Design of Steel Cable-stayed Bridge with Low Height Towers

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Summary

A large cable-stayed bridge with low height towers is planned crossing a canal near one of the major airports in Japan. As a result of the low towers and since the angle between girder axis and cable is small, the increase of deflection of stiffening girder becomes a design issue for earthquake and wind resistance performance. In addition, there is the issue of soil-liquefaction during earthquake because the bridge is located in a reclaimed soft ground area. In order to solve these issues, structural stability of the main structure was confirmed by FE analysis. For wind resistance performance, the behavior of the bridge was examined by wind tunnel experiment, and for earthquake-resistance performance of the basement, the movement of the tower foundations was checked by 2-D dynamic effective stress analysis of the ground.

Keywords: Cable-stayed Bridge; Low height towers; Ultimate strength; Earthquake resistance performance; Wind resistance performance; Soil liquefaction.

1. Abstract

The proposed cable-stayed bridge planned at a harbor adjacent to a major airport in Japan has low towers compared to ordinary cable-stayed bridges due to aviation control restriction by the airport. The structure overview of this bridge is shown in Figures 1 and 2, and Table 1. It is planned to be a

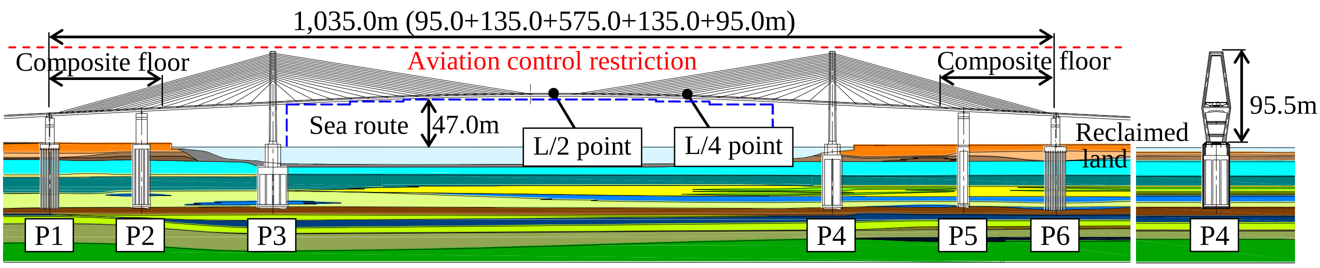

Fig. 1: General view of cable-stayed Bridge (planned)

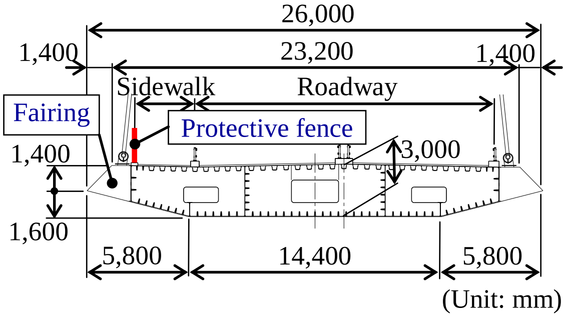

Fig. 2: Detail of stiffening girder (planned)

Table 1: Structure specifications (planned)

Items		Specifications
Bridge type		5 spans cable-stayed bridge
Bridge length (Span length L)		1,035m (L=575.0m)
Tower height		95.5m (clearance 47.0m)
Superstructure	Girder type	Flat 3 cells box girder (steel)
	Tower type	A-shaped form (steel)
	Cable system	Multi-cable system (Fan type)
Substructure	Pier type	RC hollow pier (P1,P2,P5,P6)
	Foundation type	Pire foundation (P1,P6) Pneumatic caisson (P2-P5)

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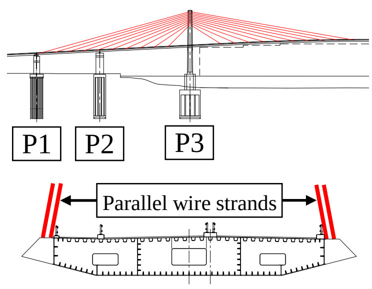
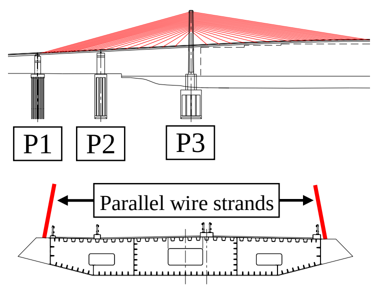
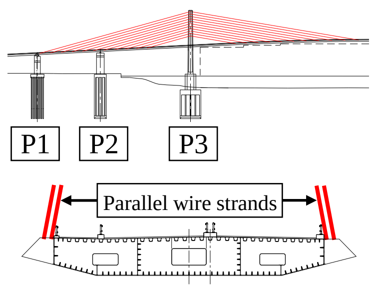
large cable-stayed bridge with 575.0 m span length and 47.0 m clearance needed to cross the route. Its unusual proportion of tower height above the girder to the main span length is 1:11, because the towers are located in the restricted area of the airport. There was concern about degradation of seismic and wind-resistance performance since the vertical supporting effect of cable is reduced due to low towers, and deflection of the stiffening girder is larger than the cable-stayed bridge of the standard tower height. There was also concern about decrease of the safety against overall buckling since the axial force of stiffening girder increases. Furthermore, foundation movement due to liquefied and laterally spreading soils by a large-scale earthquake can be predicted because the towers and piers will be constructed on soft ground reclaimed land.

In order to solve these bridge design issues, we studied placing the intermediate supports of the side span to decrease deflection of main span, employed multi-cable system is shown in Table 2 and the main structure by High Performance Steels in Japan, and confirmed ultimate strength by elasto-plastic FE analysis. In addition, for wind resistance stability, the wind-resistance behavior of the cable-stayed bridge with low height towers was verified by executing of wind tunnel experiment using a girder section model and full aeroelastic bridge model. For foundation movement due to liquefied and laterally spreading soils by a large-scale earthquake, seismic performance of the foundation was confirmed by 2-D dynamic effective stress analysis of the ground. In this paper, we report some technical issues and the solutions of this bridge found in the early stages of planning.

Table 2: Comparison table of cable layout

	CASE 1:4 cable planes (fan type)	CASE 2:2 cable planes (fan type)	CASE 3:4 cable planes (harp type)
Sketch			
Layout	10 cables of 4 vertical planes	20 cables of 2 vertical planes	11 cables of 4 vertical planes
Cost	Cost ratio:1.03	Cost ratio:1.00	Cost ratio:1.15
Review	1) Economy is no good. 2) Wind-resistance performance is no good.	1) Economy is good. 2) Wind-resistance performance is superior to others.	1) Economy is bad. 2) Wind-resistance performance is no good.

2. Conclusion

(i) Deflection for live load in cable-stayed bridge with low-height towers can be satisfied with the design allowable limit of deflection by placing the intermediate supports of the side span and multi-cable placement of “parallel wire strands” as two vertical cable plane fan system.

(ii) For the overall buckling in the stiffening girders where axial force and bending moment are high compared to ordinary cable-stayed bridges, it was verified that safety on buckling resistance of the bridge can be ensured by a design utilizing elasto-plastic buckling analysis applying effective buckling length method (Ef method).

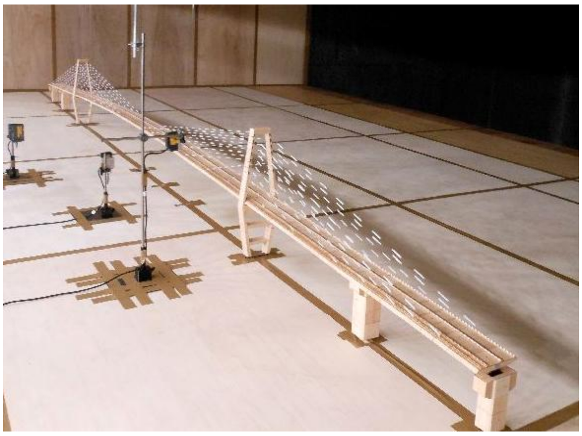


Fig. 3: Full aeroelastic model (S=1:150)

(iii) For torsional flutter vibration, wind tunnel experiment confirmed that critical flutter wind speed tended to be low due to the effect by densely placed cables and protective fence. As a countermeasure, by reviewing the fairing shape of the stiffening girders it was confirmed that such vortex induced vibration, which affects adversely to the structure itself or torsional flutter vibration which becomes problem on wind-resistance performance, does not occur.