STUDY ON SIMPLIFICATION OF GIRDER STRUCTURE IN SUSPENSION BRIDGE

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ABSTRACT

A cable-stayed bridge is often constructed rather than a suspension bridge in the case of the center span length ranging from 500m to 1,000m due to its economic efficiency and aesthetics. In order to get an advantage of a suspension bridge over a cable-stayed bridge, a study on the girder structures of a suspension bridge focusing on a simpler and lighter girder was conducted. Firstly, a feasibility study on deck frames of edge girder beam with concrete composite deck and H-shape steel opening deck was performed. Secondly, a wind tunnel test was conducted in order to investigate the aerodynamic characteristics of those girder structures. As a result, the opening deck girder structure realized a lighter superstructure as well as a good aerodynamic stability if aerodynamic countermeasure: triangle-shape faring is attached.

Keywords: Suspension bridge, Edge girder beam, Composite deck, Opening deck, Wind tunnel test, Aerodynamic stability

1. INTRODUCTION

In recent years, a cable-stayed bridge is very likely to be selected as a bridge form of around 500m span from the viewpoint of economic efficiency and its aesthetics. However, it is possible that suspension bridges have adequate competitiveness against cable-stayed bridges if they have an economical advantage by a simplified form of structure. Recently, a box girder structure with a hexagonal cross section is commonly adopted in suspension bridges. The box girder structure is light in comparison with a conventional truss structure so that it can reduce steel weight, as well as that required torsion rigidity may be secured to satisfy its aerodynamic stability. However, this box girder structure has a limit for realizing lower manufacturing cost due to complicated welding, and many vertical and lateral ribs.

Targeting these problems, a simpler girder structure was proposed by employing the so-called edge-beam girder structure in which main girders are arranged on the both outsides and a composite deck slab is placed between the two girders. However, this edge-beam girder is inferior to

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aerodynamic stability as reported, for example, in cases of Tacoma Narrows Bridge and Alex Frazer Bridge. In this study, aiming for ensuring lighter weight and aerodynamic stability by constructing a deck with only steel H-shaped beams providing openings between each beam, hereinafter called "an opening deck" was proposed and studied with respect to its structural efficiency and aerodynamic stability. Aerodynamic stability of the opening deck girder structure was evaluated by a wind-tunnel test. A composite deck girder structure was also tested for comparison. This paper presents a trial design of a suspension bridge with the opening deck structure and results of the wind-tunnel test.

2. DESIGN STUDY

2.1. Target bridge for design

Basic dimensions of the target bridge for design followed those of Toyoshima Bridge recently constructed in Japan, which has two main steel towers and a single span steel box girder with the central span length of 540 m. Basic dimensions of the target bridge are shown in Table 1.

Table 1: Dimensions of target bridge for design

Type of bridge	Single span suspension bridge
Span length	127 + 540 + 158 m
Cable	Sag ratio: 1/10, Cable spacing: 13 m, Hanger interval: 15 m
Deck	2 vehicle lanes and 2 sidewalks (total width: 11 m)

2.2. Primary members and deck framing formation

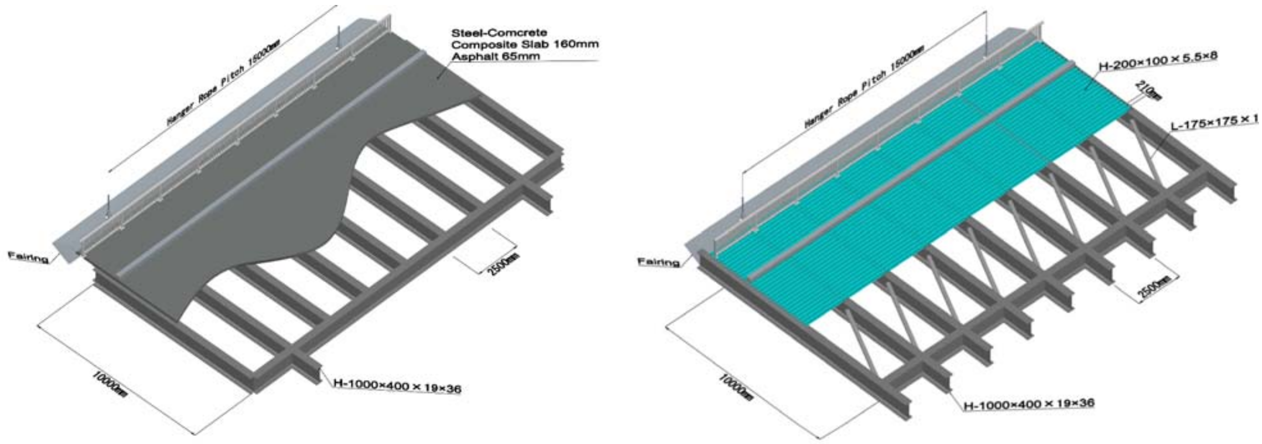
When a common rolled H-shape steel is employed, the size of around 1000 x 400 x 19 x 36 is currently available for a main girder and lateral girders. Specifically, deck framing was configured with main girder spacing of 10 m and lateral girder spacing of 2.5 m. At this time, such configuration of road surface can accommodate the two lanes and the two sidewalks. The girder web height will be approximately two times as much as the above web height if four lanes and two sidewalks are accommodated, however.

2.3. Deck slab configuration

The deck slab on the road surface was selected based on two major ways of concepts. The first one is simplification realized by using composite deck slabs with concrete and steel plate, and the other one is aerodynamic stability improved by arranging deck slabs with H-shape steels, as shown in Figure 1. A H-shape steel with a size of 200 x 100 x 5.5 x 8 mm was intentionally arranged with gaps left parallel to the longitudinal direction. The opening ratio at that time results in approximately 50 % (see Figure 2).

2.4. Design condition

An axial load of 200 kN: 100 kN per wheel, as vehicle loads for deck slabs, and equivalent live



a) Edge girder with composite deck slab b) Edge girder with H-shape open deck

Figure 1: Girder structures.

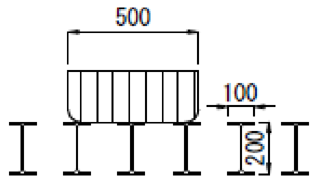


Figure 2: Opening deck by H-shape steels

loads for deck frames were taken into account [Honshu-Shikoku Bridge Authority, 1989]. The design wind speed on the level of girder and on the level of cables was calculated with the basic wind speed of U_{10} = 40 m/sec, and with the altitude correction in accordance with a power law of α = 1/7 [Honshu-Shikoku Bridge Authority, 2001]. Composite deck slabs were regarded as the composite beam having the effective width for main girders and lateral girders. Deck slabs with openings by H-shape steels were united with lateral girders. Design was checked against live loads and wind loads. The towers were planned to be of a steel rahmen frame with uniform section for simplicity of analysis and no seismic loads were taken into consideration. Analysis was conducted by using a FEM analysis software of Midas-Civil 2010.

2.5. Result of design study

The design result of a composite deck slab and an opening deck slab are tabulated in Table 2, in which the steel weight of the superstructures is compared. A schematic view of the suspension bridge with a H-shape open deck is shown in Figure 3. In addition, major vibration modes are shown in Figure 4. When compared with the Toyoshima Bridge having a steel box stiffening girder, while the steel weight is considerably reduced by employing a composite deck slab, the whole weight of the superstructures increases. Meanwhile, when opening deck slabs are employed, while the steel weight does not vary so much, the whole weight becomes remarkably lighter. Referring to vibration modes, torsional modes appear with considerably low order in both deck types, and this is caused by the reduction of torsion rigidity.

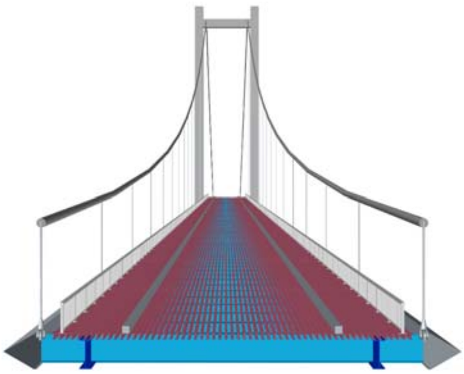


Figure 3 Schematic view of suspension bride of edge girder with H-shape open deck

Table 2: Weight comparison of superstructure

	Toyoshima Bridge (Single box girder)	Composite deck slab	H-shape opening deck
Steel weight of girder (t)	2,640	1,223	1,462
Composite deck slab (t)	0	2,700	0
H-shape opening deck (t)	0	0	679
Pavement (t)	737	1,009	0
Cables (t)	914	1,208	962
Hangers (t)	21	30	23
Total (t)	4,312	6,170	3,126
Only steel weight (t)	3,575	2,461	3,126

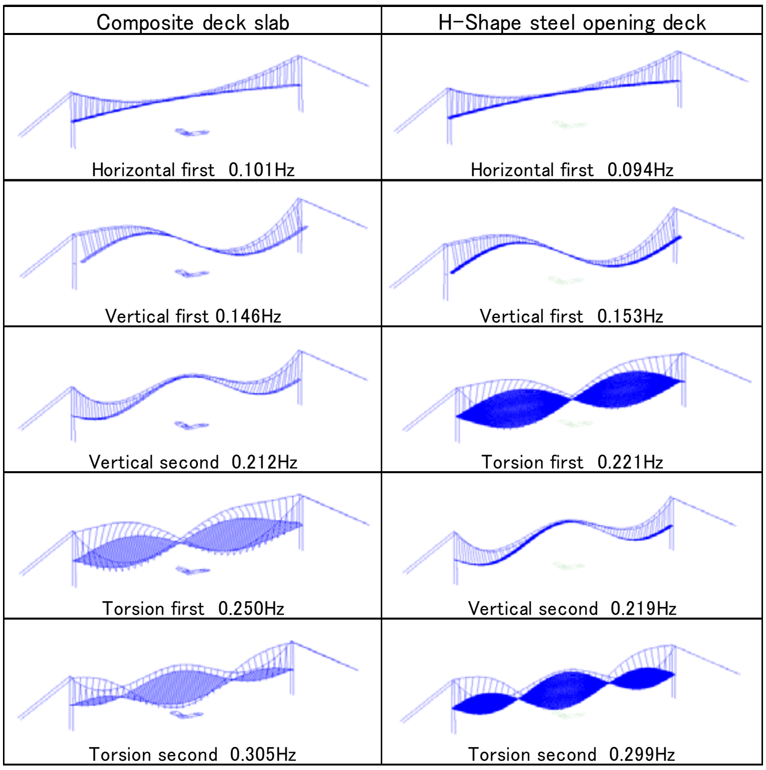


Figure 4: Vibration modes

3. WIND-TUNNEL TESTING

3.1. Wind-tunnel facility

The aerodynamic characteristics at the completion stage of the design bridge were investigated by a section model wind-tunnel test. A wind tunnel facility at Yokohama National University (Eiffel type) was used for the wind tunnel test. The size of the measurement section of the wind tunnel is 1.8 m in height, 1.3 m in width and 12.0 m in length, and a maximum wind speed is approximately 22 m/s.

3.2. Testing method and models

In the wind-tunnel testing, a two-degree-of-freedom spring supported test in which vertical and torsion dynamic responses are measured was conducted. Uniform air flows with three angles of attack: -3°, 0° and +3° were used.

A 1/40-scaled model; the model size of H = 1250 mm in length, B = 338 mm (w/o fairing) in girder width and D = 40 mm in girder height (including the thickness of deck slab and 40% parapet height) was used as the test model in which similarity requirements are satisfied, as shown in Figure 5. The model was reproduced by constructing the model of composite deck slabs with added weight and closed openings on the basis of the form of deck slab with opening (Figure 6). Besides, a wind speed ratio was approximately U_p/U_m = 4.5 for the composite deck and 3.5 for the opening deck. In the wind-tunnel test, parapets were attached in both cases provided with and without fairings. Triangle-shape fairings were attached at the outsides of both girders.

Comparison between the model parameters and the design ones is shown in Table 3 together with the critical wind velocity of flutter onset calculated by Selberg’s Equation.

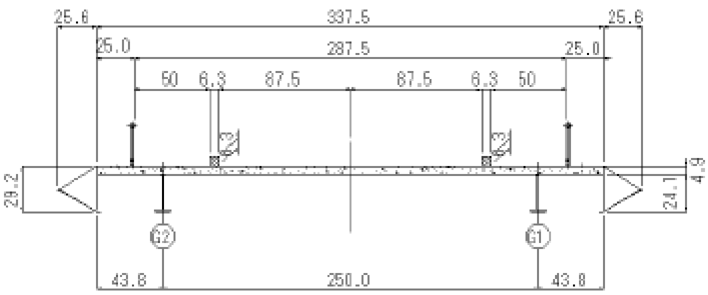


Figure 5: Cross section of model

Figure 6: Wind-tunnel test model

Table3: Comparison between model and design parameters

		Design of bridge		Model (1/40 scale)	
		Composite deck slab	H-Shape opening deck	Composite deck slab	H-Shape opening deck
Unit weight (inc. cable weight)	M_p (kg/m)	9624	6051	6.015	3.782
Polar moment of inertia	I_p (kgm)	175.1×10^3	81.5×10^3	0.0684	0.0318
Vertical frequency	f_η (Hz)	0.146	0.152	1.280	1.733
Torsional frequency	f_θ (Hz)	0.250	0.221	2.209	2.684
Structural damping (Vertical)				0.020	0.020
(Torsion)				0.020	0.020
Selberg's flutter onset	U_{cf} (m/s)	38.1	22.2		

3.3. Test result

The results of the two-degree-of-freedom spring supported test are shown in Figures 7 and 8.

It turns out that divergent vibration (flutter) in the composite deck slab case occurred when a wind speed surpasses a certain level or more regardless of with/without fairings. In the case with fairings, at -3° of the angle of attack, flutter onsets at a reduced wind speed of $U/fB = 3$ (equivalent to 10 m/s in the actual bridge). On the other hand, in the case without fairings, at 3° of the angle of attack, flutter onsets at a reduced wind speed of $U/fB = 5$ (17 m/s in the actual bridge).

Meanwhile, while generation of vortex-induced vibration is recognized for the opening deck slab, no divergent vibration occurred regardless of with/without fairings. It is observed that a little large torsional vortex-induced vibration occurred at around $U/fB = 3$ (9 m/s in the actual bridge) in all angles of attack in the case of a without fairing case.

As described above, aerodynamic stability more than that by the Selberg's Equation was verified for the opening deck slab since it has good air ventilation; however, to the contrary, it was confirmed that a composite deck slab is necessary to be studied on the solution against flutter.

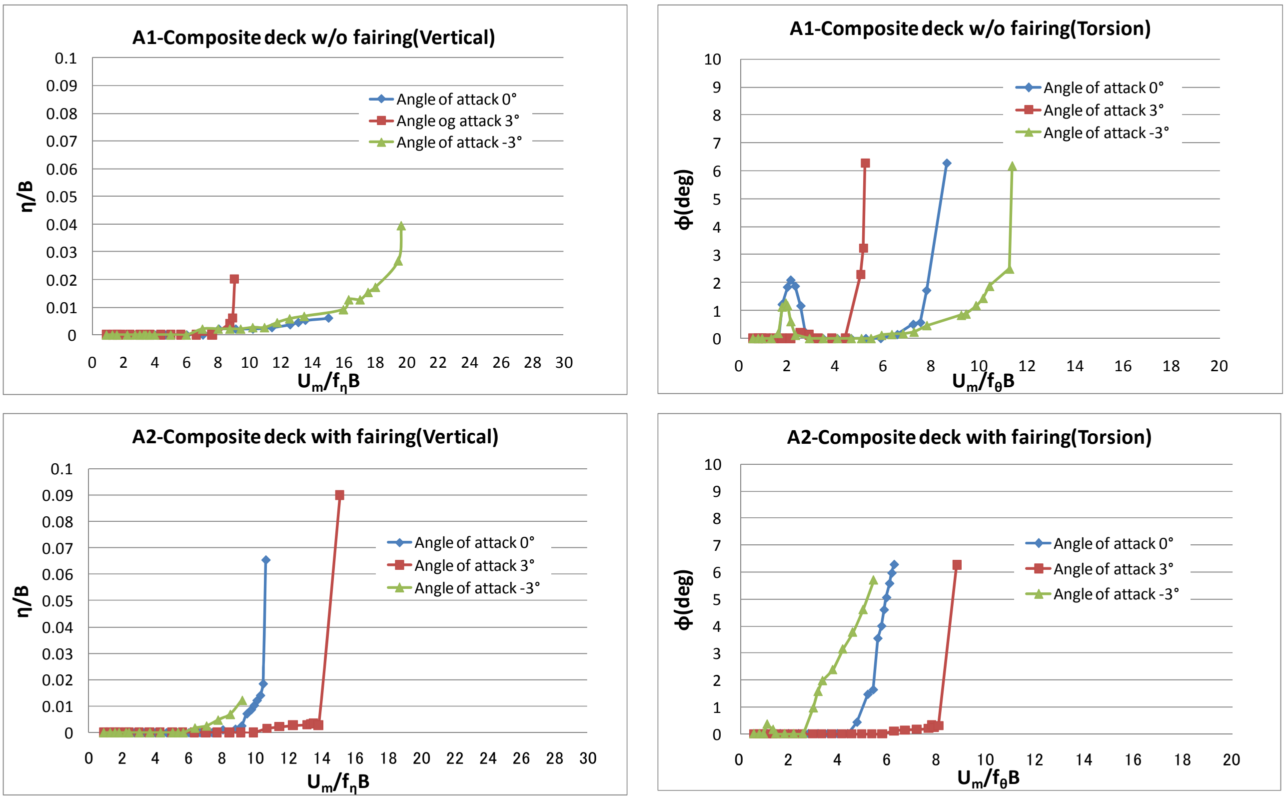


Figure 7: V-A diagrams for composite deck slab

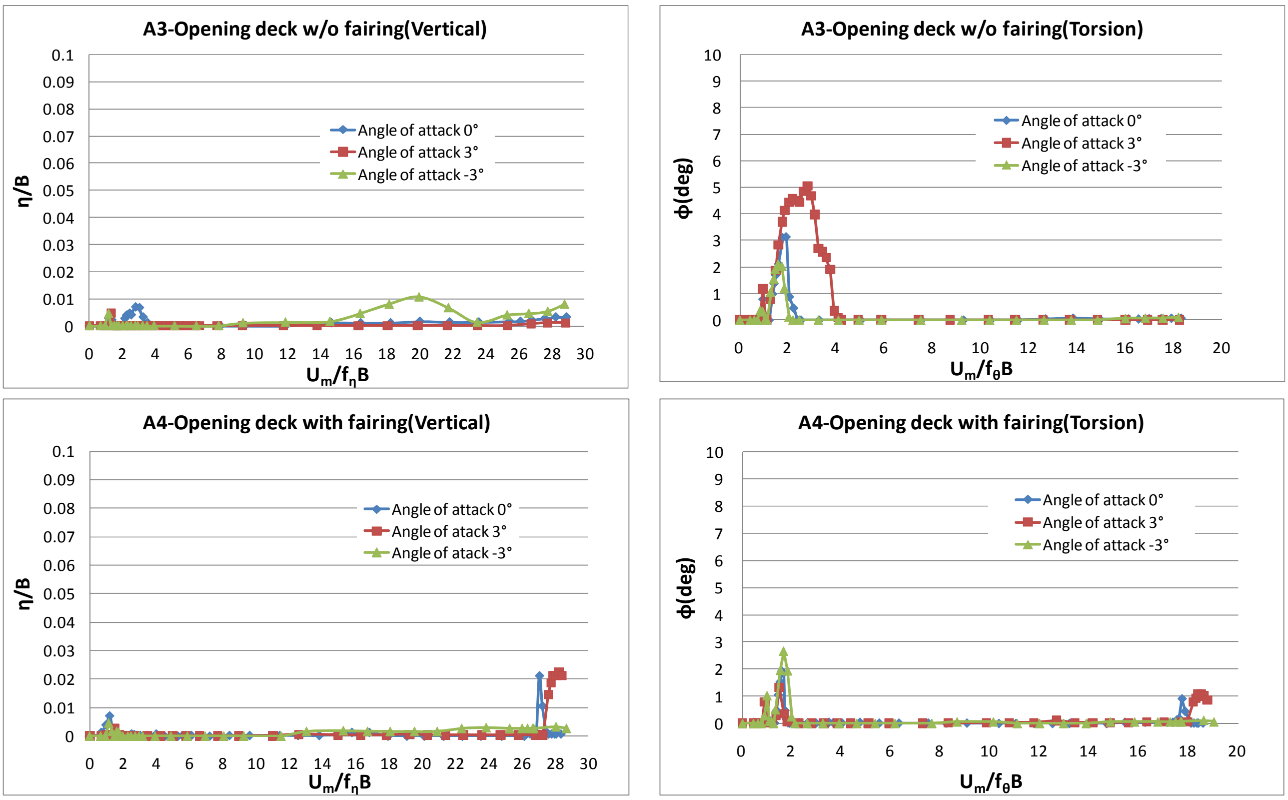


Figure 8: V-A diagrams for H-shape opening deck

4. CONCLUSIONS

A suspension bridge of an edge girder form with rolled H-shape steels used as main members is proposed, and such bridges having composite deck slabs and opening deck slabs were analyzed. Good results of aerodynamic stability for the opening deck slabs were obtained despite the small torsion rigidity of girders. On the other hand, regarding the composite deck slabs, flutter onset velocity was very low although employing modest fairing structure. Hence, hereafter, it is necessary to consider the improvement of fairings and baffle structures for the stability. In order to apply deck slabs with opening to actual bridges, many problems such as slipping and passage on motorbikes still remain to be solved. Nevertheless, those bridges are assumed to be possible to be applied to not only a medium size but also an ultra-long size of those, since they have very excellent aerodynamic characteristics [Sato et al., 1994].

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