FAILURE MODES AND INSPECTION METHODS FOR NON-COMPOSITE ADJACENT PRESTRESSED CONCRETE BOX BEAM BRIDGES

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ABSTRACT

During the highway construction boom of the 1950's and 1960's adjacent non-composite prestressed concrete box beam bridges were often used. Due to the advent of prestressing and precasting techniques these systems could be prefabricated and erected much more quickly than cast-in-place concrete bridges commonly used at the time, making them an ideal choice for moderate spans. These systems remained popular over the years. Today over 20,000 bridges of this type are still in service in the U.S. Unfortunately a few failures of these systems, characterized by collapse of a beam, have occurred since the late 1970's. The paper presents the background and causes of the failures that occurred in Indiana, Ohio, Illinois, and the 2005 failure of the Lakeview Drive Bridge in Pennsylvania. Destructive evaluation of the Lakeview Drive Bridge beams and a number of other decommissioned beams from Pennsylvania Bridges was conducted at Lehigh University. The commonality of these failures was shown to be directly related to corrosion deterioration of the prestressing strands caused by chloride intrusion from de-icing salts. Recommendations for improved inspection techniques, rehabilitation measures for these bridge types, and lessons that can be applied to new construction are provided.

Keywords: Bridge Inspection, Prestressed Concrete, Box Girder, Corrosion

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INTRODUCTION

Adjacent non-composite prestressed (PS) concrete box beam bridges were a popular form of construction from the late 1950s to through the present day. In the northeast U.S., this form of construction typically consists of precast prestressed box beams laterally post-tensioned together to form the superstructure of the bridge. A grouted shear key is used to seal the joint between beams and to provide resistance against relative vertical forces between beams. While details vary from state to state, in many cases due to the skew of the bridge the post-tensioning is conducted only between adjacent members. The system relies on the integrity of the shear key and the lateral post-tensioning to allow distribution of traffic loads to adjacent beams. The system is often topped with asphalt to provide a uniform wearing surface. In the early stage of this construction method the asphalt was placed directly on the beams. Today a waterproof barrier is installed prior to placement of the wearing surface.

An illustration of a typical system is presented in Figure 1. The figure presents a four span skewed bridge system. Eight beams are used per span each laterally post tensioned to the adjacent beam during erection. The beams supported on pedestals of varying height to create the required bridge profile as illustrated. Post tensioning is installed through staggered diaphragms along the length of each beam.

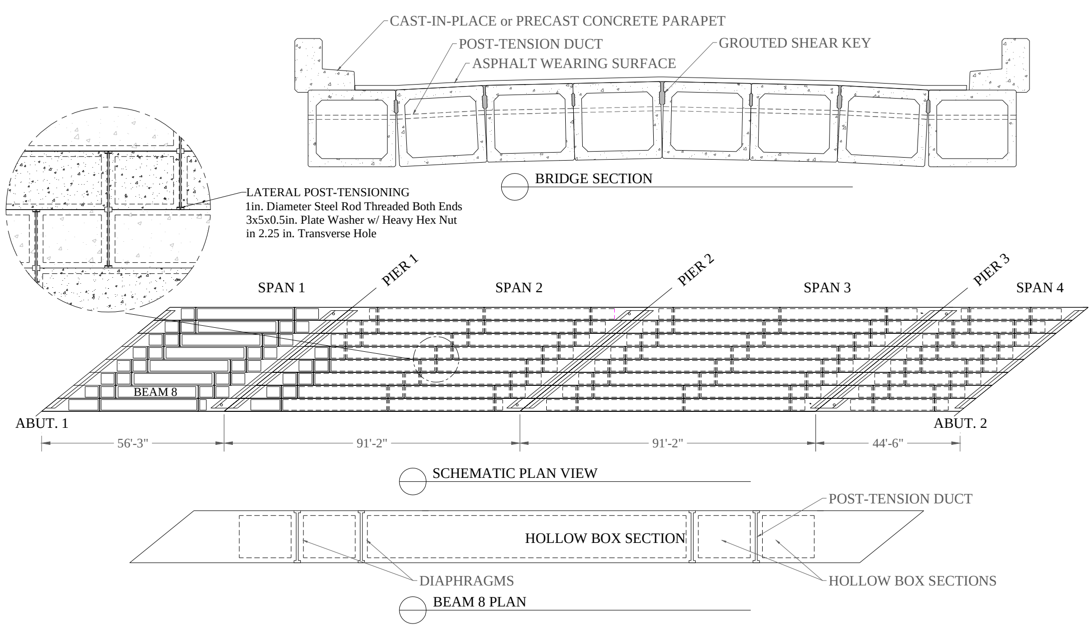

Figure 1: Typical non-composite adjacent prestressed concrete box girder bridge details

While this form of construction was easily facilitated through the advent of prestressing concepts and precast plant production the resulting system did not allow for inspection of the lateral ties. Furthermore, the construction details in some of the early systems provided only a narrow opening through which to grout the shear key. As illustrated in Figure 2, demolition of decommissioned bridges indicates that in many cases incomplete grouting of the shear keys occurred. The staggered lateral post-tensioning combined with improperly fabricated shear keys laid the ground work for long term serviceability issues.

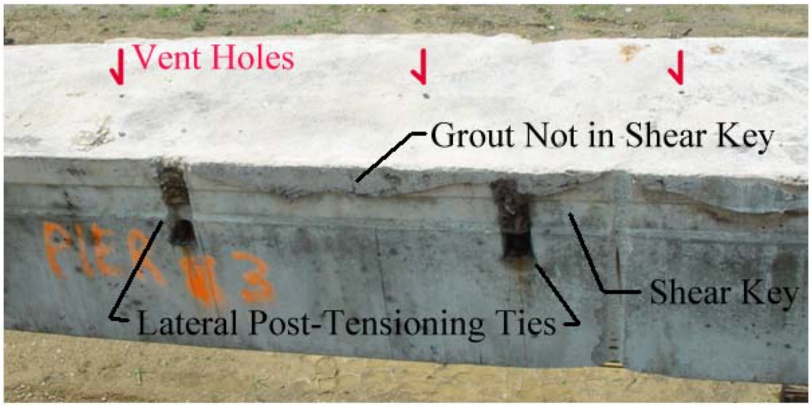

Figure 2: Improper grouting of a shear key

BOX BEAM FAILURES

A survey of State Department of Transportation Officials conducted by PennDOT revealed six occurrences where deterioration had led to a closure or failure of this bridge type. The occurrences were noted in New York, Indiana, Ohio, Illinois, and Pennsylvania, and Florida. The majority of problems had occurred in the Northeastern United States where winter snow and ice requires regular use of road salts to maintain safe driving conditions. The outlier occurred in Florida where the failure was directly attributed to salt spray from recreational water vehicles near the bridge. While this is a clear concern for the longevity of bridges, the spray issue from sea water is a design consideration only for isolated cases in the US and is not examined here in detail.

The first failure of this system type was noted in Indiana in the 1970’s. The failures were described as deterioration of the box beam top flange and blow-out of the bottom flange. As a result of these problems a major rehabilitation was conducted in the 1980’s. The rehabilitation consisted of removal of the asphalt surfaces and re-decking with a concrete overlay. Since that time no significant problems have been noted in Indiana.

Three beam failures followed the problems in Indiana. In 1986 inspection of a Cuyahoga County bridge in Ohio revealed complete spall of the fascia beam soffit and severed strands (Figure 3). A sag of 6 in. was noted in February 1989 and by August 1989 a complete failure of the beam had occurred. In 1997 an inspection of Illinois IDOT structure 046-0055 noted longitudinal cracking of the bottom flange, spalling and corrosion of the strands on a fascia beam. Within 6 months of the inspection the beam had failed. In Pennsylvania a 2004 inspection of the Lake View Drive Bridge over Interstate 70 revealed spall of the bottom flange and over 20 broken strands on the fascia beam. By December of 2005 strand deterioration progressed to the point where the beam failed near midspan and ended up in the Interstate below. These failures are illustrated in Figure 3.

Figure 3: Adjacent non-composite box beam failures (from top left clockwise: Ohio bridge pre-failure, Ohio bridge post-failure, Pennsylvania failure, Illinois failure)

The commonality of these failures was clearly observable deterioration of the prestressing steel strands. The steel reinforcement was heavily corroded and significant spalling of the concrete cover on the beam bottom flange had occurred. Based on the post failure inspection of the beams the question was not why the beams had failed but how they had remained in service with such high levels of corrosion and steel section loss.

INSPECTION METHODS

As a direct result of the Lake View Drive Bridge failure in Pennsylvania PennDOT made changes to the inspection procedures for Non-Composite Adjacent PS Concrete Box Girder Bridges. A refined condition rating [PennDOT 2007] was developed which provides a direct correlation between surface conditions and rating level. The rating procedure associates longitudinal, transverse, and web cracks, spalls and camber with the numeric condition of the bridge. In addition the overall rating of the superstructure was changed to represent the condition of the beam with the lowest rating. This was a departure from the normal rating process where the rating was determined by the general condition of the superstructure beams. Prior to this change the bridges illustrated in Figure 3 could remain in service since only one of the superstructure beams was heavily damaged. With the new rating system bridges in this condition would be flagged and closed for repair/replacement.

DETERIORATION CONDITIONS

The failure of non-composite adjacent PS box beam bridges can be directly attributed to water borne chlorides and the resulting corrosion of the primary prestressing strands. A study was conducted by Lehigh University to assess the causes of damage on the Lakeview Drive Bridge [Naito, et. al. 2006]. The chloride level present in the box beams was measured to identify the region of highest concentration. Beams over traffic and not over traffic were assessed to identify the effect of salt spray from passing traffic on chloride levels. Fascia and interior beams and chloride levels within the beams were also examined. It was found that the chloride levels on the exterior web of the fascia beam were below the threshold needed to initiate corrosion. The levels on the bottom flange of both the fascia and interior beams both over traffic and not over traffic were found to be highly elevated. It was concluded that chloride was being transported primarily from the deck above and to a much lesser degree from traffic spray from below. This supports the failures in Ohio and Illinois which occurred in bridges over stream crossings.

In many Northeastern states deicing chemicals are used in the winter to ensure safe driving conditions. These deicing chemicals typically come in the form of sodium chloride (NaCl), calcium chloride ($CaCl_2$), or magnesium chloride ($MgCl_2$). The chloride present in the deicing chemicals wash from the road surface through the longitudinal bridge joints and onto the supporting beams. In most adjacent box beam bridges a curb and parapet is fabricated on the fascia beam. This curb section combined with cross-slope of the bridge deck, the permeable asphalt wearing surface, and either damaged or non-existing waterproof barriers result in water seepage onto the beams. The concept and a photo of the water transmission are illustrated in Figure 4.

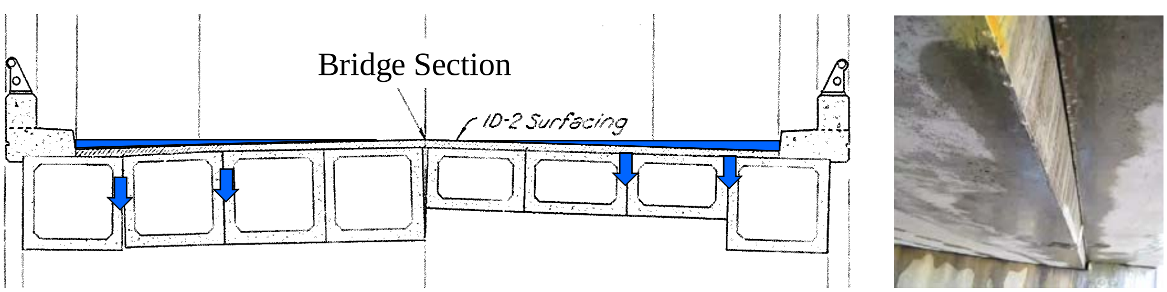

Figure 4: Water transmission from deck to beams

The cross-slope of the bridge and the placement of the sidewalk can directly influence the long-term damage to the individual bridge members. A section of the Main Street Bridge in South Strabane Township is illustrated in Figure 5. Bridge inspection revealed heavy corrosion damage only on beams 2 and 3. Due to the placement of the sidewalk, the fascia beam was protected from continual water flow. These observations can be used to identify failure of water barriers and shear keys on existing systems. Also, this concept can be used to identify likely areas of corrosion initiation.

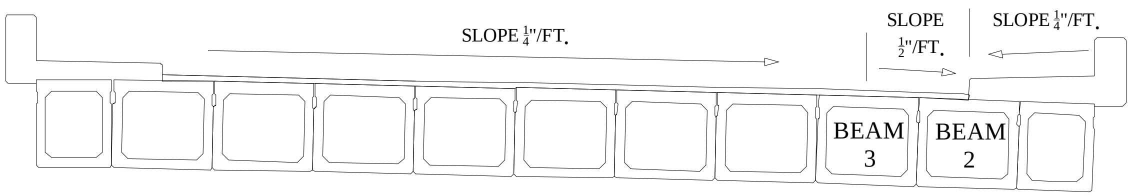

Figure 5: Main Street Bridge section

Once elevated levels of chloride are absorbed into the concrete the corrosion mechanism initiates. The chlorides create an ionic defect in the passive layer of protection around the steel resulting in corrosion product formation. The corrosion process results in an increase in volume of up to 6.5 that of the original strand size. As the strands corrode and increase in size a compression force is placed on the surrounding concrete. In accordance with mechanics concepts a tensile stress also forms perpendicular to the compression force. When the tensile stress exceeds the tensile capacity of the concrete a crack is formed. These cracks can occur horizontally in the form of delaminations or vertically as longitudinal cracks. Typically, delamination cracks form when corrosion occurs over multiple strands and the volumetric expansion of the individual strands work together to split a horizontal section. For regions where isolated corrosion is occurring, a longitudinal splitting crack is more common.

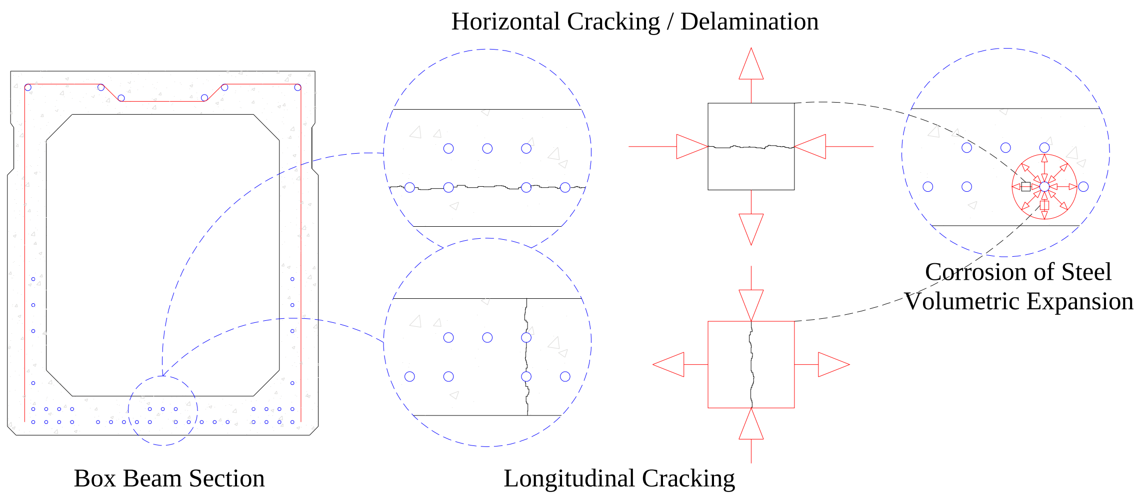

Figure 6: Corrosion induced cracking

The formation of longitudinal cracking can indicate significant damage to the strand above the crack. Research on longitudinal cracking by Lehigh University revealed that hairline cracking of the bottom flange can correlate to heavy pitting of the prestressing strand above the crack (Figure 7). As a consequence it is recommended that strands above and adjacent to a longitudinal crack shall be discounted when estimating the remaining capacity of a deteriorated beam.

External Surface Condition	Strand Condition (In-situ)	Strand Condition (Removed)	Region Shown	Wire Condition	Average Condition
 0.2-mm (0.01-in.) Crack			3A at section 3 Strand D	Missing 0	# samples 2
				Corrosion 6	w/ Corrosion 4.5
				Pitted 6	Pitted 1
				Heavily Pitted 0	Heavily Pitted 3

Figure 7: Strand and surface condition correlation

CONCLUSIONS

Over 20,000 non-composite adjacent prestressed concrete box beam bridges exist in the local, state and federal highway infrastructure of the United States. While this bridge type has proven to perform well when properly constructed; a few failures in Indiana, Illinois, Ohio, and Pennsylvania indicate that problems may occur when poor detailing and inspection practices are used. As discussed in this paper the failures are directly attributed to intrusion of chlorides from deicing salts used on the deck of the bridge. Over time seepage through the longitudinal joints between beams results in corrosion of the prestressing steel, longitudinal cracking, delamination of the beam bottom flange, and failure of the strands.

Historical inspection procedures allowed bridge ratings to be based on the overall condition of the superstructure. As a result of this procedure bridges with heavy damage of one or two beams were allowed to remain in operation. This resulted in the failures observed in Ohio, Pennsylvania and Illinois. New recommendations have been established by PennDOT to rate the bridge based on the worst bridge beam. This procedure in combination with a detailed condition assessment procedure has provided more accurate assessment of bridge conditions.

The failure of non-composite adjacent PS box beam bridges is directly related to the intrusion of chloride laden water. The system as a whole is sound and provides a cost effective and rapid construction method. To enhance the longevity of these structures a proper waterproof seal of the bridge deck should be maintained. This can be accomplished through one of the many waterproof barrier systems available. As an alternate and rehabilitation method for existing bridges these systems can be topped with a reinforced concrete deck. Using dowels in the beam flanges the beams can be made composite this allows the system to support the additional deck load without a decrease in traffic load capacity.

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