Experimental Study on Aerodynamic stability and vibration characteristics of steel two-girder bridges

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ABSTRACT

Simplified girder bridges with two main girders (steel two-girder bridges) have come into use as economical bridges in Japan, with spans more than 50m. As they have lower structural dumping and smaller torsional stiffness than conventional girder bridges, they can be vulnerable to the wind-induced vibrations when their spans become longer. In this study, aerodynamic stability of steel two-girder bridges was checked by wind tunnel test, and the vibration characteristics were investigated by vibration test using an exciter on an actual two-girder bridge with span length of 60m.

KEYWORDS: two-girder bridge, aerodynamic stability, wind tunnel test, vibration test

1. INTRODUCTION

Simplified girder bridges with two main girders and concrete decks (steel two-girder bridges) have come into use as an economical bridge type in Japan. This type was initially adopted for bridges with relatively short spans less than about 50m. Recently they have become longer and longer, with spans more than 50m, some of them reaching even 80m. As they have lower structural dumping and smaller torsional stiffness than conventional plate girder bridges, they can be vulnerable to the wind-induced vibrations when their spans become longer. In this study, aerodynamic stability of steel two-girder bridges of typical cross section was checked by wind tunnel tests (spring-supported rigid model tests). In evaluating the aerodynamic stability of the bridges, their vibration characteristics such as natural frequencies and structural dampings are important parameters, which have hardly been measured accurately by using an exciter on two-girder bridges. Vibration characteristics of them were also investigated by vibration tests using an exciter on an actual continuous two –girder bridge with span length of 60m.

This study was conducted by Public Works Research Institute and Japan Association of Steel Bridge Construction as part of the cooperative study on development of prediction method for aerodynamic stability of steel two-girder bridges.

2. WIND TUNNEL TESTS ON SECTION MODEL OF TWO-GIRDER BRIDGE

2.1 Testing methods

Wind tunnel tests were conducted for typical cross section with 8m-deck-width shown in Fig.1. Based on the dimensions of actual two-girder bridges with span of about 60m, two-dimensional rigid models of 1/40 scale were fabricated. Table 1 shows the dimensions of the section models. Each model has 1.1m-high steel guardrails and 1.1m-high concrete barriers respectively. Except for types of traffic barriers, the shapes of the cross sections are the same.

Table 2 shows the test cases for the spring-supported tests. The tests were conducted

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in smooth flow with angle of attack -3, 0 and 3deg. Logarithmic decrements were set to be within the range of 0.02 to 0.06. The models were elastically supported to allow two-degrees-of-freedom vibration to clarify the wind-induced response characteristics. In this paper, test results are described focusing on the effect of logarithmic decrements.

2.2 Test results

Figs. 2 and 3 show bending and torsional amplitude responses to wind speeds measured for the two models in smooth flow with horizontal angle of attack when the logarithmic decrement δ was changed from 0.02 to 0.05.

(1) Effects of traffic barriers

As for vortex-induced vibrations shown in Figs. 2 and 3, the amplitudes in Model A(steel guardrails) were smaller than those in Model B(wall-type concrete barriers) at all values of logarithmic decrement δ. The wind speeds at which vortex-induced vibrations occurred in Model A were also higher than those in Model B. As for divergent type vibrations, it was noticed that the critical wind speeds for galloping in Model A were higher than those in Model B. Similar tendency was observed when angle of attack was changed to +3 and -3 deg., although the results are not shown here.

(2) Effects of structural damping

As for the vertical flexural response shown in Fig. 2, the vortex-induced vibrations occurred at δ = 0.02 and vanished at δ = 0.04 in both models of guardrails and concrete barriers. Divergent amplitude type vibrations occurred from higher wind speed with increase of structural damping and vanished at δ = 0.05 in both models of guardrails and concrete barriers. Similar tendency in vibration amplitude characteristics was observed at different angles of attack.

As for torsional response shown in Fig.3, vortex-induced vibrations became smaller with increase of the structural damping. In case of δ=0.05, they almost vanished in both models. Divergent type vibrations occurred from higher wind speed with increase of structural damping in both models. In case of δ=0.05 of Model B, it changed to a limited vortex-induced vibration in higher wind speed range. Similar tendency in vibration amplitude characteristics was observed at different angles of attack.

From these results, aerodynamic stability of two-girder bridges with typical cross section in smooth flow was confirmed in case of $\delta \geqq 0.05$, which suggests setting of damping characteristics of the girders is critical in evaluating the aerodynamic stability of two-girder bridges.

3. VIBRATION TESTS OF ACTUAL BRIDGE

3.1 Testing methods

Vibration tests were performed on an actual two-girder bridge of Japan Highway Public Corporation using exciter of PWRI (Type: Unbalanced-mass type, Maximum force:12tonf, Frequency range:0.2-20Hz). Fig.4 shows general views of the bridge, which is a 225m-long, 11m -wide continuous four-span bridge with the longest span length of 60m using rubber bearings. The location of the exciter and accelerometers are also shown in Fig. 4. The exciter was set to be on the road surface at span center of the 3rd span as shown in Photo 1. The dynamic response of the bridge was measured using servo-type accelerometers which were installed on the bridge deck at every span center.

Regarding testing procedure, ambient vibration measurements were conducted first to specify the excitation frequency range by the exciter. After estimating the natural frequencies, vibration tests with the exciter were conducted by forced vibration(sweep excitation) and free vibration methods in order to identify natural frequencies and structural damping for the first vertical-flexural and the first torsional mode of the bridge. The frequency of sweep excitation was changed in the range from 20% lower to 20% higher than the center frequency to obtain the resonance curve (the frequency of a resonance peak). The damped free vibration measurements were performed 11 times for each mode, and then structural damping values in logarithmic decrement were extracted from the optimal peak ratio of the damped free vibration records.

3.2 Test results

(1) Natural frequency

According to the power spectra obtained through the ambient vibration measurements, the natural frequencies were estimated around 1.9Hz for the first vertical flexural mode and 2.2Hz for the first torsional mode respectively. Fig. 5 shows resonance curves obtained by the sweep excitation. The natural frequencies were estimated to be 1.88 Hz for the first vertical flexural mode and 2.15Hz for the first torsional mode respectively.

Table 3 shows the measured frequencies and analytical frequencies which were obtained through the finite element analysis of the bridges modeled with beam elements (see Fig.6). The analytical values are small about 15% as compared with the measured values. In order to predict the natural frequencies more accurately, improvement of the analytical model of the bridge are necessary.

(2) Structural damping

Table 4 shows the range of estimated values of logarithmic decrement and their average values. Fig. 7 shows a damped free vibration curve and its amplitude decrement curve plotted for the first torsional mode, which seemed to be measured accurately under the condition of large amplitude level.

Past vibration test results for other two-girder bridges are shown in Table 4. These were obtained by excitation with cranes, therefore the accuracy of identified damping values is considered to be less than that by the vibration test with exciter. According to the Wind Resistant Design Manual[1)], prediction equation of structural damping for conventional girder bridges (box girders with steel bearing) is provided as $\delta = 0.75/\sqrt{L}$ ($\delta > 0.04$) where L is the maximum span length. Applying this equation to a span length equal to or less than 100m, it is set to $\delta > 0.075$. As shown in the table, logarithmic decrements of vertical flexural vibrations range from 0.040 to 0.064, and those of torsional vibrations from 0.043 to 0.083. These values are lower than those provided for conventional girder bridges.

Considering the vibration test results of the actual bridge and the wind tunnel test results mentioned above, it was confirmed that two-girder bridges up to the span around 60m have sufficient aerodynamic stability.

4. CONCLUSIONS

Wind tunnel tests were conducted for section models of steel two-girder bridges with the span around 60m in smooth flow, and vibration tests were conducted for an actual two-girder bridge. The main findings are as follows:

1)From the results of the wind tunnel tests, it was confirmed that the steel two-girder bridges with typical cross section have sufficient aerodynamic stability under the condition of $\delta \geqq 0.05$.

2)From the results of the vibration tests, the logarithmic decrement δ of the bridge with the span length of about 60m is expected to be equal to or larger than 0.04 for the first vertical flexural mode and 0.05 for the first torsional mode respectively.

In order to evaluate aerodynamic stability of steel two-girder bridges, simple formulae to predict wind-induced vibrations are under developing.

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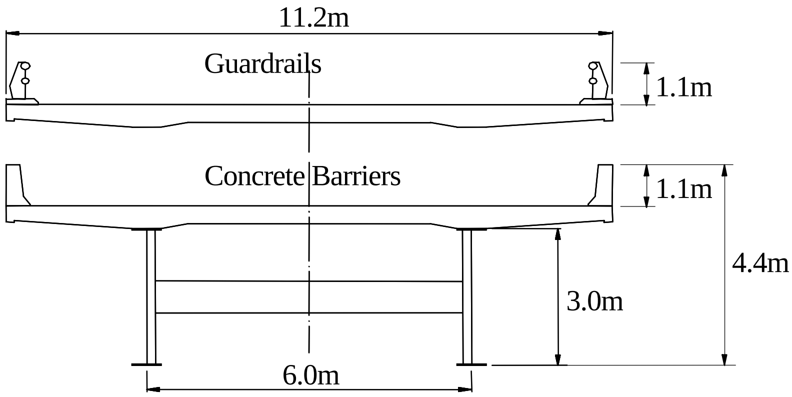


Fig. 1　Cross section of two-girder bridges considered
（Model A:Steel guardrails, Model B:Wall-type concrete barriers）

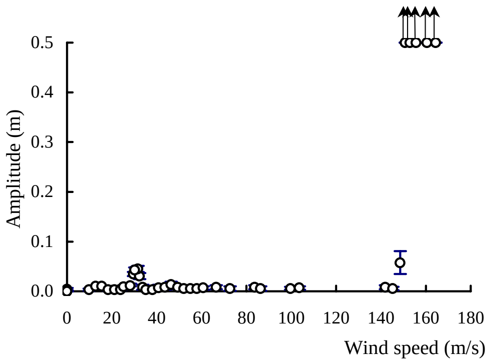
Table 1　Structural dimensions of section models

Item		Actual bridge	Model value	
			Guardrails	Concrete barriers
Scale		―	1/40	1/40
Girder size	Width	11.2 m	0.28 m	0.28 m
	Depth	4.4 m	0.11 m	0.11 m
	Spacing	6.0 m	0.15 m	0.15 m
Mass		15.8 t/m	※1 9.79 kg/m	※1 9.76 kg/m
Polar moment of inertia		175 t・m^2/m	※2 0.0669 kg・m^2/m	※2 0.0681 kg・m^2/m
Natural frequency	Vertical	1.49 Hz	3.49 Hz	3.49 Hz
	Torsional	1.82 Hz	4.05 Hz	4.06 Hz
	Ratio	1.22	1.16	1.16

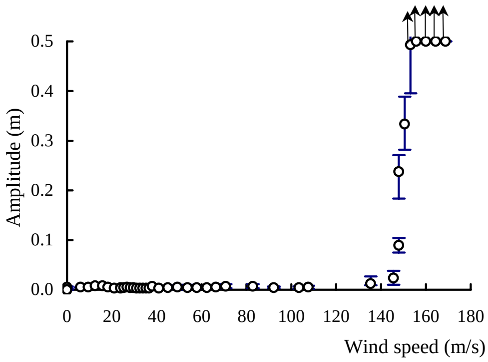
※1：Required 9.88 kg/m , ※2：Required 0.0684 kg・m^2/m

Table 2　Test cases

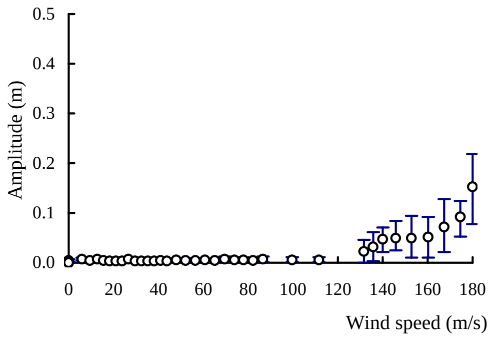
Item	Test case
Type of barriers	Steel guardrails, Wall-type concrete barriers
Structural damping	δ = 0.02, 0.03, 0.04, 0.05, 0.06
Angle of attack	α = +3°, ±0°, -3°



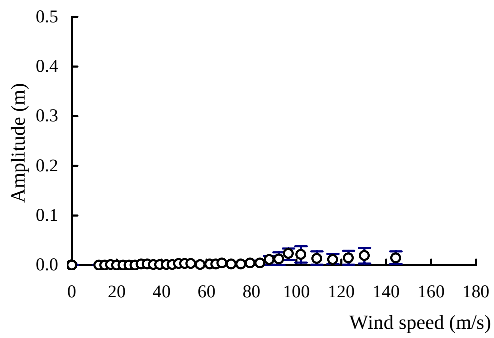
(a) Guardrails (δ =0.02)



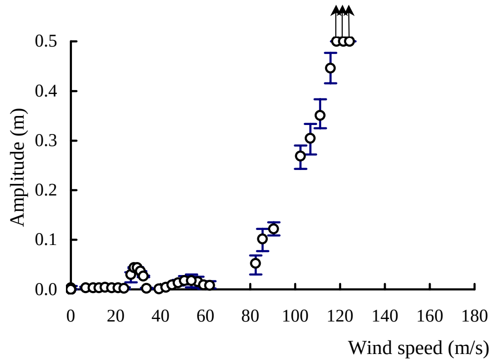
(b) Guardrails (δ =0.03)



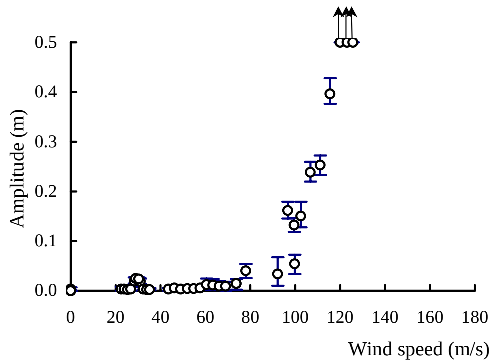
(c) Guardrails (δ =0.04)



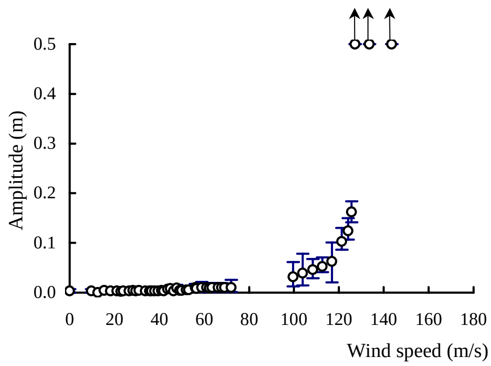
(d) Guardrails (δ =0.05)



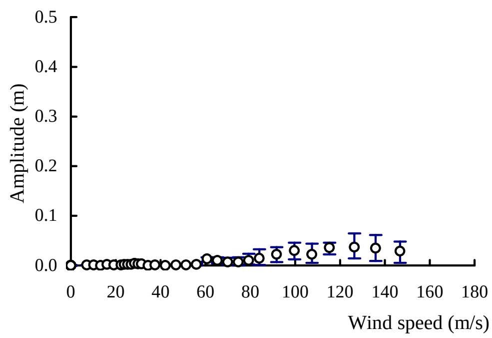
(e) Concrete barriers (δ =0.02)



(f) Concrete barriers (δ =0.03)



(g) Concrete barriers (δ =0.04)



(h) Concrete barriers (δ =0.05)

Fig. 2 Amplitude response to wind speed
(Vertical flexural vibration, angle of attack α =0 deg.)

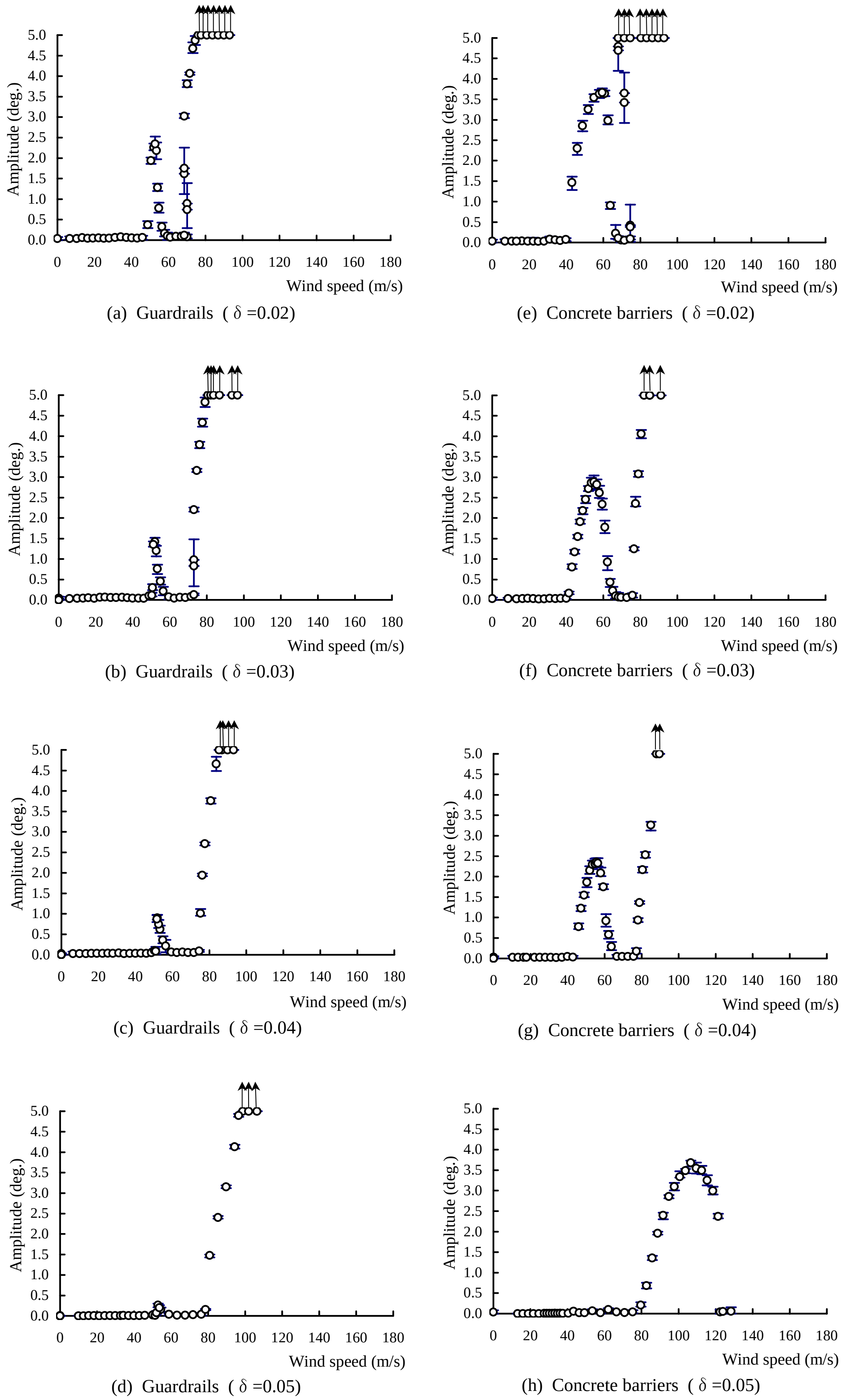


Fig. 3 Amplitude response to wind speed
(Torsional vibration, angle of attack α =0 deg.)

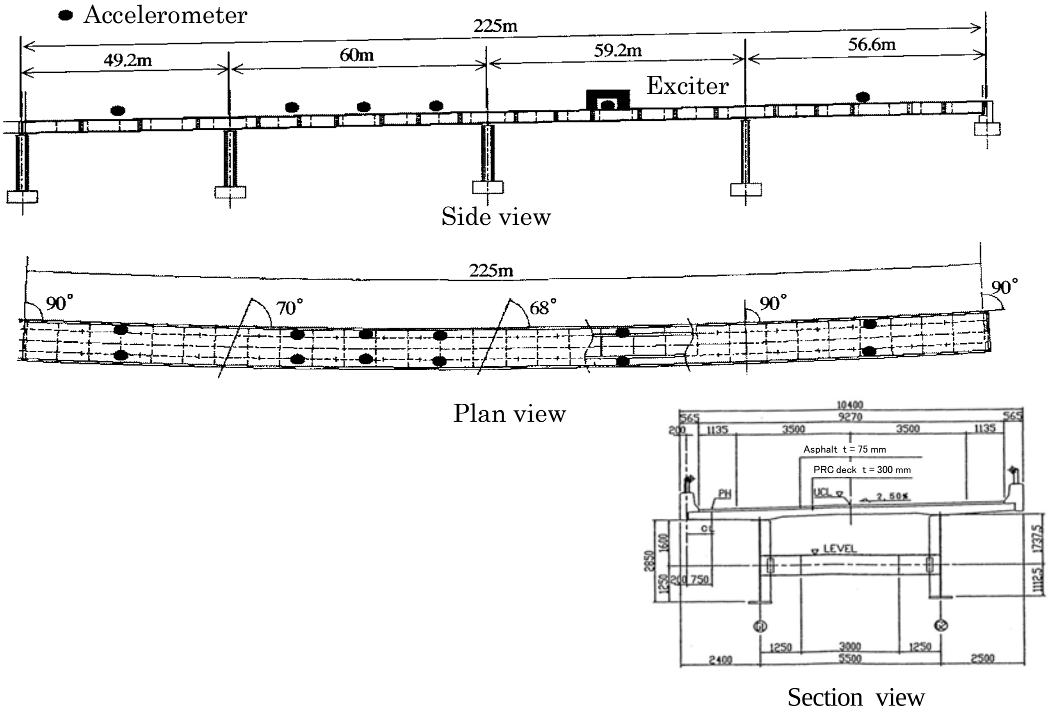
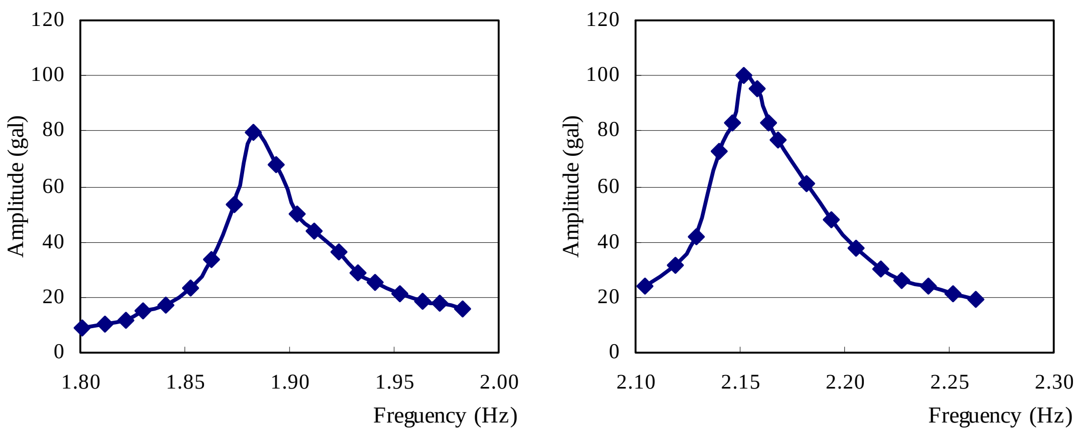


Fig. 4 General view of the tested bridge and instrumentation locations

Photo 1 Installation of the exciter on the road surface



(a) First vertical flexural mode (b) First torsional mode

Fig. 5 Resonance curve obtained by the forced vibration measurements

Table 3 Measured and analytical frequencies

Mode type	Natural frequency (Hz)		
	Measured (A)	Analytical (B)	(B/A)
First vertical flexural mode	1.88	1.63	0.87
First torsional mode	2.15	1.82	0.85
Frequency ratio (torsional/vertical flexural)	1.14	1.12	0.98

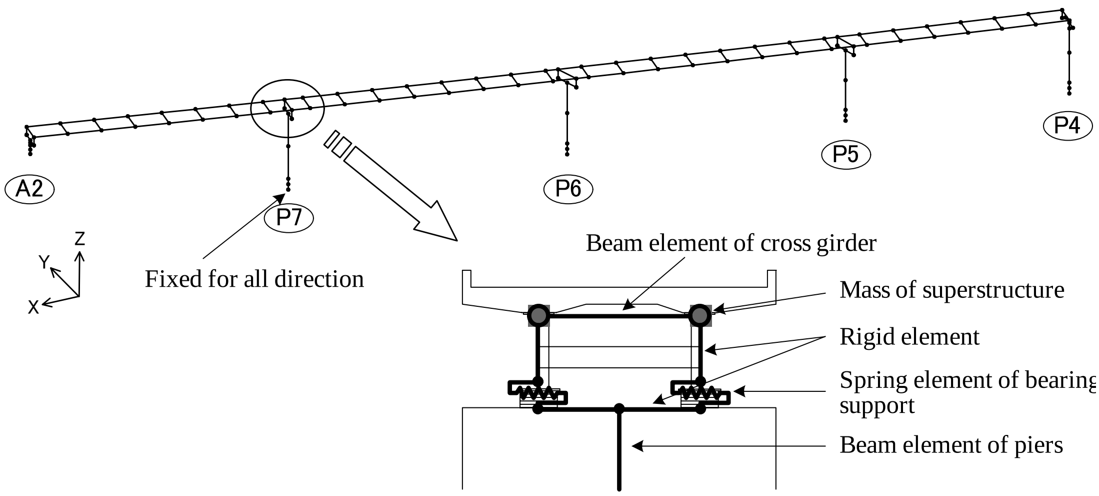


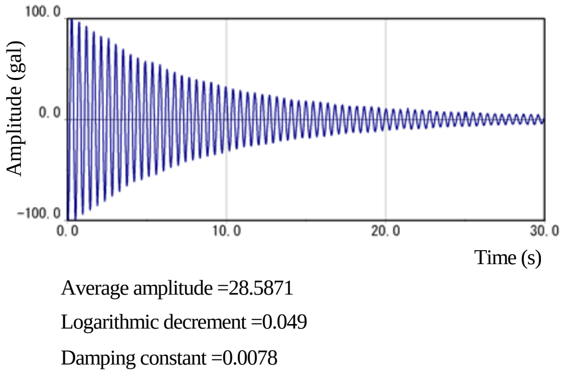
Fig.6 Frame model of the two-girder bridge

Table 4 Measured logarithmic decrement

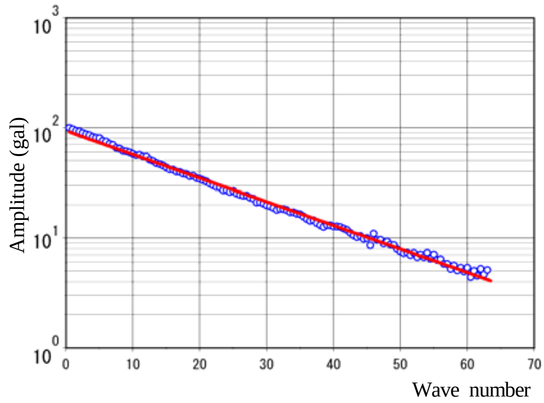
Mode type	Logarithmic decrement	
	Range	Average
First vertical flexural mode	0.043-0.048	0.044
First torsional mode	0.048-0.052	0.050

Table 5 Past vibration test results of other two-girder bridges

Name of bridge	Maximum span length	Frequency ratio (torsional/ flexural)	Log. decrement	
			1st vertical flexural mode	1st torsional mode
Toshibetsu River Dai-ichi Bridge (continuous six-span bridge)	86.5 m	1.05	0.040 - 0.046	0.081 - 0.083
Hibakaridaira Viaduct (continuous four-span bridge)	48.5 m	1.08	0.062 - 0.068	0.062 - 0.098
Chidorinosawa River Bridge (continuous four-span bridge)	53.0 m	1.11	0.064	0.064



（a）Damped free vibration record



（b）Amplitude decrement curve

Fig.7 Estimation of structural damping for 1st torsional mode