IMPACT DAMAGED PIER STRENGTHENING USING CFRP FABRIC

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Abstract

On October 21, 2015, a semi-trailer truck traveling south on the W.H. Natcher Parkway, near Bowling Green, Kentucky collided with the north pier supporting the Elrod road overpass. The impacted bridge is a four-span, 67 m (220 ft) long, reinforced concrete deck girder bridge. Large diagonal cracks propagated up the entire height of the column from the impact point. Horizontal cracking also appeared around the entire circumference near the point of impact. Large cracks occurred on the top face of the pier cap, between the girder pedestals, extending in the transverse direction. Because winter weather was approaching, the Kentucky Transportation Cabinet (KYTC) deemed a rapid retrofit necessary to maintain the bridge's structural integrity. Two types of uniaxial Carbon Fiber Reinforced Polymer (CFRP) fabric and one braided triaxial CFRP fabric were utilized in the retrofit design. A heavy uniaxial CFRP fabric was utilized as the primary strengthening material for the impacted column. A finite element model was utilized to analyse the effectiveness of the column retrofit. The retrofit construction work was completed in five workdays spread over an eight day period. The CFRP fabric-strengthened pier column is expected to be stronger than the original column.

1. INTRODUCTION

The use of composite material to strengthen reinforced concrete (RC) piers and columns has become well-established over the last few decades. Compared to traditional methods like steel jacketing, the use of Fiber Reinforced Polymer (FRP) material for column confinement can be cost effective due to their high strength and light weight properties promoting faster retrofits. Due to their inherent corrosion resistance this can also lead to lower life-cycle costs. Previous studies have shown that RC columns that are fully wrapped with FRP has increased ductility, moment and ultimate compressive load capacity, ultimate deformability and energy absorption compared to unconfined columns [1,2]. This can be advantageous when retrofitting damaged and/or deteriorated RC piers and columns. Design guides by the American Concrete

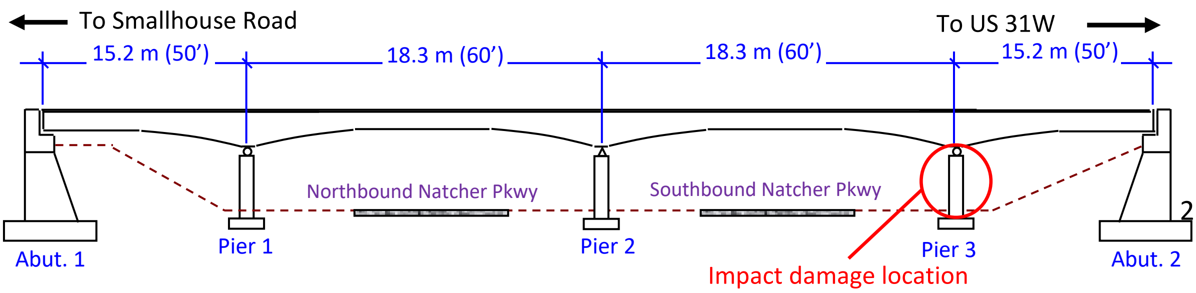
Institute [3], American Association of State Highway and Transportation Officials [4], and International Federation for Structural Concrete [5] are available on the use of FRP for confinement of RC concrete columns. Numerous field applications of FRP for retrofit of RC columns for axial loads and confinement, corrosion damage, and seismic loads have been reported [6].

Another method of bridge pier damage is due to accidental heavy vehicle collision, sometimes leading to loss of life and complete destruction of the bridge [7]. While certain code provisions such as AASHTO [8] exist for the design and placement of bridge piers next to roadways, these typically do not address vehicle characteristics and travel speeds [7]. The present paper details bridge pier damage due to an accidental truck impact, and the subsequent retrofit design and construction using Carbon Fiber Reinforced Polymer (CFRP) fabric. On October 21, 2015, a semi-trailer truck traveling south on the W.H. Natcher Parkway, near Bowling Green, Kentucky collided with the north pier supporting the Elrod road overpass. While a guardrail existed between the roadway and the pier, the semi-trailer truck had overrun the guardrail prior to impacting the pier column as shown in Figure 1.

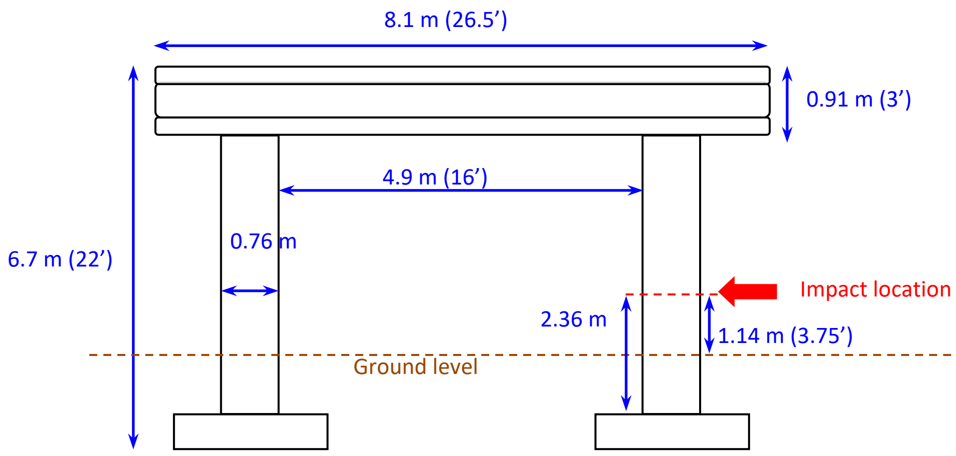
Figure 1: Semi-trailer truck impact on Elrod road bridge

2. BRIDGE AND DAMAGE DETAILS

The Elrod road impacted bridge is a four-span, 67 m (220 ft) long, reinforced concrete deck girder bridge. The two center spans of the overpass are over the northbound and southbound lanes of W. H. Natcher Parkway in Kentucky. Each pier of the bridge is comprised of two reinforced concrete pier columns supporting the pier cap. The four cast-in-place reinforced concrete girders are continuous across the length of the bridge. While the girders were fixed over the center pier (pier 2), at all other locations including the impacted pier (pier 3) the girders rested on roller supports which allowed translational movement. The 0.76 m (2.5 ft) diameter RC pier column is reinforced by 8 No.32 (#10) rebars with a nominal diameter of 32.26 mm (1.27 inch). A general layout of the bridge and cross section of a pier identifying the impact area is shown in Figure 2.



(a) General layout of the bridge



(b) Cross section of the Pier

Figure 2: Layout of the Elrod Road bridge with impact damage location

The semi-trailer truck collided with the north pier column of pier 3. Possibly due to a low impact speed and the guardrail potentially reducing the force of impact, the structural damage to the pier did not cause immediate failure of the bridge. The impact force had caused sufficient lateral movement between the pier and the beams that the rocker socket ends on each of the four RC beams were sheared. Concrete was damaged at the impact location, approximately 1.14 m (3.75 ft) above ground elevation, producing cracks on the impacted pier column as well as the pier cap above. Figure 3 highlights the damage at the impact location and the cracking in the column and pier cap.

Large diagonal cracks propagated up the entire height of the column from the impact point (Figure 3(b)). Horizontal cracks appeared around the column's entire circumference near the point of impact. Diagonal cracking occurred at the top of the column, where it intersects the pier cap (Figure 3(a)). Large transverse cracks appeared on the top face of the pier cap, between the girder pedestals (Figure 3(d)). Some transverse cracks spanned the entire width of the pier cap, with others extending down along the two vertical side faces. The cracks on the impacted column and pier cap affected the structural integrity of the bridge and raised concerns over whether they would accelerate corrosion of the reinforcing steel and lead to the deterioration of concrete. The objective of the retrofit was to repair and strengthen the impacted pier column and pier cap. Due to approaching winter weather, the Kentucky Transportation Cabinet (KYTC) required that the retrofit be designed and constructed rapidly.

(a) Impacted area of column

(b) Impacted column east face

(c) Top of impacted column

(d) Cracking on top of pier cap

Figure 3: Damage details and cracking in the pier column and pier cap

3. RETROFIT DESIGN

The axial capacity of the impacted column was of concern due to cracking. The structural integrity of the pier cap was concerning due to the cracks on the top of the pier cap. CFRP fabric was selected as the retrofit material for the damaged pier column and pier cap due to its high strength-to-weight ratio, which makes it an ideal material for quick and efficient repairs. Along with providing strength, the repair scheme was selected to protect the steel reinforcement, as corrosive agents could potentially penetrate the widening cracks. Several different types of CFRP fabric, including two uniaxial CFRP fabrics and a braided triaxial CFRP fabric, were used for the retrofit. The fabric selected depended on the type of strengthening being carried out. Table 1 lists the physical and mechanical properties of the CFRP fabric.

Table 1: Physical and mechanical properties of CFRP fabric

CFRP fabric type	Fabric width (mm)	Laminate thickness at 55% fiber volume (mm)	Fabric weight (g/m^2)	Tensile strength (MPa)	Elastic modulus (MPa)
UCF 120	305	0.76	757	2,848	139×10^3
UCF 055	305	0.36	305	2,848	139×10^3
TCF 012*	508	0.28	272	800	44×10^3

* The mechanical properties are the minimum for both longitudinal and transverse directions

3.1 Retrofit of pier cap

All three types of CFRP fabric were utilized for the pier cap retrofit. The UCF 120 uniaxial fabric, which can carry 535 kN of tensile force per 305 mm (120 kips of per 1-ft) width of fabric, was the first CFRP fabric used. To strengthen the top of the pier cap with cracked concrete, a layer of the UCF 120 fabric was placed on the top horizontal face of the pier cap, along both sides of the girder pedestals as well as in between the pedestals, parallel to the pier cap's longitudinal direction. The uniaxial UCF 055 CFRP fabric has a tensile capacity of 245 kN per 305 mm (55 kips per 1-ft) width of fabric. It was placed in continuous horizontal strips around the perimeter of the pier cap. To anchor the retrofit, a layer of the braided triaxial TCF 012 CFRP fabric was wrapped perpendicular to the previous two layers within the spaces along the pier cap between the pedestals. The triaxial fabric is a quasi-isotropic CFRP fabric with braided fibers running in 0°, and ±60° directions. The primary advantage of this fabric is that it provides approximately the same tensile capacity along any direction in the plane of the fabric. The triaxial CFRP fabric used in the present design has a tensile capacity of 53 kN per 305 mm (12 kips per 1-ft) width of fabric in all directions.

3.2 Retrofit of pier column

Two types of CFRP fabrics were used for the pier column retrofit. The first layer utilized the UCF 120 CFRP fabric. Fabric was placed in 305 mm (12-inch) wide strips around the circumference of the pier column. The second layer of fabric used on the column was the triaxial TCF 012 CFRP fabric. This fabric was placed in 508 mm (20-inch) wide strips around the circumference of the pier column, with a 100 mm (4-inch) vertical overlap between each strip. The purpose of the wrapping is to confine the concrete and increase the column's load carrying capacity. The FE model was used to model the impacted column, where the triaxial CFRP fabric is modeled as a linear orthotropic material where material properties are logged in the longitudinal and transverse directions. The loads applied on the column are calculated using the bridge plans to identify the attributed concentric axial load (P) and bending moment (M).The analysis found that the axial capacity of the column, at a load eccentricity of 276 mm (10.86 inch), increased by 260% [9]. Figure 4 presents the general retrofit design for both the pier cap and the impacted pier column.

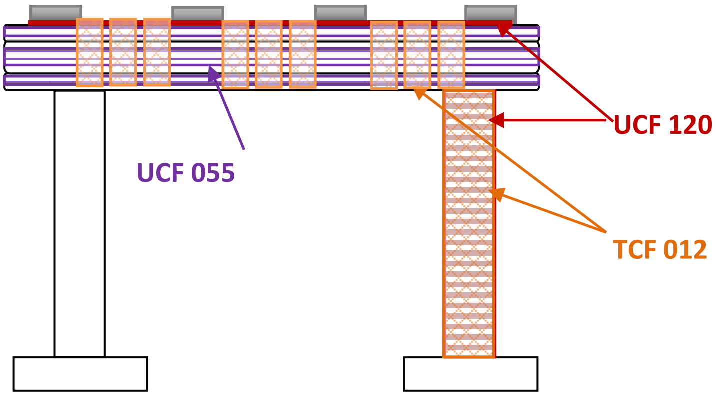


Figure 4: General retrofit scheme for impact damaged pier cap and column

4. RETROFIT CONSTRUCTION

After removing all loose material around the impact area, crews sandblasted the entire retrofit area to remove all loose material and to provide a roughened surface for CFRP fabric application. The sandblasting exposed previously unseen cracks while also cleaning the rebar steel exposed during the impact. After the placement of wooden formwork around the two repair sections, a rapid set repair mortar was applied to damaged areas on the pier column. After the mortar cured for a day, formwork was removed and the mortar ground down to remove surface variations with the pre-existing concrete column surface.

CFRP fabric was placed according to the design details provided in Section 2. Before applying the CFRP fabric, a primer coat was applied to the surface of the concrete. Laminating rollers were used to smooth out air pockets, voids, and irregularities in the fabric during its placement. Pier cap strengthening was carried out first. Initially the top of the pier cap was strengthened by placing strips of the UCF 120 fabric between the concrete pedestals as well as on either side of the pedestals. The pier cap was then wrapped with a layer of UCF 055. Due to a rustication detail on the pier cap, UCF 055 strips of two different widths were used to wrap the pier cap, as seen in Figure 5(a). Finally, a layer of TCF 012 CFRP fabric was placed, confining and anchoring the previous layers of CFRP fabric (Figure 5(b)).

(a) UCF 055 application

(b) TCF 012 application

Figure 5: CFRP fabric application on pier cap

The UCF 120 CFRP fabric was wrapped on the impacted pier column without any vertical overlap between strips. Figure 6(a) depicts the application of UCF 120 at the top of the pier. The second layer of fabric, the TCF 012, was placed (Figure 6(b)) over the first layer of UCF 120. The joints for the TCF 012 layer were placed on the opposite side of the column from the joints of the UCF 120 CFRP fabric. Three days after the CFRP fabric application, a protective coating was applied over the retrofit area in order to protect against UV degradation. For aesthetic reasons, the entire pier, including the column that was not strengthened was coated. Repair and strengthening work was completed over four consecutive days, with the final day spent on the CFRP fabric wrapping. Including the day spent coating the pier, the project was completed in five work days spread over an eight-day period. Figure 7 captures the pier following the completion of the retrofit and application of the UV protective coating.

(a) UCF 120 application (b) TCF 012 application

Figure 6: CFRP fabric application on pier column

(a) Pier after CFRP wrapping (b) Following application of protective coating

Figure 7: Completed retrofit

5. SUMMARY AND CONCLUSIONS

The pier cap and pier column on an overpass over W.H. Natcher Parkway, near Bowling Green, Kentucky was damaged when a semi-trailer truck collided with the pier. Large diagonal cracks propagated up the entire height of the column from the impact point. Horizontal cracking also appeared around the entire circumference near the point of impact. Large cracks occurred on the top face of the pier cap, between the girder pedestals, extending in the transverse direction. Two types of uniaxial Carbon Fiber Reinforced Polymer (CFRP) fabric and one braided triaxial CFRP fabric were utilized in the retrofit design. A heavy uniaxial CFRP fabric was utilized as the primary strengthening material for the impacted column. A finite element model was utilized to analyse the effectiveness of the column retrofit.

The use of CFRP fabric enabled the retrofit construction work to be completed in five workdays spread over an eight day period. Excluding the final protective coating, all work was also completed within one month of the impact. Periodic inspections were conducted over a period of two and a half years, during which time no signs deterioration of the retrofit were observed. The CFRP fabric-strengthened pier column is expected to be stronger than the original column.

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