TO:	Town of Plymouth	DATE:	June 21, 2022
FROM:	Howard Stein Hudson	HSH PROJECT NO.:	2021246.00
SUBJECT:	Brook Road over Beaver Dam Brook Bridge No. P-13-011 (9KM) – Peer Review & Preliminary Structural Analysis		

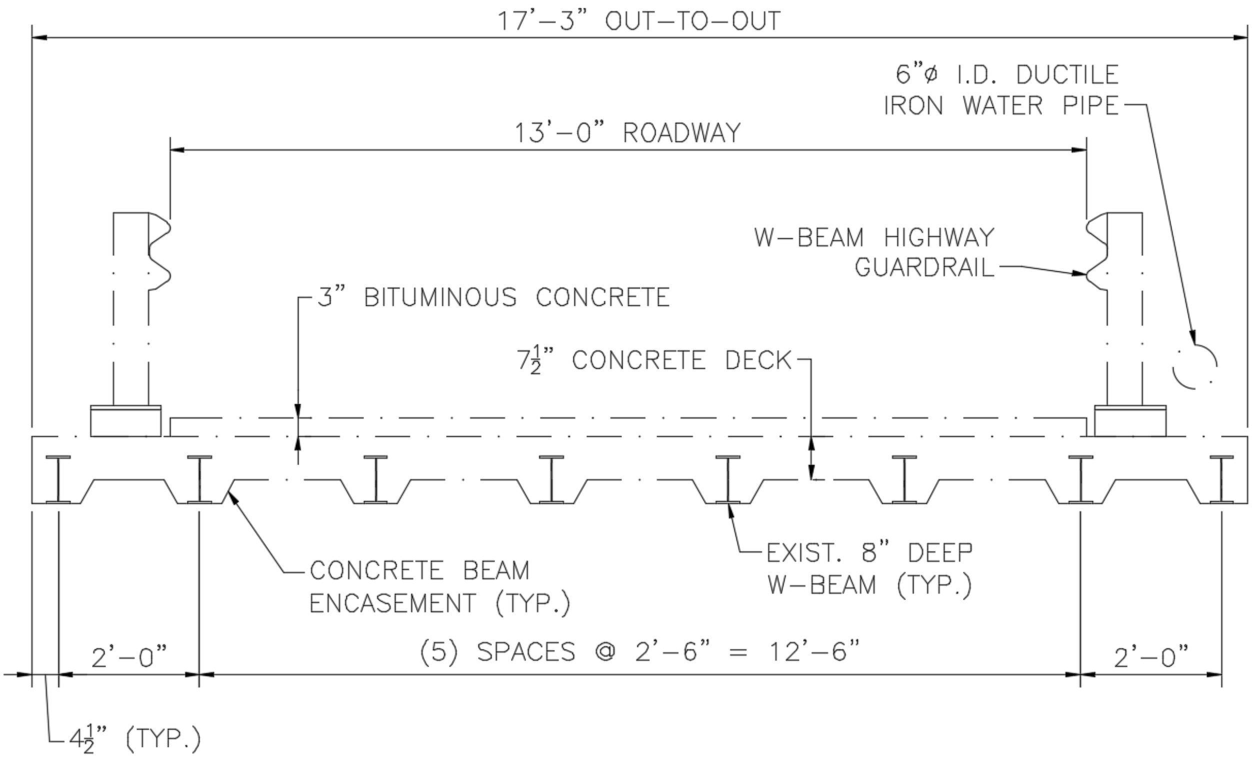
Introduction

Howard Stein Hudson (HSH) is working as a consultant to the Town of Plymouth for the referenced project and has performed a series of analyses for Bridge No. P-13-011 (9KM). It is HSH's understanding that the project history for this bridge includes a proposed bridge replacement concept which was presented to the residents of Plymouth and that the bridge has been closed since 2021. It is also understood that the replacement option was not favorably received by the public due to the proposed size and the Right of Way (ROW) required to replace the structure to current standards. The Town of Plymouth has asked HSH to evaluate if there was another alternative for the existing structure. HSH evaluated whether a bridge preservation project would be suitable for this location. If possible, reuse of the existing structure provides a solution that limits or eliminates the need for ROW impacts, environmental filings, construction duration, and cost, as well as preserves the historic nature of the existing structure. For further analysis and discussion on these project aspects, please see the **Findings – Superstructure** section.

The existing bridge structure, originally constructed in the 1800s and reconstructed in 1926, is a single span bridge supported on stone masonry abutments. There are no known plans for the existing structure; however, based on field measurements taken by HSH personnel, the bridge span length is 13'-10" from centerline of bearing to centerline of bearing and is normal to the roadway (i.e. no skew). The superstructure consists of eight (8) concrete encased steel girders with a 7½" concrete deck and a 3" bituminous concrete wearing surface.

The interior beams are spaced at 2'-6" with exterior beams spaced at 2'-0" and 0'-4½" wide overhangs, resulting in a total out-to-out width of 17'-3". The existing roadway width is 13'-0" from face of guardrail to face of guardrail (see **Figure 1**). There is also a 6" diameter water line along the south side of the bridge which is supported on concrete blocks sitting on the top of the deck.

Figure 1. Existing Cross Section



Per the *Routine Inspection Report* dated August 10, 2020, the following conditions and deficiencies exist:

- Deck Condition = 6 (Satisfactory) M-P (Minor – Prioritize)
  - The fasciae of the concrete deck have areas of scale up to ¼" deep.
  - Beam 1 concrete encasement, north elevation near the west abutment has a spall 4' long x 3" high x ½" deep.
  - Beam 7 concrete encasement, south elevation near the east abutment has a spall 3' long x 2" high x 2½" deep.
  - Beam 7 concrete encasement, south elevation near west abutment has a spall 1' long x 2" high by 2½" deep.
  - Bay 6 near the east abutment has a spall 4" long x 4" high x 1" deep with exposed rebar.
- Superstructure Condition = 5 (Fair) S-A (Severe – ASAP)
  - Beam 1 bottom flange has heavy rust areas of 100% section loss up to 1' long x full width.
  - Beam 8 bottom flange has areas of pitting up to full length.

- Substructure Condition = 6 (Satisfactory) M-P (Minor – Prioritize)
  - The stone masonry abutments have voids up to 10” deep with areas of cracked and missing mortar (approximately 20% of total abutment area).
  - The northwest corner has multiple voids to the stone masonry, up to 22” deep.
  - The reinforced concrete cap at the west abutment has areas of honeycombing.
  - The reinforced concrete cap at the east abutment has a full height vertical crack up to ⅛” wide below beam 3.
  - The reinforced concrete cap at the west abutment has a full height vertical crack up to ⅛” wide below beam 4.
  - Wingwalls have moderate vegetation growth and the northwest wingwall is leaning outward up to 3” over 2’ high.

Superstructure Exploration

Since no existing plans exist for the structure, and the beams are encased in concrete, an exploratory assessment of the superstructure was performed to determine the exact beam dimensions. Under the supervision of HSH personnel, on March 22, 2022, Jerico Concrete Cutting, Inc. of Hanson, MA performed a series of concrete cores to the topside of the existing concrete deck to expose the top flange of beam 8.

A 4” diameter core was taken approximately 12” from the face of the existing west abutment. The top of beam 8 was encountered at a depth of 3½” from the top of deck (see **Photos 1 and 2**). Based on a depth of 11½” from bottom of beam to top of deck, it was determined that the existing beams have an overall depth of 8”. Coring operations also revealed the presence of a bent ½” square reinforcing bar in the deck that appears to run transversely through the deck.

Photo 1. ***4” Diameter Concrete Core, Above Beam 8, 12” From Face of West Abutment***

Photo 2. ***4” Diameter Concrete Core, Above Beam 8, 12” From Face of West Abutment***

An additional 6" diameter core was taken approximately 6" from the face of the existing west abutment to facilitate exposing the top flange thickness. Using a micrometer, the top flange thickness was measured at 0.256 inches (see **Photos 3 and 4**). American Institute of Steel Construction (AISC) historic shapes databases were referenced as they will provide more accurate beam section properties for the era in which this bridge was constructed. Based on the measurements obtained, the beam is classified as a CBL8 having an overall depth of 8", and flange width and thickness of 4" and 0.254", respectively.

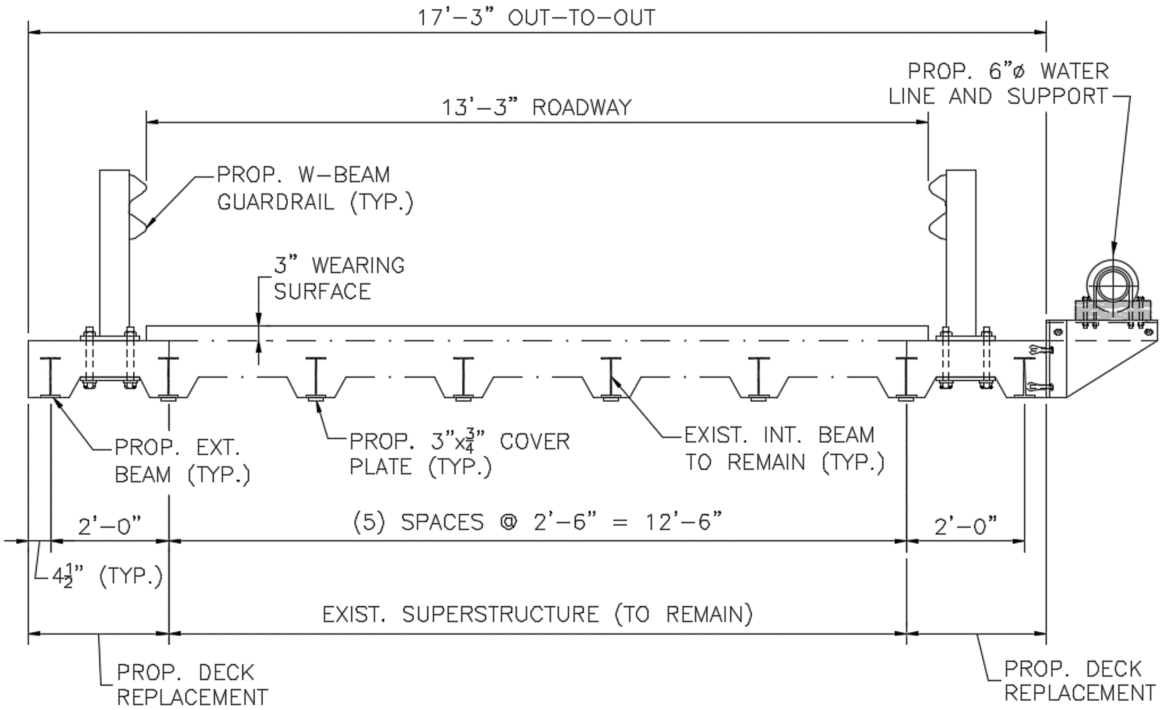
Photo 3. ***Flange Thickness Measurement***

Photo 4. ***Flange Thickness Measurement***

Findings – Superstructure

Based on the findings of the superstructure exploration, HSH has run a superstructure analysis to see if reuse of the existing steel beams and reinforced concrete deck is possible. Due to the existing deterioration of both exterior beam bottom flanges, replacement of the beam and deck would be required at these locations. The exterior beams and deck would be replaced "in kind" to negate additional loading to the existing substructure. The proposed layout would also allow for the existing waterline to be repositioned away from the guardrail, which is currently susceptible to damage in a collision event. The proposed cross section would maintain the existing overhang widths at 0'-4½", an overall deck out-to-out width of 17'-3", and utilize new w-beam guardrail resulting in a roadway width of 13'-3" (see **Figure 2**).

Figure 2. Proposed Cross Section



HSH utilized AASHTOWare Bridge Rating (BrR) software and hand calculations to analyze the structural capacity of existing steel girders. The analysis uses Allowable Stress Rating (ASR) methodology, in accordance with the Massachusetts Department of Transportation (MassDOT) *Bridge Manual* (BM) and the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Bridge Evaluation* (MBE). MassDOT's Posting Vehicles H20 (20 Tons), Type 3 truck (25 Tons), and Type 3S2 truck (36 Tons), along with an HS20 truck (36 Tons) were used in the analysis. Prior to being closed, the structure was posted for 3 Tons, 5 Tons, and 8 Tons for the H20, Type 3, and Type 3S2 trucks, respectively.

In accordance with MBE Table 6B.5.2.1-1, since this bridge was reconstructed in 1926 (between 1905 and 1936), the existing structural steel was taken to have yield stress, F_y, equal to 30 ksi. Per BM 7.2.5.11, the existing concrete was assumed to have an f_c' equal to 2000 psi for structures built prior to 1931. Since the beam is embedded 4" into the concrete deck, and presence of reinforcing steel witnessed during coring operations, the beam is assumed to act compositely with the concrete deck.

HSH has calculated concrete beam encasement non-composite dead loads and distributed them by tributary area, in accordance with the MassDOT BM 3.5.3.3. Based on the existing and proposed geometry, utility loads were considered superimposed dead loads since the deck was poured and composite action achieved prior to the utility load being installed over the bridge. Superimposed dead loads (w-beam railing and utility) have been calculated and distributed in accordance with the BM 3.5.3.4, using pile cap analogy for the exterior beam, and using equal distribution (i.e. dividing total load by all exterior and interior girders) for interior beams. Wearing surface was equally distributed to all beams in the cross section in accordance with BM 3.5.3.4.

Live load distribution factors were calculated in accordance with Section 3 of AASHTO's *Standard Specifications for Highway Bridges*. The exterior beam Live Load Distribution Factors (LLDF) were calculated with the wheel line located two feet from the face of guardrail for the Inventory and Operating condition. In both the Inventory and Operating conditions, live load does not impact the exterior beams (LLDF equals 0); therefore, beam ratings are not required. There are no pedestrian facilities on this bridge so pedestrian loading was ignored.

Non-composite and composite section properties were calculated, and moment and shear rating values obtained, using hand calculations for a typical interior beam for both Inventory and Operating conditions. Results of the analysis show that H20 and HS20 for both Inventory and Operating conditions have ratings below statutory load. The Type 3 and Type 3S2 trucks also have ratings below statutory in the Inventory condition only. Per MassDOT BM 7.2.4.2B, since H20 rates below 12 Tons, the rating should also be checked using lane loading. However, for a bridge with such a short span, the lane loading does not govern over the truck loading. Although the analysis shows rating values below statutory, it would allow for the bridge to be reopened with an appropriate posting. Please refer to **Table 1** to see all rating values.

Table 1. Bridge Rating Summary

Bridge Element		Inventory Rating by Allowable Stress Method (English Tons)				Operating Rating by Allowable Stress Method (English Tons)			
		H20	Type 3	Type 3S2	HS20	H20	Type 3	Type 3S2	HS20
Typ. Int.	Flexure	9.1	14.7	23.2	16.4	17.5	28.3	44.7	31.5
	Shear	41.6	58.1	91.7	74.9	61.8	86.2	136.1	111.2

HSH also evaluated use of the structure for vehicles which are not considered MassDOT posting vehicles such as school buses, trash trucks, and emergency vehicles like ambulances and fire trucks. MassDOT BM 7.2.4.3B says that emergency vehicles should be evaluated for the Operating condition only. Due to the limited frequency that the above referenced vehicles would be utilizing the bridge, it is appropriate to evaluate these loadings for the Operating condition only as well.

A typical school bus has a Gross Vehicle Weight Rating (GVWR) of 33,000 pounds. Typical axle spacings exceed the length of the bridge (13'-10") and therefore only one axle will be on the bridge at any time. Conservatively, the rear axle weighing 21,000 pounds was used to determine live load bending moments. Analysis showed that the existing beams have satisfactory strength in the Operating condition, having a rating factor of 1.33 (22.0 Tons), to support typical school bus loading.

A trash truck has a typical GVWR of approximately 50,000 pounds, which matches that of a Type 3 truck and has similar axle spacing. In the Operating condition, the Type 3 truck is controlled in flexure with a rating factor of 1.13 (28.3 Tons). Therefore, in the Operating condition, the existing beams have sufficient strength to also support typical trash truck loading.

Emergency vehicles such as ambulances and fire trucks were also considered. Ambulance loading very closely match that of an H10 truck which has a rear axle weight of 16,000 pounds and axle spacing of 14'-0" which exceeds the bridge length. Based on the results presented above for H20 loading, the existing beams would have sufficient capacity in the Operating condition to support an ambulance which weighs half of what an H20 truck does. Fire trucks, however, have typical axle weights that exceed that of the H20 and Type 3 trucks (with similar axle spacings). Due to the added axle load, the existing beams would not provide satisfactory rating values for a fire truck in the Operating condition.

After discussion with the Town of Plymouth, HSH understands that the ability for emergency vehicles, including fire trucks, is necessary. An additional analysis was performed to increase the load carrying capacity of the existing beams to allow for emergency vehicle use. A 3" wide x ¾" thick cover plate, welded to the bottom of the existing bottom flange, was added to the existing beam, and it was analyzed in the Operating condition for fire truck use. Analysis showed that the addition of the cover plate provided satisfactory strength to allow fire trucks to use the bridge. The additional cover plate will also increase the necessary load posting of the structure for the MassDOT posting vehicles. The resulting load rating values for the strengthened bridge structure are listed in **Table 2**.

Table 2. Strengthened Bridge Rating Summary

<table>
<tr><th colspan="2" rowspan="2">Bridge Element</th><th colspan="4">Inventory Rating by Allowable Stress Method (English Tons)</th><th colspan="6">Operating Rating by Allowable Stress Method (English Tons)</th></tr>
<tr><th>H20</th><th>Type 3</th><th>Type 3S2</th><th>HS20</th><th>H20</th><th>Type 3</th><th>Type 3S2</th><th>HS20</th><th>EV2</th><th>EV3</th></tr>
<tr><td rowspan="2">Typ. Int.</td><td>Flexure</td><td>15.3</td><td>24.7</td><td>39.1</td><td>27.6</td><td>29.9</td><td>48.3</td><td>76.2</td><td>53.8</td><td>41.0</td><td>45.5</td></tr>
<tr><td>Shear</td><td>41.6</td><td>58.1</td><td>91.7</td><td>74.9</td><td>61.8</td><td>86.2</td><td>136.1</td><td>111.2</td><td>84.9</td><td>81.3</td></tr>
</table>

Findings – Substructure

ABUTMENTS

The *Routine Inspection Report* from August 10, 2020, listed the substructure to be in satisfactory condition overall. A stability analysis of the substructure is not required for this structure in accordance with general MassDOT rating practices. The *Routine Inspection Report* does not document any settlement issues which would indicate that the bearing soils are overstressed given the current structure loading. Additionally, there is no evidence of scour at this bridge or historical evidence of flooding which would indicate that the current hydraulic opening is substandard and in need of widening. Therefore, reuse of the existing abutments as part of a bridge rehabilitation is feasible for this bridge.

Recommendation

HSH recommends the current bridge structure be repaired by replacing the two deteriorated exterior beams and portion of the concrete deck, adding cover plates to the existing interior beams, replacing the existing guardrail, and repositioning the location of the existing water line as is shown in **Figure 2**. Additional repairs would also include patching the deck, re-pointing stone masonry substructure, and leaning wingwall deficiencies noted previously. Performing these repairs would address the deficiencies listed in the August 10, 2020, *Routine Inspection Report* and allow the existing structure to be re-opened to traffic with a revised load posting to be coordinated with the MassDOT District 5 office. Repairing the existing structure would also provide additional benefits as opposed to a complete bridge replacement (see **Table 3** for comparison of the two options).

The proposed structure repair would minimize or even eliminate the need for ROW impacts and environmental permitting which would make the design process much more streamlined. Additionally, construction costs and duration are substantially reduced, which benefits the residents of Plymouth and abutters who would be impacted by construction activities. Finally, the proposed repair would maintain the historical significance of the existing structure which would be lost if a complete bridge replacement were performed. However, it is important to note that the bridge repair option would likely only extend the service life of the structure by approximately 20 years and still require a load posting. The complete bridge replacement would design the new structure for current design loadings and be detailed for a 75-year service life.

Table 3. Repair vs. Replacement Comparison

Project Task	Bridge Repair	Complete Replacement
Right-of-Way	No	Yes
Geotechnical	No	Yes
Hydraulics	No	Yes
Environmental Permitting	No	Yes
Construction Duration[1]	8-10 weeks	6-8 months
Construction Cost[2]	$	$$$
Service Life[3]	20 years	75 years
Historic Significance	Yes	No

1. Construction duration for the complete replacement option is assumed based on past project experience for projects of this size. Duration could vary depending on final layout of a proposed structure; however, the duration can be anticipated to be much longer than that of the bridge repair.
2. Anticipated construction costs for a complete bridge replacement are expected to be much greater than that of the bridge repair.
3. The proposed repairs can anticipate having a service life of 20 years while the existing structure should achieve a similar service life if general inspection and maintenance is performed on a regular basis.