Report No. UT-002

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

Prepared For:
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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 second quarter, we have completed to a large part Task 1, and have focused most of our effort on Tasks 2 and 3.

According to the proposal, the following activities should have taken place in the second quarter:

1. Corrosion Mapping of Two Columns from Pier #3 WB

In the second quarter, the following activities were initiated or completed:

1. Corrosion Tests of Small-scale Columns with Steel Reinforcement

The corrosion system for the small specimens was based on the Florida Method of Test for an Accelerated Laboratory Method for Corrosion Testing of Reinforced Concrete Using Impressed Current (Florida DOT, 2000). A power supply with a max capacity of 12 volts and 3 amps was used and attached to two specimens. These specimens were placed in a tank with 5% salt solution by weight, as shown in Figure 1. The tank was filled with the salt solution up to approximately half the height of the small-scale columns, or 14 in. In order to induce the current, a metal grate was placed at the bottom of the tank to receive the current leaving the specimens and thus completing the circuit. This induced current accelerates the corrosion process. The two specimens were constructed with steel vertical bars and with steel hoops as described in the first quarterly report (Pantelides et al. July, 2009).

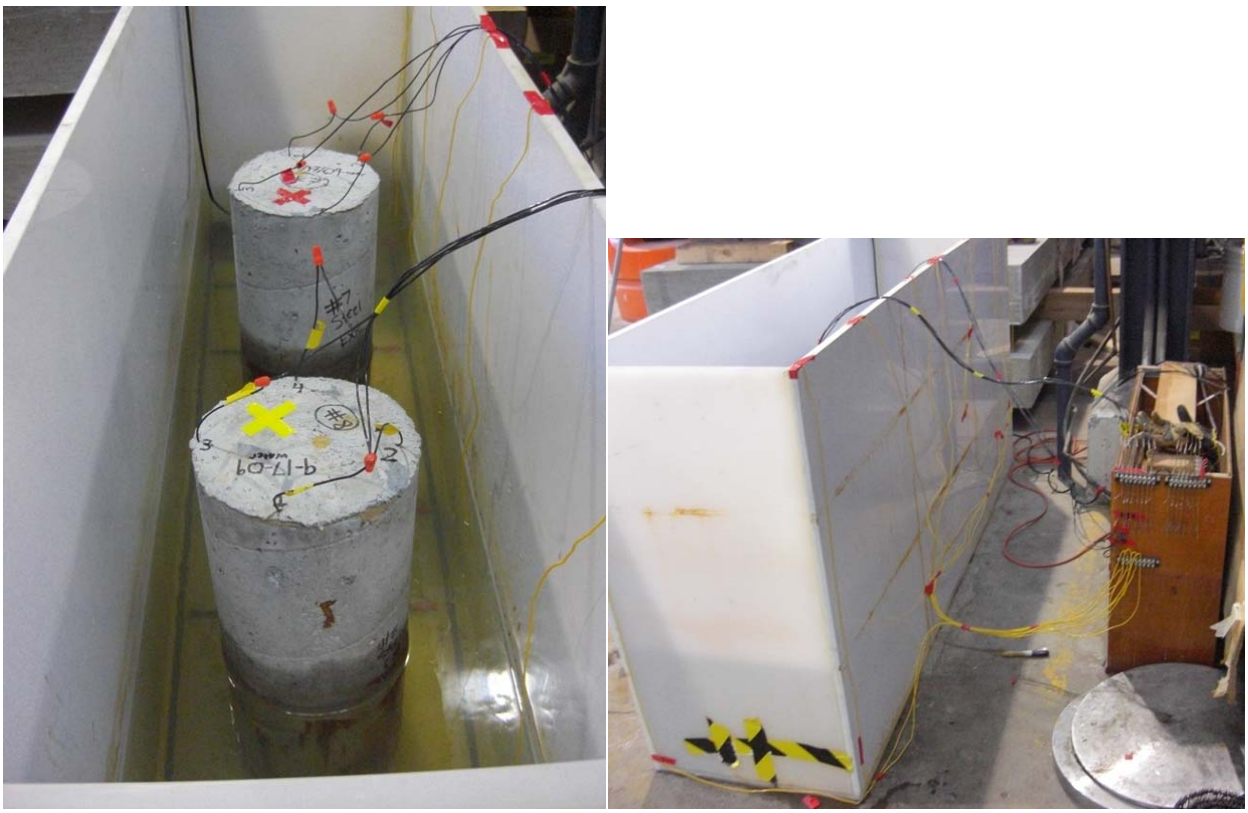


Figure 1. Corrosion system for small-scale steel reinforced columns.

The power supply was initially set at a constant voltage equal to 6 volts and the corrosion process was started on September 17, 2009. Current measurements were taken daily. The specimens had cracked within one week of initiating the corrosion environment. This was made evident by a jump of 1mA in the current for each specimen, and was later confirmed by visual observation. After starting the corrosion, a few changes were made to the corrosion system. The steel grate at the bottom of the tank was a different grade steel than the rebar so it was replaced by several pieces of rebar placed around each of the specimens. The power supply was unable to maintain a constant voltage of 6V due to the increase in current exceeding the 3 amp capacity. Therefore, the constant voltage was adjusted from 6V to a constant voltage ranging from 3V to 5V over a period of four weeks. The ideal voltage was determined to be 5V for the existing power supply; this is the highest constant voltage that keeps the current under the maximum value.

The two specimens were observed on a weekly basis and pictures were taken. One of the two initial test specimens was removed from the corrosion environment on October 23, 2009, and is shown in Figure 2; it is clear that corrosion, discoloration and cracking are limited to the portion of the small-scale column below the water line. This specimen will be tested in compression and the amount of rebar corrosion will be determined. The second test specimen will stay in the corrosion environment for as long as needed based on the state of corrosion of the first test specimen and the strength degradation observed. Therefore, the amount of time needed for the other small specimens to remain in the corrosion environment will be determined by using these two test specimens.

Figure 2. Corrosion deterioration of first small-scale steel reinforced column.

2. Material Properties of Two Columns from Pier #3 WB

The two columns removed from the Highland Drive Bridge at I-80 in Salt Lake City, rehabilitated with carbon FRP composites, were saw-cut at their ends, on August 20, 2009, as shown in Figure 3. The saw-cut was performed using 36 in. diameter diamond blades with three movements of the location of the blade at approximately 120 degrees to be able to cut the 36 in. diameter column. The cut face of the top of one of the columns is also shown in Figure 3. The original specified concrete strength of the columns in the design drawings was 3000 psi.

Concrete cores 4 in. in diameter were taken from the cut-off column sections, as shown in Figure 4, to determine the compressive strength of the concrete; this will be evaluated on the day of the axial load tests of the two full-scale columns.

Figure 3. Saw-cut of 36 in. diameter column from Highland Drive Bridge.

Figure 4. Concrete cores from cut-off column section.

3. Concrete Carbonation and Corrosion Progression of Pier #3 WB Columns

Penetration of carbonation into the concrete can be one of the causes of corrosion. The depth of penetration of the carbonation was found by using a Gilson HM-261 Carbonation Detection Kit on the saw-cut ends of the two full-scale columns. This kit contains a phenolphthalein solution that is sprayed over a freshly cut or fractured surface. The solution causes the concrete that has not been exposed to carbonation to turn into a pink color and the carbonated concrete appears normal. This solution was applied to the four cut surfaces of the two full-scale columns after they were cleaned. Minimal carbonation penetration was observed. Carbonation does not appear to have reached the column steel reinforcement in significant amounts, as shown in Figure 5. On average only the outer ¾ in. layer was observed to have high carbonation content. However, this finding may not be accurate at locations where the concrete had fallen off and was replaced in the rehabilitation process, as shown in Figure 6.

Figure 5. Concrete carbonation at perimeter of cut-off column section.

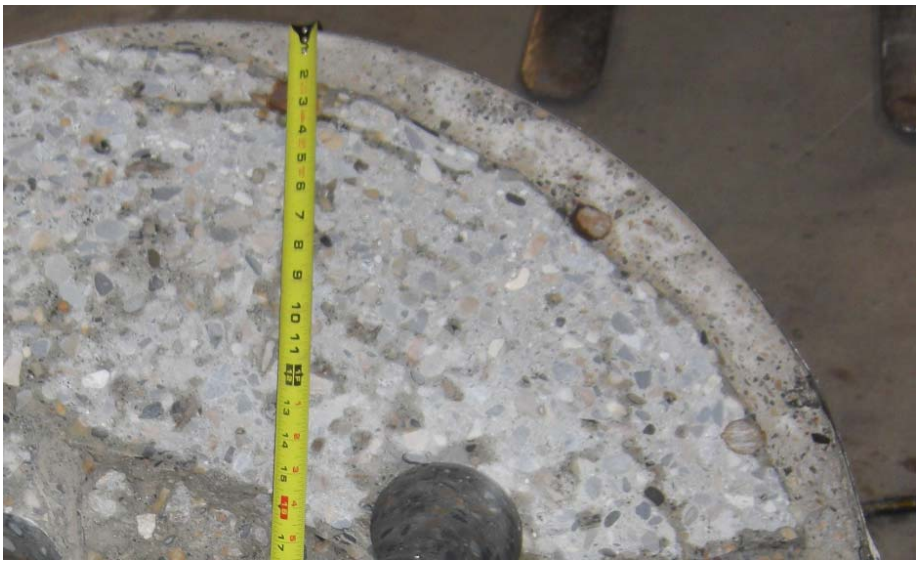
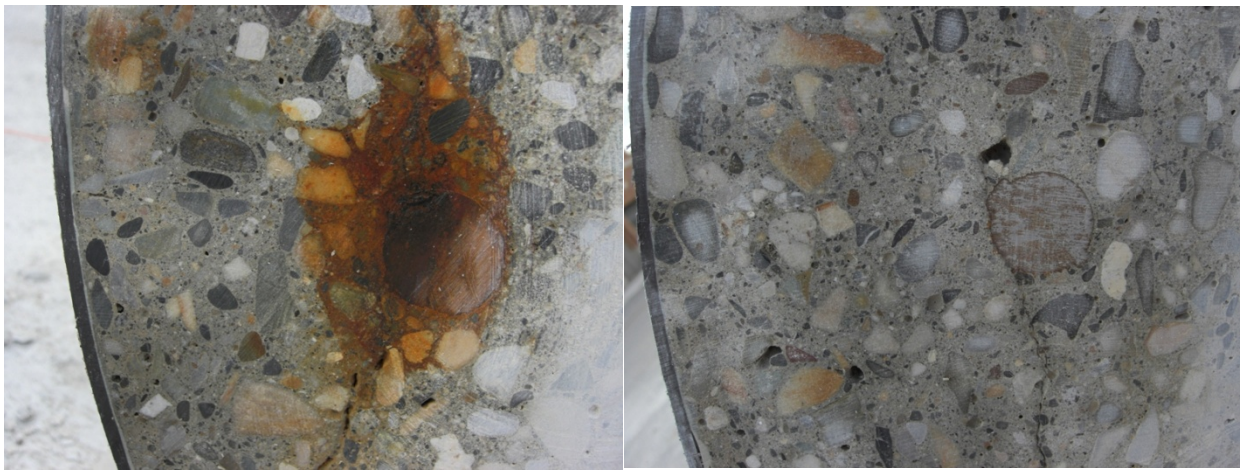


Figure 6. Replaced concrete around the perimeter of column section.

Corrosion in the vertical steel reinforcing bars of the full-scale columns was evident as shown in Figure 7. In general, bars with a smaller cover, resulting from construction tolerances, had higher levels of corrosion as shown in Figure 8(a), compared to bars with a larger cover, as shown in Figure 8(b). However, there are other factors to be considered, such as the flow of the salt water de-icing solution from the deck joints to the cap beam and then to the columns. To investigate this topic further, the corrosion patterns and concrete cover of all bars at the top and bottom of both columns has been recorded, as shown in Figure 9. The notations for bar number and amount of concrete cover are given in Figure 9 and Table 1.

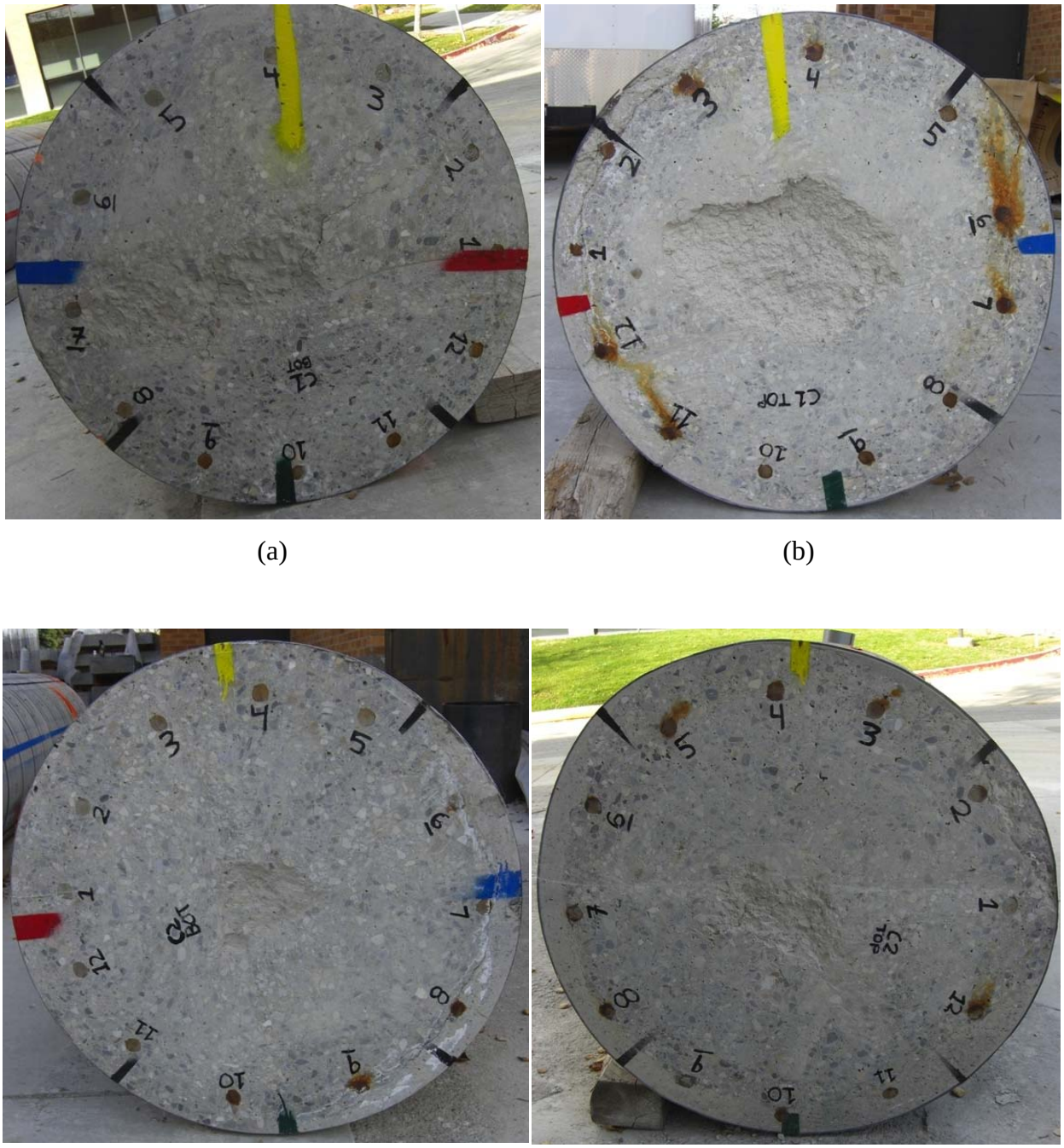
The observed corrosion patterns indicate that the top of the columns had a higher frequency of corrosion and a more significant section loss, compared to the bottom of the columns. This is due to the presence of the salt water solution which is sprayed for de-icing; the decks had open expansion joints until the time of rehabilitation of the columns in 2000, when the deck joints were closed. A number of #9 vertical steel bars and #4 steel hoops bars from the cut-off portions of the two columns have been set aside; these bars will be examined for area section loss due to corrosion along with the steel bars inside the columns after the axial load tests of the columns have been performed.

Figure 7. Corrosion of vertical steel reinforcing bars at the top of full-scale column C1.



(a) (b)

Figure 8. Influence of column concrete cover on corrosion.



(a) (b)

(c) (d)

Figure 9. Column concrete cover: (a) C1 bottom, (b) C1 top, (c) C2 bottom, (d) C2 top.

Table 1. Concrete cover for top and bottom cross section.

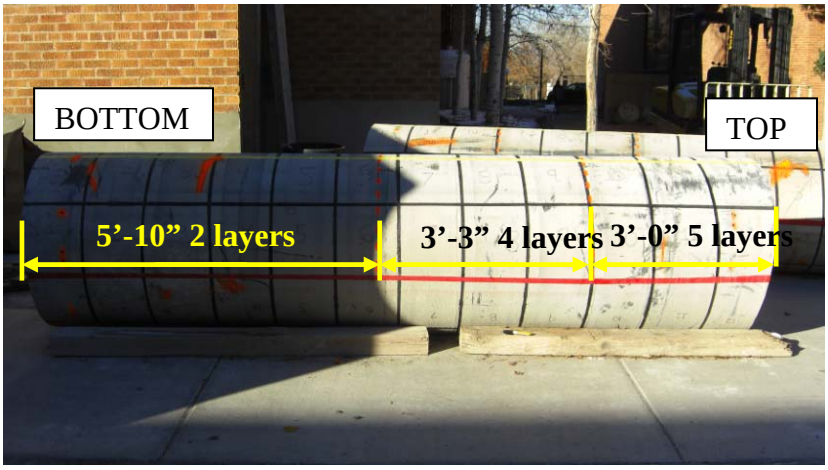
Top of Column #1		Bottom of Column #1	
Rebar #	**Cover (in.)**	**Rebar #**	**Cover (in.)**
1	$1\frac{1}{4}$	**1**	$1\frac{7}{8}$
2	$1\frac{1}{4}$	**2**	2
3	$1\frac{1}{2}$	**3**	$2\frac{1}{2}$
4	$2\frac{1}{8}$	**4**	$3\frac{1}{4}$
5	$2\frac{3}{4}$	**5**	$3\frac{1}{2}$
6	3	**6**	$3\frac{1}{4}$
7	3	**7**	3
8	$3\frac{3}{4}$	**8**	$2\frac{3}{8}$
9	$3\frac{1}{4}$	**9**	$2\frac{1}{4}$
10	$2\frac{3}{4}$	**10**	$1\frac{7}{8}$
11	$2\frac{1}{8}$	**11**	$1\frac{7}{8}$
12	$1\frac{3}{4}$	**12**	$1\frac{3}{4}$

Top of Column #2		Bottom of Column #2	
Rebar #	**Cover (in.)**	**Rebar #**	**Cover (in.)**
1	$2\frac{7}{8}$	**1**	$3\frac{5}{8}$
2	$2\frac{3}{8}$	**2**	$3\frac{5}{8}$
3	$2\frac{1}{2}$	**3**	$3\frac{1}{4}$
4	$2\frac{5}{8}$	**4**	$2\frac{3}{4}$
5	$3\frac{1}{8}$	**5**	$2\frac{1}{2}$
6	$2\frac{1}{2}$	**6**	$2\frac{1}{4}$
7	$2\frac{1}{4}$	**7**	$2\frac{1}{8}$
8	$1\frac{7}{8}$	**8**	$1\frac{7}{8}$
9	$1\frac{3}{4}$	**9**	$2\frac{1}{8}$
10	$1\frac{1}{8}$	**10**	$2\frac{3}{4}$
11	$1\frac{7}{8}$	**11**	3
12	$2\frac{7}{8}$	**12**	$3\frac{1}{2}$

4. Surface Evaluation Survey of Pier #3 WB Columns

Once the two columns were saw-cut the column surfaces wrapped with CFRP composite were inspected. No voids between the CFRP composite and the concrete surface were detected by the method of tapping the surface with a quarter. By comparing pictures taken of the Pier #3 WB before demolition and the design drawings, the location of the column sections obtained were determined. It was found that the top of each specimen corresponded to the top of each column in the as-built pier. By measuring the CFRP thickness, the number of layers for each region was determined as shown in Figure 10 for both columns 1 and 2. It should be noted that one layer of CFRP composite is 0.04 in. thick.

Column 1



Column 2

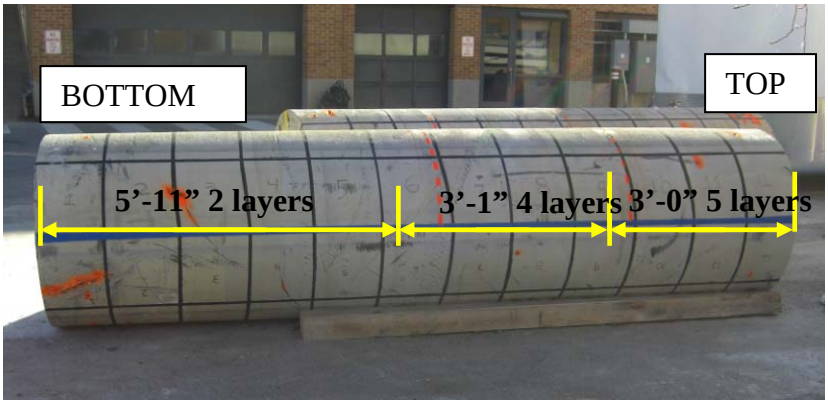


Figure 10. Mapping the CFRP number of layers and location with respect to the column orientation.

The damage levels on the carbon fiber polymer composite (CFRP) was determined using visual observations on two different dates. An ad-hoc terminology was used and is documented with extensive descriptions in Figure 11 and Table 2. This was done to identify weak locations of the CFRP wrap prior to testing, which will be helpful in interpreting the test results.

Description of Terminology

Gash = damage that has completely penetrated the carbon fiber wrap.

Minor Scrape = superficial damage that has not done much more than remove the outer paint and epoxy covering the carbon fiber wrap.

Moderate Scrape = damage that has penetrated the top layers of the carbon fiber wrap approx. 20% to 50% of the carbon fiber has been penetrated.

Severe Scrape = damage that has penetrated 50% or more of the carbon fiber wrap, but usually not completely penetrated it.

Anchor-bolt Holes = these are drilled holes, usually 2 in. to 3 in. deep, that were used to anchor the saw that cut the ends off the columns. In most cases the anchor sleeve for the bolt is still inside the hole. In other cases the hole hit a rebar and had to be re-drilled – in these cases the hole does not have the sleeve inside it.

Some words such as small, medium, and large are used instead of actual measurements. These terms are with respect to an approx. 1ft by 1ft section. If a better understanding is desired pictures can be used to verify actual size of affected area.

Figure 11. Diagram of typical column grid.

Table 2. Damage levels for CFRP composite.

Date: 11/05/09 Column #1

Station (ft)	Red (0°)	45°	45°	Red (360)
1	3 Anchor holes – 2 sleeved 1 not sleeved		Gash 1” by 2”. 1 severe scrape 6” line and several minor scrapes	
2	Good with one minor scrape 12” long		Gash on line between stations 1 and 2 1” by 4”. 1 severe scrape 4” by ½” and a CF seam is visible	
3	Good with two minor scrapes – one 12” line and one 2” by .5 “ scrape		1 Large gash 13” by 1.5” along the line between stations 3 and 4	
4	1 minor scrape 12” line and 1 moderate scrape ½” by 5”. There is also a CF seam visible		Good – CF seam is visible	
5	Good with 1 minor scrape 9” line		Good – CF seam is visible	
6	Very good – CF seam visible		Good with a couple very minor scrapes	
7	Very good – CF seam visible		Good	
8	2 small moderate scrapes and a couple very minor scrapes		Good with one minor scrape 6”by ½”	
9	Good with a few minor scrapes		Good	
10	Several minor scrapes and 2 very small moderate scrapes. CF seam visible		Good	
11	Several minor scrapes. 2 moderate scrapes one 8” by ¼” and the other 1” by 3”		Covered in several minor scrapes	
12	3 sleeved anchor holes. One sleeve sticks out about ½” from surface of column		Minor scrape 3” by 13”	

Date: 11/05/09 Column #1

Station (ft)	Yellow (90°)	135°	135°	Blue (180°)
1	2 Gashes one is 8”by ¾” on 135 line the other is 7” by 2”. These gashes spill over into other stations, but these are the overall approx size. Several minor scrapes as well		Sleeved anchor hole and 3” by ½” of gash from adjacent station 1	
2	Good – CF seam is visible		Good. Few minor scrapes	
3	Good		1 Large gash 8” by 13” lots of splitting an chunks of concrete are missing	
4	Good – CF seam is visible		Good with a CF seam visible	
5	Couple minor scrapes one is 13” by ¼ “		1 Large minor scrape 14” by ½”	
6	Good with a few minor scrapes		Good with a few minor scrapes	
7	Good with a few minor scrapes		2 moderate scrapes – 3” by 1” and 1” by 2”	
8	Good		Few minor scrapes	
9	Very good		Very good	
10	Very good – CF seam on line between stations 10 and 11		Few minor scrapes and 1 moderate scrape 3” by ½”. CF seam visible as well	
11	Good with a few very minor scrapes		One moderate scrape 1” by 2” and one minor scrape 7” by ¼”	
12	Gash with a chunk of concrete missing as well 3” by 1”. Another gash 1” by 1”		One sleeved anchor hole and one moderate scrape 1”line	

Date: 10/23/09 Column #1

Station (ft)	Blue (180°)	225°	225°	Green (270°)
1	Few minor scrapes		Long minor scrape Hole in CF 1" diameter on black line toward blue line. One anchor hole with sleeve	
2	One gash 5" long 1" wide Many moderate scrapes as well		2 minor scrapes and a carbon fiber seam is visible	
3	Two holes in CF 1" and 2" in diameter – surrounded by splitting in the CF		Good with one minor scrape	
4	Good with a couple minor scrapes		One minor scrape and one small moderate to severe scrape	
5	Good with a couple minor scrapes		3 small minor scrapes and 2 small moderate scrapes	
6	One small moderate scrape Bulge in CF wrap approx. 4" diameter		Few minor scrapes, a carbon fiber seam, small line gash 1.5" long	
7	One large minor scrape		Good	
8	Good with one minor scrape		Good with 2 minor scrapes	
9	Gash 2" by 1" surrounded by minor to moderate scrapes and one line gash 4" long		One gash with CF splitting around it ¾" wide 3" long and 2 moderate scrapes	
10	Station half covered by a minor scrape		Good with one minor scrape	
11	Several minor scrapes		Few large minor scrapes	
12	Good with sleeved anchor bolt hole in blue line		Good one sleeved anchor hole and one long minor scrape	

Date: 10/23/09 Column #1

Station (ft)	Green (270°)	315°	315°	Red (360°)
1	Two holes in CF approx. 1in diameter One Sleeved Anchor bolt hole		Thin line gash approx. 5in long in radial direction	
2	2 medium size gashes through CF 1 large gash through CF		Good	
3	Good		2 holes through CF approx. 1" and ¼" in diameter	
4	Good		Several sever scrapes – concrete is visible in two spots	
5	Good with one minor scratch		Good	
6	Good a carbon fiber seam is visible		Good with one long minor scrape	
7	Good a carbon fiber seam is visible		Very good	
8	Good with a couple minor scrapes		3 minor to moderate scrapes	
9	Good with a couple minor scrapes		3 small minor scrapes	
10	3 moderate scrapes 1 severe scrape		1moderate and 2 minor scrapes	
11	Sever scrape continues into this station. Concrete is visible in a few spots		Good with 2 minor scrapes	
12	1 Very large severe scrape – concrete is visible in some areas		Good with 2 minor scrapes	

Date: 11/05/09 Column #2

Station (ft)	Red (0°)	45°	45°	Yellow (90°)
1	Good with one sleeved anchor hole		Good with 1 sleeved anchor hole	
2	Good		Good with a CF seam visible	
3	1 moderate to severe scrape - 13" line. Gash in stations 3, 4 and on 45°line – entire size = 7" by 4"		Part of a large gash Near 45° line and station 4	
4	Gash see station 3 for entire dimension. There is also a CF seam visible. Some very minor scrapes as well		Good with CF seam visible	
5	Good with one minor scrape across the 45°line		Good	
6	Very good – CF seam visible		Good CF seam is visible	
7	Good with several minor scrapes		Minor to moderate scrape by 45°line 3" by 13". By station 6 2" by 7" minor scrape	
8	Good with several minor scrapes		Minor scrape on 45°line 3" by 13"	
9	Good with 2 minor scrapes		Minor scrape on 45°line 3" by 13"	
10	Good with 2 minor scrapes		2 moderate line scrapes one 7" and the other 3". Some minor scraping as well	
11	Very good		Large moderate to severe scrape 13" by 3" –in widest spot	
12	Very good		1 sleeved bolt hole and 2 minor scrapes one 7" by 1" and the other is 2" by 1"	

Date: 11/05/09 Column #2

Station (ft)	Yellow (90°)	135°	135°	Blue (180°)
1	1 sleeved anchor hole with a few minor scrapes		Good with some minor scrapes	
2	1 small moderate scrape 1" by ¼"		Part of gash from station 3 - 1" piece	
3	Very good		One sever scrape. Starts with small gash 1 " by ½" the continues 7" and a severe line scrape	
4	Good with a large CF seam visible		Good	
5	Good		Good with some minor scrapes	
6	Good with CF seam visible		Good with some minor scrapes and a CF seam visible	
7	Good with some very minor scrapes		2 small moderate scrapes	
8	Very good		Some minor scrapes and 1 moderate scrape ½" by 12"	
9	Very good		2 minor to moderate scrapes 1" by 1" and ¼" by 7"	
10	Very good		Part of one minor scrape bear blue line and 1 moderate to minor ¾" by 9" scrape	
11	Good with a couple minor scrapes		1 moderate scrape with fracturing and splitting of CF 1" by 3"	
12	1 sleeved anchor hole, 1 moderate scrape 2" by ½", and a couple minor scrapes		Good with 1 minor scrape	

Date: 10/23/09 Column #2

Station (ft)	Blue (180°)	225°	225°	Green (270°)
1	Large gash approx 12” long running vertically and many minor to moderate scrapes		Two anchor holes – one without sleeve and a few small minor to moderate scrapes	
2	Small portion of gash continued from previous station and many minor to moderate scrapes		One very small moderate scrape	
3	Few large skinny minor to moderate scrapes		Good with one minor scrape	
4	One small moderate scrape and a seam appears to be separated in the CF		Good two minor to moderate scrape	
5	Many minor scrapes		good	
6	Many minor scrapes		One moderate to severe scrape continuing form green line and one small minor scrape	
7	Few minor scrapes		Good with two small minor to moderate grazes	
8	Few small minor scrapes and one hole that doesn’t completely penetrate CF		Good with one part of a moderate scrape	
9	Good with 1 small minor scrape		One small moderate to severe scrape	
10	1 large minor scrape and a few other minor scrapes		good	
11	good		good	
12	Sleeved anchor hole and a couple minor scrapes		Bad gash CF is lifted up area approx 4” square. Also has 2 anchor bolt holes one sleeved one not and one moderate graze near bottom of column	

Date: 10/23/09 Column #2

Station (ft)	Green (270°)	315°	315°	Red (360°)
1	few small minor scrapes		Few minor scrapes and few moderate scrapes and one sleeved anchor hole	
2	Good only 2 spots with outer coating scrapped off		Few minor scrapes and 2 moderate scrapes	
3	Jagged line cut – only through top layers not all the way through, a few cracks in the CF and a large rust mark		1 large severe scrape near 315 line and 3 more small moderate to severe scrapes	
4	One large scrape near the 4 ft line		Good with couple minor scrape	
5	Bad – Large gash by green line as well as a large scrape continued from station 4		Good with couple minor scrapes	
6	Few minor scrapes near the green line. One severe scrape on green line		One radial gash 4” long in center of station and one minor scrape	
7	Good with a couple minor scrapes		Good with one minor scrape	
8	Several minor scrapes		good	
9	Several minor scrapes		1 Large minor scrape	
10	good		Good	
11	Good with a couple very minor scrapes		good	
12	Good with one moderate scrape on very top of column		Good with two sleeved anchor bolt holes – one on the red line	

References

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