A STUDY ON COUNTERMEASURE FOR REDUCING EFFECT OF TSUNAMI ON HIGHWAY BRIDGES

Guangfeng Zhang[1], Jun-ichi Hoshikuma[2] and Toshihiro Usui[3]

Abstract

In order to mitigate tsunami effect on bridge structures, tsunami induced forces are needed to be understood and countermeasures for reducing these forces are also required to be established. In this research, a countermeasure by means of installing a fairing on the side surface of superstructure was studied with purpose to reduce tsunami induced forces acted on superstructure. Influences of fairing shape on hydrodynamic forces were investigated based on hydraulic flume tests. It is confirmed that fairing can provide well reduction effect on hydrodynamic forces including surge force and drag force.

Introduction

In Japan, large off-shore earthquakes including the Tokai earthquake, the Tonankai earthquake, the Nankai earthquake and earthquakes around Japan Trench and Chishima Trench are predicted with high possibility of occurrence in the next few decades. Figure 1 shows estimated epicenter area and estimated tsunami wave height along the coasts according to the reports issued by the Central Disaster Prevention Council, Cabinet Office, Government of Japan. It can be seen that wide area will be attacked by tsunamis with wave height more than five meters when the Tokai, Tonankai and Nankai earthquakes occurs. Furthermore, tsunamis with maximum wave height more than twenty meters are estimated in some regions of Tohoku and Hokkaido district. Tsunami is an essential issue for disaster prevention of coastal infrastructures in Japan.

Bridges near the coasts may be subjected not only by seismic force but also by tsunami induced forces when large off-shore earthquake occurs. The potential risk of bridge structures attacked by tsunami was recognized again by the 2004 India Ocean tsunami. Many bridges were destroyed or washed out entirely and traffic networks were damaged severely in this disaster. Because bridges are important parts of a traffic network, it is very essential for evacuation and emergency transportation to ensure the function of bridges in disaster.

In order to mitigate tsunami effects on bridge structures, tsunami induced forces

[1] Researcher, Bridge and Structural Technology Research Group, Public Works Research Institute, Japan
[2] Chief Researcher, Bridge and Structural Technology Research Group, Public Works Research Institute, Japan
[3] Bridge Engineer, Honshu-shikoku Bridge Expressway Co., Ltd. Kobe, Japan

are needed to be understood and countermeasures for reducing these forces are also required to be established. In this research, a countermeasure for reducing tsunami forces acted on superstructures was proposed and the reduction effect was investigated by means of using hydraulic flume tests. This paper gives a report on proposed countermeasure and test results.

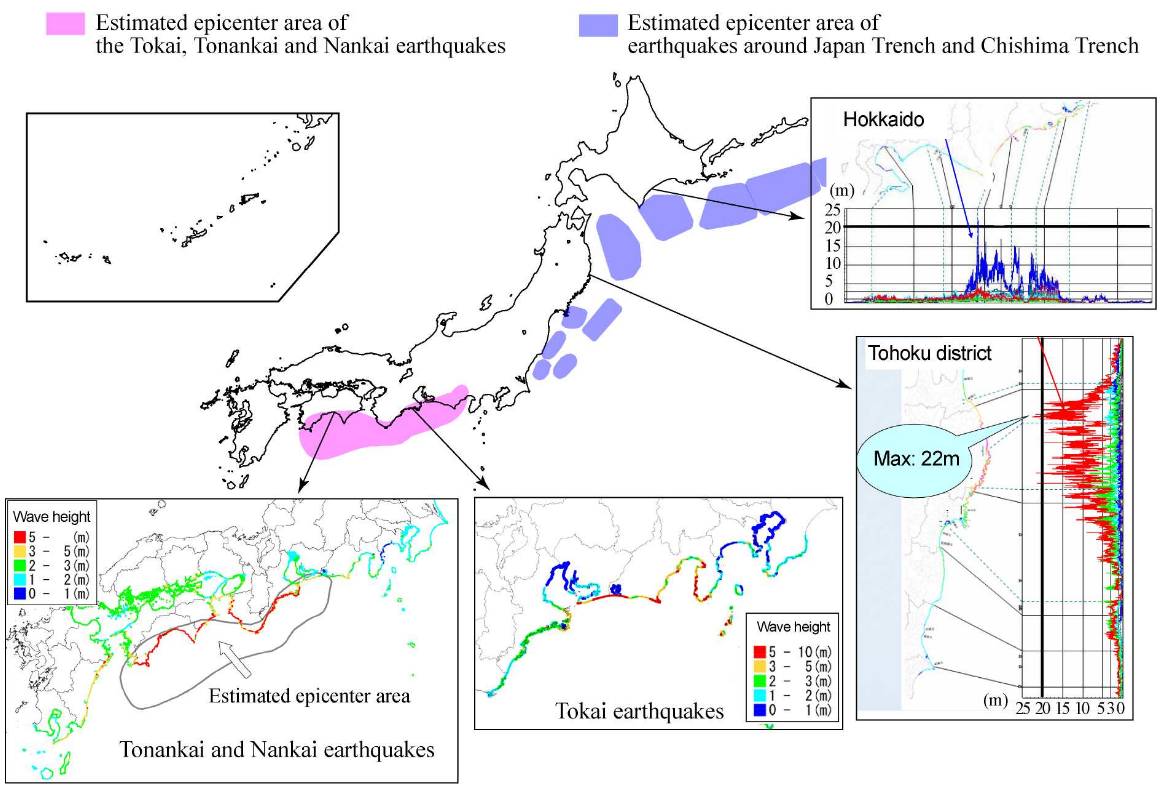


Fig. 1 Predicted large off-shore earthquakes in Japan

Countermeasure for Mitigating Tsunami Effect on Highway Bridges

Tsunami effects on bridge structures include hydrostatic force, buoyant force, drag force, surge force and other effects including foundation scour and debris impact force (Yim, 2005). Surge force and drag force are hydrodynamic forces induced by tsunami wave. Surge force is generated by impingement of the leading edge of tsunami wave on bridge structures and drag force is generated by steady flow followed the leading edge of tsunami wave. Debris impact force is induced by impact of floating debris carried by tsunami flow. In this research, the emphases are focused on study of a countermeasure for reducing hydrodynamic forces acted on superstructures. Foundation scour and debris impact will not be taken into account in this research.

Fairing is a well-known countermeasure for reducing effect of wind on long-span bridge. It changes the streamline of the air around the deck and effect of wind is reduced as a result. Based on the same consideration, it can be considered that fairing may also be used for reducing tsunami effect on superstructures. In this research, a countermeasure by means of installing a fairing on the side surface of superstructure was proposed for reducing tsunami induced hydrodynamic forces. Figure 2 shows the schematic of this countermeasure. Side surface of the superstructure is changed into two plane surfaces after the fairing was installed. It can be considered that hydrodynamic reduction effect depends on the shape of the fairing.

In this research, preliminary studies were conducted for confirming the reduction effect of fairing on tsunami forces. Furthermore, influences of fairing shape on effectiveness of reduction are also investigated.

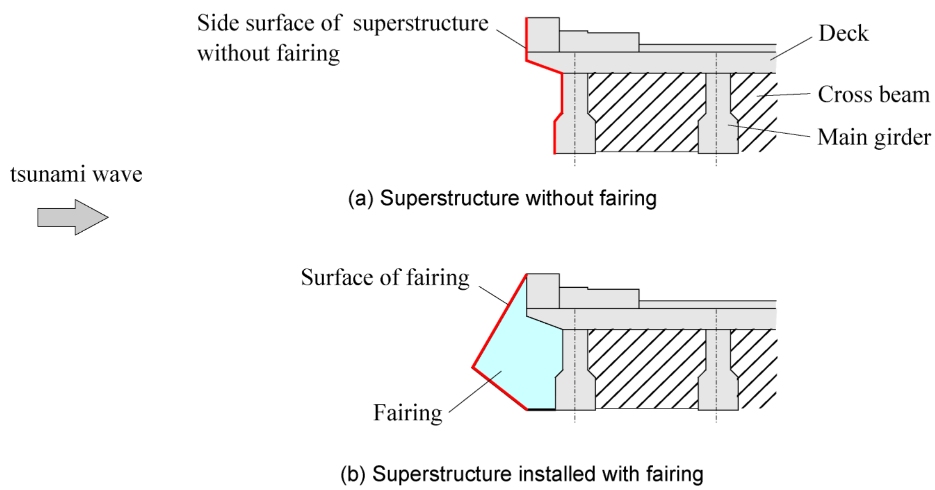


Fig. 2 Schematics of countermeasure for reducing hydrodynamic forces

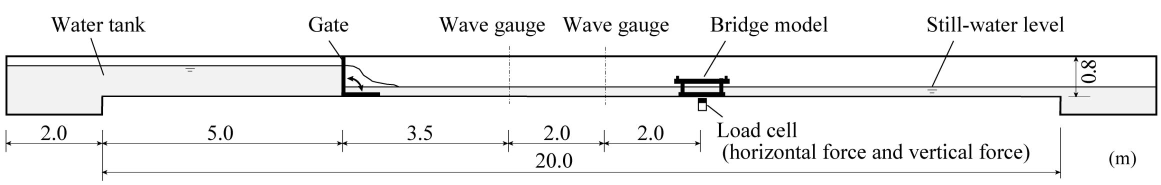
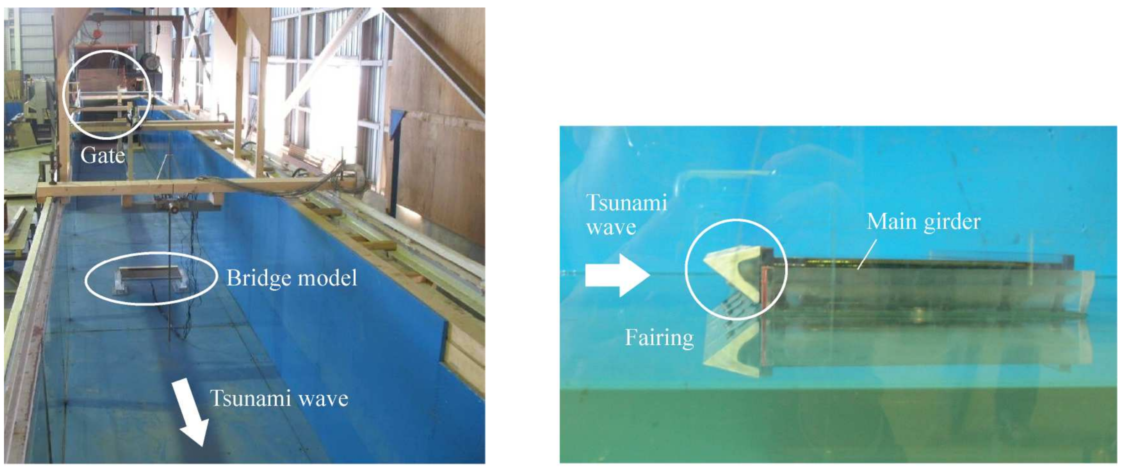


Fig. 3 Setup of flume test

Overview of Tests

Figure 3 shows the setup of flume test. Figure 4 shows photos of the flume and bridge mode. Tsunami waves were generated by opening the gate. Tsunami wave height was controlled by water level of the water tank. Relationship between water level of the water tank and tsunami wave height was calibrated prior to the test. Hydrodynamic forces in horizontal direction (surge force and drag force) and vertical direction (buoyant force) were measured with load cell installed under the bridge model. Clearance of the real bridge is 3.5 meters. Still-water level was set as 600 mm (3 m for real bridge) in the tests.



(a) Flume (b) Bridge model

Fig. 4 Photos of the flume and bridge model

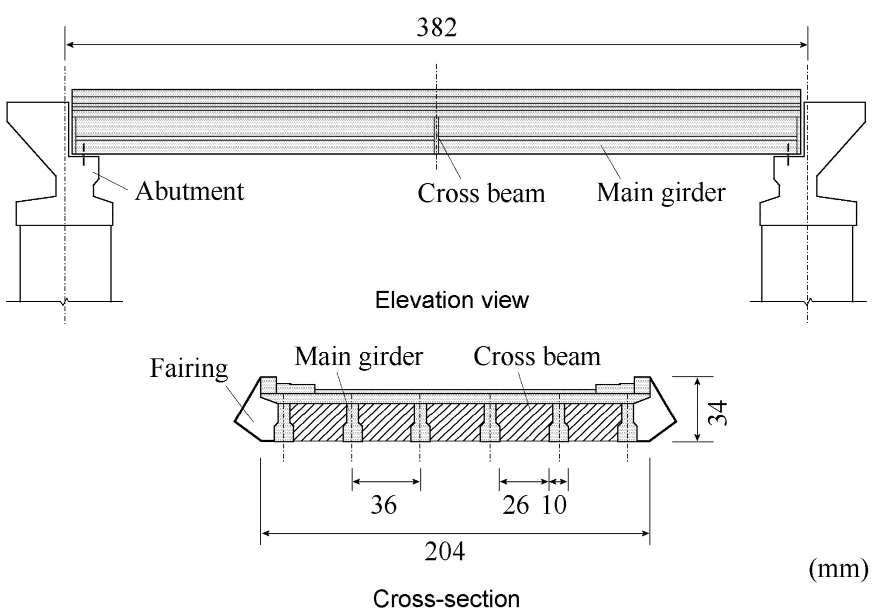


Fig. 5 Details of bridge model

Figure 5 shows details of bridge model. It was a reduced model of Lueng Ie bridge, which was damaged in the 2004 Indian Ocean tsunami (Japan Society of Civil Engineers, 2005). Superstructure of this bridge was moved in the transverse direction about 3 meters. Reduction scale was set as one to fifty taking into account of dimension of the flume. Based on Froude similarity, wave height and wave forces for real bridge can be calculated from the test results of the bridge model using the following equations.

$$H_R = \frac{H_m}{\lambda} \tag{1}$$

$$P_R = \frac{P_m}{\lambda^3} \tag{2}$$

where, H_R and P_R are wave height and wave force for real bridge, H_m and P_m are wave height and wave force for bridge model, λ is the reduction scale. In the following discussions, all of the test results are shown as values for real bridge.

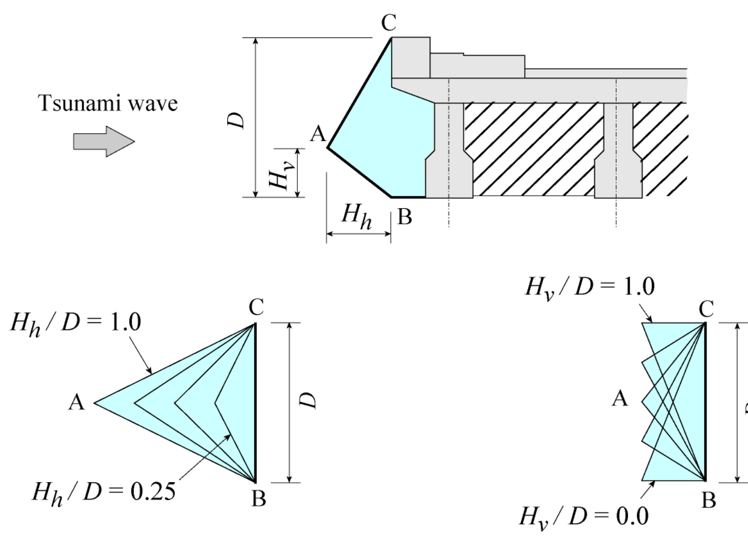


Fig. 6 Shapes of fairing

Table 1 Parameters taken into account in the tests

H_h/D	H_v/D	Tsunami wave height
0.25	0.00	3 m
0.50	0.25	5 m
0.75	0.50	
1.00	0.75	
	1.00	

Total twenty kinds of fairing shapes as shown in figure 6 and table 1 were tested. Fairing shape was changed by changing the location of point A relative to point B. The relative locations of point A are indicated as H_h/D in horizontal direction and H_v/D in vertical direction. H_h/D and H_v/D were varied with four and five kinds respectively in the tests. Each kind of the shape was tested with two kinds of tsunami wave height.

Test Results and Discussions

Figure 7 shows snapshots of the moment of tsunami wave impinging against the bridge model for the case without fairing and the case with fairing shape of $H_h/D = 0.5$ and $H_v/D = 0.25$ as examples. Here, test case with fairing shape of $H_h/D = 0.5$ and $H_v/D = 0.25$ are the case that both of the maximum surge force and vertical force are the lowest among all the cases. It is noted that flow overtopping occurred in both of the two cases. There are no significant differences between the two cases.

(a) Bridge model without fairing (b) Bridge model with fairing (H_h/D = 0.50, H_v/D = 0.25)

Fig. 7 Snapshots of the moment of tsunami wave impinging against the bridge model

Figure 8 shows time histories of wave forces for the case without fairing and the case with fairing shape of $H_h/D = 0.5$ and $H_v/D = 0.25$. As for the results of the case without fairing, a peak of horizontal force (surge force) occurs at the moment of tsunami wave impinging against the bridge model. Horizontal force drops sharply after the peak and drag force is about one third of the maximum surge force. Maximum vertical force occurs shortly after the peak of horizontal force. Vertical force after the peak become minus because of the gravity of the overtopped flow. As for the results of the case with fairing shape of $H_h/D = 0.5$ and $H_v/D = 0.25$, it is noted that there is no obvious peak of horizontal force at the moment of tsunami wave impinging against the bridge model. Distribution of vertical force is similar to that of the case without fairing.

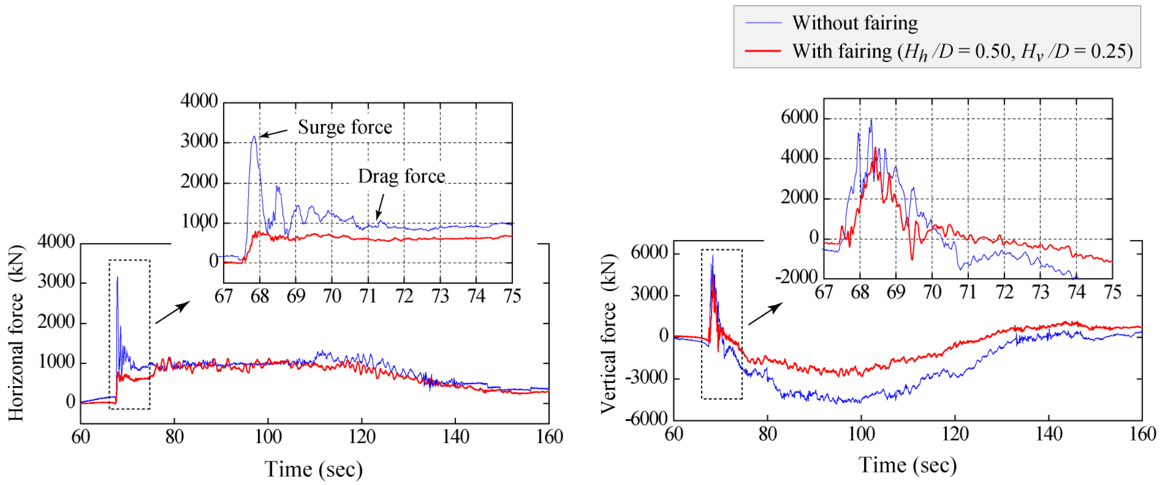


Fig. 8 Time histories of wave forces (tsunami wave height: 5 m)

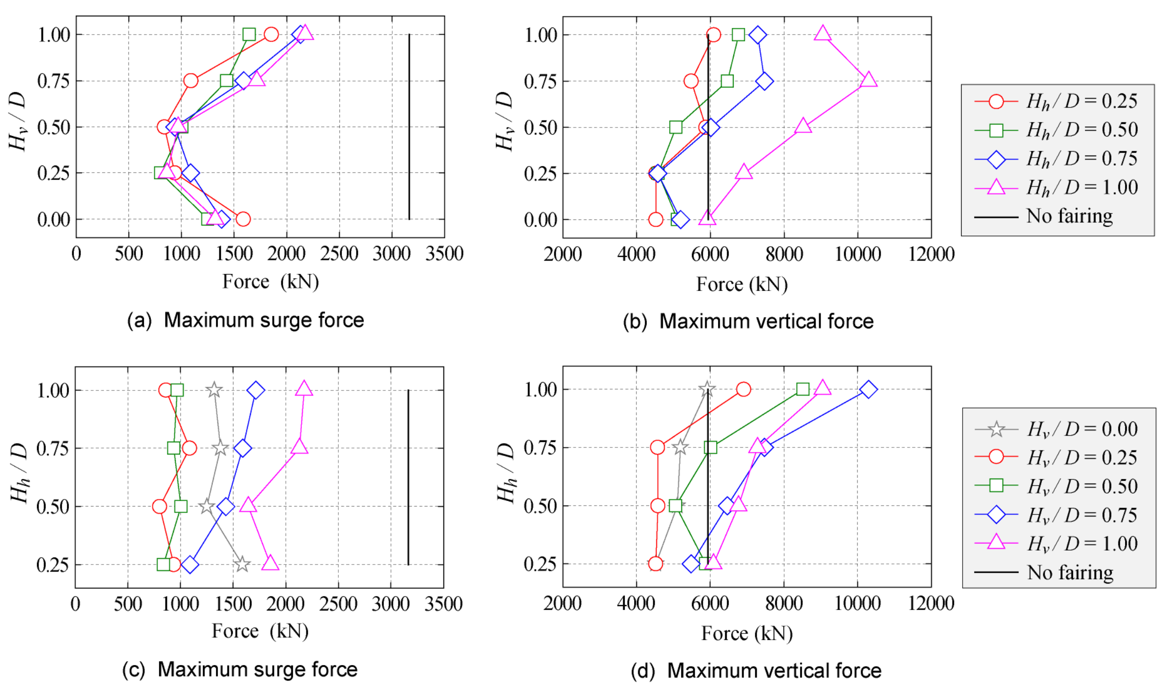
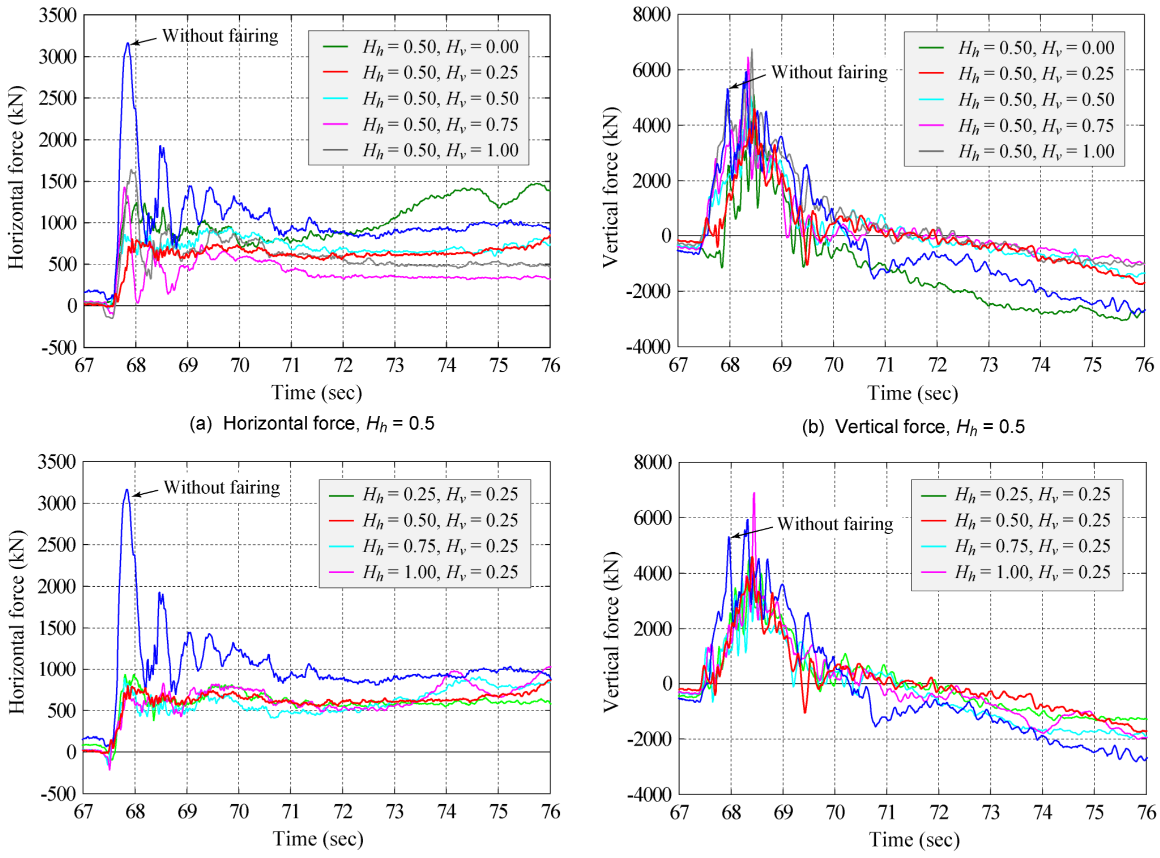


Fig. 9 Comparison of maximum forces (tsunami wave height: 5 m)

Figure 9 shows comparison of maximum forces for discussing the influence of fairing shape on hydrodynamic forces. Figure (a) and (b) arrange maximum forces with vertical axis of H_v/D and figure (c) and (d) arrange the maximum forces with vertical axis of H_h/D. It is noted that maximum surge forces were reduced remarkably regardless of shape of the fairing. Comparison of figure (a) and figure (c) shows that varying of H_v/D

affect the maximum surge force more obvious than that of H_h/D. In comparison with horizontal forces, maximum vertical forces were reduced in some cases but there are cases that maximum vertical forces were increased oppositely.



(a) Horizontal force, H_h = 0.5

(b) Vertical force, H_h = 0.5

(c) Horizontal force, H_v = 0.25

(d) Vertical force, H_v = 0.25

Fig. 10 Comparison of time histories of wave forces (tsunami wave height: 5 m)

Figure 10 shows comparison of time histories of wave forces. Figure (a) and (b) are cases with fairing shape of $H_h/D = 0.5$ and figure (c) and (d) are cases with fairing shapes of $H_v/D = 0.25$. Similar to figure 9, it can be seen that influence of varying of H_v/D on time histories of horizontal force is more obvious than that of H_h/D. However, influence of fairing shape on vertical force is not obvious.

Conclusions

A countermeasure by means of installing a fairing on the side surface of superstructure was studied with purpose to reduce tsunami effects on highway bridges.

Influences of fairing shape on tsunami induced forces were investigated based on hydraulic flume tests. It is confirmed that fairing can provide well reduction effect on hydrodynamic forces including surge force and drag force. Reduction effect depends on the shape of fairing. Influence of varying of H_v/D on time histories of horizontal force is more obvious than that of H_h/D .

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