Numerical simulation of tsunami focusing effect by an island

その他（別言語等）のタイトル	島による津波レンズ効果の数値実験
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Numerical simulation of tsunami focusing effect by an island.

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abstract

A tsunami focusing effect of an island was reproduced by numerical simulations. Linear long wave equation was solved on a difference scheme for an incident plane wave with solitary typed function of $\exp\{-0.5\pi(t/T-1)2\}\cos 2\pi(t/T-1)$, in which t, T is time and period, respectively. A cylindrical island with a conical slope was assumed in a shallow sea with a constant depth. Time histories of water level were computed to an island of 3 km in diameter for three periods of T, (T=5, 10 and 20 minutes). The maximum heights were plotted in the back side of the island. Profiles in the direction perpendicular to a center line were obtained and distance variations of the peak heights, widths and sharpnesses were invesigated. As the result the height ratio reached about 2 at the opposite side of incidendent directoin in the island and decreased to 1 at sea distant from the island for the shortest period, T=5 min. The decreasing ratio decreased with an increase of periods. On the other hand the width increases to a distance of 8 km from the island in every case but decreased gradually in the longest period, T=20 min for a distance longer than 8 km. Sharpness of the profile is approximated with an exponential decay and the slope decreased with an increase of wave period. They were compared with the result observed at the coasts opposite islands for the 1993 Hokkaido Nansei-oki Tsunami and the wave height ratio's decrease from 2 to 1 in the computation is possibly effective to explain the

observed variation of the height ratio in the distance.

Therefore a comparative amplitude increase in the backward radiation is explained from a superposition of two refracted waves around the island.

Introduction

Tsunami focusing effect caused by an island slope was observed in the 1993 Hokkaido Nansei-oki Tsunami on 7 July 1993(Abe, 1994a).Characteristics of the wave height profile were analyzed by Abe (1994 b).He noticed a focus at which the peak height was observed at the coast opposite the island and pointed out an amplitude decrease from 2 to 1 in the ratio to the average, which is defined as the height observed at the coast distant from a focus. This fact suggested that the maximum level is attained as a superposition of two waves refracted by the island slope at the back side of the island. This explanation will be checked by the use of numerical simulations.

As far as island effects of tsunami most interest have been directed at the wave height distribution at the coast of the island. This is reflected to no observation outside the island. Recently Imamura et al.(1990) noticed in their numerical simulation that Polynesian and Hawaiian islands had a role to concentrate tsunami energy. At this circumstance the 1993 Hokkaido Nansei-oki tsunami brought extraordinary high wave at the coasts near to islands.

Numerical simulation

An island in the shallow sea is idealized as a cylinder with conical slope in a constant-depth sea. It is illustrated in Figure 1. For this topography tsunami is assumed to be incident as a plane wave with solitary-like time function as

$$z=\exp\{-0.5\pi(t/T-1)^2\}\cos 2\pi(t/T-1),$$

in which t and T represent time and a constant corresponding to a period, respectively, and z is variation of sea level. Linearized long wave equation is used as a basic equation and the finite difference equation is solved on a leap-frog scheme. Boundary conditions are classified into three. One of them is a total reflection at an island-sea boundary and side walls assumed at the computation boundaries parallel to the

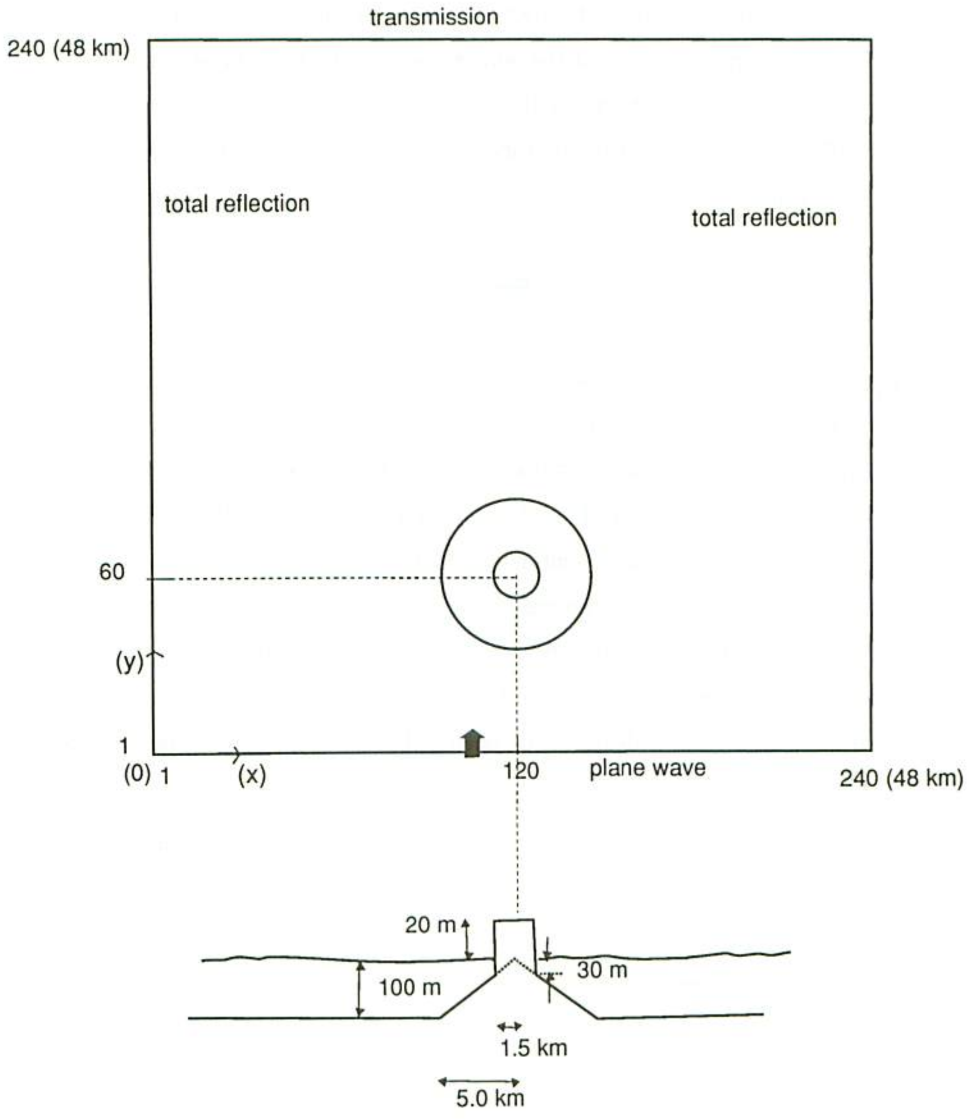

Fig. 1: Island model in a constant depth sea (upper figure) and the profile (lower figure).

incident direction, another is a perfect transmission at a bondary perpendicular to the incident direction. The incident wave is a plane wave. An initial condition is assumed to be a quiet sea. Sea levels in the computation area are computed at every 2 s (time step) and every unit grid of 200 m interval for an elapsed time long enough for the maximum phase to pass the second boundary.

Geometrical parameters are as follows: diameter of the island is 3 km, sea depth at the slope is 1/50 from the center of the island and diameter of the sloping region is 10 km, a constant sea depth outside of the slope is 100 m. The time constants T are assumed 5, 10 20 minutes. The time histories, shown in Figure 2, are given at the lower boundary of Figure 1.

Results

One of examples obtained is shown in Figure 3. It is a collection of snapshots computed for the time constant $T=10$ minutes. The time series show a propagation process of plane wave around a cylindrical island with a linear slope. Particularly it is noticed that wave, being refracted on the sloping region, rounds the cylindrical island and is radiated backward along a center line of the island perpendicular to wave front of the incident wave. The result suggests a convergence of energy in the backward direction. The maximum levels for the three incident waves are shown in Figure 4. It is predicted from the result that at the front side of the island the maximum level increases from 1 to 2 with a decrease of period. For a long limit of the period a role

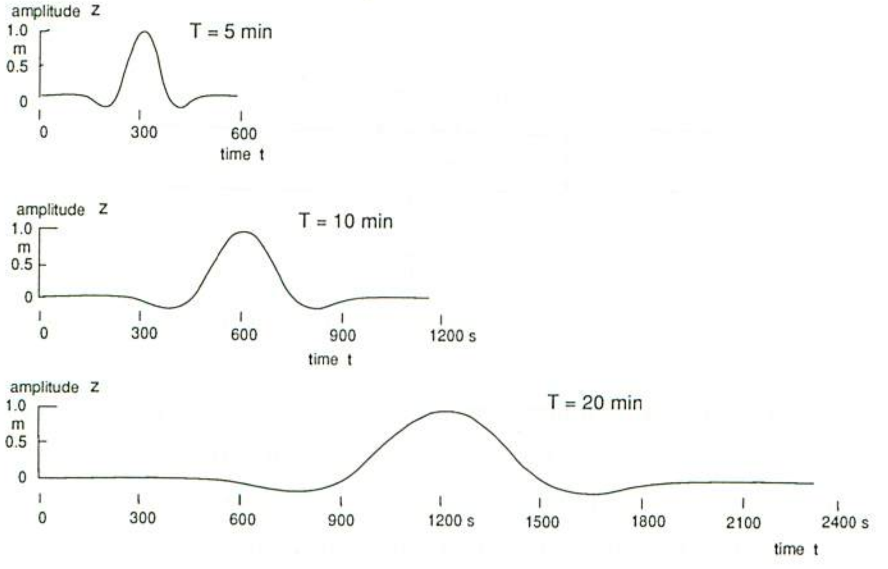

Fig.2: Time histories of incident waves with periods of 5, 10 and 20 minutes.

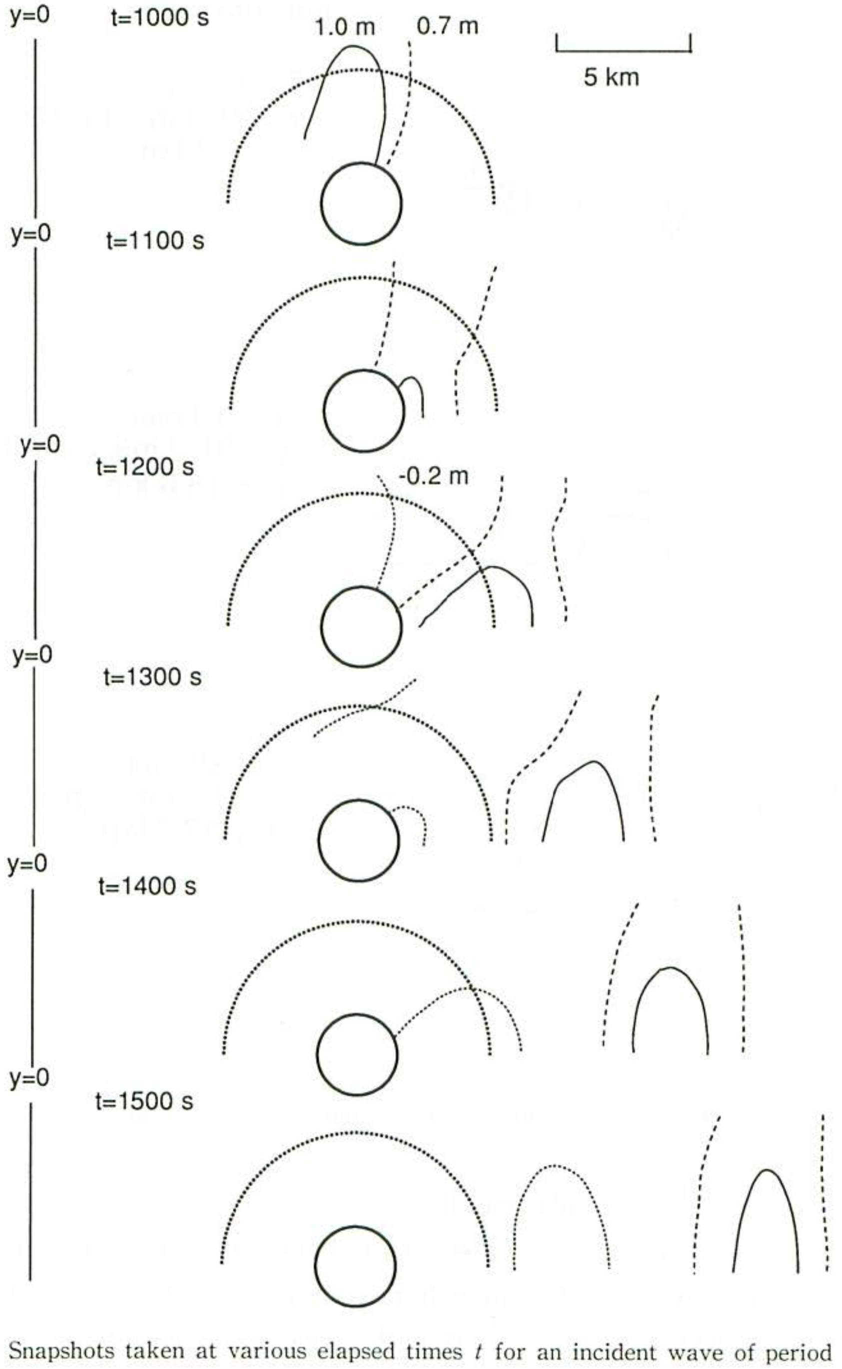

Fig.3: Snapshots taken at various elapsed times t for an incident wave of period $T=10$ minutes.

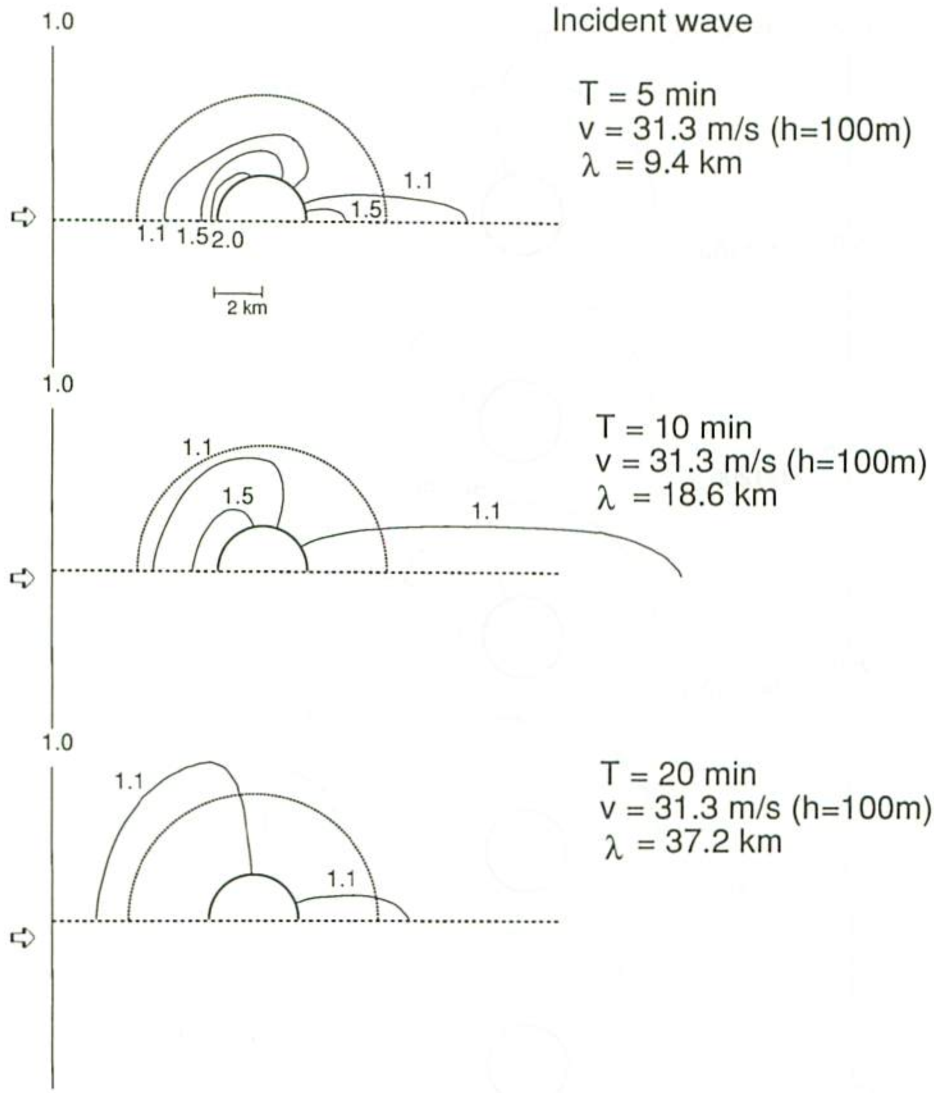

Fig.4: Maximum level distribution around the island.

of the island is negligibly small in the effect of wave propagation but for a short limit of the period the island represents a perfectly reflecting wall. The maximum level at the back side increases proportionally with one at the front side. It is of interest to note that the maximum level at the back side of the island reaches 3/4 of one (=2) at the front side for the period of 5 minutes. It is important to point out comparative sizes of the island to wavelengthes. They are 1/3 to 1/12 for the periods of 5 to 20 minutes, respectively.

To compare wave height profiles, observed at the coast in the backward direction, with ones computed we will define a peak height h_p and width W for a tail along the center line as shown in Figure 5. Distance dependences of the height ratio and the width of the peak are plotted with ones summarized by Abe (1994 b) in Figure 6. The height is converted to the height ratio for the comparison. The height ratio's decrease with an increase of distance and the decreasing ratio of them is inversely proportional to the period. The computed values vary approximately from 2 to 1 and observed ones distribute in the range of 3 to 1. In the computation pickup points are on the sea but in the observation they are on the coasts, which have their own sloping topographies. Accordingly another converging effect due to the slope is considered. The larger values of the observed wave height ratios are possibly explained from such a convergence. As for width a different behaivior was obtained among three waves. In the shortest period width increases linearly but in the longest one it decreases gradually after a small increase. The difference corresponds to one of concentrated energy behind the island. The observed width increase corresponds to the case of period $T=10$ minutes. The unified result between height and width makes us to understand the wave radiation behind the island as flatting process of the tail. The process is represented with a decrease of sharpness δ, defined as twice difference height by width W. That is

$$\delta = 2(h_p - 1)h_o / W$$

in which h_o is a height of incident wave. In this case it is 1 m.
Distance dependence of the sharpness δ is shown in Figure 7. It is approximated by an exponential decay. The slopes, obtained from a curve fitting, were shown beside lines. The slope depends on the wave period and the absolute value is inversely proportional to the period. The slope of -0.305, which was obtained from the observation, is within two slopes obtained from the shortest and intermediate periods. Nevertheless they are obtained at various epicentral distances, that means different incident height to each island, it is interesting to obtain a similar slope with the computed one, which was derived from the same incident wave. This fact suggests that the observed tsunami had a period from 5 to 10 minutes.

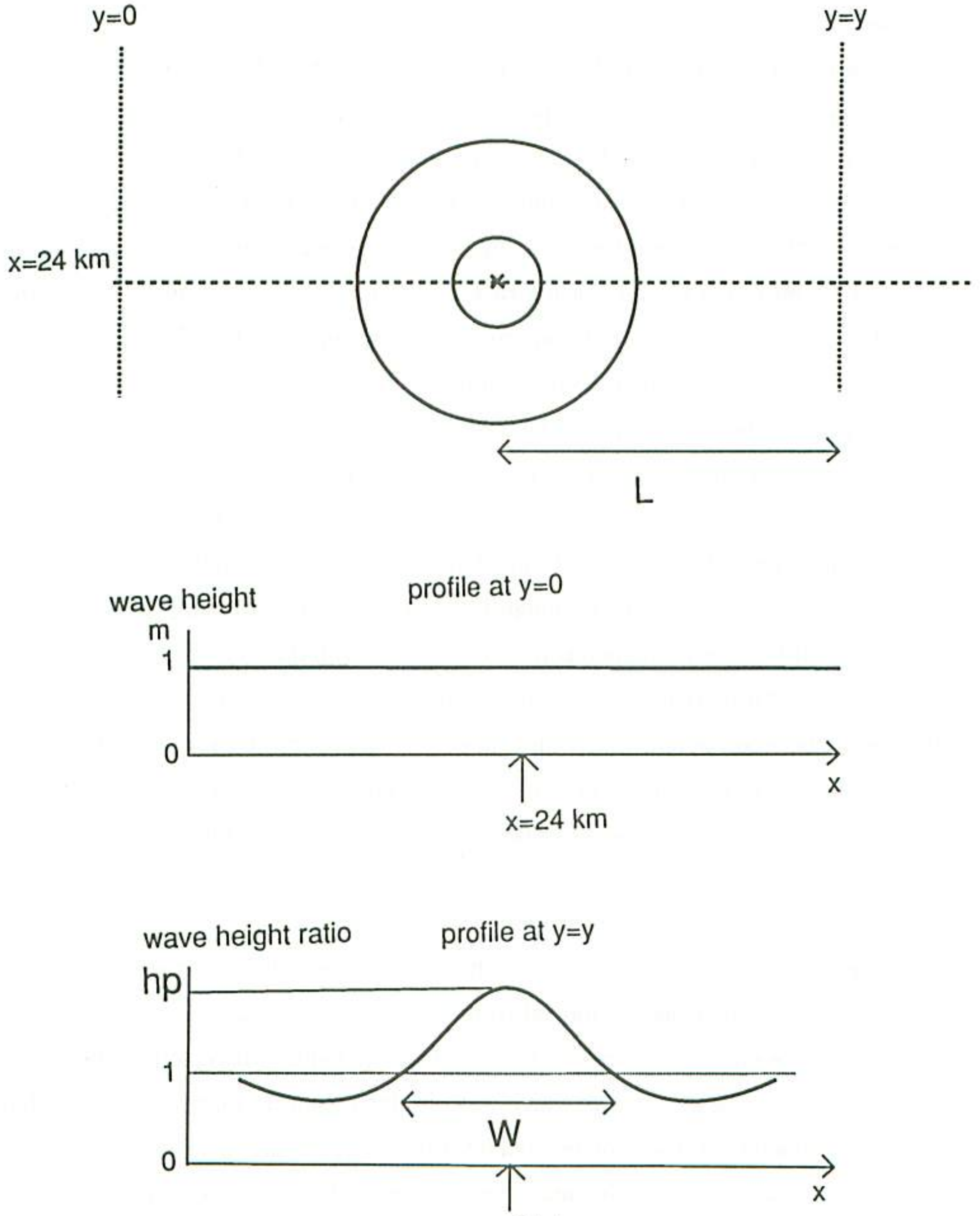

Fig.5: Definitions of a peak height ratio h_p and a width W in a wave profile at a distance L from the island.

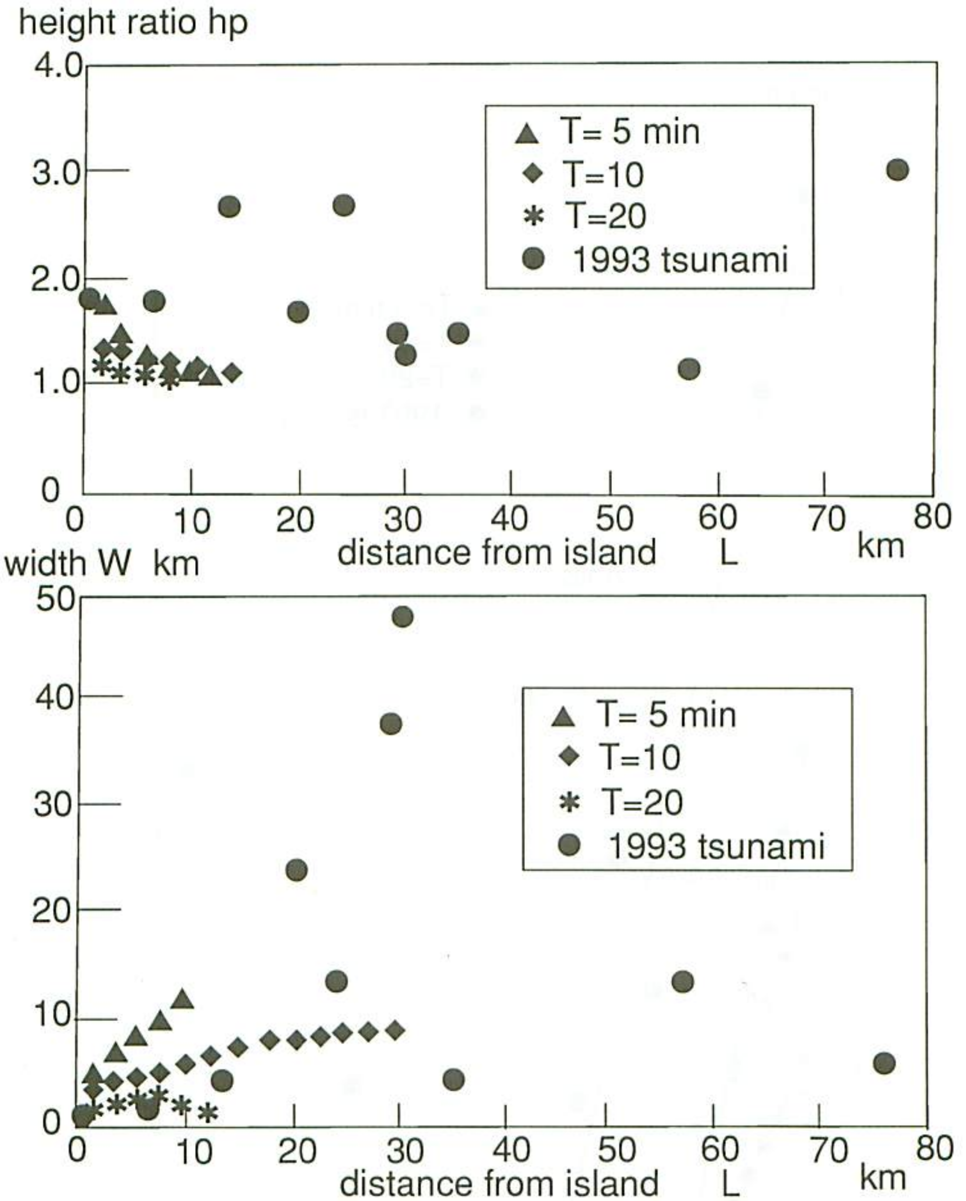

Fig.6: Distance dependence of peak height ratio (upper figure) and width (lower figure) with an observed result at 1993 Hokkaido Nansei-oki tsunami after Abe (1994 b). Distance L, height ratio h_p and width W are given in Figure 5.

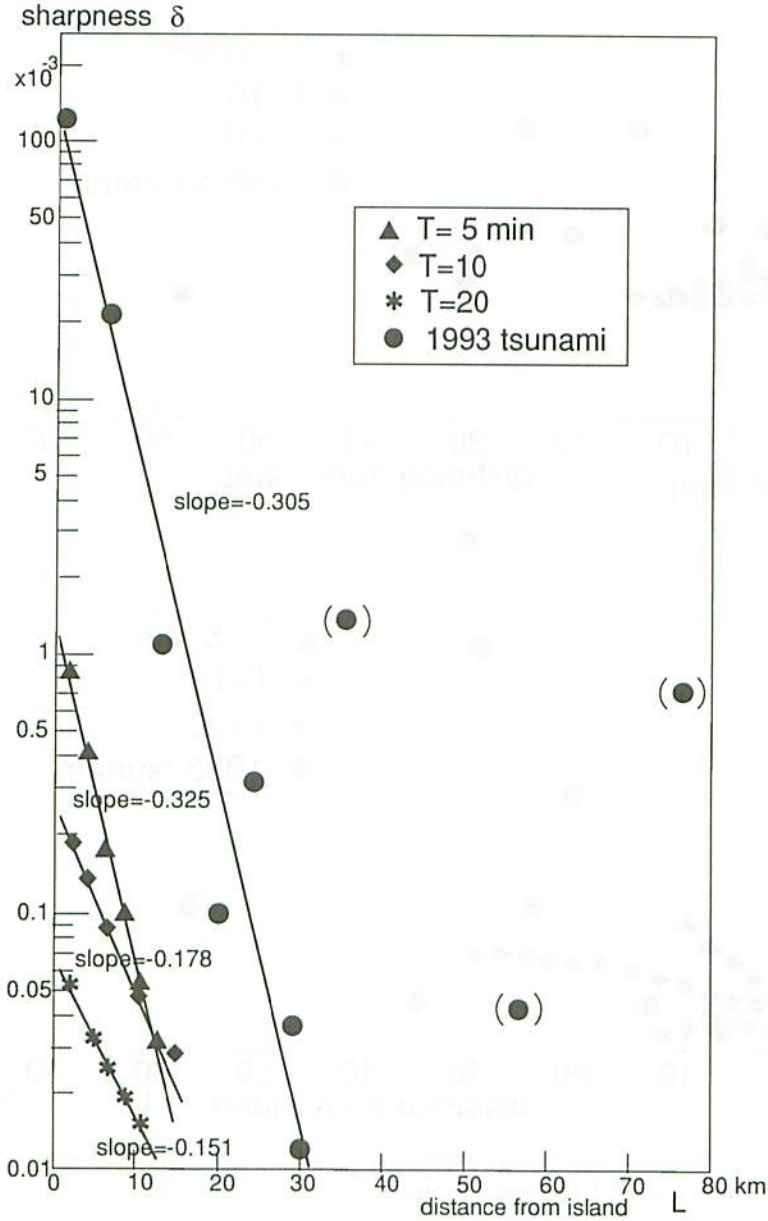

Fig.7: Sharpness of wave profile and fitting to exponential decays. Observed result from Abe (1994b).

Discussion

Numerical simulation was carried out for a cylindrical island with a linear slope in the flat sea and backward radiation was noticed. For the radiation a peak height, a width and a sharpness are defined to the profile, and the variations due to the distance from the island were discussed. As the result it is proved that in the short limit of incident wave's period backward radiation starts from 2 in the amplitude ratio and rapidly decreases. The ratio of 2 is explained by superposition of two refracted waves. The observed height ratio tends to converge to 2 in the small limit of island distance. Thus it is concluded that the observed focusing effect of tsunami is caused from a superposition of refracted waves. Sharpness of the wave profile is approximately reproduced from the simulation in the decreasing ratio but not explained in the absolute value.

Conclusion

Backward radiation of tsunami for a cylindrical island was reproduced from numerical simulations and it is clarified that the wave height ratio approximately decreased from 2 to 1 with an increase of distance from the island and the limiting value of 2 is the same as one observed at the 1993 Hokkaido Nansei-oki tsunami. This fact supports an explanation of the focusing effect, pointed out at that tsunami, from superposion of two waves being refracted on the sloping sea bottom around the island.

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