Study on steel box girder with partial precast concrete deck by top-down method

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Abstract

Top-down construction method is one popular used method in constructing steel box girder throughout the world. But the existing method is uneconomical due to using closed rectangular section and full in-situ casting concrete in the deck. An open-trapezoidal steel box-girder cross section and partial precast concrete deck is proposed here. To evaluate practicability of this method, finite element computer model has been set up for simulating the behaviour of the continuous steel box girder during construction, and then the elastic stresses of steel and concrete during construction stages were analyzed by considering the full-scale model of bridge.

*Keywords: s*teel box girder, top-down construction method, precast concrete deck, finite element analysis

1 Introduction

Steel box girders have a proven high structural efficiency because of their large bending, torsion stiffness as well as rapid erection and therefore used in a wide variety of structural applications. Simultaneously many researchers carried out study on various performances of steel box girders [1-5]. However, they have comparatively big section, noise and vibration [6-8]. These defects can be reduced by using top-down construction method. Top-down method can be used for steel box girder and it can improve the bending stiffness in negative moment and make composite section at top and bottom flange by casting concrete at the bottom of the steel box girder. Moreover, it improves stiffness necessary for taking tension force when design load are applied, compressive stresses are induced in the negative moment area on upside of deck concrete. This method also connects separate beams to become a continuous bridge, thus prevents decay in the steel box by casting concrete at the bottom of the negative moment area and obtain effects that absorbed and vibrations [1,4].

However, the existing top-down method for steel box-girder is uneconomical because of using closed rectangular section and full in-situ casting of concrete in the deck. Therefore, an open-trapezoidal steel box-girder cross section and partial precast concrete deck is proposed in this paper. The open-trapezoidal with inclined faces give a better aesthetic appearance and aerodynamic than vertical faces. While the partial precast concrete deck give higher rigidity and stability of top flange, eliminate stiffener for top flange and save the time of casting concrete in field due to in-situ casting of concrete along a small length near the support. Besides that, some stiffeners at the bottom of the flange can be eliminated because the filled concrete prevents any local buckling of bottom flange. In order to evaluate practicability of this method, this study estimates analytically the elastic stresses of steel and concrete during construction stages by considering full-scale model of bridge.

2 Top-down construction method in continuous steel box-girder with trapezoidal cross section

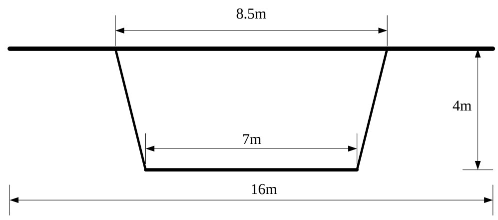

FIGURE 1 dimensions of trapezoidal cross section of steel-concrete composite box girder

A three-span continuous trapezoidal steel box girder bridge with 100m length of each span is considered. The sizes of trapezoidal cross section are shown in Figure 1 in which its height of 4m, deck width of 16m, box width of 7m at bottom and 8.5m at the Top. There are five longitudinal stiffeners at bottom flange as shown Figure 2. The K-frame bracings and vertical stiffeners are provided at every 5m along the length of the girder.

There are five stages in top-down method of bridge erection as shown in Figure 2. First, the separate pre-fabricated (pre-casted concrete elements a, c and e) beams are launched and supported on auxiliary supports as shown in stage 1. Secondly, they are connected with each other by welding. Thirdly, the concrete is casted in the field near supports at bottom flange (concrete elements f and g) as shown in stage 3, and after curing the concrete, the interior support are lifted upward by 1.20m. Fourthly, the concrete is casted in the field at the top flange (concrete elements b and d) as shown in stage 4, and interior supports are lowered by 0.95m (net height compared with initial position is 1.20-0.95=0.25m). Finally, the dead load and traffic loads are applied (service stage) as shown in stage 5.

In order to decrease the amount of costly steel material the web and flange have variable thicknesses due to the notable changing of the distribution of moment along the length. The thickness of concrete deck at the top flange is

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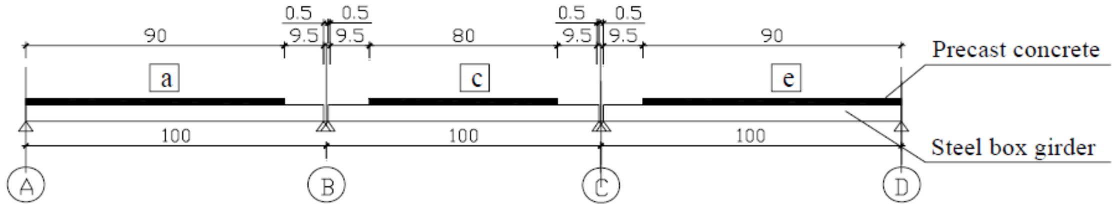
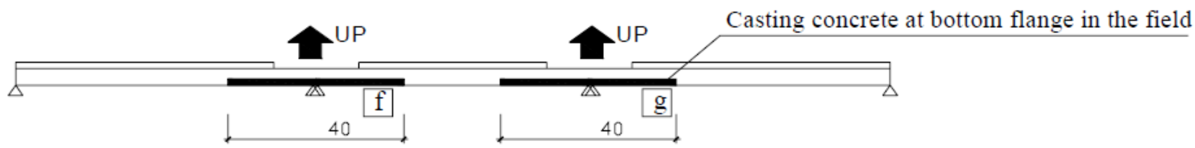
0.2m (average) while that of filled-concrete is 0.4m. Precast deck concrete is used at top flange 80m for interior span and 90m for exterior span. The properties of steel and concrete material are shown in Table 1.

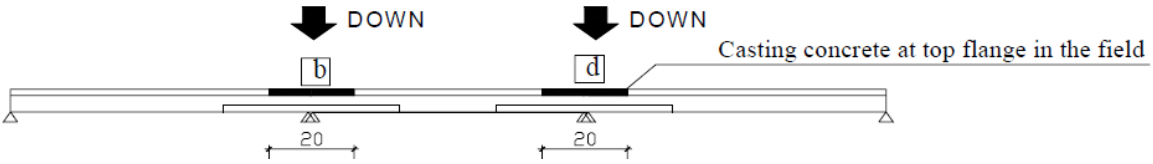


a) Stage 1: Install auxiliary supports, pre-fabricated components

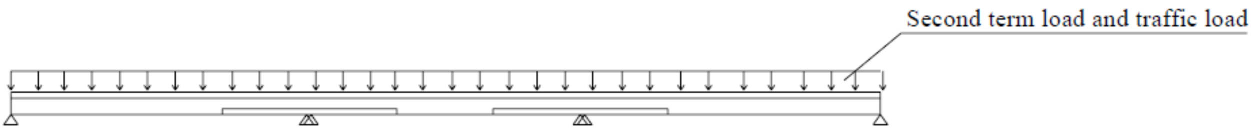
b) Stage 2: Carry out connections: connect steel joint



c) Stage 3: Lifting interior supports and then casting filled-concrete at bottom flange



d) Stage 4: Casting deck concrete at top flange and then lower interior support



e) Stage 5: Add the second term dead load and traffic load

FIGURE 2 Construction sequence (unit: m)

TABLE 1 Section properties

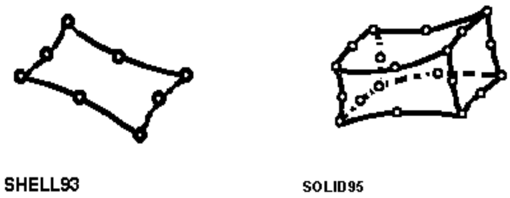
Material	Steel	Concrete
Elastic Modulus (kg/cm^2)	2.06x10^6	2.1x10^5
Poisson Ratio	0.30	0.1668
Density (kg/cm^3)	7.85x10^{-3}	2.5x10^{-3}
Yielding Strength (kg/cm^2)	3200	270(for top deck) 400(for bottom filled concrete)

3 Finite element modelling and analysis

As an approximate solution, Finite element method is one of the most useful ones in solving complex problems encountered in practical engineering. Also it is applied successfully in steel concrete composite box girders in some extent [9-11]. A finite element method was proposed to analyze the mechanical performance of flat steel box girder of cable-stayed bridge. In the method both beam element with six free degrees and shell element were employed to simulate different parts of girder simultaneously [11]. Learner Gara F and his team carried out much finite element analysis for steel-concrete composite box girder and obtained many useful achievements [9, 10]. However, little research has been done on the partially prefabricated steel-concrete composite box girder by top-down construction method.

Here ANSYS is used for modelling and analysis. ANSYS is a powerful finite element analysis software and is suitable for analysis of structure during construction because of its capability to kill and alive the element. Element Birth and Death is extremely suitable for the analysis of structures in top-down method. The 3D finite element program ANSYS is used to study the behaviour of continuous trapezoidal steel box-girder during construction. For the cross section of box girder 8-node shell element, SHELL93 is used. While the concrete is modelled by SOLID95 with 20-node solid element, and internal K-frame is modelled by BEAM4 with 3-D elastic beam.

Figure 3 displays elements Shell93 and Solid95 of ANSYS used in modelling and analysis. Figure 4 shows the section of modelled box girder after meshing, and Figure 5 shows the detailed connections among elements in ANSYS.



a) Shell 93 element b) Solid95 element

FIGURE 3 Applied finite element in ANSYS

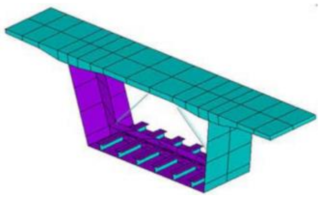


FIGURE 4 Model cross section in ANSYS

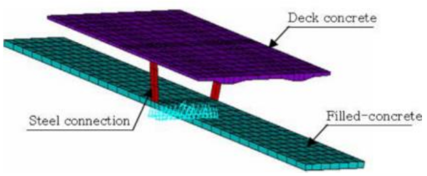


FIGURE 5 Connection detail in ANSYS

The majority of the loading during constructions come from self-weight with gravitational acceleration value about 9.8m/s^2. At service loading stage, a uniform loading is applied on entire deck concrete. The paper will focus on the longitudinal stress of steel box top and bottom plate and longitudinal stress of concrete deck as well as filled-concrete at each construction stage. The analysis results of only one and a half span bridge are presented due to symmetry.

4 Results and discussions

Table 2 and 3 show the maximum value of longitudinal stress of steel plate in top and bottom flange and that of concrete in top deck and bottom filled-concrete. The result indicates that all stress is less than the yielding strength 3200kg/cm^2 for steel and 270kg/cm^2, 400kg/cm^2 for deck concrete and filled-concrete, respectively. In order to identify further detail about the distribution of stress, stress values are illustrated in Figure 6. However, stress value increases rapidly near the support due to reaction forces at these locations. These values are local stresses and to outline the exact behaviour of the structure these stresses can be ignored.

TABLE 2 Stress in steel plate (unit: kg/cm^2)

Position			**Construction sequence**				**Service stage 5**
			1	*2*	*3*	*4*	
At middle span	Top section	1st span	-220	-204	-200	-194	-208
		2nd span	-251	-210	-205	-191	-205
	Bottom section	1st span	249	239	238	234	286
			-1112	-734	-658	-523	-669
		2nd span	239	217	215	207	252
			-1146	-368	-280	7	-3
At support	Top section	Support B	-	-265	-274	-475	-501
	Bottom section	Support B	-	-2584	1557	-1470	-1849

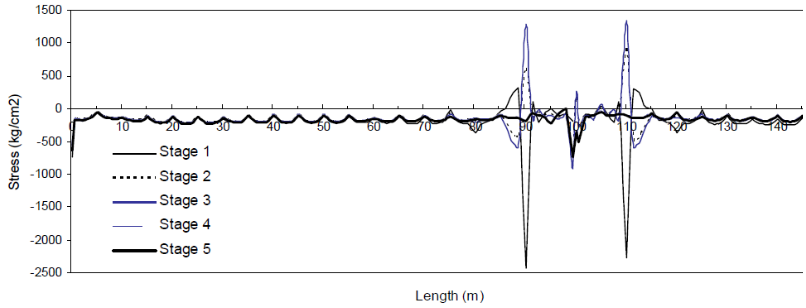
TABLE 3 Stress of concrete (unit: kg/cm^2)

Position		**Construction sequence**				**Service stage 5**
		1	*2*	*3*	*4*	
At middle span	1st span	-85	-84	-84	-84	-107
	2nd span	-89	-84	-83	-81	-104
At support	Support B	-	-	-230	-366	-380

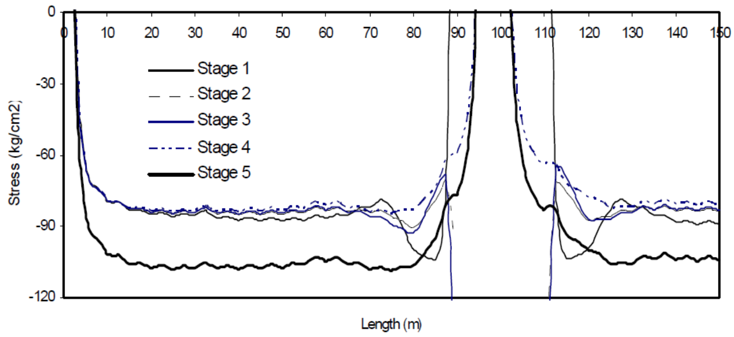
Figure 6a illustrates the variation of stresses in the top flange. The value is smooth except for the 10m segments located on both sides of the support 1 (segment b and d, see Figure 1). During stage 1 to 3, there is remarkable difference in stresses, however during stage 4 and 5 there is a little difference in stresses, the reason is that the segment b and d is casted in stage 4. In addition, about all stresses in top flange have negative values. The maximum value of stress (-251kg/cm^2) is in the middle top flange of second span in stage 1 and at the support, the maximum value of stress is -501kg/cm^2 in stage 5.

Figure 6b illustrates the variation of stresses in the bottom flange. The values change from negative to positive and vice versa. That means the transverse stiffeners behave like supports and stress values change their sign at these locations. The same result is with the top flange, there are remarkable difference of value in segment f and g. The maximum stress values of bottom flange at the middle span are 286kg/cm^2 (positive value) in stage 5 and -1146kg/cm^2 (negative value) in stage 1. The maximum value of stress at the supports is -2584kg/cm^2 in stage 1. The maximum value of stress is obtained in stage 1 instead of stage 5 because in stage 1 box-girder beams are separated while in stage 5 it is continuous beam and there is a redistribution moments.

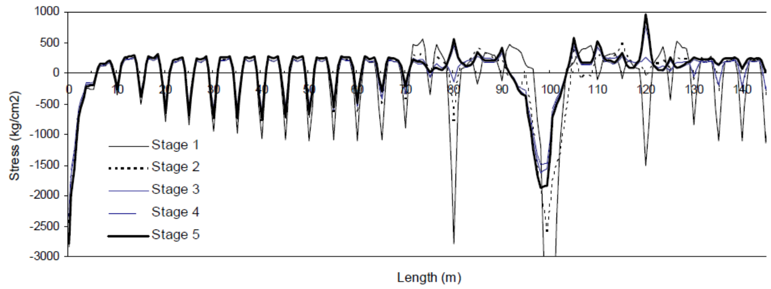
For the stresses in concrete material, Figure 6c illustrates the stresses of top deck concrete and Figure 6d illustrates the stresses of bottom filled-concrete. In segments a, c and e the stresses are almost the same during all construction stages. In segments b and d, the value of stress exist only in stage 4 and 5 due to pouring of deck concrete in these segments. The maximum stress value at the middle span is -107kg/cm^2 in stage 5. The maximum stress of bottom filled-concrete at the support is -380kg/cm^2 in stage 5 while average value of stress is about -200kg/cm^2. Concrete is filled inside the box girder only near the intermediate support, where the hogging bending moment is dominant. Therefore, the required length of filled-concrete is about 10% or 15% of span length.



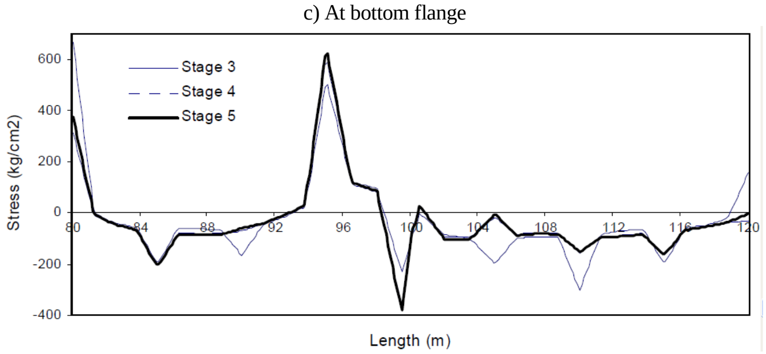
a) At top flange



b) At top deck concrete



c) At bottom flange



d) At bottom deck concrete

FIGURE 6 Stress of half-girder during construction

5 Conclusions

Top-down method for open-trapezoidal steel box-girder with partial precast concrete deck increases the bending strength of beam, reduces the section height, eliminates some stiffeners at top as well as at bottom flange, creates pre-stress in deck concrete at negative moment area, decreases noise and vibration due to composite design section at bottom and top flange of negative moment area and shortens construction time. Compared with existing top-down method for closed-box, the innovative method saves steel material due to smaller top flange area.

Therefore, the technique mentioned in this study has a significant economic value and social meaning to be recommended applying in construction of steel-concrete composite box girder bridges.

Acknowledgments

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