

Transverse Analysis and Design of Box Girder Bridge by using STAAD.Pro

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Abstract. In this paper, a box girder bridge, made up of prestressed concrete and constructed by using cast in situ variable depth Balance Cantilever Method was used as a case study. The objectives were to analyse transversely and design the box girder bridge by using both Ultimate Limit State (ULS) and Serviceability Limit State (SLS). This study was only limited to one section of the box girder. STAAD.Pro software was used to analyse and design for both limit states. The results of both analyses were used for obtaining the amount of reinforcements needed and for checking the crack width limit. Hopefully, this paper can be used as a guideline for engineers in designing box girder bridge transversely.

1. Introduction

Bridge structures vary in term of many aspects as well as its computational analysis and design. In this paper, box girder bridge was chosen to be analysed and designed. The studied box girder here, was made up of prestressed concrete and the bridge was constructed by mean of cast in situ variable depth Balance Cantilever Method. Normally there are a few sections for one span of box girder bridge. But in this paper, only one section was analyzed.

This technical paper will only cover the transverse analysis of the box girder. The design is carried out in accordance with BS 5400 Part 4 [1], BD37/01 [2] and Design Statement whichever relevant and analysis of the sections have been conducted by using STAAD.Pro [3]. This paper will outline the geometrical configuration of the box girder section in question, the properties of the associated construction materials and reinforcement details and identify the loads applied to the section through modelling of the structure. A brief explanation of the modelling and analysis procedure, as well as any assumptions made will also be provided. The analysis of this section will identify the amount of reinforcement required within the section, subsequently enabling the reinforcement to be detailed appropriately. This task will be undertaken under ultimate limit state (ULS) conditions; however, crack widths will be checked under serviceability limit state (SLS) conditions.



2. Loading and geometrical configuration

All loads considered in the analysis of the sections are applied in conjunction with the Design Statement and in accordance with BS 5400 – Part C or BD 37/01 whichever is relevant. The loads under consideration in the transverse design of the deck sections are as outlined below:

a) The computation of dead load shall be based on the following load intensities: -

Concrete 24.5 kN/m^3 , Premix 22.0 kN/m^3 , Self-weight of slab,

Premix of 100mm thick, Super Imposed DL @ SIDL Loading = $0.10 \text{ m} \times 22 \text{ kN/m}^3 = 2.20 \text{ kN/m}^2$

Parapet: Parapet Cross Sectional Area = 0.30 m^2

Total Loading, (railing) = $0.30 \times 24.5 + 1 = 8.35 \text{ kN/m}$, say = 9.0 kN/m

b) The live load - HB45 will be generated and applied to the numerical model as moving load transversely and it is shown in Figure 1.

HB 45 = 4 axle 450kN each

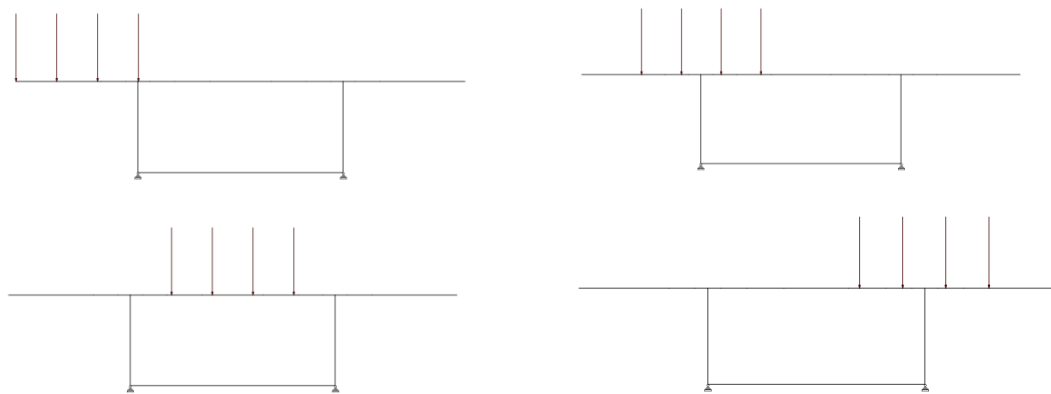


Figure 1: Moving load due to HB45

All the above loading will be combined and analyzed accordingly to the requirement stated in BD 37/01 to obtain the maximum and minimum forces on the structural elements under consideration.

Figure 2 shows the geometrical configuration of the Box Girder selected section (Section A-A), in which its section depth is 2750mm, top slab thickness 300mm, cantilever thickness 250mm, bottom slab thickness 400mm and web thickness 361mm.

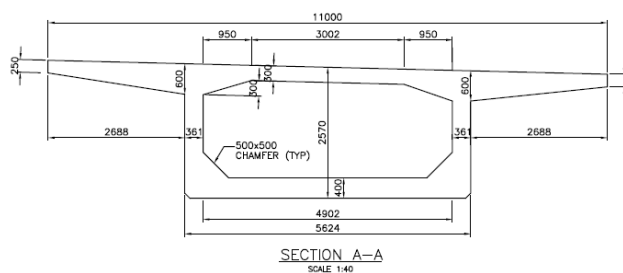


Figure 2: Geometrical configuration of Section A-A Box Girder

3. Transverse analysis of Box Girder Bridge – STAAD.Pro Model

For box girder bridge analysis, the segment is modelled transversely to represent box girder segment. The modelling was carried out by using STAAD.Pro software. One-meter length of the box girder is modelled by using beam element and illustrated in Figure 3. The model is subjected to load effect from dead load including weight of concrete, parapet and 100mm thick of wearing course. For maximum load

effect from traffic load, the box segment is subjected to HB 45 loading as moving load of 4-point loads in series with each one is 112.5kN. The geometric arching from haunches was considered in this model as recommended by Abdullah Zaid and David Collings [4]. They have concluded that this arching action can reduce the reinforcement amount in the deck slab. Thus, it must be considered for accurate analysis at both ultimate and serviceability limit states.

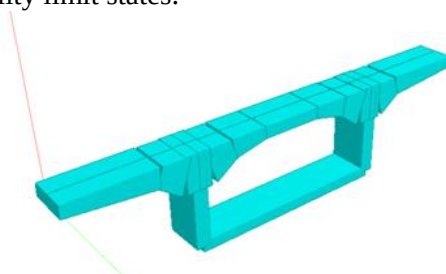


Figure 3: Numerical model for transverse analysis

The transverse model is formed of beam elements assigned with the appropriate material properties and depth. Figure 4(a) illustrates the node position in the model, whereas Figure 4(b) depicts its element numbering.

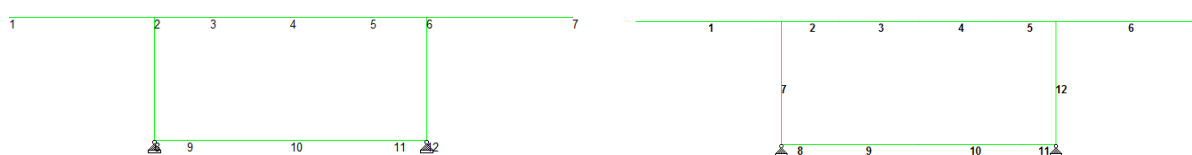


Figure 4: (a) Typical Node Position in STAAD Pro Box Girder Model (b) STAAD Pro Box Girder Model with the element numbering

Pinned supports are applied to the bottom slab at both ends and loads are applied on the span in accordance with the specifications of the design statement. SIDL and live loads are applied as uniformly distributed loads and point loads respectively as shown in Figure 5 and Figure 6. Whereas, Parapet loads are applied as point loads at the ends of the top cantilevers depicted by Figure 7.

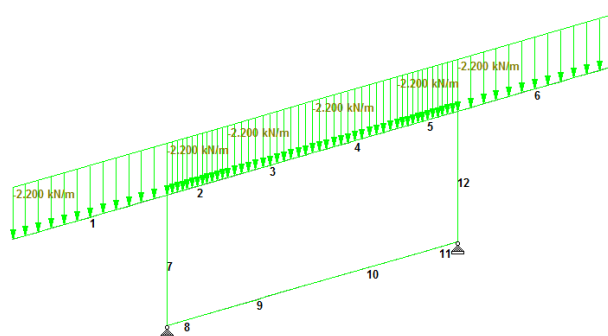


Figure 5: Uniformly distributed loads representing the SIDL

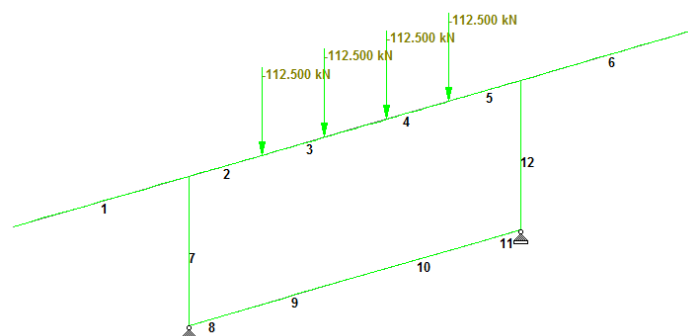


Figure 6: Point loads representing the live load (HB45)

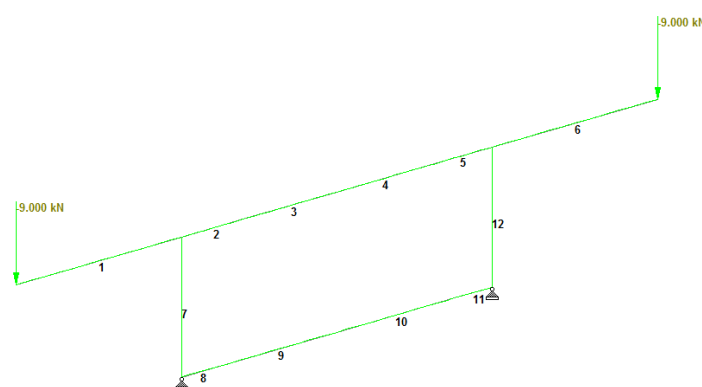


Figure 7: Point loads representing the Parapet

Stresses at five (5) points on bridge deck should be checked as stated by Theryo [5]. However, in this study, bending moments and shear forces are extracted at 4 specific points on the deck section as depicted in Figure 8 below.

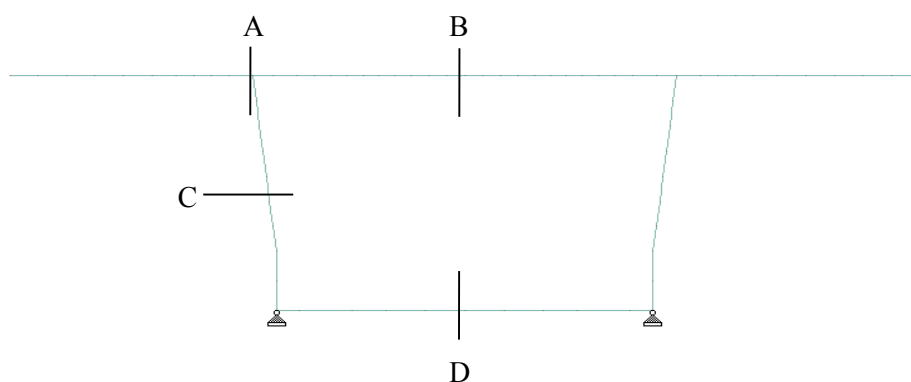


Figure 8: Four (4) points considered in the section

Cut Location: -

- | | |
|---|--|
| A | Cantilever at point of maximum depth at the web centreline |
| B | Top slab centre span |
| C | Web centre span |
| D | Bottom slab centre span |

The worst case of transverse Bending Moment and Shear Force values obtained from each load type being applied to the deck section are shown in Figure 9,10,11 and 12. The maximum positive moment was found to be at midspan, maximum negative moments at supports, maximum shear force at support and minimum shear force at midspan. According to Design Manual for Roads and Bridges, BD 37/01[1], the analysis and design for deck component of bridge shall satisfy the Serviceability Limit State (SLS) and Ultimate Limit State (ULS) under the chosen load combination.

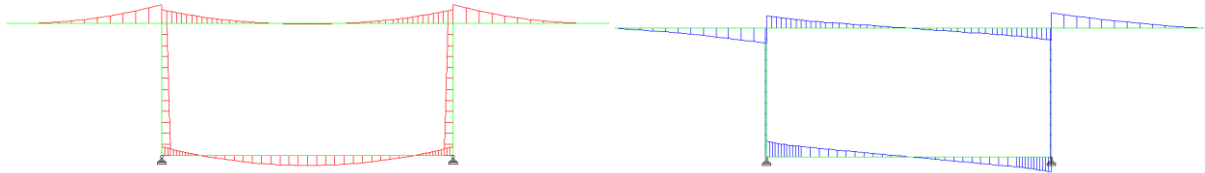


Figure 9: (a) Bending Moment Diagram (BMD) and (b) Shear Force Diagram (SFD) due to Selfweight

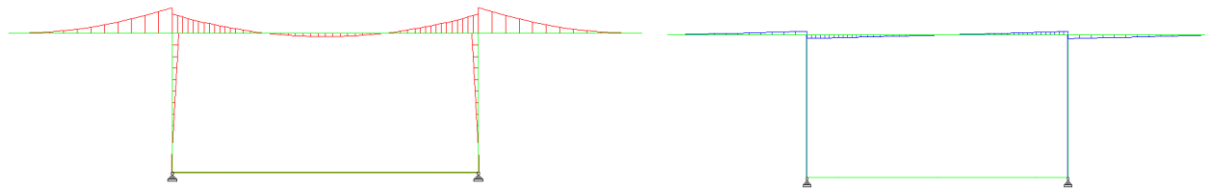


Figure 10: (a) Bending Moment Diagram (BMD) and (b) Shear Force Diagram (SFD) due to SIDL

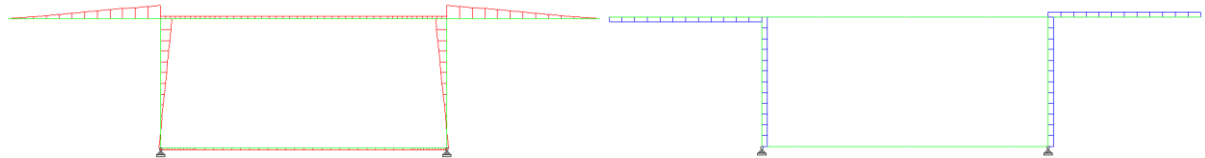


Figure 11: (a) Bending Moment Diagram (BMD) and (b) Shear Force Diagram (SFD) due to Parapet

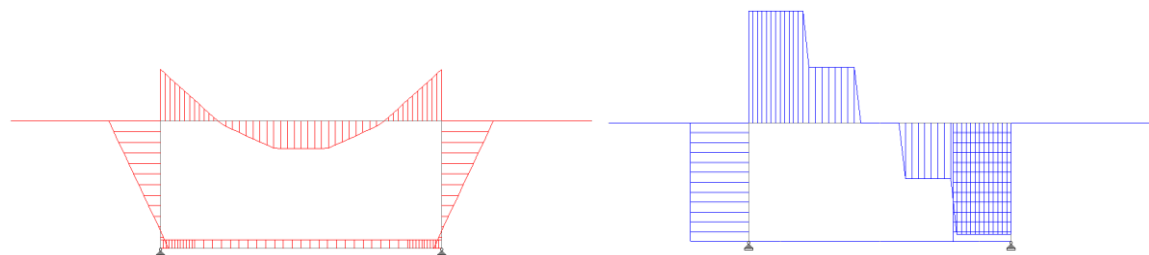


Figure 12: (a) Bending Moment Diagram (BMD) and (b) Shear Force Diagram (SFD) due to Live Load

4. Reinforced Concrete design - BS5400

In general, the design of reinforced concrete member is controlled by the ultimate limit state, whereas the limitation on crack width is controlled by the serviceability limit state. For the reinforcement properties, high yield deformed type with yield strength (f_y) value of 460 N/mm² was used, whereas for

the concrete, grade strength (f_{cu}) of 50N/mm² was used. According to BS 5400 Part 4 [1], nominal cover requirement and crack width limit for precast superstructure external and internal faces that shall be used are 30 mm and 0.25 mm respectively. For the slab section which is without compression reinforcement, the ultimate moment resistance shall be taken as the lesser of the values obtained from Equation 1 and Equation 2, whereas shear stress value is obtained from Equation 3.

$$M_u = (0.87 f_y) A_s z \quad (1)$$

$$M_u = 0.15 f_{cu} b d \quad (2)$$

Where

M_u is the ultimate resistance moment;

A_s is the area of tension reinforcement;

b is the width of section;

d is the effective depth to the tension reinforcement;

f_y is the characteristic strength of the reinforcement;

z is the lever arm $\left(1 - \frac{1.1 f_y A_s}{f_{cu} b d}\right) d$;

f_{cu} is the characteristic strength of the concrete.

$$v = \frac{V}{bd} \quad (3)$$

Where

V is the shear force due to ultimate loads;

b is the width of slab under consideration;

d is the effective depth to tension reinforcement.

No shear reinforcement is required when the stress, v , is less than $\xi_s v_c \times 2d/a_v$, but should not exceed $0.75(f_{cu})^{0.5}$ or 4.75 N/mm², whichever is lesser. Refer Equation 4.

$$\xi_s = \left(\frac{500}{d}\right)^{\frac{1}{4}} \quad (4)$$

The maximum surface crack width, w , for flexural is calculated in BS 5400 using Equation 5:

$$w = \frac{3a_{cr}\epsilon_m}{1 + 2\left(\frac{a_{cr} - c_{min}}{h - x}\right)} \quad (5)$$

The maximum crack width for tension is calculated from Equation 6:

$$w = 3a_{cr}\epsilon_m \quad (6)$$

where

a_{cr} is the distance from point (crack) considered to the surface of the nearest bar which controls the crack width;

c_{min} is the required nominal cover to the outermost reinforcement given;

x is the depth of the concrete in compression (if $x = 0$ the crack width should be calculated using Equation 6)

h is the overall depth of the section;

ε_m is the calculated strain at the level where cracking is being considered, allowing for the stiffening effect of the concrete in the tension zone; a negative value of ε_m should be obtained from Equation 7:

$$\varepsilon_m = \varepsilon_1 - \left[\frac{3.8 b_f h (a' - x)}{\varepsilon_s A_s (h - x)} \right] \left[\left(1 - \frac{M_q}{M_g} \right) 10^{-9} \right] \quad (7)$$

But not greater than ε_1

5. Results and discussion

Table 1 summarized the transverse analysis results from the STAAD.Pro, whereas Table 2 summarized the design results obtained accordingly. The maximum moment occurred at the haunch between the cantilever and top slab and the maximum shear force occurred at supports as expected. The crack limit check was found to be influenced by the applied service moment, modulus of elasticity of both concrete and steel, modular ratio, cover, concrete grade, reinforcement strength, diameter and spacing. The limit set by BS5400 is significant in ensuring the structure remains in the elastic phase under loading. All design checks were found to be satisfactory.

Table 1: Summary of STAAD.Pro analysis

Structural Element	Cut Section	Cases	ULS Envelope	SLS Permanent Load	SLS Live Load
Cantilever Max	A	Max Moment (kNm)	996	72	631
		Max Shear (kN)	542		
TopSlab	B	Max Moment (kNm)	495	38	311
		Max Shear (kN)	490		
Web	C	Max Moment (kNm)	502	35	320
		Max Shear (kN)	203		
BottomSlab	D	Max Moment (kNm)	74	12	41
		Max Shear (kN)	59		

Table 2: Summary of reinforcement design

Structural Element	Cut Section	Bending Check	Shear Check	Crack Width
Cantilever Max	A	PASSED	PASSED	PASSED
TopSlab	B	PASSED	PASSED	PASSED
Web	C	PASSED	PASSED	PASSED
BottomSlab	D	PASSED	PASSED	PASSED

6. Conclusion

Thus, it can be concluded that, the transverse analysis (STAAD.Pro) and design of the structural element in the box girder studied, were found to be satisfactory under both ultimate limit state (bending and shear check) and serviceability limit state (crack limit check) conditions specified by BS5400.

References

- [1] BS 5400-4:1990 Steel, concrete and composite bridges. Part 4: Code of practice for design of concrete bridges.
- [2] BD37/01: Design Manual for Roads and Bridges (2001), vol. 1, Highway Structures: General Design, Loads for Highway Bridges.
- [3] STAAD.Pro V8i, Technical Reference Manual (2012). Bentley System Incorporated.
- [4] Abdullah Zaid and David Collings (2016). Transverse Assessment of a Concrete Box Girder Bridge. Proceeding of the Institution of Civil Engineers.
- [5] Teddy S Theryo (2014). Segmental Concrete Bridges. Edited by Wai-Fah Chen, and Lian Duan, Bridge Engineering Handbook Second Edition - Superstructure Design (pp. 91-169). Boca Raton: Taylor & Francis Group.