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Repairing/Strengthening of Bridges with Post-tensioned FRP Materials and Performance Evaluation

INTRODUCTION

One of the challenges that transportation agencies are facing is keeping bridges in good condition during their service life. Numerous bridges are classified as structurally and/or functionally deficient in the country. In the state of Louisiana, 4,591 bridges or 34 percent of the total 13,426 bridges are classified as substandard. Load capacity degradation, increased gross vehicle weight, and increasing traffic demand lead to the deficiencies.

One of the most effective ways to solve the problem is to use composite materials to strengthen existing bridges. As rapidly developed over the past several decades, different kinds of composite fiber reinforced polymers (FRP) have been regarded as one of the best solutions to several problems associated with transportation and civil engineering infrastructures. Some of the major benefits of FRP include its high strength to weight ratio, high fatigue endurance, excellent corrosion resistance, low thermal expansion, and the ease of fabrication, manufacturing, handling, and installation.

OBJECTIVE AND SCOPE

The main objective of this research was to develop a flexural resistance designing process using post-tensioning prestressed carbon reinforced polymers (CFRP) laminates adhering on bridge girders to avoid various possible flexural failure modes. It is noted that, in the original plan, a steel bridge and a concrete bridge was to be rehabilitated with prestressed FRP laminates or rods, and the bridge performance was to be monitored. However, the sponsor decided not to pursue the field implementation due to cost, and this report summarizes the up-to-date work by the research team.

This report presents a review of the up-to-date work on bridges strengthened with FRP materials. Mechanical properties of FRP fibers and composite were presented in detail. The investigators presented previous research findings on experiments of FRP composite materials used as various prestressed tendons, and the analyses for different failure modes were introduced. To investigate the effect of rehabilitation with prestressed CFRP laminates, two 3-D finite element analyses were conducted to examine the deflection and bottom fiber stress at the mid-span. A detailed designing process of rehabilitation with prestressed CFRP laminates was presented in this report. A feasible plan to enhance the flexural capability of an existing bridge with externally prestressed CFRP laminates according to AASHTO and ACI code specifications was also proposed in this report.

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Read online summary or final report:
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METHODOLOGY

To achieve the research objective, the research work included designing and/or checking the bridge repairing/strengthening scheme with FRP strands and finite element prediction. In the finite element analysis, 3-D finite element models were developed to simulate the performance of a selected bridge. The post-tensioned FRP strands were then designed with an HL-93 load.

CONCLUSIONS

A comprehensive review of the up-to-date work on bridges strengthened with prestressed FRP composite is presented in the accompanying final report. Different types of rehabilitation methods with various commercial products were introduced. The performance of rehabilitation of existing bridges with prestressed external FRP materials was evaluated by tentative design and a 3-D finite element analysis. A case study demonstrated the designing procedure of rehabilitation with bonded post-pretention prestressed CFRP laminates. In the case study, the performances of the selected bridge were evaluated before and after the rehabilitation. The following conclusions were made:

1. The safety factor of every span of an existing bridge can be non-uniform. In this case, the flexural capability of the 64-ft., 6-in. span steel I-beam is sufficient to meet the current traffic requirement, but not the 38-ft.,0-in. cast-in-place concrete tee beam approach span.
2. The stress of the steel I-beam span girders under the service load is beyond 55 percent of the steel yield strength f_y.
3. Rehabilitation with externally prestressed CFRP laminates is a feasible way to enhance the flexural capability. For the cast-in-place concrete tee beam approach span, the ultimate capability is improved by 39 percent; for the span steel I-beam, the stress under service load can be reduced from 75 percent to less than 55 percent of the steel yield strength f_y.
4. The longitudinal bottom fiber stresses calculated in the 3-D finite element analysis is smaller than that derived from a tentative design following code specifications.

RECOMMENDATIONS

From the previous analysis and results, the following recommendations can be made. Since the loss of the prestress in the CFRP materials is determined by the type of the products and method of construction, a special field test is needed to determine the stress variation during construction. Although durability has been cited as a strong selling point for FRP composite materials, polymer matrices do degrade when subjected to environmental attacks or long-term loading. These attacks include, but are not limited to, moisture, alkali, thermal, freeze/thaw, creep/stress relaxation, fatigue, ultraviolet radiation (UV), fire, and of course, the various combinations of the environment and loadings. However, not all the attacks or their combinations can be found for a specific application and not all of them or their combinations have the same detrimental effect. It is expected that a long-term field monitoring of the girders to determine the actual durability under field conditions over extended periods of time is essential for the optimal design of FRP composites for use in civil infrastructure.