Fairing with slits for reducing damage of bridges by tsunami

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ABSTRACT

Tsunami by the 2011 off the Pacific coast of Tohoku Earthquake caused serious damage to bridges near the coast in Japan. In particular, the outflow damage of superstructures of large-scale bridges was noticeable. As a measure for bridges near coast, we have focused on fairing that is effective in wind resistant stability. In the experiment, two kinds of fairing, i.e. one is a fairing mounted only on the side of the bridge, the other is a box-shaped fairing enclosing the girder were used. From previous studies, it has been found that fairings are effective for horizontal drag, but they are not effective for vertical drag because of the buoyancy. Therefore, hydraulic experiments were conducted on the effect of having to open a slit in the fairing, to smooth the flow of water into the fairing within. This paper described the experimental outline and results.

1. INTRODUCTION

In the damage of bridges caused by the 2011 off the Pacific coast of Tohoku Earthquake, the damage due to tsunami was more significant than that due to the ground motion. In bridges constructed in coastal areas, the outflow of the superstructure was the characteristic damage. This damage has influenced the relief and reconstruction of the affected areas. Conventionally, in the superstructures design of Japanese bridges, tsunami load is not considered. In Japan, especially including coastal areas, the occurrences of large earthquakes are predicted, tsunami measures for bridges are important and urgent.

In response to the bridge disaster at 2004 Sumatra earthquake, as tsunami countermeasures for existing bridges, ZHANG et al (2010) verified experimentally the effect of installing fairings to the superstructure, and discussed the relationship between tsunami forces and shapes of fairings. The authors (2013) also tested the effect of installing fairings by using hydraulic experiments for two kind of fairing, L-shape and box-shape. As the model in the experiments, the affected bridge, Kesen-bridge was used. As the results from the experiments, a large effect can be obtained with respect to the horizontal drag. However, in the vertical drag, the effect as the horizontal drag can’t be observed because of buoyancy by the residual air in the fairing inner. Therefore, the method of forming rectangular slits in the fairing was proposed, and experimentally investigated.

1) Engineer
2) Professor
2. FAIRINGS AND OUTLINE of EXPERIMENTS

2.1 Bridge model and Fairings

Fig.1 shows the picture of Kesen-bridge used as the model, after affected by tsunami. We can see the piers without girders. Main girder was swept away to about 300m upstream. Parts of the RC slab were swept away to about 500m upstream. Piers and abutments had not received serious damage. Considering the size of experimental flume, bridge model was set at scale 1/50 as Fig.2. Bridge model was made of transparent acrylic. Sway bracings were installed in the bridge model but bridge railings were not installed considering the influence. Bridge model is 270mm in length, 48mm in high including wheel guard.

Two type fairings, L-shape fairings which are attached to both sides of bridge and box-shape fairings which cover the sides and bottom of the bridge, were used. Considering the former experimental results, The shapes in Table.1 were selected for two types of fairings. Slits, consisted by rectangle 10, as shown in Fig.3, were used. The six types of up to 21mm from 4mm were used for the width of each rectangle. Table.2 shows specimen name slit width and two kinds of rate of slit. As two kinds of the rate of slit, the ratio of the slit width to the full width of the fairing in the mounting position and the ratio of the slit area to the total area of the fairing were used.
Fig.3 Fairing with slits (L-shape and Box-shape)

Table 1 L-shape and Box-shape fairings

<table>
<thead>
<tr>
<th>kind</th>
<th>name</th>
<th>shape</th>
<th>Cubic diagram</th>
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<tbody>
<tr>
<td>L-shape</td>
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<tr>
<td>Box-shape</td>
<td>FB0</td>
<td><img src="Box-shape" alt="Diagram" /></td>
<td>![Diagram](Cubic diagram)</td>
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Table 2 L-shape and Box-shape fairings

<table>
<thead>
<tr>
<th>Name of Specimen</th>
<th>Width of slit (mm)</th>
<th>RS-1 (%)</th>
<th>RS-2 (%)</th>
<th>Specimen</th>
<th>Width of slit (mm)</th>
<th>RS-1 (%)</th>
<th>RS-2 (%)</th>
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<tr>
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<td>L-shape</td>
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<td>SFB7</td>
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<td>28.0</td>
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<td>53.5</td>
<td>SFB21</td>
<td>21</td>
<td>77.8</td>
<td>65.1</td>
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</tbody>
</table>

RS-1: Ratio of slits on width, RS-2: Ratio of Slits on area
MK0: Bridge-model without fairing
2.2 Outline of experiments

Fig.4 and Fig.5 show a cross-sectional view and the side of the experimental channel. In addition, Fig.6 and Fig.7 show the installation status of the measuring equipment and the bridge model. The experimental channel in total length 16.99m, is divided into a downstream side 11.30m and upstream side of 5.69m this. By pulling-up the gate between both streams, tsunami wave will be caused. The bridge model was located at position of 5.0m from the gate. A partition plate was set in middle of longitudinal direction of the channel in order to observe the flow velocity in the model center and two dimensional behavior of the bridge model. The model was set on the right side of the partition plate and a current meter was set on the left side.

From the video recording of suspended solids at tsunami arrival time near Kesen-bridge, the velocity of tsunami has been estimated to 7.0m/sec (ZHENG 2013), then, 1m/sec was used for the experimental velocity to constant the Froude number. And, from the calibration for the flow velocity, the water level of the constant water tank and water storage tank were set 20cm, and 4cm, respectively. The lower end of the model bridge is located at the height of 1cm from the water before tsunami arrives.
Fig. 6 Installation Conditions (Side)

Component Force Meter
Wave Height Meter

Fig. 7 Installation Conditions (Front)

Current Meter
Partition Plate
3. RESULTS AND DISCUSSIONS

Here, as an index for evaluating the size of the slits, the ratio of 10 slits width to fairing entire width (RS-1) is used. Fig.8 shows the time history curve of vertical force Fz and horizontal drag Fx in three cases of (MK0) not attached fairing, (F2) attached side fairing without slits, and (SF14) attached side fairing with 51.9% rate slits. Positive Fz is taking downward. In the time history, the time from touch to impact and steady flow after that are observed. So, we call impact state and steady state, respectively. In impact state, Fz(i), Fz(-i) mean the maximum value Fz in positive direction, the maximum value Fz in negative direction, respectively, Fx(i) means the maximum value Fx. Fz(s), Fx(s) in a steady state were calculated as an average of 3 seconds to 5 seconds from 2 seconds after the tsunami arrival time.

According to Fig.8 the figure above, installation of the fairing can reduce the tsunami force Fx at the time of impact and at the steady state also. Reduction at the time of impact is particularly large. From Fig.8 the figure below, Fz differences due to fairing installation is not clear compared to Fx. Fig.9. shows the changes of Fz and Fx due to slit rate. Vertical axis is dimensionless force divided by the component force generated when a fairing is not attached, and the horizontal axis is a slit ratio obtained by dividing the entire width of the slit width. Upper row L-shape, lower indicates the Box-shape.

(1) Discussions on Fx

In case of L-shape faring, the reduction rate has declined with an increase in the rate of slit (RS-1) in impact state and in steady state. The impact force can be reduced to about 80% of the force which the model without L-shape faring should be acted even if RS-1 is 80%. However, in the steady state, if the rate of slits exceeds about 50%, the L-shape fairing would lose the effect. The box-shaped, the reduction rate of both steady state and impact state was decreased rapidly with the ratio of slits. Further, if the rate of slits exceeds about 30%, the box-shape faring with slits lose the effect for Fx. Therefore, it should be understood for Fx that box-shape is more effective than L-shape when fairing has no slits, however L-shape is more effective than box-shape when bridge has fairing with slits.

(2) Discussions on Fz

In case of L-shape, Fig.9 right above, the relationship between Fx and the rate of slits is not clear. From Fig.9 right low, F(-i), which is lift at impact state, can be decreased with the ratio of slits in case of box-shape. If the ratio of slits exceeds about 40%, the lift should be similar to the force which the model without fairings should be acted.

Taken together these results, reduction of vertical force in the L-shape can’t be expected. For horizontal forces, slits in fairing lose the effect to reduce the horizontal force. In box-shape, the slits of about 40% is necessary in order to keep the lift to the level which the model without fairings should be acted, at that time the effect of horizontal force should be lost.
(3) Discussions on behavior of tsunami

Table 3 shows the behavior of the tsunami of the model around from the arrival of the tsunami to the steady state for three specimens same as Fig. 8. At touch to the bridge, if the bridge has no fairing, water impacts to the web of the outer girder, water moves to upper and lower direction. The water which moves in upper direction impacts to the overhanging slab. If a fairing is attached to bridge, the wave should be separated at the protrusion to upper and lower direction along the fairing. If the protrusion has a sharp angle, the impact should be smoothened. If the fairing has slits (SF14), wave flows into three directions in upper, lower and inner direction. While it is complicated, it is expected that disperse the flow of the wave.

Fig. 8 Time-history of component forces
Above: Horizontal force Fx,  Below : Vertical force Fz
MK0: bridge-model without fairing
F2:L-shape fairing without slits
SF14:L-shape fairing with slits (RS-1 = 51.9%)
Fig. 9 Ratio of slits (RS-1) and forces
Left: Horizontal force Fx, Right: Vertical force Fz
Above: L-shape, Below: Box-shape
F0 means the force in case of bridge-model without fairing

Table 3 Behavior of tsunami from touch to steady state

<table>
<thead>
<tr>
<th>Model</th>
<th>Touch</th>
<th>Impact</th>
<th>Jump</th>
<th>Steady</th>
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<tbody>
<tr>
<td>MK0</td>
<td>![Image](MK0 Touch)</td>
<td>![Image](MK0 Impact)</td>
<td>![Image](MK0 Jump)</td>
<td>![Image](MK0 Steady)</td>
</tr>
<tr>
<td>F2</td>
<td>![Image](F2 Touch)</td>
<td>![Image](F2 Impact)</td>
<td>![Image](F2 Jump)</td>
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<tr>
<td>SF14</td>
<td>![Image](SF14 Touch)</td>
<td>![Image](SF14 Impact)</td>
<td>![Image](SF14 Jump)</td>
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</tbody>
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MK0: bridge-model without fairing,
F2: L-shape fairing without slits,
SF14: L-shape fairing with slits (RS-1=51.9%)
3. CONCLUSIONS

By attaching slits to two kinds of fairing, the effect to reduce the tsunami force was verified experimentally. The following conclusions were obtained.

(1) By attaching slits to fairings, reduction of vertical force in the L-shape can’t be expected. For horizontal forces, slits in fairing lose the effect to reduce the horizontal force.

(2) In box-shape, the slits of about 40% is necessary in order to keep the lift to the level which the model without fairings should be acted, at that time the effect of horizontal force should be lost.

It can be considered that the fairing having a slit is effective in dispersing the tsunami and facilitating the tsunami entering into the fairing. It is necessary to study continuously on the shape of slits and the ratio of slits.

REFERENCES
