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Long-Span Composite Cable-Stayed Bridge with New Hybrid Girder

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Summary

In this paper, the possibility to construct a 3-span continuous composite cable-stayed bridge with main span of 890m was studied. In the objective bridge, the new composite 2 girder structure, which uses steel-pipe structure filled with concrete as main girder together with prestressed concrete deck slab, was adopted in part of central span, and prestressed concrete girder was used in other parts. Through the study, it was confirmed that the static behavior of the objective composite bridge was almost the same as that of the basic model (prestressed concrete cable-stay bridge), and the dynamic behavior was also satisfactory, and the possibility to construct the objective composite bridge was verified. In addition, it was clarified that the construction of the objective composite bridge could be performed with easier procedure at lower cost.

1. Introduction

Recently, the opportunity to adopt the composite structure in large cable-stayed bridge has increased. In this paper, the design of a 3-span continuous composite cable-stayed bridge with main span of 890m was conducted. In the objective bridge, the new composite 2 girder structure, which uses steel-pipe structure filled with concrete as main girder together with prestressed concrete(hereafter called PC) deck slab, was adopted in part of central span, and PC girder was used in other parts. Before the design of the composite cable-stayed bridge, as the basic model which demonstrates the possibility of realization, the design of a 3-span continuous PC cable-stayed bridge was performed. The static behavior, dynamic behavior and structure detail of design were investigated.

2. Basic structure

2.1 Objective bridge

The 3-span continuous PC cable-stayed bridge as shown in Fig.1, the design of which was already conducted in separate study, was selected as the basic model (hereafter called allPC model), and the objective composite bridge was determined by changing part of central span of the basic model to composite section as shown in Fig.2 (hereafter called composite model). As for the composite section, the steel-pipe structure filled with concrete was used as main girder, and PC slab was adopted.

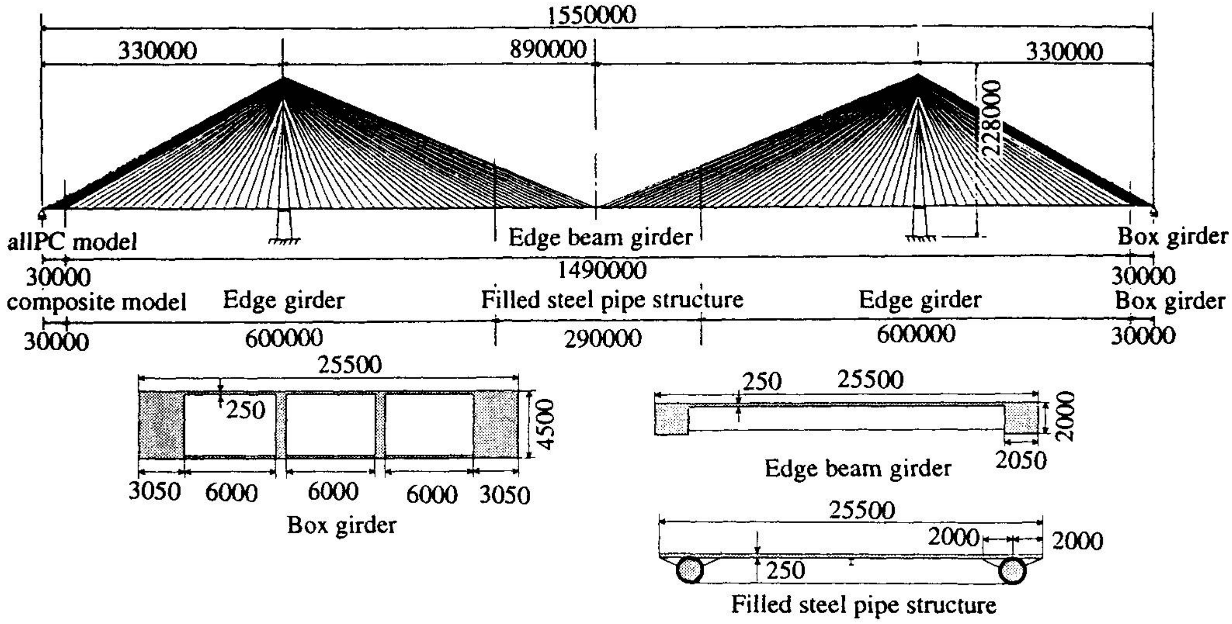


Fig.1 Model for study

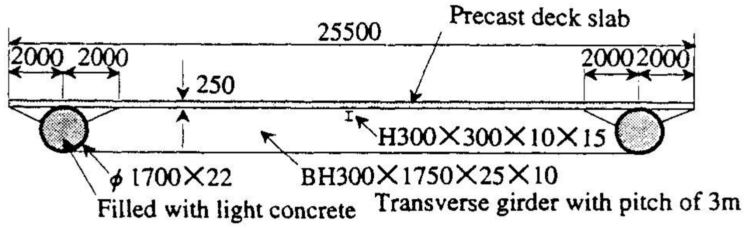


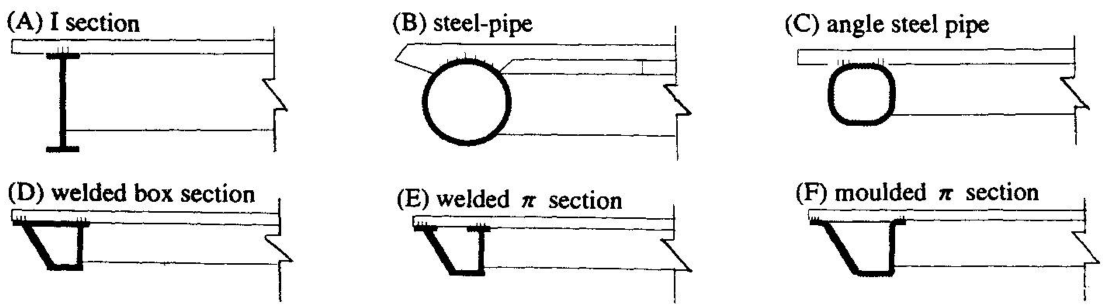
Fig.2 Filled steel pipe girder

2.2 Determination of section of composite main girder

Table.1 Type and features of main girder section

Type	Structural features	Cost	Capacity	Field joint	General evaluation
A	I beam	1.0	△	○	○
B	steel-pipe	0.8	○	○	◎
C	angle steel pipe	1.0	△	△	△
D	welded box section	1.2	◎	○	△
E	welded π section	1.0	△	○	△
F	moulded π section	0.8	○	△	△

As composite main girder, following 6 types of girders were studied and compared: (A) I section, (B) steel-pipe, (C)angle steel pipe, (D)welded box section, (E) welded π section, and (F) moulded π section. Table1 represents the study cases.Considering the construction cost, the capacity and the construction procedure, (B)steel-pipe was finally adopted as main girder.



2.3 Structure features of new composite main girder

The new type structure has following three features: (1) 2 girder structure using steel-pipe; (2) steel-pipe main girder filled with concrete; and (3) composite structure consisting of PC slab and steel-pipe main girder. The details of the features are described as following.

(1) 2 girder structure using steel-pipe
Compressive force and bending moment are acting on the main girder of cable-stayed bridge at the same time. Compared with plate girder, the steel-pipe is more difficult to buckle locally, and has higher capacity against compressive loading. In addition, compared with girder with I section, the steel-pipe section has larger torsional stiffness and smaller drag coefficient, and thus has better performance when being used in cable-stayed bridge.

(2) Steel-pipe main girder filled with concrete
In order to increase the capacity to resist compressive force, the steel-pipe was filled with concrete. As light concrete was used, the weight was reduced by 5tf/m. Therefore, in composite model, the whole dead load and the weight of cables were reduced by 5% and 7%, respectively, compared with allPC model.

(3) Composite structure consisting of PC deck slab and steel-pipe main girder
To increase the capacity to resist the combined loading of compressive axial force and positive bending moment, and to improve the wind-resistant performance, not the torsional stiffness, the combination of PC deck slab and steel-pipe main girder was adopted. Figure3 indicates the function of PC deck slab in the stress analysis of section and the process of producing the filled concrete.

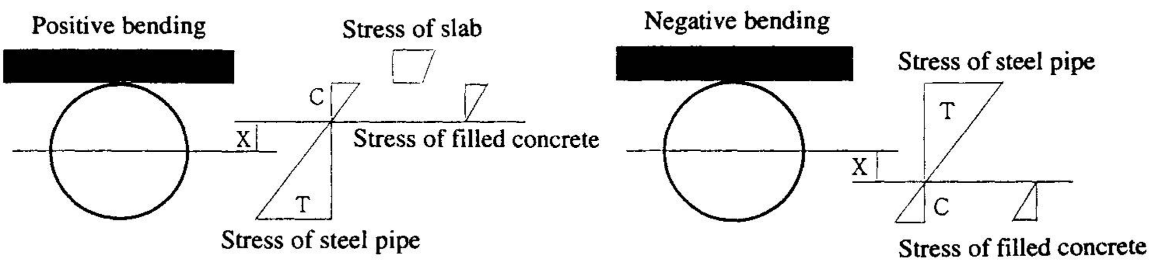


Fig.3 Distribution of stress

3. Study on static behavior

In this section, the computed section forces and reaction forces in allPC model and composite model, which were computed through static plane frame analysis, are compared, and the effects of creep and drying shrinkage are described. The analysis model of plane frame is shown in Fig.4.

(1) Characteristics of section forces
The bending moments of main girder due to dead loads and prestress in cables are shown in Fig.5, and the axial forces are indicated in Fig.6. By adjusting the forces in cables based on allPC model, the bending moments and axial forces in composite model could be almost the same as those in allPC model. The reaction forces at bearing points are represented in Table 2. It can be seen that, in composite model, no negative reaction force could occur either when dead load was applied to bearing point P1, or when bending moment due to live loads reached the maximum and minimum value.

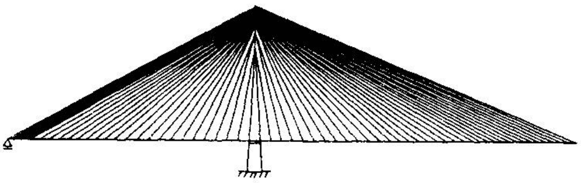


Fig.4 Plane frame analysis model

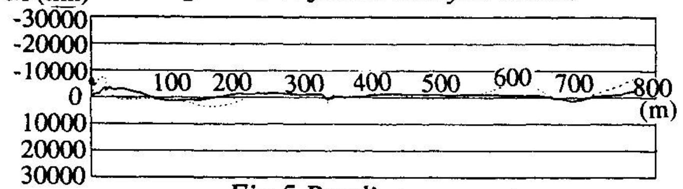


Fig.5 Bending moment

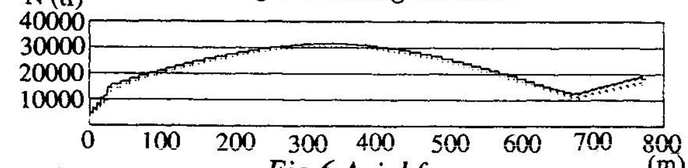


Fig.6 Axial force

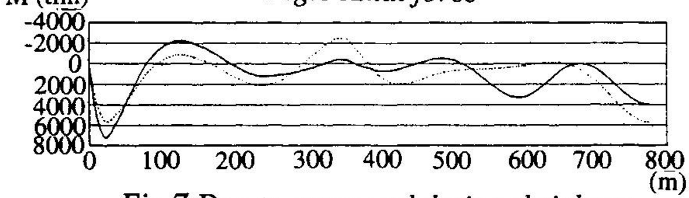


Fig.7 Due to creep and drying shrinkage

(2) Effect of creep and drying shrinkage
The variation of bending moment due to creep and drying shrinkage is indicated in Fig.7. In addition, the relationship between the section force at composite steel-pipe part after creep, and the allowable section force is shown in Fig.8.
From the figure, it can be confirmed that the section force generated after creep was smaller than the allowable section force.

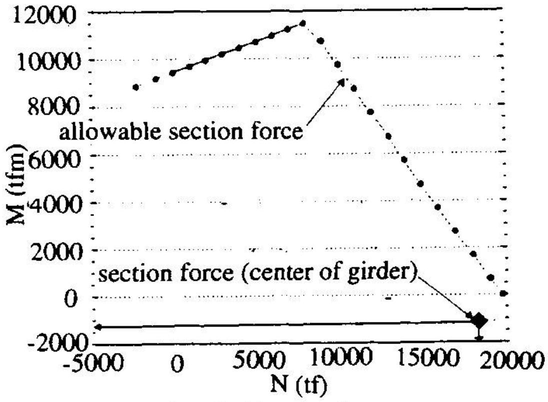


Fig.8 Check of stress

	Permanent load	When maximum bending moment occurred	When minimum bending moment occurred
Before creep	1556tf	2283tf	384tf
After creep	2573tf	3299tf	1400tf

Table.2 Reaction force at bearing point

4. Study on dynamic behavior

The mode analysis of the bridges using allPC model and composite model was carried out to investigate the fundamental behavior. And then, earthquake response analysis was conducted using acceleration response spectrum method. Three dimensional frame model was employed, and elastic spring (4000tf/m) was set at the top of column as damper. The acceleration response spectrum shown in Fig.9 was adopted. The mode shapes in the case of composite model are represented in Fig.10. The computed horizontal displacement at center of girder was 0.66m. In addition, it was confirmed that the section forces of main girder and tower were smaller than the allowable values. As for aerodynamic stability, the investigation using Selberg formulation was conducted, and the fundamental response behavior was studied. The more detailed investigations are planned to be conducted through wind-tunnel test.

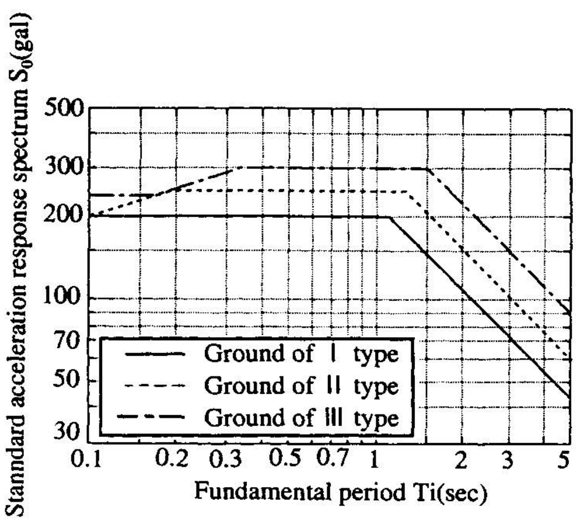


Fig.9 Acceleration response spectrum

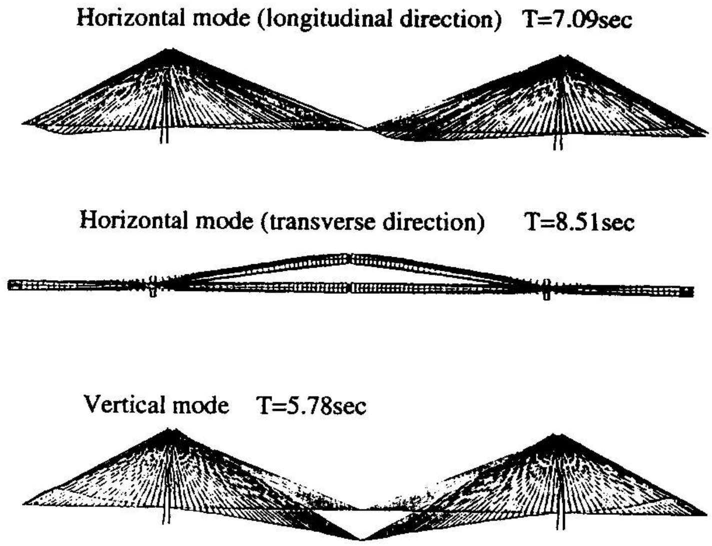


Fig.10 Vibration mode shapes

5. Structural details

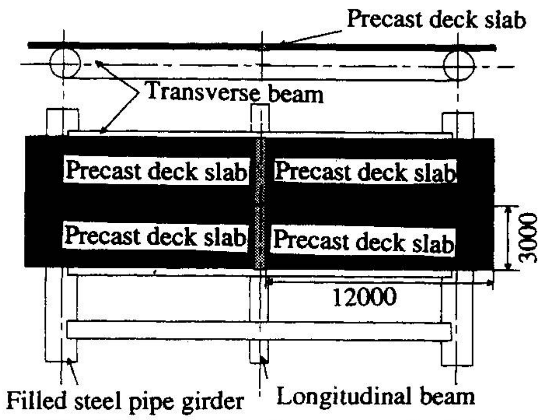


Fig.11 Example of precast sdeck lab

(1) Deck slab and frame structure
Figure 11 shows an example of precast PC deck slab. As the deck slab used for 2 main girder section, RC deck slab, PC deck slab and composite steel slab may also be adopted. However, precast PC deck slab is the most appropriate choice because the construction term could be shortened and the effects of creep and drying shrinkage are small.

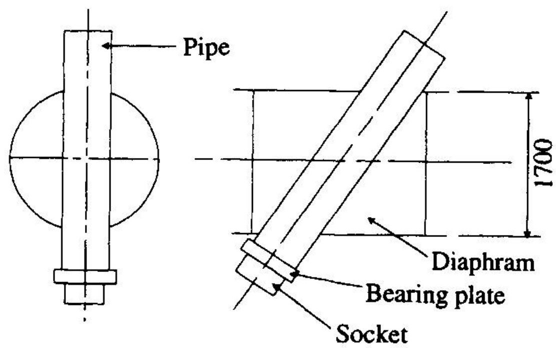


Fig.12 Anchor part for cables

(2)Anchor structure
As indicated in Fig.12, the steel pipe used for anchor part, which passes through the steel-pipe main girder, is separately made, and the cables could be connected successively. In addition, by using the method, the construction could be performed at low cost. As the tensile force of cables is applied at the center of steel-pipe girder, it could be smoothly transferred to the main girder and slab through diaphragm.

8. Conclusions

In this paper, the design of a composite cable-stayed bridge with main span of 890m was conducted. In part of central span, composite steel-pipe 2 girder was adopted. It was confirmed that it is possible to construct the presented composite bridge as well as allPC bridge. In addition, compared with allPC model, in the case of composite model, the weight could be reduced, and the construction could be performed with easier procedure at lower cost by appropriately designing the structural details. It is hoped that the results of this study could be helpful to the future research, design and construction of large composite cable-stayed bridge.

Reference

(1) Nakamura, Okimoto & Takeda: Structural characteristics of large composite cable-stayed bridge with steel-pipe as main girder, Steel Construction Engineering, No.17,1998.