Trial design of tied CFST arch bridge with steel web PC tied beam

Chao Sun, Fan Zhang and Baochun Chen
College of Civil Engineering, Fuzhou University,Fuzhou, China

ABSTRACT: The tied beams of tied CFST arch bridges are usually PC beams, heavy self weight of the beam resulting difficulty in construction. In this paper, steel web PC beam is introduced into the tied CFST arch bridge as the tied beam in order to reduce the self-weight of the bridge. Steel web PC beam or girder is a new composite structure in which the web is corrugated or planar steel and has been applied to many bridges. A trial design of tied CFST arch bridge with steel web PC tied beam is carried out in this paper, taking a completed tied CFST arch bridge as the prototype. The results indicate that such a new type structure can meet the design requirement with light self weight, easy and economic to built.

1 INTRODUCTION

Tied CFST arch bridge is one of the main five CFST arch bridges and have been widely used in China, in which the arch rib is made of CFST arch ribs while the tied beam usually is PC beam because steel beam is more expensive. The construction difficulty of this type of bridges will increase with the span of the bridge because the horizontal reactions are not available until the tied girder is completed. Therefore, how to reduce the self weight of the tied beam but not make the material cost rised up too much is a challenge for bridge engineers in China. The last author of this paper has an idea to use the steel web PC beam as the tied beam in tied CFST arch bridge.

Steel web PC beam or girder is a new composite structure in which the web is corrugated or planar steel and has been applied to many bridges. Corrugated steel plate has been applied in civil engineering structures for a few decades. Many PC box girder bridges with corrugated webs have been built all over the world. The prestressed forces can be efficiently introduced into the top and bottom concrete flanges due to so-called “accordion effects”. In Japan corrugated steel web box girder has been used as the main girder of extradosed bridge and cable-stayed bridge in Rittoh Bridge and Toyota Arrows Bridge, respectively. Plane steel plate was once used in PC box girder, however, the weak in shear buckling and the absorbment of prestress forces by the planar steel web prevent it furthor ultilization. Therefore, though there are more than one hundred bridges with corrugated steel webs that have been constructed worldwide, but only one used plane steel web. However in the tied beam, the dominant forces are tensile and the bending moments are very small compared to that in girders, so the shear buckling is not a serious problem, moreover, the planar steel web good in carrying tensile forces, therefore it is possible to subtitute concrete web by plan steel plates. So both corrugated steel web and plane steel web can be adopted in tied beam in this new type arch bridge.

Taking the Pushan Bridge as the prototype, which is a tied CFST arch bridge completed at the end of 2009, a trial design of tied CFST arch bridge with steel web PC tied beam is carried out in this paper. In convenice, the original Pushan Bridge will be called as Bridge A, the trial designed bridge with corrugated steel web PC tied beam will be named as Bridge B and the trial bridge with planar steel web PC beam as Bridge C.

2 THE TROPOTYPE---- PUSHAN BRIDGE

The Pushan Bridge is a tied CFST arch bridge comprising the concrete filled steel tube arch ribs and the traditional PC rigid tie beams. The main bridge has a total length of 225m and a calculation span of 219m. The bridge has three arch ribs, carries two-way six lanes with a deck

width of 38.8m. The schematic diagram of this bridge is shown in Fig.1. The cross-section of arch ribs and tied beams are shown in Fig.2 and 3, respectively.

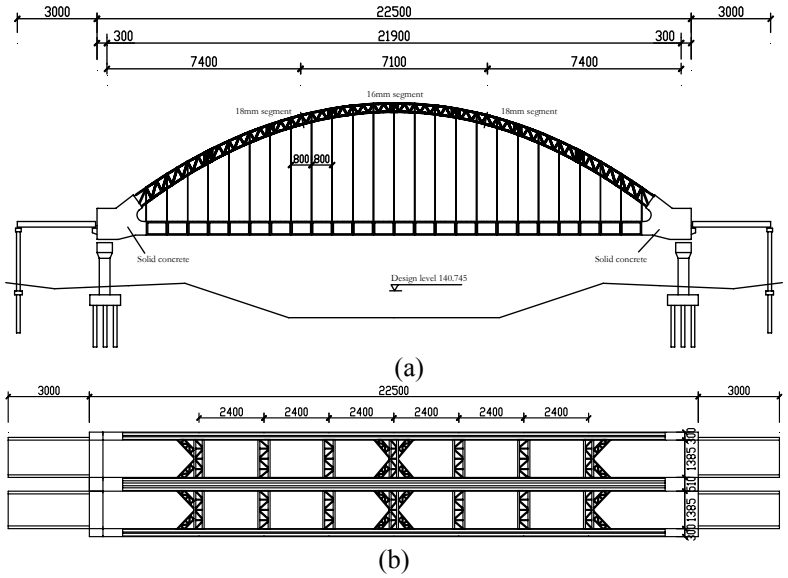

Figure 1 : Schematic diagram of the Pushan Bridge (unit: cm): (a) Elevation, (b) Plane.

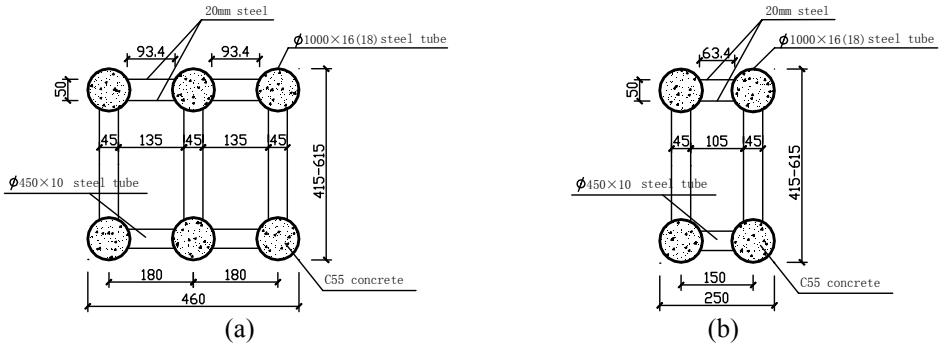

Figure 2 : The arch rib cross section (unit: cm): (a) Center arch rib, (b) Side arch rib

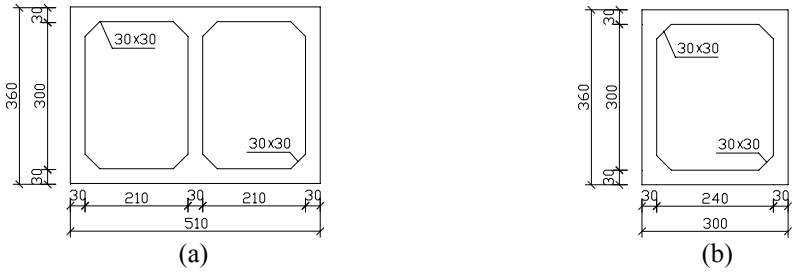

Figure 3 : The tied beam cross section (unit: cm): (a) Center tied beam, (b) Side tied beam.

3 TRIAL DESIGN OF TIED CFST ARCH BRIDGE WITH STEEL WEB PC TIED BEAM

In the trial design, the corrugated or planar steel webs were used for the Pushan Bridge to replace the concrete webs of the tied beams, while all other design parameters were remained as the original one. The webs adopted Q345c steel. The planar steel web with 12mm thickness has longitudinal and lateral stiffeners, as shown in Fig.4. The corrugated steel web composite beam

sections are shown in Fig.5 and the corrugated-steel-web configuration is illustrated in Fig.6.A A corrugated steel web segment is 6.5m long and the they will be connected to each other by the butt welds (Fig.7).

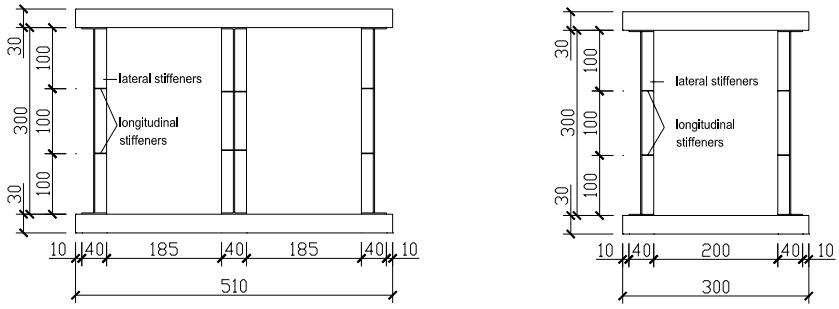

Figure 4 : Cross section of tied beam with planar steel webs (unit: cm)

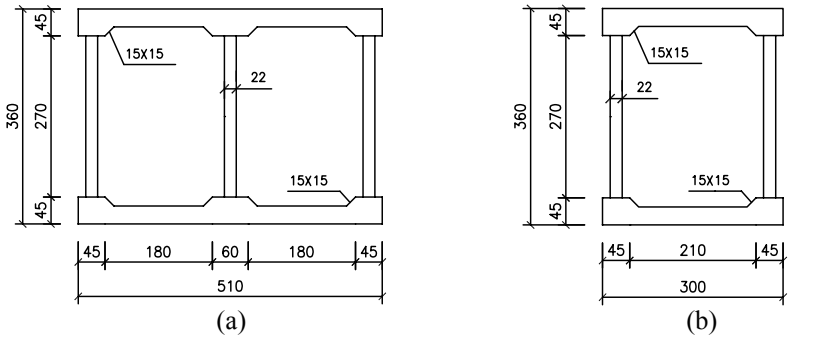

Figure 5 : Cross section of tied beam with corrugated steel webs (unit: cm): (a) Center tied beam, (b) Side tied beam

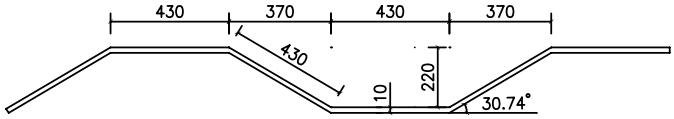

Figure 6 : The corrugated steel webs (unit: cm)

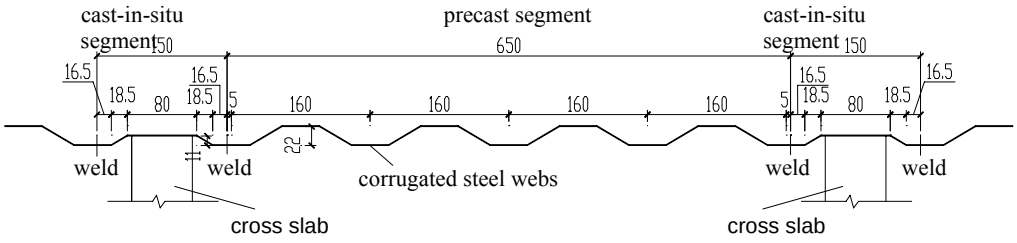

Figure 7 : The tied beam corrugated steel webs (unit: cm)

The connection in Bridge C is more simple than that in Bridge B, therefore only the structure and connection in Bridge B will be introduced in detail later. The corrugated steel webs and the concrete flange plates are connected by PBL shear connectors as shown in Fig.8.

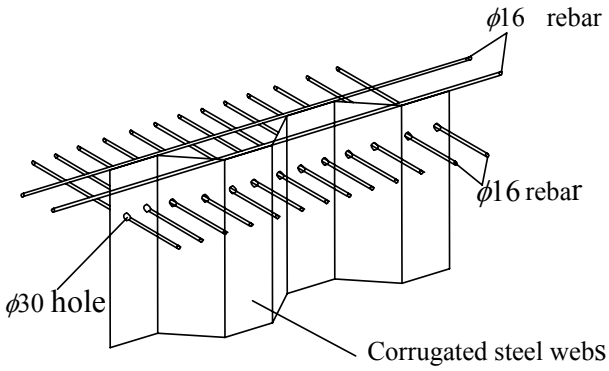

Figure 8 : The shear connector for the corrugated steel webs and the flange plates

The embedded-type shear connectors are adopted to connect corrugated steel webs and the end of the tied beam, as shown in Fig.9. The steel bars passed through the hole drilled on the steel plate embedded in the tied beam ends. Concrete will be cast in the range of the two wavelengths of the corrugated steel webs away from the tied beam ends in order to reduce the stress concentration caused by the beam stiffness mutations.

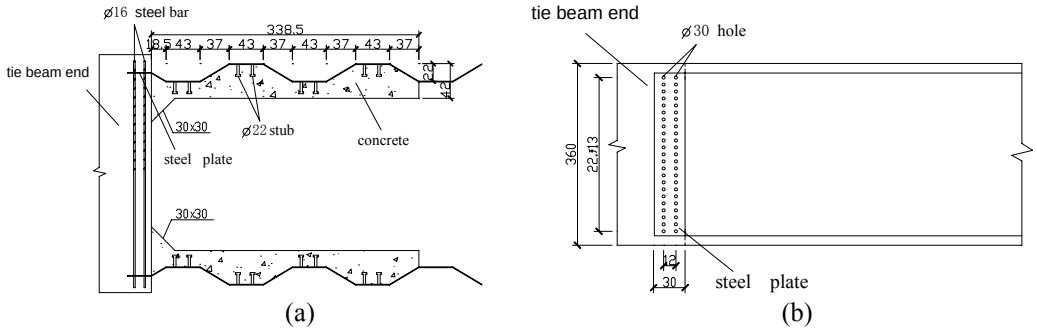

Figure 9 : The shear connector for the corrugated steel webs and the tied beam ends(unit: cm): (a) Planar, (b) Elevation

The shear connectors for the corrugated steel webs and the cross beams are shown in Fig.10. The studs are used to connect the side tied beams' outside webs and the cross beams. The embedded-type shear connectors are used to connect tied beams' other webs and the cross beams.

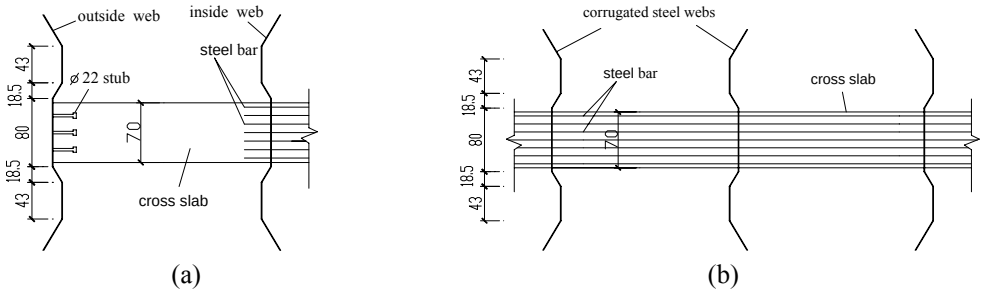

Figure 10 : The shear connectors for the corrugated steel webs and the cross beams (unit: cm): (a) The planar of side tied beam, (b) The planar of center tied beam

4 COMPARISON OF TRIAL DESIGN BRIDGE AND ORIGINAL BRIDGE

Three FE models named as Model A, Model B and Model C were established corresponding to Bridge A, B and C on the enviromental of software MIDAS-Civil 7.2. The arch ribs, tied beams, cross beams and decks were simulated by the beam elements. The suspension rods were simulated by the truss elements. For the tied beams in Model B with corrugated steel web, only the stiffness of flange slab was considered to form the flexural rigidity. Fig.11 shows the Model B, which has 2407 nodes and 4760 elements.

The inner forces of the bridge structures were analzed by the three FE models and checked to the Chinese Design Code of Highway Bridge JTG D62-2004. The analysis results demonstrate that both the trial designed bridges with corrugated steel web PC tied beam and with planar steel web PC tied beam, can meet the design requirements..

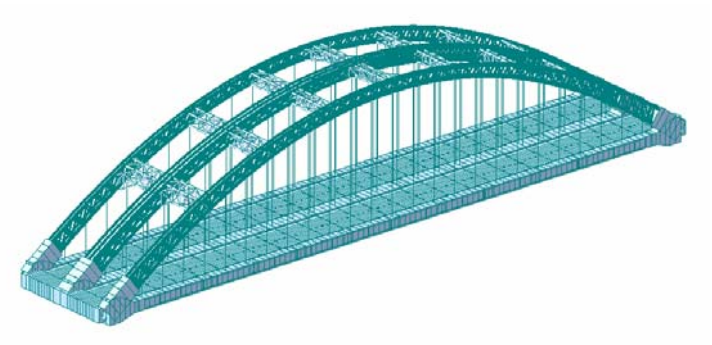

Figure 11 : The three-dimensional FE model of Bridge B (Model B)

Compared with the original bridge (Model A), the tied beams' axial forces in trial designed bridges decrease about 28% and 22% under the dead loads in Model B and Model C, respectively, while they will decreases about 20% under the live loads for the two trial designed bridges..

The stability will be improved in the trial design bridges because the self weights are reduced. Natural frequencies are listed in Table 1. The out-of-plane frequencies of three bridges are almost the same, wheras the in-plane frequencies in Model B and C are reduced by 20.7% and 19.9%, respectively, indicating that the stiffness reduction of the tied beam affects the dynamic behavior of the entire structure.

Under three dimensional earthquake actions, the lateral moments of the tied beams in the corrugated and planar steel web plans are only 44.3% and 54% of the original bridge, respectively. The moments and axis force in Model B are reduced by 81% and 38%, respectively. And in tModel C, they are 77% and 29%. Earthquake-resistant behaviors of the trial designed bridges are better than those of the original bridge.

Table1 Natural frequencies(Hz)

Type	No.	Vibration mode	Model A	Model B	Model C	B/A	C/A
In plane	1	Anti-symmetric	0.733	0.581	0.587	0.793	0.801
	2	Symmetry	1.190	1.108	1.121	0.931	0.942
Out of plane	1	Symmetry	0.432	0.429	0.430	0.994	0.995
	2	Anti-symmetric	0.933	0.890	0.893	0.953	0.957

Comparision of three bridges in materials are given in Table 2. Compared with the original bridge (Bridge A), the concrete, steel and pre-stressed reinforcement of the tied beams decrease 28%, 27% and 20% in Bridge B n and 32%, 9% and 20% in Bridge C. The dead load of the tied beams and the superstructure decrease about 27% and 6 % in Bridge B and 29% and 7 % in Bridge C.

Table 2 Comparision of three bridges in materials

		Bridge A	Bridge B	Bridge C	B/A	C/A
Tied beam	Steel (t)	1176	861	1075	0.73	0.91
	Pre-stressed reinforcement (t)	466	374	374	0.80	0.80
	Concrete (m^3)	3039	2177	2057	0.72	0.68
Superstructure	Steel (t)	5596	5281	5495	0.94	0.98
	Pre-stressed reinforcement (t)	524	432	432	0.82	0.82
	Concrete (m^3)	13380	12518	12398	0.94	0.93
Weight of Superstructure(t)		39570	37057	36967	0.94	0.93

Tied arch bridge can be erected in situ from beam to arch or from arch to beam. And the global superstructure can also be fabricated in shop, then transported to the site and erected. The Pushan Bridge is a bridge over railway and a small canal, therefore falsework was utilized in its construction, and the same construction method are employed in the trial design. However, the tied beams in the two trial designed bridges are much lighter than that in the original one, which will result light falsework. Moreover, no formwork, reinforcing bars and concrete casting for the concrete web is needed because it is replaced by steel web in the trial designed bridges. Thus the construction period can be shorted and the construction costs will be more cheap than that in the original one.

5 CONCLUSION

A new type of tied CFST arch bridge is proposed in this paper, by using steel webs instead of concrete webs in PC tied beam. Trial designs, taking Pushan Bridge as prototypes, show that self-weight of tied beams is decrease obviously and construction days are saved for free of concreting the webs. It is worth to point out that not only corrugated steel web can be used in the tied PC beam in tied CFST arch bridge, but also plane steel web.

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