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Parametric Study on Behaviour Twin-I girder Bridge Systems with Cross-beams

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ABSTRACT

Application of twin I-girder bridge structure with cross-beams is rare in China. Such systems have only two main girders, and cross-beams are not connected to the deck within the span. In the paper, the behavior of twin-I girder systems is studied to find the parameters that affect the stability and capacities. The parameters include girder depths, flange width-to-thickness ratio, web depth-to-thickness ratio, number of stiffeners, and cross-beam spacing. The results show that flange width-to-thickness and web depth-to-thickness ratios are related to affect the failure mode of the systems; it is not economical to attach many stiffeners to improve the stability; Girder depth has a big effect to the material amount of the systems that a higher depth makes the system more economical when the girder depth design is not limited for traffic requirement; cross-beam location has some effect to the distortion of the system.
Keywords: twin-I girder, local buckling, stability, vertical displacement

1. INTRODUCTION

Twin I girder bridge structure systems have two main girders connected with cross-beams with limit cost use of steel, which is convenient for fabrication and erection, which is a good application for bridges with medium spans. Two types of cross-beams are used for a twin-I girder system including directly supporting cross-beam and cross-beam. For twin-girder cross-beam bridges, cross-beams are not connected with concrete deck within the span; for twin-girder directly supporting cross-beam bridges, cross-beams are connected to concrete deck within the span. In China, multiple-I girder bridge structure is mostly used in railway bridges in China. The application of twin I girder bridge in highway bridges is used but not a lot. Twin-I girder bridge structures are started to be designed and applied in practice recently. The traffic pattern and the design consideration of highway bridge structure are different from that of railway bridges. The design of twin-I girder bridges cannot be conducted according to design criteria in railway bridges. Usually twin I girder highway bridge has a large deck width, and the response is more significant than multiple-I girders.

I girder bridge system is used often in Europe, USA, and Japan [1-5]. Most designs use multi-girder systems [6]. For multi-girder systems, adjacent girder are connected by diaphragms or cross frames which supply large torsion stiffness [7]. Twin I girder application is mostly used in France in Europe [8 and 9]. Some guides are given to design the cross sections. The dimensions are given with some experience equations [8 and 9]. These provisions are limited and cannot be used to practice in

China.
In the paper, the parameters of girder are varied to find the effect to the behavior of the system. The parameters include girder depth, flange-thickness ratio, web depth-thickness ratio, stiffeners, and cross-beams.

2. FINITE ELEMENT MODEL

Three dimension analysis software ANSYS is used to develop analysis. Solid 45 elements are used to model concrete deck, and shell43 elements are used to model steel girders, stiffeners and cross beams. The model is shown in Figure 2.

The density of concrete is 26kN/m3, linear expansion coefficient is 1.0x10-5, Young's modulus is 3.45x104Mpa. Q345D is used for steel. The density of steel is 78.5kN/m^3， linear expansion coefficient is 1.2x10^{-5}， Young's modulus 2.1x10^{5}Mpa.

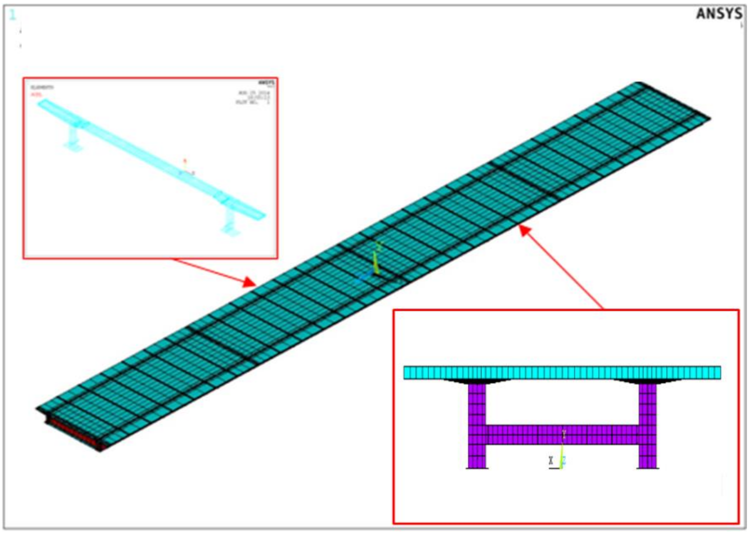


Figure 1　Finite element model of twin-I girder bridge

3. STUDY ON SAME SECTION AREA

The study is developed based on a twin I girder bridge with four spans of 35m. The girder spacing is 7.225m. The precast concrete deck width is 13.25m with an overhang of 2.9m. Figure 1 shows a typical cross section of cross-beam twin-I girder system.

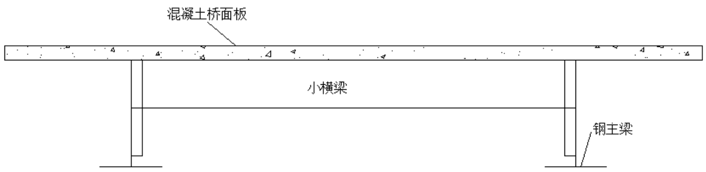


Figure 1 Cross-beam twin-I girder

Four types of girder depths are designed including 1.25m,1.50m,1.75m, and 2.0m. The designs following the rules below:

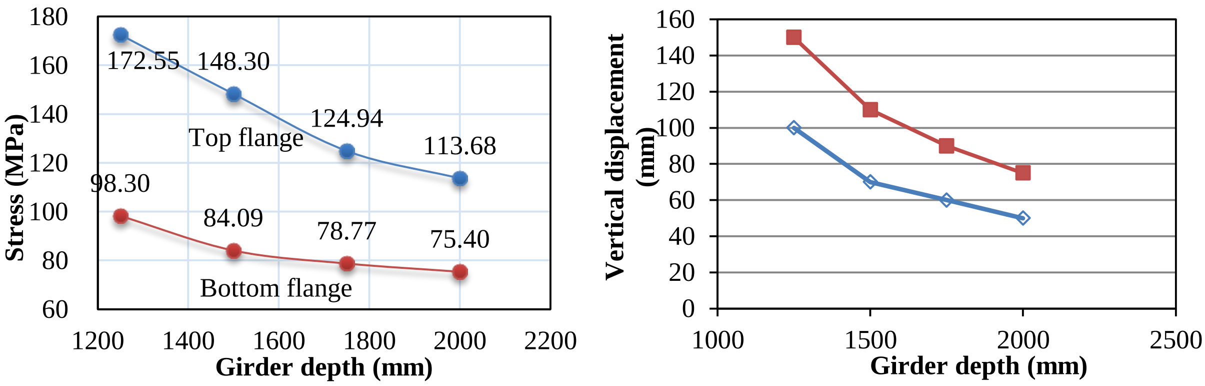
1) Web depth-thickness ratio is not smaller than 120, and the minimum thickness is 14 mm;
2) Flange width-thickness ratio is not bigger than 12;
3) Flange width is typical.

Table 1 shows cross section dimensions for different depths.

Table 1 Cross section dimension based on same section area

Span *L* (mm)	35000			
Girder depth *h (mm)*	2000	1750	1500	1250
Web thickness t_f *(mm)*	18	16	14	14
Top flange width d_s *(mm)*	740	790	830	840
Top flange thickness t_s *(mm)*	24	26	26	28
Bottom flange width d_d *(mm)*	1070	1150	1180	1230
Bottom flange thickness t_d *(mm)*	34	36	40	40
Web depth-thickness ratio h/t_f	111.11	109.38	107.14	89.29
Top flange-thickness ratio d_s / t_s	15.42	15.19	15.96	15.00
Bottom flange-thickness ratio d_d / t_d	15.74	15.97	14.75	15.38
Section area *A* (mm^2)	89096	88948	88856	89268
Moment of inertia I_s (mm^4)	5.98E+10	4.86E+10	3.65E+10	2.61E+10
ENA from section top	1202.48	1073.31	957.20	796.35

Figure 2 shows the stress and displacement response for different girder depths. In Figure 1a, the stress in top and bottom flange increase along with the decrease of girder depth; in Figure 1b, the displacement increases with the decrease of girder depth. When girder depth is smaller, the stress in the section is much larger than that with girder depth is bigger.



a) Stress of noncomposite state for different depth b) Displacement for different depth

Figure 2 Stress and displacement response comparison

From the section properties and response of different girder depth, girder section with higher depth has smaller stress and displacement response than that with lower girder depth under the condition that same material is used. In other way, with the same stress requirement, girder with higher depth may save material which is more economical.

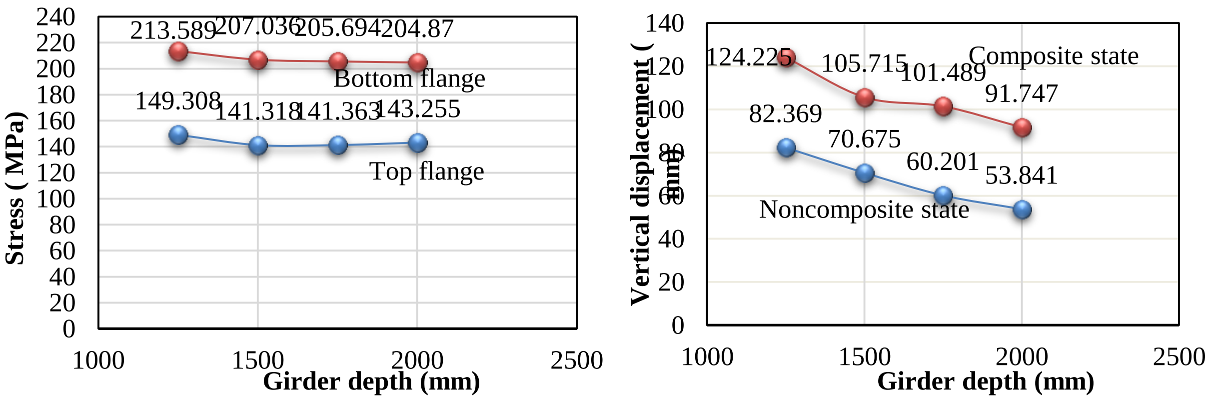
4. STUDY ON SAME STRESS REQUIREMENT DESIGN

4.1 Girder depth

Based on the conclusion of comparisons in the previous section, another four types of sections are redesigned to make each section have similar stress and displacement response under the same load condition. Table 2 shows the cross section dimension based on same stress requirement.

Table 2: Cross section dimension based on same stress requirement

Span *L* (mm)	35000			
Girder depth *h (mm)*	2000	1750	1500	1250
Web thickness t_f *(mm)*	20	16	14	14
Top flange width d_s *(mm)*	600	700	800	920
Top flange thickness t_s *(mm)*	25	30	34	40
Bottom flange width d_d *(mm)*	800	900	980	1100
Bottom flange thickness t_d *(mm)*	34	38	42	46
Web depth-thickness ratio h/t_f	111.11	109.38	107.14	89.29
Top flange-thickness ratio d_s / t_s	12.00	11.67	11.76	11.50
Bottom flange-thickness ratio d_d / t_d	11.76	11.84	11.67	11.96
Section area *A* (mm^2)	81020	82112	88296	103696



b) Stress of composite state for different depth b) Maximum displacement for different depth

Figure 3: Stress and displacement response comparison

Figure 3 shows the stress and displacement response for different girder depths. As shown in the figure, the stresses in top and bottom flanges are similar for each depth. The maximum vertical displacement for girder system with smaller depth is larger than that with higher depth.

Table 3 shows the stability coefficient for different girder depths. For these four types of girder sections, the systems have similar stability, which is corresponding to similar response. Based on the stress, displacement and stability results, based on similar response requirement, the girder system with higher depth is stiffer than that with lower depth.

From the area of main girders, it seems the higher girder section saves more material. Including the material of cross-beams and stiffeners in the system, the steel material used in the system is compared in Figure 4. From the comparisons, to save steel material without consideration of girder depth, girder depth is better to use about 1/20 of the span.

Table 3: Stability coefficient for different girder depths

Girder depth （mm）	Elastic stability coefficient (noncomposite state)	Elastic stability coefficient (composite state)
2000	451	4.31
1750	4.39	4.10
1500	4.71	4.32
1250	4.65	4.22

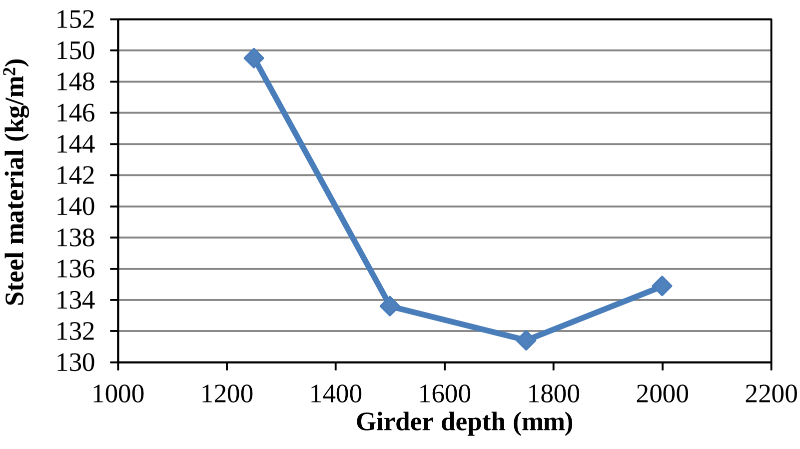
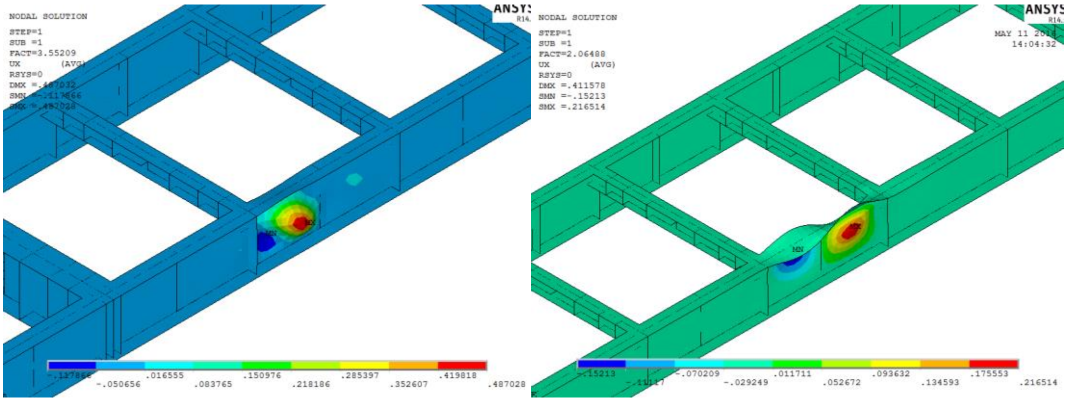


Figure 4: Steel material comparison for different girder depths

4.2 *Flange width-thickness ratio*

For cross-beam twin girder system, local buckling often occurs. Figure 5 shows two possible local bulking modes that happen including local buckling of web and flange. Different flange width-thickness ratio is key parameter that affects the response of the system. Different flange width-thickness ratios from 8 to 12 is studied and compared.

Figure 6 shows the stability coefficients for different flange width-thickness ratios. The stability coefficient becomes stable when flange width-thickness ratio is smaller than 12; when width-thickness ratio is larger than 12, the stability coefficient decrease fast. Different buckling modes occur with different flange width-thickness ratios. When the ratio is smaller than 11, web buckling occurs.



a) Local buckling of web b) Local buckling of flange

Figure 5 Local buckling of twin-I girder bridge under construction condition loading

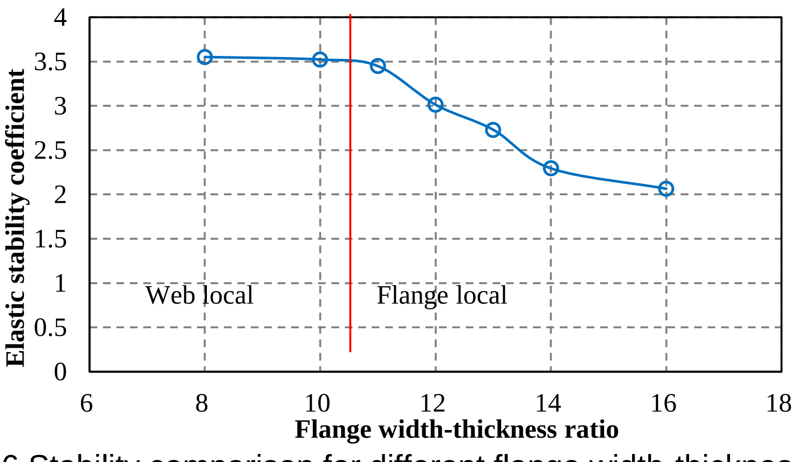


Figure 6 Stability comparison for different flange width-thickness ratios

4.3 Web depth-thickness ratio

Different web depth-thickness ratios are studied from 90 to 180. Figure 7 shows the stability comparison results. When depth-thickness ratio is smaller than 100, the stability coefficient increase fast; for depth-thickness ratio between 100 and 120, the stability coefficient varies slightly; when the ratio is larger than 150, the stability coefficient doesn’t change.

4.2

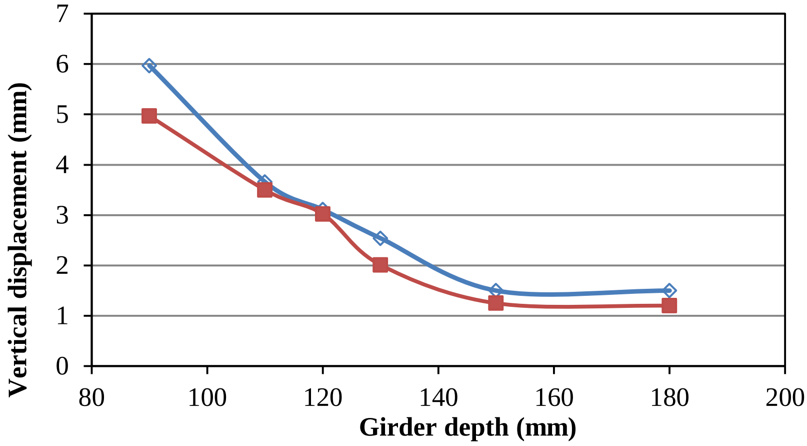


Figure 7 Stability comparison for different web depth-thickness ratio

4.4 Stiffener spacing

The effect of stiffener thickness and spacing is studied. The thickness results show that stiffener thickness has small effect to the system behavior. Figure 8 shows the comparisons for different stiffener spacing. Web aspect ratio denotes the ratio of distance between stiffener and web depth. The results show that when the stiffener spacing is smaller than girder depth, the stability coefficient is much larger. But when the spacing is larger than 3 m, the stability coefficient varies slightly. Therefore, the stiffener spacing is not needed to be small or number of stiffeners is arranged a lot.

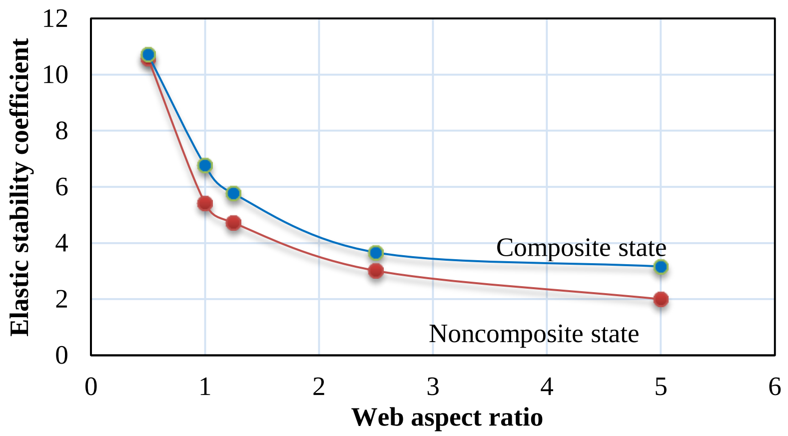


Figure 8 Stability comparison for different stiffener spacing

4.4 Cross-beam

The effect of cross-beam spacing and location is studied. Table 4 shows the displacement and stress results for different cross-beam spacing. The results show that the transverse displacement and relative displacement increase with the increase of cross-beam spacing. The stress in the girder varies a little with the variation of cross-beam spacing.

Table 5 shows the displacement and stress results for different cross-beam location. The cross-beam is more near to the girder bottom, the transverse displacement and relative displacement decrease. The stress in mid-span is not sensitive to the location of cross-beam. But the stress at support varies, and the difference is up to 20 MPa. Therefore, the cross-beam is suggested to arrange near girder bottom.

Table 4 Stress and displacement response for different cross-beam spacing

Cross-beam spacing (mm)	Maximum transverse displacement (mm)	Relative transverse displacement (mm)	Stress at mid-span (MPa)	Stress at support (MPa)
2.5	4.184	0.048	176.224	206.170
5	4.317	0.274	175.813	203.582
8.75	4.492	0.495	178.220	202.484
17.5	4.748	0.845	182.144	201.690

Table 5 Stress and displacement response for different cross-beam depth

Location from girder bottom flange (mm)	Maximum transverse displacement (mm)	Relative transverse displacement (mm)	Stress at mid-span (MPa)	Stress at support (MPa)
400	4.317	0.274	175.813	203.582
900	4.702	0.457	175.731	210.100
1300	5.392	0.134	175.55	220.423

5. CONCLUSIONS

In the paper, a parametric study is developed to study the response of twin I girder systems. From the analysis results and comparisons, some conclusions are made as follows:

1) Different girder depth can be used for twin-I girder bridge systems; Girder depth has a big effect to the displacement and steel material of the system.
2) Flange width-thickness ratio can affect the failure modes of the system; when depth-thickness ratio is smaller than 100, the stability coefficient increase fast; for depth-thickness ratio between 100 and 120, the stability coefficient varies slightly; when the ratio is larger than 150, the stability coefficient doesn't change.
3) Stiffener spacing has an effect to the system, but it is not necessary to arrange many stiffeners.
4) Cross-beam location can affect the transverse displacement and stress at support, and it is better to arrange near girder bottom.

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