

# Research Record

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## Box-Beam Concerns Found under the Bridge

### Expanding Inspector Handbook Promises Timely Bridge Care

Since the 1950's, prestressed concrete beams have become a factor in almost one third of all new bridge construction in the United States. In Michigan, prestressed concrete was introduced in 1954 and the first prestressed concrete side-by-side box-beam bridge was built in 1955.

Pontis data indicates 2,054 side-by-side prestressed concrete box-beam bridges in Michigan; 236 are part of the National Highway System (NHS) and under the responsibility of MDOT. The remaining 1,818 bridges are under local agency control.

A side-by-side box-beam bridge under MDOT jurisdiction is constructed by placing precast prestressed box-beams adjacent to each other, grouting full depth shear-keys, applying transverse post-tensioning, and casting a six-inch thick reinforced concrete deck (see Figure 1).

The side-by-side prestressed concrete box-beam bridge design is generally used for short (30-60 feet) or medium (60-110 feet) bridge spans. This bridge type is popular with local agencies for single span and multi span bridges because the low depth-to-span ratio maximizes clearance under the bridge. In fact, this is the bridge of choice in Michigan for spans less than 110 feet.

Side-by-side box-beam bridges are popular because of four key advantages: (1) simple designs;

(2) low life cycle costs; (3) quick and easy construction; and (4) industry accepted and promoted. In summary, prestressed concrete side-by-side box beam bridges are strong, tough, durable, attractive in appearance and have a low depth-to-span ratio.

It is not enough just to understand the role that prestressed concrete performs in box-beam bridge construction. Understanding how both engineering and environmental forces affect these structures resulting in structural breakdown is equally important. The thorough familiarity of these processes can provide insight into improving the inspection techniques as well as the overall design and construction methods. This is critical in Michigan where the prestressed concrete bridges are showing signs of premature aging. As stated above, the advantages of the box-beam design are significant, but unexpected deterioration may force highway agencies to reconsider the application of this particular bridge type.

Timely assessment is critical in order to maintain the performance that was established immediately after construction. The *FHWA Bridge Inspectors Training Manual 90* is the existing standard for inspecting all bridge types and generally covers the bridge mechanics, materials, and inspection practices. Unfortunately for box-beam bridges, the nine categories of concrete deterioration in this manual do not provide enough detail to establish descriptions of inspection results that are uniform and not subject to inspector interpretation.

### Help is on the Way

A joint team of researchers from Michigan Technological University (MTU) and Wayne State University (WSU) investigated the current condition of the prestressed box-beam bridges in Michigan. The goal of the research was to refine existing inspection techniques to make them more proactive. Preventing deterioration and protecting the bridge structure before deterioration reaches level of replacement is important.

The researchers defined six objectives for the study. (1) Identify common types and states of deterioration in side-by-side prestressed concrete box-beam bridges in Michigan. (2) Develop inspection techniques that result in early

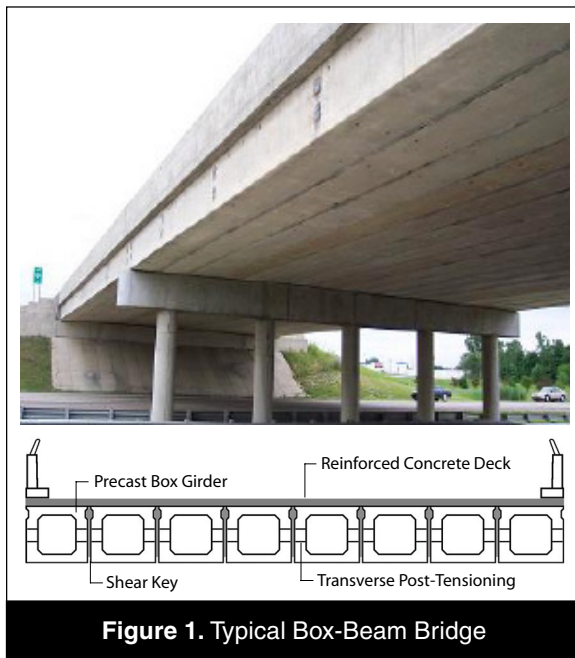


Figure 1. Typical Box-Beam Bridge

identification of cracking and strand corrosion at the ends of the prestressed box-beams. (3) Develop guidelines to assist inspectors in determining when section loss may reduce structural capacity. (4) Provide guidelines for load capacity assessment of bridges with distressed beams based on finite element modeling. (5) Identify effective maintenance and/or repair techniques for the deteriorated regions, especially for bridges in good or fair condition. (6) Develop recommendations for changes or modifications to the current bridge design based on analytical modeling.

An additional result of the research was the development of the *Prestressed Box-Beam Inspection Handbook*; a resource that will assist bridge engineers in uniformly evaluating and reporting the condition of their box-beam bridges.

### What Do We Know About Box-Beams?

Box-beams are referred to as thin-walled structures because of their cross-sectional dimensions. They are preferred because of the ease of construction, favorable span-to-depth ratios, aesthetic appeal, and high torsional stiffness.

When the box-beams are placed adjacent to each other, there is no continuity enabling the beams to function as a single structure. Creating an interconnection between the beams with transverse post-tensioning and shear keys modifies the structure to behave as a single plate instead of several individual beams. Under applied loads, the beams deflect simultaneously due to transfer of vertical shear force through the shear keys. The required depth of the shear keys between the beams should not be less than 7 inches according to AASHTO LFD specifications.

The addition of the concrete deck is intended to integrate the box-beams with the transverse post-tensioning and the shear keys, such that the superstructure acts as a single unit to distribute loads over the deck. The composite concrete cover helps protect the box-beam below. The Michigan Bridge Design Manual (2003) requires a 6-inch thick reinforced concrete cast-in-place slab.

The failure of the shear keys is a well-understood problem with side-by-side box beam bridges. The location of the shear keys and the usage of non-shrink grout material has significant potential for increased cracking due to thermal stress. Temperature stress creates the initial crack; loading causes the crack to propagate. Water penetration in these cracks increases the rate of deterioration of the grout material and the eventual failure of the shear key. This creates the issue of individual beams carrying greater loads than originally designed. Overstressed beams show excessive relative displacements, which results in failure of the waterproofing system or the cast-in-place concrete deck.

Common forms of concrete distress include cracking, spalling, delaminations, and minor surface damage. In Michigan, the most common environmental conditions

that challenge concrete durability and cause concrete distress are thermal cycles, freeze-thaw cycles, exposure to acidic gases ( $\text{CO}_2$ ), and exposure to deicing solutions.

In a deicing environment, pre- and post-tensioned structures, such as box-beams, show susceptibility to corrosion at localized points on the structure. This localized damage was found at the end of expansion joints separating the deck slab from the approach slab, at joints separating the spans along the length of the bridge, through longitudinal spaces between adjacent box-beams, and at anchorage zones in post-tensioned members. The forces of traffic and environment promote joint failure due to the loss in water tightness. Deicer solutions pass through the joints to the pier caps and onto the sides of the box-beams, thereby increasing the rate of reinforcement corrosion and eventually requiring bridge replacement.

The presence of cracks in prestressed concrete is more critical than for conventional reinforced concrete. In prestressed concrete, cracks allow moisture and chloride to reach the prestress strands, which can lead to reinforcement corrosion. The cracks could indicate that loads are greater than anticipated on the structure, the beam is not properly reinforced, the prestressing strands were released prior to the concrete reaching minimum strength, or a loss of prestress has occurred. Other reasons cracks are found along the beams are shrinkage/improper curing of the concrete or material degradation.

Recommendations from existing research to diminish the rate of deterioration and for future inspection of distressed box-beams are: (1) Cracks in concrete beams should be sealed to prevent corrosion of the strand and reinforcing steel. The sealant used in wide cracks should be flexible, while narrow cracks should be filled with a low viscosity, crack penetrating sealant; and (2) Provide for a maintenance program that keeps the cracks sealed. As part of the ongoing inspection process, the damaged areas of a beam should be carefully monitored, measured and recorded to determine the rate of deterioration over time.

### Standardizing the Inspection

As previously stated, the *FHWA Bridge Inspectors Training Manual 90* is the current guide for inspecting bridges. The guide covers bridge mechanics, materials, and accepted inspection practices. The manual has an eleven-step inspection procedure for prestressed concrete box-beam bridge structures. Most inspectors evaluate the bridge elements as a whole structure instead of permitting individual locations of distress to determine the inspection status. In addition, damage severity classification for the various distresses is not uniform in the manual.

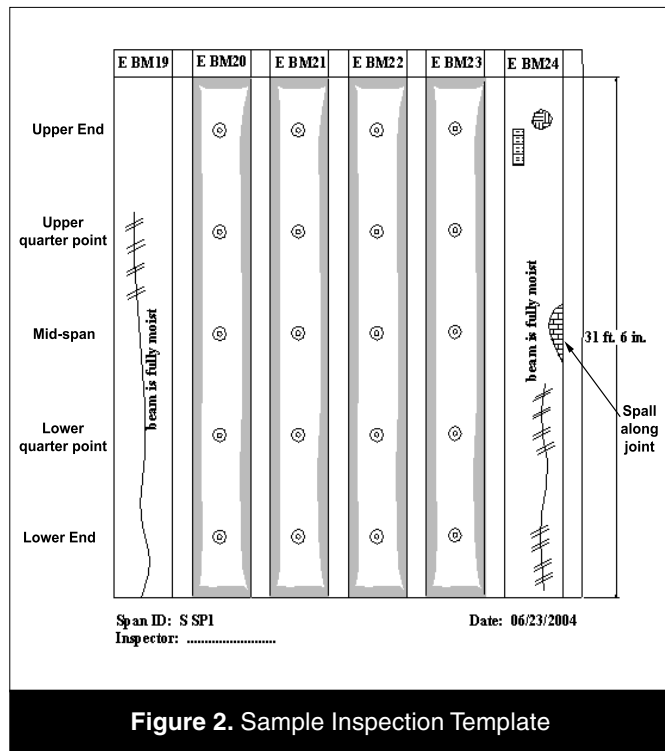
*Manual 90* outlines the tools for the cleaning, inspection, visual aid and measuring, and the documentation used during routine inspections. Listed are chipping hammers, mirrors, and optical crack gauges. Currently, in-

spectors augment the inspection tools with a magnifying glass, flashlight, and camera. In addition to physical tools used by an inspector, good eyesight and a critical mind are essential personal qualities. The most useful tool in performing assessments of beam deterioration is a thorough understanding of prestressed concrete beams and how the concrete distresses form.

### Choosing Wisely

The researchers selected 15 side-by-side prestressed concrete box-beam bridges based on manageable accessibility, number of spans, and construction date, with skew angles less than or equal to 30 degrees. Field inspection records indicated the condition of the box-beams, joints or shear keys, bearing, and deck.

A key focus during inspection was beam condition. Data collection was on the type, severity, and location of distresses on the beam. The researchers used MDOT bridge plans to develop inspection templates to document the condition of the box-beam components. A separate inspection template was created for recording the condition of the deck (see Figure 2). Where appropriate, photographs were taken to record the distress types and severity level of the deterioration.



All forms of concrete distress (cracks, corrosion, spall, etc.) need to be included in the inspection by drawing the length, location, and orientation on the inspection template. The presence of rust stains or efflorescence, or the evidence of differential movement on either side of the crack should be indicated. When reporting cracks, the length, width, location, and orientation (horizontal, vertical, or diagonal) should be noted.

### Findings

The quantitative inspection data for the major distress types was categorized according to beam moisture, shear key moisture, beam cracking, spall, and deck condition.

**Beam Moisture:** Prolonged moisture exposure allows water penetration into the concealed sides of the beams. The moisture appeared to result from surface water leaking through deck cracks onto the shear keys. Effluorescence and/or calcium carbonate (CaCO<sub>3</sub>) deposits were observed along the beam edges, indicating long term moisture exposure. Of the 15 bridges inspected, 14 revealed sustained moisture exposure.

**Beam Cracking:** Continual exposure to moisture causes tendon corrosion leading to concrete cracking. Water collecting and freezing in the hollow cells is a potential source of longitudinal cracking observed on the beams in bridges built prior to 1985. No longitudinal cracking was observed in bridges built after 1985.

**Spall:** The prolonged exposure of moisture led to tendon and rebar corrosion causing the concrete cracking, delamination, and spalling. Corrosion stains were seen along the cracks on bridges constructed before 1985. No concrete spalling was observed among inspected bridges built after 1985.

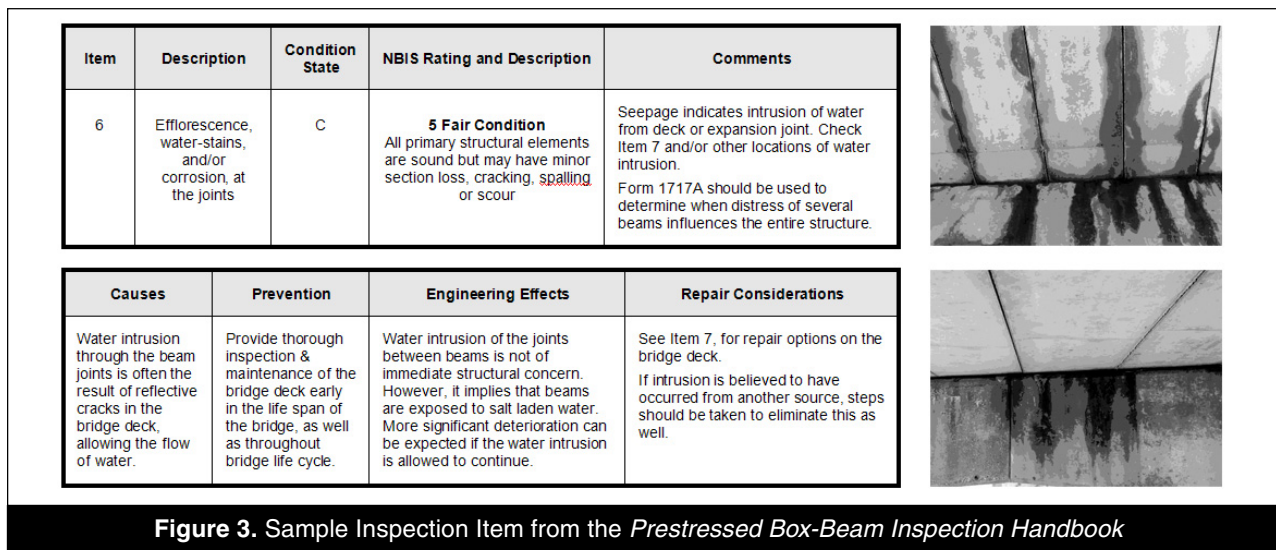
**Shear Key Condition:** Bridges built before 1985 had partially grouted shear keys that are not visible from the bottom flanges, therefore only bridges after 1985 could be inspected. The customary types of distress are signs of moisture (moisture stains, efflorescence or deposits) and grout that was cracked or spalled. The majority of the bridges had shear keys that showed repeated and extended moisture exposure resulting in cracked or spalled grout.

**Bridge Deck:** All bridges built before 1960 exhibited longitudinal deck cracking and distressed joints over the abutments and piers. Evidence of crack sealants being applied to longitudinal cracks were observed, though significant lengths of deck cracks were found not to be watertight. Extensive distress was recorded for expansion joints located over the abutments and piers.

Bridge decks constructed after 1985 were found to display longitudinal cracking and the deck joints showed forms of distress and breakdown. A recent technique to eliminate the problem with expansion joints is to replace the joint with a continuous deck slab. Over the piers, transverse cracking was still reported with increased crack propagation observed at the slab interfaces.

### Transferring the Knowledge

Analysis of the field data led to the categorization by distress type and ranking of the severity levels from least to most serious within each category. Distress types for box-beam bridges are defined across nine categories in the *FHWA Bridge Inspectors Training Manual 90*. It is the opinion of the research team that FHWA Ratings of



**Figure 3.** Sample Inspection Item from the *Prestressed Box-Beam Inspection Handbook*

4 (poor) & 5 (fair) were too broad and covered too many degrees of distress types. The researchers expanded the FHWA nine categories to thirteen categories to completely identify and rank the types of degradations by level of structural significance. This is the basis of the *Prestressed Box-Beam Inspection Handbook*. The guide serves as a supplement to existing bridge inspection manuals. A series of detailed flowcharts further aid in the evaluation of the results with suggested repairs for the damaged structural components (see Figure 3). Further assessment is recommended if deterioration has compromised the structural integrity of the bridge and adjustment to the bridge load rating is required.

**Conclusion**

The accurate identification of deterioration and timely maintenance are essential to preserve Michigan’s bridges. The creation of the *Prestressed Box-Beam Inspection Handbook* provides an expanded resource necessary to locate, identify, and document existing box-beam bridge deterioration through a series of repair option flowcharts.

Future recommendations by the researchers are: (1) inspect the concrete cover of the prestressing tendon near the top of the bottom flange; and (2) develop finite element models to represent the entire bridge system as a way to analyze shear key cracking, movement between adjacent beams, and structural capacity. Additional work is required to validate the maintenance and repair techniques described in the handbook.

**Contact Information**

For more information regarding side-by-side prestressed concrete box-beam bridges in Michigan and this study, please contact Steve Kahl, Experimental Studies Supervising Engineer, at (517) 322-5707 or by e-mail at kahls@michigan.gov.

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