Steady Flow Experimental Study for Tsunami Vertical Force on Concrete Girder

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1. Introduction

After the destructive tsunami damage caused by 2011 Tohoku Earthquake, the authors analyzed the videos recording the tsunami in Rikuzentakata, Utatsu and Koizumi areas. It is found that besides bore wave at surge front, tsunami wave seemed quasi-steady flow form (called steady flow). And most of the bridge girders were swept away by the steady flow itself. Thus, the authors conducted a steady flow experiment to study the wave forces on bridge girder. And in this research, the wave vertical force is analyzed.

2. Steady Flow Experimental Program

As plotted in Fig. 1, in the water channel, a pump was applied to make a steady flow. The steady flow velocity was controlled by the pump. Wave gauge H6 was used to obtain the flow depth at the model. Velocity meter V3 was setup at the center of the steady flow to manage the flow velocity. Velocity meters V1 and V2 were setup at the same height as the model to measure the flow velocity that affected the model. The force transducer T1 measured the wave vertical force Fz.

The girder model (scale: 1/50) and the setup of the pressure meters are shown in Fig. 2. P5~7 and P8~10 measured the wave pressures on the girder top and bottom, respectively.

3. Experimental Results and Evaluation of Vertical Force

Two types of parameters were considered: flow velocity Vx and model position Z (height from the water surface to the girder center). The parameters are plotted in Fig. 3 and the standard case was set as [Vx=100cm/s (7.1m/s), Z=-7cm (-3.5m)]. Besides, every case was conducted by three times.

Afterwards, the experimental result of the standard case is introduced, and the average output was used for evaluation. From Fig. 4, it is known that the average velocity (result of V1,

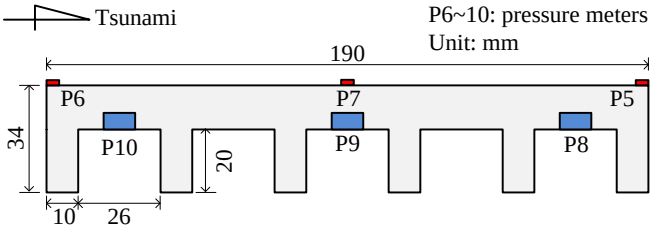


Fig. 2 Girder Model and Setup of Pressure Meters

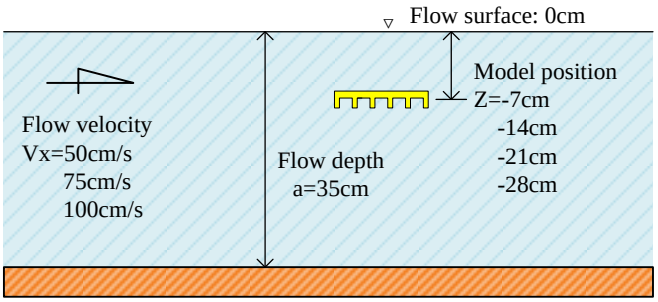


Fig. 3 Experimental Cases

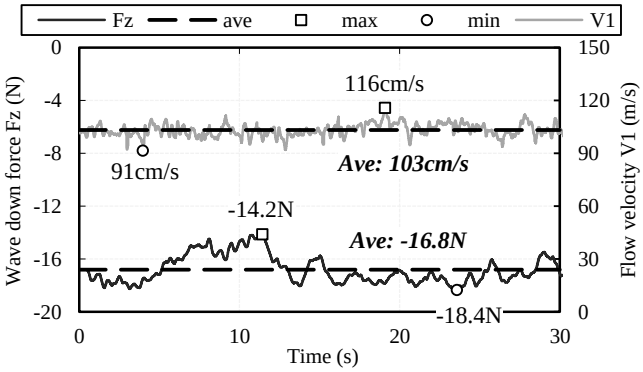
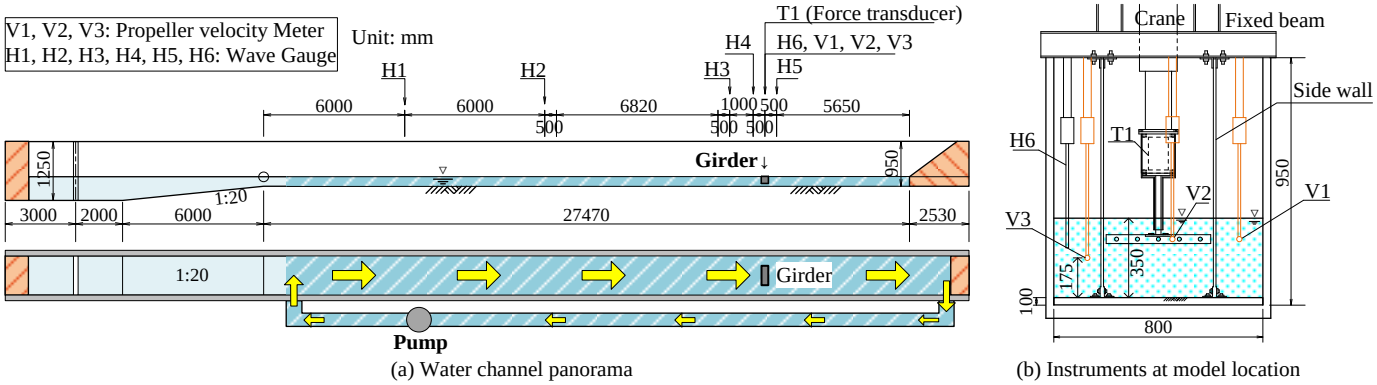
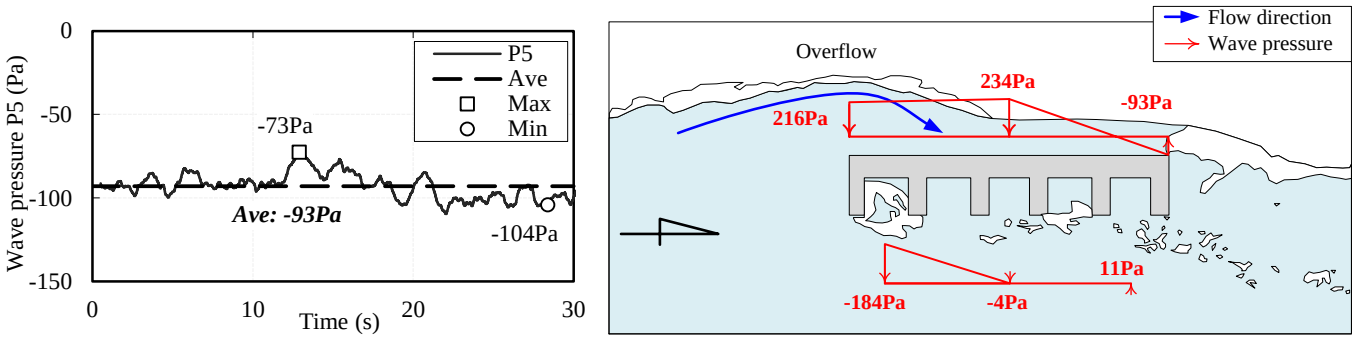


Fig. 4 Wave Down Force and Flow Velocity Histories



(a) Water channel panorama (b) Instruments at model location

Fig. 1 Setup of Instruments

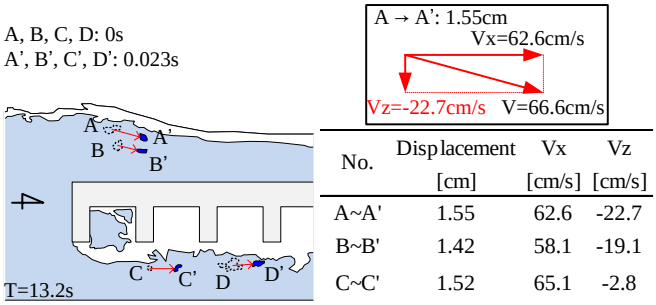


(a) Pressure time history of P5　　(b) Wave pressure distribution

Fig. 5 Distribution of Wave Pressure

V2 was influenced by the model) was confirmed as about 100cm/s and the average vertical force Fz was a minus 16.8N, which means downward force occurred.

By the similar average output of P5 (-93Pa), the pressure distribution is obtained in Fig. 5 and it is considered that the overflow led to a great downward pressure on the model top, which further led to the downward Fz. In Fig. 6, using the video with a recording time interval of 0.0033s, the air bubbles' movements at the model top and bottom were traced to study the overflow effect. For example, at T=13.2s, the bubbles A, B, C and D produced. Then, it took 0.023s for them flowing from A~D to A'~D'. The velocities of the bubbles were calculated by the ratio of the displacements to the time span (0.023s). As a result (table in Fig. 6), the downward velocity about 20cm/s was confirmed existing in the flow at the model top. Thus, it is confirmed that the downward overflow itself caused the downward pressures.



No.	Displacement [cm]	Vx [cm/s]	Vz [cm/s]
A~A'	1.55	62.6	-22.7
B~B'	1.42	58.1	-19.1
C~C'	1.52	65.1	-2.8
D~D'	1.43	61.3	3.4

Fig. 6 Analysis of Flow Velocity Vectors at Model

In order to obtain the down force Fz' caused by steady flow only, the buoyancy U (15.1N) on the model was subtracted (standard case: Fz'=-16.8N-15.1N=-31.9N) and the Fz' of all cases are plotted in Fig. 7. As a consequence, it is found that almost no uplift force happened and the Fz' became greater if flow velocity became faster.

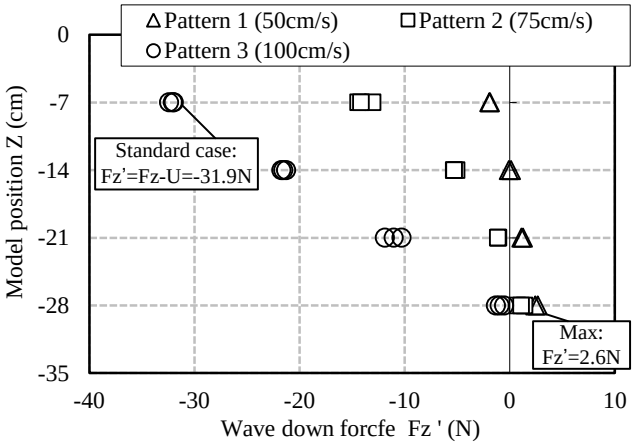


Fig. 7 Results of Wave Down Forces of All 12 Cases

At last, the reason why flow velocity shows the same change trend with Fz' is explained simply. The comparison of water heads of the three cases that Z=-7cm, is plotted in Fig. 8, and it is observed that in the case of Vx=50cm/s, almost no overflow happened (h1=0.6cm); but in the case of Vx=100cm/s, the biggest overflow (h3=3.9cm) occurred, which means a powerful downward flow affected the model. Thus, the greater flow velocity led to the bigger water head of overflow and further led to the greater downward force.

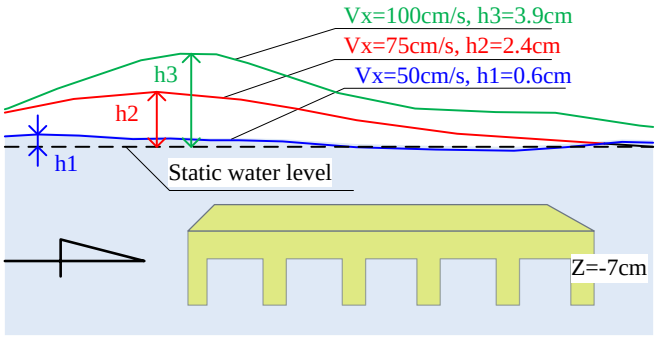


Fig. 8 Comparison of Water Heads of Overflow

4. Conclusions

(1) From the measured vertical force (Fz') and pressures, it is noted that the steady flow caused a downward force, because the downward pressures, which was caused by overflow effect, affected the model top.

(2) From the water head comparison of the three cases that Z=-7cm, it is found that the greater flow velocity led to the bigger water head of the overflow and further led to the greater downward force on the model top.