Concrete Box Beam Risk Assessment and Mitigation: Volume 2—Evaluation and Structural Behavior

Introduction

Adjacent prestressed box beam bridges account for approximately 25% of Indiana’s bridge population. In fact, over 4,000 of Indiana’s bridges are box beams. Unfortunately, adjacent box beams have a history of poor long-term performance including premature deterioration and failures. Leaking joints between box beams allow chloride-laden water to migrate through the superstructure and initiate corrosion. The nature of this deterioration leads to uncertainty of the extent and effect of deterioration on structural behavior.

The objective of this research is to develop recommendations for the inspection, load-rating, and design of adjacent box beam bridges. This research focuses on the following: correlating visual damage to internal deterioration, understanding the capacity of deteriorated beams, understanding the live load distribution of adjacent boxes, developing procedures to estimate the remaining capacity of deteriorated beams, and providing recommendations for the design of the next generation of adjacent box beam bridges.

A review of the Indiana Department of Transportation (INDOT) standards and bridge design manuals was conducted to track the historical development of box beams in Indiana. The INDOT database of box beam bridges was also analyzed for trends in deterioration. To supplement the database analysis, a series of bridge inspections were conducted to further identify the common types and potential causes of deterioration. These inspections identified a series of deteriorated box beams with common deterioration that were subsequently acquired for experimental testing. Experiments were conducted to determine the extent of deterioration and effect of deterioration on structural capacity. In addition, load tests were conducted on an in-service bridge to investigate live-load distribution. The research is presented in two volumes. Volume 1 presents the evolution and performance of box beam bridges in Indiana while Volume 2 presents the evaluation and structural behavior of deteriorated box beams.

Findings—Volume 2

Based on completion of the experimental program and field testing, the following findings were developed:

Extent of Deterioration

- The ingress of salt-water to the bottom flange of box beams from leaking joints or drainage over the side of the bridge results in corrosion of the strands at the edge of the box section. Where longitudinal cracks or spalls exist, strands at the longitudinal cracks or concrete spalls were corroded. Where staining was present in addition to transverse cracks, the strands at the cracks were also corroded.
- Longitudinal cracks located away from the edge of the bottom flange of box beams were caused by water freezing in the void. Cracks were observed in many cases away from reinforcement. Furthermore, corrosion was not observed on the longitudinal strand except at localized locations where the longitudinal crack traversed the strand. These findings indicate that corrosion was not the cause of longitudinal cracking. Evidence of corrosion in strands adjacent to the strands at longitudinal cracks was not found.
- Visual inspection of bottom flange deterioration proved to provide the most reliable method for determining the extent of deterioration. The NDT methods, GPR and CEPRA, may be used to augment visual inspection. For example, GPR may be used to locate reinforcement such that the number of strands intersecting or aligning with a crack may be determined. Also, CEPRA and GPR may be used to identify corrosion at the edge of a bottom flange where delamination may be suspected.
- GPR is extremely useful to identify the number of strands actually provided in the section, especially when construction drawings are not available.

Capacity of Deteriorated Box Beams

- Delaminated concrete exhibits brittle behavior. Structural capacity calculations considering delaminated concrete in compression should limit the compressive strain to \( 0.5/E_\text{e} \).
- Only strand corrosion located within the development length from the point of maximum moment needs to be considered as reducing the flexural capacity. Strands with corrosion and fractured strand outside of the maximum moment region can redevelop capacity and maintain prestress force.
- Reduced ductility of corroded strand led to reduced overall ductility of the beam specimens. Therefore, the strain in corroded strains should be limited to 0.01 for structural capacity calculations. If minor pitting is observed, the strain should be further limited to \( 0.75f_p/E_\text{ps} \) consistent with 75% of the strand strength. If severe corrosion or fractured wires are observed, the strand should not be considered.

Live-Load Distribution

- Shear keys showing evidence of leaking may have no impact on live-load distribution.
- The results of the load tests indicate that a 5-in. thick concrete...
deck reinforced with a single mat of #4 bars spaced at 8 in. in both the longitudinal and transverse direction can restore load distribution after the primary load distribution mechanism (shear keys) were disabled.

- A concrete deck placed on concrete beams can achieve full composite action through adhesion of the deck concrete to the concrete beams. The surface should be properly cleaned and roughened prior to placement of the concrete deck.
- The 2017 AASHTO LRFD equations for live-load distribution factors for moment are suitable for estimating the live-load distribution factors for a reinforced concrete deck on adjacent concrete beams without shear keys.

Implementation

Based on the findings of the research, the following recommendations are provided for the improved inspection, load rating, rehabilitation, and design of box beams bridges.

Inspection

A visual inspection of the deteriorated box beam bridge that documents the location and extent of all cracks and concrete spalls should be conducted. Where cracks and concrete spalls exist, the strand at these locations should be considered corroded, while strand outside of these locations may be assumed to have negligible deterioration. In addition, where heavy concrete staining from joint leakage or delaminated concrete is suspected, CEPRA and GPR can be used to identify corrosion of the edge strand.

Load Rating

Based on the laboratory testing of decommissioned box beams, an analysis procedure was developed to estimate the capacity of box beams with visual signs of deterioration. The analysis procedure considers both initial failure capacity and residual capacity. The controlling capacity is determined by comparing the minimum values of the initial deteriorated capacity to the minimum reserve capacity. The overall deteriorated capacity is then equal to the maximum value between the controlling initial capacity and reserve capacity.

Restoring Live-Load Distribution

The restoration of load distribution may be achieved by casting a reinforced concrete deck over the existing box beams. Based on load tests of an in-service adjacent box beam bridge, the live-load distribution of a bridge rehabilitated with the addition of a reinforced concrete deck may be estimated using AASHTO LRFD (2017) equations for load distribution. In addition, with proper surface preparation, the concrete deck may be assumed to act compositely with the existing box beams.

New Design

The following recommendations are provided for the improved performance of adjacent box beam bridges.

General Recommendations

- A drip bead is recommended to be added to the current INDOT standard box beam sections. A drip bead should be located on each edge of the bottom flange between the side of the box section and the edge strand.
- Flexible sealant is recommended to be placed at the top of the longitudinal joint between beams to prevent leakage.
- Concrete decks are recommended with a minimum thickness of 5 in. and a single mat of corrosion resistant #4 bars at 8-in. spacing in the longitudinal and transverse directions. Where curbs or concrete barriers are not used at the exterior edges of the bridge deck, a drip edge should be provided to prevent water from draining down the sides of the box beams.
- The use of concrete curbs or barriers is recommended to prevent water from flowing down the sides of exterior box beams. If deck drains through the deck and beam cannot be avoided, a non-metallic drain pipe should be specified to extend past the face of the bottom flange to prevent water from curling onto the bottom flange.
- Bituminous wearing surfaces should not be used.

New Box Beam Section

- To facilitate the inspection of the sides of box beams, a winged beam section is recommended. The proposed section includes drip beads on either side of the longitudinal joint to prevent water from draining down the side of the beam.
- The proposed section considers the use of a composite concrete deck. Composite action between the deck and beams can be developed by intentionally roughening the top surface of the beam. This system allows for ease of deck replacement to provide future bridge rehabilitations.

Recommended Citation for Report

Frosch, R. J., Williams, C. S., Molley, R. T., & Whelchel, R. T. (2020). Concrete box beam risk assessment and mitigation: Volume 2—Evaluation and structural behavior (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2020/07). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317118

View the full text of this technical report here: https://doi.org/10.5703/1288284317118

Published reports of the Joint Transportation Research Program are available at http://docs.lib.purdue.edu/jtrp/.