Large-Scale Physical Model Test on Tsunami Overtopping and Bed Scour Around Coastal Revetment

by

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Abstract

A series of hydraulic model tests was performed to investigate tsunami overtopping and bed scour around coastal revetments. The overtopping motion of tsunami and bed scour in front of the revetment were recorded by a video camera. Water surface elevation, flow velocity and overtopped water mass were measured. Sixteen runs of experiments were performed for various combinations of water levels and incident wave heights. The pattern of tsunami overtopping was classified into 6 groups. It is found that the overtopping rate can be estimated from incident tsunami profile. A large-scale scour was produced in front of the revetment by a standing vortex generated by return flow.

Key Words: Tsunami, Overtopping, Scour, Coastal revetment

1. Introduction

The necessity of integrated countermeasure for tsunami disasters has been remarked by Japanese Government since Nihon-Kai Chubu Earthquake tsunami. This countermeasure is structured into three categories, which are coastal structure, regional planning and tsunami evacuation system. In order to plan this countermeasure effectively, it is necessary to study tsunami behavior around coastal structure as a gate of inundation. Tsunami disaster around coastal revetments, one of the coastal structure, will be occurred by tsunami runup and collapse of revetments.

In the numerical simulation of tsunami flooding, inundated tsunami is generally approximated as long wave, even if it overtopped revetments. However, the fluid motion above the revetment has not yet well described. At the same time, the bed in front and back of the revetment would be scoured. In fact some of coastal revetments and sea walls were collapsed by Hokkaido-Nansei Oki earthquake tsunami and Nihon-Kai Chubu earthquake tsunami.

Former laboratory studies about tsunami behavior around coastal structures have been performed under small scale conditions. Therefore, they could not reproduce the size of bed scouring and fluid motion in detail. In this study, a series of large scale hydraulic model tests were performed for

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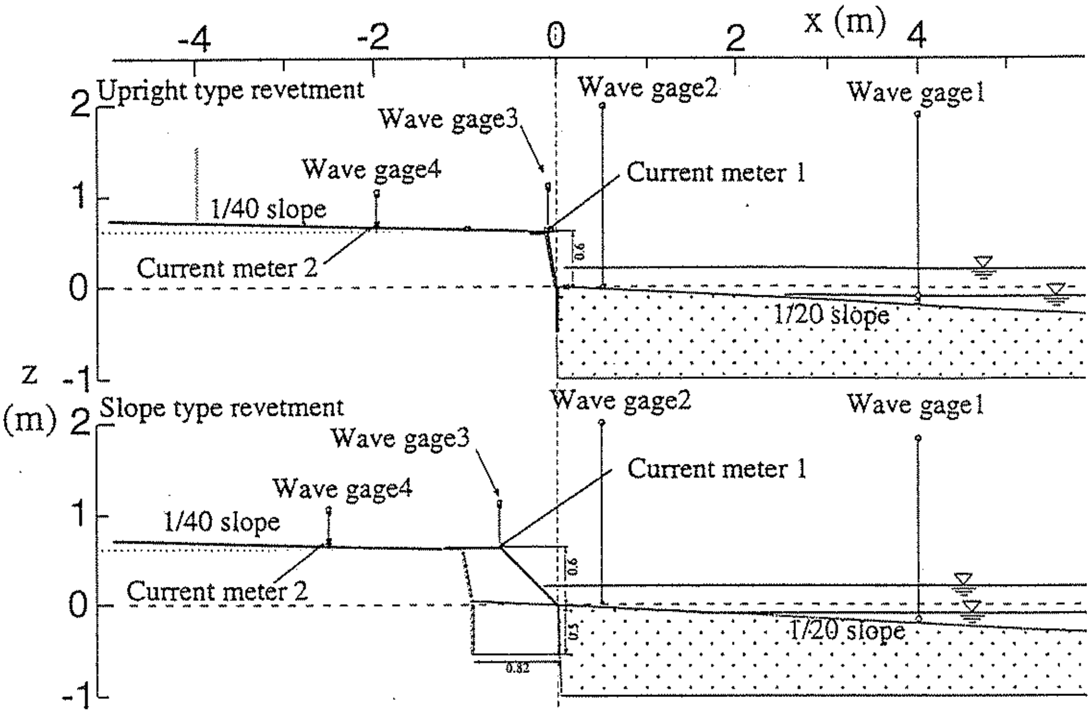

Figure 1 Revetment models and location of instruments

tsunami overtopping and bed scouring in front of a structure.

2. Implementation of hydraulic model tests

Experiments were preformed in a wave channel which is 5m deep, 1.9m wide and 135m long. The channel is equipped with a piston type tsunami wave generator. The wave generator pushes water forward to generate a tsunami with hyperbolic tangential motion within 2m length stroke. The model of sea bottom was filled with fine sand with a 1/20 slope. The wave channel was divided into two channels by a partition wall. A revetment model was installed on one side, in which waves, currents and bed scour patterns were observed. On the other side, in which a trap tank was installed behind the front face of the revetment, the water mass of overtopped tsunami was measured. The coastal revetment

Table 1 Experimental condition and results of overtopping

Case	Incident tsunami height (m)	Initial water level (m)	Overtopping type	Unit width overtopping rate (m^3/m)
1	0.21	0.3	a	0.56
2	0.42	0.3	b	2.67
3	0.21	0.2	a	0.20
4	0.31	0.2	c1	0.88
5	0.20	0.1	a	0.07
6	0.30	0.1	c1	0.44
7	0.18	0	c1	0.06
8	0.40	0	d1	0.60
9	0.40	-0.1	d1	0.35
10	0.41	-0.1	d2	0.41
11	0.20	0	c2	0.03
12	0.30	0.1	c1	0.66
13	0.20	0.1	a	0.06
14	0.40	0	d1	0.65
15	0.41	-0.1	d2	0.58
16	0.21	0.2	a	0.27

model was made of wood. Shoreward floor above the revetment was fixed as a 1/40 slope by cement mortar. The coastal revetment model was 0.6m height and made with 1/10 scale. Revetment types were upright one and sloped one. To protect against the suction of inner material, a cutoff board was settled to 0.5m depth as a fundamental work.

Wave profiles were measured by capacitance type wave gages situated at offshore (x=90m), in front of revetment (x=0.5m and 4m), above revetment (x=-0.1m) and on the shoreward slope (x=-2m). Velocities were measured by propeller current meters situated above revetment and at offshore, which were at the same points with wave gages. Motions of tsunami overtopping and bed scouring in front of revetment were recorded by a video camera.

The physical model tests were performed for 16 cases with incident tsunami wave height ranging from 0.2 to 0.4m. Experimental conditions were arranged for several combinations of among wave height, water level against height of revetment and two revetment types. According to Street and Camfield(1966), the breaker type of tsunami almost depends on the slope of sea bottom. In this study, all the cases were expected to be plunging breaker since offshore slope was 1/20. To produce several phenomenons, initial water level was changed.

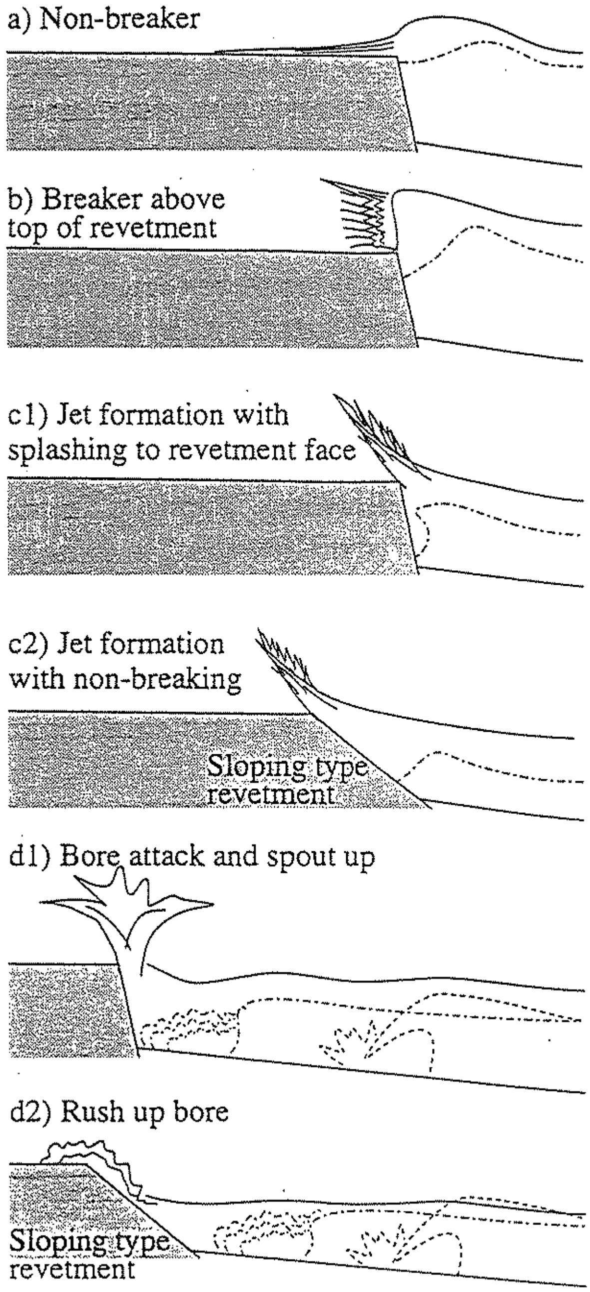

Figure 2 Pattern of overtopping

3. Results of Test

3.1 Patterns of overtopping

Patterns of overtopping were classified into the following 6 patterns shown in Figure 2 by video capture; "a" overflow without breaking, "b" bursting to forward over the revetment, "c1" wave crest splashing to the revetment face with formation of jet from the top of the revetment face, "c2" formation of jet from the revetment face by non-breaking wave, "d1" strong bore attack after breaking and "d2" rushing up of strong bore after breaking.

Details of patterns are explained in the followings. Type "a" is similar to weir overflow that is usually approximated in tsunami inundation numerical simulation. This pattern occurred under high initial water level from 0.1 to 0.3m, and small incident wave.

In the motion of "b", tsunami arrived at revetment without breaking. When the wave crest reached the top of revetment face, wave front bursts forward.

Though "c1" and "c2" are characterized by jet formation from top of the revetment face, they had different process. Process of "c1" was first plunging breaking in front of revetment, splashing directly to the top of the revetment or via reflected from seabed of front, rushing up along slope and finally to launch jet. Pattern "c2" did not break before the formation of jet which was produced from the loop of partial standing wave formed on the sloping face of the revetment.

Though both "d1" and "d2" occurred by broken bore rushing to the revetment, they showed different motions owing to the difference in the slope angle of revetment face. In case of steep face, bore splashed and breezed up from top of revetment. On the other hand, when the face was more gentle, bore rushed up along the face and directly inundated shoreward of the revetment.

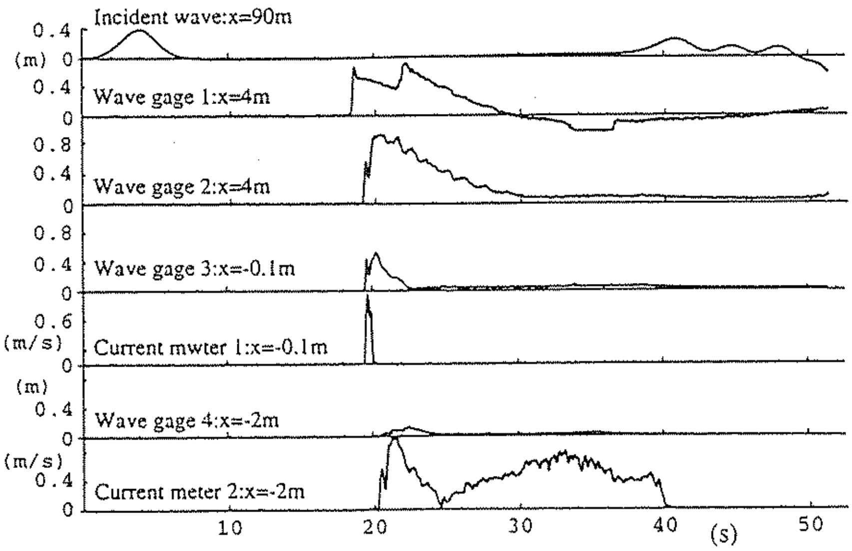

Figure 3 Wave and current profiles (case 8)

3.2 Time series of tsunami profile and flow velocity

Figure 3 shows time series of h and u of case 8 which is discussed in detail later. Pattern of overtopping of case 8 was "d1". The symbol "t" denotes the time from the initiation of data sampling. Tsunami incident wave, which is illustrated on the top, was a single positive wave. At the revetment, a part of tsunami was reflected to offshore and the other overtopped and inundated. The reflected wave was noticed by the second peak at 22s of No.1 wave gage.

No. 2 current meter shows positive value for both directions, since this current meter does not detect the flow direction. Runup velocity reached almost 1m/s. This value is scaled to 3.2 m/s with proto-type scale. The return flow occurred from 24.5s judging from the wave profile. The return flow exceeded 0.6m/s and continued for 15 second.

3.3 Overtopping rate

Overtopping rate and runup height were obtained by two methods. One is known Aida method (1977) similar to formula of discharge for weir. The other is integrated mass flux estimated from water surface elevation and inlet velocity. The unit width mass flux was estimated with the following equations:

The Aida method is expressed by

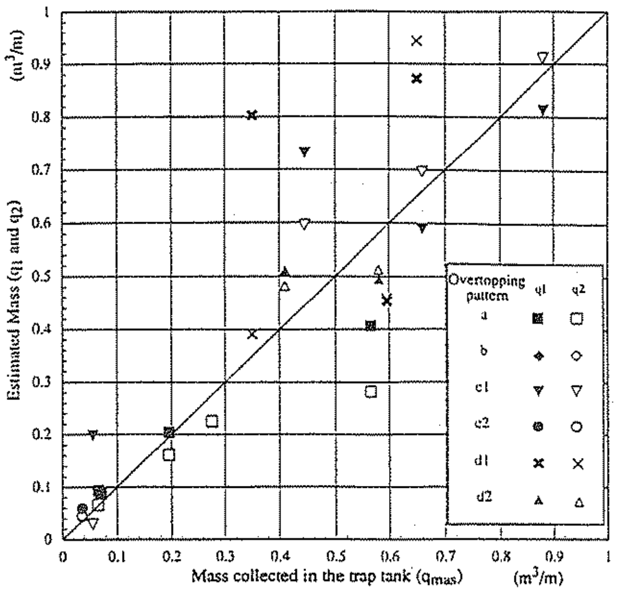

Figure 4 Correlation between overtopped mass and computations by two different methods

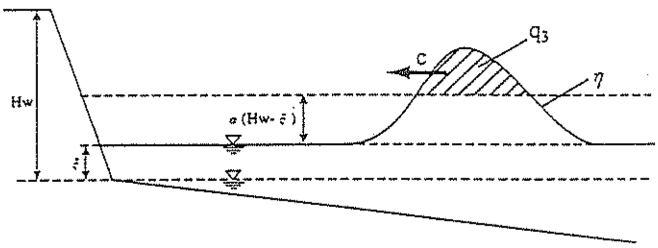

Figure 5 Concept of overtopping mass estimation from incident tsunami profile

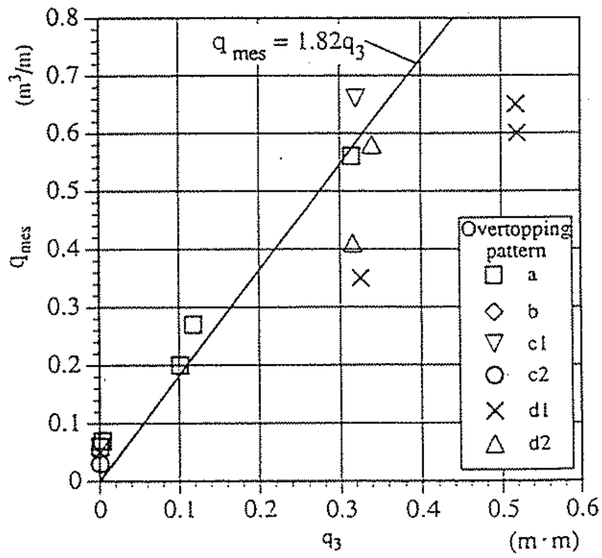

Figure 6 Estimation of mass of overtopped tsunami

$$q_1=\int_{t_s}^{t_e}\frac{1}{2}\eta\sqrt{g\eta}\,dt \quad \text{---(1)}$$

Integrated mass flux is expressed by

$$q_2=\int_{t_s}^{t_e}\eta\cdot u\,dt \quad \text{---(2)}$$

In this test, they could be calculated from water surface elevation (η) and flow velocity (u) above the revetment top. In each equation, "ts" is the start time of inundation and "te" is the start time of backwash. Figure 4 shows correlation between the mass (qmes) of overtopped water collected in the trap tank and estimated mass (q1 and q2). According to this figure, Strong correlation was observed between the mass of overtopped tsunami and the integrated mass flux.

Then, overtopping rate will be estimated from the incident tsunami profile. The concept is illustrated in figure 5. Overtopping rate is supposed to be proportional to the hatched area of tsunami profile that was cut by the broken line. Then it can be written by the following equation.

$$q_3=c\int_{t_{is}}^{t_{ie}}\left\{\eta-\alpha\cdot\left(H_w-\xi\right)\right\}dt \quad \text{---(3)}$$

Where "Hw" is revetment height from origin, "ξ" is initial water, "α" is a parameter obtained from test, "η" is the time series of water surface elevation,

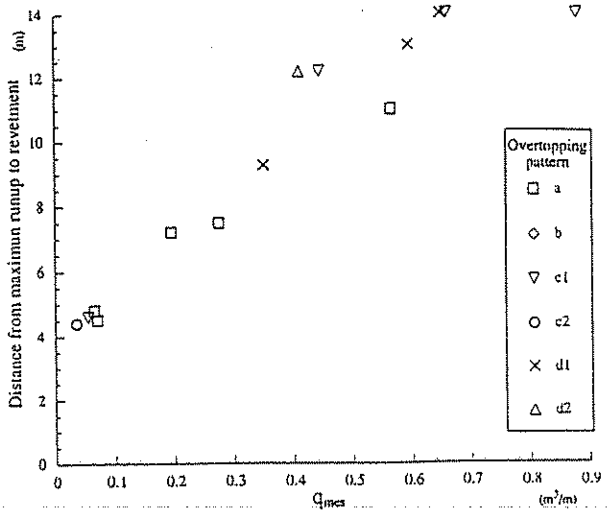

Figure 7 Overtopping rate and runup distance

$c=\sqrt{g\cdot h}$ is wave celerity, g is gravity acceleration and h is water depth.

Figure 6 shows the correlation between q3 and qmes. The line in the figure shows qmes=1.82 q3. The data follow the line well expect for the overtopping pattern of d1 and d2. The reason why d1 and d2 did not match the line was explained from the fact that the energy had decreased significantly by wave breaking for d1 and d2.

Figure 7 shows relation between the overtopping rate and the distance from revetment edge to maximum inundated point. They show strong correlation irrespective of the pattern of overtopping.

3.4 Bed scouring in front of revetment

Bed scouring was analyzed by video. Bed scouring is supposed to be caused by rushing wave and return flow from revetment top. By rushing wave, however, bed scouring was little

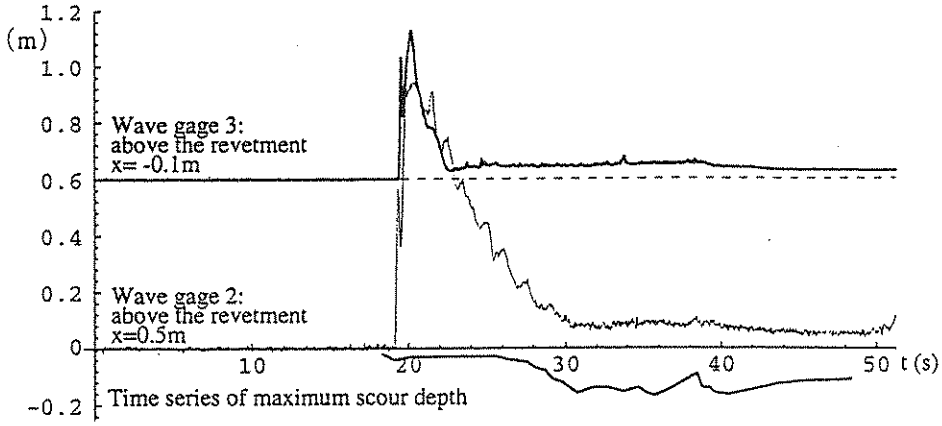

Figure 8 Time series of bed scour depth in front of the revetment (case 8)

and appeared only for low water level and large wave height. By return flow, the bed scour was generated by a standing vortex growing in front of revetment while the return flow continued. The scour depth was almost the same as the vortex diameter. Scoured bed was rapidly recovered by settling sand when the vortex decayed. Significant deposition occurred in 5 cases. The deposited sand, which was captured in vortex, was settled from the vortex area area after the vortex strength became weak.

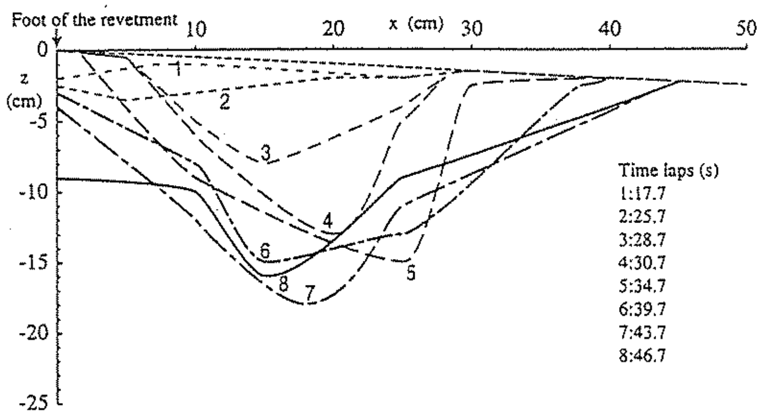

Figure 9 Scoured bed profile change (case 8)

Figure 8 shows time series of scour depth. Scouring in this case was produced firstly by swash, later by return flow and deposition by released sand from vortex. Two sets of time series of water elevation above the revetment and in front of the revetment were illustrated together. For easy to understand, the illustration of revetment top wave elevation was raised 0.6m since the wave gage located 0.6m height from initial water level. Small scouring occurred at the tsunami arrival at the revetment. Main scouring process started after the water level in front of the revetment decreased. Finally, there seems to be equilibrium depth. At last, scoured bed recovered by the released sand along with vortex decay.

Figure 9 shows the profile change of scoured bed in Case 8. Though the bed scour began near the revetment wall, the deep scour areas moved to the area around x=20cm and z=-15cm where the vortex was agitating sand with a strong scour, This profile is shaped by standing vortex in front of the revetment.

4. Conclusions

Main conclusions are as follows:

1. The pattern of tsunami overtopping was classified into 6 groups.
2. Strong correlation was observed between the mass of overtopped tsunami and the integrated mass flux, which was estimated from water surface elevation and flow velocity above the revetment edge.
3. Overtopping rate was estimated from incident tsunami profile.
4. Scouring by swash was relatively negligible.
5. In front of revetment, a large-scale scour was produced by standing vortex generated by return flow. The scour depth had a strong correlation with overtopping rate.

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