JOINT TRANSPORTATION RESEARCH PROGRAM

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Repair and Strengthening of Bridges in Indiana Using Fiber Reinforced Polymer Systems: Volume 1–Review of Current FRP Repair Systems and Application Methodologies

Introduction

Concrete bridge components experience damage and deterioration due to a variety of sources that range from environmental conditions to vehicle impacts. Such damage and deterioration can lead to reduced structural capacities, necessitating that action be taken to either repair or replace concrete bridge components. Innovative repair and strengthening techniques can provide a cost-effective means to lengthen the service life of bridges, providing cost savings compared to more traditional methods of repair or replacement. Fiber reinforced polymer (FRP) systems are a rapidly emerging solution for such applications. The need to investigate the use of FRP for the repair and strengthening of bridges in Indiana was identified, including the need to study specific applications to structural components that often experience deterioration in the field.

A research project was conducted to develop guidance for the application of FRP systems for the repair and strengthening of bridges in Indiana. To accomplish this objective, a study was first conducted to (1) summarize the current state-of-the-art for the application of FRP to concrete bridge components, (2) identify successful examples of FRP implementation for concrete bridges in the literature and examine past applications of FRP in Indiana through case studies, and (3) better understand FRP usage and installation procedures in the Midwest and Indiana through industry surveys. The details of this study are presented in volume 1. Two experimental programs were then performed to determine the most effective uses of FRP in Indiana for (1) flexural strengthening and (2) girder end region repair. The details of the experimental programs are presented in volume 2.

Findings

Volume 1
The primary findings of the literature review, case studies, and industry surveys include the following.

- Common FRP strengthening systems include near-surface-mounted (NSM) strips or bars and externally bonded sheets. Prestressed NSM or prestressed externally bonded systems can be implemented to achieve improved serviceability of beams.
- When using externally bonded FRP or near-surface-mounted FRP, proper anchorage or embedment should be provided. A common type of anchorage for externally bonded sheets is the FRP fan anchor, or spike anchor. Its major benefits include compatibility with the FRP strengthening system, ability to anchor flexural or shear strengthening systems, corrosion resistance, and ease of constructability.
- Issues encountered with previously conducted FRP repairs and retrofits in Indiana include inconsistent layering of FRP sheets, premature termination of FRP sheets near support locations or points of intersection of bridge elements, improper epoxy quantities, uneven distribution of epoxy, and inconsistent surface preparation.
- The dominant applications of FRP systems in Midwestern states have included beam shear strengthening and column confinement.

Volume 2
The primary findings of the flexural strengthening and end region repair experimental programs include the following.

Flexural Strengthening Experimental Program

- Both externally bonded FRP and NSM FRP are effective techniques for the strengthening of flexural members if properly designed and installed. Appropriate anchorage of the externally bonded FRP must be ensured.
- All FRP-strengthened specimens experienced reduced ductility compared to the specimens without FRP. Furthermore, while the FRP-strengthened specimens achieved post-cracking stiffnesses similar to that of the control specimens without FRP, all FRP-strengthened specimens exhibited significantly higher post-yielding stiffnesses relative to the control specimens.
- Considering the anchorage of externally bonded sheets, specimens with FRP spike anchors only at the ends of the primary FRP sheet consistently gained more capacity than specimens with spike anchors at multiple locations along the length of the primary sheet. The separation and redirection of fibers in the FRP sheet required for the installation of the spike anchors likely contributed to premature rupture at the anchor locations.
- The eccentricity of longitudinal steel reinforcement and the relative placement of NSM strips did not play a significant role in the effectiveness of the strengthening systems or the overall performance of the members.

End Region Repair Experimental Program

- The deterioration of the end regions of prestressed concrete girders due to leaking expansion joints can result in significant reductions in strength.
- Restoring the tensile capacity lost due to deteriorated and ineffective prestressing strands in the bottom flange of prestressed concrete girders and ensuring adequate confinement of the repair region are critical factors when designing end region repair systems.
- An externally bonded FRP laminate system proved to be a viable technique for restoring the strength and stiffness of a bridge girder with end region deterioration.
- The use of NSM FRP strips for the repair of the deteriorated end region of a prestressed concrete girder did not provide adequate confinement of the repair region, and therefore, the strength and stiffness of the girder was not restored. If combined with externally bonded FRP laminate, the use of NSM strips may be a viable repair solution.
- Providing a supplemental diaphragm to repair a deteriorated end region of a girder and transfer load to new bearings did not restore the strength of the member. The use of a continuous diaphragm between adjacent girders may provide a more favorable result.

Implementation

Based on the findings of the research, updates to the *Indiana Design Manual* to allow the use of FRP for strengthening purposes is recommended. The experimental programs demonstrated that, if properly designed and detailed, FRP systems can be successfully used for flexural strengthening and for the repair and strengthening of deteriorated girder end regions. Past research has demonstrated other successful applications and provide guidance for proper anchorage. Current guidelines available for the design and implementation of FRP systems should be referenced within the *Indiana Design Manual*. Furthermore, special long-term considerations for the inspection of FRP systems are recommended.

Through performing the repairs on the deteriorated end regions during the research program and based on the test results, recommendations for end region repair were developed and delivered to INDOT. Design-related guidance based on the results of both experimental programs is also included in the final report.

To assist with the implementation of the research findings, an FRP guidebook has been developed and provided to INDOT. The document contains general FRP design guidance, key considerations when designing bridge repair systems, suggested language for the *Indiana Design Manual*, and recommendations for FRP installation procedures.

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