LOW PROFILE RAILROAD BRIDGE
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ABSTRACT

A unique low-profile steel box girder railroad bridge design is discussed in this paper which requires low fabrication and maintenance costs. A 100 foot span was designed with a depth between bottom of girder and top of rails of 5’-4” which meets the stiffness requirement of AREMA. Computer simulations were preformed using STAAD using a 3-D model of the bridge. The STAAD analysis verified the exterior web’s ability to support the external loading and the box’s torsional stiffness to distribute the loads to all the webs. Based on the STAAD analysis, additional transverse reinforcing steel was added at the center of the concrete deck in the sidewalk area. The steel box girder design offered an economical low profile between the rail and the bottom of the girder as is often needed in the railway over the roadway grade separation. The low profile box girder bridge was successfully built in Iowa City, Iowa, at a substantial savings of approximately $1 million over a traditional through-girder bridge.

INTRODUCTION

STEEL BRIDGES

Throughout history bridges have been used to extend roadways and railways across bodies of water and diverse obstacles. In bridge building various materials are used- among the most common are timber, concrete and structural steel. While timber and concrete are good substances for building bridges of any type, size or for any purpose, for railroad bridges, the option of choice is steel. This hard, durable and strong metal is readily available and can be fabricated rather economically. Nevertheless, over the past few years the cost of labor has increased dramatically. This factor lead us to pursue different options resulting in the design of a cost efficient bridge demanding the least amount of manual labor possible during construction. We designed a unique low-profile steel box girder bridge that fit the job site perfectly, provided pleasing aesthetics and allowed the necessary clearance for traffic below.
Through Plate Girder Bridges

Many of the railroad bridges over roadways in the United States today are through-plate girder bridges similar to the one shown above: Through-plate girder bridges have been used for railroads in areas where the clearance below the bridge was of concern. Another element considered when working with bridges and with respect to sufficient clearance is grade. Does the bridge design provide the grade separation necessary to obtain the desired clearance? Raising the railroad grade is very expensive since raising the railroad tracks would require thousands of feet of grade work in each direction from the bridge to accommodate the maximum slope requirements. However, this design allows for the rails to be low in relation to the bottom of the plate girders to attain the desired clearance. These deep exterior girders are required to support the heavy railroad loads and meet the deflection criteria.
The cross section shown in Figure 1 illustrates a conventional through plate girder bridge which was not a feasible option since it required the use of large amounts of steel that needed to be manually fabricated and assembled. As stated earlier, steel fabrication is very economical provided automatic welding processes can be used; however, the process of fabricating and assembling required by the above design is very labor intensive. Stiffeners are required every couple of feet to provide internal support to the compression flange. Additionally, a floor beam is required every three feet for railroad load transfer to the main girders. A steel ballast pan is then set on these crossbeams to form a trough, which will hold all the ballast, ties, and rail. This system requires many pieces and multiple connections all of which are very labor intensive.

Steel Box Girder Design

Recently, the author designed a steel box girder bridge to span 100 feet over a roadway. A cross section of the bridge is shown Figure 2:

Figure 2: Steel Box Girder Cross Section
The box girder consists of three cells with steel bottom and web plates composite with a folded concrete deck. The folded deck forms the trough for the railroad ballast. Expensive diaphragm fabrication is avoided due to the inherent torsional stability of the box section. The proposed bridge was successfully built at a substantial savings over the traditional through-girder bridge.

The cross section had a depth between bottom of girder and top of rails of 5’-4” which made this a low-profile bridge. The steel “tub” was fabricated in two sections 100’ long joined with a splice at the center as seen in Figure 2. The box girder design utilizes the concrete deck as a compression member which makes efficient use of the concrete compression strength. To further streamline the design, the box girder used a concrete diaphragm rather than steel diaphragm at midspan and at the supports.

The concrete deck inherently forms a trough for the ballast to be placed. Deck drains where placed on each side to drain to one abutment. After this was completed, the railroad ties and rails where placed in the ballast.

**Design Requirements**

The bridge superstructure was designed to meet AREMA\textsuperscript{1} specifications and had many design components taken into account. The following is a list of some of the major design criteria:

- Stress in box steel: the steel stresses were taken to be less than 0.55F\textsubscript{y}.
- Live load deflection criteria: L/640 deflection limit, which is 1.875 inches for a 100 foot span.

The materials chosen to resist the loads and construct the box were:

- Steel Plates: ASTM A709, Grade 50
- Concrete deck: Minimum concrete compression stress of 5,000 psi.

Both of these materials are readily available in the area where this bridge was constructed.
Stress Analysis

The stress of the steel was computed by using the moment of inertia method and calculating the bending stress of the box girder with the following interaction equation:

\[
f_b := \frac{M_{1d1} y}{I_{x3}} + \frac{M_{2d1} y}{I_{x1}} + \frac{M_{LL} y}{I_{x1}}
\]

Equation 1: \( M_{1d1} \) = Moment due to dead load on steel section, \( M_{2d1} \) = Moment due to dead load on composite section, \( M_{LL} \) = Moment due to live load plus impact, \( I_{x1} \) = Moment of inertia of composite section, \( I_{s} \) = Moment of inertia of steel section, \( I_{x3} \) = Moment of inertia of composite section with \( K=3 \) for creep.

The live load plus impact consisted of E80 loading as per AREMA\(^1\) which is applied to the composite section.
The dead loads are a combination of the concrete and steel which are applied to the steel section, and ballast, and rail which are applied to the composite section with a k value of 3 to account for creep in the concrete deck. The total stress in the box girder steel was 15.66 ksi (see table 1) which is much less than the allowable stress of 27.5 ksi.

**Deflection Analysis**

The steel design was governed by the live load deflection criteria of L/640 as required by AREMA\(^1\). The live load deflection had to be less than 1.875 inches for the 100-foot span.

The bottom plate thickness and the thickness of the upper concrete flanges over the exterior webs were the variables used to obtain the required stiffness. The lower concrete flange was too close to the neutral axis to be very effective so its thickness was held at 8 inches. These variables could be adjusted without substantially affecting the depth of the structure between the top of rail and bottom of girder. The final dimensions were 2 inches for the bottom plate and 12 inches for the upper concrete flanges. The live load deflection was verified by STAAD.

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<th>TABLE I</th>
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<tr>
<td>D.L. #1 k/ft</td>
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<td>REACTION (ONE BEARING) k</td>
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</table>

Dead load #1 consists of the steel and concrete selfweight. Dead load #2 consists of the ballast and rail selfweight.
Compression Flange Analysis

The upper concrete flanges were designed as concrete columns, fully supported. The longitudinal steel in the flanges were computed using the following equation:

\[
\Phi P_\alpha := 0.80 \Phi \left[ 0.85 f'_c \left( A_g - A_s \right) + A_s f_y \right]
\]

Equation 2: Concrete Compression Strength

The concrete deck utilized the inherent compression capacity of concrete.

A subsequent review of all the above equations was completed by performing a finite element analysis of the superstructure. Computer simulations were preformed by STAAD using a 3-D model of the bridge. As expected, the stress in the steel was greatest at midspan as shown in Figure 3:

![Area of Maximum Stress](image)

Figure 3: Steel Stress

The geometry of this design requires the live load to be applied over the shorter (interior) webs. This, plus the fact that there is a significant difference in web heights, and thus stiffness, caused some concern as to the ability of the exterior webs to pick up the load. A STAAD analysis confirmed the exterior webs ability to pick up the load and vanished any concerns that had surfaced. Since the deflection at the bottom of the box was nearly the same at the interior web as at the exterior web it was concluded the torsional stiffness of the box was adequately transferring the load (see Figure 4).
STAAD also showed an unanticipated stress in the center of the concrete deck. This section near the middle of the span in the sidewalk areas required additional transverse reinforcing steel to compensate for this transverse stress. The higher stress in the sidewalk near midspan is shown in Figure 5.

Box Webs and Diaphragms

To further simplify fabrication, the idea of steel diaphragms was discarded and concrete diaphragms were used instead. These concrete diaphragms are attached to the steel box by standard shear studs welded to the steel plate and connected to the concrete slab with stirrup reinforcing.

The steel webs were sized to meet the thickness requirements of AREMA, without stiffeners. The exterior webs are 1.25 inches and the interior webs are ¾ inches thick. Although this meant more steel
than standard transversely stiffened webs, significant savings were realized in the simplicity of the fabrication.

**Economy**

The estimated savings using this low profile box is approximately $1,000,000. Currently, the average cost per pound of fabricated and erected steel in this region is $1.57. The cost for this bridge was $1.07 per pound. Although the web steel added some additional pounds, the 1/3 savings in the unit cost effectively compensated for the additional weight. The cost of the basic 100-foot span bridge was $960,000 with an additional $315,000 spent on aesthetics items such as limestone, lighting and decorative railing. The temporary shoo-fly added and additional $520,000 bringing the total construction cost to $1,795,000.

**ADVANTAGES OF THE BOX GIRDER SYSTEM**

The box girder design utilizes the concrete deck as a compression member, which makes efficient use of the concrete compression strength. Also, the folded deck allows the lowest possible railway to roadway difference and enables clearance requirements to be met. To follow are photographs (Figure 6 through 10) that show certain phases of the construction process:
Figure 6: Placement of Steel Girders
Figure 7: Bottom Girder Assembly

Figure 8: Placement of Deck Reinforcing
Figure 9: Poured Concrete Deck

Figure 10: Placement of Rails
Figure 11: Open for Business
The time needed to construct the bridge was accelerated by eliminating the need for any field welding. The steel beams were brought to the site in two separate pieces, spliced together, set in place and then ready to have the concrete deck formed. As seen in figure 9, the deck forms a nice trough for the ballast and rails, which worked to provide a smooth transition across the bridge.

AESTHETICS

Some fundamentals on what aesthetically pleasing bridges have in common are:

- they are simple (fewer individual members)
- girders are relatively thin (large span to depth ratios)
- the lines in the structure are continuous

The box girder design eliminates the need for all interior bracing members of a through plate girder bridge. This keeps the design looking simple, clean and appealing.

The typical railroad bridge appears to be bulky from the roadway below due to the large plate girders on each side of the tracks. The box girder design decreases the depth of the structure thus making the bridge more attractive.

Finally, the box girder design has two continuous lines running the length of the bridge. The top line is the concrete slab and the bottom the actual steel girder. Using two lines is more aesthetically pleasing since the appearance of two thin lines is more appealing than one thick line.

Completing its appeal is fiber optic lighting running next to the bridge girders which accentuates this bridge and adds a line of interest at the steel/concrete interface. The limestone veneer applied to the columns of the abutments enhances its beauty while virtually see thru rail keeps the bridge looking
slender. These features along with special landscaping make the bridge a useful yet aesthetically pleasing structure fulfilling its purpose and existing in harmony with the distinctive surroundings of a unique town full of architectural virtues.

CONCLUSIONS

The steel box girder design offers an economical low profile between the rails and the bottom of the girder as needed in most railway over roadway applications. While the price of producing steel has not risen in recent years the increased cost of labor has caused the expense of fabricating steel bridges to rise significantly. This box girder design minimizes the fabrication costs while maintaining all design requirements. Overall it produces a clean, aesthetically pleasing, and cost effective bridge.
REFERENCES

Equations Used in Paper

Equation 1: Stress Equation
Equation 2: Concrete Compression Strength

Figures Used in Paper

Figure 1: Conventional Through Plate Girder Cross Section
Figure 2: Steel Box Girder Cross Section
Figure 3: Steel Stress
Figure 4: Mid Span Deflection
Figure 5: Concrete Stress
Figure 6: Placement of Steel Girders
Figure 7: Bottom Girder Assembly
Figure 8: Placement of Deck Reinforcing
Figure 9: Poured Concrete Deck
Figure 10: Placement of Rails
Figure 11: Open for Business

Tables used in Paper-

Table 1: Loads, Section Properties and Stresses
### TABLE I

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BLACK AND WHITE FIGURES

Figure 1: Conventional Through Plate Girder Cross Section

Figure 2: Steel Box Girder Cross Section
Figure 3: Steel Stress

Figure 4: Mid Span Deflection
Area of Maximum Stress

Figure 5: Concrete Stress
Figure 10: Placement of Rails

Figure 11: Open for Business

Figure 12: Elevation of Bridge