Concrete Box Beam Risk Assessment and Mitigation: Volume 1—Evolution and Performance

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 about 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 1

Based on the standards review and database analysis, the following findings were developed:

History

• The first set of standards for adjacent box beams was published in 1961, providing the basis of design in Indiana.
• The second set was published in 1965, which made multiple changes to the first set. A modification of shear-key locations, a decrease in void geometry, and the inclusion of ½ in. diameter high-strength prestressing strands were detailed. Indiana used this standard until the 1980s.
• After the 1980s, most of the state adjacent box beam bridges were designed on a case-by-case basis. The designs were then approved by a “qualified state bridge engineer” before construction. The counties, however, continued to use the 1965 standards well into the 1990s.
Inventory

- There are 4,054 adjacent, prestressed, box beam bridges in Indiana. Of those bridges, 140 are on the state system and 3,914 are on the county system.
- There is a correlation between bridge age and the superstructure rating of adjacent box beam bridges. As expected, superstructure condition decreases with age.
- Location plays a role in the deterioration of adjacent box beam bridges in Indiana. It was shown that northern bridges, on average, have lower condition ratings compared to southern bridges.
- Of the 4,054 adjacent box beam bridges in Indiana, 2,640 of those bridges have a bituminous wearing surface. This accounts for more than 65% of the bridges. Analyzing superstructure ratings based on wearing surfaces, it was found that bridges with bituminous surfaces deteriorate more than bridges with concrete wearing surfaces.
- The presence of a membrane appears to decrease deterioration of adjacent box beam bridges in Indiana. The average superstructure rating with a preformed fabric membrane is 6.6 compared to 6.3 without a membrane.
- The average span length for adjacent box beam bridges in Indiana is 40 ft, and approximately 90% (3,655) of the bridges have a maximum span length between 20 ft and 60 ft. Box beam bridges in Indiana are typically constructed with widths ranging from 21 ft to 40 ft. A majority of the bridges, 5%, do not have any skew (0°). No correlations were found between the superstructure rating and span length, bridge width, or skew. While no correlation was found, these geometric properties provide valuable insight regarding the primary market for this bridge type.

Field Observations

- Wearing surfaces, regardless of material, allow water and deicing salts to penetrate the top surface of the superstructure. It should be noted that membranes, if functioning properly, can prevent this penetration.
- Tapered wearing surfaces direct water to the edges of the structure. Curbs collect this water which is then directed by drain management systems to the edge of the bridge. Bridges that lack curbs, or have curbs with outlets, allow water to run onto the side of the exterior girder. Because exterior girders are typically not detailed with drip beads, water then curls onto the bottom side of the box resulting in staining, chloride penetration, and eventually corrosion of reinforcement and spalling of concrete.
- Leaking longitudinal joints is a common deficiency of this bridge type. Cracked shear keys and reflective cracking in the wearing surface allow water to seep through the joint. Leakage is most common at joints between the first interior girder and exterior girder. This localization is likely due to eccentricity of the exterior girder which causes tensile stresses in the joint. The location of the wheel path may also create stress on the exterior joints resulting in cracking and leakage. Seepage of salt water through longitudinal joints leads to chloride penetration adjacent to the joint resulting in corrosion of reinforcement (prestressing strands and stirrups). As corrosion progresses, cracks form along the reinforcement, eventually causing spalling.
- Water and deicing salts also are penetrating past the walls of the box beam into the void. A lack of drain holes, or plugged drain holes, leads to water accumulation within the void. Standing water in the void can cause corrosion of the reinforcement, especially in the bottom flange. Regardless of drain holes, water and chlorides inside the void can lead to corrosion and deterioration of the box beam.

Implementation

Please see Volume 2 for recommendations regarding implementation.

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