



LONG BRIDGE STUDY Bridge Load Capacity Analysis



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Introduction

Effective evaluation of a bridge requires accurate calculation of its load capacity. To assess the load capacity and serviceability of the Long Bridge, a technical analysis was conducted to load rate a representative through girder span and the two swing truss spans on the bridge. The span selected for the through girder load rating was the longest span at 113 feet in length.

The existing Long Bridge is comprised of 22 through girder spans and a double span swing truss for a total of 24 spans over the Potomac River. The bridge elements were constructed in either 1904 (the swing truss, its piers, and every other pier supporting through girder spans) or 1942 (the through girder spans and the remaining piers). Figure 1 shows the through girder approach spans as well as the main swing span truss over the navigable channel. The through girder spans vary from 85 – 113 feet in length while the two swing truss spans measures 280 feet in total length.



Figure 1 – Long Bridge Views: Approach Spans & Swing Truss

As input to the process of analyzing the structure and computing the load rating, physical characteristics of the structure, including member dimensions and thicknesses, are based on the original 1904 and 1942 design plans. Field measurements of the bridge components were not available to the load raters.

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1. Analysis & Rating Methodology

All load ratings were determined in accordance with accepted methods in the *2012 Manual for Railway Engineering published by American Railway Engineering and Maintenance-of-Way Association (AREMA)*. The load ratings were conducted at two levels:

Normal Rating - the load level which can be carried by the existing structure for its expected service life; and

Maximum Rating - recognizes that loads producing stresses higher than design values may be imposed on a structure, however, to reduce the effect of fatigue, these loads should be allowed only infrequently. The AREMA Code permits the engineer to authorize more frequent Maximum Rating loads with the caution that the useful life of the structure will be reduced. If more frequent Maximum Rating loads are contemplated, it is appropriate to conduct more frequent and detailed inspection of the structure.

The analysis and load rating results are documented in a separate document in excess of 1,000 pages and is not included as part of this document. It includes:

1. Calculations of the cross-sectional properties of each member. Incremental scenarios were analyzed for the steel superstructure members to evaluate the effects of aging and corrosion on rating. The initial analysis was per the original design sections with no section loss followed by three additional scenarios that analyzed incremental overall section losses of 1/16, 1/8, and 3/16 inches of loss.
2. Calculations of the dead load, wind load, and breaking load of each member.
3. Superstructure load analysis using SAP2000 software.
4. Substructure load analysis using RC-Pier software.
5. Calculations of load rating of each member.
6. Special spreadsheets to facilitate load rating of truss gusset plates.
7. Calculations of load rating of truss gusset plates.

The rating was expressed in terms of Cooper E, and was calculated at all

significant locations in the swing truss and through girder span, including their floor systems. Cooper's E-80 loading, or its alternative loading when governed, was used as the live load.

2. Assumptions and Material Properties

The key properties of the structure were from the original plans, and per AREMA. However, the properties of the steel could not be positively identified from the original plans. The steel properties of yield strength (F_y) and ultimate strength (F_u) were obtained from the *American Institute of Steel Construction Manual, AISC Rehabilitation & Retrofit Guide, A Reference for Historic Shapes & Specifications*, as determined by the year of design or fabrication. Accordingly, for Long Bridge the component assumptions were as follows:

2.1 1942 Through Girder Spans

1. Steel Girders & Floor Beam: $F_y = 33$ ksi, $F_u = 66$ ksi (Fabricated in 1942)
2. Steel Stringers: $F_y = 26$ ksi, $F_u = 52$ ksi (Fabricated in 1904+, reused in 1942 construction)

2.2 1904 Swing Truss Spans

1. Steel in all Locations: $F_y = 26$ ksi, $F_u = 52$ ksi
2. Steel in Top Chord Eyebar: $F_y = 30$ ksi, $F_u = 60$ ksi

2.3 1942 Piles in Piers of Through Girder Spans

1. Steel H-Piles: 14"x14 ½" @73 pounds/foot with 12,600 psi allowable stress

2.4 1904 Piles in Piers of Through Girder Spans

1. Timber Piles: 12" Diameter with 800 psi allowable stress

2.5 Soil Bearing Capacity under 1904 Swing Truss Caisson Piers

1. Center Pier: 8,000 psf
2. End Piers: 7,500 psf

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3. Results and Recommendations

3.1 Swing Truss

Superstructure (Table 1 – Original Design; Table 2 – 1/16" Loss): These results indicate that the superstructure of the swing truss designed in 1904 rates less than Cooper's E-80 loading, even in its original condition. The controlling member of the truss, a gusset plates, rates 0.42 (E-34) and 0.45 (E-36) at Normal Rating for train speeds of 60 and 25 miles/hour, respectively. The Maximum Rating for this member is 0.86 (E-69) and 0.93 (E-74) for train speeds of 60 and 25 miles/hour, respectively. However, the rating decreases by an increment of 0.12 for every 1/16" loss of the section, up to 3/16" loss. Assuming 1/16" section loss for the current condition, the truss rates 0.74 (E-59) and 0.80 (E-64) at Maximum Rating.

Recommendation: The structure does not have sufficient capacity for long-term service under the current loads. It is recommended that the controlling members (3 gusset plates, 2 diagonals, and 2 top chords, as shown in the rating tables) be strengthened. More frequent and detailed inspection of all members is recommended. Reduced train speeds are recommended to reduce fatigue effects.

Substructure (Table 3 – Original Design): The substructure of the swing truss consists of solid concrete caissons under the center pier and the two end piers. These concrete caissons in their original condition have capacity for Cooper's E-80 load. However, their capacity is not quite sufficient under combined Cooper's E-80 load and longitudinal braking loads. The governing stress mode is the soil bearing capacity under the caissons.

Recommendation: Underwater inspection of the substructure is recommended to determine the existing condition in order to confirm the reported rating, or modify the rating if the condition is different from the assumed condition. Reduced train speeds are recommended to decrease the intensity of braking forces.

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Table 1 – Swing Truss, Original Design Condition

Long Bridge-Swing Truss

Superstructure

Cooper E Ratings

(Governing Members)

Member Description			Check			Normal Allowables	Normal (E-80 Rating Factor) E Rating		Maximum Allowables	Maximum (E-80 Rating Factor) E Rating	
Name (Location)	Member Type	Construction Type	Type of Check	At	Gross, Net, or Shear Section	Allowable Stress (Psi)	60 m/h+	25 m/h+	Allowable Stress (Psi)	60 m/h+	25 m/h+
Stringer	Beam	Riveted Built-up	Flexure -T	Mid-Span	Net	14,300	(0.65) E-52.0	(0.72) E-57.6	-	-	-
Floor Beam	Beam	Riveted Built-up	Web Shear	End	Gross	9,100	(0.55) E-44.0	(0.59) E-47.2	15,600	(1.00) E-80.0	(1.07) E-85.6
Truss L3-U4	Diagonal	Riveted Built-up	Axial T	-	Gross	14,300	(0.59) E-47.2	(0.63) E-50.4	-	-	-
Truss U4-U5	Top Chord	Eyebar	Axial T	-	Net	13,500	(0.59) E-47.2	(0.63) E-50.4	-	-	-
Truss L2-U3	Diagonal	Riveted Built-up	Axial T	-	Gross	14,300	(0.72) E-57.6	(0.78) E-62.4	-	-	-
Truss L5	Gusset PL	Riveted	Rivet Shear	L5-U5	Shear	13,500	(0.42) E-33.6	(0.45) E-36.0	20,000	(0.86) E-68.8	(0.93) E-74.4
Truss L4	Gusset PL	Riveted	Rivet Shear	L4-U5	Shear	13,500	(0.54) E-43.2	(0.57) E-45.6	-	-	-

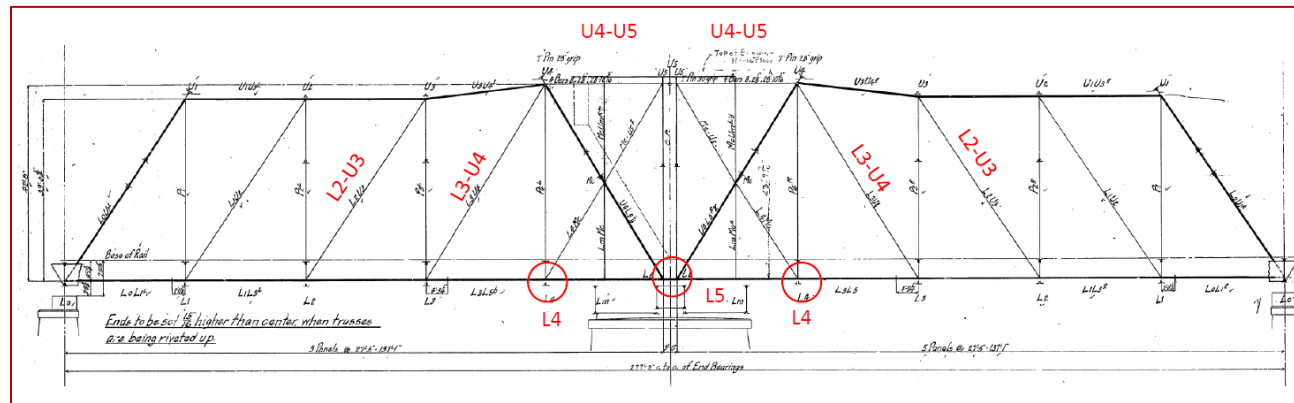


Table 2 – Swing Truss, 1/16" Overall Section Loss

Long Bridge-Swing Truss

Superstructure

Cooper E Ratings

(Governing Members)

Member Description			Check			Normal Allowables	Normal (E-80 Rating Factor) E Rating		Maximum Allowables	Maximum (E-80 Rating Factor) E Rating	
Name (Location)	Member Type	Construction Type	Type of Check	At	Gross, Net, or Shear Section	Allowable Stress (Psi)	60 m/h+	25 m/h+	Allowable Stress (Psi)	60 m/h+	25 m/h+
Stringer	Beam	Riveted Built-up	Flexure -T	Mid-Span	Net	14,300	(0.58) E-46.0	(0.65) E-52.0	-	-	-
Floor Beam	Beam	Riveted Built-up	Web Shear	End	Gross	9,100	(0.47) E-37.0	(0.50) E-40.0	15,600	(0.86) E-68.0	(0.92) E-73.6
Truss L3-U4	Diagonal	Riveted Built-up	Axial T	-	Gross	14,300	(0.53) E-42.4	(0.57) E-45.6	-	-	-
Truss U4-U5	Top Chord	Eyebar	Axial T	-	Net	13,500	(0.54) E-43.2	(0.58) E-46.4	-	-	-
Truss L2-U3	Diagonal	Riveted Built-up	Axial T	-	Gross	14,300	(0.65) E-52.0	(0.70) E-56.0	-	-	-
Truss L5	Gusset PL	Riveted	Rivet Bearing*	L5-U5	Rivet	27,000	(0.34) E-27.2	(0.36) E-28.8	20,000**	(0.74) E-59.2	(0.80) E-64.0
Truss L4	Gusset PL	Riveted	Rivet Shear	L4-U5	Rivet	13,500	(0.46) E-36.8	(0.49) E-39.2	-	-	-

*Rivet bearing controls normal rating due to bearing on connected material for section loss

**Per AREMA T15-7-1, rivet bearing check disregarded without visible deformation of parts in contact, therefore rivet shear reported.

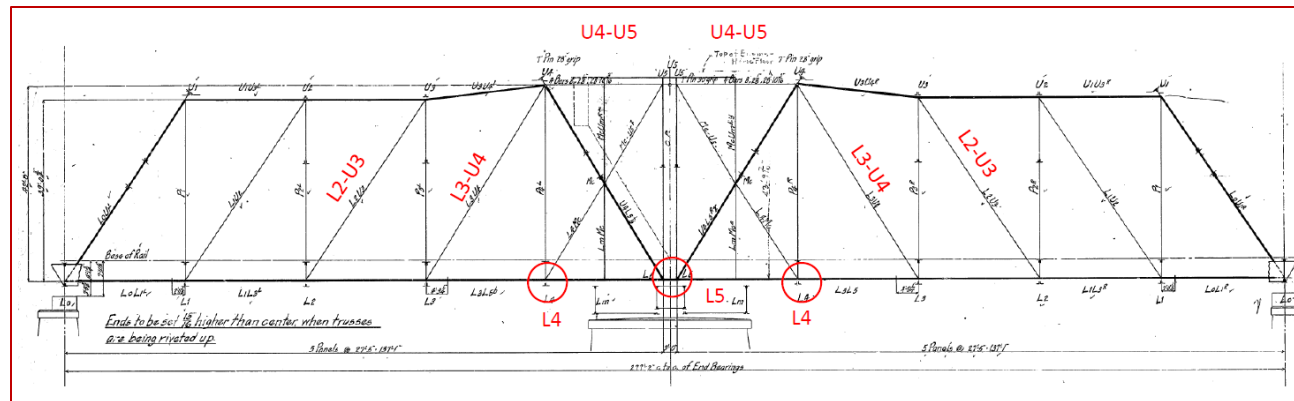


Table 3 – Swing Truss Piers, Original Design Condition

Long Bridge-Swing Truss Span Substructure Cooper' E-80 Stress Effects (Governing Members)							
Member Description			Check	AREMA Group I* Allowables	AREMA Group I Allowable to Actual Stress Ratio	AREMA Group III** Allowables	AREMA Group III Allowable to Actual Stress Ratio
Name (Location)	Member Type	Construction Type	Type of Check	Allowable Stress (psf)		Allowable Stress (psf)	
Center Pier	Caisson	Concrete	Soil Bearing Stress	8,000	1.09 > 1 : E-80 OK	12,000	0.83 < 1 : E-80 NG
End Pier	Caisson	Concrete	Soil Bearing Stress	7,500	1.10 > 1 : E-80 OK	11,300	0.89 < 1 : E-80 NG

*Gravity Loads

**Gravity plus Braking and wind loads

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3.2 Through Girder Span

Superstructure (Table 4 – As-Built; Table 5 – 1/16" Loss): The superstructure of the through girder span, designed in 1942, also rates less than Cooper's E-80 loading, even in its original as-built condition. The controlling members are the stringers which rate 0.85 (E-68) in their as-built condition. It is noteworthy that the through girder spans were designed in 1942 for Cooper's E-65 Loading. The rating for this member decreases about 0.10 for every 1/16" loss of the section, up to 3/16" loss. Assuming 1/16" section loss for the current condition, the current structure rates 0.75 (E-60). These latter ratings are at a Normal Rating level and for a 60 miles/hour train speed. At Maximum Rating for a 60 miles/hour speed, this member's rating increases to 1.10 (E-88), for 1/16" section loss.

Recommendation: The structure does not have sufficient capacity for long-term service under the current loads. It is recommended that the controlling members and stringers be strengthened. Floor beams also need to be strengthened, but stringers have priority due to the lower rating. Reduced train speeds and more frequent inspections of all members are recommended.

Substructure (Table 6- As-Built): The substructure of a typical through girders span consists of a pier with 1904 timber piles and a pier with 1942 steel piles. Both timber and steel piles in their original as-built condition and under gravity loads have sufficient capacity for Cooper's E-80 loading. The governing stress mode in this case is the stress in the pile. These piles lack sufficient capacity under longitudinal braking loads, especially the timber piles.

Recommendation: Underwater inspection of both steel and timber piles is recommended to determine the existing condition in order to confirm the reported rating, or modify the rating if the condition is different from the assumed condition. Reduced train speeds are recommended to decrease the braking force effects, especially on timber piles.

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Table 4 – Through Girder, Original Design Condition

Long Bridge-Through Girder Span											
Superstructure											
Cooper E Ratings (Governing Members)											
Member Description			Check			Normal Allowables	Normal (E-80 Rating Factor) E Rating		Maximum Allowables	Maximum (E-80 Rating Factor) E Rating	
Name (Location)	Member Type	Construction Type	Type of Check	At	Gross, Net, or Shear Section	Allowable Stress (Psi)	60 m/h+	25 m/h+	Allowable Stress (Psi)	60 m/h+	25 m/h+
Stringer	Beam	Riveted Built-up	Shear	End	Web	9,100	(0.85) E-68.0	(0.94) E-75.2	20,800***	(1.26) E-100.8	(1.39) E-111.2
Floor Beam	Beam	Riveted Built-up	Flexure-T	Mid-span	Net	18,150	(0.87) E-69.6	(0.94) E-75.2	-	-	-
Girder	Beam	Riveted Built-up	Flexure-T	Mid-span	Net	18,150	(0.95) E-76.0	(1.03) E-82.4	-	-	-

***Flexure-T controls maximum ratings for stringer

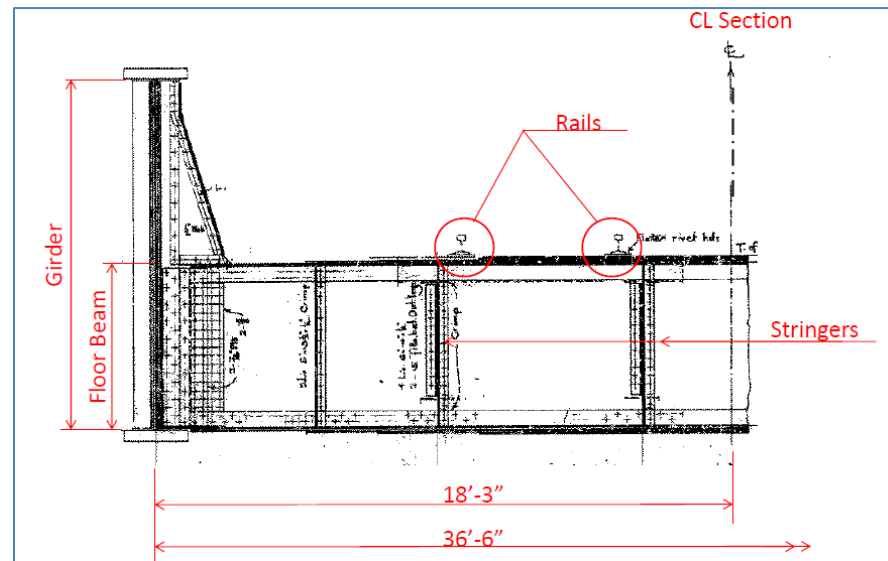


Table 5 – Through Girder, 1/16" Overall Section Loss

Long Bridge-Through Girder Span											
Superstructure											
Cooper E Ratings (Governing Members)											
Member Description			Check			Normal Allowables	Normal (E-80 Rating Factor) E Rating		Maximum Allowables	Maximum (E-80 Rating Factor) E Rating	
Name (Location)	Member Type	Construction Type	Type of Check	At	Gross, Net, or Shear Section	Allowable Stress (Psi)	60 m/h+	25 m/h+	Allowable Stress (Psi)	60 m/h+	25 m/h+
Stringer	Beam	Riveted Built-up	Flexure-T	Mid-span	Net	14,300	(0.75) E-60.0	(0.83) E-66.4	20,800	(1.10) E-88.0	(1.22) E-97.6
Floor Beam	Beam	Riveted Built-up	Flexure-T	Mid-span	Net	18,150	(0.83) E-66.4	(0.90) E-72.0	-	-	-
Girder	Beam	Riveted Built-up	Flexure-T	Mid-span	Net	18,150	(0.93) E-74.4	(1.00) E-80.0	-	-	-

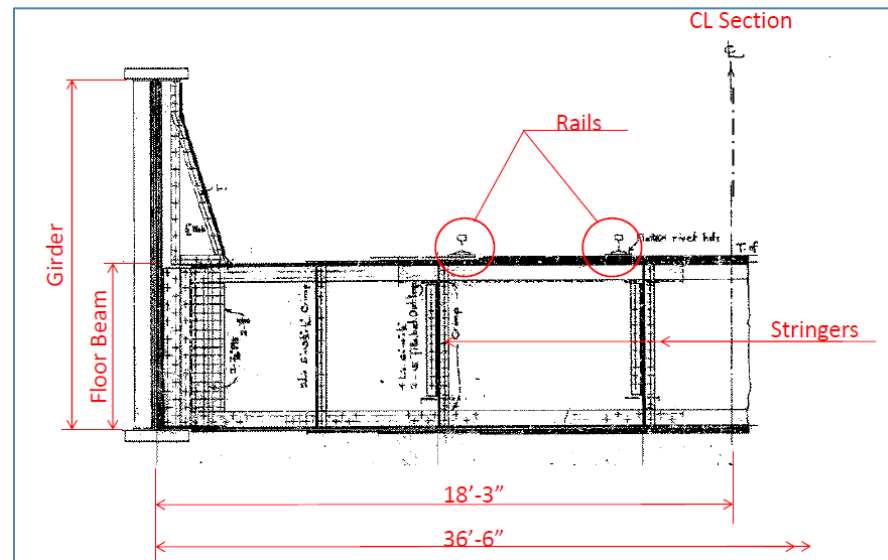


Table 6 – Through Girder Piers, Original Design Condition

Long Bridge-Through Girder Span Substructure Cooper' E-80 Stress Effects (Governing Members)							
Member Description			Check	AREMA Group I* Allowables	AREMA Group I Allowable to Actual Stress Ratio	AREMA Group III** Allowables	AREMA Group III Allowable to Actual Stress Ratio
Name (Location)	Member Type	Construction Type	Type of Check	Allowable Stress (psi)		Allowable Stress (psi)	
Pier (Built 1904)	Timber Pile	Bearing Pile	Axial Stress	800	1.04 > 1 : E-80 OK	1,000	0.32 < 1 : E-80 NG
Pier (Built 1942)	Steel Pile	Bearing Pile	Axial Stress	12,600	1.81 > 1 : E-80 OK	15,750	0.89 < 1 : E-80 NG

*Gravity Loads
 **Gravity plus Braking and wind loads

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The Long Bridge capacity analysis and load rating results reported here have been conducted to the highest possible accuracy within the standards of the practice, based on certain assumed conditions for the bridge components in the absence of an inspection.

K. Babaei

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4-5-2013

Date



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LONG BRIDGE STUDY

Bridge Load Capacity Analysis

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