FRP APPLICATION TO REMEDY AS-BUILT CONSTRUCTION DEFECTS

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ABSTRACT

This paper will address the use of FRP to remedy construction defects in fast track construction projects in North America. One case study will be presented to expound on the application of the use of CFRP when intrinsic defects are built in construction projects. The development and use of non-destructive testing to assess the problem, the protocol for witness testing for the FRP retrofit application and the post installed FRP QA/QC testing will be presented. Discussion of durability and fireproofing concerns from the owner’s side for such projects will be included in this paper.

KEYWORDS

FRP, Shear, Contact Critical, Bond Critical, Splice, Construction Defects, Strengthening.

INTRODUCTION

“Fast Track Construction” is not a contractual arrangement, but an approach used to allow for the earliest completion time possible by overlapping the design and construction phases. Under this approach, the General Contractor is usually working for the Owner under a guaranteed maximum or design/build contract. This method attempts to reduce the total design and construction schedule because the contractor is securing firm pricing, ordering long-lead delivery items, and starting construction as design phases are completed by the architect/engineer, The General Contractor can begin work on this phase immediately as opposed to waiting for the whole project to be designed and bid. However, the sheer speed of construction on such projects can result in field changes being made by the erector without fully understanding the actual impact of those changes and also as-built construction defects.

The case study presented in this paper relating to use of FRP to remedy construction defects in a fast track stadium expansion project. A college football stadium was undergoing a $75 million dollar expansion project to increase the capacity of the stadium to 55,000 spectators and columns on the gridline G of the main concourse exhibited cracking during construction. An evaluation was conducted understand the reason/s for the distress and subsequently an FRP strengthening scheme was implemented quickly with limited impact on construction schedule.

CASE STUDY 1 – FOOTBALL STADIUM EXPANSION

PROJECT DESCRIPTION

The college stadium expansion project’s focal point was a north end zone expansion where seating was added at two levels above the main concourse. The additions consisted of about 15000 upper concourse seats, 10 luxury boxes, 7000 square feet player’s locker room, 3000 square feet player’s lounge, office for the coaches and other areas for the press. The new upper concourse framing was structural steel supported on reinforced concrete columns.
THE PROBLEM

In order to support the upper concourse the reinforced concrete columns on gridline G (G202 through G 209) were designed with an embed plate on the north face of the columns (see Figure 2). These columns, typically 30” inch x 42”, inch were designed with embed plates and gusset plates that would connect to strut elements to carry loads from the suite level, the upper concourse level and additional upper level bleachers. Figure 2 shows a schematic cross-section of the north end zone. The design called for gusset plates to be shop welded to the embed plates prior to being attached to the column. The embed plates were designed to extend for the full width of the north face (30 inch) of the columns on gridline G for a height of 6-1/2 feet and was 1-1/2 inch thick. The embed plates were attached to the concrete columns with 13 rows (6 rows wide) of ¾” inch diameter x 8” inch long headed studs (total of 78 studs for the 30 inch wide columns). The columns were designed with 26 #11 bars with #4 ties at 3” inch on center in the embed plate zone. The clear cover to the ties was specified as 1-1/2 inch. Figure 3 shows a schematic of a typical column on gridline G.

During the construction of the columns on gridline G at the main concourse level the embed plates were fabricated and placed without the gusset plates. After these columns were poured the gusset plates were subsequently field welded on the associated embed plates. As mentioned above the original design documents called for shop welds between the gusset plates and embed plates. Cracking distress was noted
subsequent to the field welding operations. At the time the cracking distress was noted on the columns on gridline G; the gravity loading was approximately 40% of the final anticipated dead loads.

Figure 3. Schematic of a typical column on gridline G.

Our field evaluation consisted of visual assessment, non-destructive testing and destructive testing. Based on our assessment we were able to determine the following:

- Cracks on the columns were primarily on the east and west faces of the columns and the widths varied between hairline cracks to 1/4 inch. These cracks typically ran the lengths of the embed plates and in some instances extended beyond it (Figures 4 and 5).
- Typically there was a 1/8 inch gap between the embed plate and concrete on the north face of the column.
- Ground Penetrating Radar (GPR) evaluation of the columns indicated variability of concrete cover between 2 inch – 6 inch from the column faces.
- Impact Echo data suggested that these cracks were deep and hence needed to be repaired.
- Ground Penetrating Radar (GPR) evaluation also suggested the tie spacing in the embed zone was excessive in the embed zone.
- Limited exploratory openings suggested that the first line of headed studs associated with the embed plate for the column G202, which displayed the worst cracking was outside the column reinforcement cage.

Figure 4. Overall view of East face of column G 202- note cracks; GPR testing in progress
Figure 5. Close-up view of cracking on east face of column G 202.

STRUCTURAL REPAIR

Based on our evaluation of the cracking distress observed in the columns along gridline G is primarily attributable to field welding of the gusset plates and due to the fact that the as-built conditions were not in conformance to the design documents. Thermal stresses produced within the concrete as a result of heating during field welding followed by rapid cooling resulted in cracking of the un-reinforced concrete. Excessive cover to the reinforcing cage and the as-built tie spacing resulted in severe cracking of un-reinforced concrete under thermal and partial service loads. Structural repair of the columns using carbon fiber reinforced composite materials is recommended.

The structural repairs of the columns should consist of the following general steps:

- Repair the small cracks upto 1/32 inch with epoxy injection.
- Pressure inject epoxy in the gap between embed plate and concrete column.
- Repair the large cracks and spalls with conventional concrete repair material.
- Prepare columns to receive CFRP. Wrap columns using a single ply of carbon fiber composite material. Provide a layer of glass fiber reinforced polymer on the carbon steel embed plate material to prevent galvanic action. Coat the CFRP installation with UV protection coating.

RETROFIT CONSTRUCTION AND TESTING

The FRP repair was designed as a single ply installation to achieve a force of 25 kips. The top coating that was specified for UV protection (Figure 6). The topcoat was to be applied only after all the specified QA/QC testing was complete. The following quality control testing was conducted:

- A delamination survey was performed using visual and thermographic techniques.
- Pull off testing was conducted on CFRP installation.
- There were witness panels that were prepared by the contractor and tested in the laboratory. There were tests done for the carbon fiber by itself.
- Glass transition temperature testing was done for the epoxy
- Bond testing of the FRP system under elevated temperature

The delamination survey suggested that the FRP installation did comply with 440.2R-02. The pull off tests showed results that far exceeded the 200 psi criteria. The average effective fiber tensile stress tested 10-30% less than what the manufacturer had suggested on its data sheet, hence it required the application of an additional ply of carbon fiber. This caused additional burden on the repair contractor to address this with the application of an extra ply of CFRP. The glass transition temperature met the manufacturer’s data sheet. This testing suggested that samples that were post cured tended to have a higher Tg value. Fire resistance was the existing structure was considered to be unchanged as the applied FRP’s contribution should be ignored under a fire scenario. The durability of FRP repair methods was always under discussion during this
implementation, since there are not as many published references available as you have for more conventional repair techniques.

Figure 6. Overall view of FRP Installed for the columns on gridline G

CONCLUSIONS

The use of CFRP for contact critical applications is a viable and cost effective repair approach. The success of these projects stems from a team effort from the project consultant, the applicator, the product manufacturer and the testing consultant. It is vital that when using FRP detailed information flows to all project team members simultaneously. Advance planning and coordination of the repair implementation and testing is critical to a project's success. Pre-construction testing in some instances can help alleviate problems during construction. Having experienced applicators and testing laboratories can define the success of the project. The presence of the product manufacturer should be mandatory through the design and implementation of the project.

REFERENCES

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