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Analysis of torsion stiffness and eccentric-loading effect for cable-stayed bridge with large width-to-span ratio

Wang Bingjian & Lu Jianming
Research Institute of Highway the Ministry of Communications, 100088, China
ZhaoYimin, Qi Xueda, WangYi & YuYamei
Manage Bureau of Lu-Shan Bridge

Abstract

The single cable plane does not provide torsion resisting for main girder of the cable-stayed bridge. During the structural analysis of cable-stayed bridges with large ratio of width-to-span under construction, some specific problems arise which are not common in other types of bridges. One of the problems is the influence of eccentric loading on the structural integrity of the bridge. This paper presents a finite element analysis for the systematic construction sequence simulation of cable-stayed bridges with a large ratio of width-to-span. The objective of this simulation is to evaluate the torsion-stiffness and short-term influences of the construction sequence on the structural integrity of the cable-stayed bridge with H-type and I-type python. Short-term effects, as defined here, are eccentric load occurring during the construction process such as the cranes. This method is applied to the specific example of the Lu-Shan Bridge under construction.

Keywords: bridge, cable-stayed, torsion-stiffness, eccentric load

1 Introduction

At present, we are in charge of the work of construction monitoring and control of the main bridge of Mountain Lu bridge, which is a cable-stayed bridge with a large ratio of width-to-span. Mountain Lu bridge is located in Hangzhou. Its total length is 1502m. The main bridge is a cable-stayed bridge with I-type pylon and harp shape arrangement cable-stayed. It consists of one 256 meters long main span, two 118 m long side spans, and one 505 m long approach span on the one side. The main span of the bridge provides more than 8 m of vertical clearance over the navigational channel. Carrying two-way traffic, the bridge has four 3.75m wide vehicle lanes plus two narrower bicycle lanes. The total width of the bridge deck is 33m as shown in Figure 2 for a typical cross section. At the intersections of the deck and the pylons all the degrees of freedom are coupled. The deck is composed of one longitudinal built-up five-cell single box girder structure of three-way prestressing system. A concrete barrier is located in the center and each side of the bridge, and two railings and additional concrete barriers are located along the edges of the deck.

The most important design concept behind the bridge is that we should maintain a harmonious relationship between the engineering project and the natural environment. The profile of the bridge looks fluent and elegant, without any assist pier or other structures below the deck. This way of design can give a wider boat lane, and a better view for the passengers to enjoy a picturesque background, i.e., the Lu Mountain, the most famous park in the city. VR Picture of Mountain Lu Bridge is shown in Figure 1.

Figure 1, VR picture of mountain Lu Bridge

Mountain Lu Bridge is very wide, and has no assist piers. So, the anti-torsion ability during construction has drawn most of our attention. For the feasibility of construction as well as the aesthetic reason, the I-type python with a single cable plane was used in the structure, which increased the shortcomings in anti-torsion. Meanwhile, during the construction procession, some eccentric loading such as cranes will be used and put on the bridge for the feasibility of construction. So the eccentric loadings and the anti-torsion ability should be considered. So as to evaluate its torsional characteristics, 3D FEM analysis is necessary. We have developed Analysis System of Bridge Testing (Chinese name abbr. QLJC) and established 3D FEM model at the maximum cantilever stage on Mountain Lu Bridge construction. This paper will present the 3D FEM model and compare torsion analysis results between two different types of bridges with I-type and H-type python.

2 Finite element model

The size of section deck and pylon as well as span arrangement of Mountain Lu Bridge is shown in Figure 2. QLJC's 3D FEA model of the maximum cantilever stage is shown in Figure 3. This is the original model and its pylon is I-type, the space between two cable planes is 1.2m. In order to investigate the torsional characteristics at different models, another QLJC's 3D FEA model of the maximum cantilever stage is shown in Figure 4. This is the counterpart model and its pylon is H-type. The space between two cable planes is 24m. During the construction, a crane with a weight of 1200KN will be put on the structure for the feasibility of construction. So the eccentric-load (1200kN) of two models is applied at the end of one cantilever. The right eccentric distance is 11m to check for the safety. Furthermore, accurate spatial and temporal estimation of wind loads on structures also plays an important role in the evaluation of the anti-torsion ability of the structure. However we will not consider this factor in the paper. Moreover, the eccentric-load is confined to the crane load. The girder and pylon of cable-stayed bridge are meshed with 3D solid element and the cable is meshed with 2 nodes link element. Girder, pylons and cables are connected with constrain equations of node displacements. 3D solid element adopted in QLJC is isoparametric element with 12 nodes, which fits bridge structure of slim structure with small size on cross section and large size on longitudinal section.

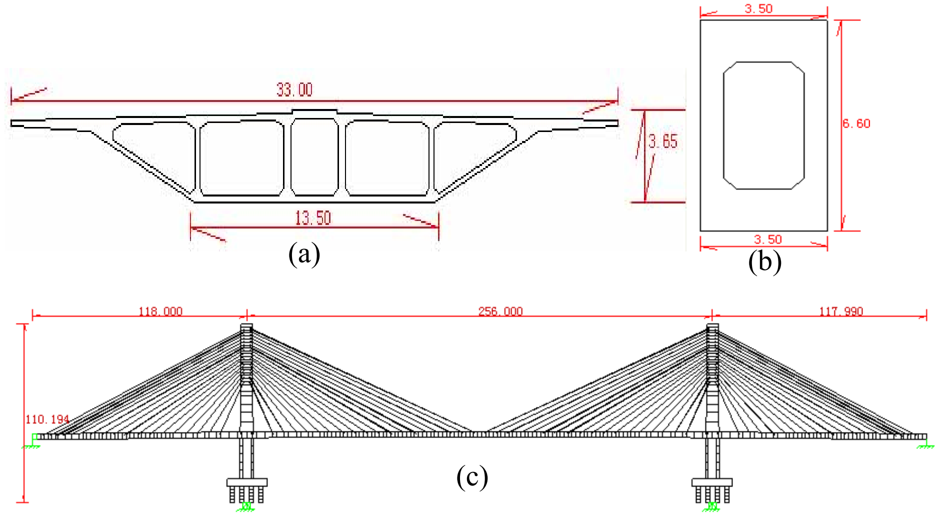

Figure 2, Deck Section (a), pylon section (b) and span arrangement(c) of mountain Lu Bridge

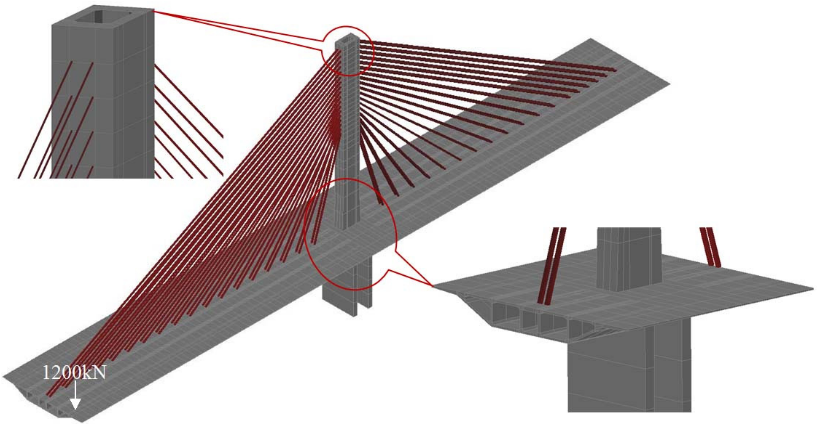

Figure 3, 3D FEA model of I-type pylon

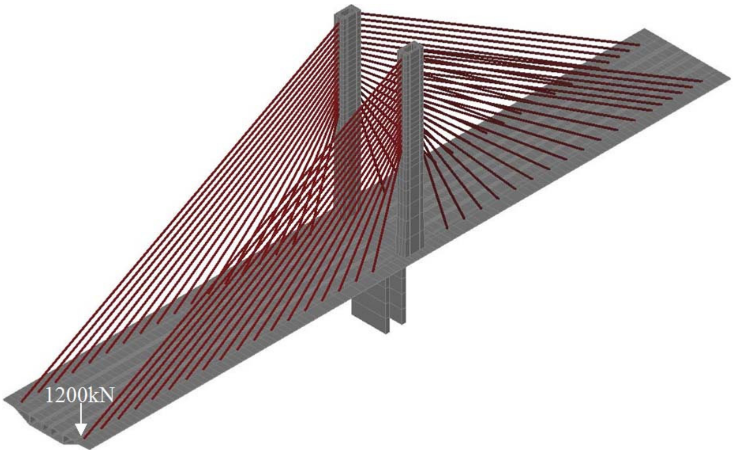

Figure 4, 3D FEA model of H-type pylon

3 Numerical results

The displacement value of two models based on GQJC analysis results which eccentric-load (120t) is applied at the end of one cantilever is shown in Table 1. Displacement nephogram of the two models is shown in Figure 5 and Figure 6.

Table 1. Displacements (unit: m)

No.	Position	Direction	I-Pylon	H-Pylon
1	cantilever end left 12m	vertical	0.649	0.648
2	cantilever end center	vertical	0.661	0.660
3	cantilever end right 12m	vertical	0.679	0.678
4	tower top center	horizontal	0.0222	----
5	tower top left 12m	horizontal	----	0.0190
6	tower top right 12m	horizontal	----	0.0208

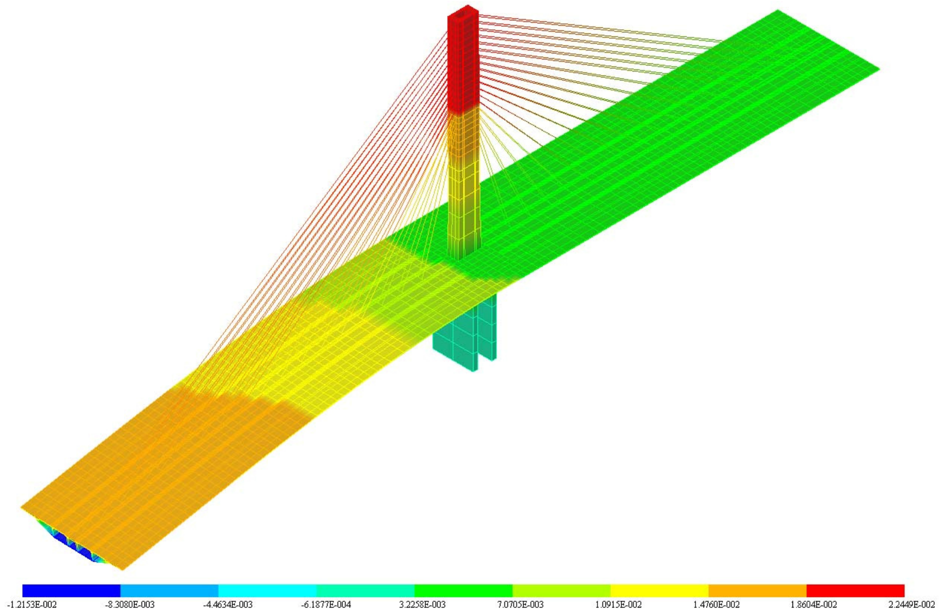

Figure 5, Displacement (magnify 25) nephogram of I-type pylon model

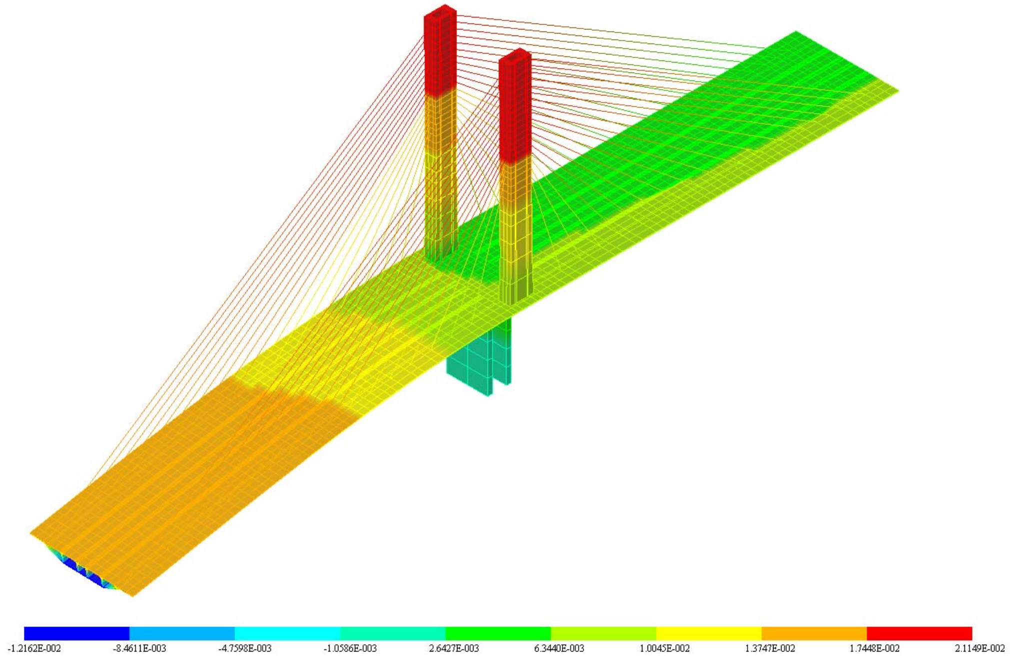

Figure 6, Displacement (magnify 25) nephogram of H-type pylon model

The section normal stress nephogram of I-type pylon model is shown in Figure 7. Z=11.5m means that the distance in side of loading from the section to the center of pylon is 11.5m. The normal stress value of two models based on the GQJC analysis results is shown in Table 2. Section of H-pylon is similar to I-Pylon.

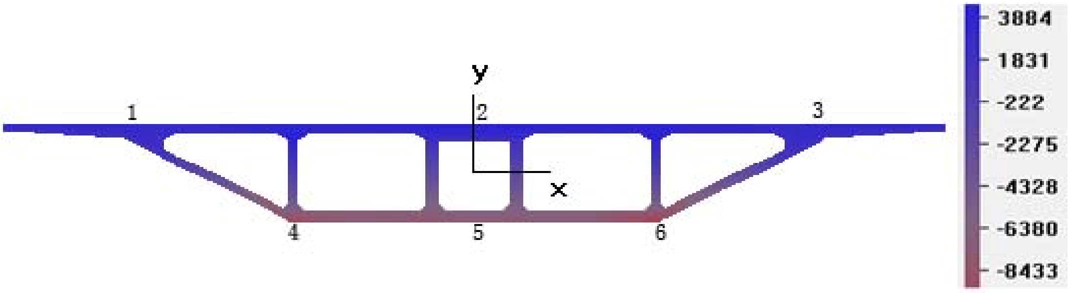

Figure 7, Section normal stress nephogram of I-type pylon model (Z=11.5m)

Table 2. Normal Stress (unit: MPa)

No.	X(center distance; right+;left -)	Y(section top distance)	I-Pylon	H-Pylon
1	-12	0.1	3.44	3.48
2	0	0.1	4.04	3.94
3	12	0.1	3.81	3.85
4	-6.5	3.35	-11.50	-11.50
5	0	3.35	-6.97	-6.95
6	6.5	3.35	-13.00	-13.00

Since the girder is meshed with 3D solid element, the analysis results of 3D solid element only have stresses and displacements. The torsional moment of the girder can't be obtained directly, so we must integrate shear stress of the section to get the torsional moment of the girder. Some integral results are shown in Table 3. Z in table 3 is the distance in the side of loading from the section to the center of pylon.

Table 3. Torsion moment (unit: kN.m)

No.	Z (m)	I-Pylon	H-Pylon
1	11.5	1207	1358
2	31.5	1663	1659
3	51.5	1811	1811
4	71.5	1805	1805
5	91.5	1820	1820
6	111.5	562	562
7	126.5	506	506

4 Conclusion

The numerical results indicate that, at the maximum cantilever stage of the bridge, the torsion moment endured by the main girder of the I-Pylon is almost the same as that of the H-Pylon. The displacement results show that the stiffness of I-Pylon structure is identical to H-Pylon in vertical direction. The normal stress results show that the torsion moments have some influence on the cable-stayed bridge with a large width-to-span ratio in construction. So as to this type of cable-stayed bridge with large width-to-span ratio, its safety must be given due attention to avoid eccentric loading in construction process. As to the cable-stayed bridge, wind load also play an important role in eccentric effect. Therefore, its effect calls for further analysis.

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