TECHSUMMARY November 2016

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Strengthening of Bridge Beams using Fiber Reinforced Polymers (FRP)

INTRODUCTION

This project was undertaken to evaluate the feasibility of using carbon fiber reinforced polymers (CFRP) strengthening to increase the live load capacity of existing bridges in Louisiana. Currently, there are many load-rated bridges—which are often reinforced concrete tee beam bridges—that are deficient in flexure. It is the intent of this project to demonstrate the application of CFRP materials in actual field environment to strengthen concrete bridges. The concrete bridge selected for this study is located in Zachary, LA, and carries Highway 19 over White Bayou. An experienced contractor (Structural Preservation Systems) was employed to install three different CFRP strengthening systems. While the installation cost of the strengthening system is discussed, it is important to note that much of the installation cost is associated with mobilization. For this reason, the costs associated with a minor strengthening effort such as the one undertaken here will not be entirely representative of more significant strengthening applications. The field installation effort is useful from the standpoint of understanding what calculations can be used for the prediction of ultimate capacity, the limitations of those calculation procedures, and the challenges that are likely to be encountered in field installations.

To better understand the behavior of the bridge both before and after strengthening, Bridge Diagnostics, Inc. (BDI) was contracted to test and evaluate portions of the structure. This procedure was also important to understand the limitations of live load testing as it relates to CFRP strengthened bridges. In addition to the significant live load testing efforts, a long-term monitoring system was installed and the details of that system are described.

OBJECTIVE

The objectives of this study were as follows:

- Summarize selected literature that is related to the field implementation of FRP strengthening systems for reinforced concrete bridges.
- Based on the summarized literature and the experience of the investigators, select and describe three different strengthening systems that are appropriate for field implementation on a selected bridge.
- Describe the strengthening systems and related calculation procedures.
- Summarize the results of the live load tests.
- Describe the long-term monitoring system.

SCOPE

The scope of this report was limited to the following:

- Literature review of FRP strengthening field applications, analysis and design methods, and laboratory investigations.
- The selection and description of three different strengthening systems for a selected reinforced concrete bridge.
- Description of calculation procedures for flexural strengthening.
- Results of the live load tests prior to and immediately after strengthening.

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METHODOLOGY

A literature review was conducted, focused primarily on the field applications of FRP strengthening projects that have been conducted on actual bridges and the analysis and design considerations for those projects. Laboratory investigations were also included, particularly when the laboratory investigations were directly related to field applications. States included are

Alabama, Missouri, Oregon, Texas, and New York. The review gives an overall picture of the systems that are commercially available and the considerations involved in their application.

A candidate bridge for strengthening was selected by DOTD in cooperation with LTRC in January 2004. Photographs of the bridge site were transmitted to a supplier of FRP strengthening systems, along with preliminary strengthening designs. As a result of the literature review, the experience of the investigators, the site visit, and input from the FRP supplier regarding preliminary cost information, three strengthening systems were selected and recommended for field implementation.

Design calculations were subsequently performed with the intent of increasing the flexural capacity of the strengthened bridge spans. A contractor, Structural Preservation Systems, was contacted to perform the strengthening of two spans and this work was completed in spring of 2007. Bridge Diagnostics, Inc. (BDI) was contacted to perform the load testing and installation of the long term monitoring system. A live load test was conducted on the portion of the bridge to be strengthened both prior to and immediately after strengthening. Conclusions regarding the performance of the strengthening systems were drawn based on the results of the installation procedure and live load testing.

CONCLUSIONS

The wet layup technique is preferred due to the ease of installation, past positive experience, and perceived reliability. The pultruded strip method was viewed in a similar light. Both methods required surface preparation prior to installation. The near surface mounted strip method, by contract, had been little used and was most difficult to install, though this method did not require as much surface preparation. The authors believe that the wet layup method has a high degree of reliability and the pultruded strip method perhaps less. This is partially due to the smaller contact area with the pultruded strip method, but is also due to the method of application itself, which involves impregnating in place in the case of the wet layup method, as opposed to pressing or rolling the cured strip in place in the case of the pultruded strip method. The near surface mounted method is believed to be the most reliable due to the relatively high amount of contact area between the strips and the surrounding concrete.

All strain measurements indicated that the structure was behaving linearly with respect to load magnitude (truck position) and all responses were elastic. The damaged beam bearings have not significantly altered the structural performance but a significant reduction in bearing area has occurred. Load test procedures and load magnitudes were nearly identical between the two load tests performed before and after CFRP strengthening. The measurements indicated a reduction of midspan strains and midspan displacement of approximately 10 percent on the interior girders for the second load test (after strengthening). The CFRP strengthening had a significant effect on the load rating factors resulting from moment capacity. The CFRP strengthening methods used were not intended to increase shear capacity; however, it is possible that shear capacity was marginally increased in some cases due an increased value of "effective depth" caused by the CFRP strengthening.

RECOMMENDATIONS

It is recommended that finalized designs based on the three systems be developed and a particular manufacturer selected. A short list of qualified suppliers and installers should be developed with input from the project investigators. Once the short-list is developed, DOTD and LTRC should select a single supplier and installer (sole source). Since all three reinforcing methods provided adequate flexural strengthening, a decision on the particular method to be used needs to be based on cost and the results of reasonable long-term performance monitoring—18 to 24 months—of the systems. The near surface mounted method is believed to be the most reliable due to the relatively high amount of contact area between the strips and the surrounding concrete. The near surface mounted system is also less intrusive visually and very little of the CFRP material is exposed to vandalism.

For strengthening applications, proper installation of the systems is critical to both the short and long-term performance. Furthermore, it will be to the benefit of the state to assess the quality of FRP systems that are installed by qualified personnel. With regard to field monitoring and load testing, systems that are durable and that have sufficient sensitivity to assess the different strengthening systems should be selected and implemented.

Because of the relatively small amount of strengthening that was provided and the research based nature of the work, the costs reported are not likely to be reflective of what would be encountered in practice for more significant strengthening projects. The cost of strengthening projects is highly dependent on access to the structure and ease with which a work crew can be mobilized.

If strengthening with CFRP materials is to be conducted on a more widespread basis in the future, the durability of the strengthening systems will be of utmost importance.