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OPTIMUM DESIGN OF COMPOSITE STEEL I-GIRDER BRIDGES

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Abstract

In this study, the analysis and optimum design of composite steel I-Girder straight bridges were performed by CSiBridge package program. Optimum design of the bridge is made according to the AASHTO LRFD specification. The HL-93 truck in the AASHTO specification is considered as vehicle load. Two-span composite steel I-girder bridge was optimized for the application. The results obtained here are compared with the results of conventional bridge solutions.

Introduction

For analysis and design of steel composite I-Girder bridges, either Line-Girder solution technique or 3D precise analysis technique is used [1,2]. The CsiBridge package program uses a three-dimensional (3D) finite element analysis technique [3,4].

In this study, the analysis and optimum design of the two-span composite steel I-Girder bridge was carried out with the CSiBridge program. The problem is taken from reference [5]. Steel girder I section dimensions for positive and negative flexure regions are given in Figure 2. These cross-sections are nonprismically defined in the CSiBridge program.

Structure of composite steel I-Girder straight bridges

A two-span continuous composite I-girder bridge has two equal spans of 165 ft and a 42 ft deck width. The concrete slab is 9.5 inch thick. A typical 2.75 inch haunch was used in the section properties. Concrete barriers weighing 640 plf and an asphalt wearing surface weighing 60 psf have also been applied as a composite dead load. HL-93 loading was used per AASHTO, including dynamic load allowance. For steel I-girders, A709Gr50 steel with a yield strength of 345 N / mm^2 was used.

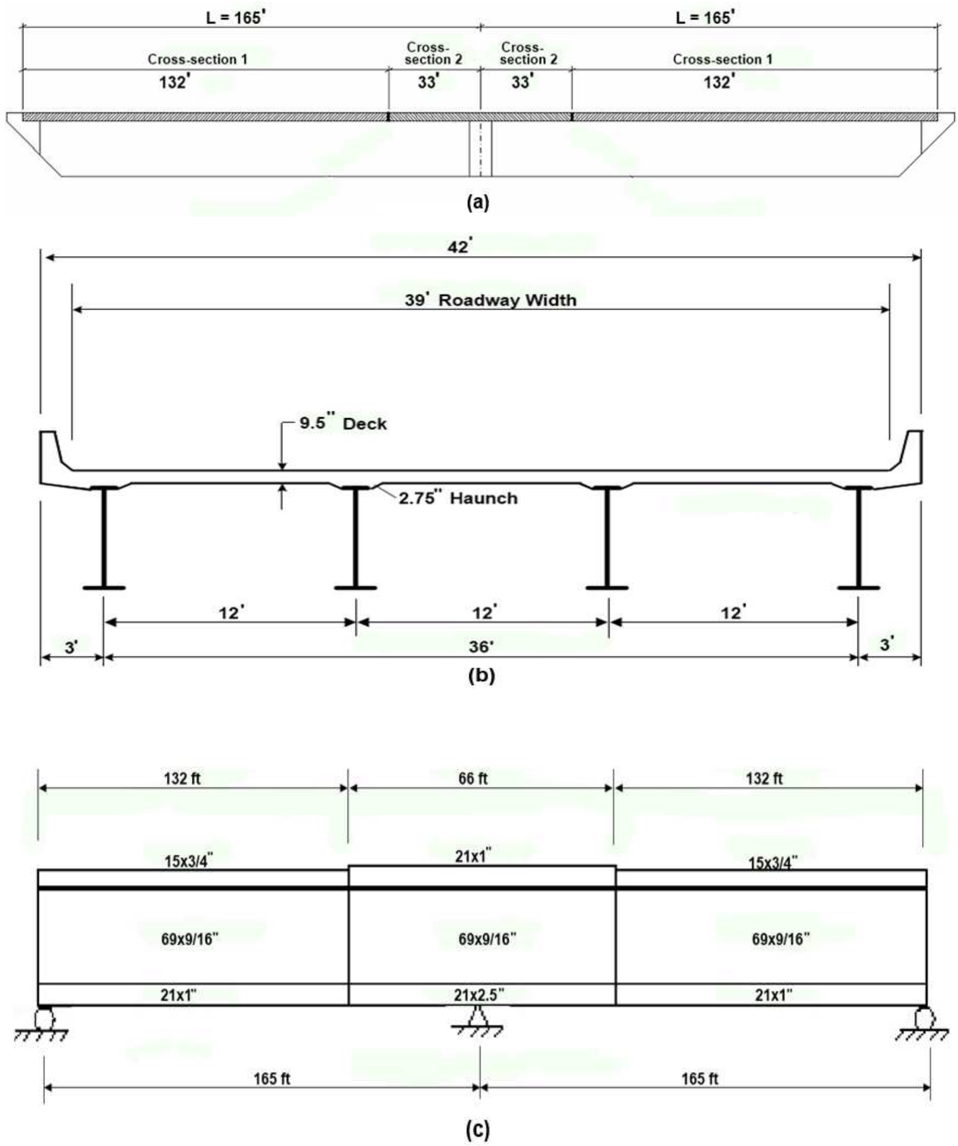

Fig. 1. Two-span composite steel plate I-Girder bridge a) Elevation b) Bridge cross-section c) Two spans non-prismatic I-girder

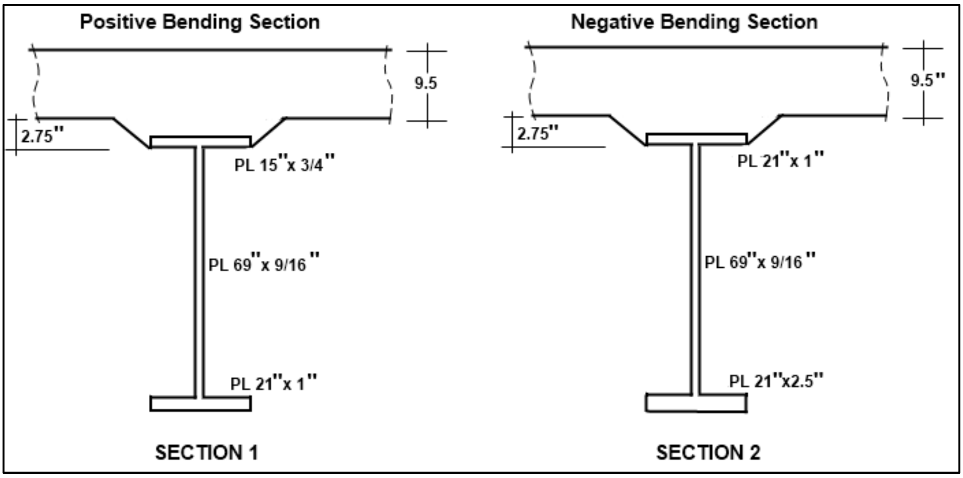

Fig. 2. Steel girder I section dimensions for positive and negative flexure regions

Optimization of the bridge

In the CSiBridge program it is possible to use the specifications of different countries for bridge design. The American AASHTO LRFD specification was used in this study [5,6]. This specification is transferred to the CSiBridge program as well as the bridge design formulas.

In this Study, it is aimed to minimize the weight of the bridge. In the figures given above, the weight obtained by the initial cross section of the bridge provides the limitations of the AASHOT LRFD specifications. In the optimum design of the bridge, stress and displacement limiters are generally dominant. However, limitations have been placed on the cross-sectional dimensions by the specification.

As Fig.1. shows, there are four steel girders on the bridge, two on the edge and two on the middle. Again, the cross-sectional areas in Fig. 2. are calculated as:

For section 1: $A_1 = 45847\ mm^2$

For section 2: $A_2 = 72460\ mm^2$

Since the bridge cross-section is non-prismatic, section 1 and section 2 lengths are; $L_1 = 80467$ mm, $L_2 = 20117$ mm.

The W_1 volume of a steel I girder beam is calculated as follows:

$W_1 = A_1 L_1 + A_2 L_2 = 45847 * 80467 + 72460 * 20117 = 51.5 * 10^8\ mm^3$

Since the system has four steel I-girder, the total beam volume is:

W = $4W_1$= $4*51.5 * 10^8 = \mathbf{2.06 * 10^{10}\ mm^3}$

(Since the density of steel is fixed, no account has been added.)

The optimum design problem of the bridge structure can be written as follows:

<u>The objective function:</u>

$$\min W = \sum_{i=1}^{n} \rho_i L_i A_i \tag{1}$$

<u>Subject to the constraints:</u>

- For displacement and stress:

$$\Delta_i \leq \Delta_{i,alw} \tag{2}$$

$$\sigma_i \leq \sigma_{i,alw} \tag{3}$$

- Cross-section proportion limits:

$$\frac{D}{t_w} \leq 150 \tag{4}$$

$$b_f \geq \frac{D}{6} \tag{5}$$

$$t_f \geq 1.1 t_w \tag{6}$$

$$b_{fc} \geq \frac{L}{85} \tag{7}$$

$$\frac{b_f}{2t_f} \leq 12.0 \tag{8}$$

$$0.1 \leq \frac{I_{yc}}{I_{yt}} \leq 1.0 \tag{9}$$

where A_i = area of the I-girder; ρ_i and L_i= the density and length of girder I, respectively; Δ_i= the displacement of joint i, $\Delta_{i,alw}$= its upper bound; σ_i= the stress in member i; $\sigma_{i,alw}$= the allowable stress; D = girder web depth; t_w= web thickness; t_f = flange thickness; b_f = width of flanges; b_{fc}= width of compression flange; I_{yc} = moment of inertia of the compression flange of the steel section about the vertical axis in the plane of the web; I_{yt} = moment of inertia of the tension flange of the steel section about the vertical axis in the plane of the web.

The optimum design of the bridge is made with the above stress and displacement limiter equations. In design, stress limiters were effective. The calculated stresses in the positive and negative moment regions approach the yield stress upper limit of the material (Figure 3):

$$max\ f_y = 315.32\ N/mm^2 < F_y = 345\ N/mm^2\ \surd$$
$$min\ f_y = 342.24\ N/mm^2 < F_y = 345\ N/mm^2 \surd$$

The AASHTO LRFD specification gives the L / 800 limit for general vehicles in maximum deflection calculations (L = girder span). The calculated deflection in the CSiBridge program did not exceed the maximum allowed deflection value (Figure 4):

$$\Delta = 45.63\ mm < \Delta_{max} = \frac{165 * 12 * 25.4}{800} = 62.865\ mm\ \surd$$

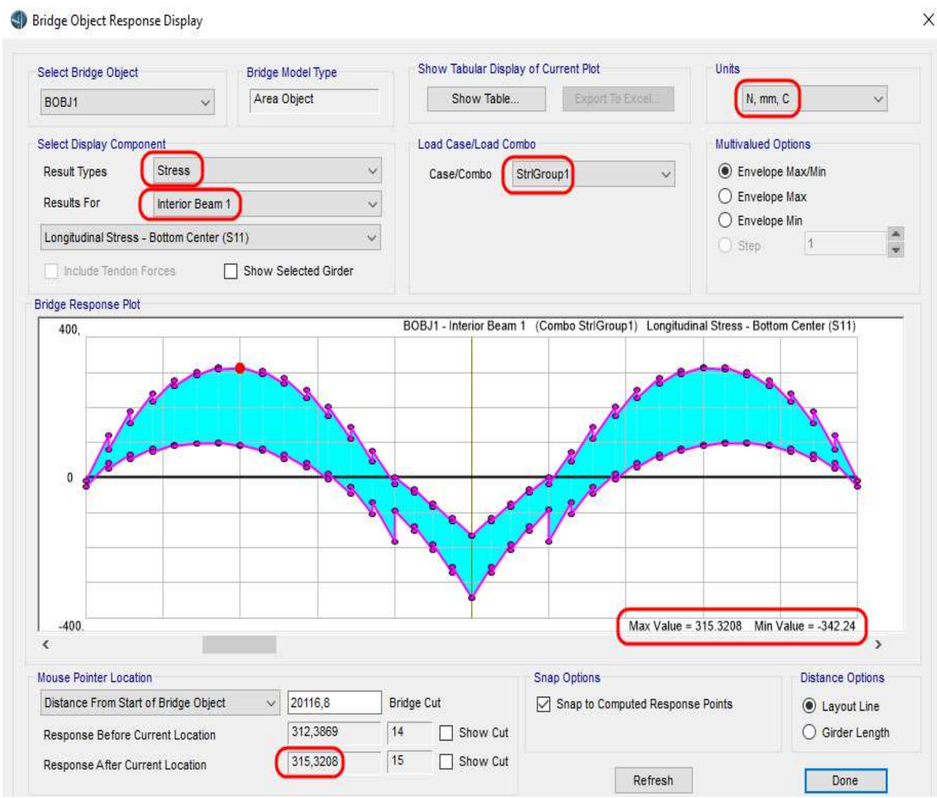

Fig. 3. Maximum stresses in positive and negative moment regions

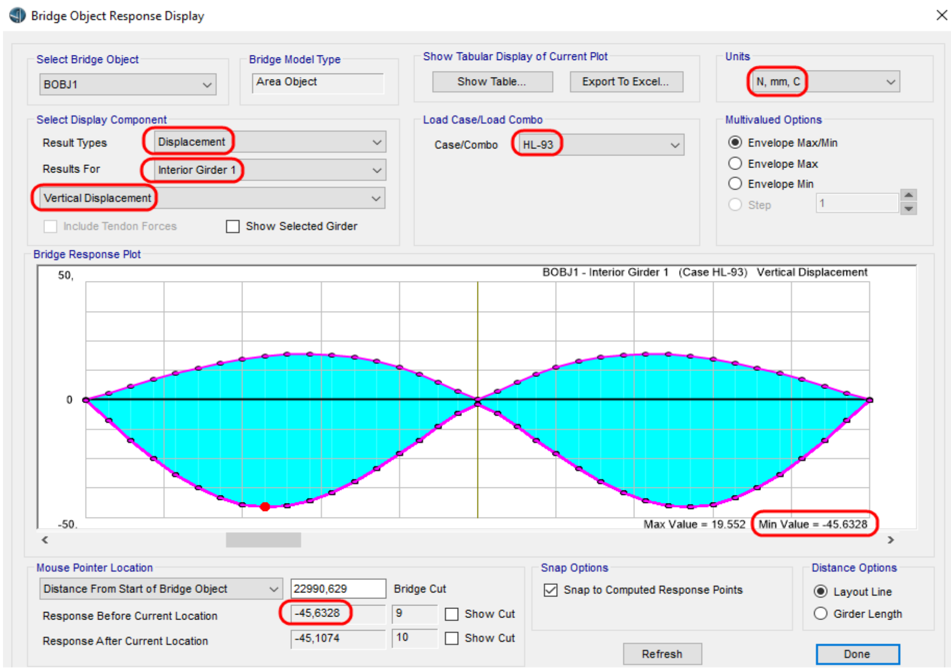

Fig. 4. The maximum displacement created by the HL-93 vehicle

The cross-sections providing the tensile and displacement limiters are given in Fig. 5. In the AASHTO LRFD specification, the limiter equations given for the cross-section web and flanges are also provided.

Here, it should be noted that the stress limiters are effective in the optimum design. It is seen that the displacement limiter is the passive limiter.

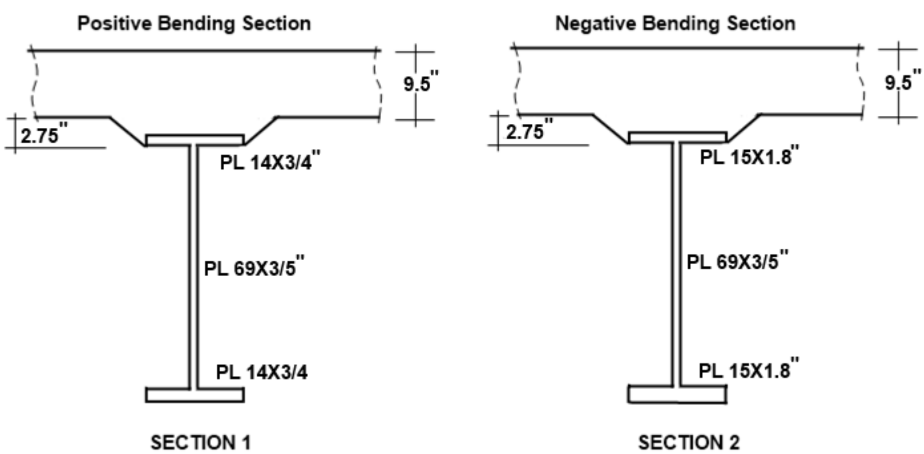

Fig. 5. Optimum sections providing stress and displacement limiters

The optimum cross-sectional areas in Figure 5 are calculated as follows:
For section 1: $A_1 = 40258\ mm^2$
For section 2: $A_2 = 61548.3\ mm^2$
The minimum W_1 volume of a steel I girder beam is calculated as follows:
$W_1 = A_1L_1 + A_2L_2 = 40258 * 80467 + 61548.3 * 20117 = 44.776 * 10^8\ mm^3$
Since the system has four steel I-girder, the total beam volume is:
$Min\ W = 4W_1 = 4*44.776* 10^8 = 1.791 * \mathbf{10^{10}\ mm^3}$
In this way, the weight of the bridge (2.06-1.791) / 1.791 = 0.15 saving is achieved.

Conclusions

Non-economical solutions are obtained in classical bridge analysis and design. In modern bridge design, there are optimum solutions. It is possible to obtain an infinite number of solutions with limitations established on the system. Only from these weights, however, minimum weighted design meets our purpose. This way, however, a safe and economical steel bridge design that meets all the limitations can be made.

In this study, the minimum weight of the composite steel I-Girder bridge was obtained under the subject specification limiters. Here, only the weight of the steel beams is minimized. Bridge deck weight is ignored for this problem.

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