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Hydraulic experiment on Kesen-Bridge outflow by tsunami

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ABSTRACT

Many bridges were suffered serious damage by the 2011 off the Pacific coast of Tohoku Earthquake. In this earthquake disaster, the damage of bridges caused by tsunami was more serious than that by the earthquake motion. In particular, the outflow damage of superstructures of large-scale bridges was conspicuous. Kesen-Bridge is one of the large-scale bridges damaged by tsunami, 5 spans, 181.5m in length. All of the superstructures of 5 spans were flown to upstream about 300m. It is not taken into consideration in bridge design that tsunami acts on superstructures. For understanding tsunami force to bridges and considering tsunami measures of bridges, the author described considerations on the mechanism of bridge outflow by the use of hydraulic experiment.

1. INTRODUCTION

Many structures were damaged by the 2011 off the Pacific coast of Tohoku Earthquake on March 11, 2011. Feature of this earthquake is that epicenter was Sanriku offshore. Therefore, the damage caused by the tsunami was outstanding than the damage caused by the seismic motion. Ministry of Land, Infrastructure and Transport Tohoku Regional Development Bureau in Japan investigated the 1572 bridges after the earthquake. Bridges affected by the tsunami were 151 bridges and about 10% of the 1572 bridges. However, the damage ratio in the disaster caused by the tsunami was found to be as high as 93.4% shown in Fig.1.

Fig.2 shows the damage on the load-bearing capacity of bridges by the effect of the tsunami. Disaster degrees are rated from As to D. As, A, B, C, D mean bridge collapse, great damage, middle damage, small damage, and no damage, respectively. Fig.2 shows that the collapse of bridges can be seen only in bridges affected by the tsunami. The degree of damage in the bridges becomes higher in bridges affected by the tsunami. Therefore, the damage of the bridge has been found to increase by the tsunami action. In the specifications of Japan for highway bridges revised after the earthquake, the structure plan for disaster prevention must consider tsunami impact for the structures located near seashore. In the specification, as examples for measures to prevent the damage by tsunami, less affective structure of tsunami and structures that are easy to recovery even if the bridges were damaged are introduced.

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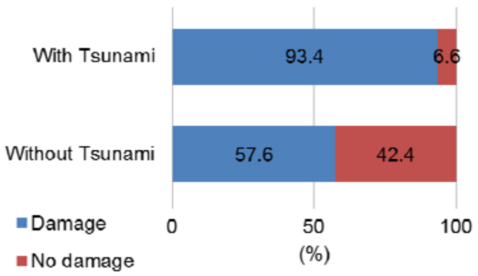

Fig.1 Influence and damage of tsunami

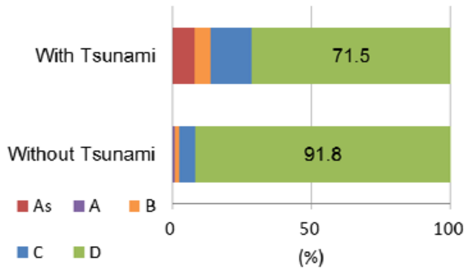

Fig.2 Damage on load-bearing capacity of bridges by the tsunami

For disaster to the bridge superstructure by tsunami like this, there are a few studies by Kenji Kosa, Shinichi Nii, Gaku Shoji, Nakao Hisashi et al. These studies should be noted that studies were based on the damage caused by the earthquake off the coast of Sumatra, calculation method of wave power acting to bridges by the tsunami, the difference on drag coefficient of tsunami acting bridges, and a difference in cross-sectional shape. However, the bridges studied are RC girder bridges, the effect of tsunami acting on steel girders is not clear. The tsunami disaster on this time, steel bridges also have received much damage. So, a model Kesen-Bridge superstructure damaged by the tsunami was selected, hydraulic experiments using the model 1/50 scale were carried out.

2. OVERVIEW OF THE EXPERIMENT

2.1 Kesen-Bridge

Kesen-Bridge had been built on national highway 45 in Iwate prefecture. Bridge type is a steel continuous girder bridge, the length is 181.5m, and span length is 35.97m. It is constituted by the 3 span and 2 spans. Superstructure is completely flown out to about 300m upstream by the tsunami, and pavement surface had been peeled off by the erosion of the embankment. Temporary bridge is now serviced. Fig.3 shows disaster situation of Kesen-Bridge, and Fig.4 shows a cross-sectional view of the Kesen-Bridge.

2.2 Experimental equipment and bridge model

Fig.5 shows the experimental flume, 17m in length, 60cm in width, and 98cm in height. The flume was separated to two tanks, Upper tank's length is 5.69m and lower tank's length is 11.3m. A Gate was set at the boundary. Tsunami wave was generated by pulling up the gate. Fig.6 and Fig.7 show the section view and side view of the

Fig.3 Damaged Kesen-Bridge

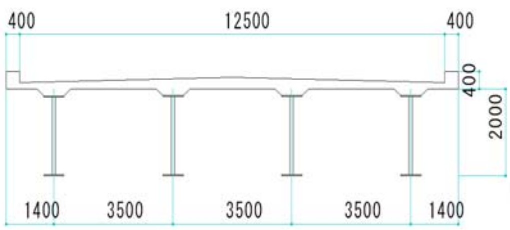

Fig.4 Cross-sectional view of the Kesen-Bridge

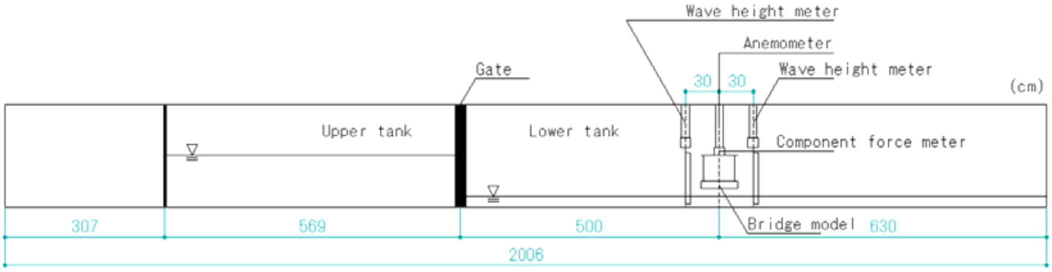

Fig.5 Experimental flume

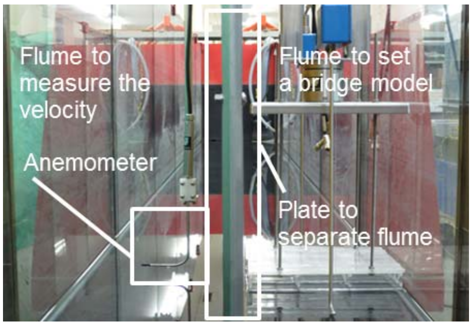

Fig.6 Cross-sectional view of the experimental flume

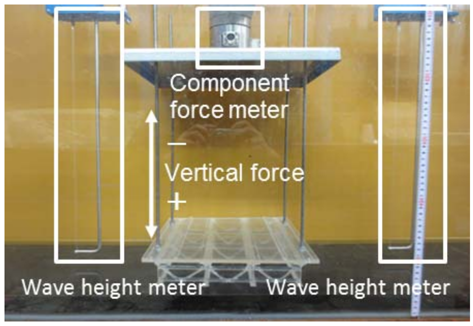

Fig.7 Setting of bridge model

experimental equipment and setting of bridge model, respectably. The flume was longitudinally separated to two flumes, one was used for bridge model to prevent the model from 3 dimensional behaviors, and the other was used for measurement of the velocity at the gravitation center of bridge model. A component force meter was set over the bridge model. Two wave height meters was set at 30cm front and rear the bridge model. Two kinds of bridge model were used, one was Kesen-Bridge model which scale is 1/50 and made of acrylic, the other was rectangular shaped model which is made of wood.

The size of bridge model is 270mm in length, 266mm in width and 48mm in height including wheel guard. The length of model was determined by considering the width of flume. Bridge railing, street light, etc. were omitted by considering less influence on tsunami force and damage at the tsunami.

2.3 Experimental conditions

Tsunami acting on the Kesen-Bridge was the height in 13m and velocity in 7.0m/sec. the height in 13m was recorded from the scar and the velocity in 7.0m/sec was observed in videos. Translations for velocity and height to match the flume were carried out. The velocity for the model was translated to 1.0m/sec using the equation (a). The height was determined to 26cm by the use of scale1/50.

Component force F_m obtained may be translated to F_r by equation (b).

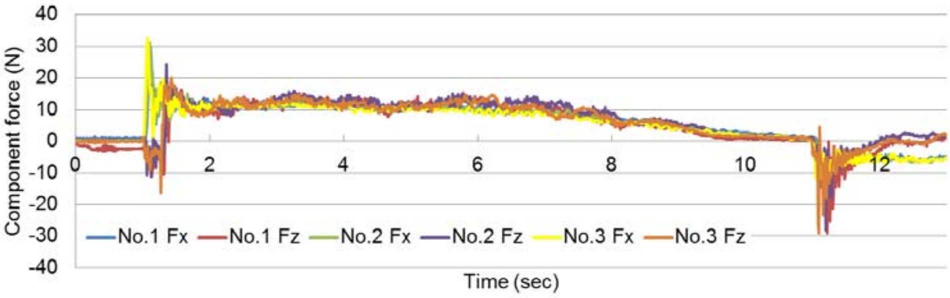

Fig.8 Time history curve of the component forces in three experiments

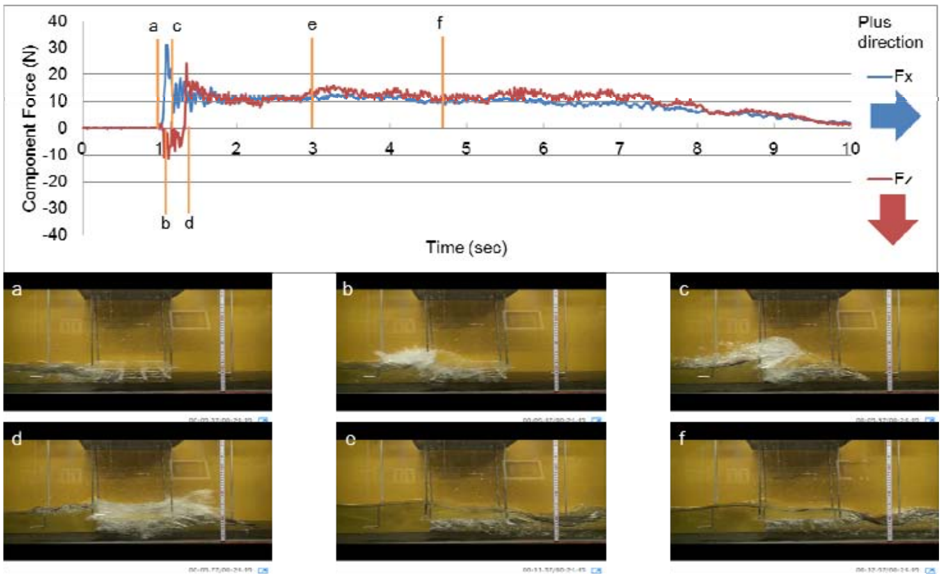

Fig.9 Time history curve of the component forces and shapes of tsunami wave

2.4 Experimental Methods

This flume could not generate tsunami wave of velocity in 1.0m/sec and height in 26cm, simultaneously. Therefore, two kinds of conditions of experiments were executed. One is executed under the height in 26cm, the other is executed under the velocity in 1.0m/sec

2.4.1 Experiment A: Wave height 26cm

Water depths of Kesen River and bridge clearance under Kesen River are assumed to 3m and 6m, respectively. Therefore, the lower tank was set to 6cm (3m/50) and bridge clearance of the model was set to 12cm (6m/50). The velocity was 2.57m/sec.

2.4.2 Experiment B: Velocity 1.0m/sec

Experiment B was executed under the condition of the velocity in 1.0m/sec. The lower tank was set to 4cm and bridge clearance of the model was set to 5cm.
This paper described the results and discussions on the experiment B in case of the velocity in 1.0m/sec.

3. EXPERIMENTAL RESULTS

The experiment was executed three times under the same conditions. Fig.8 shows an example of the results of the component forces of three times. There is a small difference in the three results. However, this experiment has a constant trend.

3.1Result of Kesen-Bridge model

Fig.9 shows a situation in which tsunami was acting to Kesen-Bridge model after reaching at the side of the model. The upper figure in Fig.9 shows the time history curve of the horizontal force and vertical force acting on the bridge model. The lower pictures in Fig.9 show the shapes of tsunami wave in different time. The positive direction of horizontal force and vertical force are right and downward, respectively.

(a) Tsunami begins to act on the bridge model
The horizontal force started to the action to the model, on the other hand, the vertical force showed no big change. Tsunami wave acted only to the bottom of the main girder.

(b) Impact force has the maximum value
The horizontal force has the maximum value. The vertical force is the minimum, conversely. Tsunami acts on the all left aspect of the bridge model. A part of tsunami wave is reflected back by hitting the girder. A part of tsunami wave has jumped over the bridge model. In the lower part of the model, the installing of water has begun.

(c) Immediately after the impact force is acted
The reflection of a part of wave is seen. However, majority of tsunami wave is jumped on the model. Because the tsunami wave is applied to the entire bottom of the main girder, the vertical force is exerted upward on the bridge model whole.

(d) Vertical force is maximum
The majority of jumped tsunami wave dropped down to the surface of the bridge model. Tsunami wave of the left aspect end is changing gently. Whole of bridge model is in the turbulent flow, horizontal force is changing to steady force from impact force.

(e) and (f) Movement of a steady wave
Tsunami waves acting on the bridge model have changed gently. Air is trapped in the interior of the girder. In this period, vertical force and horizontal force show similar values. Force pressing the bridge from the top is exerted long period of time.

Impact force is maximized when the wave hits the bridge model. Steady force became about 1/3 of the maximum value. Vertical force has the strong force upward when the wave hits the bridge model. On the other hand, vertical force has strong force downward when steady force acts. From the pictures in Fig.8, tsunami wave into the bottom of the bridge model generates the floating force, and then tsunami waves jumped to bridge model will push down the bridge model in long time.

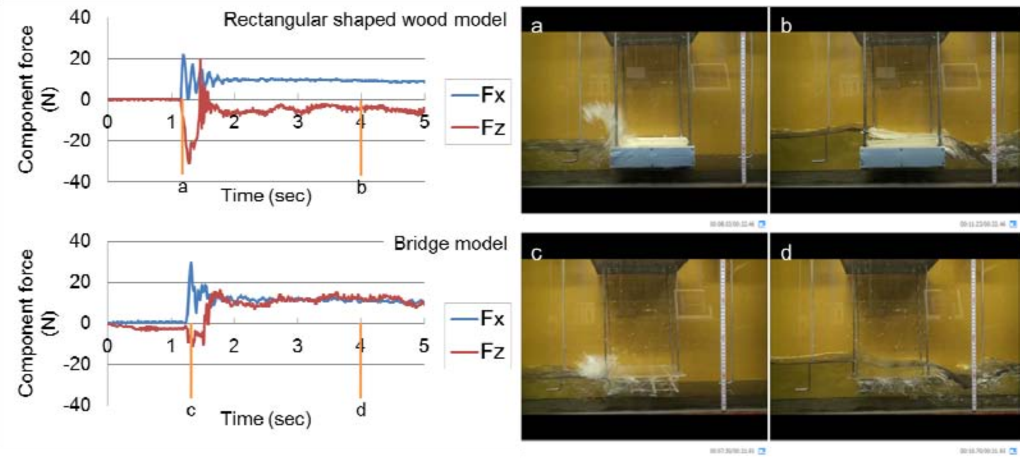

Fig.10 Time history curves and wave shapes of rectangular model and bridge model

Model type	No	Impact force (N)		Steady force (N)		(b)/(a)
		Fx	ave (a)	Fxs	ave (b)	(%)
Bridge model	1	29.8	31.1	12.0	11.5	36.9
	2	31.0		11.1		
	3	32.5		11.4		
Rectangular shaped wood model	1	21.9	19.1	9.9	9.5	49.8
	2	17.6		9.3		
	3	17.8		9.4		

Table 1 Ratio of the horizontal force

Model type	No	Impact force (N)		Steady force (N)		(b)/(a)
		Fz	ave (a)	Fzs	ave (b)	(%)
Bridge model	1	16.2	20.3	10.4	11.7	57.9
	2	24.3		12.4		
	3	20.3		12.4		
Rectangular shaped wood model	1	-30.2	-36.4	-4.4	-4.6	12.6
	2	-42.4		-3.9		
	3	-36.5		-5.5		

Table 2 Ratio of the vertical force

3.2 Comparison of the bridge model and the rectangular shaped wood model

Fig.10 shows the time history curves of the rectangular shaped wood model and bridge model.

In case of impact of the wave, the value of horizontal force of the rectangular shaped wood model showed about 20N. Horizontal force of the bridge model showed about 30N. Vertical force of the rectangular shaped wood model showed about -30N.Vertical force of the bridge model showed about -10N. Tsunami wave acting on the rectangular shaped wood model jumped up in the vertical direction to draw an arc. However, majority of the wave acts on the overhanging portion of the bridge model, the force to overturn the bridge is considered.

Comparing the steady period of two models, horizontal force of steady state of both is almost same, about 10N. Vertical force is about -10N in the case of the rectangular shaped wood model. The value -10N is different from 10N in the case of the bridge model. The rectangular shaped wood model has simple structure, so the air turbulence is not seen.

The following reasons can be considered.

1) Horizontal force in case of the bridge model is increased by reason that tsunami wave acting on the overhanging portion lost the upper way.
2) Buoyancy of rectangular shaped wood model is calculated to 32N by the whole volume. So, the maximum vertical force downward is almost the buoyant.

From these discussions, using structure without the overhanging portion can reduce the possibility of overturn of the girder. However, Vertical upward force is increased.

Table 1 and Table 2 show the stationary force and impact force. Impact force is the maximum value of the force. Steady force is the average in one second where the component force is stable. Impact force in the horizontal force of the bridge model was

31.1N. Steady force in the horizontal force of the bridge model was 11.5N.Ratio of the horizontal force was 36.9%. Impact force in the horizontal force of the rectangular shaped wood model was 19.1N. Steady force in the horizontal force of the rectangular shaped wood model was 9.5N.Ratio of the horizontal force was 49.8%.

Impact force in the vertical force of the bridge model was 20.2N. Steady force in the vertical force of the bridge model was 11.75N.Ratio of the vertical force was 57.9%. Impact force in the vertical force of the rectangular shaped wood model was -36.4N. Steady force in the vertical force of the rectangular shaped wood model was -4.6N.Ratio of the vertical force was 12.6%. Impact force is about 2~3 times of steady force of the horizontal force. In case of the vertical force, Impact force is about 2~8 times of the steady force. It should be understood that measures for the impact force are important.

4. CONCLUSION

This paper described the outline of the experiment using the bridge model of the Kesen-Bridge damaged by tsunami and discussions on the behavior of the bridge in tsunami. The following conclusions were obtained;

[1] Impact force is maximized when the wave hits the bridge model. Steady force became 1/3 of the maximum value. Vertical force is strong in floating force when collide with the bridge model. Vertical force is strong in hold force when acting steady force. Tsunami wave into the bridge model bottom generate floating force. Tsunami waves jumped to bridge model push down the bridge model in long time.

[2] Using closed structure without the overhanging portion is possible to reduce the force girder to overturn. However, Vertical upward force is increased because of the buoyant.

Tsunami by the 2011 off the Pacific coast of Tohoku earthquake gave us big damages to bridges near seashore. In Japan, a few big earthquakes are predicted, so similar damages should be considered. This study has just started. The continuous studies are needed.

5. ACKNOWLEDGMENT
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