An experimental study of the highest run-up height in the 1993 Hokkaido Nansei-oki earthquake tsunami

Masafumi Matsuyama and Hiroyoshi Tanaka

Hydraulics Department, Central Research Institute of Electric Power Industry, Abiko, Chiba, Japan[1]

Abstract. Experiments in Large Wave Flume were carried out to reproduce maximum tsunami run-up heights at Monai zone in Okushiri Island in 1993. The flume is 3.4 m wide, 205 m long. Maximum water depth is 4 m. A model, which consists of a small, curved pocket beach (200 m long) with a small valley, was set in the flume. The model scale is 1/400 with no distortion. Input wave data was modified by the time series data picked up from numerical simulation, of which the source model is based on DCRC26.

This experimental result could well reproduce the distribution of tsunami heights surveyed in the pocket beach at Monai zone, including the highest one. That is, the maximum height was over 30 m in the south valley; on the other hand, the averaged value of run-up heights along the pocket beach was about 24 m. Pictures by a high-speed camera precisely showed the motion of the tsunami near the shore and on the land, and indicated that the highest tsunami height was caused by the first steep wave, the duration of which from trough to crest is about 100 s, on the peculiar topography consisting of a pocket beach and a small valley.

1. Introduction

On 12 July 1993 a big earthquake occurred in Japan Sea and generated a huge tsunami, the Hokkaido Nansei-oki earthquake tsunami (Okushiri tsunami). This tsunami caused devastation on Okushiri Island and along the south-west coast of Hokkaido. One of the remarkable features of this tsunami is that maximum run-up height is 31.7 m at Monai zone in Okushiri Island (Fig. 1). This tsunami height was measured at the bottom of a small valley (Fig. 2; Shuto, 1994) which opens onto a small pocket beach. On the other hand, tsunami run-up heights along this beach are from 23.19 m to 25.31 m (Figs. 2 and 3). That is, the highest value was 1.32 times as long as the averaged one (23.93 m), except for 31.7 m along the pocket beach. This peculiarity was one of the mysteries of this tsunami. Some scientists tried to reproduce this tsunami motion around Okushiri Island by computation (Yeh *et al.*, 1995), but no proper model has been proposed. So, physical model tests were performed in the present study to investigate the mechanism of tsunami run-up motion in the pocket beach.

2. Model Test in Flume

The Large Wave Flume (Criepi Flume) is shown in Fig. 4. The dimensions are 205 m long, 3.4 m wide, and 6 m deep in the 115 m-long generator-side flat section. The wave generator is the piston type blade with no water behind it. The maximum stroke is 2200 mm. The area, which was reproduced

[1]Central Research Institute of Electric Power Industry, Hydraulics Department, Abiko Research Laboratory, 1646 Abiko, Abiko-shi, Chiba-ken 270-1194, Japan (matsu@criepi.denken.or.jp)

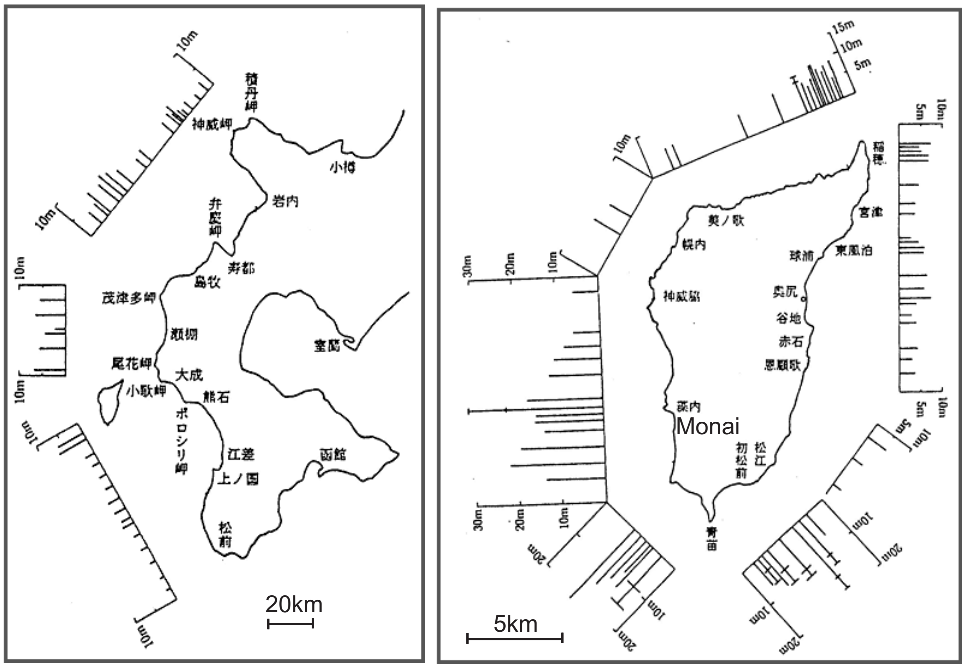

Figure 1: Hokkaido and Okushiri Island with distribution of tsunami height.

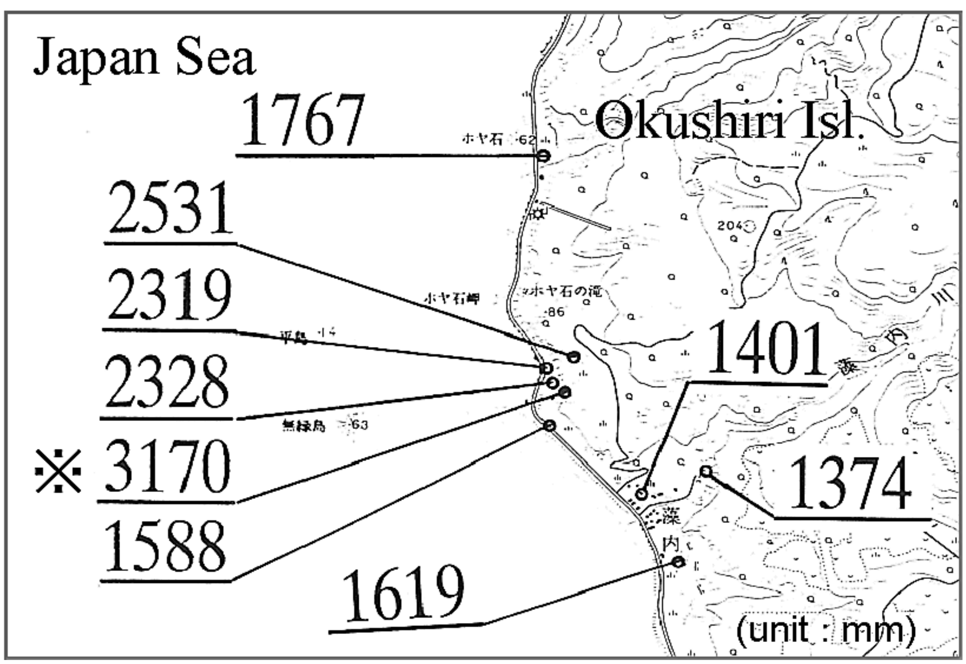

Figure 2: The distribution of tsunami height around Monai (Shuto, 1994).

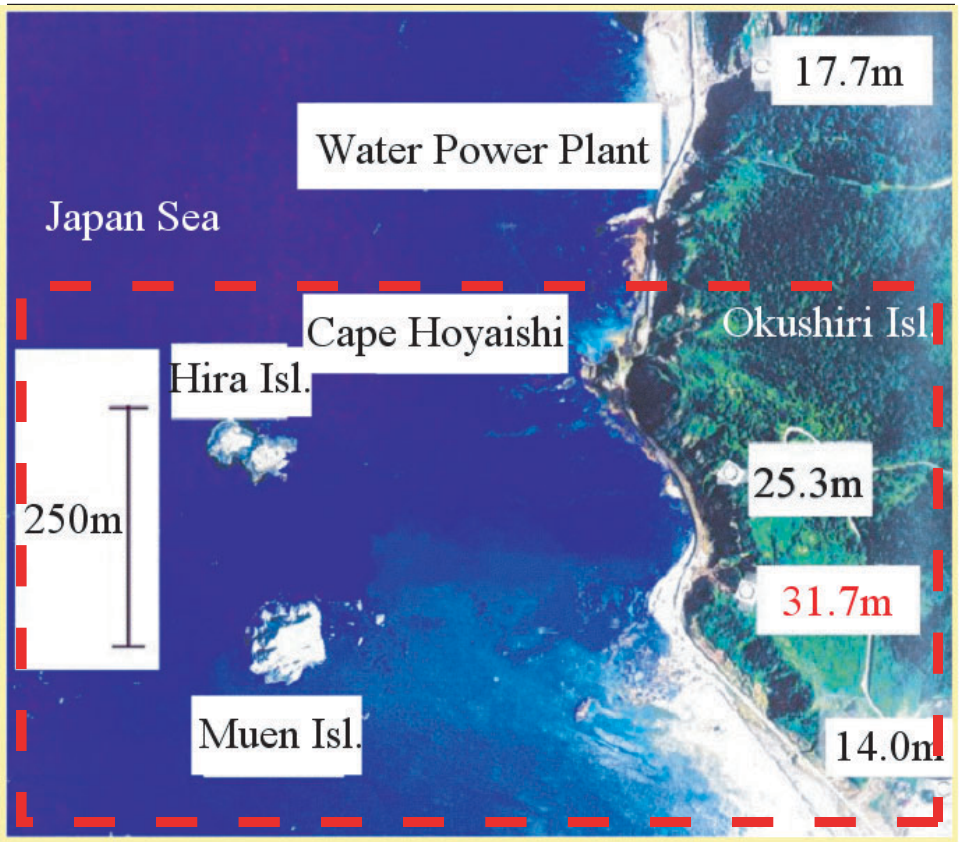

Figure 3: Aerial photo around Monai (taken by Kokusai Kogyo Col., Ltd.) and the reproduced area in the flume.

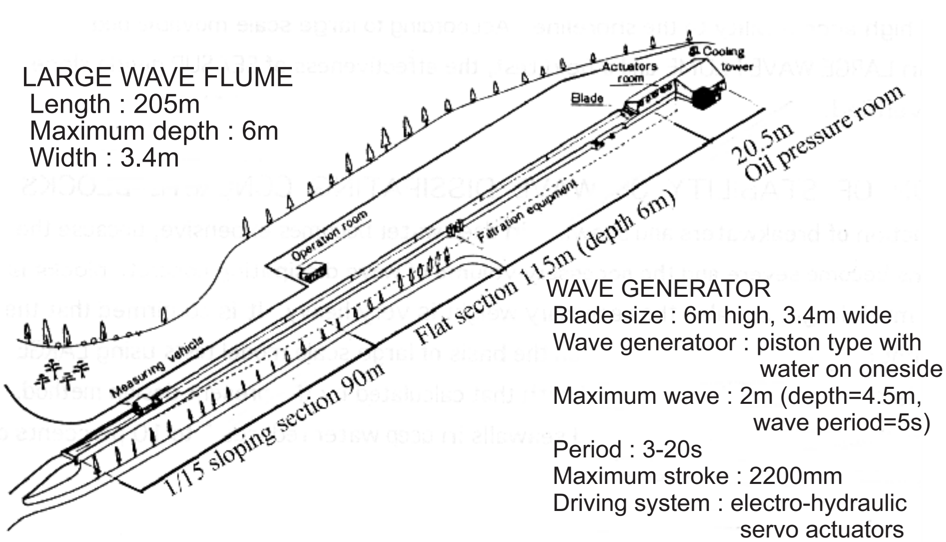

Figure 4: Large Wave Flume (Criepi Flume).

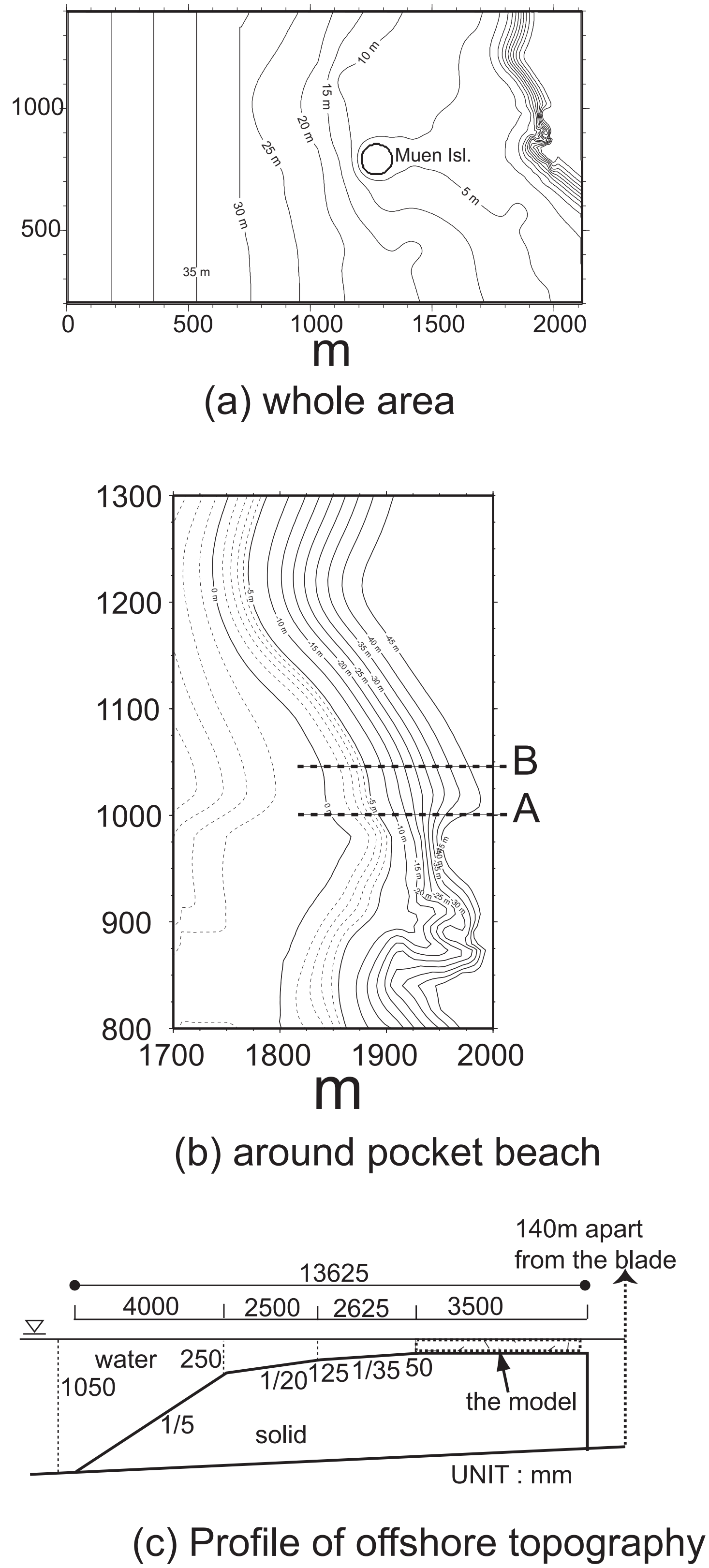

Figure 5: Topography reproduced in the flume, near the pocket beach.

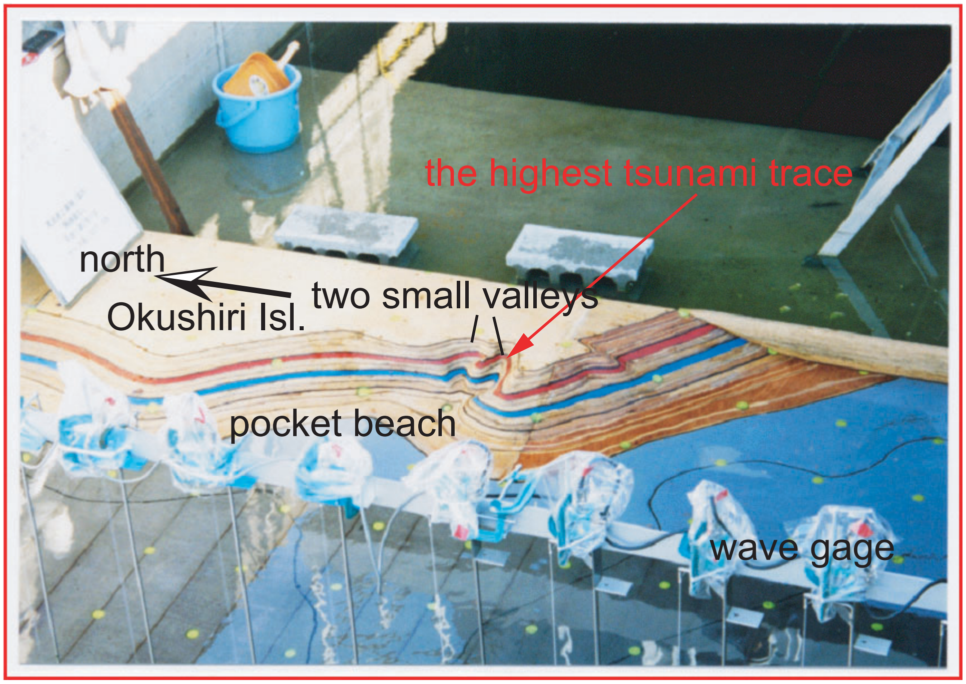

Figure 6: A photo view of the model around the pocket beach in the Criepi Flume.

in the flume, was selected to be a rectangular area enclosed by a broken line in Fig. 3. Offshore topography was shown in Fig. 5. The scale of this experiment model is 1/400 with no distortion. The water depth was 4 m in front of the blade. Figure 6 shows the model near the shore in the flume. This consists of some pieces of plywood 9 mm thick. In the pocket beach, two small valleys can be seen, of which the maximum run-up height was recorded in the south (right) one. Contour lines were drawn at every 3.6 m ground height on the model. Also, Muen Island (Fig. 5a) was imitated by a wooden column, which was removable to check the effect of this island. In the flume there was no land except Muen Island and the pocket beach. The physical model tests were performed for 6 cases, each of which consisted of both conditions with and without Muen Island. The free surface displacements were measured by capacitance-type wave gages. At the same time, by normal and high-speed digital video cameras, moving pictures were taken from several angles. Their snapshots were used for checking run-up heights and tsunami motion near the shore.

The input tsunami wave was produced from a numerical simulation result, which applied a finite deference method based on non-linear long wave theory. Figure 7 shows the computation domain and the initial condition of the Hokkaido Nansei-oki earthquake tsunami, which has been proposed by Tohoku University (DCRC26) (Takahashi, 1994). Time series data in Fig. 8 was picked up near point P (58.1 m depth), and was processed to make the input signal for the wave generator. Input data was amplified adequately for the wave run-up to meet the averaged height of 24 m measured by the field survey.

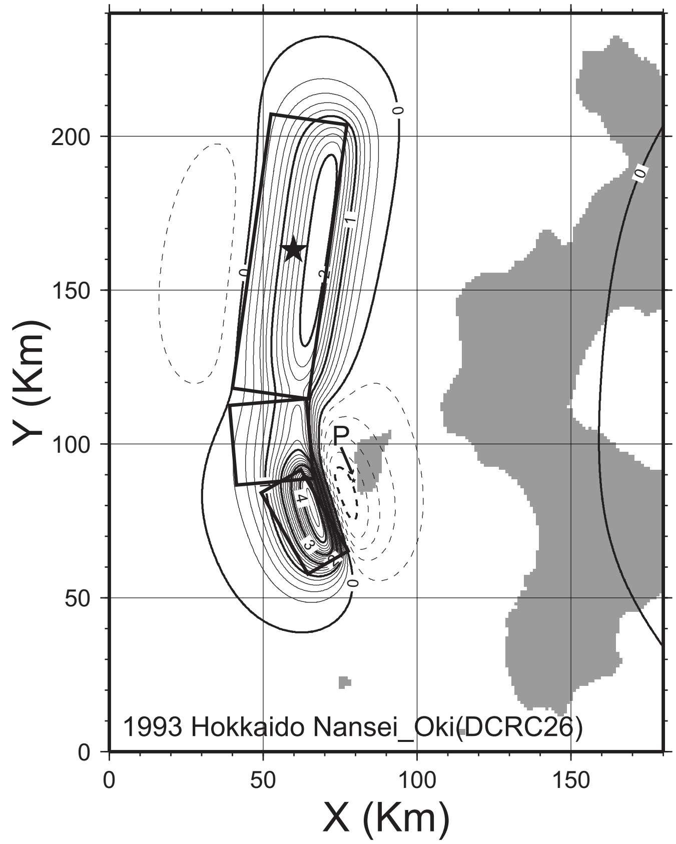

Figure 7: Computation domain and source model for numerical simulation.

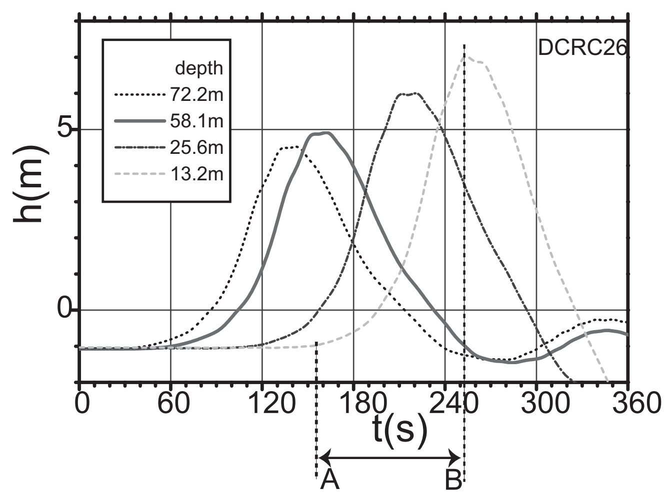

Figure 8: Time series data for water surface change at P in Fig. 7 by computation.

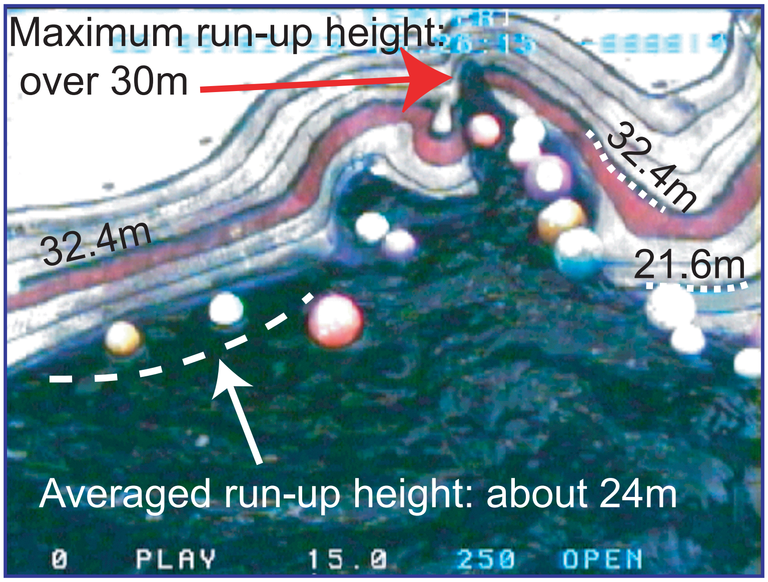

Figure 9: A snapshot at the moment when the tsunami went up on the south valley.

3. Results of Experiments

3.1 Distribution of run-up heights, including the highest one

Distribution of run-up heights, including the highest one, in the pocket beach at Monai zone could be reproduced in this Criepi Flume. Figure 9, taken by high-speed camera, shows the moment when the tsunami reached a little higher than a contour line of 32.4 m in the small south valley, and the averaged run-up heights along the pocket beach was about 24 m. Figure 10 shows wave shoaling from deep (4 m) to shallow (0.05 m) water. Subscript "r" means a real scale. It was recognized that wave shape is smooth and asymmetric at depth 0.05 m, which was expected. Time from trough to peak (AB in Fig. 10, trough-peak time) is about 100 s on a real scale, which harmonized with the numerical result (AB in Fig. 8). The averaged ratio, which is of maximum height to the averaged one along the pocket beach, is 1.49 (Table 1a). This value means that this test could reproduce the tsunami motion around Monai in 1993, however it is a little higher than the measured one (1.32). In the high-speed camera pictures we could see the motion of the tsunami front mass (Fig. 11). After the tsunami front reached the edge of the beach (Fig. 11a), the tsunami covered the whole beach from south to north gradually, and the upsurge became visible in the middle of it beside the small valleys (Fig. 11b). Then its surge flew into the south valley (Fig. 11c). This flux makes the maximum run-up over 30 m (Fig. 11d). This indicates that the maximum height was mainly caused by the peculiar location, which consists of a pocket beach and a small valley.

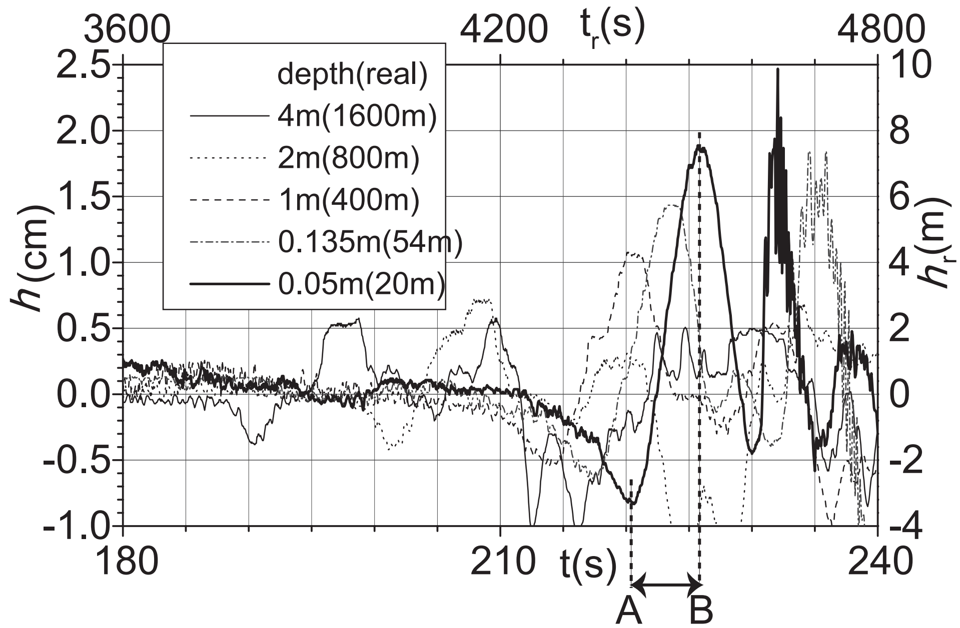

Figure 10: Time-histories of free surface displacement from deep to shallow water.

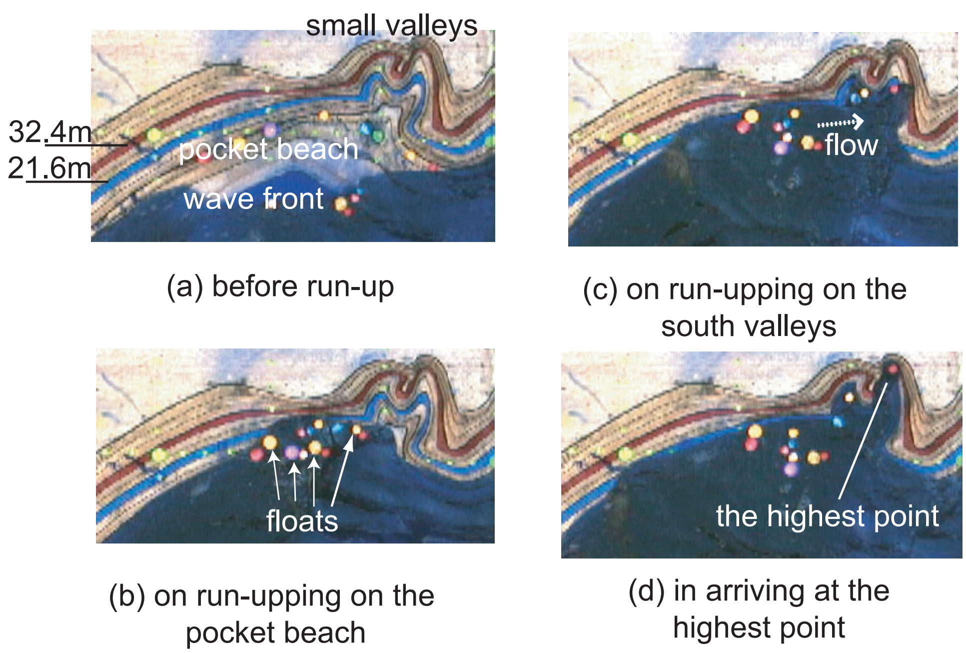

Figure 11: Snapshots of tsunami run-up motion by digital video camera.

Table 1: Run-up heights on three lines in Fig. 5 with and without Muen Island.

Case	Max. (m)	Line A	Line B	Max./A
		(a) With Muen Island		
209_105	35.00	21.00	21.00	1.67
209_106	36.00	23.00	22.00	1.57
209_107	32.00	22.00	22.00	1.45
210_101	36.00	26.00	23.00	1.38
210_102	40.00	27.00	23.00	1.48
210_103	36.00	26.00	23.00	1.38
average	35.83	24.17	22.33	1.49
		(b) Without Muen Island		
217_206	36.00	23.00	23.00	1.57
217_207	38.00	22.00	22.00	1.73
217_208	36.00	22.00	23.00	1.64
217_209	33.00	24.00	22.00	1.38
217_210	33.00	23.00	22.00	1.43
217_211	23.00	22.00	36.00	1.05
average	33.17	22.67	24.67	1.46

3.2 An effect of Muen Island (lens effect)

We checked an effect of Muen Island on the run-up heights in the pocket beach, i.e., whether tsunami energy was concentrated at the south valley by the island or not. Table 1 shows the run-up heights along the coast in two cases, with and without Muen Island. The ratio is 1.49 with Muen Island, and 1.46 without, respectively. So, no significant difference can be seen in Table 1. Tsunami motion is almost similar in both cases from video pictures as well. This indicates that Muen Island, as a shelter to diffract, did not have much influence on tsunami propagation in the shallow sea (less than 20 m).

3.3 An effect of wave steepness (wave period)

To check the effect of wave steepness (period) on the run-up height, several kinds of input wave data were used. In Fig. 12 the solid line is the original data from numerical simulation DCRC26, and a broken line is the time-stretched one, whose trough-peak time is about 160 s. Fig. 13 shows the moment, at which the time-stretched tsunami went up to the highest point. The highest value is about 25 m in the south valley, and about 22 m along the pocket beach. So, the 1.6-times longer wave could not run-up over 30 m in the south valley, and produced almost the same run-up heights on both valleys and along the pocket beach, about 22–25 m. The trough-peak time of the input wave needs 100 s to run-up over 30 m in height. A steeper wave without breaking could easily run-up higher. This indicates that steepness of the wave front is important for the tsunami run-up motion on the complicated topography.

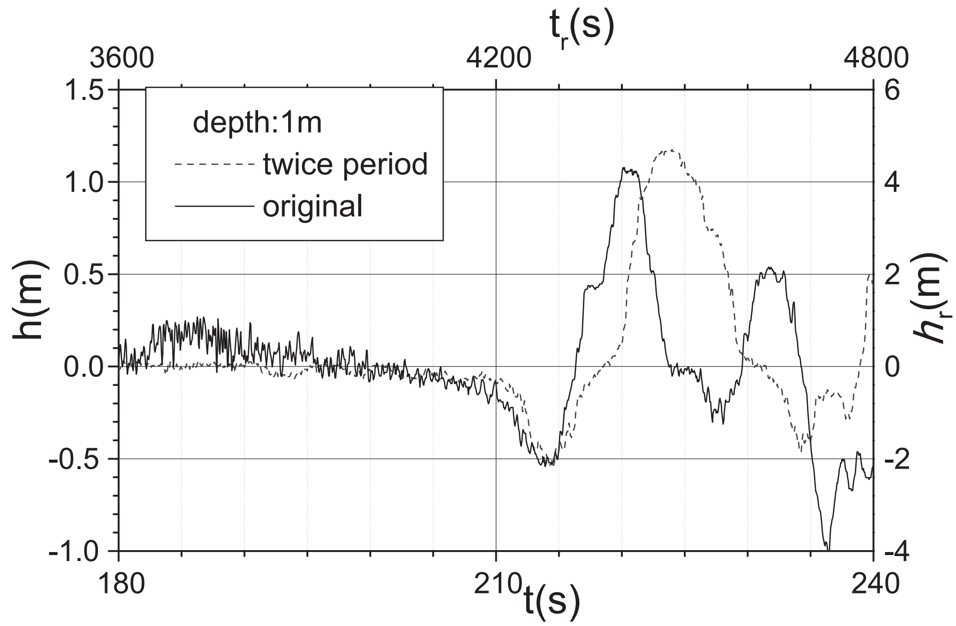

Figure 12: Comparison of input wave for the model between original and time-stretched tsunami.

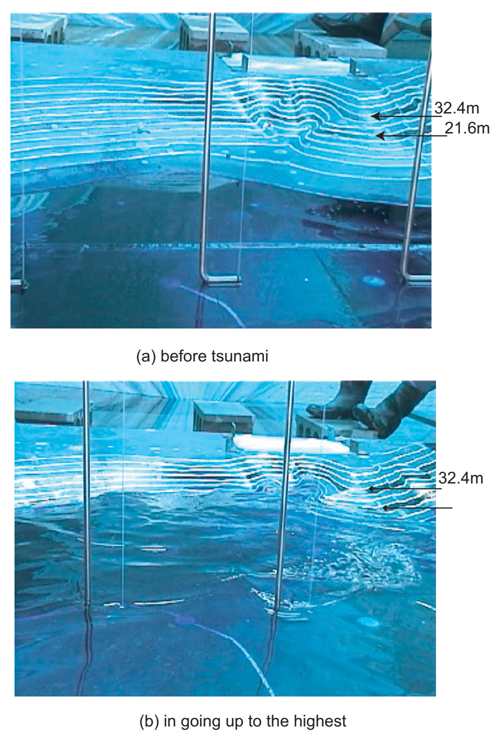

Figure 13: Snapshots of the time-stretched tsunami case (an interval at every contour line is 3.6 m.)

4. Conclusion

The major conclusions of the present study can be summarized as follows:

1. We succeeded in reproducing the distribution of tsunami run-up heights, including the maximum one (31.7 m), around Monai in the 1993
Hokkaido Nansei-oki tsunami in the Criepi Flume experimentally.

2. Muen Island did not have much influence on tsunami propagation and run-up.

3. The trough-peak time of the input wave needs at least 100 s to run-up over 30 m high on the south valley.

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5. References

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