EVALUATION OF DAMAGED PRESTRESSED CONCRETE BRIDGE BOX BEAMS

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ABSTRACT

The paper discusses the evaluation of damaged prestressed box beams removed from a bridge in central Ohio that has been in service since 1980. The adjacent box beam bridge consisted of three spans of 31'4", 37'6" and 31'4". The evaluation consists of full scale destructive testing of four beams and forensic evaluation of three other beams with varying degrees of damage.

Full scale testing involves loading beams removed from the center span in four point bending to determine flexural behavior. One box, with 6 of 14 strands completely deteriorated, has been tested. One strand was partially deteriorated with only 2 of the 7 wires intact. The beam held a maximum total load of approximately 40 kips when the deteriorated strand began to rupture and concrete spalled off the bottom. In the end, the beam maintained a total load of 34 kips and showed excellent ductility. Preliminary investigation show that deteriorated stand maintained some prestressing force. The effective prestressing force was estimated at 178 kips.

The forensic investigation includes visual inspection of external surfaces as well as sections of the beams, NDT techniques, concrete cores, strength of deteriorated strands, bond of exposed strands, and chloride contents.

Keywords: Prestressed Concrete Box Beams, Bridges, Flexural Testing, Damage, Forensic Investigation, Chloride Content.

INTRODUCTION

Adjacent prestressed concrete box beam bridges are popular at the local level as well as the state level in Ohio. These bridges account for approximately 17% of all bridges in Ohio.

The typical box girder bridge in Ohio and in many states is a non-composite bridge consisting of side by side girders connected only by a grouted shear key. These bridges usually have an asphalt overlay. Over time, the grouted joints crack and the cracks reflect into the asphalt layer. Chlorides penetrate through cracked joints and can infuse into the side of the girder. Eventually, these chlorides accelerate corrosion of the prestressing strands. Because the girders are adjacent, the sides are not visible and the corrosion may not be observed during inspections. Although this problem is most prevalent with non-composite bridges, it can also occur in composite bridges when the shear key cracks reflect through the concrete overlay.

With such a significant portion of the bridges being prestressed concrete adjacent box beam bridges and being aware that deterioration of strands may not be visible during inspection, it is imperative to have well developed inspection, rating and analysis procedures in place that can be supported by experimental data. Therefore, testing and evaluation of prestressed concrete boxes that have been in-service and are of varying degrees of visible deterioration are warranted.

Research has been performed in Ohio and other states related to adjacent prestressed box beam bridges. Some of this research has examined the behavior of the shear keys[1,2] and the assessment of the beams through inspections or analysis[3]. While there have been several tests of full scale testing of box beams, limited testing has been performed on deteriorated prestressed concrete bridge girders[4-7]. Shenoy and Frantz[4] tested deteriorated girders, but these girders did not have broken or missing strands. Miller and Parekh[5] tested a deteriorated girder and a girder that did not show any signs deterioration. The deteriorated girder had 2 damaged strands and one missing strand in one corner of the box. The study concluded that the capacity of the girder was reduced because of the deteriorated strand, but the more important conclusion related to other behaviors. Due to the unsymmetrical deterioration, the girder showed significant sideways deflection. The final failure was brittle with the beam suddenly collapsing. This brittle failure was attributed to the lateral bending of the girder. A report by Naito, et.al.[6] summarizes the findings of the forensic investigation of several beams removed from the Lake View Drive Bridge over I-70 after it failure in December of 2005. This worked found numerous construction issues including but not limited to concrete cover of the strands less then specified, reduced flange and web dimensions, unobstructed vent holes on the top of the beam likely allowing water intrusion to the beam's void, and various levels of dampness of the cardboard voids including one void being partially full of water. The intrusion of water into the void was also verified by some chloride test samples that showed higher chloride contents toward the inside of the box. The work by Naito, et.al.[6] also concluded that even a hairline crack could indicate severe strand corrosion and conservatively recommended the strength of any strand located above a longitudinal crack and at least one strand on either side of the crack strand should not be considered when determining the damaged beam's strength. Harries, et. al.[7] tested one interior and one exterior girder removed from the Lake View Drive Bridge. This work also provided recommendations on the inspection and load rating of prestressed concrete box beams. Naito, et. al.[8] also reported on prestressed boxes that showed signs of distress only after 12 years of service. Inspections revealed numerous cracks in beams near the piers and abutments and recommendations from the research focused on the transfer length of the prestressing strands.

The objective of the research presented partially in this paper was to determine the behavior of box girders with deteriorated strands. To meet this objective, a forensic study and full scale testing was undertaken on box girders removed from a bridge. From these assessments, recommendations will be made on inspection procedures, rating methods and structural capacity for deteriorated box girders for the Ohio Department of Transportation (ODOT).

BRIDGE DETAILS

The box beams used in this investigation were removed from a three span bridge located in central Ohio in Licking County. The end spans of the bridge were 31'4" and the center span was 37'6". The bridge had been in service since 1980 and its beams showed a variety of deterioration levels. Figures 1-3 are photos of the bridge taken in June of 2007. Bridge demolition and beam removal occurred on July 17, 2007.

Fig. 1: South Span

Fig. 2: Middle Span

Fig. 3: Middle Span West Side

As shown in the figures, a variety of deterioration levels exist for the 36 prestressed concrete beams from limited deterioration to those with severely exposed and broken strands hanging down from the bridge. The beams are 17" deep by 36" wide and contain 14 - ½" diameter strands for the center span and 8 - ½" diameter strands for the end spans. The strands are outside the stirrups. A typical cross-section of the beams for the center span is shown in

Figure 4. The 2nd, 4th and 6th strand from each side are eliminated from the strand pattern shown to arrive at 8 strands for the end spans.

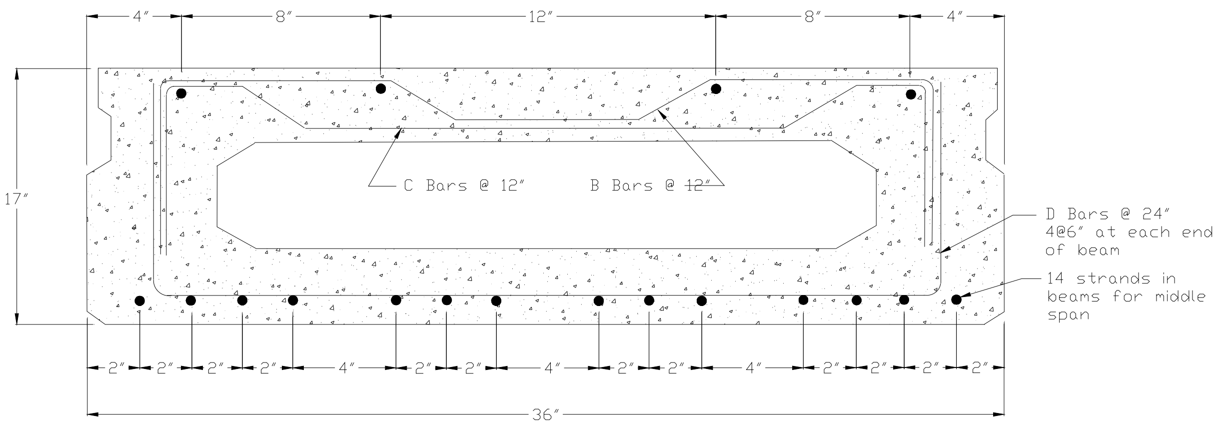

Fig. 4: Box Beam Cross Section

The beams removed for testing included six beams from span 2 and one beam from span 1. The span 1 beam was the 4th beam from the western edge (3rd interior beam). The six beams from span 2 were all the interior beams closest to the western edge. This resulted in all interior beams on the western portion from the bridge's longitudinal centerline and one beam east of the bridge's centerline. Figure 5 provides a plan view of the bridge's 1st and 2nd spans along with the beams taken for examination. Ohio University obtained beams 4, 15, and 18 for forensic investigation. Beams 14, 16, 17 and 19 were transported to the University of Cincinnati for full scale destructive testing.

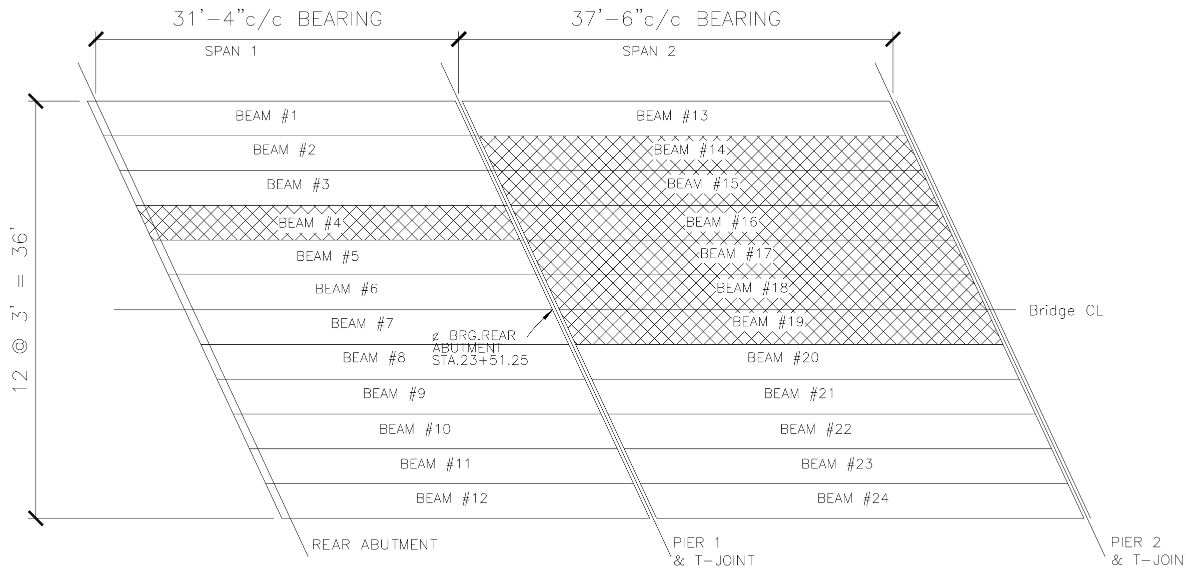

Fig. 5: Box Beams for Testing

FORENSIC INVESTIGATION

Beams 4, 15 and 18 were examined through visual inspection, nondestructive testing, sectioning, chloride testing, strand testing, and coring to assess their condition. The forensic investigation has not been completed but results to date are reported.

VISUAL INSPECTION

Beam 4

Beam 4 had 8 total strands. The two of the strands on the eastern edge were exposed near the beam's midspan (see Figs. 6 and 7). The outside strand was completely broken. The other strand was severely corroded, but broken wires were not visible prior to any concrete removal. In addition a longitudinal crack ran above the location of the exposed inside strand (Fig. 7).

Fig. 6: Exposed Strands of Beam 4

Fig. 7: Exposed Strands of Beam 4

Beam 15

Beam 15 had 14 strands. A total of four strands from the east edge of the beam were exposed near the beam's midspan (Fig. 8). Two of these strands were also exposed near the pier. Close visual inspection of this beam has not yet occurred.

Fig. 8: Exposed Strands of Beams 15 and 18

Beam 18

Beam 18 had 14 strands. A total of eight strands from the east edge of the beam were exposed near the beam's midspan (Figs. 8 and 9). Four strands from the east edge were broken. Strands 5 and 6 from the east edge had 5 out of the 7 wires broken. Strand 7 did not appear broken but its partial embedment made visual verification of this difficult. Strand 8 was exposed over a short distance compared to the other strands and showed severe corrosion but did not appear to have any broken wires.

Fig. 9: Exposed Strands of Beam 18

SECTIONING

In order to view the beams internally, the beams were cut into sections. This allowed measurement of strand location, cross-sectional dimensions, and concrete cover remaining at sections.

Beam 4

Beam 4 was cut transversely at two locations to divide the beam into approximately thirds. The south section and the north section are shown in Figs. 10 and 11, respectively (note: beams are shown with the bottom surface upward). As can be seen in the figures, no strands were exposed at the section cuts.

Fig. 10: Beam 4 South Section

The bottom flange and the webs were specified to be 5" thick. Only the bottom flange at section 1 was slightly less than specified by approximately 1/8". It should also be noted the external faces of the webs were very uneven due to the contractor's cutting of beams during removal. However, the webs on both sides at both sections were larger than specified leading to the conclusion the Styrofoam block to create the void was smaller than necessary.

The strand spacing deviated as much as ½" from specified locations along the width of the beam. The strands were positioned outside of the transverse reinforcement. The specified clear cover to the transverse reinforcement was 2"resulting in a 1-1/2" cover for the strand. The observed cover was in general agreement with cover varying from 1-5/8" to 1-1/8".

Fig. 11: Beam 4 North Section

Beam 18

Beam 18 was also cut into approximately three equal length sections. The north section is shown in Fig. 12. As can be seen in the figure, numerous strands are affected by the spalled concrete and little to no cover exists for the majority of strands.

The measured dimensions for the bottom flange were within 1/8” of the specified 5” dimension. The widths of the webs at both sections revealed that the Styrofoam block was likely smaller than required. The East web at section 2 was slightly less than specified. This may have been caused by a shift in the Styrofoam block used to create the void.

The strand spacing deviated as much as ¼” from the specified location for interior strands and those with concrete cover still existing. The strand spacing deviated from the specified spacing by as much as 5/16” for all strands including those that were exposed. The strands were positioned outside of the transverse reinforcement. The cover was in general agreement with the cover specified with the largest deviation being ±1/16” for strands which did not have any concrete spalling.

Fig. 12: Beam 18 North Section

NONDESTRUCTIVE TESTING

Nondestructive testing is planned for the beams and will include the use of a rebound hammer and a pulse velocity system. To date the use of the rebound hammer has been completed on beams 4 and 18. The data was taken with the device in a grid of approximately 4' along the length of the beam and in four locations along the width of the beam. Variations from this grid pattern were necessary due to spalled concrete or areas of interest. The specified concrete compressive strength was 5,500 psi.

Beam 4

The rebound hammer results for beam 4 showed a compressive strength as high as 8,430 psi and a low of 1,507 psi. Lower values were obtained near concrete spalls and cracking leading to the belief the concrete has delaminated at these locations.

Beam 18

The rebound hammer results for beam 18 provided a compressive strength as high as 8,321 psi and a low of 5,977 psi which was still in excess of the specified strength. Lower values were generally near the spalled concrete, but did not reveal any concrete that was believed to be delaminated.

CHLORIDE TESTING

Samples for chloride testing were obtained by collecting the concrete fines from drilling into the beams. The chloride content was determined in accordance with standard practice per AASHTO T-260. All samples were taken from two different depths of approximately 1/8" to 1.5" and then approximately from 1.5" to 2.5". Samples taken from the side of the beams were approximately 4" from the bottom.

Beam 4

A total of 9 holes were drilled into beam 4 resulting in 18 chloride samples. Three of the holes were drilled into the side of the beam and 6 more were drilled into the bottom of the beam. All holes avoided reinforcement. The average chloride content was 0.243% for the samples near the surface and 0.246% for the samples deeper. This showed little difference in chloride content with the sample depth. However, the samples from the side of the beam showed an average chloride content of 0.152% and 0.293% from the bottom of the beam for samples taken from the depth nearest the surface. A similar result was shown from the samples taken at the deeper into the member, 0.119% from side samples and 0.305% for bottom samples. This leads to the belief that the chlorides ingress is from bottom of the bridge. The bridge spanned a stream and not another roadway so the likely transport of the chlorides was from chloride laden water leaking between longitudinal joints. The leakage was likely not a the location of the side samples

Beam 18

A total of 12 holes were drilled into beam 18 resulting in 24 chloride samples. Six of the holes were drilled into the side of the beam and 6 more were drilled into the bottom of the beam. All holes avoided reinforcement. The average chloride content was 0.197% for the samples near the surface and 0.195% for the samples deeper. This also showed little difference in chloride content with the sample depth. However, the samples from the side of the beam showed an average chloride content of 0.174% and the samples from the bottom of the beam showed an average chloride content of 0.220% for samples taken from the depth nearest the surface. A similar result was shown from the samples taken at the deeper into the member, 0.169% from side samples and 0.189% for bottom samples. This again leads to the belief that the chlorides ingress is from bottom of the bridge due to joint leakage. Beam 18 was from the bridge's second span and in general had lower chloride contents than beam 4 which was from the first span of the bridge. The other point of interest was the corrosion damage of beam 18 was much more severe than that of beam 4 which had lower chloride levels.

DESTRUCTIVE TESTING

The full scale destructive testing involves loading the beams in four point bending to determine flexural behavior. Cracking moment, effective prestress and flexural capacity will be determined for all 4 specimens. To date, one beam has been tested destructively, beam 16. The beam had a test span of 33’ 5” in order to deal with the skew at the ends as well as to support the beam sound concrete. The beam originally had 14 strands. Of the 14, six were completely deteriorated. One was partially deteriorated with only 2 of the 7 wires intact.

The testing of beam 16 is shown in Figs. 13-15. Fig. 13 shows the significant deflection the beam underwent during the test. Figs. 14 and 15 show the bottom of the beam with corroded strands as well as strands that were not corroded but exposed due to spalling concrete from the applied loading.

Fig. 13: Destructive Test of Beam 16

Fig. 14: Destructive Test of Beam 16 (Bottom)

Fig. 15: Destructive Test of Beam 16 (Bottom)

After testing, it was found that two more strands embedded in the concrete had large amount of corrosion, but appear to have been mostly intact when the test began. The beam held a maximum total load of approximately 40 kips (20 at each point) when the deteriorated strand began to rupture and concrete spalled of the bottom. In the end, the beam maintained a total load of 34 kips (17 at each point) and showed excellent ductility. The beam deflected to L/36 before the test was stopped when further deflection was not possible due to the height of the specimen in the test frame. Figure 16 shows the load-deflection plot of the beam 16. The slight increase in load at approximately 12" of deflection was due to the beam coming in contact with spalled concrete on the test bed floor. The dashed line in Fig. 16 is an initial assessment of the test using the Response program to predict behavior. This initial model used 5,500 psi concrete and assumed all concrete below the strands had been lost.

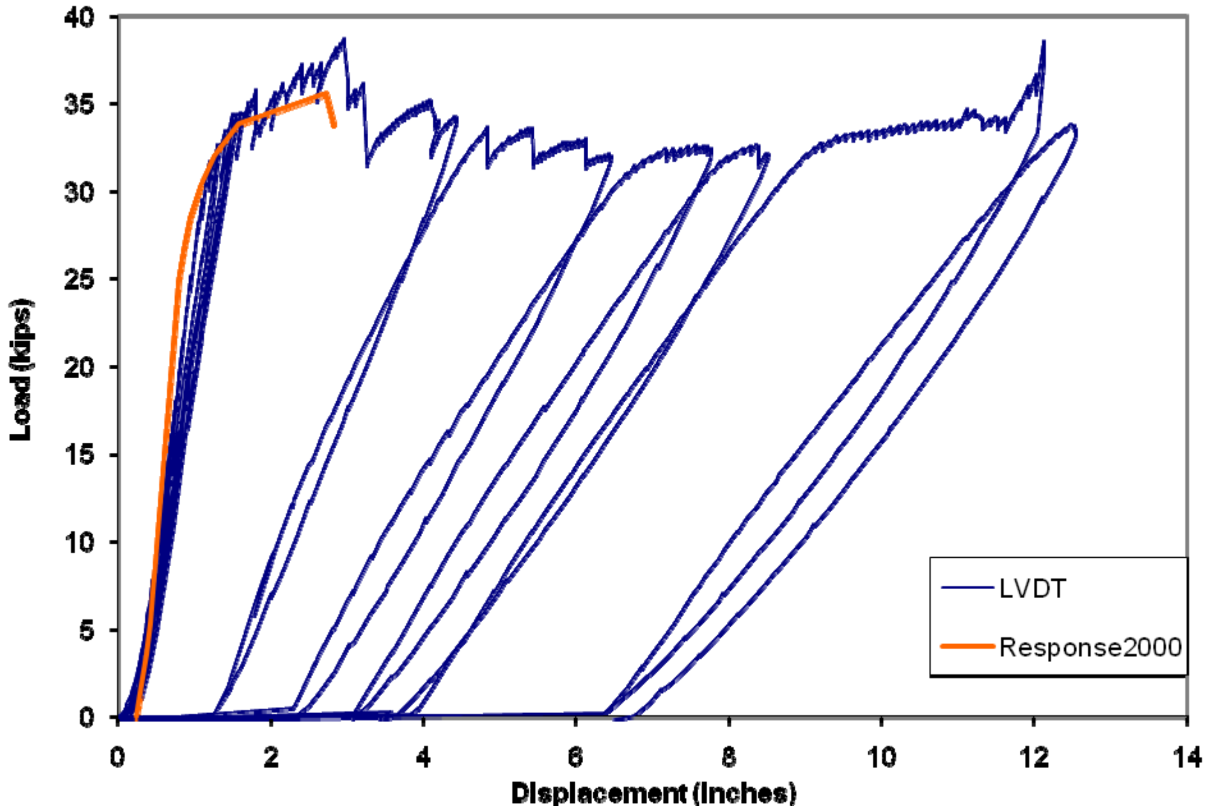

Fig. 16: Load-Deflection for Beam 16

The load of 34 kips was consistent with having 5 intact strands. Preliminary investigation show that deteriorated stand maintained some prestressing force. To estimate the effective prestress, the beam was loaded until a crack was visible and then the beam was unloaded. Clip gages were mounted across the crack and the beam reloaded. The data from the clip gages allow an accurate estimate of the effective prestress force and this technique has been used by others[3,9,10]. The effective prestressing force was estimated at 178 kips, a force too large to be maintained by only 5 strands.

SUMARRY

Visual inspections of the cross sections of the beams investigated revealed that the location of the strands could vary as much as ½” from specified locations and cover varied from 1/8” more to 3/8” less than specified. Initial results from the use of a rebound hammer can assist in determining locations of poor concrete. The chloride testing of samples removed from the beams showed that the levels of chloride were sufficiently high to cause the corrosion witnessed in the visual inspections. Destructive testing of beam 16 revealed that the behavior of the damaged beam could be predicted if sufficient information on the number of damaged strands could be determined.

The remaining testing for the research project discussed in this paper should be completed in early September of 2009. Modeling and data assessment should be completed in November of 2009.

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