NEW GENERATION OF CORROSION-FREE & LONG LASTING CFRP PRESTRESSED CONCRETE HIGHWAY BRIDGES

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SUMMARY

The use of CFRP materials as an alternative to steel reinforcement in precast prestressed concrete beams have been thoroughly evaluated through experimental and theoretical investigations. Results from these investigations have been deployed in the construction of multiple concrete bridges reinforced, prestressed, and post-tensioned with CFRP.

Keywords: Precast, Prestressed, CFRP, Highway bridges.

INTRODUCTION

In Michigan and other regions with harsh environmental conditions, the use of steel reinforcement in precast prestressed concrete elements poses an overwhelming corrosion and durability problem. Therefore, the use of carbon fiber reinforced polymer (CFRP) materials has been introduced as a non-corrosive alternative to steel. Numerous investigations have been conducted to evaluate the performance of CFRP materials as flexural and shear reinforcement. Half-scale Laboratory models for various beam configurations including box beams, AASHTO I beams, and decked bulb T beams have been constructed with CFRP reinforcement and tested to failure under flexural and shear loads. The results from the experimental investigations were evaluated theoretically and performance criteria have been established.

Motivated by the exceptional performance of CFRP and the results from experimental and theoretical investigations, Authorities in Michigan Department of Transportation (MDOT) have recently besought the deployment of CFRP in bridge construction. Over the last 13 years, four bridges have been constructed in Michigan with CFRP reinforcement; two bridges were fully reinforced and prestressed with CFRP reinforcement with no steel reinforcement, while the other two bridges were transversely post-tensioned with un-bonded transverse post-tensioning CFRP strands.

CFRP MATERIALS FOR PRESTRESSING AND POST-TENSIONING

CFRP materials are anisotropic materials with modulus of elasticity of nearly two thirds that of steel. They do not exhibit any yield plateau. Rather, they exhibit elastic performance to failure, which occurs at a stress level higher than the ultimate strength of steel strands. Therefore, the current investigation focuses on the performance of CFRP materials with respect to aspects such as: effective prestressing force, average prestress loss, ultimate load carrying capacity of beams with CFRP reinforcement, anchorage details, and shear load carrying capacity for members with CFRP stirrups.

Laboratory beams and bridge models with CFRP reinforcement

Three beam configurations with CFRP reinforcement have been evaluated experimentally: (1) side-by-side box beams, (2) AASHTO I-beams, and (3) decked bulb T beams. For each beam configuration, individual control beams as well as a complete bridge model have been constructed and tested to failure.

Control side-by-side box beams had a span of 9.44 m, width of 457 mm, and a total depth of 356 mm including a 76-mm thick cast-in-place deck slab. The bridge model was composed of seven side-by-side box beams connected together using a 76-mm.-thick deck slab, full-depth shear keys cast from non-shrink fast-setting grout, and five transverse post-tensioned diaphragms. Both the longitudinal and transverse reinforcement of the control beams and the bridge model were made of CFRP materials.

Control AASHTO I beam had a span of 12.5 m, a depth of 565 mm, and deck width of 500 mm. The bridge model was composed of five I beams with center to center spacing of 500 mm, which resulted in a total bridge deck width of 2.5 m. The beams were connected together with a 63-mm. deck slab and five transverse diaphragms.

Control decked bulb T beam (Grace et al 2013) had a span of 12.5 m, top flange width of 457 mm and a depth of 406 mm. The bridge model was composed of five decked bulb T beams connected together with shear key joints cast from ultra-high performance concrete and seven full-depth transverse diaphragms. The diaphragms were provided with ducts for possible transverse post-tensioning.

All control beams and bridge models were subjected to loading and unloading cycles and then loaded to failure under either flexural or shear loading setup. The age of the specimens on the test day ranged from 28 days to 18 months. Overall, the test results demonstrated that the performance of CFRP either as shear or flexural reinforcement is consistent and can be safely predicted using the appropriate theoretical approach.

Field deployment of CFRP in bridge construction

The first bridge in USA with CFRP reinforcement as the main reinforcement was Bridge Street Bridge, Southfield, MI. It was completed and opened for traffic in 2001. The bridge composed of three spans with average span length of 21 m. Each span consisted of four double T beams prestressed longitudinally with pre-tensioned CFRP strands and external un-bonded post-tensioning CFRP cables (Figure 1). The beams were connected transversely with a 76-mm thick reinforced deck slab and un-bonded CFRP transverse post-tensioning.

The second bridge with CFRP components was Pembroke Bridge over M-39 in Detroit, MI. This is a two-span side-by-side box beam bridge that was completed and opened for traffic in 2011. The beams in this bridge are transversely post-tensioned with un-bonded CFRP strands passing through six transverse diaphragms for each span. Formerly, this type of bridges used to be transversely post-tensioned with bonded steel strands, a technique that posed a restriction on maintenance and partial deck replacement (Grace et al 2012).

The third bridge with CFRP component was the M-50/US-127 Bridge over Norfolk Southern Rail Road (NSRR) in Jackson, MI. This bridge was opened for traffic in 2012. It is a three-span side-by-side box beam bridge that is also provided with un-bonded CFRP transverse post-tensioning strands to ensure the integrity of the bridge in the transverse direction.

The fourth bridge (Figure 1) with CFRP reinforcement was completed in 2013 and is carrying M-102 over Plum Creek in Southfield, MI. This 21-m-long simply supported bridge consists of 8 spread box beam supporting a 230-mm.-thick reinforced deck slab. Both the beams and the deck slab are completely reinforced with CFRP reinforcement. Each beam is prestressed with 37 CFRP strands with a diameter of 15.2 mm and is also provided with CFRP stirrups with a diameter of 15.2 mm.

Figure 1: Left: Bottom view of Bridge Street Bridge. Right: Construction of M-102 Bridge.

CONCLUSIONS

CFRP materials promote the construction of an infrastructure system with a long lifespan and minimum maintenance cost while satisfying the need for increased load carrying capacity and traffic safety.

REFERENCES

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