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NUMERICAL SIMULATION OF 1993 TSUNAMI FLOODING ONTO AONAE DISTRICT, OKUSHIRI ISLAND

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INTRODUCTION

On July 12, 1993, a large earthquake (M=7.8) occurred off the south-west of Hokkaido, Japan. The tsunami generated by this earthquake caused a disaster which took a heavy toll of lives, more than 200 persons dead, by the flooding of tsunami in the area of Aonae district in Okushiri island. Investigation after the disaster made clear that southern lowland was flooded by the tsunami coming from west about 5 min after the shock and the second tsunami from the east attacked eastern lowland of the Aonae District about 10 min after the shock. To simulate such an interesting tsunami behavior, numerical simulation was carried out by using the hydrodynamic model and two types of fault model estimated by seismological study. Simulated tsunami height distribution along the Hokkaido coast showsthat the fault model of westward slip with steep angle is much better than that of eastward slip with low angle. Mechanism of tsunami flooding onto the Aonae district, Okushiri island was also made clear by the simulation in which shoaling, diffraction and refraction due to the southern shallow area of the island amplified tsunami height and changed its direction from east to southwest. The computed tsunami near the Aonae district well simulates the tsunami behavior which was made clear by the investigation after the disaster. This simulation result will give us information about the way to reduce the disaster around the Aonae district. As an extension of the numerical model, it is of course useful to simulate the effectiveness of tsunami defense works and structures to be constructed.

NUMERICAL MODEL

(a) **Hydrodynamic Model:** Numerical model used is developed and coded by Yamashita et al (1990) which employs the time fractional finite difference method of three steps, advection, diffusion and propagation. For advection calculation the method of characteristics (Two-Point Fourth-Order Scheme) is employed and for diffusion and propagation steps, ADI and iterative ADI methods are used, respectively. This method was originally proposed by Benque et al (1982).
(b) **Moving Boundary Condition:** The term "moving boundary" means the boundary at the edge of body of water mass which is in motion with horizontally two-dimensional characteristics. Several types of moving boundary conditions have been proposed and practically used in the simulation of wave-front flooding on dry land. All of them are based on the idea of so-called weir model in which a threshold depth is introduced to judge whether the water is moving or stopped in the computational cell. The model used is also based on the weir model, in which the balance of forces between bottom friction and pressure gradient near the front region is introduced into the moving boundary condition through the weighting parameter which is introduced to discretize the second derivative with respect to the water surface.
(c) **Fault Model:** Vertical displacement of the sea bottom is calculated by the Mansinha and Smylie(1974) model which is based on the assumption of an isotropic homogeneous elastic medium. The initial tsunami profile is nearly equivalent to the bottom displacement due to earthquake fault when fault is large compared with the water depth and the rupture velocity is very fast compared with the tsunami propagation velocity. Fault parameters which have to be specified are earthquake moment M_0, width W, length L, depth H_d, strike angle, dip angle d, slip angle l and dislocation D.

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When these parameters are specified, the vertical displacement of the sea bottom can be calculated by the theory.

TSUNAMI PROPAGATION AND FLOODING

Investigation after the disaster made clear that the southern lowland was inundated by tsunami waves coming from the west about 5 min after the main shock and a second tsunami from the east attacked the eastern lowland of Aonae district about 10 min after the shock. To simulate such an interesting tsunami behavior, numerical simulation was carried out by using the hydrodynamic model mentioned above and two types of fault model estimated by seismological survey .

Computational domains for the tsunami simulation consist of a wide area of 1 minute mesh size for tsunami propagation, a narrow area of 1/3 minute, and 25m mesh of Aonae district, Okushiri island. Computational conditions are listed in Table 1, and fault model parameters obtained by the National Research Institute for Earth Science and Disaster Prevention just after the earthquake are in Table 2. Two types of fault model, dipping westward fault and dipping eastward fault, are proposed.

Table 1 Computational conditions

	Δx (m)	Δy (m)	Δt (sec)
Wide area	1,350	1,800	9
Narrow area	450	600	3
Aonae district	25	25	0.5

Table 2 fault model parameters obtained by National Research Institute for Earth Science and Disaster Prevention

North fault	Dipping westward fault	Dipping eastward fault
Length x width (km)	90 x 25	900 x 50
Dislocation(x,y) (cm)	(400, 21)	(100, 10)
Dip angle (deg)	55	-35
Azimuth	N181E	N9E
South fault	Dipping westward fault	Dipping eastward fault
Length x width (km)	75 x 15	75 x 25
Dislocation(x,y) (cm)	(500,0)	(300, 0)
Dip angle (deg)	55	-10
Azimuth	N145E	N35W

Assuming a displacement of the sea bottom calculated by both dipping westward fault and dipping eastward fault models, maximum tsunami height distribution along the west coast of Hokkaido is computed as shown in Fig.1. We may conclude from this figure that the fault model of dipping westward with steep angle predicts tsunami height distribution much better than that of dipping eastward with low angle. Then we use a fault model of dipping westward for a computation of tsunami propagation near Okushiri island (in the narrow area) and flooding onto Aonae district.

Snapshots of tsunami propagating in the wide computational domain are shown in Fig.1. It is observed that the first tsunami wave arrived at Hokkaido island within 10 min after the shock.

Figure 2 shows snapshots of tsunami propagating and flooding onto the Aonae district. Mechanism of tsunami flooding onto the Aonae district is made clear by these figures. Shoaling and refraction of tsunami waves due to the southern shallow area of the island are evident and these amplified tsunami in its height and changed its direction from east to west. The first wave attacked the southern lowland from the west direction around 5min after the shock, and the tsunami wave refracted around the southern shallow ridge attacked Aonae district from the north-east direction around 9 min after the shock. This may be recognized as the second tsunami wave observed by residents in this area. Such tsunami behavior simulated by this study agrees well with the investigation after the disaster. Results of this simulation give us many information about tsunami behavior near Aonae district. As an extensive numerical simulation, it is of course possible to make clear the effectiveness of tsunami breakwaters and sea-walls.

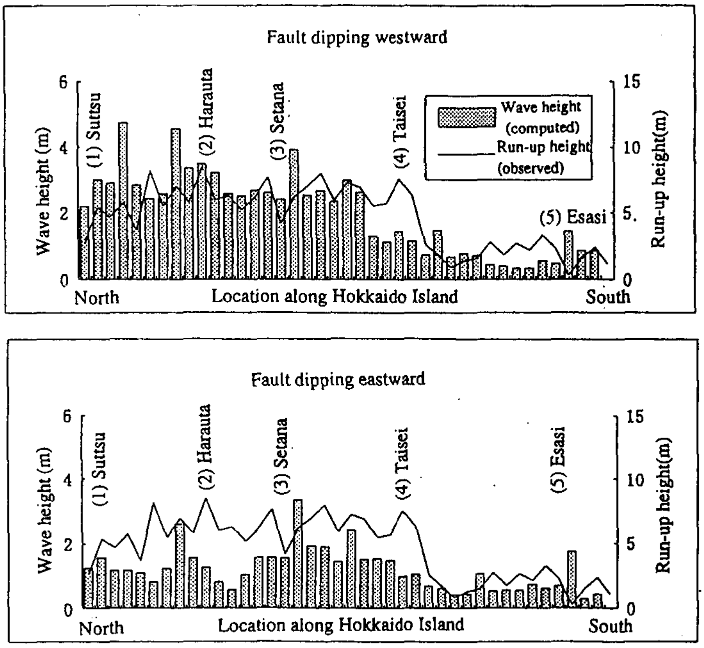

Fig.1 Maximum tsunami height distribution along the west coast of Hokkaido (a) assuming dipping westward fault, (b) dipping eastward fault.

CONCLUSIONS

Numerical simulation of the 1993 South-West Off Hokkaido Earthquake tsunami was carried out. The main conclusions are listed below.

(1) Simulated tsunami height distribution along the coast of Hokkaido island supported the fault model of a westward slip with steep angle (dipping westward fault).

(2) Tsunami propagation in the wide computational domain showed that the first tsunami wave arrived at Hokkaido island within 10 min after the shock.

(3) Simulation of tsunami flooding in Aonae district shows that diffraction and refraction of tsunami waves due to the southern shallow area of the island amplified the tsunami in its height and changed its direction from east to west. The first wave attacked the southern lowland from the west direction around 5min after the shock and the tsunami wave refracted by the southern shallow ridge attacked Aonae district from the north-east direction around 9 min after the shock. The simulated tsunami behavior agrees well with the investigation after the disaster.

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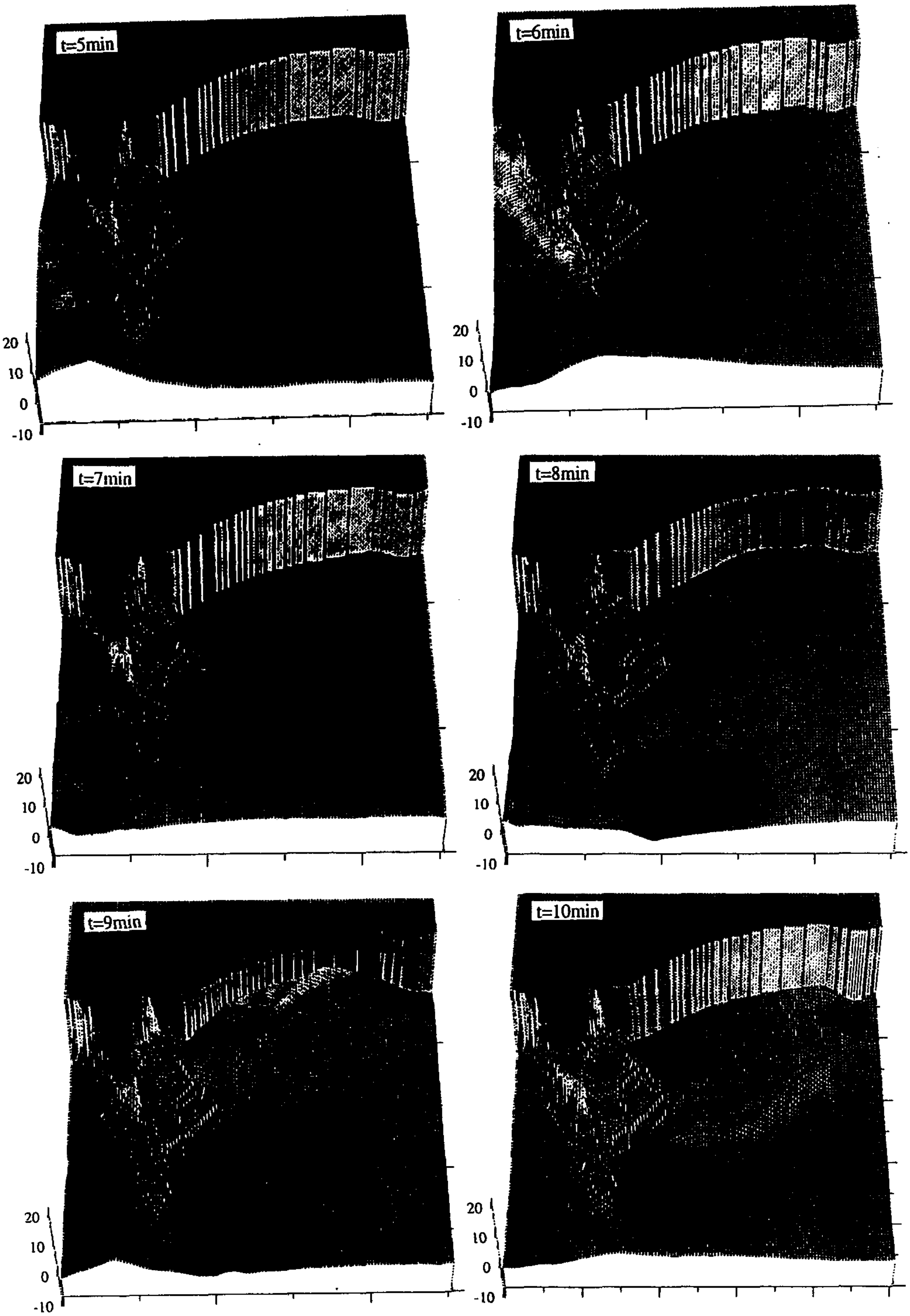

Fig. 2 Snapshot of tsunami propagating and flooding on Aonae district.