8

Table 1: Crack Measurements

Column # 7 Steel EXP		
Crack #	Size (in)	Length (in)
1	0.013	4
2	0.01	10
3	0.007 to .03	31
4	0.003	4
5	0.01	6.5
6	0.009	8.5
7	0.007	4
8	0.003	3
9	0.016	13
10	0.009	14

Table 2: Crack Measurements

Column # 8 Steel EXP		
Crack #	Size (in)	Length (in)
1	.016 to .02	5
2	.007 to .013	9
3	.003 to .01	(2.5) 9
4	.007 to .026	15.5
5	.005 to .025	13
6	.005 to .016	31
7	.009 to .04	15

Corrosion of the remaining six small-scale columns was initiated in March of 2010. Four of the six columns have all steel reinforcing and two have steel vertical bars with glass fiber reinforced polymer (GFRP) spirals. The columns were placed in the corrosion tank with 5% salt water solution, and were left to soak in the solution for one week to allow the water to penetrate to the rebar - before the 5.0 volt potential was applied on March 24, 2010 (see Figure 2). Initial readings were taken right after the 5.0 volt potential was applied. Readings were taken frequently at the start, on March 25, 26, 29, 30, 31, and April 1, 2, and 7 to ensure the corrosion process was running correctly. From this time onwards readings were taken weekly.

Three DC power supplies were required to implement corrosion of the six columns. Each power supply is connected to two columns and supplies a constant 5.0 volt potential across each vertical rebar. This 5.0 volt potential is checked with a voltmeter every time readings are taken to ensure it stays constant. This was done at initial set up and the potential has remained at a level of 5.0 volts.

Figure 2. Corrosion system for small-scale steel reinforced columns

2. Full Scale Column Test Preparation

Intermountain Rigging Company was contracted to transport the full scale columns inside the laboratory and stand the columns in the loading frame in December of 2009. A steel collar had to be designed to lift the columns vertically into the frame, and maneuver them afterward. The steel collar had a length of 1 ft.-6 in. and was constructed out of a 36 in. diameter steel pipe as shown in Figures 3 and 4. The steel pipe was cut in half with two ¾ in. thick steel lifting tabs attached and 3/8 in. thick bolt plates that were stiffened with ¼ in. stiffener plates as shown in Figure 5. The bolt plates allowed for a total of eight ¾ in. bolts to tighten the collar onto the column as shown in Figure 5. Once inside the frame, the column had to be adjusted to stand in the vertical position and in the center of the frame. To achieve this, the column was suspended and square metal tubing was welded into the frame to hold the bottom centered; then the top was adjusted until the column was vertical. Once the column was vertical it was braced and a form was built around the base; Hydrostone, a high strength plaster, was poured in to fill the small gap between the column and the bottom steel plate. Hydrostone was placed to provide a uniform bearing area beneath the column and on top of the column so that there would be no unintended loading concentrations that could affect the test results.

Figure 3. Steel collar

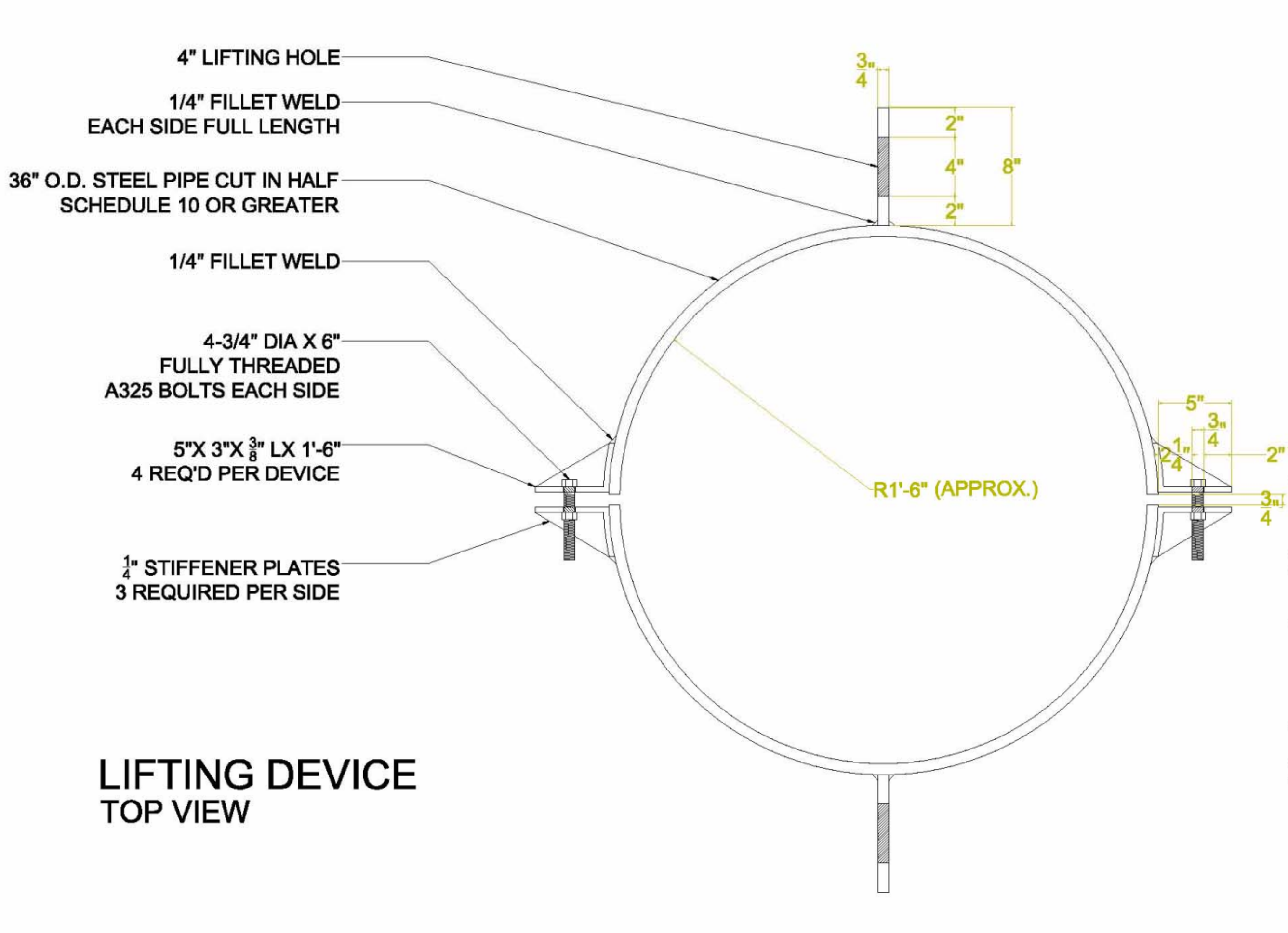


Figure 4. Top view of steel collar

Hydrostone was used to cast the base cap and top cap of the column. Prior to casting the top and bottom caps, test batches of Hydrostone were tested in compression. Test batches at 32% water to plaster ratio, by weight, gave an average strength over 7,000 psi, and at 25% water to plaster ratio test samples had an average strength over 10,000 psi. The 25% water to plaster ratio mix was much more viscous than the 32% water to plaster mix which was very fluid and self-leveled easily.

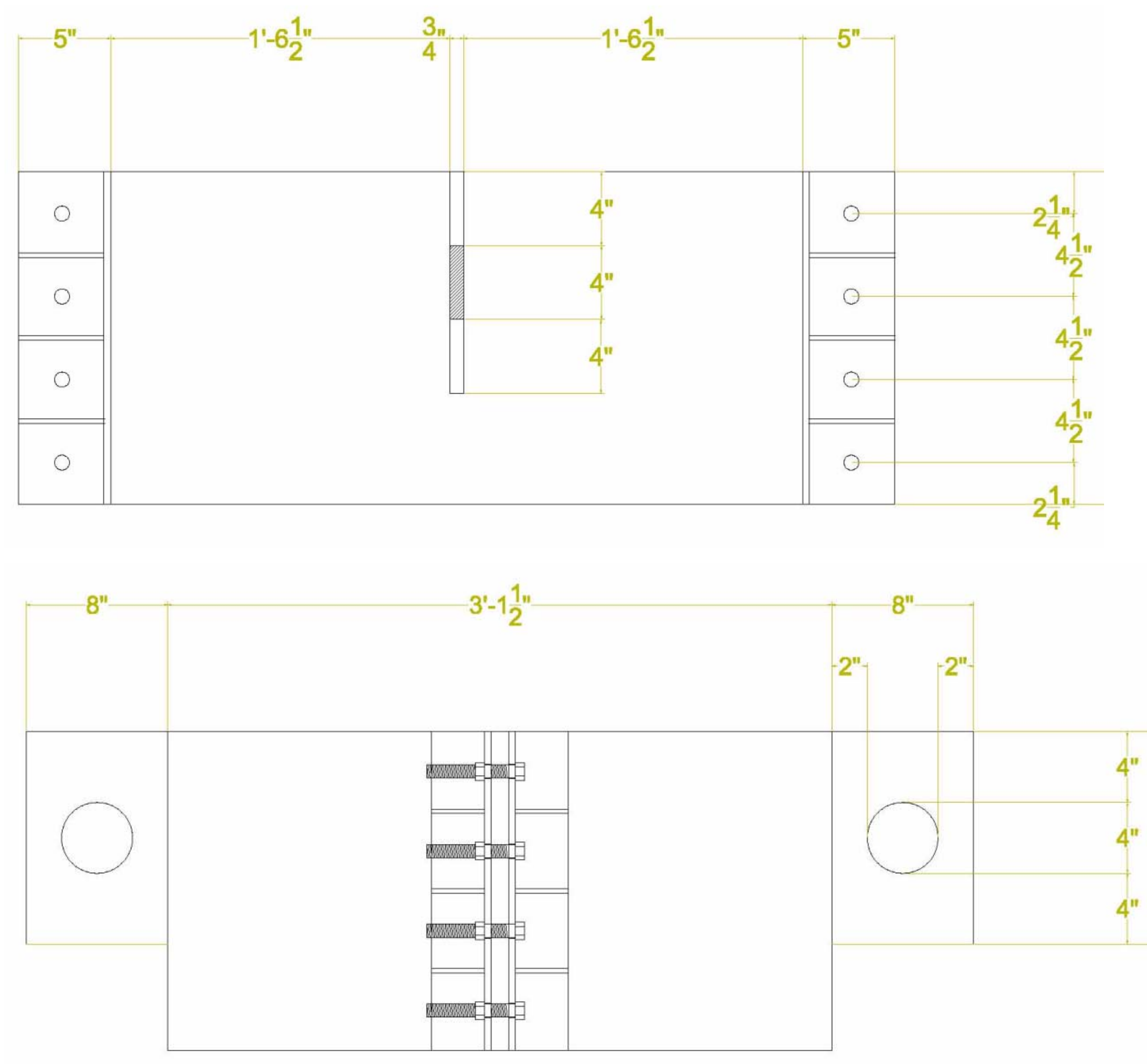


Figure 5. Elevation views of steel collar

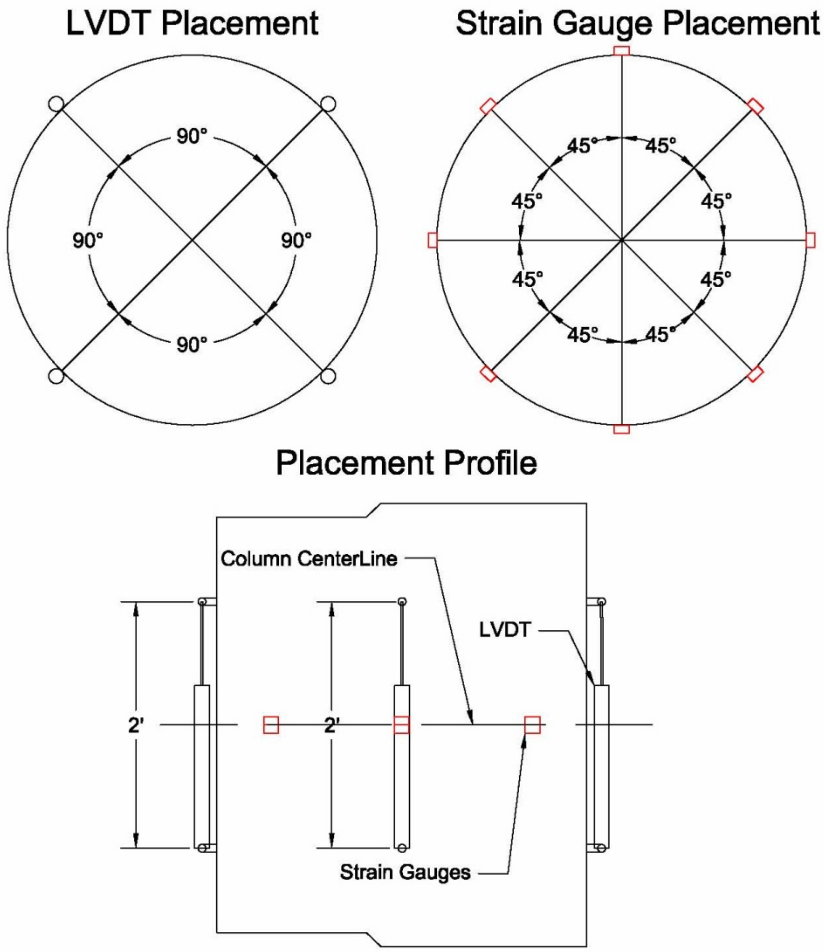
A small batch of 25% water to plaster ratio was used to fill in the bottom of the column where there was a large piece of concrete missing from the center due to the cutting off of the top and bottom of the columns to achieve the exact height of the 12 ft high columns. This was done to avoid an air pocket forming when the base was poured and the column was in the vertical position. Once the plaster hardened, the top bracing was removed and the column stood vertical on its own base as shown in Figure 6. The steel collar used to lift and hold the column was then loosened and raised to make a form to cast the top cap. All gaps around the steel collar were filled with silicon and the top cap was subsequently cast. The thickness of the top and bottom caps was limited 2 in.

Figure 6. Bottom column cap (thickness between bottom of column and steel plate 2in.)

Strength tests were performed on cubes made during casting of the top and bottom column caps. The compressive capacity of the plaster was over 7,000 psi which is much greater than the design strength of the concrete columns which was 4,000 psi. Concrete cores were taken from the cut-off portion of the column that will be used to determine the actual concrete strength, which is expected to be higher than the design strength of the concrete columns.

After the plaster caps were cast, a total of 24 electrical strain gauges were placed around the column perimeter in the hoop direction at mid height and at eight locations (every 45 degrees). At each 45 degree location, two strain gauges were placed to measure radial strain while one gauge was attached to measure vertical strain as shown in Figure 7. Four Linear Variable Differential Transducers (LVDTs) will also be placed every 90 degrees around the column perimeter and span a vertical distance of 2 ft, centered around the column mid height, to measure axial strains. A diagram showing the arrangement of the electrical strain gauges that will be used to measure hoop strain and the four LVDTs that will be used to measure axial strain is provided in Figure 8.

Figures 7. Strain gauge arrangement and close up of strain gauges



Figures 8. Diagram showing strain gauge and LVDT placement

A W 14 x 283 steel column was cut to length and designed to connect to the actuator to apply the force to the top of the columns as shown in Figure 9. This W 14 x 283 steel column was 6 ft- 6 in. long, and it was restrained in the frame with 6 in. square tubing to avoid the possibility of bending the actuator rod during the eccentric load test as shown in Figure 10. Steel plates measuring 1 in. thick, will be used to achieve various eccentricities; two of the steel plates are 6in. wide and the other two 12 in. wide. The plates will be placed in-between the two 40 in. by 40 in. by 3 in. thick plates that are located at the base of the load frame, shown in Figure 6. All plates will remain in during the centric load test, but for eccentric loading the plates on one side can be slid out. Having multiple plates will make it possible to test different eccentricities one right after the other. It is anticipated that the two full-scale columns, 3 ft diameter and 12 ft high, will be tested in May 2010 in the configuration shown in Figure 11.

Figure 9. Column connector to actuator (W 14 x 283 steel column)

Figure 10. Restraining system for column connector to actuator

Figure 11. Test setup for the 12 ft high – 3 ft diameter columns