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Destructive Testing of IDOT Bridge Structure Number 020-3087

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16. Abstract The partial collapse of Illinois Department of Transportation structure 020-3087 on October 1, 2019, provided IDOT with the opportunity to evaluate the in situ strength of a precast, prestressed concrete deck beam bridge after 50 years in service. An undamaged beam was transported to the Newmark Structural Engineering Laboratory and tested in three-point bending to failure on February 25, 2020. The beam supported a peak load of 33.14 kips before failure, an ultimate moment of 227.5 kip-ft. Upon failure, the concrete around the prestressing strands was removed to expose the strands. All strands were present; however, the strands were in a different configuration than shown on design drawings. None of the strands showed visible corrosion.		
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EXECUTIVE SUMMARY

On October 1, 2019, a loaded grain wagon crossing Illinois Department of Transportation (IDOT) structure 020-3087 caused a partial collapse of the bridge. With the bridge slated for demolition and replacement, IDOT elected to use an undamaged portion of this bridge for a destructive load test to confirm the deteriorated-strength prediction methodologies currently used in the IDOT Bureau of Bridges and Structures Division of Highways Structural Services Manual Section 4.3.4.2.4 and Appendix A-10: Guidelines for Estimating Strand Loss in PPC Deck Beam Bridges (IDOT, 2017). An undamaged bridge beam was brought to the Newmark Structural Engineering Laboratory on November 4, 2019. Transportation of the beam required removing some of the tar and chip wearing surface, exposing the concrete. This concrete surface on both ends of the beam appeared to be in somewhat poor condition. To determine quantitively whether the concrete at the ends of the beam was of lower quality than midspan, a rebound hammer test was performed along the length of the beam. This test showed relatively consistent concrete quality throughout the length of the span, justifying the decision to support the beam near the ends. Additionally, the orientation of the supports used were orthogonal to longitudinal axis of the beam, rather than at a 10 degree skew. On February 25, 2020, the beam was loaded to failure in a three-point bending test with a span length of 27.5 ft. The beam supported a maximum load of 33.14 kips before softening and failing, which corresponds to an ultimate moment of 227.5 kip-ft. Upon failure, the exposed prestressing strands were inspected and all were found to be in very good condition, with no visible corrosion. The strands were, however, found to be in a different configuration than specified on the design drawings.

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CHAPTER 1: INTRODUCTION

IDOT STRUCTURE 020-3087

Illinois Department of Transportation (IDOT) structure number 020-3087 is a two-span simply supported precast, prestressed concrete (PPC) deck beam bridge that carries 4000N (TR 207) “Airport Rd” over Friends Creek in De Witt County, Illinois. The bridge location is shown in Figure 1. On October 1, 2019, the bridge was damaged by a loaded grain wagon crossing the span. Photos of the bridge before and after the collapse of two beams are shown in Figures 2 and 3, respectively.

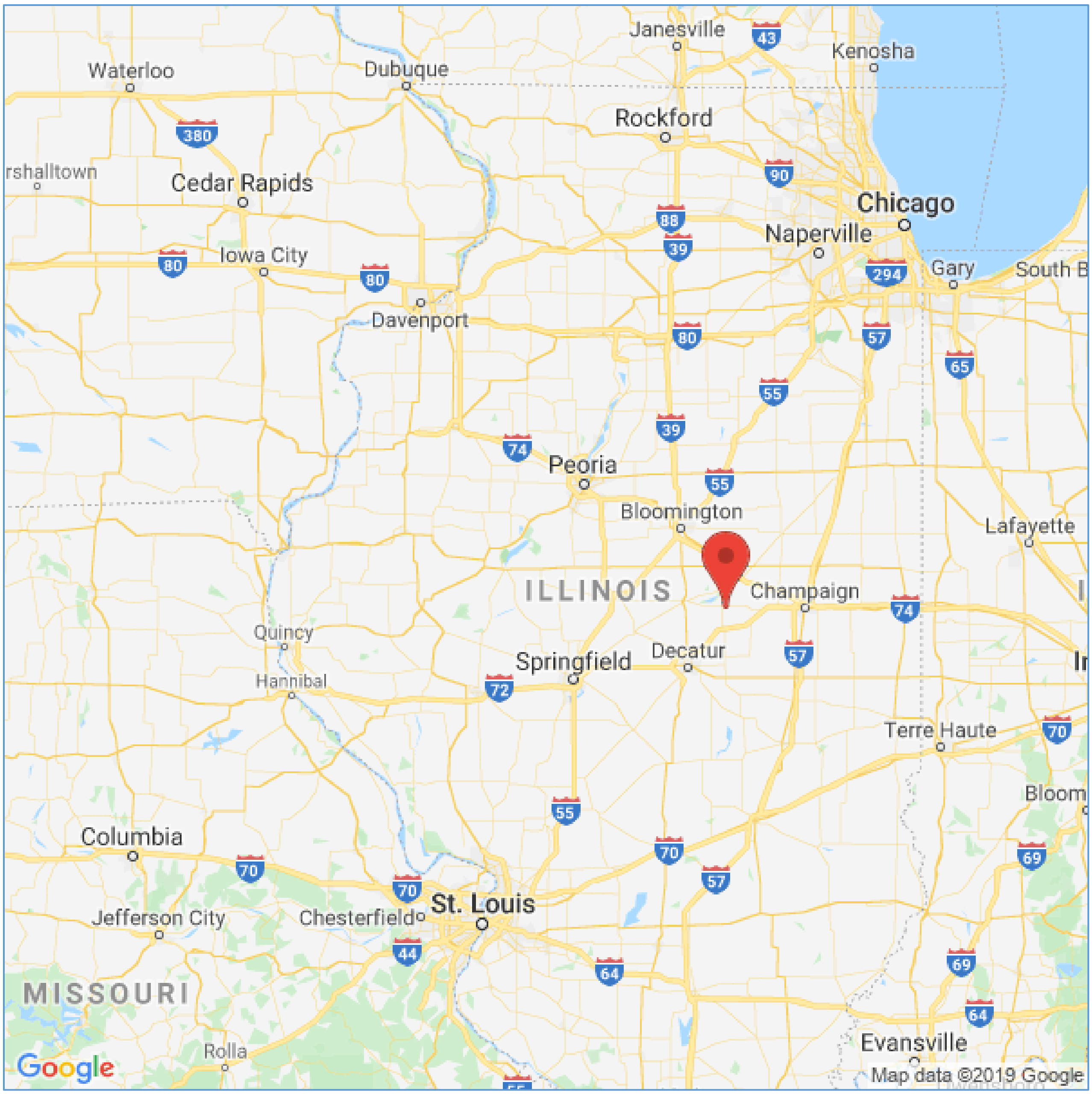

Figure 1. Map. Structure number 020-3087 location.

Figure 2. Photo. A picture of structure number 020-3087 taken in October 2015 via Google Maps.

Figure 3. Photo. A picture of structure number 020-3087 after the failure of two beams, taken in November 2019 by the authors.

The bridge was built in 1967 and consists of six PPC deck beams per span. Each span is supported by an abutment and the center pier. The original design drawings indicate that the design vehicle is HS15-44 and design strengths are listed in Table 1. Note that these are “design stresses” and not the nominal material strengths.

Table 1. Material Strengths as Specified in Design Drawings

Description	Symbol	Value
Class X Concrete	f_c	1,400 psi
Prestressed Beams	f_c	2,000 psi
Reinforcing	f_s	20,000 psi
Prestressed Cable	f_s	173,400 psi
Class X Concrete	n	10
Prestressed Concrete	n	8

The f_c value of prestressed concrete of 2,000 psi corresponds to an f'_c value of 5,000 psi per the 1973 AASHTO specification, which specifies a design strength of 40% of nominal for prestressed concrete. The cross-section of the PPC deck beams showing the prestressing strand layout is included in Figure 4.

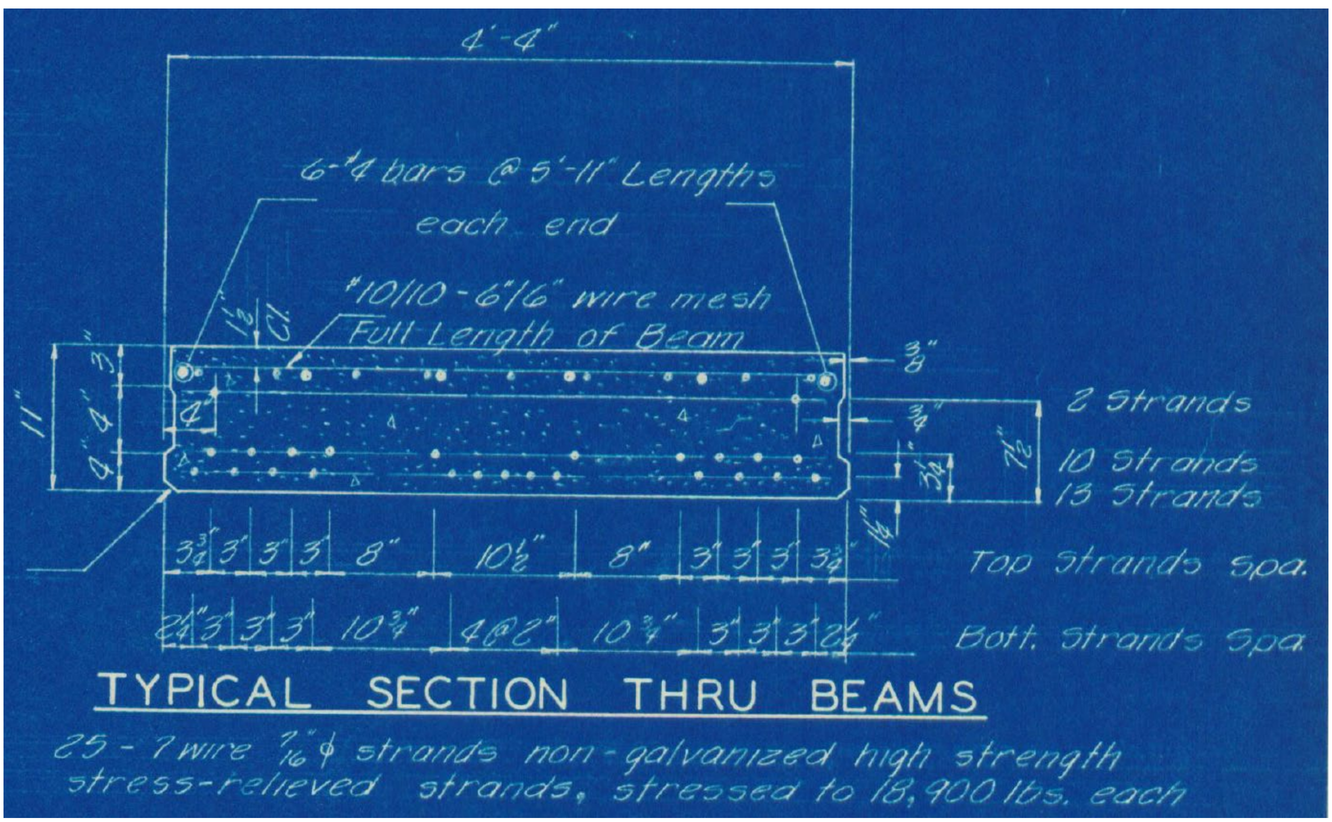

Figure 4. Photo. Cross-section of PPC deck beam per original design drawings.

The design drawings indicate 25-7 wire high-strength, stress-relieved strands that are non-galvanized, stressed to 18,900 lbs each. This corresponds to 0.108 in^2 cross-sectional area stressed to 70% of its ultimate strength of 250 ksi per appendix A-5 in Nawy (2009).

IN SITU DAMAGE

On October 1, 2019, the bridge was damaged by a tractor pulling a loaded single-axle grain wagon crossing the span. The load caused the collapse of two interior beams on the north side of the western span. The southern beams on the west and east spans were undamaged. The weight of the grain wagon is not known.

After deciding to replace rather than repair the bridge, IDOT chose to utilize one of the undamaged beams for a destructive load test to determine its flexural capacity. This test would allow for a comparison of the actual strength with the current methods for strength prediction. The method for estimating the flexural capacity of PPC deck beam bridges is described in the IDOT Bureau of Bridges and Structures Division of Highways Structural Services Manual Section 4.3.4.2.4 and Appendix A-10: Guidelines for Estimating Strand Loss in PPC Deck Beam Bridges (IDOT, 2017). This method is based on visual observations of cracking or staining on the underside of the beam and discounting any strands in these areas.

CHAPTER 2: TESTING

NONDESTRUCTIVE TESTING

To transport one of the undamaged beams from the bridge location to the Newmark Structural Engineering Laboratory (NSEL), the tar and chip wearing surface was first removed, which allowed for the beam to be lifted off its supports. The concrete below the wearing surface appeared to be in relatively poor condition. Hammer sounding indicated large areas of delaminated concrete. Whether this delamination was caused by the removal of the wearing surface or if this condition had already been present was unclear. Because the objective of this project is to evaluate the flexural strength of the beam, the test setup should attempt to avoid a shear failure if possible. If the beams are low strength near the ends, shear failure, rather than bending failure, may occur. To assess the concrete quality throughout the length of the beam, a nondestructive rebound hammer test was performed. This test is described in ASTM C805 (ASTM International, 2018). The rebound hammer applies a consistent impact and returns a nondimensional “rebound number,” which is a quantitative measure of concrete quality at the impact location. This approach allows for a comparison of concrete quality at different locations along the beam. This test was performed at six locations along the length of the beam both in the shear key and below the shear key on the edge of the beam. The locations of tests and rebound numbers are shown on a schematic in Figure 5 and plotted vs position along the span in Figure 6.

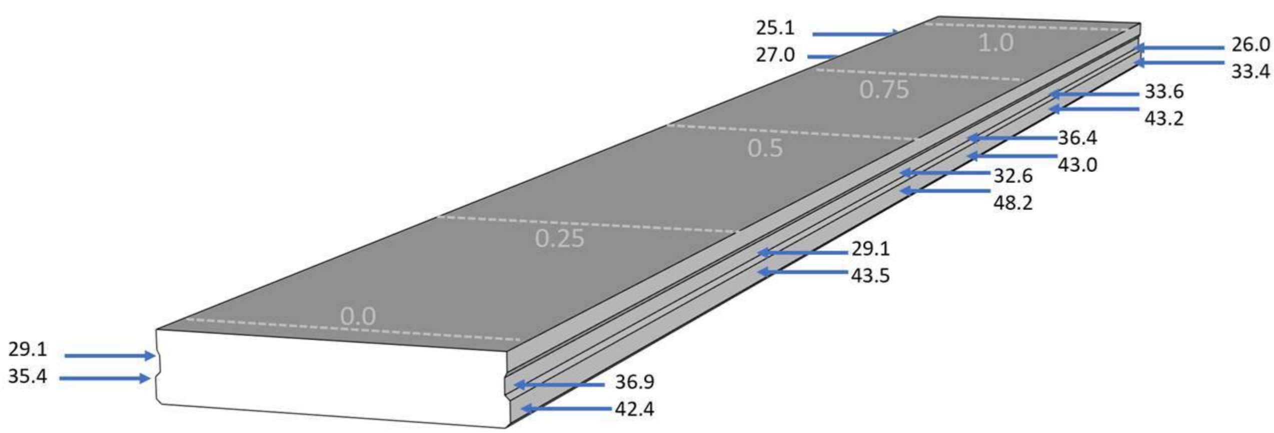

Figure 5. Photo. Schematic of a PPC bridge beam showing average rebound numbers at various locations.

The rebound hammer test results were used to determine that the concrete quality was not significantly different at the beam ends, compared to the midspan location. This result justified the decision to support the beam near its ends.

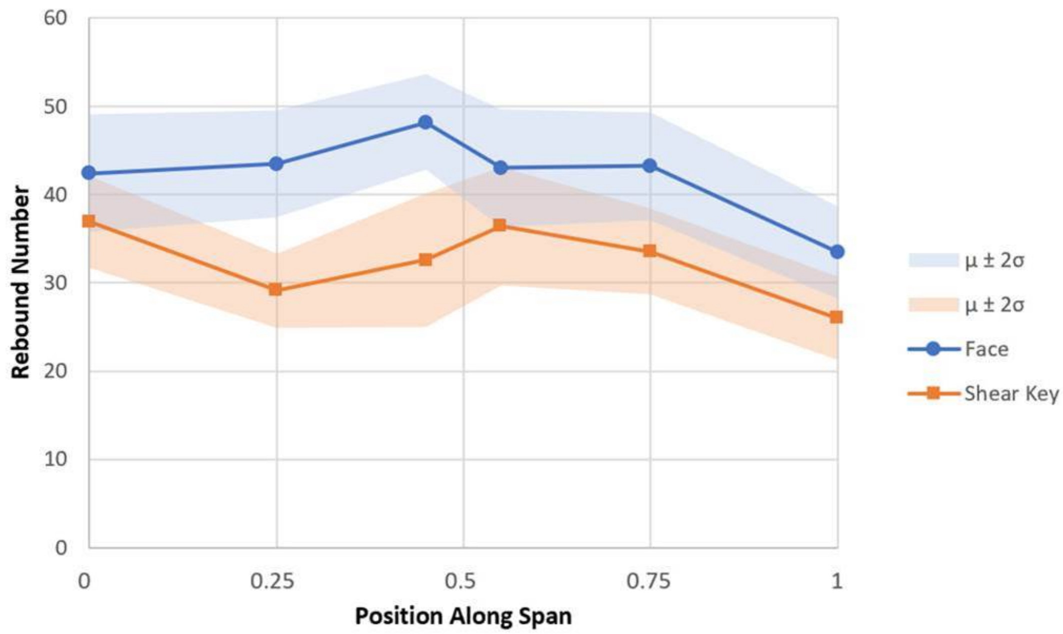

Figure 6. Graph. Rebound number along the length of the beam.

THREE-POINT BENDING

On February 26, 2020, the beam was loaded to failure in a three-point bending configuration. The beam was supported on 4″ diameter steel rollers with a center-to-center spacing of 27.5 ft aligned perpendicular to the longitudinal axis of the beam and not along the skew. Schematics of the test setup are shown in Figures 7 and 8. The load was applied at the midspan location via a hydraulic actuator bearing on a wide flange beam section, which served to spread the load across the full width of the beam. During testing the load applied was recorded via a load cell on the actuator and the midspan displacement was recorded via two string potentiometers between the beam and the laboratory floor. Data from both sources were collected at 20 Hz. Additionally, a noncontact coordinate measurement system (Metris/Krypton K600) consisting of two cameras and 24 active targets allowed deflections in three dimensions to be captured at 20 Hz with a resolution of 0.008 in. This system serves as additional confirmation of the recorded displacements and allowed for assessment of the spatial variation of deformations if required. Photos of the test during and after failure of the specimen are presented in Figures 9 through 11.

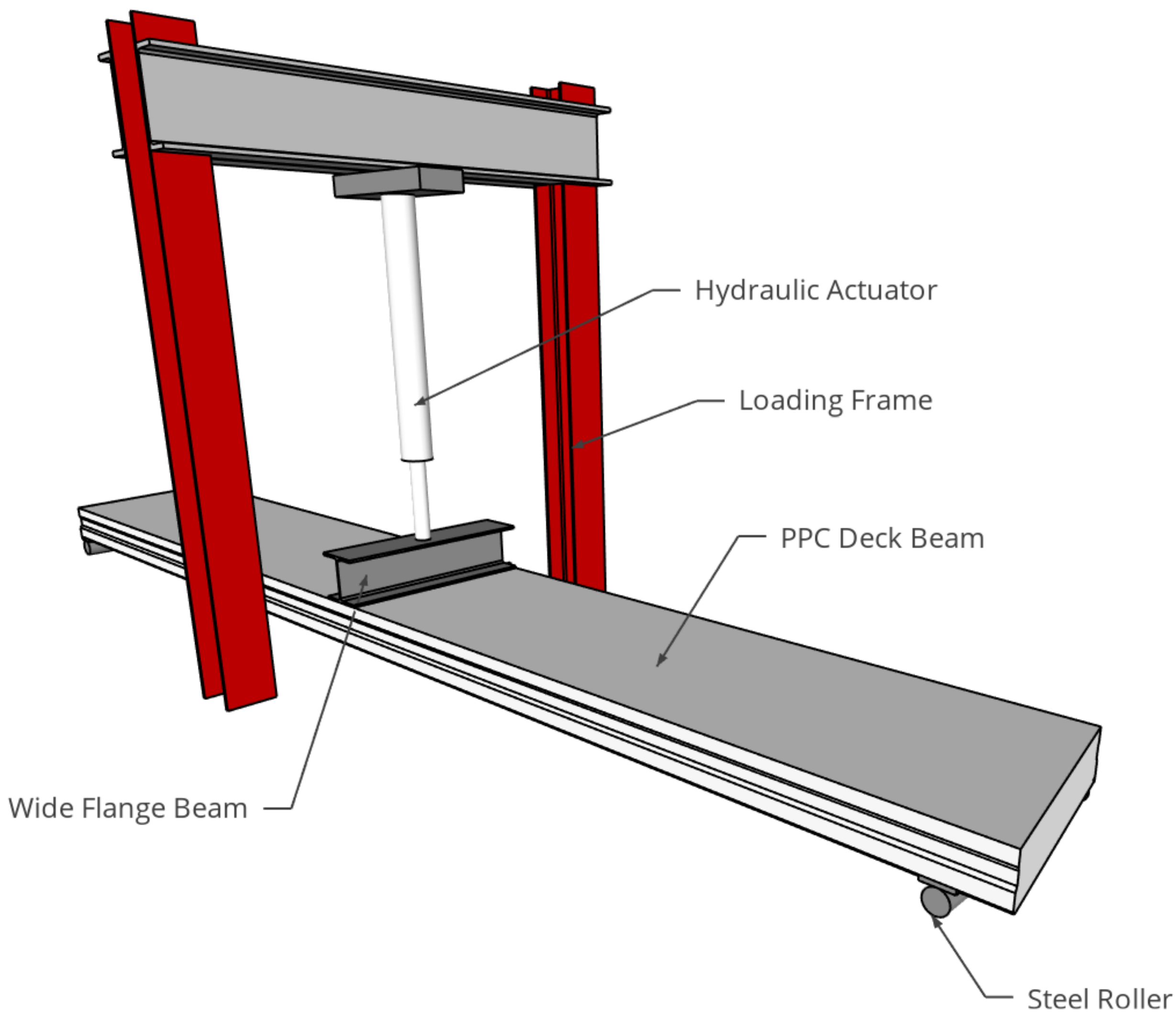

Figure 7. Photo. Schematic of the three-point bending test configuration.

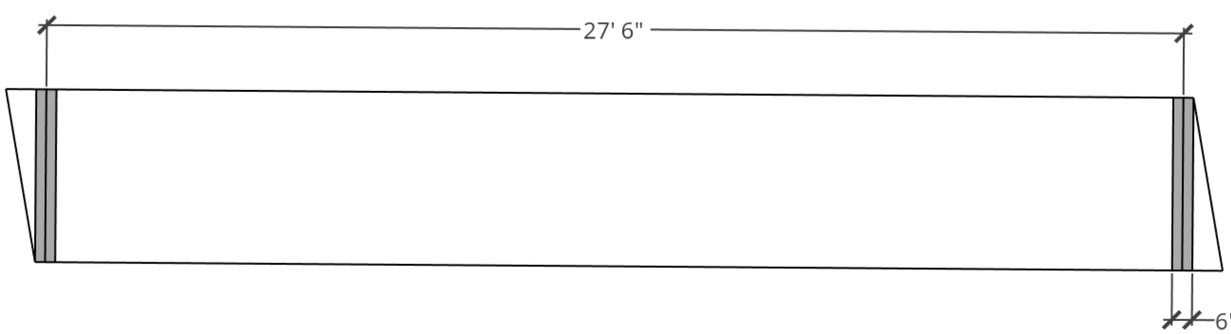

Figure 8. Photo. Schematic plan of the bridge beam showing location and orientation of supports relative to the skew of the beam.

Figure 9. Photo. Test specimen during the three-point bending test.

Figure 10. Photo. Test specimen after completion of the test.

Figure 11. Photo. A picture of the flexural failure at midspan.

The test was carried out using displacement-controlled loading at a rate of 1/4 inch per minute. The three-point bending test results are shown in Figures 12 and 13. The initial loading showed an instability in the load application, which resulted in large jumps of applied force in very short time increments. This test was immediately halted and the actuator tuning corrected. As seen in Figure 12, the restarted test showed nearly identical results in the low displacement range compared to the initial test. This result indicates that the instability in the initial test likely did not damage the specimen, as there was no change in initial stiffness. The complete load vs displacement plot is shown in Figure 13. A peak load of 33.1 kips was reached at a displacement of 3.5 in, after which a steep drop in applied load is seen. This drop is the result of crushing the concrete on the surface of the beam. The post-peak plateau sustained around 21 kips of loading for an additional inch of displacement before the cracks propagated completely through the depth of the beam, causing collapse. The noncontact displacement measurements closely match the string potentiometer measurements. The peak load of 33.1 kips corresponds to a moment of 227.5 kip-ft.

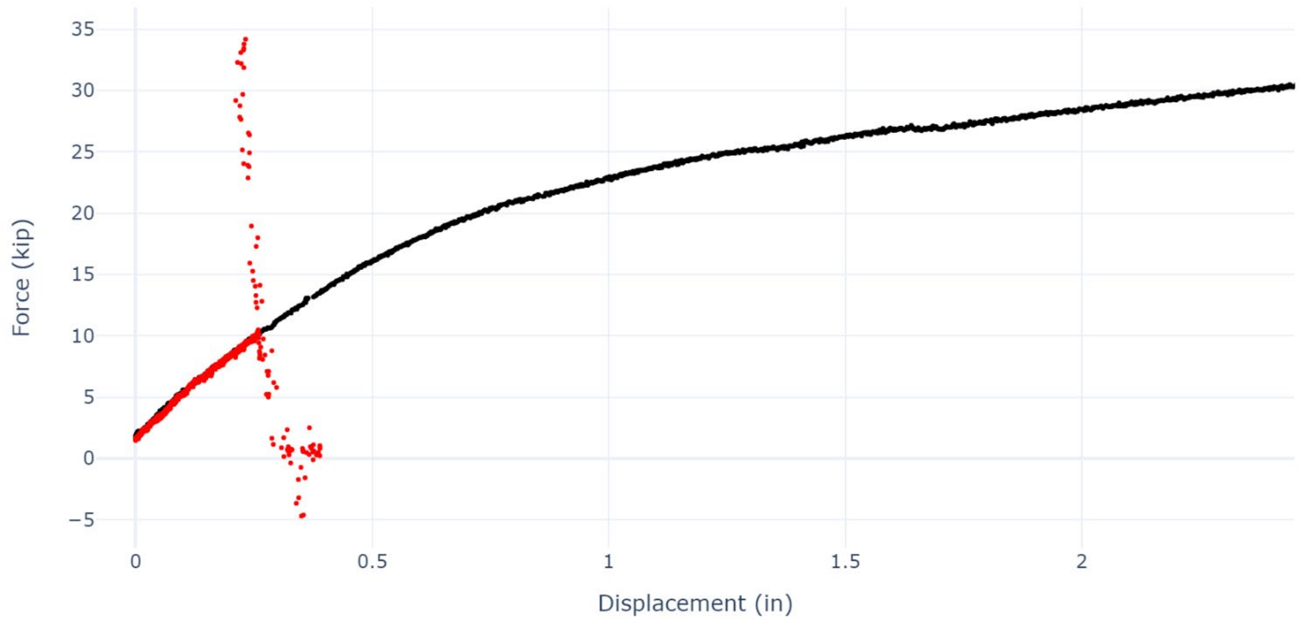

Figure 12. Graph. Force vs displacement plot of the initial loading (in red) and the corrected loading (in black)

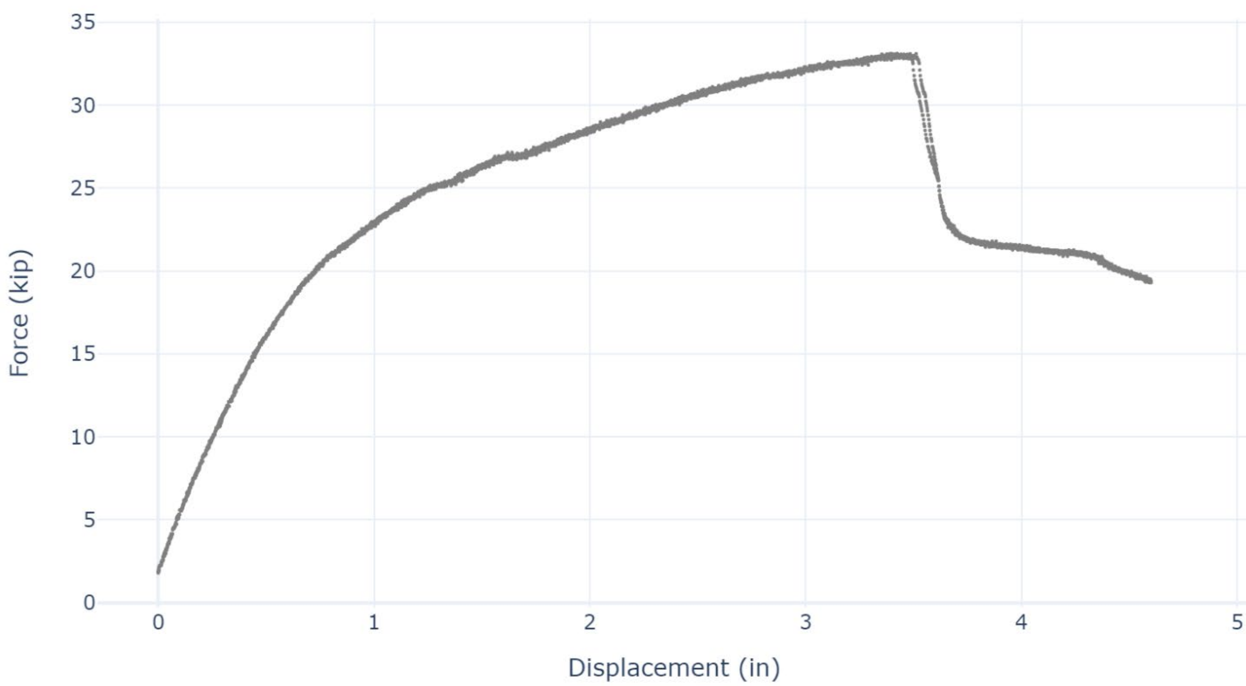

Figure 13. Graph. Force vs displacement plot of the complete load test showing displacement data from both string potentiometers.

Following the three-point bending test, the damaged concrete near midspan was removed to expose the prestressing strands, as shown in Figures 14 and 15. Note that all strands are in very good condition, with no corrosion or deterioration visible on any strands.

Figure 14. Photo. Exposed prestressing strands near midspan of the test specimen.

Figure 15. Photo. Cross-section of the beam specimen after cutting prestressing strands. Note that the configuration of the strands is different than shown in Figure 4.

CHAPTER 3: CONCLUSIONS

The three-point bending test successfully loaded the member to a flexural failure that consisted of concrete crushing at the top surface. The load-displacement behavior of the three-point bending test resulted in an ultimate strength well below a moment capacity computed using nominal material strengths. When the laboratory reopens following the COVID-19–related closures, concrete core samples will be taken from the undamaged portion of the deck and tested to determine the actual concrete strength of the beam.

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