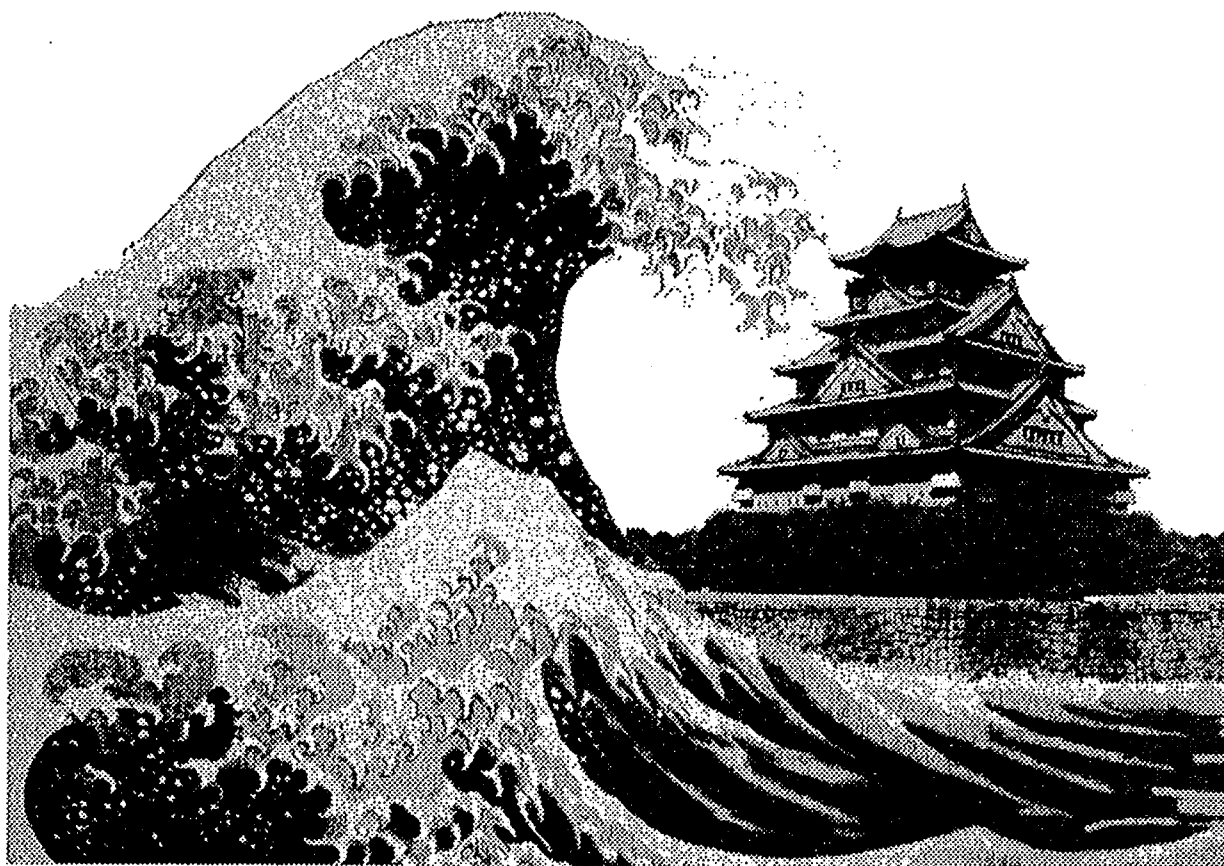


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3RD UJNR TSUNAMI WORKSHOP

**OSAKA, JAPAN
28 August 1993**

PROCEEDINGS



**Coastal Engineering Division
River Department
PUBLIC WORKS RESEARCH INSTITUTE
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3RD UJNR TSUNAMI WORKSHOP

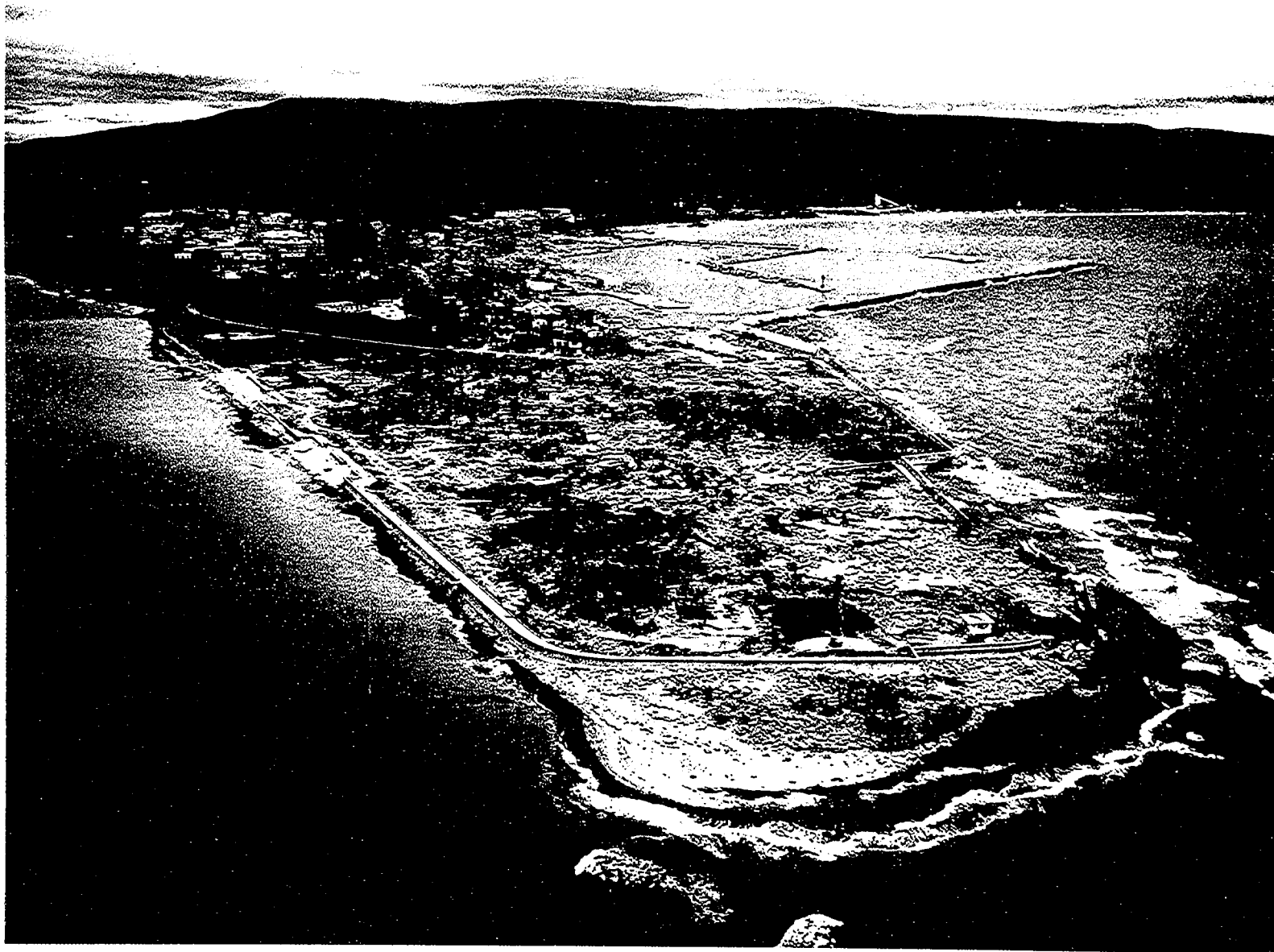
OSAKA
28 August 1993

PROCEEDINGS

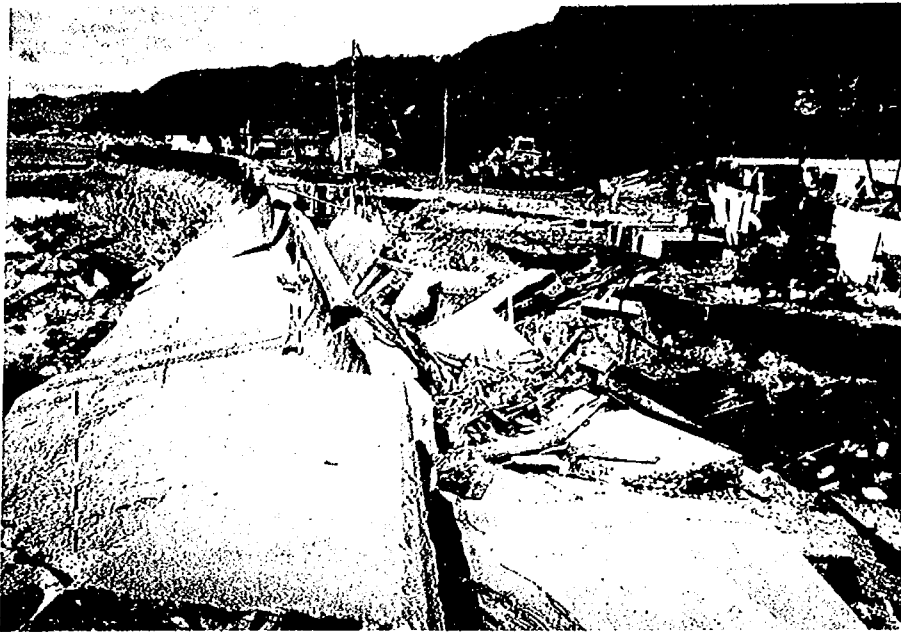
Edited by

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and
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Coastal Engineering Division
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September, 1994



Hokkaido Nansei-Oki Earthquake Tsunami devastated Cape Aonae, Okushiri Is. on 12 July 1993.
(photo. by Hokkaido-shinbun)



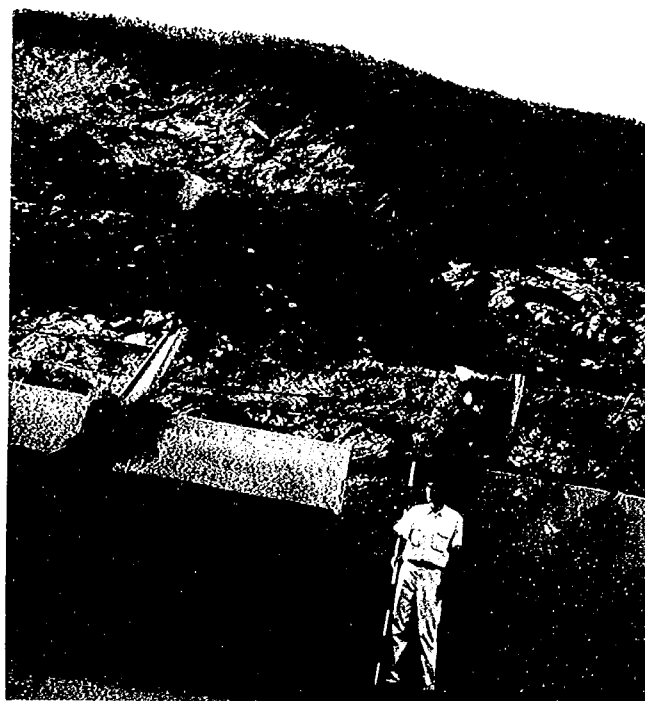
Sea wall broken down by Tsunami
(Futoro Town, Hokkaido Island)



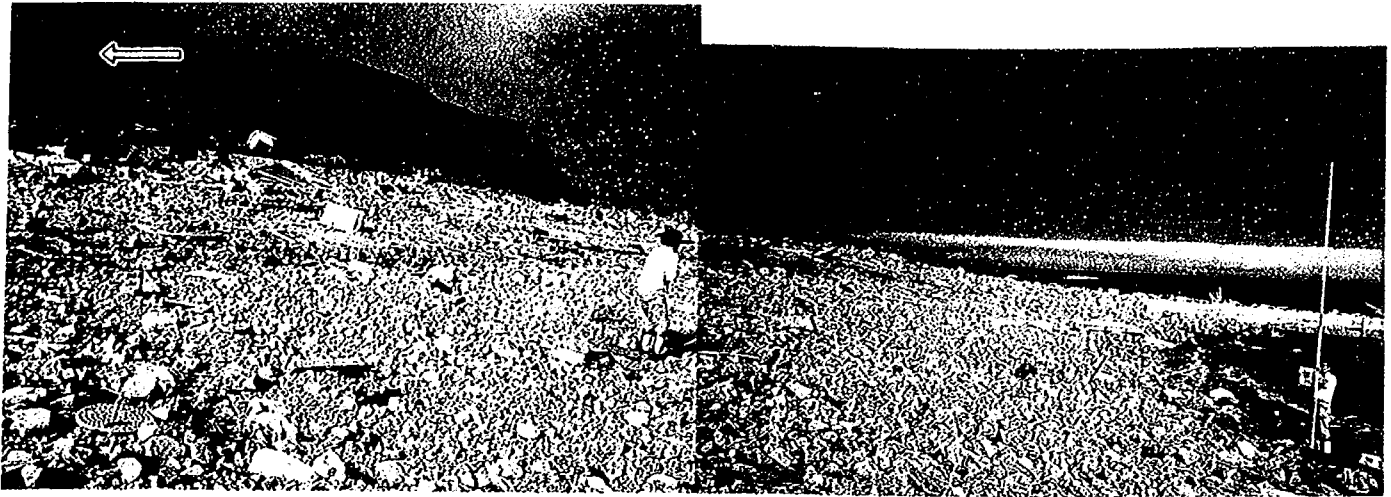
Houses broken by Tsunami
(Inaho, north of Okushiri Island)



Tsunami inundation area
(the east of Cape Takinoma, north of Okushiri Island)



Damage of road facilities
(Matsue, Okushiri Island)



Trace of tsunami runup
(Hamatsumae, Okushiri Is.)



Trace of tsunami runup
(east of Cape Kuki, Okushiri Is.)

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Osaka, Japan, 28, August, 1993

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Introduction

The 3rd UJNR Tsunami Workshop was held at KKR HOTEL OSAKA in Osaka, Japan, on August 27-28, 1993. This workshop was conducted as an activity of the Task Committee of Storm Surges and Tsunami, a Task Committee under the panel on wind and seismic effects of the United States-Japan Conference on Development and Utilization of Natural Resources. This workshop was 3rd one previous two which were 1st in Tsukuba and 2nd in Honolulu.

This workshop was advanced mainly discussion. Because, we got a huge disaster one and half months before on July 12 which has been called Hokkaido Nansei-oki earthquake tsunami, and IUGG/IOC International Tsunami Symposium, "Tsunami '93", had opened forward 2 days in Wakayama. Then we considered many lively discussions are more significant than recognitions by presentation. So, any papers for workshop were not prepared specially. But to remain the record of the 3rd workshop is important for advancing tsunami study. Then this report is structured same style to workshop that one session had a presentation and next discussions. And the papers in this report were written after this workshop to support understanding the proceedings of discussions.

In this season, many typhoon attack Japan. The day before this workshop, Tokyo area had heavy rain and wind by typhoon. And airports were closed and Shinkansen-line was interrupted. It was very sorry that some expected participants could not come to the place.

Thanks are Kinki Regional Construction Bureau, Min of Construction and Technology Research Center for River Front development.

The Conveners would also like to recognize the special dedication of many of the participants who took time from very busy schedules to prepare presentation and post papers for publication and their unfailing cooperation to complete our tasks within the time allowed.

Co-conveners

James F. Lander

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August, 1994

AGENDA

3RD UJNR TSUNAMI WORKSHOP KKR HOTEL OSAKA, JAPAN

August 28, 1993

9:00 Opening remarks(Japan)

9:10 ~ "Numerical Simulation Model"

(moderator Mr. Tanaka and Mr. Lander)

Matsutomi, H.: Some Matters to be Improved in Numerical Simulation
Technique of Tsunami
(Discussion)

Yeh, H.: 3D Modelling
(Discussion)

Carrier, G.: 3D Modelling
(Discussion)

Coffee Break

10:50 ~ "Tsunami Gauge Technology"

(moderator Mr. Tanaka and Mr. Lander)

Okada, M.: Some Topics on Tsunami Observation in Japan
(Discussion)

Gonzalez, F.: Deep sea gauges
(Discussion)

12:00 ~ Lunch (Group Photograph)

13:00 ~ "Mitigation and Others"

(moderator Mr. Tanaka and Mr. Lander)

Abe, K.: Characteristic Properties of the 1992 Nicaragua
Earthquake Tsunami
(Discussion)

Sigrist, D.: July 12 Tsunami Effects and Observations
(Discussion)

Lander, L.: Some Results of Studies of U.S. Tsunamis
(Discussion)

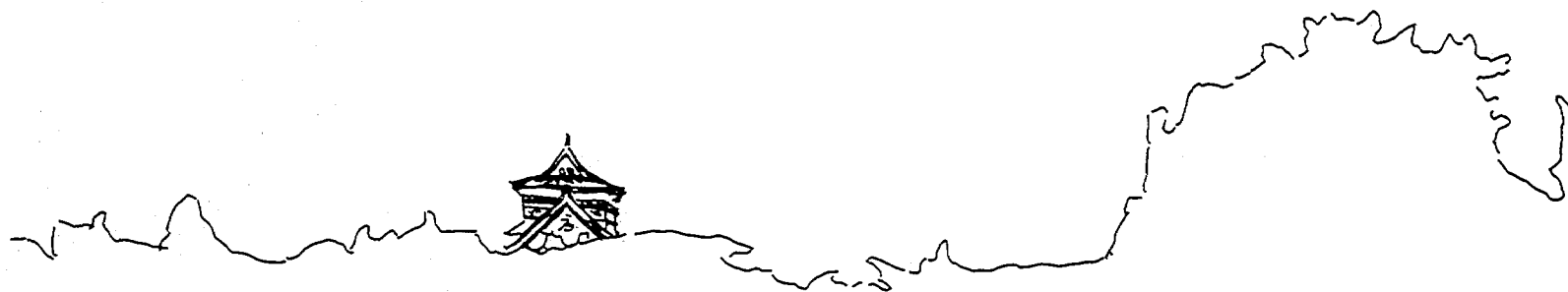
Tsuji, Y.: The report on the Tsunami Disaster in Indonesia.
(Discussion)

Tanaka, S.: The Report on the Tsunami Disaster in Hokkaido.
(Discussion)

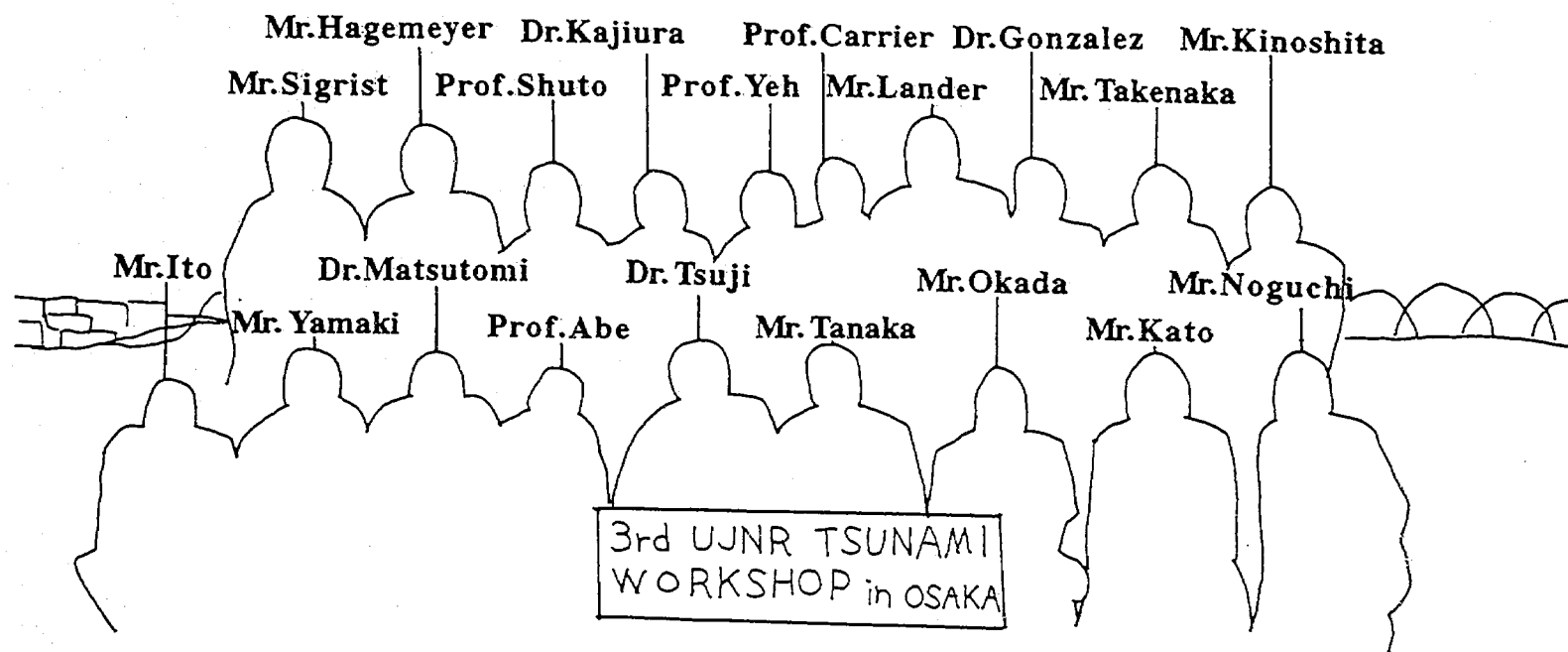
Shuto, N.: Damage to houses in case of Aonae
(Discussion)

15:50 ~ 16:00 Closing Address(US)





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3rd UJNR Workshop on Tsunamis

Osaka

August 28, 1993

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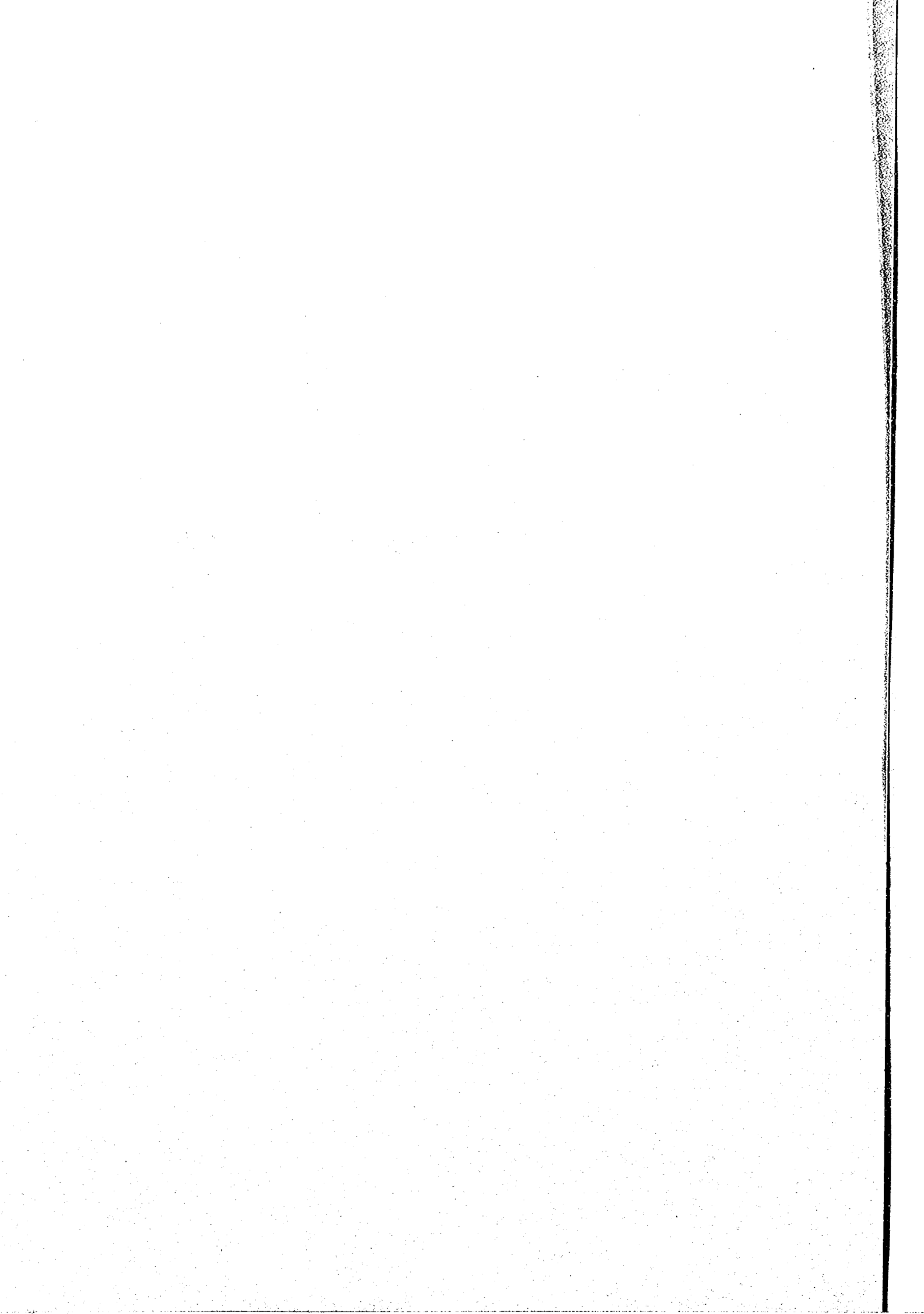
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A: Numerical Simulation Model

J. Lander and S. Tanaka, moderators



Some Matters to be Improved in Numerical Simulation Technique of Tsunamis (Abstract)

by Hideo MATSUTOMI

Dept. of Civil Eng., Akita Univ., Akita, Japan

The present state and near future problems of the tsunami numerical simulation was delineated, from a wide standpoint, by Shuto(1989). In this presentation, a concern is focused on a review of numerical simulation technique and the following items are taken up. The review is done from an engineering standpoint, and tsunamis are restricted to ones generated by submarine earthquakes.

1. Source Area and Initial Wave Profile

An estimation of the source area and initial wave profile would be the most important and difficult problem in the numerical simulation of tsunamis, especially for the tsunami or silent earthquakes. It is well-known that the fault model is useful to estimate the source area and initial wave profile, but it has a tendency to underestimate them. It is necessary to use tsunami data for more precise estimation, excepting the case of the tsunami forecast.

One of questions from a viewpoint of the numerical simulation technique would be that 'Is it necessary to use 3-D model in source region ?'.

2. Far-field Tsunamis

It was confirmed that the linear Boussinesq equation with the Coriolis force was satisfactory in accuracy to simulate transoceanic tsunamis (Imamura, Goto & Shuto, 1986). The difference equation of the linear long wave equation by the leapfrog scheme has a numerical dispersion term implicitly. Imamura (1989) suggested that if the grid length Δx is determined from Eq.(1), the linear long wave equation yields the same results as the linear Boussinesq equation.

$$(\Delta x/2h)[1-(C_0 \Delta t/\Delta x)^2]^{1/2}=1 \quad \dots\dots\dots(1)$$

where h is the depth of still water, $C_0=(gh)^{1/2}$, g is the acceleration of gravity and Δt is the time interval. His method brings much the saving of CPU time and memory size. However, it is a little difficult to apply the method efficiently for an actual topography.

3. Near-field Tsunamis

3.1 Offshore Boundary

The offshore boundary should be placed as seaward and parallel to the mean coastline as possible. On the boundary, the linear characteristic relations are usually used to transmit reflected waves outside. There is yet room for improvement in the boundary condition. However, it is not necessary to use such relations for the boundary in the inner region computation.

3.2 Side Boundary

The side boundary is very important to accomplish a computation stably because it extends across a region in which the nonlinearity of waves is not negligible. The nonlinear characteristic relations, at least, must be used in this region. This boundary should be placed as far from the area of concern and at right angle to the mean coastline as possible even if it is the boundary in the inner region computation.

3.3 Moving Boundary

In a practical computation, an artificial moving boundary condition must be employed to simulate the tsunami run-up on dry land. There are two main methods. One is the use of the broad-crested weir formula proposed by Aida (1977) or Houston & Butler (1979). The other is the use of a topographic form condition proposed by Iwasaki & Mano (1979). Each condition is an approximate one and has a trivial matter to be solved. There is room for improvement at the time of the receding front in the former. Depending on the situation, the submerged weir formula should be employed. There is room for improvement at the time of the advancing front on horizontal land and downward slope in the latter.

Wanting to discuss the impulsive force due to tsunamis, it is necessary to estimate the wave-front profile and velocity exactly. For that, it is also necessary to know the friction law at the front region. Fujima & Shuto (1988) examined the friction law at the surge front through experiments suggested by Le Mehaute (1979). They derived Eq.(2) as a friction law for smooth bed and besides carried out a numerical simulation of a surge flow with Eq.(2).

$$f = 0.025(Q/\nu)^{-0.23} \dots\dots\dots (2)$$

where f is the friction factor, Q is the discharge per unit width and ν is the coefficient of kinematic viscosity. Their results were that 1) the friction law was almost the same as that for the smooth flat plate and 2) the wave-front profile was more correctly predicted by using Eq.(2). Though their work is restricted to the smooth bed, judging from their results, the friction law for the rough flat plate would be applicable to rough bed.

3.4 Convection Terms

The up-wind scheme is usually used for the difference of the convection terms. They have an accuracy of $O(\Delta x)$ and cause numerical dissipation. Other terms have the accuracy of $O(\Delta x^2)$. Hence, solving them more exactly is very important, especially on dry land. In diffusion problems, some new schemes, for example, Holly-Preissmann scheme, Six-point scheme, Split operator approach and so on, have been developed. However, those schemes can not be directly applied to the convection terms. Some devices would be necessary for that.

3.5 Threshold Depth

Threshold depth Δh is often introduced at the tip of a flow on dry land to avoid a numerical instability. It is possible to use the depth as a moving boundary condition (Iwasa et al., 1980). Hence, it is important to examine how depth should be adopted as the depth. Matsutomi (1988) examined it through numerical experiments of a dam-break flow on an inclined dry land and reached a conclusion that $\Delta h/\Delta x < 10^{-3}$ should be satisfied.

Dr. MATSUTOMI

Dr. Gonzalez: Dr. Matsutomi, with regard to numerical modeling, do you have an opinion on the variable grid approach, the finite element or finite triangles? Some people are also using variable grid, but I know there are problems with that too. Do you have an opinion on the variable grid?

Dr. Matsutomi: Using the variable grid is, I think, an efficient method, but on the Japan side we always stand by the engineering concept, how to decrease the CPU time and computer memory. On the basis of such a notion, we divided the full region into large and small.

Prof. Shuto: The variable grid and also the finite element method. This method is better than FDM analysis. But there is one thing. To create the topography data will take a lot of your research time. If there is a simple way to construct the topographic data, it is better; because you can hire any amateurs or part-time workers and ask them just to draw a grid not. If you would like to have a very wide area with a very fine mesh, by hiring this kind of person, it is easier for you to create the topographic data.

NUMERICAL SIMULATIONS OF TSUNAMI-BORE RUN-UP USING THE RANDOM CHOICE METHOD

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Abstract

The Random Choice Method is used as a numerical scheme to solve the shallow-water wave equations, which is a nonlinear system of hyperbolic equations. A shock is preserved in this method so that a bore front formed after wave breaking is represented by discontinuity without dispersion. Numerical solutions to several selected classic shallow-water wave problems are presented. The numerical method is then extended to include sloping bottom conditions so as to investigate the tsunami bore run-up.

Introduction

A bore and the preceding run-up on a uniformly sloping beach can be modeled by the shallow-water wave equations. For a uniform velocity distribution over flow depth under the hydrostatic pressure field, the equations of motion in the one propagation direction x can be written as,

$$h_t + (uh)_x = 0, \quad (1)$$

$$u_t + uu_x + g(h - H)_x = 0, \quad (2)$$

where $u(x, t)$ is the fluid velocity, $h(x, t) = \eta(x, t) + H(x)$, $\eta(x, t)$ is the water level from the undisturbed water level $H(x)$ from the bottom and g is the gravitational acceleration (see Figure 1). The run-up problem of a bore has been investigated previously both by laboratory experiments and numerical methods. As a bore approaches the shoreline, the propagation speed first decelerates by compressing the bore waveform and then suddenly accelerates at the shoreline, hence the initial run-up velocity is large. The run-up velocity then decreases due to the gravitational effect. Experiments by Yeh et. al. [1] have shown that turbulent motion influences the run-up process therefore it can not be expected that simple numerical models can capture every detail of the process.

Numerical approaches have been used previously to solve the shallow-water wave equations to model run-up motion of a bore on a sloping beach. The ordinary finite-difference methods, however, have several disadvantages. For example, numerical instability problems are often caused at a numerical discontinuity, i.e. at a bore front. The moving boundary at the fluid and dry surface interface needs special attention because it often leads to unsatisfactory location of the 'last wet' gridpoint. Numerical dissipation is usually induced in the finite-difference methods which can lead to problems. Some of the numerical problems mentioned above can be avoided in the Random Choice Method.

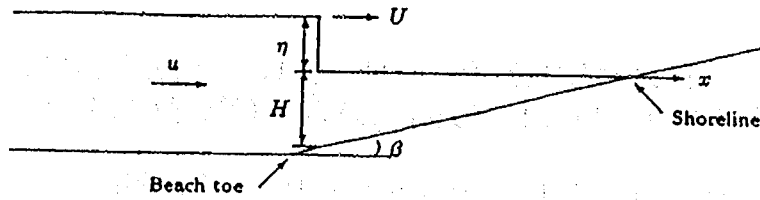


Figure 1: Notation for the shallow-water wave equations.

The Random Choice Method

In the Random Choice Method, the fluid domain is divided into n intervals. At a time t_j , the Riemann problem is solved at each pair of gridpoints i and $i+1$, (i is an integer). The Riemann problem of the shallow-water waves is also called 'the dam break problem', where the fictitious discontinuity is located initially at the midpoint between the gridpoints i and $i+1$ and the problem is solved for the flow condition at $\Delta t/2$ after the dam breakage. Figure 2 shows an example for a part of the calculation space at time $t = t_j$. The notation $w_{i,j}(x, t)$ will be used to denote the solution of a Riemann problem at gridpoint i for time t_j . From the solution $w_{i,j}(x, \Delta t/2)$ only one point between $x = \Delta x i$ and $x = \Delta x(i+1)$ is sampled randomly, say $x = x^*$, and the sampled value $w_{i,j}(x = x^*, \Delta t/2)$ is assigned to the gridpoint $i + \frac{1}{2}$. This process is repeated for the next half time step to obtain a solution for gridpoint i and time $t = t_{j+1}$. The procedure for the sampling is based on a uniformly distributed pseudo-random variable $\theta_j \in [-\frac{1}{2}, \frac{1}{2}]$ which is generated at each half time step. The method used to generate the random number θ_j is described in detail in Chorin [2].

The Random Choice Method is stable if there is no interaction between adjoining Riemann solutions. This means that the zone disturbed by a 'dam breakage' must be smaller than Δx . Basically a solutions of the dam breakage problem will contain a shock running in one direction and a depression wave (an expansion fan) running the other direction. Therefore a Courant-Friedrichs-Lewy condition must be constructed as:

$$\Delta x / \Delta t > \max(S, u_1 - c_1), \quad (3)$$

for a right running wave, and

$$\Delta x / \Delta t > \max(S, u_0 + c_0), \quad (4)$$

for a left running wave where S is the shock speed and $c_i = \sqrt{gh_i}$.

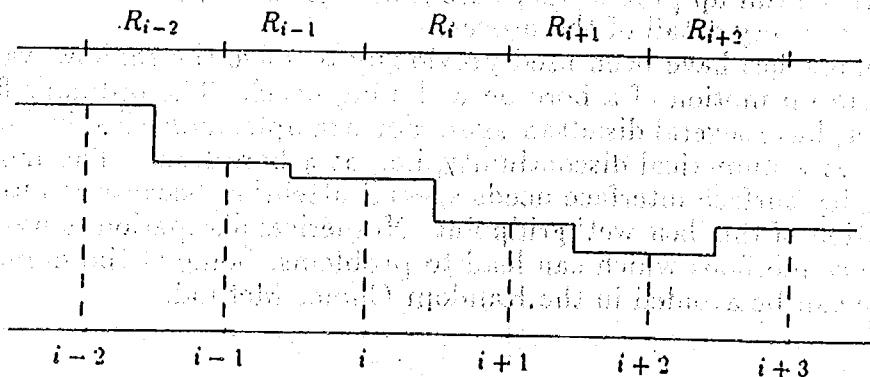


Figure 2: Part of the calculation space at time t_j .

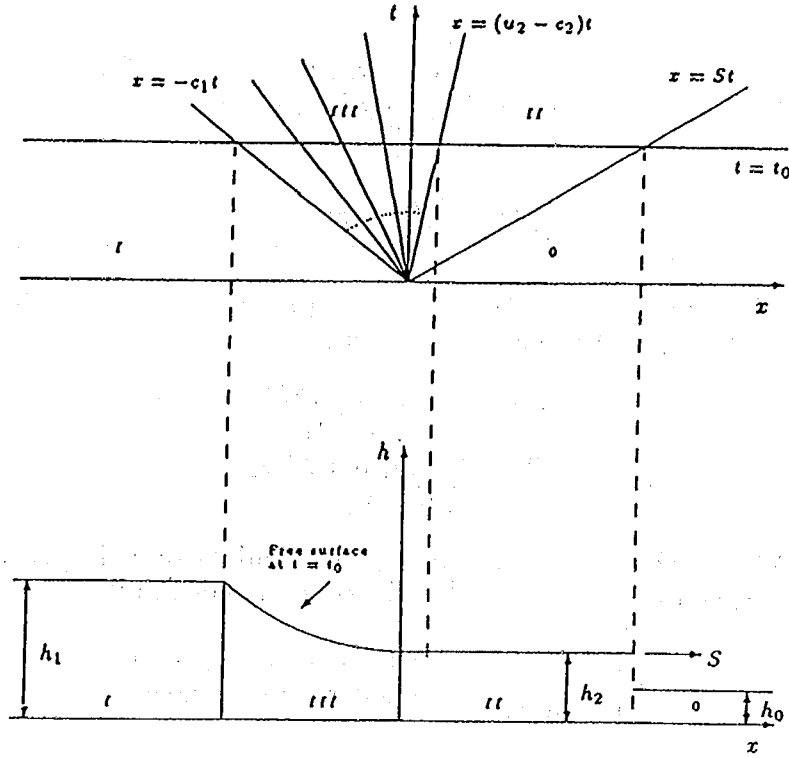


Figure 3: Dam break at time $t_0 > 0$ (from Stoker [3]).

In the dam break problem, the water surface will consist of four different zones. Far enough to the right and the left, the depths remain h_0 and h_1 , respectively. The disturbed zone consists of a zone with constant depth h_2 and an expansion fan where the water depth changes parabolically from h_2 to h_1 as shown in Figure 3 (e.g. Stoker [3]).

The variables h_0, h_1, u_0 and u_1 are given as initial conditions. The unknown variables are the depth h_2 , the fluid velocity u_2 and the shock speed $S = \tilde{S} + u_0$. The state (II) can be connected to the state (0) through the shock relations (Figure 3):

$$h_2(u_2 - \tilde{S} - u_0) + \tilde{S}h_0 = 0, \quad (5)$$

$$-(\tilde{S} + u_0)(u_0 h_0 - u_2 h_2) + u_0^2 h_0 - u_2^2 h_2 + \frac{1}{2}g(h_2^2 - h_0^2) = 0. \quad (6)$$

The state (I) can be connected to the state (II) by using the Riemann Invariants

$$u_2 + 2c_2 = u_1 + 2c_1. \quad (7)$$

Eliminating $\tilde{S}$ in (6) by using (5) yields

$$\frac{\frac{1}{2}g(h_0^2 - h_2^2)}{u_0 - u_2} = \frac{(\frac{1}{2}g(h_0^2 - h_2^2))^{1/2}(h_2 h_0)^{1/2}}{(h_0 - h_2)^{1/2}}. \quad (8)$$

By defining the functions $M_0 = (P_0 - P_2)/(u_0 - u_2)$, $M_1 = (P_2 - P_1)/(u_1 - u_2)$ and $\phi = (h_2/h_0)^2$ where $P_i = \frac{1}{2}gh_i^2$, equation (8) becomes

$$M_0 = \left(\frac{1}{2}gh_0^3\right)^{1/2}(\phi + \sqrt{\phi})^{1/2} \quad \text{for } \phi \geq 1. \quad (9)$$

For a left running shock the connection between the state (II) and the state (0) is through the Riemann Invariants and therefore, with help of equation (7), M_0 will be

$$M_0 = \left(\frac{1}{2}gh_0^3\right)^{1/2} \frac{1}{2\sqrt{2}}(\sqrt{\phi} + 1)(\phi^{1/4} + 1) \quad \text{for } \phi < 1. \quad (10)$$

Expressions for M_1 can be derived in the same manner. In summary, for both right and left running wave,

$$M_0(\phi = (\frac{h_2}{h_0})^2) = \begin{cases} (\frac{1}{2}gh_0^3)^{1/2}(\phi + \sqrt{\phi})^{1/2} & \text{for } \phi \geq 1, \\ (\frac{1}{2}gh_0^3)^{1/2}\frac{1}{2\sqrt{2}}(\sqrt{\phi} + 1)(\phi^{1/4} + 1) & \text{for } \phi < 1. \end{cases} \quad (11)$$

and

$$M_1(\phi = (\frac{h_2}{h_1})^2) = \begin{cases} (\frac{1}{2}gh_1^3)^{1/2}(\phi + \sqrt{\phi})^{1/2} & \text{for } \phi \geq 1, \\ (\frac{1}{2}gh_1^3)^{1/2}\frac{1}{2\sqrt{2}}(\sqrt{\phi} + 1)(\phi^{1/4} + 1) & \text{for } \phi < 1. \end{cases} \quad (12)$$

Using the previous defined functions $M_0 = (P_0 - P_2)/(u_0 - u_2)$ and $M_1 = (P_2 - P_1)/(u_1 - u_2)$, the following expressions for P_2 and u_2 can be derived,

$$P_2 = \frac{(u_1 - u_0)M_1M_0 + P_0M_1 + P_1M_0}{M_1 + M_0}, \quad (13)$$

$$u_2 = \frac{P_1 - P_0 + M_1u_1 + M_0u_0}{M_1 + M_0}. \quad (14)$$

Equations (11), (12) and (13) are solved for M_0 , M_1 , and P_2 by using Newton's root-finding method. The shock speed S can be calculated using the continuity

$$S = \begin{cases} \frac{h_0u_0 - h_2u_2}{h_0 - h_2} & \text{for right running wave,} \\ \frac{h_1u_1 - h_2u_2}{h_1 - h_2} & \text{for left running wave.} \end{cases} \quad (15)$$

Numerical results for horizontal bottom

The developed numerical scheme is first applied to some traditional problems. The first test case is a dam break problem on a horizontal bed with the following initial conditions:

$$\begin{array}{llll} h_1 & = & 1.00 & \text{m} \\ h_0 & = & 0.40 & \text{m} \\ u_0 & = & 1.80 & \text{m/s} \\ u_1 & = & 0.72 & \text{m/s} \end{array} \quad \begin{array}{llll} i_{max} & = & 100 & \text{gridpoints} \\ \Delta x & = & 0.10 & \text{m} \\ \Delta t & = & 0.02 & \text{s} \end{array}$$

The sequence of results shown in Figure 4 displays the water-depth profiles as a function of time. We can observe that the shock is sharp, being represented by two adjacent gridpoints; it appears to generate no numerical dispersion around the shock. The location of the shock does not deviate more than one space step from the theoretical location and the same holds true for the rarefaction. The quality of the solution increases with time, because the solution scheme is based on convergence of the random variable.

For a dam break onto a dry bed, the transition from a dry state to wet state and vice versa, often causes problems for numerical schemes. The Random Choice Method handles this without ordinary finite-difference problem. The following initial values and numerical values are used:

$$\begin{array}{llll} h_1 & = & 1.00 & \text{m} \\ h_0 & = & 0.00 & \text{m} \\ u_1 & = & 0.72 & \text{m/s} \end{array} \quad \begin{array}{llll} i_{max} & = & 100 & \text{gridpoints} \\ \Delta x & = & 0.100 & \text{m} \\ \Delta t & = & 0.013 & \text{s} \end{array}$$

Note that when the dam breaks at time $t = 0$, we have the artificial initial condition $u_1 > 0$. The sequence of the results shown in Figure 5 display the water-depth profiles as a function of time. The shape of the disturbed zone, the location of tip and beginning of the rarefaction appear to be in excellent agreement with the theoretical results (see e.g. Stoker [3]).

An interesting thing happens to a sinusoidal standing wave in a rectangular tank with the initial conditions:

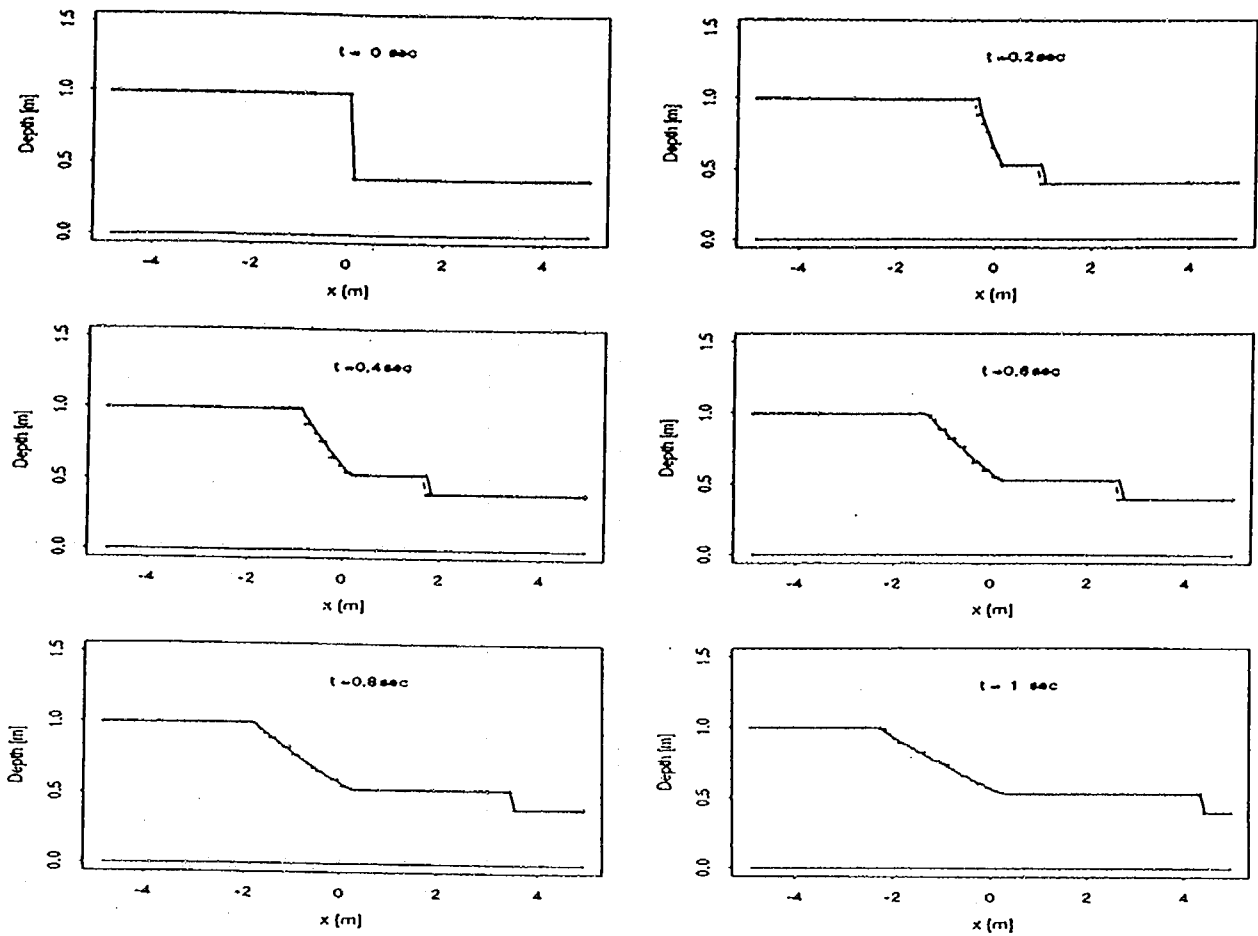


Figure 4: Solution for breaking of a dam with water on both sides. Theoretical solution —; Numerical solution ---.

Wavelength	L	$=$	4.00	m	i_{max}	$=$	500	gridpoints
Amplitude	A	$=$	0.02	m	Δx	$=$	0.004	m
Wave period	T	$=$	3	s	Δt	$=$	0.0025	s
Mean depth	h_o	$=$	0.18	m				

As shown in Figure 6, even though the initial wave steepness is small, the wave travels back and fourth with increasing steepness and eventually a distinguish breaking wave front is formed. This is a consequence of the fact that the Random Choice Method does not cause any numerical dissipation or dispersion and the governing equation is the fully nonlinear, non-dispersive, shallow-water wave equations (see Airy 1945).

Numerical results for sloping bottom

The general step in the Random Choice Method is solving the dam break problem for the gridpoints i and $i+1$. Let the depths and the velocities at these two points be h_i , h_{i+1} and u_i , u_{i+1} , respectively, and let's define dy as a difference in bottom elevation between those two gridpoints. In the case of the sloping bottom, if both h_i and h_{i+1} are greater than zero the dam-break problem is solved using the modified depths $h'_i = h_i - dy/2$ and $h'_{i+1} = h_{i+1} + dy/2$ as an initial condition but the velocities are not modified. The solution is constructed from the modified depths if the selected location by the random variable is inside the disturbed zone, but outside the zone the original depths are used. If either of the

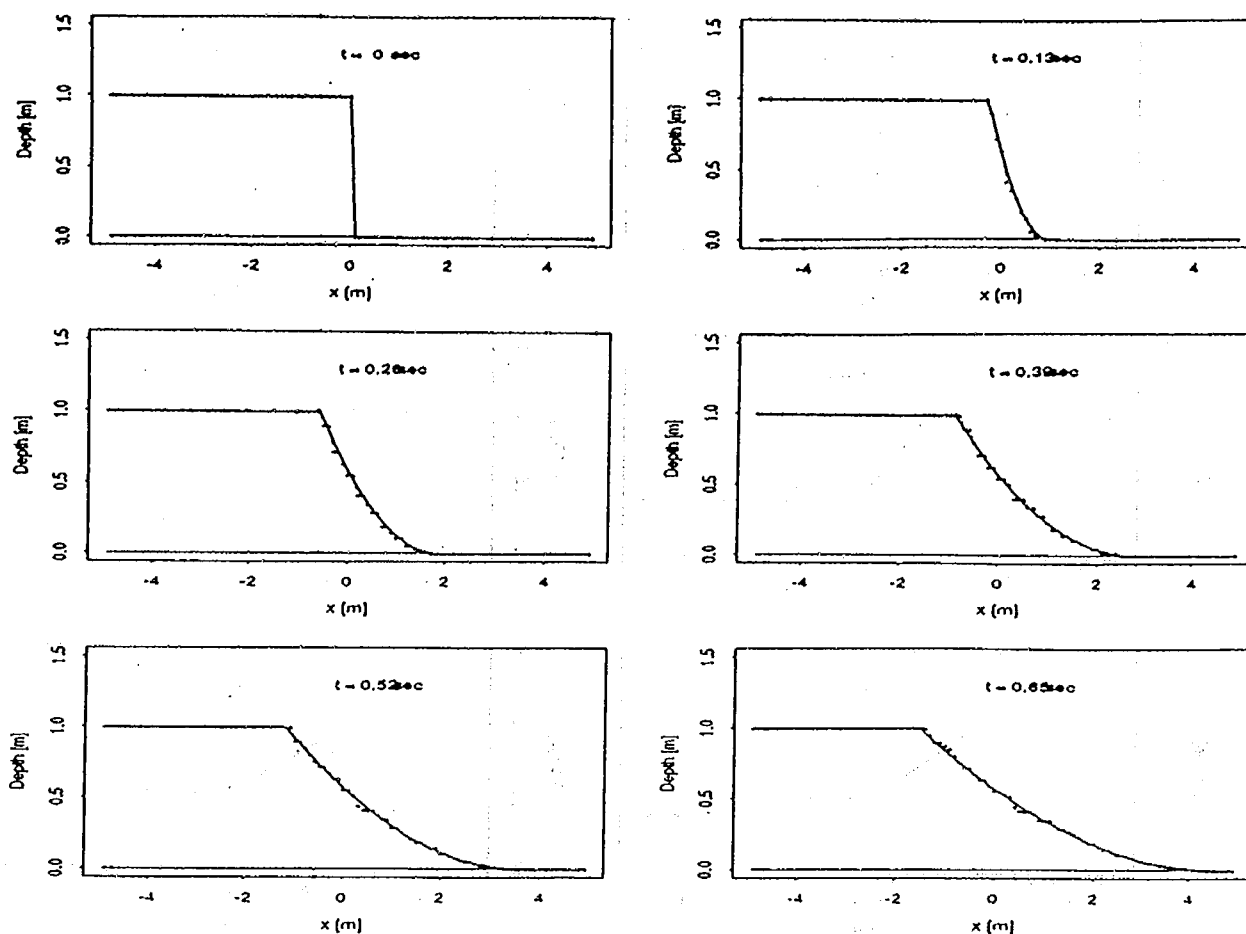


Figure 5: Solution for breaking of a dam with dry bed on right hand side. Theoretical solution $+$; Numerical solution $-$.

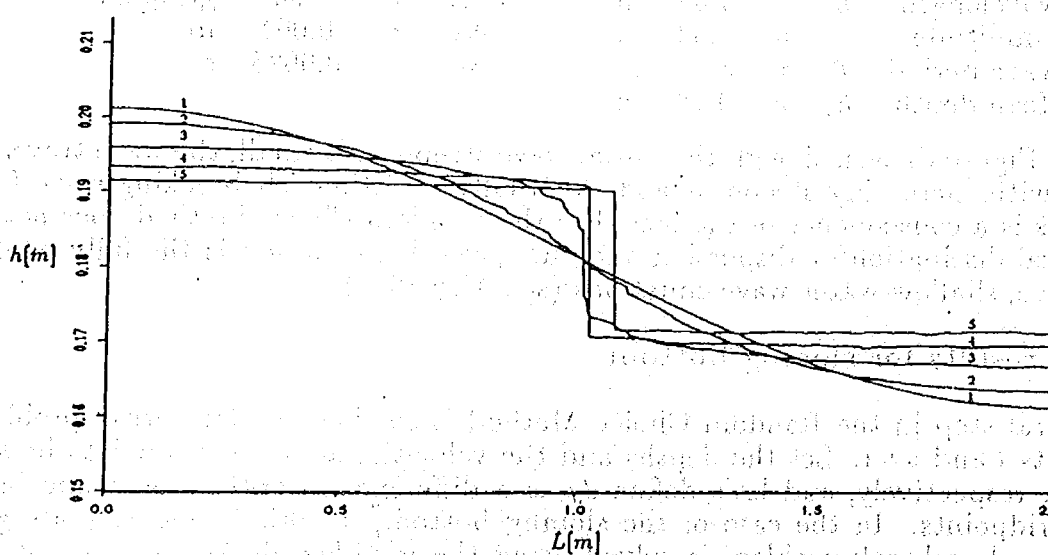


Figure 6: Sinusoidal wave. The number on each line indicate the oscillation cycle.

gridpoints has zero depth, the dry bed procedure is implemented. Let's assume that $h_{i+1} = 0$. If $h_i > dy$ then $h'_i = h_i - dy/2$ but if $h_i \leq dy$ then $h'_i = 0$ and the dam-break problem is not solved. The boundary conditions at the shoreline are that the depth is zero and the velocity of the shoreline equals that of the water. This is exactly fulfilled in the above formulation except that the shoreline movement is modeled based on the dam breakage problem on a dry horizontal bed.

Whitham [4] and Keller, Levine and Whitham [5] derived an approximate solution for the problem of a bore propagation on a plane beach. They found that at the shoreline, the fluid velocity u , and bore front velocity U , approach their common finite value U^* ,

$$U^* = 1.7632\sqrt{Ag}, \quad (16)$$

where A is constant to be determined from the initial strength of the bore.

Shen and Meyer [6] found that the run-up front velocity is totally governed by the gravity force in the following way

$$U = \frac{dx_s}{dt} = \sqrt{U^{*2} - 2g \tan \beta x_s}, \quad (17)$$

where $x_s(t)$ is the position of the run-up front and β is the beach slope from the horizontal. Hence, the maximum run-up height, R , is

$$R = \frac{U^{*2}}{2g}, \quad (18)$$

which represents a total conversion of kinetic energy at the shoreline to potential energy at the maximum run-up height.

Motion of a bore incident onto otherwise undisturbed water on a beach is investigated. The initial conditions for the calculations are shown in Figure 7. The beach slope is set to $\beta = 15^\circ$. The coordinate origin is set at the shoreline with the x -direction pointing inshore and the y -direction pointing vertically upward. An initial depth discontinuity is located at $x = -1.15$ m ($xg \tan \beta / U^{*2} = -0.39$) with water of depth $h_0 = 0.20$ m on the right side and a depth of $h_1 = 0.36$ m on the left side of the discontinuity. The initial velocities are zero everywhere. The grid size is $\Delta x = 0.005$ m, the time step size is $\Delta t = 0.001$ sec and the computational domain has a total of 1000 gridpoints.

The calculations start with instantaneous removal of the 'dam' which created the discontinuity. A bore forms and propagates towards the shore and a depression wave will propagate to the left, see Figure 7. (Note that the time $t = 0$ is set when the bore reaches the shoreline.) The bore speed is constant at $U_0 = 1.788$ m/s when the bore front is propagating in the horizontal-bottom region. The offshore Froude number is $F = U_0 / \sqrt{gh_0} = 1.27$, and the bore depth is $h_2 = 0.275$ m ($h_2/h_0 = 1.375$) and $U^* = 2.785$ m/s. When the bore propagates onto the sloping bottom region, the bore speed U decreases first and then increases until it reaches its maximum value U^* at the shoreline; this is consistent with theoretical prediction. The computed depth profiles for the bore until it reaches the beach are shown in Figure 8.

The run-up profiles of the water depths and velocities are shown in Figure 9. Initially the bore front accelerates when it begins the run-up, then gravity dominates the movement and it slows down. In the first part of the run-up, the numerical solutions oscillate slightly but then smooth out when the run-up continues. Once the water surface of the run-up motion smooths out, a successive run-up front (i.e. the secondary bore) forms with a thin layer of water in front of it. There is also a very clear jump in water velocity at the same location. The minimum value of the water velocities during the run-up occurs just ahead the successive bore front and that portion of the water body starts to recede prior to the time when the tip reaches the maximum location. Yeh, Ghazali and Marton [1] observed a similar successive bore formation in their experiments and concluded: "this double structure of the run-up motion must be related to the transition process at the shoreline." They also identified the appearance of run-up processes: "the run-up of the pushed-up water mass at the shore is followed by the original bore 'front' motion which was once decelerated during the transition

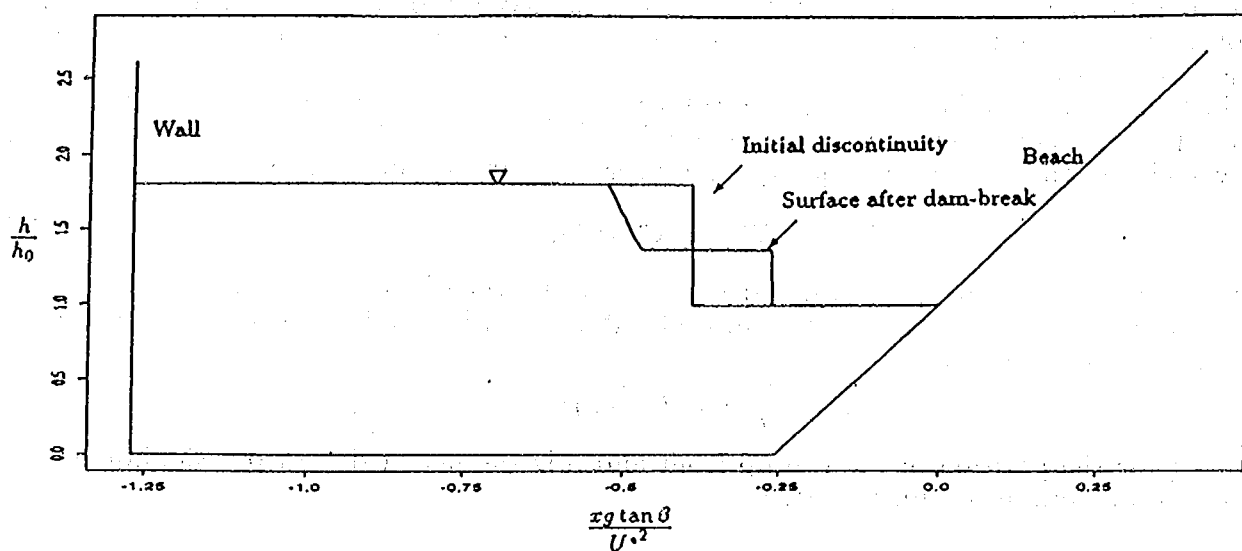


Figure 7: Initial conditions for the run-up problem and the shape of the bore before it reaches the sloping bottom region.

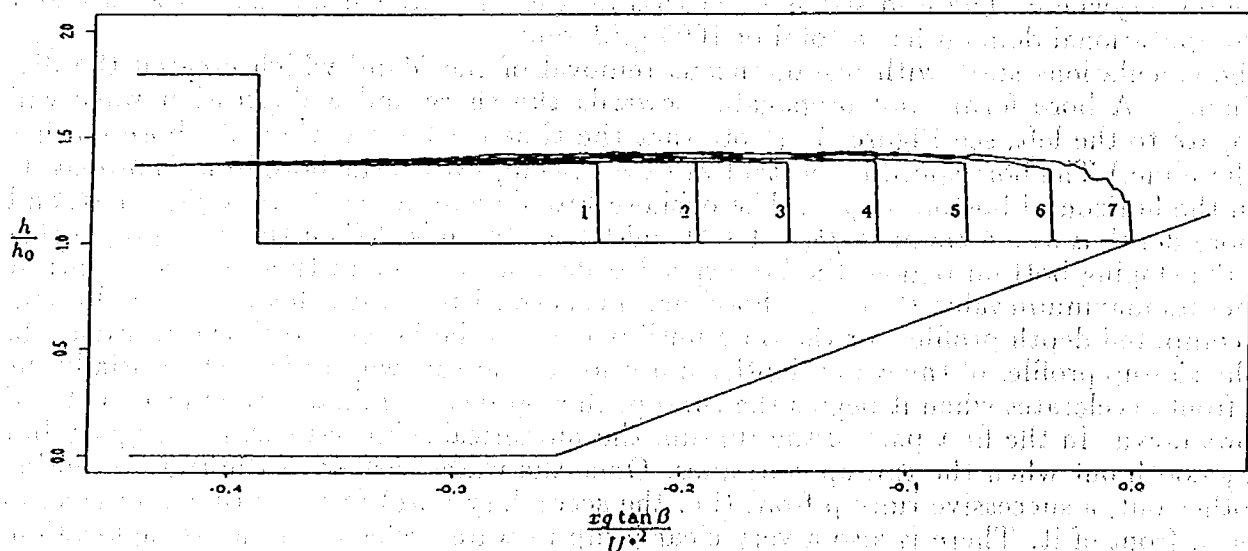


Figure 8: The development of the bore before it reaches the dry surface. 1) $t = -0.3750$ sec. 2) $t = -0.3125$ sec. 3) $t = -0.2500$ sec. 4) $t = -0.1875$ sec. 5) $t = -0.1250$ sec. 6) $t = -0.0625$ sec. 7) $t = 0.0$ sec

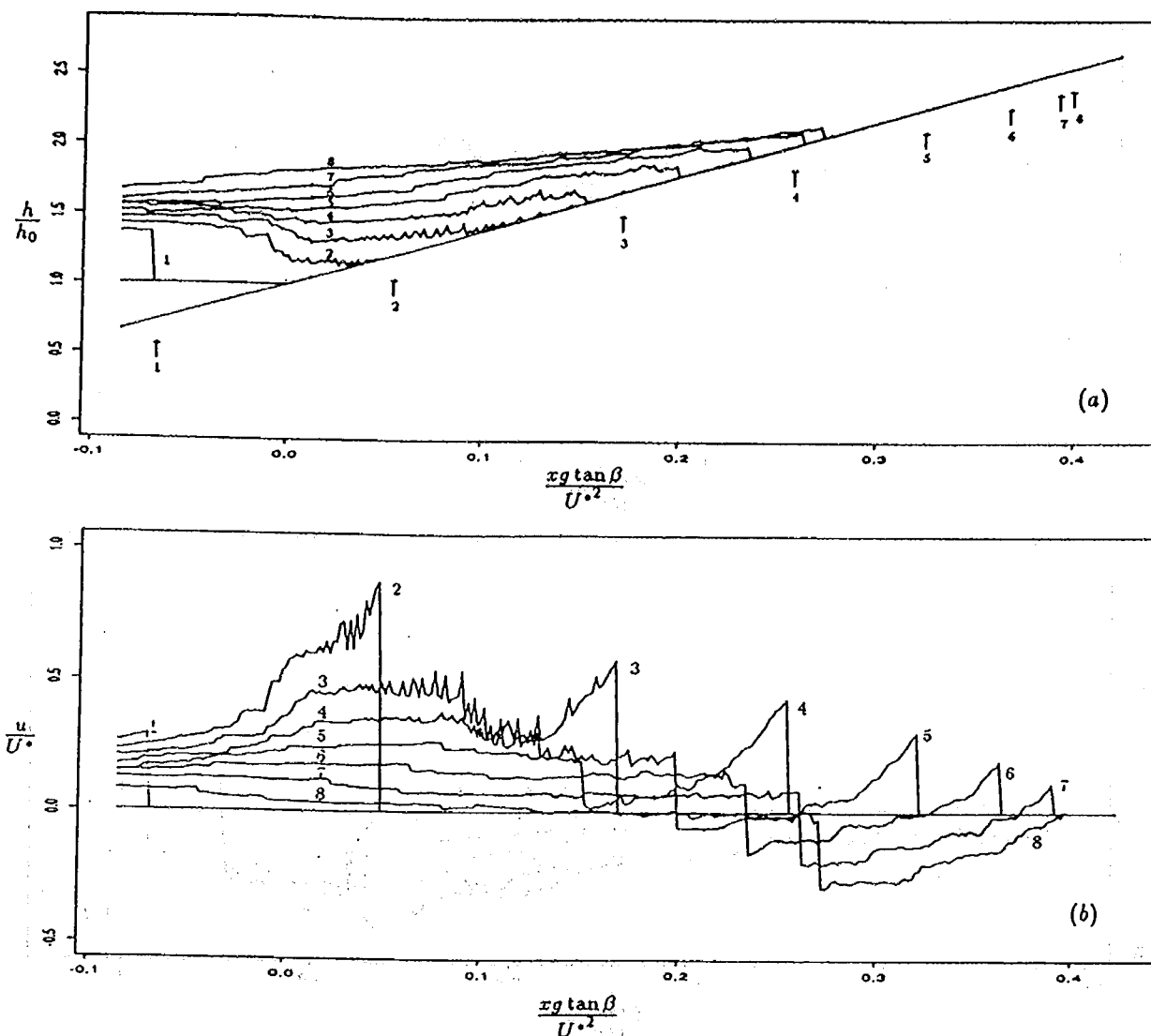


Figure 9: Computed solution for the run-up of a uniform bore. The arrows indicate the locations of the run-up tip. 1) $t = 0.347$ sec., 2) $t = 0.547$ sec., 3) $t = 0.747$ sec., 4) $t = 0.947$ sec., 5) $t = 1.147$ sec., 6) $t = 1.347$ sec., 7) $t = 1.547$ sec., 8) $t = 1.747$ sec. (a) Surface elevation. (b) Water velocity.

process." It is interesting that a model like the shallow-water wave equations solved by the Random Choice Method appears to be able to describe a complex flow structure like this successive bore formation, even though considerable simplifications have been made in the model. The model based on the Lax-Wendroff finite-difference method by Hibberd and Peregrine [7] could not simulate the successive bore formation and got much less receding effects before the tip reached its maximum.

The backwash water depths and velocities are shown in Figure 10. The run-up front starts to recede but the secondary front is still running up at $t = 1.947$ sec. Near the run-up tip, where the water is very thin, the back-wash velocity increases rapidly. (Note that in a real (viscous) fluid environment, it is anticipated that due to viscous effects, a thin layer of water can not be moved as fast as the prediction.) When the depth at the tip increases, the backwash velocity decreases again, by forming a landward facing back-wash bore. This bore was also identified in Hibberd and Peregrine [7] and predicted theoretically by Shen and Meyer [6].

Comparisons of the simulated bore and run-up front velocities with the theoretical pre-

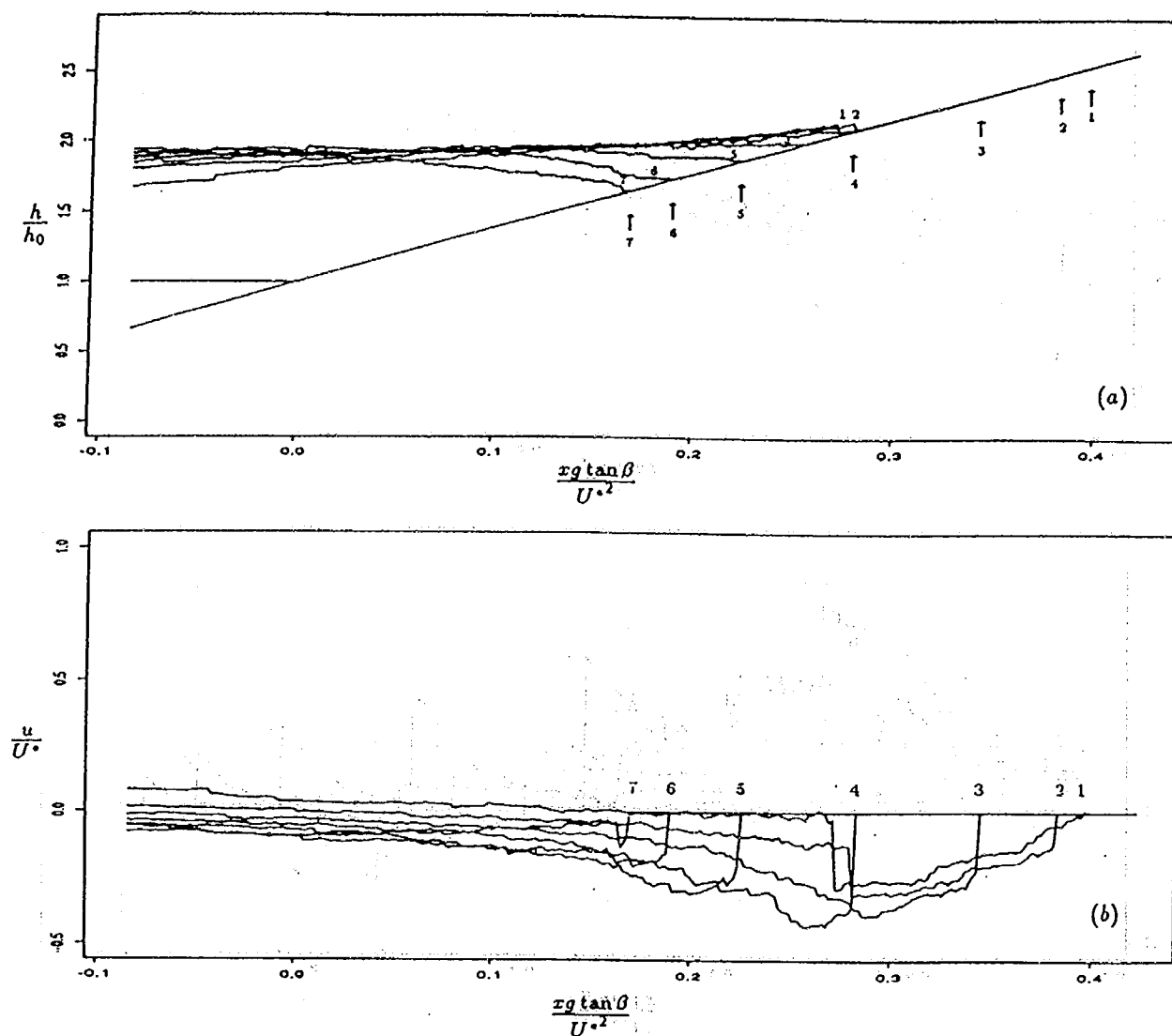


Figure 10: Computed solutions for the backwash of a uniform bore. The arrows indicate the locations of the run-up tip: 1) $t = 1.747$ sec., 2) $t = 1.947$ sec., 3) $t = 2.1947$ sec., 4) $t = 2.347$ sec., 5) $t = 2.547$ sec., 6) $t = 2.7947$ sec., 7) $t = 2.947$ sec. (a) Surface elevation. (b) Water velocity.

dictions based on equation (17) show that U_{sim} for the simulation is lower than U_{theory}^* or around $U_{sim} = 0.835 U_{theory}^*$. The run-up height is also lower than the theoretical predictions or around $R_{sim} = 0.8 R_{theory}$. On the other hand the value of U_{sim} is in good agreement with that what Yeh, Ghazali and Marton [1] found in experiments. Their measured run-up height $0.6 R_{theory}$ is somewhat lower than R_{sim} . A possible explanation is the absence of friction effects in the simulation. Therefore, it could be proved worthwhile to try to incorporate friction into the method.

Summary

The Random Choice Method was used to simulate a single uniform bore incident to a uniformly sloping beach. The bore propagates towards initially undisturbed shoreline and is transformed into a run-up that surges up the beach and is followed by the backwash. The broad features of the numerical results are similar to the previous results based on finite-difference methods, e.g. the Lax-Wendroff finite-difference method used by Hibberd and Peregrine [7]. While the general results are similar there are some significant differences. The tip computed by the Random Choice Method does not advance as fast or as high up as the predictions by Hibberd and Peregrine [7] (as well as the theoretical prediction by Shen and Meyer [6]) but the present results are in closer agreement with the values measured in experiments by Yeh, Ghazali and Marton [1] and Miller [8]. The formation of the successive bore run-up found in experiments by Yeh, Ghazali and Marton [1] was not predicted by Hibberd and Peregrine [7] but is simulated in the Random Choice Method. The reason for this could be the fact that the Random Choice Method is a shock preserving scheme (i.e. no numerical smoothing is involved). The numerical dissipation included in finite-difference methods could tend to smoothed out every discontinuity, hence the initially small discontinuity associated with the successive run-up could have been smoothed out from the results. Handling of the moving boundary conditions in the present model is also very different from that used in Hibberd and Peregrine [7]. Hibberd and Peregrine [7] found that the "numerical implementation of these conditions proved to be troublesome." They tried numerous schemes and used a scheme "which has proved most successful." In the Random Choice Method the boundary-condition formulation is much more straightforward.

Acknowledgment

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Prof. YEH

Dr. Kajiura: In your numerical result you show in the run-up many small wiggles. What are they? Is it noise?

Prof. Yeh: It is not noise. The Random Choice Method uses statistically converging solutions. So, if there is a shock, or discontinuity in the solution, the location of the shock is scattered around the exact location. My results presented here are not smoothed at all. Considering that, the results presented here are not bad.

Dr. Kajiura: That is errors? Probability or something like that? Probability of errors. Uncertainties.

Prof. Yeh: Probability of errors? For the Random Choice Method, the values at the next time step are determined by choosing the values randomly from the Riemann-problem solution. Nonetheless, we cannot simply use a random-value-generator program available in a canned computer program. Because, if we used a standard random-value generator to choose a value between minus one and plus one, the selected values can be a series of positive numbers or negative numbers, for example, positive, positive, positive, negative, negative, etc. The numbers of successively same sign would cause problems; for example, the computed wave front can go through an impermeable wall. To circumvent this type of problem, the generated random number must have pluses and minuses alternatively. For this reason, we must use a pseudo-random number generator.

I should add one comment on this method. This method is not efficient for prediction of runup simulations. The computation involves the Riemann-problem solvers at each grid point and takes a long time to compute.

Dr. Kajiura: In that case that means if you make many numerical computations and make an average, then it will be all right?

Prof. Yeh: Yes. However, if we use a pseudo-random number generator, the convergence is quick, and the ensemble averaging is not necessary.

Dr. Kajiura: Because you are treating it as a statistical problem, you need to conclude with a statistical sense.

Prof. Shuto: I would like to comment on this kind of numerical simulation. To begin a numerical simulation, we have to consider the stability, truncation error and the convergence of the simulation. Thanks to the principle of equivalence developed by Lax, if we can satisfy the stability condition, it is equivalent to the condition of convergence. After learning this, I always neglect to show the convergence of our scheme. And next important is the truncation error, because we have to continue simulation for a long time in the case of a tsunami. Therefore the accumulation of truncation error will become of non-negligible magnitude. The truncation error depends on which different scheme you use. So, in the Godunov scheme or Lax-Wendoff, all of these schemes have different truncation errors.

Prof. Yeh: As far as truncation errors are concerned, you have to think of it from a different viewpoint, because I am solving the Riemann problem for a flat bottom exactly as the analytical solutions. So all the truncation errors must come from the random choice scheme. That is the one point. Another point is numerical stability. I did work on the Courant-Fredric

number and the interesting thing is that previous literature shows all the Courant number is based on just the shock speed, like x/t has to be greater than the shock speed. Sometimes the expansion wave is faster than the shock speed, so I did include both, because the dam break problem considered how does not come from just still waters. Both sides can be moving. So sometimes the expansion wave is faster than the shocks. So I included both. Our results appeared to be stable.

Prof. Shuto: Another difficulty is the truncation error. In the case of a tsunami, truncation error has some relationship with the topography. So the topography changes from one problem to another problem, from one place to another place. So it is very difficult to control this.

Prof. Yeh: Right now I'm just using a flat bottom for that.

Dr. Gonzalez: This random variable here. I am unfamiliar with this approach, so is there a physical interpretation you can put on that random variable? Is it related to turbulence?

Prof. Yeh: No, it is not. There is no physical meaning. I have just shown you a view graph, at the very beginning. I am saying that compared with simple Godunov scheme, suppose we start like this, if we move this disturbance to one notch from the left each time, it would be overestimated all the time. In order to circumvent this problem, we use random variables. So this characteristic line, this is the actual data X divided by 2. I want to have it here, rather than here, in the statistical sense. That is why I am using random variables.

Dr. Gonzalez: But you did say that you really had three things going on here. You have what you are calling your exact solutions and they can be either analytic or numerical.

Prof. Yeh: Analytic solutions.

Dr. Gonzalez: Then you have your new random choice method. But then the third thing is the real world. And what you said was that neither one of these will actually show up exactly in the wave tank because of dispersive effects. Is that correct?

Prof. Yeh: That is correct. Because this is not a real wave tank.

Dr. Gonzalez: So maybe you have introduced something physical here.

Prof. Yeh: You have to include the dispersion effects in the model. I don't have one at this point. If you do that, you have to put it explicitly based on its physics, not by adjusting the numerical dispersions.

Dr. Gonzalez: Do we know what the dispersion relation is for this problem? We do not. So you cannot simulate it with the numerical dispersion, is that right?

Prof. Yeh: There is no numerical dispersion in the numerical scheme.

Prof. CARRIER

Dr. Gonzalez: I wonder if you would expand a little bit on what you called the three issues, sediment, seismology and fluid dynamics. You say maybe we need to consider more carefully, for example, how the sediments behave and interact with the water column.

Prof. Carrier: The original seismic motion makes a macroscopic disturbance essentially at the base of the sediments. And that base may be very close to the water or it may be somewhat distant from the water. And the response of those sediments, which is tightly coupled to the response of the water, as far as that is concerned, but nonetheless the relocation of those sediments may play an important role in modifying the source motion you would attribute to the seismic thing alone. And that redistribution of sediment position may be the clue to why the seismic event does not fit with the final water motion in the current calculations. I don't know that that is true and in a conversation with Kanamori, he also admits that seismologists do not really know what the structure within the faulting material is. They think they can do certain macroscopic things with some confidence, but there may be a smaller structure that is not captured within their means of doing the seismic calculations.

But in any event, I think there are 3 regions. There is the fault region where the damage originates, there is this intermediate stuff which seemingly differs greatly from the location where one event occurs to a location where another event occurs. And then finally there is the water motion about which we probably do understand more than the other things.

Dr. Gonzalez: So in particular, say at the sediment water interface, what your general comments might refer to when you talk about displacement of the sediments, those might be interfacial waves or instabilities and movement, underwater landslides, that kind of thing?

Prof. Carrier: Let me give you an example which I think Kanamori had in mind and which certainly occurred to me as he talked. Namely, suppose we have a rather broad seismic faulting motion. But suppose the sediments move in such a way that the region over which that motion occurs is narrower, but bigger, higher, simply because we conserve volume. If it's higher and narrower, the amplification factor is bigger; bigger by almost the square root of the product of those things, and that may be a significant modification that is real, but I don't know. It's only a suggestion.

I did want to make one other remark, because of something you said or will say. In the modeling process we really need some data on early waves, in some instances at least. And I think it is very important to get sensors into places where we may get such data, in moderately deep water I think that implies. But I think it is very important that we understand the role of the sensors and the need to have data on the early motion in order to verify or give confidence in our models.

Mr. Sigrist: Just a follow-up comment. When we talk about a study of the earthquake motion, does it imply that we would be conducting some basic geophysical work in the source area to help define the earthquake mechanism? For example, this might include high definition seismic reflection profiling or core sampling to really get a better picture of what the sediments are doing. Are those some of the detailed studies we should pursue?

Prof. Carrier: I am not expert, so I can only say I think they are, but I don't really know. I'm never quite sure when I hear talk in which they quote that Harvard CMC or CMR or whatever model it is. I don't know whether that is already an effort to do what you are talking about. I do know that Rice and Jowanski and those people do try to understand in more detail the faulting motions, but I don't really know whether it requires seismologists or whether it requires material scientists or just what the expertise is. But certainly we need to understand better what the faulting kinematics are and the dynamics that underlie them.

Dr. Kajiura: You said that you may be able to estimate the dispersive effect afterwards, by computing the long wave computations and then take into account the dispersion. Is that some kind of weighed average, or filtering?

Prof. Carrier: Let me give you an example and then I'll distort the example a little. In 1990 at the UJNR meeting I presented an aspect ratio study in which I did a non-dispersive calculation; the result of which showed that for large aspect ratio, large size source regions, the propagated wave is still very much like the original wave. With a real topography of course, there would be some large radius of curvature modifications, but generally speaking, the wave that goes 3,000 km toward Hawaii for example, should remain in its major aspects, and is shown to remain in its major aspects, in that calculation, very closely related to the source motion itself. And if you re-do that calculation with dispersion, that is one thing, or if, two, you do it without dispersion but then just take the plain wave dispersion and modify it by that, you have a degeneration of the front wave and you have following waves of certain sizes. And those are all worked out. They are in my 1965 paper without numbers, just with formulas. But those things could all be tabulated very easily and the results are the same.

And out at the edges where the wave is weak and curved, you can take the cylindrical wave for which all of these things are easily delineated and use that correction for dispersion on the non-dispersive calculation. I am very confident that that could be made practical, and should be helpful in making prompt calculations for use by the warning system.

Dr. Gonzalez: I have one comment. It has to do with what Prof. Carrier said about, generally speaking, the field of seismology and hydrodynamics, how there has to be more discussion. I wonder are there any seismologists on this UJNR committee? Are there any seismologists here? Maybe that is one thing that the UJNR committee can consider is to include some people that are not experts in hydrodynamics but that are experts in the other fields. And then my second comment also has to do with something Prof. Carrier said. There are these very standard solutions, like the Harvard CMT solution and these epicenter determinations, and they are done very quickly. They are operationally-oriented solutions. They are done very fast and those perhaps -- I don't know, but it is something I would like to ask a seismologist -- I think perhaps one of the problems we have is that these are standard solutions. They are oriented towards quick, operational applications, to make quick estimates, but those are different from perhaps techniques right now being developed by seismologists which could give additional information on the tsunami problem but that are experimental, that are their research models, and so maybe that is our problem, that we are now using the operational products, when we should be talking to researchers who are looking at those problems with other methods that we

never see perhaps.

Mr. Lander: A comment on the question of the possibility of having seismologists on our Task Committee. The UJNR is an group of activities in many disciplines. There is one panel on earthquake prediction which is where most of the seismologists are located. Our Panel on wind and Seismic Effects has some seismologists but tends to concentrate on the engineering aspects. It probably would be useful to have seismologists knowledgeable about focal mechanisms involved in our meetings and workshops.

Dr. Gonzalez: I have one more comment, separate from this. Most people who do numerical models apply them to real tsunamis of the past and try to understand the phenomenon in hindsight, which is a very good thing to do. But also one should use models to attempt to learn general things that give good insight, both in the operational circumstances where one is trying to make warning judgments, and also for purposes of really understanding the phenomenon. One should try to deal with problems which bring forth the dependence of important aspects of the tsunami on the parameters that characterize the source motion, rather than the overall, fully detailed, very complicated interplay of lots of local topography and so on. One needs general results that have to do with the macroscopic parameters and which give one an initial view of whether amplification in a given locality will be big when the parameters have these values. Not many people do that, it seems. I don't know what the right balance is, but we should not let that part of the research effort escape.

Dr. Gonzalez: A quick related comment. There is a third type of computation also that is very important and that would be an attempt to, I don't want to use the word forecast, but to run some kind of site specific worst case scenario to provide something like at least rough estimates of inundation for a particular community which could then be used as guidance by community planners and officials who are responsible for civil defence. And in that particular type of computation, we again run into very serious problems when we are trying to define a reasonable worst case scenario, and the reason for that goes back to the same question of initial conditions. A very good example are some attempts to create inundation maps, and Chuck MADER is involved in this, for communities along the northern California coast. What you have in mind for a worst case scenario is some very large earthquake along the Cascadia subduction zone. So you get a lot of seismologists together, as Eddie Bernard has done, at a workshop, and you say, alright now we need some fault plane parameters that we can use for our models for a worst case scenario. And they huddle and they give you 3 sets of fault plane parameters and you use those fault plane parameters, and you get very small waves on the coast for magnitude 8 earthquakes like the one in Alaska in 1964.

And so, what this goes back to, are the kind of effects that Hiro Kanamori was talking about, the whole notion that even though you have these fault plane solutions, there are very smooth solutions and they represent averages over very large areas. And what you really want for these specific worst case scenarios is some kind of estimate of the roughness, some horizontal or vertical linked scale that might be appropriate as a worst case scenario; that in a magnitude 8 earthquake somewhere in that region you may expect to have one or two or three localized regions, 10 km or 20km scale regions, with substantially higher vertical deformation by a factor of 5 or 10 or whatever. So some guidance like that is what is required for

this third kind of calculation.

Prof. Shuto: May I have a comment on this problem. When we made a disaster protection plan for some prefectures in the Sanriku district, we made some assumptions of a hypothetical earthquake fault and we calculated, starting with the hypothetical fault model given by seismologists. We simulated this tsunami. But we were reluctant to make the results open to the public, because from the starting point, many things are unknown and not sure. So we used the results only to let persons responsible for the defence work know the characteristics of that area for some earthquake which might happen in the future. We did not use these results directly to make the protection plan.

I think that every difficulty lies in the validity of the initial conditions, regardless it is hypothetical or actual. Your proposal that we should have some seismologists in this room is a very nice suggestion at this moment of tsunami study, because everything starts with the ambiguity of the initial conditions. Once the initial condition is given, maybe the hydrodynamical effect can be examined with many different kinds of means. We have an hydraulic experimental way or a numerical way, many ways, but the first point, the ambiguity of the starting point, no-one can check it. So this is the origin of all the difficulties that we have now.

Mr. Sigrist: I would just like to make a quick comment about what you said, Prof. Shuto, and what you mentioned, Frank. The issue of developing these worst case scenario inundation maps and the associated cultural reaction of people living in those areas may imply we identify (developed) areas in the inundation zone that might be uninsurable. What might the reaction be within the community as well as the larger socio-economic impact to that area?

Prof. Shuto: When we use the worst tsunami in the past, the coastal resident will accept the result very easily, even if the inundation area might be changed due to the construction of a harbor or the construction of sea walls. If we say that due to the construction of this breakwater, the tsunami will be concentrated in this point, then you may have a higher tsunami wave than you had, this fact is acceptable because the simulation used the actual tsunami they had before. Therefore they can accept this kind of scenario very easily. But once we start a very, very hypothetical one, no-one can accept it.

Prof. Carrier: That's very true, but that is something that we live with all the time. In the United States, for example, we have had a program going for a number of years now in which we have developed inundation maps for all major coastal areas that would be impacted by a tropical cyclone. We do, for Charleston harbor for example, maybe 200 or 250 simulations on various strength tropical cyclones and various paths. And the people who use those understand that there is a degree of uncertainty involved.

Mr. Hagemeyer: The approach that Frank was talking about is the approach that Eddie and I are looking at, to try and develop a center who would do a similar kind of simulation for a number of different kinds of hypothetical earthquakes, then to develop potential or worst case flooding for tsunami as opposed to tropical cyclones. I guess that because I am a weatherman I am used to dealing with a high degree of uncertainty, but that kind of uncertainty does not bother me, because I look upon it as being a source of

information that is usable that otherwise would not be available.

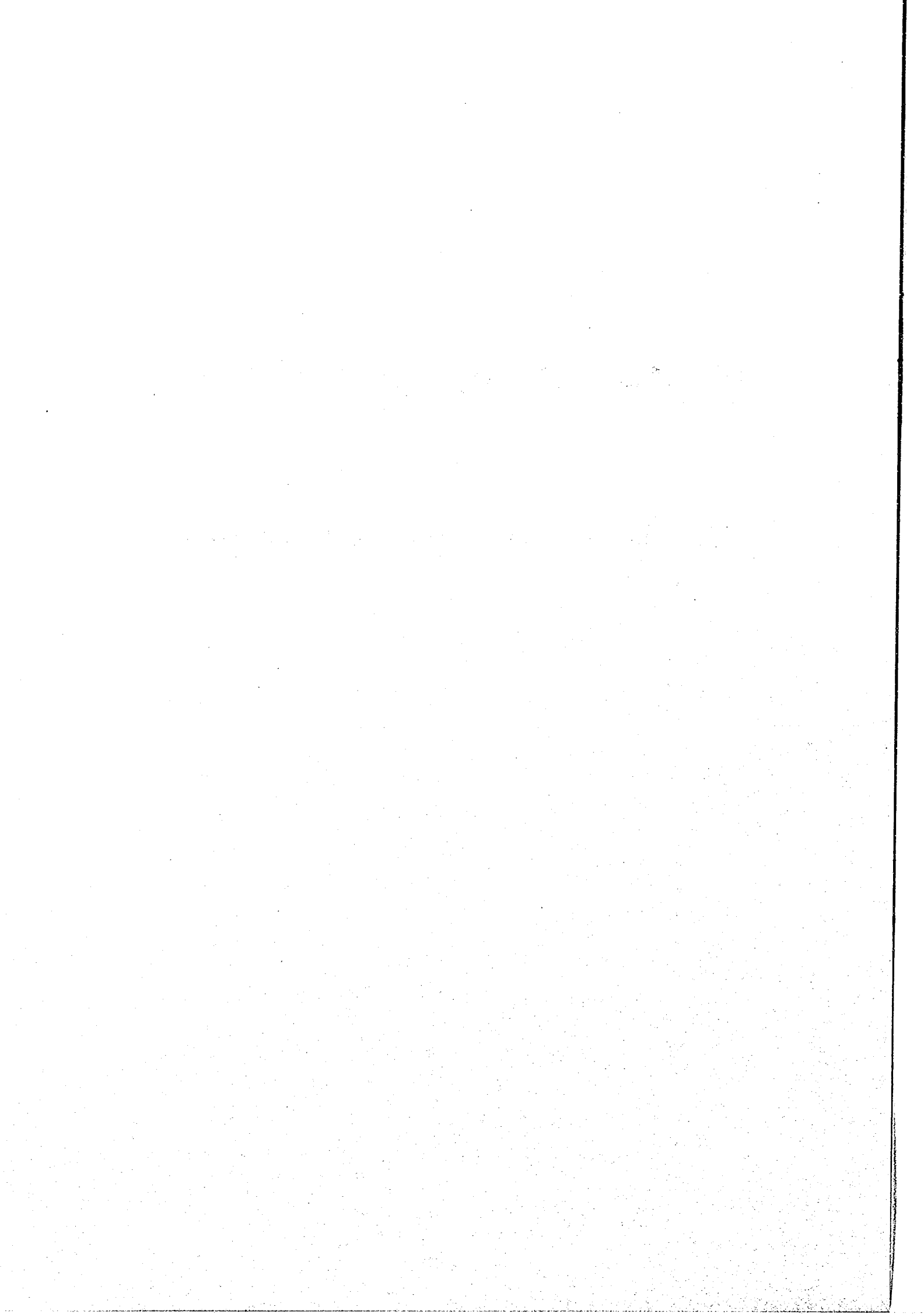
Prof. Shuto: I remember one thing. Prof. Imamura was asked by one of the TV companies on the Japan Sea side to create a CG animation of a hypothetical tsunami and the result will be televised maybe during the first week of this September. I don't know what the reaction will be from the people there. It may be interesting.

Dr. Tsuji: The computer graphics was shown just 2 days ago. Local NHK television at Fukui broadcasting station made the program at the local coast and I and Prof. Otake, the seismologist at Tohoku University, made some explanation about it. It has already been broadcast.

Dr. Gonzalez: I would like to make a quick comment again on this problem of how to approach inundation maps or this kind of guidance. Sometimes I think that we should stop using earthquakes as initial conditions, that there may be some situations where it may be more appropriate not to worry about getting an earthquake correctly, but to do an analysis of the response of a particular area to waves which approach from different directions, with different wave lengths, and then to examine those results to try to provide a more general product to the community which is based only on the incident angle of the wave offshore and the period perhaps, and the wave height. Then from a collection, an ensemble of such numerical experiments, then perhaps you can give some guidance to the community about certain places that are in danger and other places that are safe.

B: Tsunami Gauge Technology

J. Lander and S. Tanaka, moderators



Some Topics on Tsunami Observation in Japan

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Abstract

Tide gauges are the most popular instrument for tsunami observation. Due to dull response of the stilling wells maximum wave height of the 1993 Japan Sea Tsunami recorded at many tide stations were much smaller than the run-up heights on the coast, and the gauge at Esashi that has a sensitive response stopped functioning after the sea level rose behind the observational range. Numerical data of the tsunami were gathered by the telemetering system from some of the tide stations. Coastal Wave Recorders have no such problem as the tide gauges have, but have capability to measure tsunami as the measurement of wind waves. Accordingly we expect to use them as a new system of tsunami observation in the near future. The data acquired in shallow water must be valuable for tsunami study, if the systems are improved to obtain continuous record of sea surface elevation. The ocean bottom pressure gauge deployed off southern Honshu recorded for the second time the tsunami in deep sea from the earthquake near Guam Island on August 8, 1993.

Introduction

The Japan Sea Tsunami on July 12, 1993 has revealed some weakness in the current system of tsunami observation in Japan. The Japan Meteorological Agency (JMA) issued the first tsunami warning in only five minutes after the earthquake, then a certain informations such as the predicted tsunami arrival times and tsunami heights which had been observed by tide gauges were broadcasted through TVs and radios on that day. But the tsunami heights recorded by tide gauge were only several tens of centimeter at most and they were much smaller than the run-up heights along the coast of southwest Hokkaido and Okushiri Island (Hokkaido Tsunami Survey Group, 1993). It will provide residents with misleading information to have a lower estimate for coming tsunami, and not to convince them a necessity of evacuation for imminent danger.

Coastal wave recorders have high ability in measuring surface waves and recorded sea level changes of the tsunami as demonstrated at many sites. But they are operated to observe wind waves, and their data are intermittently recorded, one observation period being 20 minutes every two or three hours. Thus we cannot monitor tsunami continuously by the current system. On the other hand four ocean bottom pressure gauges have been operating on real time basis in the Pacific, which detected the tsunami caused by the earthquake near Guam Island on August 8, 1993.

In this papers I will talk about some recent topics on the current tsunami observation systems, tide gauges, coastal wave recorders and ocean bottom pressure gauges, in Japan, and compare the merits and demerits of these systems.

Tide Gauge

Tide gauge is the most popular instrument to observe tsunami, and about five hundred stations are established along the coast of Japan, in which the sea level is recorded continuously by tide gauges. About 60 of them are operated or monitored by JMA for the purpose of coastal disaster reduction. Figure 1 shows a typical structure of tide station. Response of water level in the stilling well to the changes of sea level outside the well depends on the effective size of the intake pipe (Satake, etc., 1988). If the response is too slow, a wave form of the large tsunami is seriously deformed in the well, and the wave amplitude becomes much smaller than it actually is.

Figure 2 shows tsunami heights (wave heights in excess of usual tide) recorded by tide gauges that were broadcasted through TVs and radios on that day. They are significantly smaller than the run-up heights experienced along the coasts. One reason for it is a dull response of the tide well and the other is the network of tide stations operated by JMA that is too sparse to study. Firemen at Fukaura, Aomori Prefecture, watched sea level changes on that day and confirmed that water rose to the height of about one meter, however the maximum height on the tide gauge record of Fukaura was only 25 centimeter. Larger wave heights were recorded by tide gauges at some other stations. Examples are Esashi and Iwanai in Hokkaido that are near the tsunami source area. They were not monitored on real time basis, hence they could not contribute to tsunami warning. Figure 3 shows the tide gauge record at Esashi; the station has a sensitive response and the maximum elevation is higher than 1.74 meter above the astronomical tide. It is pity that the tide gauge stopped functioning when the drawing pen was caught by the recording chart since water in the well had risen out of measuring range.

Telemetry systems for the tide gauge are expanding in Japan year by year, and many of them are capable to providing numerical data of sea level as well as conventional analog records (Segawa, 1991). Numerical data are more suited for processing than analog records. In digitizing the conventional tide gauge records, an accuracy of time is considerably further, as chart speed is very slow, 2cm/h, for recording. Therefore it is difficult to remove effect of intake pipe from the conventional analog records (Okada, 1990). If we use numerical data obtained by a telemetry system, it is easy to correct the wave form that has been deformed by non-linear response as mentioned above. Figure 4 shows an example of wave form correction for numerical tsunami data at Fukaura Tide Station (Nishizawa, personal communication). This is the first time to correct tsunami wave form obtained numerically by the telemeter. The heights of tsunami waves become much larger and their maximum height is close to the one witnessed by firemen.

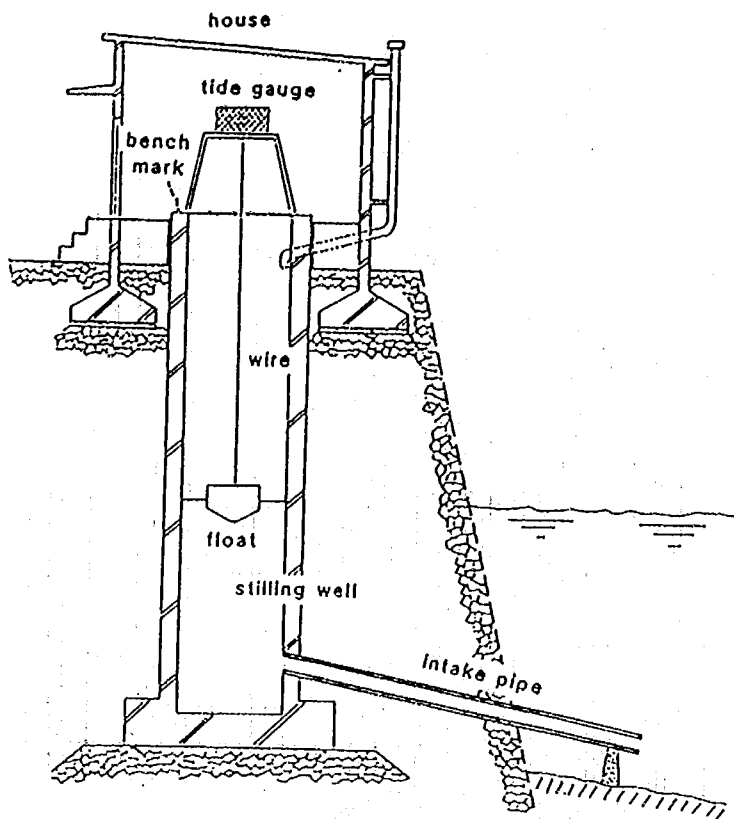


Figure 1. Schematic structure of tide station.

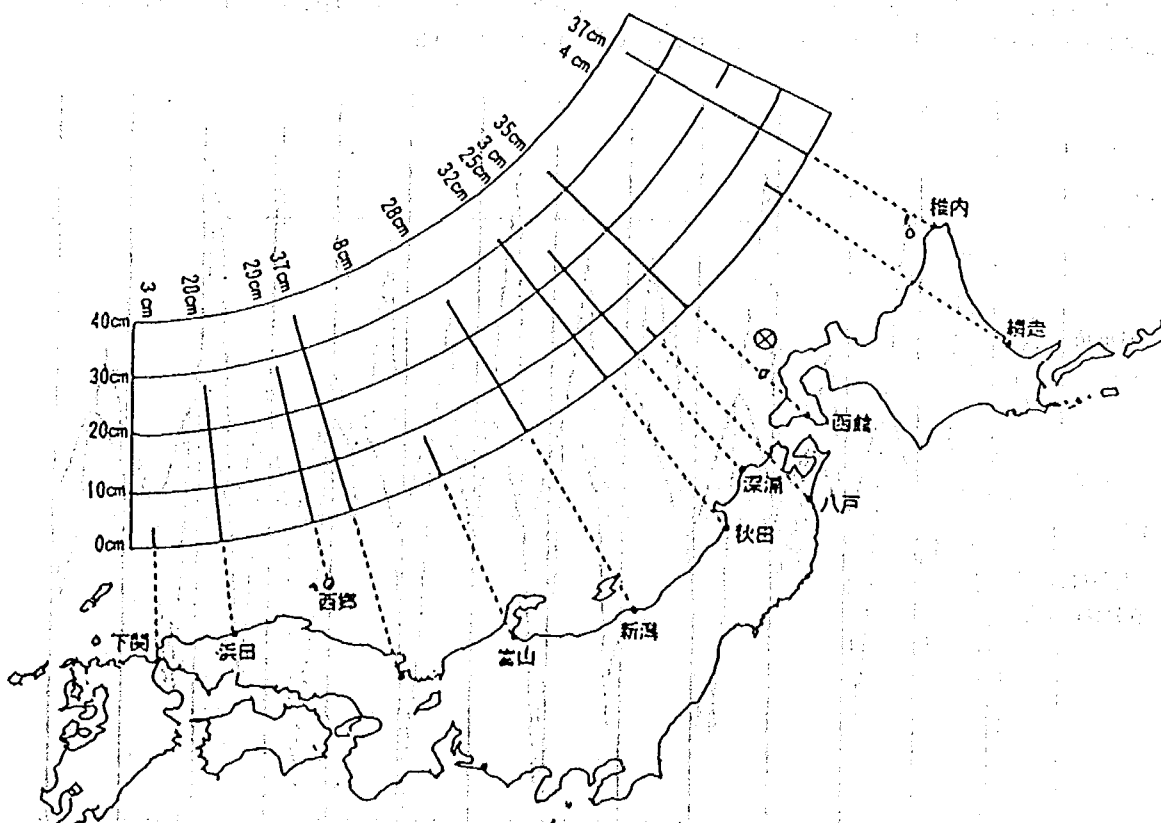


Figure 2. Maximum heights of the Japan Sea Tsunami on July 12, 1993, recorded by tide gauge and broadcasted as tsunami information through TV and radio during tsunami warnings.

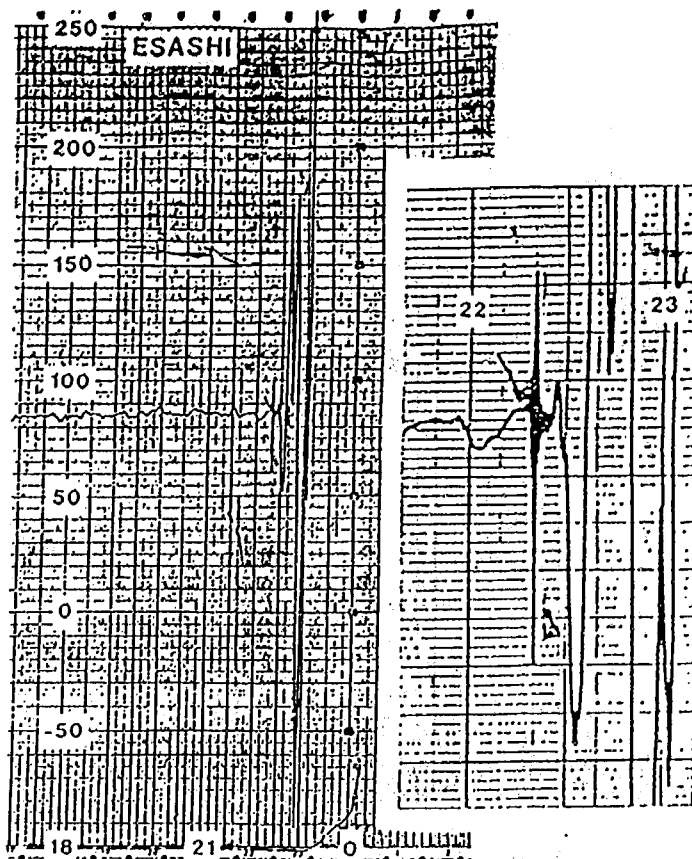


Figure 3. Tide gauge record (left) at Esashi, Hokkaido and its enlargement (right). The gauge stopped recording after water level rose out of the range.

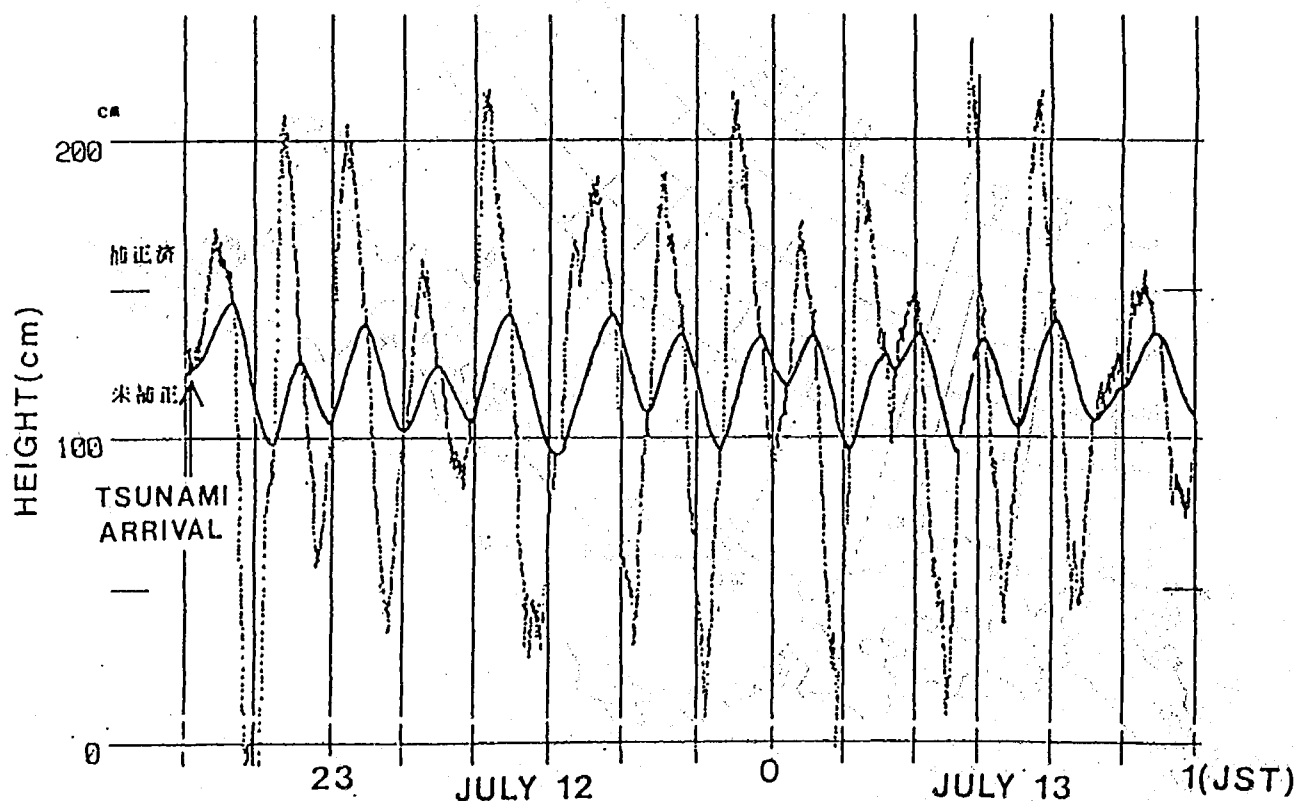


Figure 4. Represent of tsunami data at Fukaura, Aomori Pref., obtained by telemetry system for tide gauge (heavy line), and the corrected wave form for the stilling well response (dotted line).

Coastal Wave Recorder

The Bureau of Ports and Harbours (BPH), and the JMA have been deploying coastal wave recorders (CWR) along the coast of Japan. The Port and Harbour Research Institute (PHRI) collects wave data every 2 hours from major 42 stations operated by BPH (Nagai, etc., 1993). Some stations measure water currents as well as surface elevations by current meter. The JMA also makes observation of wind wave at 11 stations every 3 hours (Hatori, 1990). The period of data collection is 20 minutes, not 2 or 3 hours, so the data of CWR is not continuous but intermittent. Figure 5 shows the location of CWRs, which might be a good network for tsunami observation, if they can furnish continuous records.

The system of CWR is shown in figure 6. In many CWR stations the ultra-sonic sensor is laid on sea bottom at a depth of 20 to 50 meters for measuring the sea surface elevation with a high frequency of 2 Hz. Then it has no difficulty of instrumental range and response to handle large tsunami such as the Japan

Coastal Wave Recorder

● PHRI ○ JMA

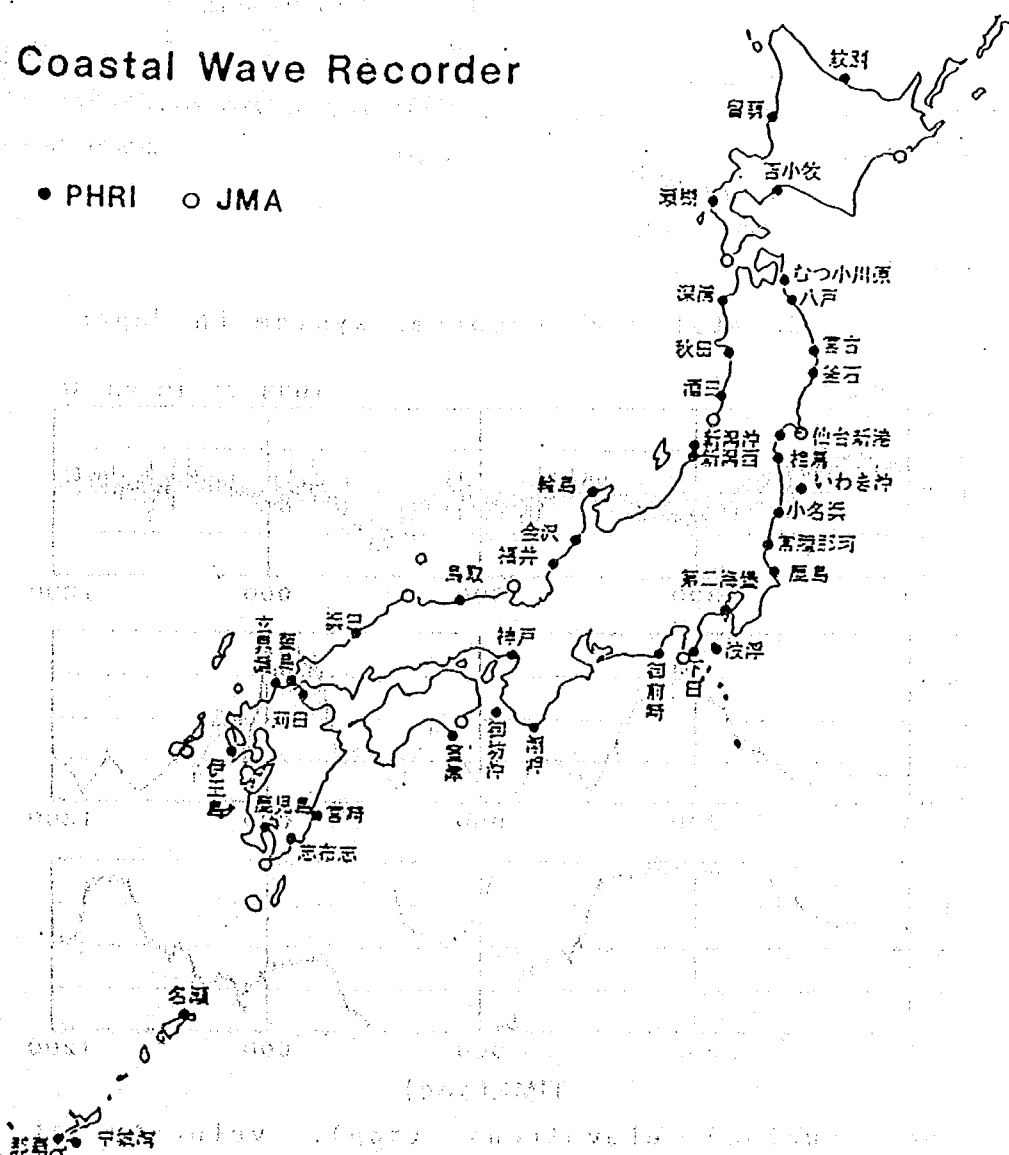


Figure 5. Location of coastal wave recorders operated by BPH (closed circles) and JMA (open circles).

Sea Tsunami of 1993. Moreover the data of CWR are more suitable than the ones of tide gauges for the purpose of comparing with the results of numerical simulation of tsunami propagation. Because CWR is located in the sea, the effects of coastal phenomena, such as run-up and bottom friction, are less influential than in the record of tide station on the shore line.

The CWR's records of tsunami were first obtained for the 1983 Japan Sea Tsunami at Fukaura, Matsumae, and other stations. The 1993 Japan Sea Tsunami was also observed by CWR at many sites along the coast of Japan. A typical data recorded at the station off Wajima, that of water surface elevation and current, are shown in figure 7. All data obtained by current CWRs in Japan are fragmentary due to the operational conditions as mentioned above. We hope that CWRs are be modified to collect continuous tsunami records longer than 20 minutes.

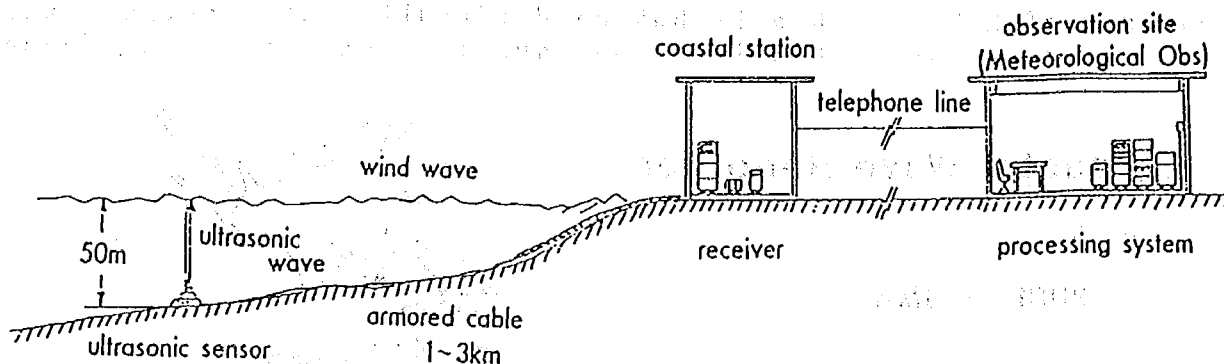


Figure 6. Coastal wave recorder system in Japan.

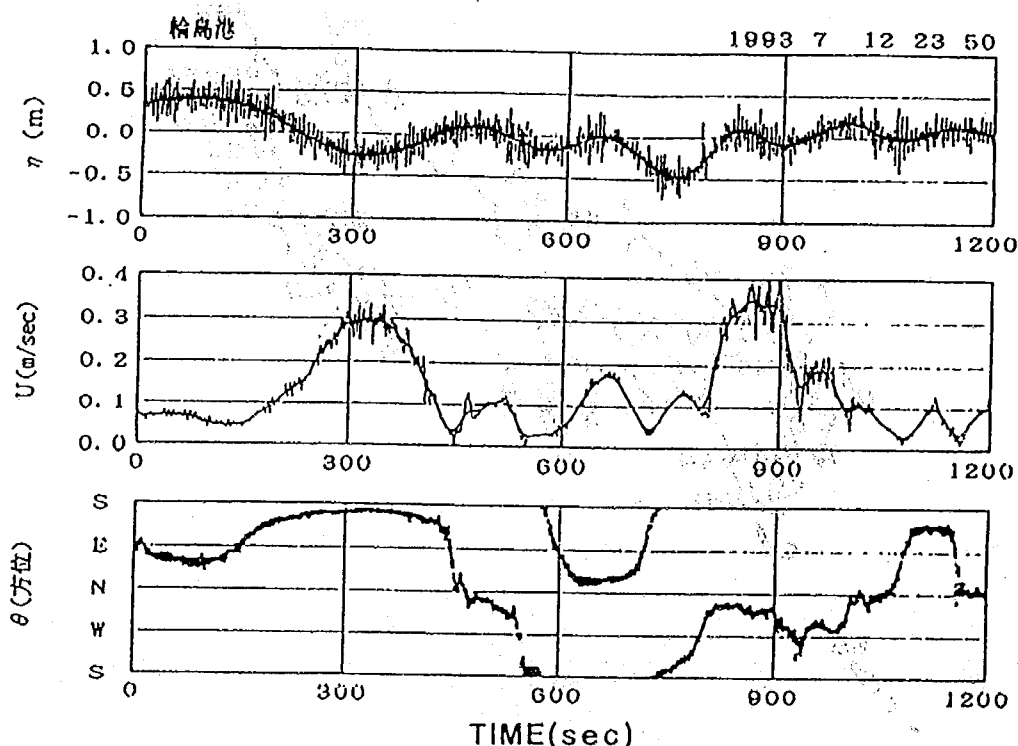


Figure 7. Sea surface elevations (top), velocity of water current (middle), and direction of current (bottom) associating the 1993 Japan Sea Tsunami obtained by CWR at Wajima. This data was collected and offered by PHRI, (Public Hydrographic Institute) of Japan.

Ocean Bottom Pressure Gauge

The JMA has been operating four ocean bottom pressure gauges (OBPG) to detect tsunamis in the deep sea as soon as possible. The transducers sensing bottom pressure are at the depths from about 1,900 through 4,000 meters off south Honshu in the Pacific Basin (Okada, 1991). Two tsunamis caused by earthquakes near Mariana Islands on April 5, 1990 and near Guam Island on August 8, 1993 were recorded by OBPGs. Though the tsunami waves in deep sea are much smaller in amplitude than in the coast, we can detect tsunami features clearly by removing noises and other effects with a band pass filter. Figure 8 shows the records by these pressure gauges and some tide gauges for the tsunami from the earthquake near Guam Island on August 8, 1993.

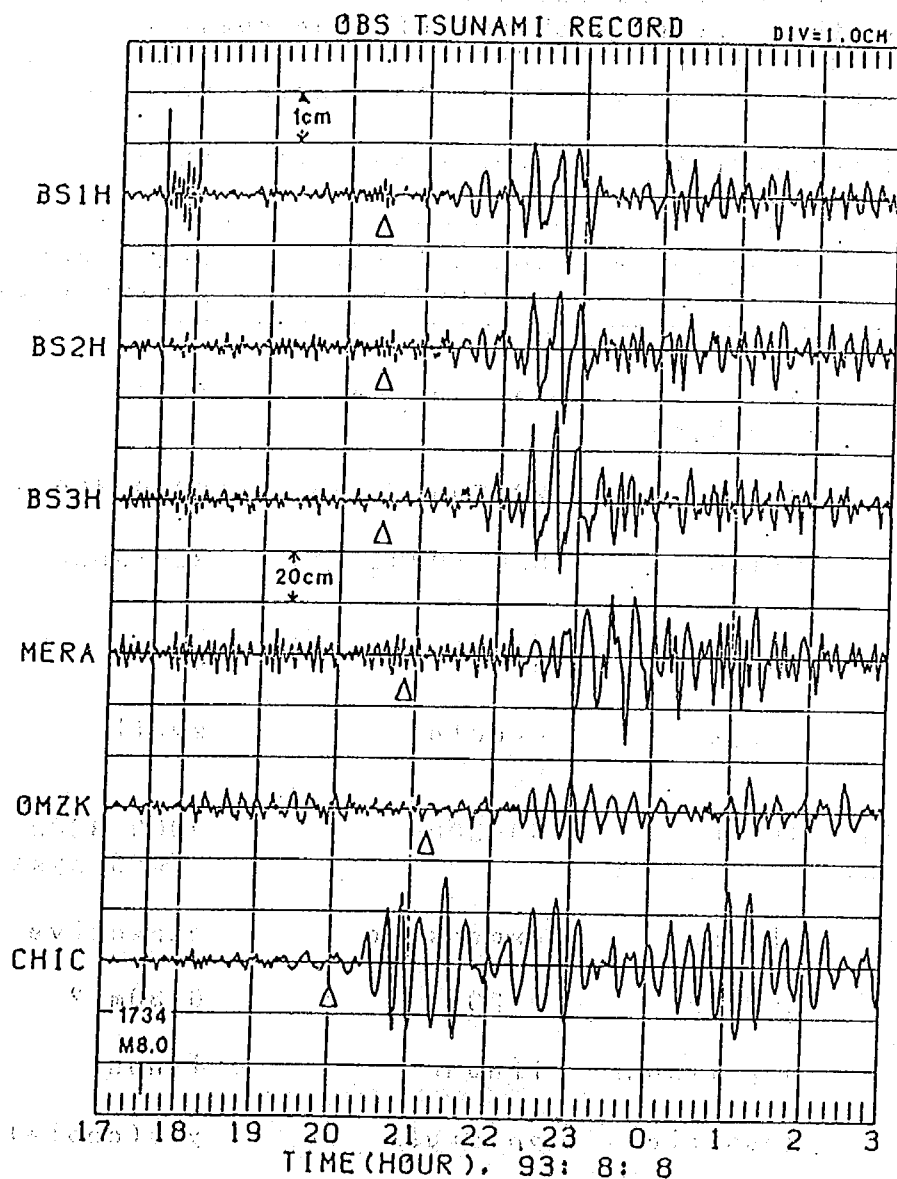


Figure 8. Tsunami records of the earthquake near Guam Island August 8, 1993, obtained by ocean bottom pressure gauges off Boso Peninsula at depths of 1912, 2098 and 4011m (upper three records) and tide gauges (lower ones). All data were processed by a band pass filter.

Discussion

Tsunami may be observed by either tide gauge, CWR or OBPG. Characteristics of these systems are listed in table 1 for comparison. Tide gauges are most common. They are installed in so many places and construction and operation are so cheap that they are used as a basic instrument for tsunami observation on the coast. Numerical data acquired by tide gauges will be more feasible as the telemetry for them is now widely used. However there seems to be no intention to remedy the draw back associated with its response of stilling well and narrow observational range. Accordingly we wish to have other kind of data measured in the sea for tsunami study.

The JMA is operating two Permanent Ocean-bottom Seismograph Observation Systems which have cables longer than 100 km to connect four seismographs and OBPGs. We hope such system to be deployed in other areas, such as off the coast of northeastern of Honshu. But it might be difficult to implement the plan in the near future, as the system is too expensive, costing 2 to 3

Table 1. Characteristics of instrument for tsunami observation in Japan

	tide gauge	coastal wave recorder	ocean bottom pressure gauge
location	port seashore	coastal sea	ocean
water depth	0-2m	20-50m	2000-4000m
distance from shore	0-10m	500-5000m	30-150km
quantity	ca. 500	53	4
tsunami amplitude	large	middle	small
construction (million yen)	10-40	50-300	2000-3000 /OBS system
maintenance	cheap	expensive	expensive
obs. range	0-3.5m	0-20m	0-30m ?
response	non-linear	linear	linear
telemetry	possible	possible	yes(cable)
numerical data	possible	possible	yes
other usage	tide	wind wave	earthquake

billion yens.

On the other hand CWR has a capability of measuring sea surface changes and its network is fairly good for tsunami observation. But the system currently in use is not capable of collecting data on sea surface variation continuously longer than 20 minutes. This is a serious defect for using the CWR system for tsunami observation, so we have to improve the CWR system. Fortunately the modification of the system may not be so expensive, costing several million yens for each station, so we can expect the system will be changed in the near future to obtain continuous tsunami data over a sufficient period.

Conclusion

Tide gauges are popular instruments to observe tsunami, and with the aid of its telemetering systems they provided numerical data on the Japan Sea Tsunami of 1993. However the tide gauge has some difficulties in the response of stilling well and the observational range. Coastal Wave Recorder is free from these difficulties, but the system currently in use has serious defect with regard to the continuous operation. We wish the coastal wave recorder were modified for tsunami observation in the near future. Ocean Bottom Pressure Gauge recorded for the second time the tsunami accompanying the earthquake that occurred in 1993 near Guam Island.

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MR. OKADA

Prof. Yeh: You say that you are revising the recording system for the coastal wave recorders. How do you do that? You have some dedicated storage disc system for the tsunami event? Right now you are recording 20 minutes to 2 - 3 hours. How do you do that?

Mr. Okada: In the coastal wave recorder all the signals are sent from the sensor on the sea bottom to the coastal station continuously. Now we send them for only 20 minutes per 2 or 3 hours. We have a plan to revise. One method is to continuously sending data from the coastal station to the observation site. Another plan is that all the data from the sensor is stored temporarily at the coastal station and sent to the observation site on request.

Prof. Yeh: One thing you can think of is to have continuous storage for a half day, or one day or so, on an erasable disc. If a tsunami event happens, you can retrieve those data. Otherwise you can erase and reuse the disc space all over again. You can make such a kind of provision for the tsunami event.

Prof. Shuto: May I make a comment on this. It is a pity we don't have Dr. Takayama here, because I heard from him that they are planning the use of a laser disc for the storage of this kind of what you are talking about.

Prof. Yeh: You have to have erasable one, maybe we can select. If an event happens, we can retrieve the data. We cannot take 10 years of data, that is impossible.

Prof. Shuto: His plan is to operate wave gauges all day long. Once some event happens, this laser disc will be stored. Otherwise they can reuse this laser disc for other purposes.

Mr. Sigrist: Dr. Okada, it is evident in your overhead that the stilling well at Esashi is not appropriate as a tsunami gauge. In the United States, the National Ocean Service uses stilling well technology for most of their tide gauging station, so we have much the same problem in accurately measuring tsunami wave activity. These systems are designed to measure tides, so most of the short and long period data are filtered. Are the JMA gauges of the stilling well type, also?

Mr. Okada: Yes, we use the stilling well.

Mr. Sigrist: Since Mike Blackford is not here to comment, I would like to mention PTWC is investigating alternate sensor technologies to detect tsunami wave activity. I believe it is not the same kind of sensor that you have pictured on the screen, the ultrasonic sensor, but rather a less sophisticated type of underwater pressure sensor. It is not a quartz sensor. The sensor actually is vented to atmospheric pressure and measures a differential between water and atmospheric pressure. PTWC plans to evaluate one of these sensors in an existing water level gauging location. If Mike Blackford arrives today, he might be able to give a detailed explanation on the sensor technology I just described. I understand the sensor does not require much maintenance and it is very cost effective.

Dr. Gonzalez: Dr. Okada, I just have a couple of questions. First of all, are

there 500 tide gauges along the Japanese coastline? Yes? Where are the records for the tide gauges?

Mr.Okada: This number is true. The records of the tide gauges are held by each organization which operates the tide gauge. For example the JMA tide gauge, the original records are stored at the weather station and the copies of the tsunami have been sent to the head of the JMA.

Dr.Gonzalez: So these 500 tide gauges are the responsibility of local authorities at a small port? Maybe private or local government authorities?

Mr.Okada: The many of them belong to local government.

Dr.Gonzalez: And I want to understand, do these small local governments copy the tsunami record and send to JMA? Yes? So in the future JMA will have 500 records of the Hokkaido tsunami along the Japanese coast?

Mr.Okada: JMA have collected, I guess, about 50 tide gauge stations for the Hokkaido-nanseioki tsunami.

Dr.Gonzalez: That is very interesting. Now I know that you wrote a paper on the response of many tide gauges, the non-linear response. So I have 2 questions. The JMA tide gauge data that you showed, have you applied your corrections for the non-linear response? And also, the other tide gauge records in the small ports, they also have non-linear response?

Mr.Okada: Yes.

Dr.Gonzalez: And have you corrected the JMA tide gauge records for the non-linear response?

Mr.Okada: No, we have not corrected the non-linear effect for Hokkaido Tsunami. But in the near future, in operational works we will correct the non-linear effect in the information about tsunami.

Dr.Tsuji: I have one comment about what you asked Okada-san, that he has a plan to gather all of the tide gauge records in his office. About that problem. On the Japan Sea coast maybe one fourth of the stations, over 100, maybe 100 or 120, exist. And JMA has several tens of stations on the whole coast, of Japan and the Maritime Safety Agency and the Geographical Survey institute each have around 20 tide gauge stations. And in addition, the prefectural office and port harbor agency have their own individual tide gauge stations. And I, with Prof. Abe at Niigata University, wrote a letter to each owner of the offices asking them to send the tide gauge records. And within maybe one or two months I and Prof. Abe and other co-tsunamiists in Japan will be filing up all the tidal gauge records and copies will be made. And if any of you want to have them, I will send you a set of the copies.

Dr.Gonzalez: Thank you very much. I think this is an important point. In the United States and I think in other countries also, we do not understand very well the Japanese system of data archiving, if I can put it this way. So you have written to many, many small ports for the data, but it sounds like there is also a JMA program to collect all of these data. Now are these complimentary or do they overlap? Does JMA have a special office or a

special program, for example because you are a government agency, to collect all of the important tsunami information in one place, or does Dr. Tsuji have to go himself to ask for these data? This is a very important question. Is there one place, maybe JMA, maybe some other agency, whose responsibility it is to collect all of the important information and make it available to scientists for modeling and research?

Mr. Okada: I think it is important to gather all the data in one place systematically, but at the present stage JMA is not responsible for sending copies to anyone.

Dr. Gonzalez: So is it possible that maybe from this workshop a recommendation can be made, suggesting that a program begin to provide this kind of service? Is it possible that this workshop could perhaps make a recommendation like that? Maybe that is not a question for you. Maybe that is a question for the workshop itself.

Dr. Tsuji: Traditionally from several years ago, our laboratory, as a volunteer I have been gathering tide gauge records. Not such a big event, but a small tsunami event. In my laboratory I worked with my students addressing requests to each owner of the tide gauge records. Okada-san also gave the Meteorological Agency's record to our laboratory and they are all compared at my laboratory. And I send to 7 or 8 tsunamiists in our country one set of the records. Even if it is a small tsunami event.

Dr. Gonzalez: I was just reminded by Commander Sigrist that I should make it very, very clear that we have the same problem, a very big problem, in the United States. I do not mean that only Japan has this problem. This may be an international problem, but certainly we have a very big problem like this in the United States also.

Prof. Abe: I have one comment. I live in Niigata, facing the Japan Sea, so this problem is a very big problem. JMA has a responsibility to make a warning and also to watch tsunami. In relation to the warning system, it has been improved because of the fast issuing of a warning in the case of this Hokkaido earthquake. But watching is not so good, as Okada says. So in relation to this problem, I think there are some points to be considered. One is that JMA's station is not located in a good place for predicting tsunami because of late arrival. There are many small islands in the Japan Sea, like Sado Island or Awashima or Okushiri. In these islands they receive tsunami in a very fast time, so in such places it is important to install a tide station. But there is the problem of preventing accidents by large waves in winter, so managers do not like to install stations in such places. So we must resolve this problem, I think.

Mr. Okada: Now JMA have a plan to make more tide stations along the Japan Sea. The newspaper said that at 6 points JMA will make a new tide station or use a conventional tide station to watch tsunami.

Prof. Yeh: I would like to talk about the ocean bottom pressure gauge. This is the place you have for the ocean bottom pressure gauge. I was watching the TV reporting JMA successfully predicted the arrival of the Guam tsunamis. That is correct, but take a look at the shape of the Pacific Ocean. If a tsunami-generating earthquake occurs in Kamchatka or Aleutian Islands or Alaska, Cascadia, Central America or South America, it would arrive either

Hokkaido or Sanriku first. Not only for near-source tsunamis, but also distant tsunamis, I think in order to have more meaningful data, perhaps you should invest in one more gauge somewhere around this red mark. Prof. Shuto already mentioned this, but I would like to make the same record.

U.S. Tsunami Measurement Capabilities

Frank González, NOAA/PMEL
Tom Mero, NOAA/NOS
Dave Castel, UCSD/SIO

Abstract

Advances in theoretical and numerical tsunami modeling have far outstripped our observational capabilities, and the paucity of high quality field observations has been a serious obstacle to further improvements in our understanding of tsunami generation, propagation and inundation dynamics. At present, there are three complementary U.S. tsunami measurement efforts in the Pacific basin: (1) the NOAA/PMEL Tsunami Project bottom pressure stations in the deep ocean, (2) the Coastal Data Information Program network of offshore shallow water pressure gauges, and (3) the NOAA/NOS Next Generation Water Level Measurement System of tide gauges in harbors and inlets.

Introduction

Many theoretical and numerical models have been developed in the past several decades to describe the evolution of tsunamis. Differences in model results are common, but since high quality tsunami measurements are almost nonexistent, it is extremely difficult to assess the accuracy of individual computations, and to investigate and resolve these differences. High quality tsunami measurements are needed in both the near- and far-field region of the source, at locations extending from the deep ocean to the shelf, in shallow water just offshore of the coast, and in ports and harbors. This report briefly describes three individual U.S. activities capable of obtaining tsunami data in these regions: the NOAA/PMEL Tsunami Project, The Coastal Data Information Program (CDIP), and the NOAA/NOS Next Generation Water Level Measurement System (NGWLMS). Station locations for these programs are presented in Figure 1.

The NOAA/PMEL Tsunami Project -- Deep Ocean Data

In 1986, the Pacific Marine Environmental Laboratory (PMEL) of the National Oceanic and Atmospheric Administration (NOAA) established five bottom pressure recorder (BPR) stations in the northeast Pacific to acquire deep ocean tsunami measurements. Since 1991, NOAA's Coastal Ocean Program has provided additional support for this activity. The observational network focuses on regions posing a direct threat to the United States. Four stations are located near the Shumagin Seismic Gap, an area in the Alaska-Aleutian Seismic Zone which is associated with high tsunamigenic earthquake probability; others are situated offshore of the Oregon-Washington coast near the Cascadia Subduction Zone, and off the island of Hawaii.

The BPR systems record data internally, and can be deployed for 15 months at maximum depths of 6000 meters. At tsunami periods (minutes to hours) the pressure sensitivity of these units corresponds to a sea level change on the order of a millimeter. First and second generation BPRs were characterized by a sampling interval of 56.25 seconds (64 samples per hour), and successfully measured tsunami as small as 1 cm. Because significant aliasing is apparent in these records, the third generation of BPRs sample every 15 seconds.

Future plans include the development and testing of a near real-time reporting system to monitor tsunamis in the deep ocean. BPR measurements will be transmitted acoustically to a surface buoy equipped with a satellite communications link for immediate delivery to NOAA Tsunami Warning Centers. Strategic siting of systems near potential tsunami source zones will provide early detection and timely estimates of tsunami amplitude and period; multiple stations would provide primary direction of energy propagation from the source. When this information is combined with state-of-the-art numerical modeling technology, improved hazard assessments will be possible for smaller-scale, individual regions. This improved capability will reduce false alarms and increase the reliability and accuracy of warnings to threatened coastal communities in the far field.

The Coastal Data Information Program -- Coastal Data

The CDIP is an extensive network for monitoring waves along the Pacific coastlines of the U.S. The system was developed and is managed by the Scripps Institution of Oceanography (SIO) at the University of California in San Diego (UCSD), under the joint sponsorship of the U.S. Army Corps of Engineers and the California Department of Boating and Waterways. The network is designed to provide long-term measurements for use in planning, designing and operating coastal projects. Parameters measured include wave height, wave period, wave direction, current velocity, and wind velocity. In cooperation with the National Weather Service Marine Advisory Program, the CDIP provides essential and timely coastal weather information to mariners, fishermen and recreational boaters. The program also furnishes long-term wind and wave statistics to coastal engineers and others in the oceanographic community.

Automatic data acquisition, transmission to shore via cable or line-of-sight radio links, validation, analysis and dissemination are performed without operator intervention; the data are available in quasi real-time and are also recorded at the Ocean Engineering Research Group's facility in La Jolla, CA. Normally, bottom pressure sensors collect 34-minute records every 3 hours, with a sampling frequency of 1 Hz. However, continuous records can be obtained if a tsunami occurs.

Future plans include the development of a radio telemetry system which will increase the effective data collection range to approximately 50 km. At the present time, the high cost of cable and logistical considerations limit the maximum offshore distance of an instrument package to about 3 km. The planned radio telemetry system is self-contained, and will consist of a radio transmitter in a buoy tethered by electro-mechanical cable to a bottom-mounted instrument package; it is designed to transmit 10 channels of continuously sampled data, with selectable sampling frequencies of 0.5 to 2 Hz.

The NOAA/NOS NGWLMS Program -- Harbor and Inlet Data

In 1983, NOAA's National Ocean Service (NOS) initiated the development of the Next Generation Water Level Measurement System (NGWLMS) as a complete replacement for the aging analog and electro-mechanical gauges of the National Water Level Observation Network (NWLON), as well as the data processing and analysis computers and software. Following a series of sensor and system development and testing efforts, a funding initiative was approved in 1987. Since that time, 250 NGWLMS field units have been procured and more than 140 have been installed in support of the NWLON and NOAA's Global Sea Level Program. Along with field systems upgrade, a new Data Processing and Analysis Subsystem (DPAS) is also being developed. DPAS is a fully integrated, state-of-the-art computer system that will perform data acquisition, processing, analysis, quality control and dissemination, as well as database management, field requirements

assessments, logistic control, and administrative activities. Completion of DPAS is scheduled before the end of 1994.

The primary measurement system is an air acoustic water level sensor with a resolution of 1 mm (Aquatrak® Model 3000) coupled to a data collection/recording platform (Sutron Model 9000). Every six minutes, a 3-minute average water level measurement is acquired and stored; every three hours, the data are telemetered via the GOES Data Collection system for near real-time processing and dissemination at NOS headquarters. An Independent backup system is comprised of a pressure sensor coupled to a second data logger (Sutron Model 8200).

Future plans include modification to provide higher frequency measurements and real-time NGWLMS tsunami measurements. The fixed reporting intervals of three hours satisfies the NGWLMS primary mission, but is not adequate for tsunami warning purposes. Furthermore, significant aliasing is apparent in tsunami time series collected at the 6-minute sampling rate. Because of this, NOS is developing two separate capabilities to provide data with better temporal resolution, one of which will be available in real time. First, 1-minute average, real-time, Aquatrak data will be available via GOES Random Transmissions initiated either by a phone call to a station site or automatically triggered by a tsunami detection algorithm; up to 20 days of these data will be stored and available for retrieval via modem or a site visit. Second, 15-second average pressure measurements for the most recent 5-day period will be stored on 8200 RAM Pack Modules, by continually overwriting the oldest data values; retrieval will require a site visit to remove and replace the RAM Pack Module. Software development for both capabilities is near completion, and installations are scheduled to begin in mid-1994.

Summary

We have briefly described three U.S. programs capable of acquiring high quality tsunami measurements. The efforts are complementary, in that each obtains data in different oceanic regions -- deep ocean, coastal, and harbor. Not surprisingly, however, coverage is most dense in ports and harbors, where the NOAA/NOS instrumentation can be installed in protected, existing structures. In contrast, coverage in the deep ocean and at exposed coastal stations is relatively sparse. The NOAA/PMEL deep ocean instruments are concentrated in a region south of the Shumagin Islands in the Aleutian Island chain, while most of the exposed coastal stations of the CDIP are situated along the California coastline.

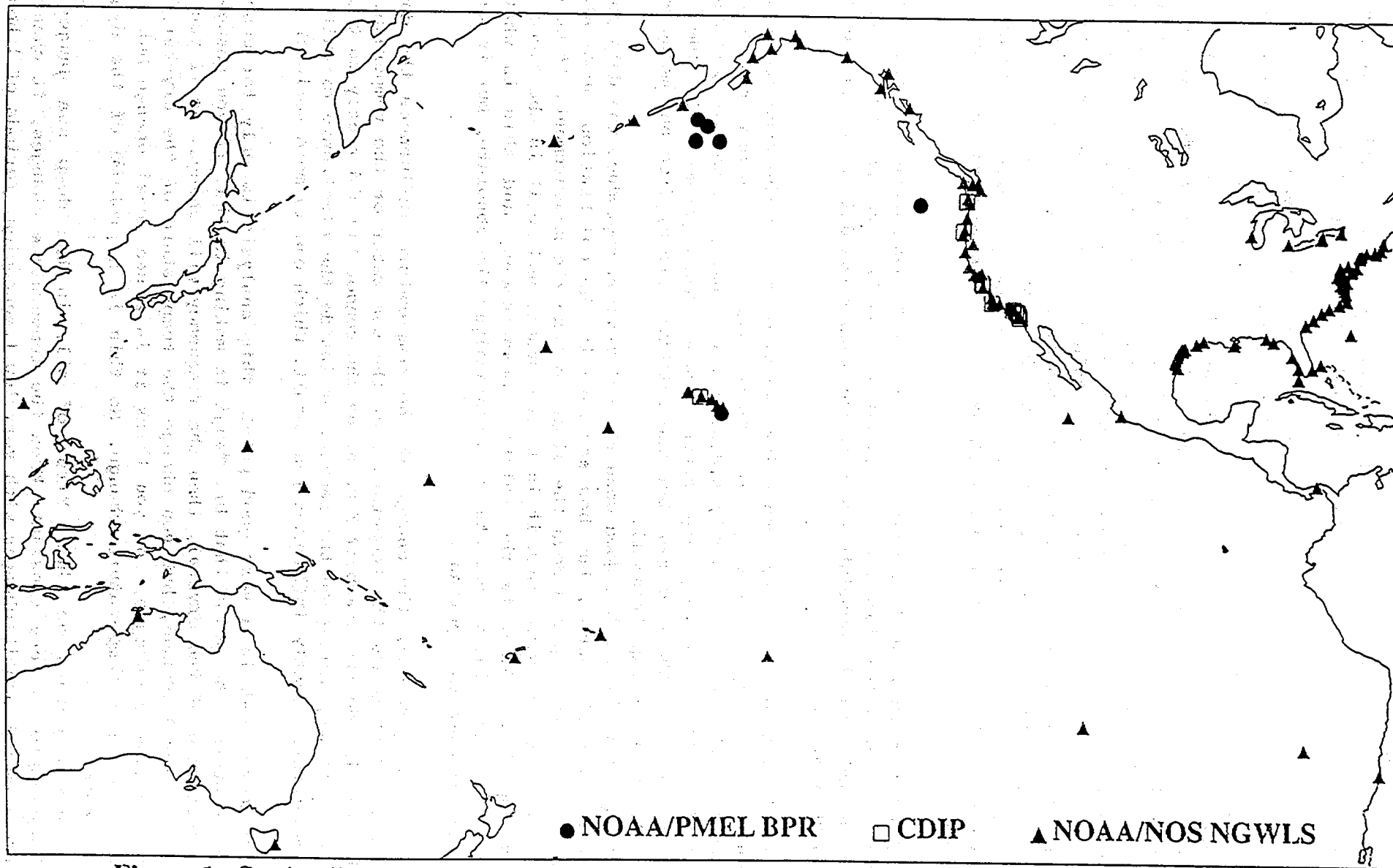


Figure 1. Station Locations

Dr. GONZALEZ

Mr. Tanaka: I have a question. In the ocean there is usually atmospheric pressure disturbance. How about the records of the deep sea gauge?

Dr. Gonzalez: That is a good question. For tsunamis maybe this is not so important, because the atmospheric disturbances tend to be lower frequency, 2 hours, 1 hour and so forth, so maybe it is not too important for tsunamis. For the longer periods we do see signals in the record that may be atmospheric. We have done analysis of tides. Very careful, you remove the tides from the records and you look at the residuals. And at the tide frequencies you see energy, and we think it is possible that this is atmospheric disturbance energy. But this is because, if the ocean responded perfectly to the atmosphere, then we would see nothing. We would not see the bottom pressure, because as the atmospheric pressure gets high, sea level goes down and the pressure of the whole water column is the same, so you see no signal. But the ocean does not respond perfectly. It is not one to one. It is not perfect. So we think we do see some atmospheric pressure signals.

Mr. Sigrist: Frank, just a basic question so I understand how the system monitors pressure. Since you are meaning tsunamis, you are most likely not concerned with the absolute pressure but rather the difference in pressure. Is this correct?

Dr. Gonzalez: That is a very good point. We also analyse the absolute errors. The absolute errors are very large. Those absolute errors mean that you can say that the depth is exactly 4,863.792635m. That is absolute. And Dennis is right. There are very large errors. Those errors are maybe 5m, 10m, 15m. Very large for these gauges. But the relative errors, from one measurement to the next, are quite small.

The question is not how good does the calibration reproduce the data points in an absolute sense, but how accurate is the calibration curve slope, because we move up and down the slope to make the measurement. If we move up the slope so much, then it is a 1m tsunami, and so it is the slope that is important. This is the relative measurement, and this is what we analyse, the relative aspects. We also analyse the absolute, but it is the relative that is important.

Dr. Tsuji: As you say, the change of the temperature influences the data's result. That means the temperature of the sea water or the temperature of the air inside the chamber? I mean, as the sensor faces directly to the sea water, it may influence the result. Or inside the electronic circuit, the temperature greatly influences the result. Which one is more serious?

Dr. Gonzalez: That is a very good point. This analysis is only for constant temperature. The point that Dr. Tsuji is making is that if you change the temperature of the crystal, then the frequency will change. So if you have no sea level change, but you change the temperature of the crystal, then the frequency changes, and you think it is a sea level change but it is not. It is a temperature change. So this is a problem of the dynamic response.

I have 2 points on that. First of all, in the deep sea gauges the temperature is very constant. When the temperature changes, it changes a small amount and it changes with very low frequencies, periods of 1 hour, 6 hours. So it is not a serious problem, but it has to be taken into

consideration.

The second thing is that we have looked at records, and we spoke to the manufacturer about this. They know these instruments very, very well. We have made many tests with our gauges and we know that the temperature effect is there if you change the temperature. What we have found is that if you have a signal, and then if the temperature changes and you have scatter, if you plot the time change in temperature versus the signal, you find a strong correlation. We are finding that the false pressure signal can be modeled very well by a constant times the first time derivative of the temperature. So we think that in the future, we can do a least square fit to remove the temperature effect. And this fit is very, very good. A very high correlation constant. .95, .96. So it is very effective.

Prof. Shuto: I don't remember very well, but in the case of the Mariana tsunami 2 years ago, Prof. Imamura told me that in the JMA's record, there is some noise or some temperature effect which disturbed the tsunami record very much. I would like to have Okada's comment on this.

Mr. Okada: I guess one reason is that we use a different type of sensor. And the other is that the oceanographical condition is different. We are operating the system near Japan under strong ocean currents, so the temperature gradient is relatively large at the bottom. The temperature effect is much greater than yours, I guess.

Dr. Gonzalez: Yes, we also have one system on the slope of the Aleutian Trench change the temperature of the gauge as they in the Gulf of Alaska. This is shallow. This is a very noisy temperature environment, because if you have horizontal gradients of temperature, they move past the gauge. In the deep ocean, this is not so much of a problem, but in shallow water it is. Now we made a mistake on our first gauges. For pressure we had $\delta t = 1$ min. For temperature, $\delta t = 15$ mins. That is no good. Now we have $\delta t = 15$ sec. for both pressure and temperature. So we can make this correction. I do not know how often JMA measures temperature, but if you measure temperature at the same rate as you measure pressure, then it is possible to remove, I think, a very large percentage of this effect using maybe the first time derivative of temperature. But it depends on the gauge. For your gauges maybe the first time derivative won't work. Maybe it is another relationships.

Prof. Shuto: Or to provide some other temperature compensation circuit to make correction?

Dr. Gonzalez: That's right. It is also important that you understand that the best temperature is the temperature inside of the gauge. So we have our gauges. And we have one quartz crystal for pressure and then inside the gauge, in the same place, as close as possible, we have another one for temperature, because what you want to measure is the temperature of the crystal if possible.

Prof. Yeh: Frank, I would like to ask a question. You showed small noises on your data. Isn't it possible those noises are caused by partial standing waves in deep water for two different storm sources?

Dr. Gonzalez: Yes, possible. You are referring to the reinforcement by reflection from the coast. Notice that these are fairly high frequency

though. They are 15 sec. samples. At least in that record that I showed, it looks like noise. But to answer your question, we have not examined the background noise thoroughly in these records. And effects like those that you just mentioned may very well be there. We have concentrated on tides and on tsunamis. But this is fairly high frequency stuff.

Dr. Kajiura: The period might be about 5 seconds or so and your sampling is 15 seconds. Maybe errors arise by very bad alias.

Prof. Yeh: The period is 2Ω I suppose.

Dr. Kajiura: In open oceans wind waves are often more than 10 seconds in period.

Dr. Gonzalez: The period is the same as seismic waves. Actually you can have these seismic surface waves and the period can go from maybe 10 seconds up to maybe 1 minute.

Dr. Kajiura: But I am talking about the generation of this microseism, as Harry says.

Mr. Okada: I have a question. Sometimes it is very difficult to retrieve or recover the deep ocean bottom pressure gauge from the sea bottom. How many systems have you missed?

Dr. Gonzalez: That is a good question. For the instruments themselves, we have better than 95% recovery rate. But sometimes the systems flood. We lost one system completely. We have had maybe now about 38 deployments. We have lost one system. We flooded and ruined maybe 3 systems. So our data recovery is less than 95%. It is maybe 90% or 89%, something like this.

Prof. Shuto: Do you have any idea how high the sea is in the very bad weather season in the area where you installed this?

Dr. Gonzalez: That's a good question. Because we operate in the Gulf of Alaska - at the other stations it is not too important - but in the Gulf of Alaska in the winter this is a very bad place to go in a ship because the waves are very, very high. So nobody in his right mind goes out except in the summer. I've been out 2 or 3 times and it is very nice and quiet. The gauges will not measure sea state because of the exponential decay of pressure for the short wave. But Dennis, how high can the waves be in the Gulf of Alaska in the winter? Maybe 10m. This is why the gauges are for 15 months, not one year. Because our operation is only during the summer. One year maybe the gauges are deployed early in the summer, in May or June, but then the next year it is possible that we recover them late in the summer. So we need one year plus a summer, i.e. plus 3 months.

Prof. Shuto: I understand the operation condition. If possible I would like to have a shorter sampling time than 15 secs. So I thought that we can reduce it to 10 secs from 15 secs, but at the expense of shortening the total duration from 15 months to 10 months.

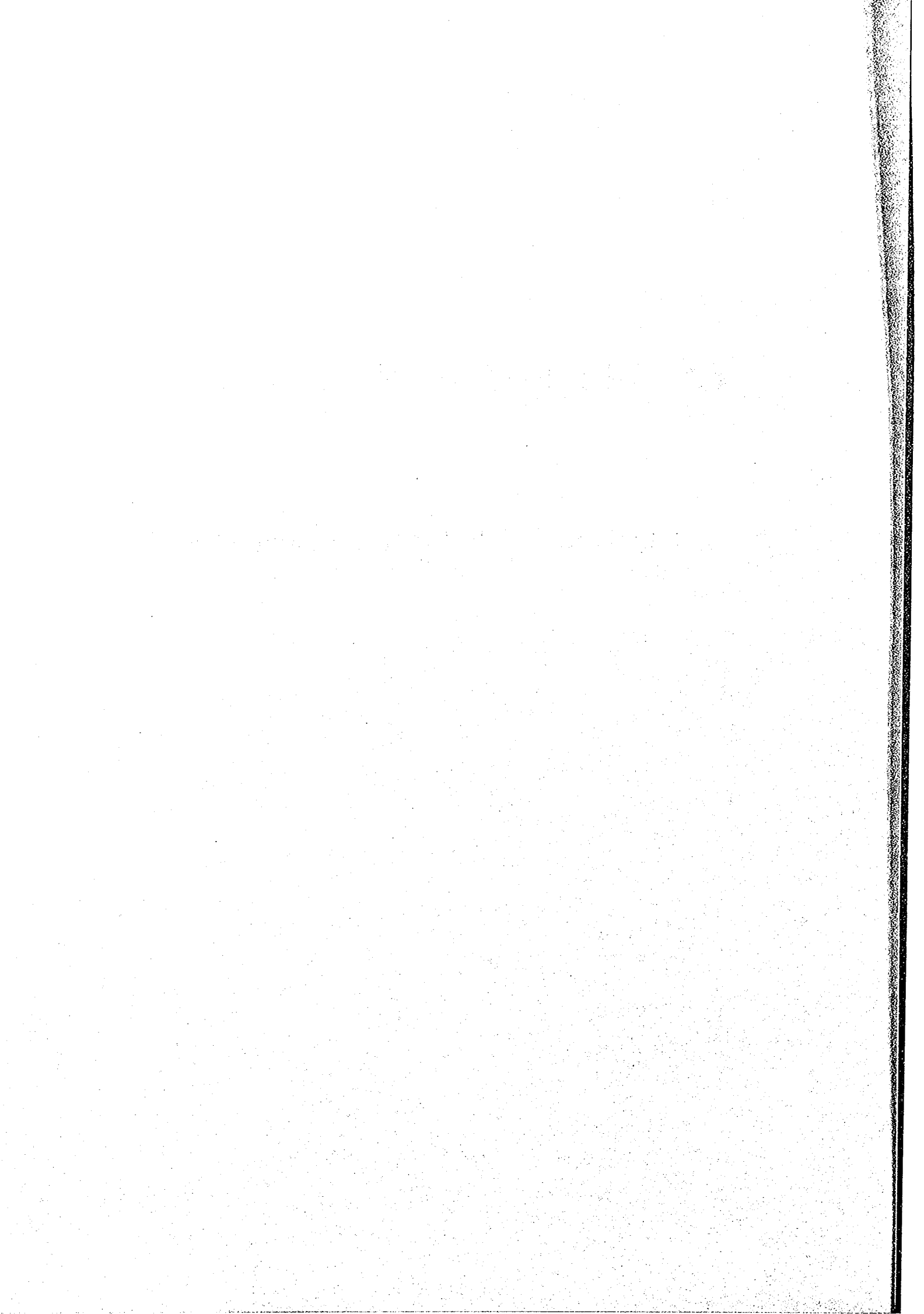
Dr. Gonzalez: It is interesting that you say that because this was the first generation of gauges. Here we have 1 min. data and we record every 15 mins. the temperature. So we got almost no data for temperature. I saw this

record and I said, Oh there is some alias here. If we want to measure small tsunamis, then that means the earthquakes are small, so the wave length will be small and the period will be small. So 1 min. is not good enough. So I went to the engineers and I said, You know what, we have to have a gauge that will measure pressure every 15 seconds. They said; "Oh, 15 seconds. Too much power, too much memory. We'll work on it." I said; "Wait, wait, wait. We also need temperature every 15 seconds." An order of magnitude increase in the amount of data. So these new gauges, it was very difficult to provide enough power and memory. Now I have asked them, Is it possible to make a gauge that will measure every 1 sec. They said, 1 second! No! But we'll think about it.

With a 1 second gauge you can measure seismic surface waves, almost like an ocean bottom seismometer. There are problems using a pressure gauge to measure ocean bottom. But it would be very, very interesting. Now they are thinking about it and the electronics keeps advancing all the time. So I think some day in the future maybe we will have 1 sec. bottom pressure recorders that will record data for 15 months.

C: Mitigation and Others

J. Lander and S. Tanaka, moderators



CHARACTERISTIC PROPERTIES OF THE 1992 NICARAGUA TSUNAMI

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March 2, 1994

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Abstract

Tsunami has a property of solitary wave originally. Oscillatory motion following the solitary wave results from reflections due to coast, shelf boundary and sharp change of sea depth nearby the source and observation station. From such a viewpoint the 1992 Nicaragua tsunami is reviewed and characteristic properties are derived from it. In conclusion the 1992 Nicaragua tsunami was observed as solitary-typed wave. It is proved from one dimensional model that a shallow shelf contributed to the separation between direct wave and following waves. The model suggests that the source was located in a continental slope. A distribution of the maximum inundation heights, observed along the Pacific coast of Nicaragua, was explained from the source assumed on the continental slope, which is almost equivalent to aftershock area. In residential area tsunami decreased in height with increase of inundation distance into half at the maximum inundation distance. The decrease characterizes an interaction of tsunami with buildings. A maximum-level dependence of killed persons in each residential

unit showed a critical increase at 4 meters above mean sea level. The fact that most part of killed persons is occupied by children suggests a gradual increase of wave height to give a time for running away to adults.

Introduction

Tsunami hit the Pacific coast of Nicaragua, Central America, on September 2, 1992 and gave a serious damage. Nicaragua is located on Caribbean plate and has a trench off the continental shelf in the Pacific Ocean. The Middle America Trench is a subduction zone of Cocos plate subducting under the Caribbean plate (e.g. Martinez and Noguera, 1992). The earthquake, generating the tsunami, had an epicenter on the slope of the continental shelf (Fig. 1). For this tsunami and earthquake a survey was conducted by a survey team consisting of Japanese, north Americans and Nicaraguans (Abe et al., 1993, Satake et al., 1993). On their results, those are maximum inundation heights and the decrease with inundation distance, tide gage records observed and the analysis, disasters, we will discuss characteristic properties of this tsunami and earthquake.

Maximum inundation heights

The maximum heights along the Pacific coast, obtained by Abe et al. (1993), is reproduced in Fig. 2. It shows the peak level of 9.9 m at El Transito in Central part of the Pacific coast of Nicaragua, gentle decrease toward north and constant level of 6-8 m to Marsella with a critical decrease toward south. Such a distribution is consistent with a assumed fault having 200 km x 100 km in size (Imamura

et al.,1993). It suggests us that the fault, which is source of tsunami, is located within total distance of the Pacific coast of Nicaragua. The distribution is also consistent with aftershock area as shown in Fig.1. The location of El Transito to the aftershock area indicates that the peak level was observed at the coast nearby the center of the source area.

The maximum heights decreased after landing. In residential area tsunami decreased in the maximum inundation heights. They were measured on the background's constructions(e.g. buildings or houses) higher than the maximum inundation levels. This fact represents that tsunami inundated repeating the interaction with buildings or something. The results are shown in Fig.3. The examples are for San Juan del Sur and Masachapa. This figure reveals that the height decreased into half from a peak value at a place nearest to seashore. This process is explained by Abe et al.(1994) as an assumption of half kinetic and half potential for total energy and loss of kinetic energy in the residential area. The inundation height is measured from mean sea level and not wave height of tsunami. But the difference is 1 meter at most. The half of the peak height is also effective to be replaced by half of wave heights. The fact suggests that tsunami was amplified by two times in front of buildings or houses and reflected totally in the approximation.

Tsunami in a shallow sea
Time histories of the tsunami were recorded with tide gages at Corinto and Puerto Sandino by Instituto Nicaraguense de Estudios Territoriales. The for-

mer is complete(Fig.4) but the latter is incomplete because of saturation. The arrival time is obtained from starting of negative wave at 19h 08m for Corinto and leads the travel time of 52 minutes. Aftershock area suggests the source distance of 50 km at most. Long wave approximation of tsunami makes us estimate the average sea depth of 26 m equivalent to velocity of 16 m/s assuming the travel time and source distance. The depth is very small and the late arrival is explained with a slow propagation on the shallow sea. The shallow sea causes non-linear effect in the propagation. Wall-like wave front, witnessed by a inhabitant at San Juan del Sur(Abe et al.,1993), was caused by the non-linearity. The shallow sea is effective to separate the main wave from following wave.

The following wave, caused by reflected wave at a shelf margin, was observed 82 minute later from the first arrival as shown in Fig.5. The late arrival is explained by step-shelf model of one dimension with a width of 34 km and a depth of 20 m(Abe and Ishii,1989). It is interesting that the phase was reversed after the reflection at the shelf margin. Fixed boundary condition explains the phase reversal at the shelf boundary. Thus tsunami at Corinto consists of direct wave and reflected wave at the shelf margin. We can identify all the main phases observed at Corinto. The simple waveform results from shallow sea in front of observation point. The separation of direct wave from the reflected wave leads us an approximation of tsunami as solitary wave.

We need notice an initial negative phase observed at Corinto(Fig.4). The negative phase was caused by subsidence in the source. This tsunami has a positive main wave following the negative phase, which corresponds to uplift in the source. It is known that a thrust fault with dip angle smaller than 30

degrees generates a small subsidence on the ground surface above the lower depth of the fault(e.g. Mansinha and Smylie,1971). This relation suggests that the tsunami was generated by the thrust fault with a small dip angle. The small dip angle is harmonious with dip angle of 16 degrees derived from surface wave inversion(Ide et al.,1993).

Recently another solitary-like tsunami was observed in the Noto peninsula, Honshu, Japan. The record at Wazima tide station installed by Geodetic Survey Institute is shown in Fig.6. The tsunami was excited by an shallow earthquake ($M=6.6$), having the epicenter on a shelf off the Noto Peninsula, on February 7,1993 and observed at tide stations within epicentral distance of about 200 km. The sea depth of the source is about 100 m and the shallow sea in the shelf contributed to solitary-like tsunami. In this case reflected wave from shelf boundary was not observed. These two examples show that a shallow shelf is effective to form solitary wave.

Victims of the tsunami disaster

Total death toll reached 117 or 118 according to a newspaper 'the Baricada'. The survey confirmed about 90% of the total death toll. Their data was connected to the maximum inundation heights(Abe et al.,1993) as shown in Fig.7. Their result represented a critical height of 4 m for accelerating an increase of death toll. The same critical height was observed in the case of the 1983 Japan Sea Tsunami. Since ground surface is higher than sea level by 1-2m, the effective height for human body is reduced to 2-3 m. But it is higher than top of standing person. Accordingly the critical value is related with increase

of drowners.

Many children including infants were killed by this tsunami as shown in Fig.8(Abe et al.,1993). The figure shows that most of total killed persons is occupied by children. This fact suggests that there was a chance for adults to run away. It is understood from interviews at El Transito that the invasion was not so rapid that people barely run in a rushing water(Abe et al.,1993). The tsunami was not forecasted beforehand and they received the tsunami as a sudden increase of sea water. Taking into consideration of such a circumstance it is concluded that number of victims was small.

Tsunami earthquake

Tsunami earthquake was defined as an earthquake generating unproportionally large tsunami by Kanamori(1972). This earthquake was identified as tsunami earthquake(e.g.Kanamori and Kikuchi, 1993, Ide et al.,1993). Kanamori and Kikuchi(1993) found the reason in discrepancy between surface wave magnitude M_s and moment magnitude M_w . Ide et al.,(1993) attributed the discrepancy to a small rupture velocity of 1.5 km/s. On the other hand the survey clarified the seismic intensities in Nicaragua as shown in Fig.9(Abe et al.,1994).From statistical viewpoint they are too small in consideration of the surface wave magnitude of 7.2. Referring Kawasumi's formula(1956) between seismic intensity(Japanese scale) and magnitude M , transforming the seismic intensity into one of modified Mercalli scale I_{MM} , we obtain an empirical relation of $I_{MM} = 3M - 6.9 \log \Delta - 0.00249\Delta + 0.02$ in which Δ is epicentral distance in km. The formula is drawn in Fig.10(Abe et

al.,1994) and the seismic intensities are plotted. This figure reveals the intensities not proportional to magnitude 7.2. The weak excitation of short-period seismic wave explains the unproportionality. It is well known that the minimum earthquake exciting tsunami has magnitude of about 6.5. The result shows that this earthquake corresponds to the minimum earthquake or less. Thus it is proved that the earthquake was received as weak one in contrast to the magnitude 7.2.

Aftershock area is shown in Fig.1. Tsunami source area, approximated with aftershock area, is consistent with fault formation due to elastic rebound of Caribbean plate for subducting Cocos plate.

Discussion

Imamura et al.(1993) carried out a numerical experiment of the tsunami using linear wave equation and showed that an assumed fault size of $200 \times 100 \text{ km}^2$ with a dip angle of 16 degrees was consistent with the pattern of the maximum inundation heights. Titov and Synolakis(1993) carried out the numerical simulation combining two dimensional and one dimensional computation. They concluded that a model revised from one by Imamura et al.(1993) could explain the maximum inundation heights observed by Abe et al.(1993). Mader(1993) used non-linear wave equation in his numerical experiment and gave a negative answer to landslide as the cause of tsunami.

Conclusion

Characteristic properties of the 1992 Nicaragua tsunami were obtained using

the result of field survey conducted by Abe et al.,(1993). Solitary waveform was explained from a shallow shelf. The long travel time is related to the shallowness. The maximum inundation heights along the Pacific coast reflects the finite length of fault. As a result it is considered that aftershock area corresponds to tsunami source area. The weak excitation of ground shaking verified tsunami earthquake.

Acknowledgement

We would like to thank the staff of INETER(Instituto Nicaraguense de Estudios Territoriales) and Geodetic Survey Institute of Japan for offering their tide-gage data.

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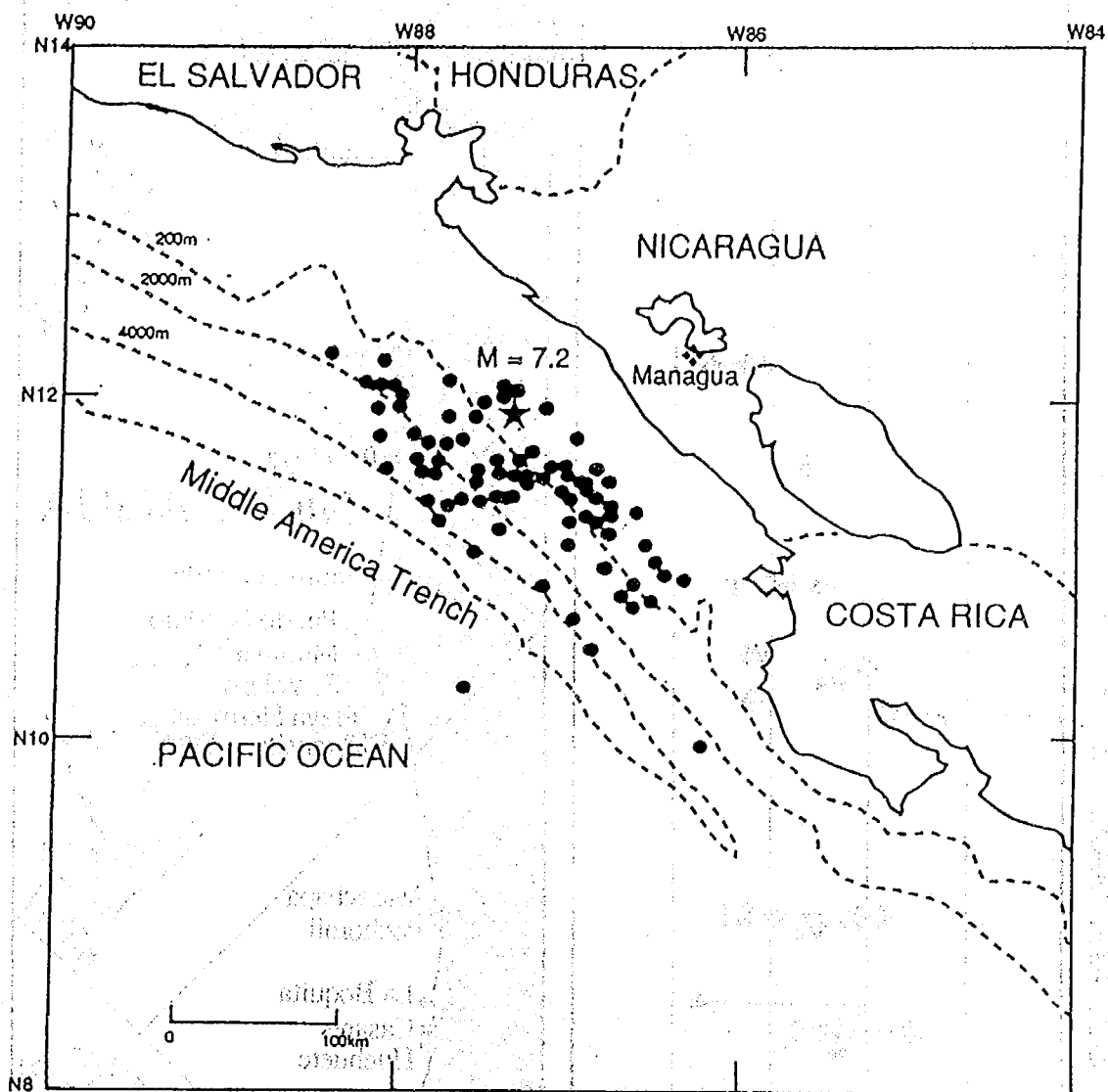


Fig.1 Epicenters of mainshock(solid star) and aftershocks for one week from the mainshock(solid circles) after National Earthquake Information Center.

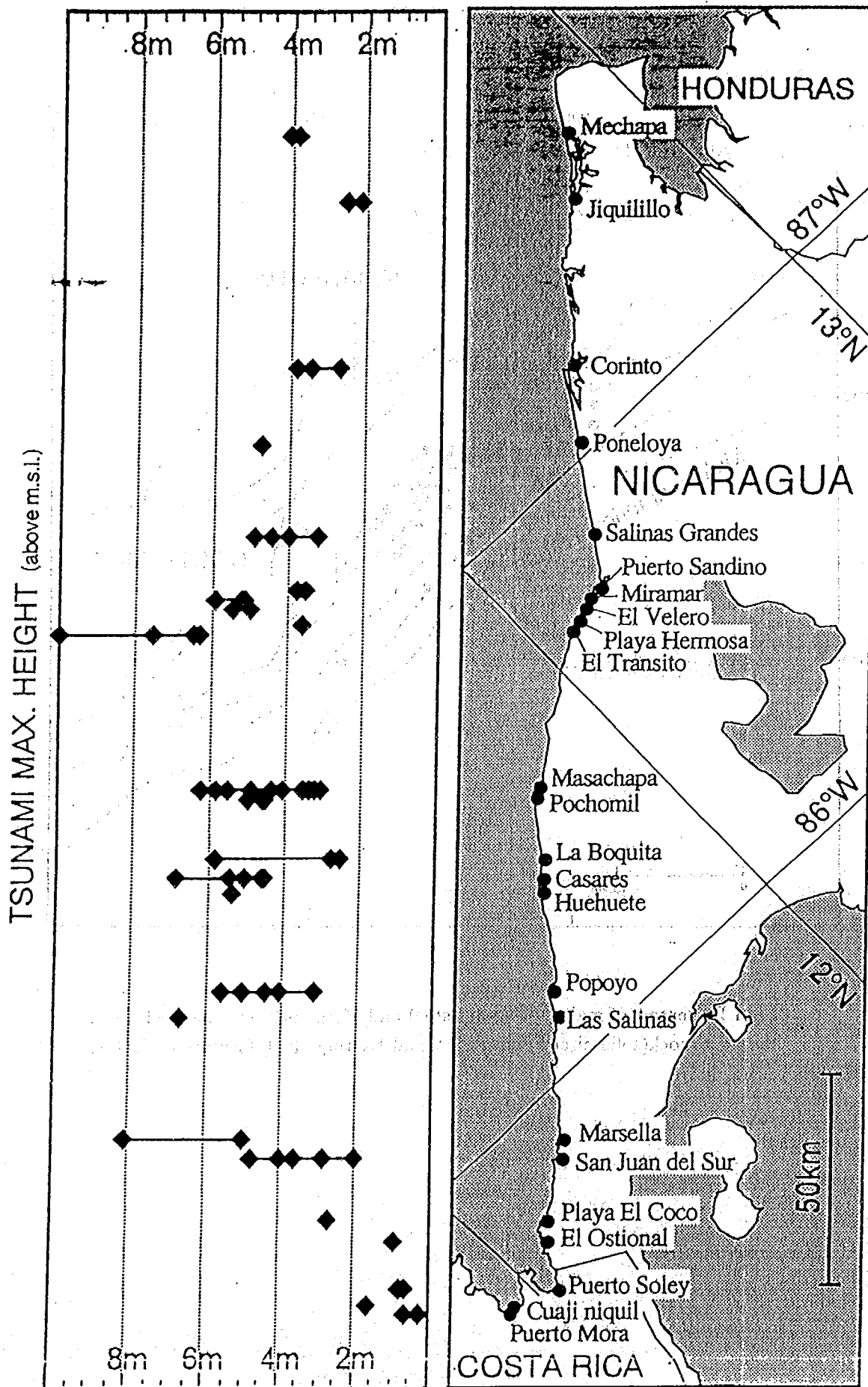


Fig.2 Maximum inundation heights above mean sea level along the Pacific coast of Nicaragua(Abe et al.,1993).

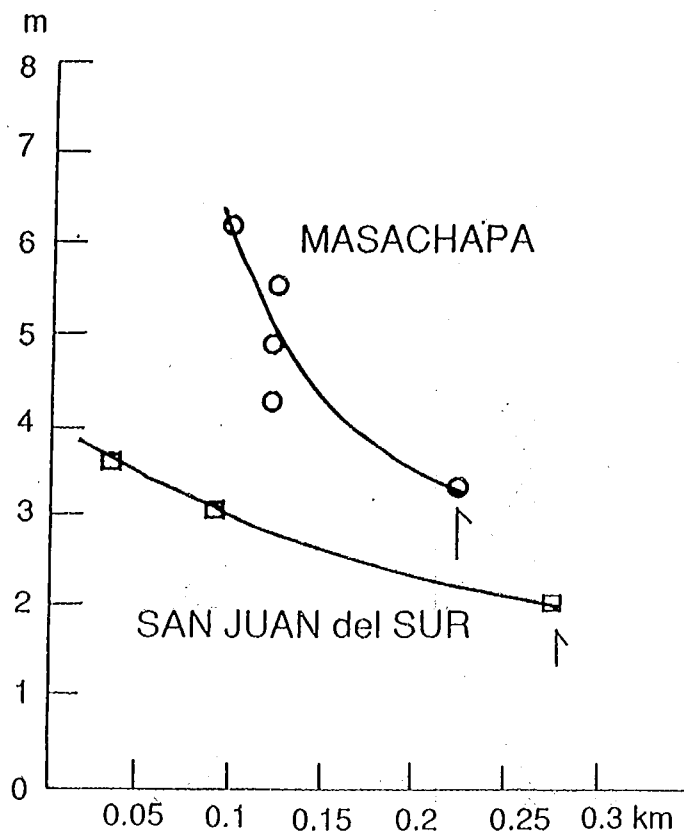


Fig.3 Decrease of maximum inundation heights with inundation distance from sea shore in residential area. Arrows indicate the maximum inundation distances.

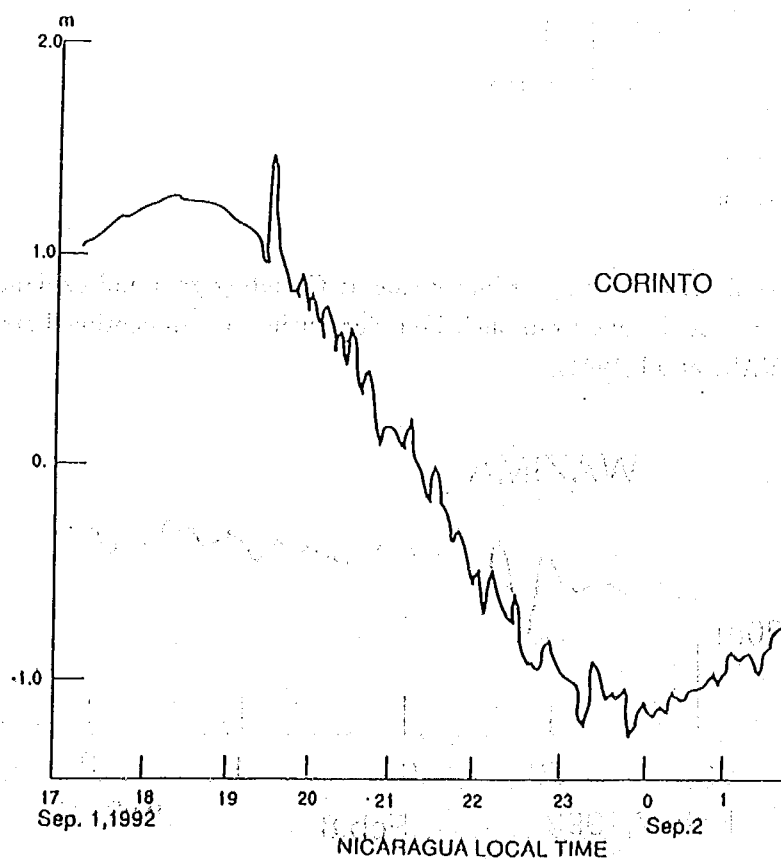


Fig.4 Tide gage record of the tsunami at Corinto(after Instituto Nicaraguense de Estudios Territoriales).

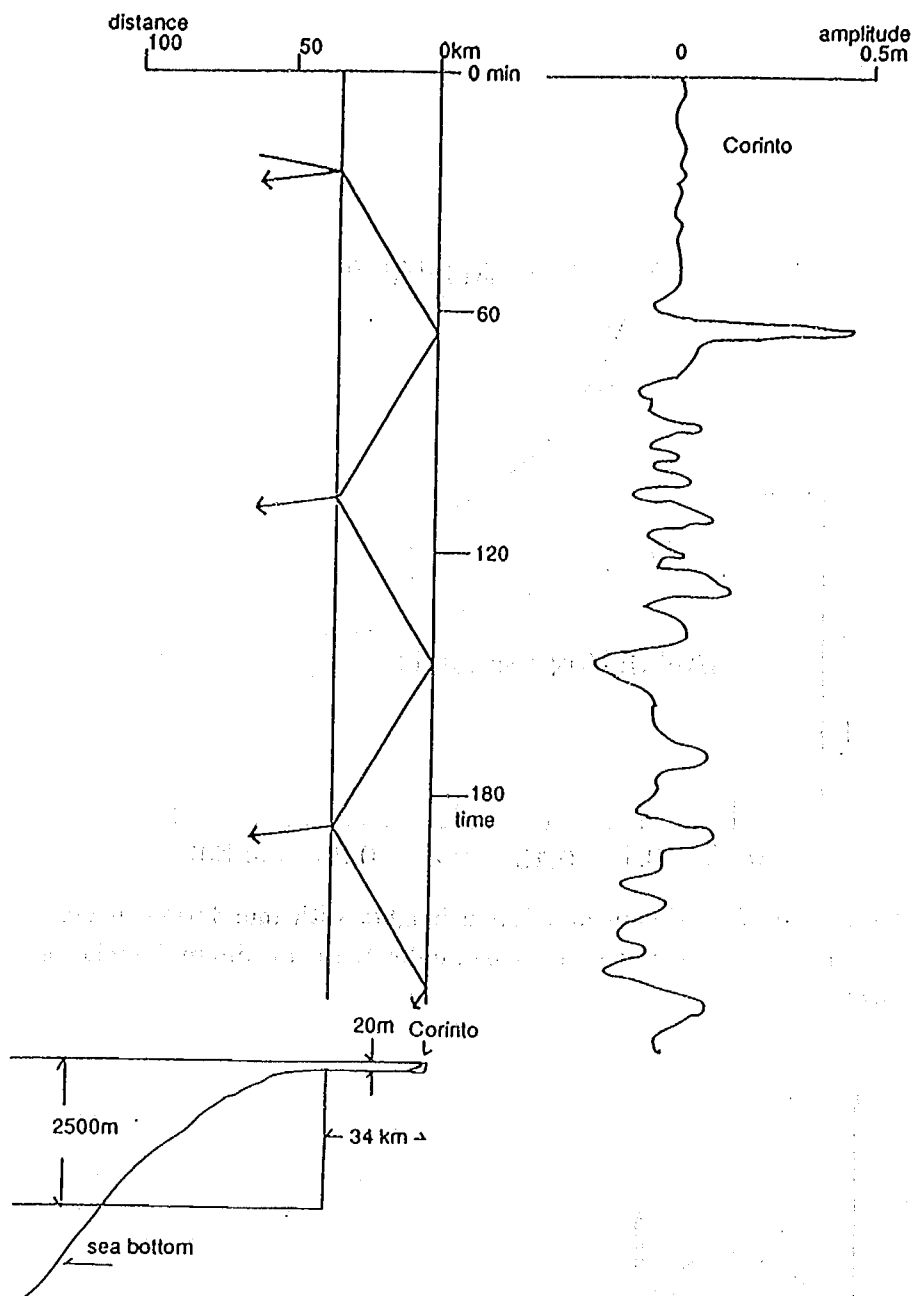


Fig.5 Tsunami after reducing ordinary tide at Corinto(right) and explanation of the reflected wave from shelf boundary using one-dimensional step model(left)(Abe et al.,1994).

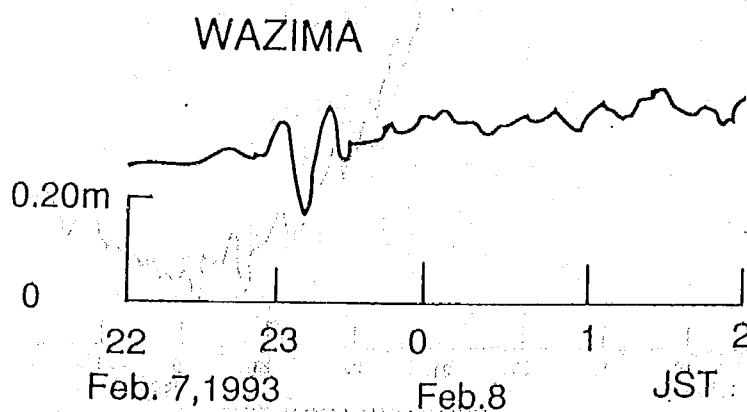
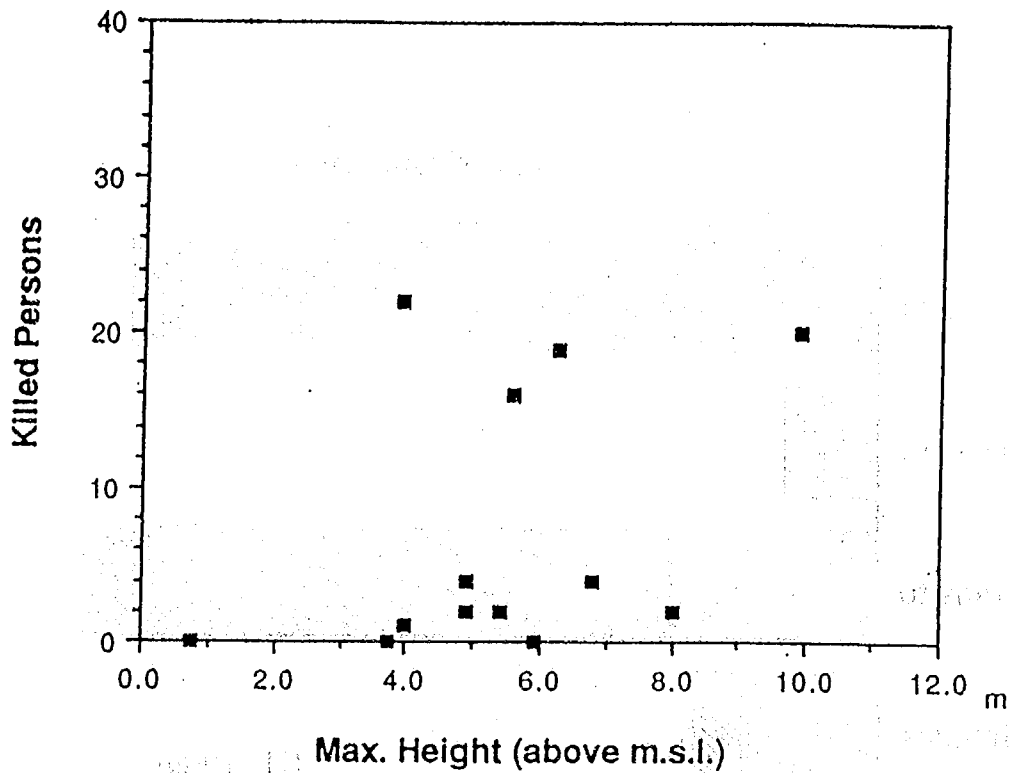


Fig.6 Another example of solitary-like tsunami. Tide gage record at Wazima(after Geodetic Survey Institute) for the Noto Peninsula Earthquake of February 7,1993.

1992 Nicaragua Tsunami



1983 Japan Sea Tsunami

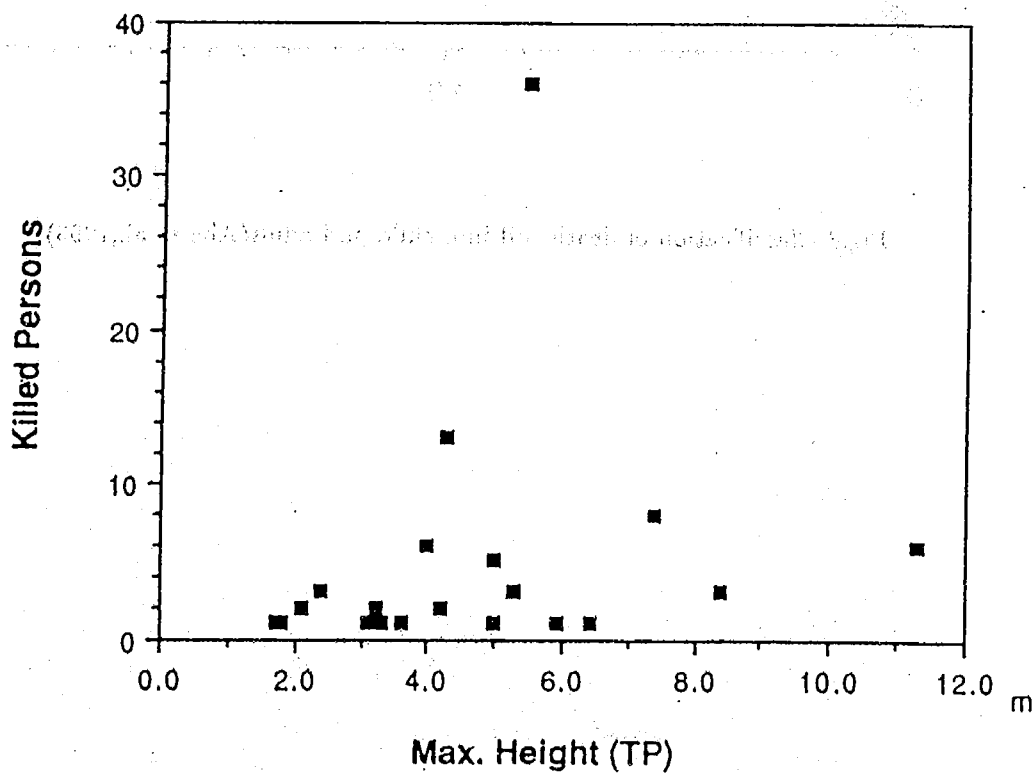


Fig.7 Killed persons vs maximum inundation heights above mean sea level for each residential unit. Upper figure:1992 Nicaragua Tsunami, lower figure:1983 Japan Sea Tsunami(Abe et al.,1993)(TP is Japanese mean sea level).

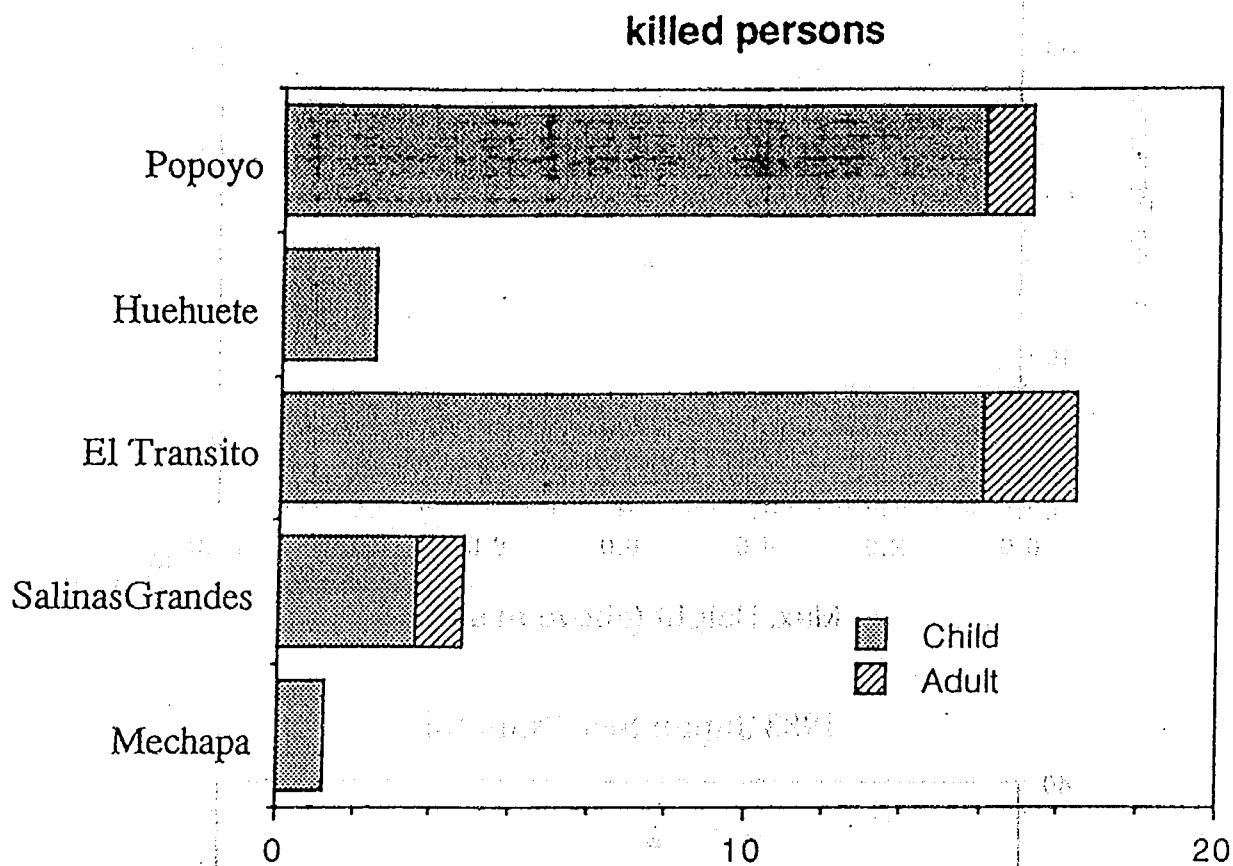


Fig.8 Classification of death toll into child and adult(Abe et al.,1993)

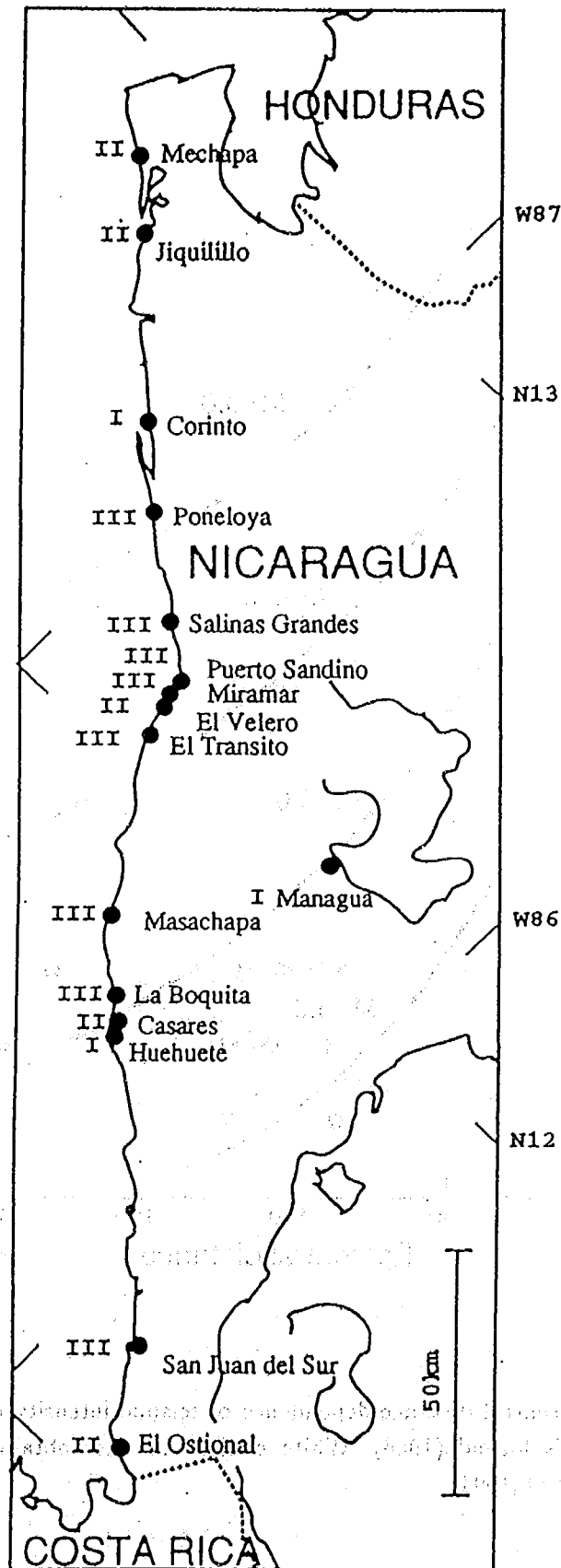


Fig.9 Seismic intensities(MM scale) obtained in the survey(Abe et al.,1994).

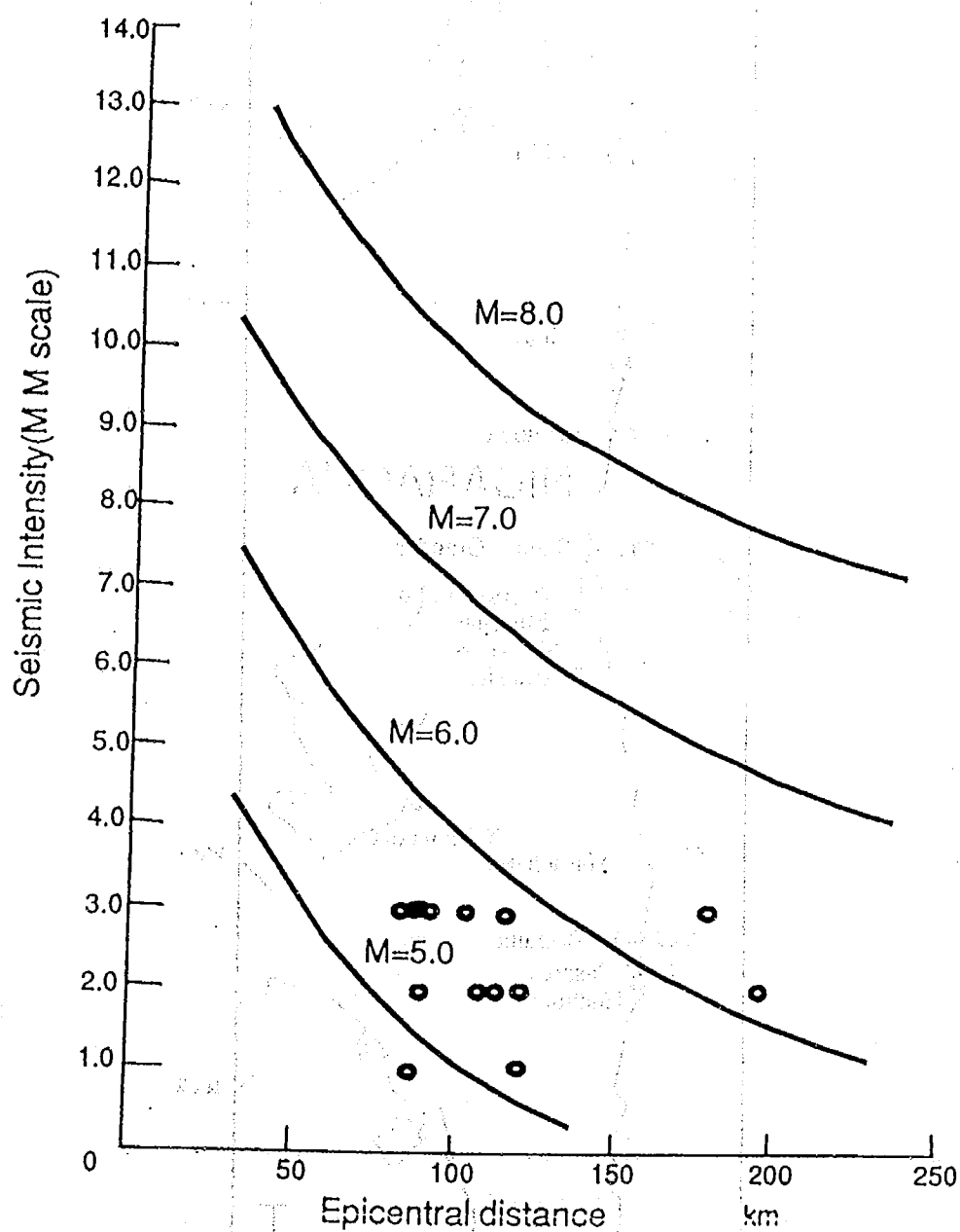


Fig.10 Epicentral distance dependence of seismic intensity calculated from Kawasumi's formula(1956). White circles are ones obtained in the survey(Abe et al.,1994).

Prof. ABE

Prof. Shuto: I have a comment. During the symposium in Wakayama you mentioned the decrease of the water level toward inland. You compared 3 cases or so. A better comparison may be given if you take the abscissa as the relative distance compared with the length of the tsunami. The total water quantity flooded on land is a part of the water which was brought in by the tsunami with this scaling, you can compare tsunamis of different length.

Prof. Abe: For example, you say it is important to compare using the relative distance between wave length and distance. It is good advice.

Dr. Gonzalez: Your model which combines the source response and the shelf response to estimate the spectrum, it fits the observations very nicely. Then the harbor response is not too important? I mean, do you think that the harbor response is also important? Or not?

Prof. Abe: We neglected the harbor response. It is very interesting because Corinto is located on an inlet, but in the background there are many small inlets in a shallow area. So perhaps such a condition neglected to excite the characteristic response of an inlet area, so perhaps it fits so well.

Dr. Gonzalez: But then that would contribute be more high frequency energy?

Prof. Shuto: Give us your figure of, the time history.

When we had one big incident wave, this incident wave might have excited the oscillation in the harbor. But we had only one big incident wave, therefore we had no such big resonance. Maybe the succeeding small oscillations reflect the local topography of that size.

Dr. Gonzalez: But the shelf response was a very important part of that spectrum as well. I was struck by that.

The other question I have is this. Do you know what the quality and the kind of instrument is for the Corinto tide gauge? Do you know if it is a stilling well?

Prof. Abe: No, we have no information about this. So we cannot consider such a detailed condition.

Prof. Abe: I'll show you the slides. This is the Masachapa's case. The wall was destroyed. This is El Transito's case. This is the maximum value of 10 points. We visited here after 2 or 3 weeks, so many puddles had been cleaned up so you see such a scene. But this area received very serious damage.

This is in El Velero, a shower room at the sea bathing area which was destroyed by the tsunami. This is in Salinas Grandes. The red brick was brought by the tsunami. This brick is not so big, it is quite light, so perhaps a tsunami can bring such a brick which is part of a house. This is the water sea level which we detected. It corresponds to the point where we found the dry seaweed.

Mr. Sigrist: How many days after the event were these pictures taken?

Prof. Abe: 3 weeks. This is Poneroya which is a resort area. The restaurant bar was destroyed and supporting bars are now being prepared. This is the sea level which we measured. Can you see this point? You can see some plants.

We obtained this level as the tsunami height. This is the same place. In the lower level we can see a change of color. This black part was caused by the long staying of the tsunami, so this is lower than the maximum level. This is the north point of Mechapa. This is the maximum inundation point, so the tsunami came through this house, so I took a picture.

**JULY 12, 1993, HOKKAIDO NANSEI-OKI TSUNAMI -
EFFECTS AND OBSERVATIONS IN JAPAN, RUSSIA, DEMOCRATIC
PEOPLE'S REPUBLIC OF KOREA AND REPUBLIC OF KOREA**

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Abstract

The tsunami generated by the Hokkaido Nansei-Oki earthquake caused significant loss of life and property damage in Japan and was observed by all countries bordering on the Sea of Japan. As of July 21, 1993, the death toll from the tsunami alone in Japan was 120. A total of 185 perished from all causes; tsunami, earthquake, fire and other causes combined (as reported by the local authorities). Combined property loss and related damages is most likely in the millions of dollars. The impact to coastal communities on Okushiri Island was devastating. With dramatic tsunami run-up evidence wide spread, Japanese as well as cooperative survey teams investigated the disastrous effects of this tsunami in Japan. The tsunami impact on other countries surrounding the Sea of Japan has not been firmly established, however, the Republic of Korea, the Democratic People's Republic of Korea and the Russian Federation all report varying levels of damage from the tsunami. This paper reports primarily on tsunami observations from countries bordering the western Sea of Japan, stimulating discussion on mitigation efforts.

Introduction

Within days of the event, the International Tsunami Information Center (ITIC) contacted the national Member-state representatives of the International Coordination Group for the Tsunami Warning System in the Pacific in all the countries surrounding the Sea of Japan where tsunami damage was reported. As part of a cooperative US/Japan survey team, the author participated in a tsunami run-up survey on Okushiri and Hokkaido Islands under the auspices of the United States - Japan Natural Resources Cooperative Program (UJNR). Anecdotal run-up reports from outside of Japan were gathered from INTERNET E-mail and from information gathering services (the media). The data reported by Byung Ho Choi (Sung Kyun Kwan University, Republic of Korea) represent a systematic investigation by the survey team studying the tsunami impact in the Republic of Korea. Dr. Victor Kaisterenko (IMGG - Yuzhno-Sakhalinsk) reported on the tsunami damages along the Russian coast exceeding 6.5 million dollars (E-mail, Kulikov). Damage reports in the Republic of Korea estimate nearly one-half million dollars in losses, mainly damage to fishing boats and equipment (Korea Meteorological Administration). At the port of Chongjin, Democratic People's Republic of Korea, the maximum run-up of 2.1 meters was measured nearly two hours after the earthquake occurred (National Oceanographic Commission, DPR of Korea).

Observations

It is evident this tsunami's impact extended to all countries bordering on the Sea of Japan. While tsunami wave activity struck Japan within minutes of the earthquake origin time, the calculated wave travel time to the Asian continent provided about 30 minutes 'lead time' before the first wave arrival on the Russian coastline (Japan Meteorological Agency). In the southern Sea of Japan, calculated wave travel time was on the order of two hours.

The 'major tsunami warning' issued by the Japan Meteorological Agency (within 5 minutes of the earthquake origin time) is consistent with the criteria established for their warning center performance for near-field events. The local warning issued by/for Russia appears to have been effective in mitigating loss of life. The Korean Meteorological Administration issued an "Earthquake Information" bulletin within 13 minutes of the event; a "Tsunami Warning" was issued within 33 minutes. The tsunami warning issued by the JMA was received in the Democratic People's Republic of Korea at 23:10 hours which provided some lead time to notify coastal communities in that country.

Conclusions

The 1993 Hokkaido Nansei-Oki earthquake/tsunami represents the first opportunity in over a decade to investigate in detail the damage to a highly developed coastal region. This research benefits all countries attacked by tsunami for the purpose of mitigating tsunami impact to a highly developed coastal infrastructure. Our American and Japanese colleagues are encouraged to continue sharing unselfishly their research papers, data surveys and results through workshops and symposiums. E-mail, telefax and electronic bulletin boards provide a 'rapid forum' in this regard. Our efforts to move ahead using the new electronic communication technologies is impressive. ITIC will support this process through the collection and further distribution of information for the benefit of all users interested in tsunamis. As part of ITIC's mandate, ITIC shall endeavor to provide coordination to expedite participation for post-disaster tsunami surveys. With three destructive near-field tsunamis in the last two years and extensive follow-up surveys, we should also consider developing standardized investigation procedures using the latest in technology to minimize expenses while covering more of the survey area in less time. One such technology is in the field of kinematic Global Positioning System (GPS) receivers operating in the 5 - 10 cm. accuracy range. Such technology, incorporating a base station and highly portable receiver/data logger, has the potential to improve accuracy and coverage during tsunami field surveys.

In the United States, particularly along the US West Coast, the application of what we have seen in the countries bordering on the Sea of Japan could be analogous to a near-field tsunami impacting California, Oregon or Washington states. Recent paleo-tsunami evidence collected along the US West Coast indicates there may have been dramatic tsunami run-ups in the recent past which, in turn, has created a heightened awareness in the research community and among disaster preparedness officials. Preliminary inundation maps, intended as guidance for local preparedness officials and disaster planners, have been developed and are being evaluated. Together with disaster preparedness and evacuation planning, and experiences learned from the Hokkaido Nansei-Oki tsunami, it is hoped these efforts will help mitigate the loss of life and property damages associated with near-field tsunamis.

Some Survey Results and Reports

The following tabulation of tsunami run-up values impacting countries on the Asian continent include:

Run-up Tabulation

Location	Country	Height (m.)	Comment/Position
Chongjin Port	DPR Korea	2.1	Maximum between 00:15/00:30, 13 July
Kangneung	R of Korea	1.1	PUV gauge located offshore, KORDI
Sanchok	R of Korea	1.0	Kenji Satake, e-mail Univ. of Michigan
Sogcho	R of Korea	2.04	max amplitude, tide gauge
Mugho	R of Korea	2.77	max amplitude, tide gauge
Ulleungdo	R of Korea	1.2-2	range, tide gauge
Pohang	R of Korea	.92	wave height, tide gauge
Ulsan	R of Korea	--	no indication
Geojin	R of Korea	0.81	38-26-44N 128-27-41E
Ayajin	R of Korea	1.39	38-16-14N 128-33-37E
Sajin	R of Korea	2.22	38-13-24N 128-35-25E
Sokcho	R of Korea	0.91	38-12-14N 128-35-50E
Daepo	R of Korea	1.63	38-10-21N 128-36-36E
Osan	R of Korea	1.26	38-05-18N 128-39-57E
Susan	R of Korea	1.85	38-05-30N 128-39-10E
Gisamun	R of Korea	2.26	38-00-23N 128-44-00E
Namae	R of Korea	1.26	37-56-29N 128-47-18E
Jumunjin	R of Korea	1.46	37-53-00N 128-49-30E
Sachunjin	R of Korea	1.46	37-50-06N 128-52-45E
Gangmun	R of Korea	1.87	37-47-38N 128-55-10E
Jungdongjin	R of Korea	2.01	37-40-55N 129-02-46E
Gumjin	R of Korea	1.17	37-38-59N 129-03-09E
Daejin	R of Korea	1.56	37-34-45N 129-30-00E
Mukho	R of Korea	1.99	37-32-50N 129-07-06E
Donghae	R of Korea	1.76	37-29-24N 129-08-40E
Chuam	R of Korea	1.77	37-28-20N 129-09-55E
Samchuk Beach	R of Korea	2.15	37-28-00N 129-10-10E
Samchuk Port	R of Korea	1.86	37-26-10N 129-12-00E
Obunri	R of Korea	1.10	37-26-00N 129-12-00E
Gungchon	R of Korea	1.74	37-17-00N 129-18-30E
Jangho	R of Korea	1.41	37-17-30N 129-18-40E
Imwon	R of Korea	2.39	37-13-00N 129-21-00E
Hosan	R of Korea	1.38	37-09-40N 129-21-00E
Bugu	R of Korea	2.57	37-06-00N 129-22-32E
Jukbyun	R of Korea	1.43	37-03-00N 129-25-40E
Nakhodka	Russia	5.0	ITAR-TASS, Southern Sakhalin area
Nakhodka	Russia	1.0	Hydromet Administration report
Nakhodka	Russia	5.0	anecdotal, newspaper account
Primorye Region	Russia	6.0	Telex fm Sakhalin; Rabinovich/Kulikov
Southern Sakhalin	Russia	4.0	Telex fm Sakhalin; Rabinovich/Kulikov
Tetyukhe, Rudnaya	Russia	2.5	Hydromet Administration report
V. Preobrazhenye	Russia	2.0	Hydromet Administration report
Vladivostok	Russia	2.0	Moscow-RIA; Considerable maritime damage
Vladivostok	Russia	0.5	Hydromet Admin. report; minor damage

Mr. SIGRIST

Dr. Gonzalez: What is the cost of one of these systems?

Mr. Sigrist: Apparently, this is the new state-of-the-art technology. I have been working with people the National Ocean Service (NOAA) investigating their expertise in enhancing accuracy processors were very expensive and not accurate enough for tsunami survey work. The technology has improved and prices have dropped dramatically. A GPS equipment package accurate enough for tsunami survey work is in the \$15,000 to \$50,000 price range. This includes a base receiver and remote measuring receiver logger that you can easily move and log positions. Just a few years ago the equipment cost was over \$100,000. The kinematic system does not use the "p" code but the manufacturers have developed systems that are very accurate. It is important to note that the kinematic system gives good lateral positions as well as elevation.

Dr. Gonzalez: But that is referred to the base station.

Mr. Sigrist: That is right. Your final, absolute survey positions and elevations are only as good as the accuracy of the position elevation of the base station. The base station receiver takes a short time to stabilize (about an hour). Once stabilized, the remote receiver logger can quickly obtain positions elevations in the survey area. I understand the remote receiver logger can capture a position following a less than one minute stabilization period.

Prof. Shuto: You use the satellite communication for that survey?

Mr. Sigrist: It uses GPS. The base receiver and remote receiver logger capture the GPS signal and also maintain communication with each other. Since the system is passive, it only receives the GPS signal and does not communicate with any other satellite.

Prof. Shuto: What I would like to know is if you go behind some hill, can you do this?

Mr. Sigrist: The system is basically line-of-sight so you will need to maintain a generally unobstructed view of the base receiver. For example, you wouldn't be able to work on the other side of a mountain, however, the system can accept some attenuation created by smaller obstacles blocking the path between the base receiver and the portable receiver logger. The distance between the base receiver and the portable receiver logger is limited to about 1 to 2 kilometers. This provides flexibility in surveying a relatively large area before you would have to relocate the base receiver.

Prof. Shuto: I would like to use this kind of machine, not only for the run-up survey but also to make the contour map of the area, because in the Okushiri case we found it was very difficult to obtain the detailed map for run-up simulation.

Mr. Sigrist: Exactly. In conjunction with the aerial photo techniques Dr. Gonzalez is developing, you can obtain some fairly accurate GPS positions and elevations. Working with stereo aerial photo pairs, you can process a lot of data very quickly. That is a real good point.

Prof. Shuto: What is the name of the company?

Mr. Sigrist: Trimble Navigation is one of the manufactures of the kinematic GPS equipment. I'll have additional information on the kinematic technology and the various manufacturers at a later date.

SOME RESULT OF STUDIES OF U.S. TSUNAMIS

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Abstract

A critical re-evaluation and improvement of the U.S. historical tsunami data base is being undertaken. The resulting data base will be useful in understanding the extent and nature of the hazard for mitigation purposes. To the extent possible primary and contemporary sources are being used including marigrams since 1854, newspapers since 1846, and church, government and private documents. This has been completed for the U.S. west coast with an unexpected conclusion being that almost all local tsunamis are best explained by landslide sources, including the San Francisco bar, a sedimentary feature west of the Golden Gate not previously considered a source of minor tsunamis. Of 62 reported possible local tsunamis on the U.S. west coast only 18 were judged to be validity 3 or 4. Work on the Alaska history includes a re-examination of Russian period documents. Teletsunamis, and tectonic, volcanic and landslide sources are examined separately. Alaska appears to have only a minor hazard from teletsunamis with only three being large enough to be directly observed. Glacial terrain features are a major and almost unique source of Alaskan tsunamis. Hawaii has the highest hazard from teletsunami worldwide.

Introduction

A detailed history of tsunamis effects for a locality and region is the essential first step in designing an effective mitigation. The general characteristics of the phenomena, its modes of generation, propagation and coastal effects, are well understood. However, the hazard at any locality is controlled by local conditions including the width of the shelf, exposure to the open ocean, shape and area of the harbor, existence of submarine canyons or trenches, islands, river channels, land topography and other factors. It also depends on the locality's relationship to possible source regions, local or teleseismic, and the directionality of these sources. Local tsunamis may originate from tectonic, volcanic, and subaerial and submarine landslide sources. Further, its hazard potential is affected by temporal conditions such as the state of the tides, and day of the week and seasonal changes in activities. Depending on local and source factors tsunamis may appear as breaking waves, fast rising tides, bores or swift currents.

A detailed history is useful for analysis of the local hazard and to support modelling, the other main approach to deal the complexity of the local hazard problem. This need for a historical data base has been recognized by the UNESCO/IOC International Coordination Group for the Tsunami Warning System in the Pacific in their Master Plan and WDC-A has recently published a "Catalog of Tsunamis on the Western Coast of Mexico," by Sanchez and Farreras. The U.S. has just completed a thorough revision now at the printers entitled, "Tsunamis Affecting the United States West Coast, 1806-1992," by Lander, Lockridge and Kozuch, and is revising the tsunami histories for Alaska and Hawaii with National Science Foundation support. These are contributions to the international program and as support for local hazard mitigation efforts. Figure 1 shows that 95% of the tsunami fatalities occur in the local range.

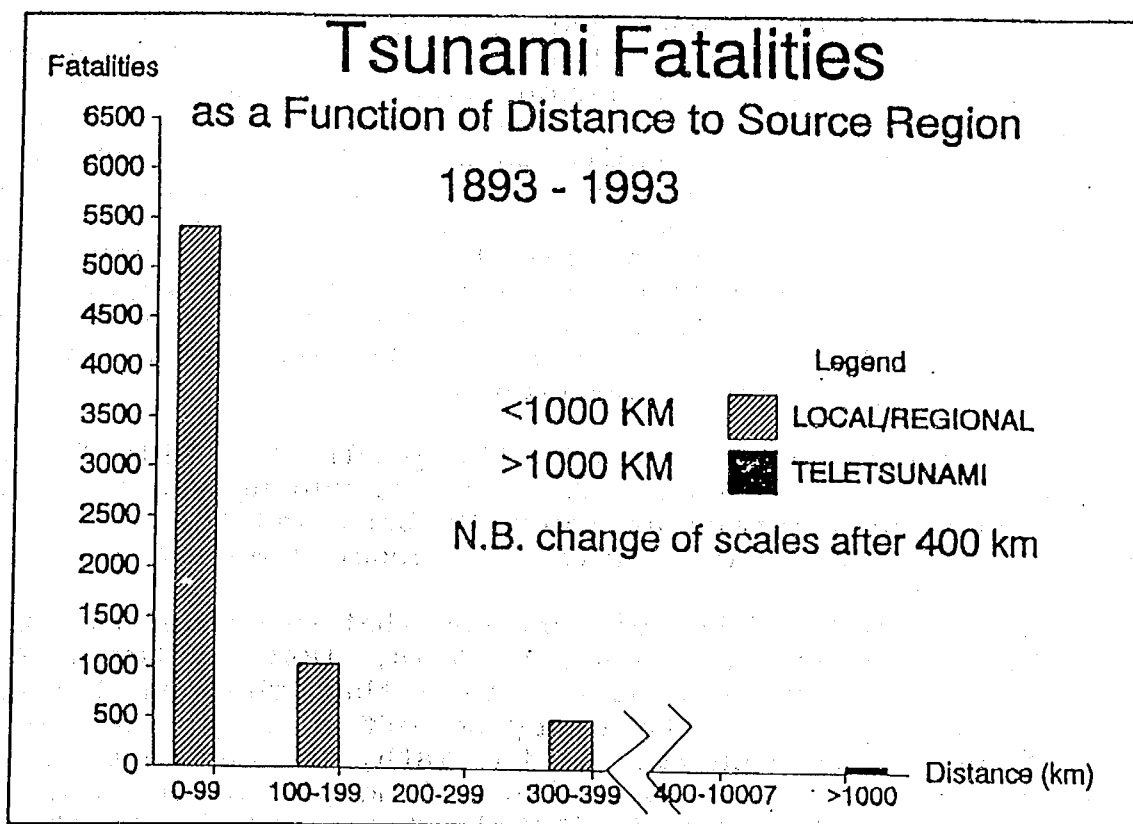


Figure 1 Number of fatalities in the last 100 years as a function of distance to the epicenter illustrating the predominance of the local hazard.

U.S. West Coast Tsunamis

In compiling the history for the U.S. West Coast 52 potential local tsunamis and 62 teletsunamis were investigated. The natures of the local and teletsunamis hazards are so different that they need to be treated separately. Early reports were sought from newspaper accounts beginning in 1846, marigrams beginning in 1854, early church records from 1789 to 1835, Russian American Fur Company records for Fort Ross, California for 1812 to 1842 and other sources.

Of the 52 possible local tsunami reports, 18 were rated as validity 3 or 4, probably or certainly valid reports (see Table 1). This is probably high, particularly for the early years as events were accepted as validity 3 if they seemed to describe a tsunami and there was no other explanation available, even if only one source reported the effect. It was considered more conservative to include them for risk evaluation than to eliminate them.

A careful reading of the effects led to a conclusion that almost all were best characterized as being submarine or subaerial landslide origin. This included having the epicenter on land or far removed from the wave or having only a low earthquake magnitude event or in the case of the 1878 tsunami no associated earthquake. Several examples follow.

December 21, 1812, a magnitude 7.7 earthquake caused damage (intensity VIII) at Santa Barbara, California and elsewhere. Accounts pieced together from church records and later interviews published in newspapers describe the water as withdrawing and forming a high hill. The inhabitants fled to the mission fearing the wave's return. The description is identical with landslide generated waves in 1964 Alaska event. If this was a tectonically generated tsunami Santa Barbara would have been at the very center of a magnitude 7.7 earthquake since they were in sight of the wave's formation and the intensity would have been several grades higher. Also, offshore is the Santa Barbara basin, a known repository for mass transport sediments.

It is quite simple to compute the predicated tide for past dates as well as future dates. The tsunami run-up was deduced as a little less than 3 meters at Santa Barbara and the tide height was +0.9 meters giving a wave height of about 2 meters.

A classic example of the distortions that can enter historical accounts is the events of January 16-18, 1840 at Santa Cruz, California. The original reports state that the sea did great damage on the 16th and 17th carrying off a supply of roofing material 182 meters from shore. On the 18th, the church tower fell due to water soaked ground following a long period of rain. The first cataloger, H. H. Bancroft (1886), described the event as an earthquake and tidal wave. The second cataloger (Holden, 1887) added intensity IX (Rossi-Forel scale) based on the reported damage. Later catalogers converted the intensity to a magnitude 6.3 and probably into acceleration and earthquake risk zones. There was no earthquake or tsunami, only storm waves and heavy rains. This illustrates the importance of checking earliest reference.

A third example was a "wave" at 3 A.M. on September 24, 1859 at Half Moon Bay, California, in which the water receded beaching and damaging the Schooner "Black Warrior." The San Francisco papers report a moderately severe shock of an earthquake at about 6 A.M. and questioned the time of the Half Moon Bay report. Again, a run of the tide predications showed a extra lower low water at 3

DATE	LOCATION	VAL	CAUSE	MAX. AMP. (m)	COMMENTS
1812 Dec. 21	Santa Barbara, CA	4	Submarine* Landslide	2.0*	Low areas flooded
1854 May 31	Santa Barbara, CA	3	Landslide?		Light earthquake, sea swell
1854 Oct. 21	San Francisco, CA	3	Landslide?		Vessel heaved
1855 Jul. 10	Los Angeles, CA	3	Submarine Landslide		Earthquake on shore, two heavy swells
1856 Feb. 15	San Francisco, CA	3	Submarine Landslide		Earthquake, Water muddy Bay rose for five minutes
1862 May 27	San Diego, CA	4	Subaerial Landslide	0.9	Earthquake generated wave on beach
1865 Oct. 8	Santa Cruz, CA	3	Subaerial Landslide		
1868 Oct. 21	San Francisco, CA	3	Landslide?		15-20 foot runup
1873* Nov. 22	Port Orford, OR	3	Tectonic or Landslide	3.0	Waves observed and debris above highest water mark
1878 Nov. 22	San Luis Obispo, CA	3	Submarine Landslide		Damage, one fatality*
1891* Nov. 29	Puget Sound, WA	3	Landslide		Two or more separate waves
1901* Mar. 2	Monterey, CA	3	Submarine Landslide		Epicenter near Parkfield
1906 Apr. 18	San Francisco, CA	4	Tectonic or Submarine Landslide	0.1	Small recorded wave, San Fran. Bar source?*
1927 Nov. 4	Point Argullo, CA	4	Tectonic or Landslide*	1.8	Byerly field investigation, Minor damage to R.R.
1930 Aug. 30	Santa Monica, CA	3	Submarine Landslide	3.0*	1 killed, 16 rescued*
1949*, April 15, April 17	Seattle, and Tacoma, WA	4	Submarine- Subaerial Landslide	1.2	Minor damage 11,000,000 cubic yards
1989* Oct. 19	Loma Prieta, CA	4	Tectonic and Submarine Landslide	1.0	Recorded
1992* Apr. 26	Cape Mendocino, CA	4	Tectonic	0.8	Recorded Minor damage*

Table 1 Validity 3 and 4 U.S. west coast tsunamis. Some validity 3 events depend on a single report and may be over rated. Entries marked with an asterisk are new in tsunami catalogs.

A.M., most likely the reason for the bottoming of the Black Warrior rather than a tsunami.

A fourth example is of a 20 foot (6m) wave (height) at Santa Monica which caused a fatality. Its first report in the scientific literature (Townley and Allen, 1939) mistakenly listed the height as 2 feet (0.6m) as did all subsequent catalogs. This again illustrates the need to check primary sources.

Only the most recent west coast tsunami, April 25, 1992, does a tectonic source seem certain and it is peculiar in several ways. It was not observed by people on the beach in the source area and was directly observed only at three localities at distances of 60, 100, 160 km from the source. The wave was generated on the Mendocino escarpment and apparently traveled parallel to the coast. The recorded wave showed an emergent and uncertain beginning and took several hours to reach a maximum recorded height of only 1 meter. There were about 50 minutes between the earthquake occurrence and the first wave's arrival at Crescent City, time enough for an advisory to have been received. No warning was issued or needed.

The small tsunami associated with the Loma Prieta earthquake which was recorded at Monterey almost certainly was a mix of a tectonic event generated near Santa Cruz and a submarine landslide near Moss Landing. Apparently three events, October 8, 1865, October 21, 1868, and April 18, 1906, were associated with the San Francisco bar, a sedimentary feature west of the Golden Gate not previously noted as a potential tsunami source.

The magnitude 7.3 November 4, 1927 Point Arguello event could be of tectonic origin as the epicenter was off shore. The fact that a similar event occurred there in 1878 without an earthquake, the rather small length of coast affected and the appearance of the marigram at San Francisco also suggest that a submarine landslide could be involved. A second earthquake 19 minutes later was smaller seismically but reported to be of a more severe intensity. Byrely (1930) deduced this even was shallower, an impossible conclusion if the first shock ruptured the surface.

The unexpected fact that almost all local tsunamis had landslide sources has several important implications. Although if some, such as the 1812 tsunami, were to re-occur the damage would be higher, the area affected is relatively small and the reaction time is short. Most were observed at a single point and the largest, 1812, was reported for only 100 km of coastline. For most, the natural warnings of an earthquake or sudden withdrawal of the water may be the best warning. Communicated warnings, if given, should be limited in area. Areas of known hazard such as submarine canyons, or basins or offshore deposits should be made aware of this hazard. Local tsunamis have caused only two fatalities.

Of the 62 teletsunami events, 47 were judged to be validity 3 or 4 due to the existence of mariographic recordings. Of these only 15 were large enough to have been observed directly and 7 were large enough to produce at least minor damage (see Table 2). 97% of the damage and 94% of the fatalities were due to a single tsunami, the April 24, 1964 Prince William Sound event. A notable phenomena was the focusing of research and reporting on the most heavily damaged area, Hilo, Hawaii for the 1946 and 1960 events, and on Crescent City for the 1964 event. This meant that for the largest and most destructive tsunami known for the coasts of Washington and Oregon there was inadequate data gathering. There is a need for a thorough field survey for all damaging tsunamis including fringe areas.

DATE-GMT	LOCATION	VAL	MAG	MAX. AMP. (m)	COMMENTS FOR WEST COAST
1896 Jun. 15	Japan	4	7.6	1.0	Damage at Santa Cruz? Observed at Mendocino, recorded at Sausalito
1946 Apr. 1	Unimak I. Aleutians	4	7.8	3.0	Recorded; a fatality at Santa Cruz, \$10,000 damage
1952 Nov. 4	Kamchatka, Russia	4	8.2	0.6	Recorded widely and boats sunk at Crescent City, minor damage
1957 Mar. 9	Aleutian Is.	4	8.3	1.0	Recorded, observed, minor damage at San Diego
1960 May 22	Chile	4	8.6	1.4	Boats sunk, injuries, \$500,00- \$1,000,000 in damage, 1 fatality
1964 Mar. 28	Alaska	4	8.4	4.8	\$15,000,000 in damage, 17 killed
1975 Nov. 29	Hawaii	4	7.2	1.4	Recorded, \$1,000 damage at Catalina Is.

Table 2 List of Teletsunamis causing at least minor damage to U.S. west coast.

The waves appeared most often as bores or surges up river and stream beds particularly on the Washington and Oregon coasts. Currents set up in relatively secure harbors such as Los Angeles in 1960 (\$1,000,000 in damage) and San Francisco in 1964 (\$1,000,000 in damage) cause extensive damage to fishing and pleasure craft. These currents depend on the height of the wave and its period and are nearly independent of the tide stage. Currents apparently can reach 50 km/hr. but none have been directly recorded. The mooring systems are inadequate to withstand these currents.

Flooding occurs in other areas and appear as a rapidly rising tide and never as a breaking wave. The popular concept of a

tsunami as a large breaking wave as in the Hokusai painting leads to widespread misunderstanding of the phenomena by officials and the public. As recently as 1960 an official of the Coast Guard at Crescent City is quoted as saying "It really wasn't a tidal wave that hit the harbor (Crescent City) but a series of surges from it, the biggest eight and a half feet."

The three tsunamis with more than trace damage occurred in 1946 from the Aleutian Islands, in 1960 from Chile, and in 1964 from Prince William Sound, Alaska. Tsunamis from Japan (1), Kamchatka (2), Chile (1) and Hawaii caused negligible damage, and no damage has occurred from tsunamis from Mexico, Central America, South Pacific Ocean or the Philippines. Due to the directionality factor the Prince William Sound event was by far the most destructive. However, the seismic energy from that source has been expended and it should be of low threat for perhaps a century. Tsunamis generated much farther west of Unimak Island probably would not be much of a threat, again due to its directionality.

Over warning is a problem. For example, the operator of a gas station in Crescent City in 1964 reported, "At 11:15 P.M. a tourist and I heard the news that a tidal wave was due to hit Crescent City about midnight. I told him we have had false alarms before. I laughed at several customers that asked me if I intended to close the station and get to safety." Within two hours the water had forced him, and three others onto the service racks, with 2.1 to 2.4 meters of water in the station. The power failed and the storage tanks caught fire. Luckily, all escaped.

To be effective a warning must be credible and acted on. A warning received for which a hazardous wave does not arrive is perceived as a false alarm and it undercuts future response.

The estimated time of arrival is often erroneously perceived as the time of maximum hazard. Warnings should carry information on the probable height range, duration of the hazard and effects of the tide stage on inundation.

Alaska Tsunamis

The work in Alaska is still in its early stages. It has four distinct sources of tsunamis - teletsunamis and local tectonic, volcanic and landslide tsunamis. An examination of the teletsunamic tsunamis shows that only one event was observed before 1944 when tide gages became more plentiful. Only three have been large enough to be directly observed and two caused very minor damage. One could conclude that teletsunamis do not pose a threat and warnings should be replaced by alerts or advisories. Tectonic local earthquakes along the Aleutian arc are hazardous both locally and at teletsunamic distance. However, the population of the Aleutian Islands is very low. Almost all of the damage associated with Alaskan tsunamis was due to the 1964 event, an event not likely to soon return. Only one volcanic event, an eruption in 1883 of Mt. St. Augustine produced a tsunami. It produced a wave

7.6 to 9.1 meters high at Port Graham, taking an hour to cross the Cook Inlet sound. The effect was similar to other subaerial landslide tsunamis in affecting only a limited area. At Kodiak, 200kms to the southeast it was recorded with an amplitude of only about 7.5cm.

Landslide tsunamis predominate along the Alaskan panhandle and are mostly related to glacial effects; collapse of steep fjord walls as at Lituya Bay, collapse of glacial outwash deltas as at Valdez and falling ice. Many but not all are associated with earthquakes and large earthquakes may cause multiple local landslide tsunamis. There were about 20 documented submarine landslides with the 1964 earthquake. About 75% of the tsunami fatalities from all sources in Alaska have been due to landslide generated tsunamis. These are very local with little time to take any evasive action and still less time for a communicated warning to be effective. The later, in effect, tells people that "there has been a strong earthquake" which they already know and "be alert for a possible tsunami" which they should know.

Hawaiian Tsunamis

Hawaii's history is better known. The principal source of damaging tsunamis are from teletsunamis although all areas are not equally dangerous sources nor are all the islands equally at risk. Oahu, where 80% of the population reside, does not have a history of extensive damage as does Hilo on the Island of Hawaii. This is due to the coral reef around Oahu but absent around the newer Island of Hawaii. Oahu is also partially sheltered by other islands. However, since so much of Hawaii is coastal and depends on marine activities warnings are particularly disruptive. A slight decrease in the false alarm rate would save substantial amounts of money and improve response when it is needed for potentially destructive tsunamis. An improved history of inundation can lead to better risk maps and have large impacts on property values. Hawaii and to a lesser extent, the U.S. west coast are nearly unique in having teletsunamis as the principal source of damaging tsunamis. Yet, to a large extent it is used as the model for much of our mitigation effort elsewhere.

Damaging local tsunamis are mostly on the south coast of the Island of Hawaii. One consequence of the fact that many of Hawaii's tsunamis are from remote sources is the problem of identifying the source of wave activity observed there. Two such problems have recently been solved. A re-examination of the date of earliest reported Hawaiian event then given as 1813 or 1814 by Doak Cox (1989), at the suggestion of the author, was able to find an improved date of December 20-22, 1812 and the probable source was the December 21, 1812, Santa Barbara, California tsunami.

The second event was recorded by three stations on the U.S. west coast on August 23, 1872. It was observed at Kauai, and Hawaii, and recorded at Honolulu. The first analyst, Professor Davidson (1872), put the source in the Kuril Islands. Jaggar

(1931) and others believed it was local to Hawaii. Soloviev & Go (1974) suggested a source in the Bonin Islands. Cox (1984) calculated a location in the Fox Islands, Aleutian Islands. This location was uncertain since it depended critically on the time of arrival of the tsunami at Honolulu as reported in the press since the marigram could not be located. A recently discovered marigram from St. Paul Island, Bering Sea, confirms the Fox Island location, ending a 120 year quest and providing the first instrumental earthquake epicenter.

Conclusion

In conclusion, each area is different and mitigation efforts should be tailored for the local problem. A thorough historical tsunami data base is an essential first step. This requires seeking out primary references in government documents, ships logs, museums, newspaper collections, marigrams, etc. Tools such as hindcasting tides can be useful. The data base can then be studied for the nature of the problem. Warnings, when needed, should carry information wave height range, duration of the hazard, tide prediction when possible and other operational information. Other forms of mitigation including education, land use, and engineering defenses are probably more important for local tsunamis than communicated warnings in these areas.

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Mr. LANDER:

Mr. Sigrist: I would like to comment on that picture of Hilo harbor where the people are patiently waiting for the tsunami to arrive. I wonder if we had a repeat of an event similar to the 1960 tsunami, and knowing how the media covers news events with live video, if we could successfully keep the media and general population away from the tsunami hazared areas.

Secondly, as we begin to protect harbors and tsunsmi prone coastlines with breakwaters and rip-rap, are these manmade structures themselves modifying the tsunami waver? For example, in harbors or protected areas, are the structures inducing damaging currents. It would be interesting to inquire if design considerations take into account the potential for inducing increased damage in one area while protecting another area.

Mr. Lander: I don't think in the United States the tsunami problem figures prominently in the design of harbors. The currents do not depend much on the state of the tides but on the wave period and its amplitude.

Concerning the first question the Civil Defense in Hilo now have police powers to force evacuation and that scene will not likely be repeated at Hilo. However, elsewhere in the United States I am sure that the curiosity seekers will gather at beaches hoping to see this rare phenomena. Most people learn about the tsunami from the radio and televison and that is an opportunity to remind people of the risks. They do not have much history of damaging waves.

Dr. Gonzalez: I was just wondering, at one point you said that there were 52 events on the U.S. west coast that you investigated. Only 18 of them turned out to be reliable and then of those only 3, and they turned out to be the most recent events, appeared to have a seismic cause. There is such a bias there towards recent events, that it made me wonder whether our information on the remaining 49 events which were older events, or at least a sub-set of those 18 events, was good enough to make a judgment on whether they were seismic or not.

Mr. Lander: This is a coincidence, I think. There isn't time in a twenty minute talk to present the evidence of a landslide origin for each of the fifty events but the following examples may suffice. Some of the tsunamis were not associated with earthquakes such as the 1878 Cape Arguello tsunami. Some tsunamis such as the 1901 Monterey Bay event with an earthquake in Parkfield were associated with earthquakes too far away to have directly caused the tsunami. For the 1812 Santa Barbara earthquake and tsunami the description says that the people saw the water reced and from a high watery hill. They fled to higher ground. It is difficult to imagine a tectonic sequence which would cause the water to recede and form a high hill. They fled to higher ground. It is difficult to imagine a tectonic sequence which would cause the water to recede and form a high hill, a classic description of submarine landslide tsunamis in Alaska. Also, if they were able to see the formation of a tectonic tsunami they would have had to have been at the very epicenter of the magintude 7.7 earthquake and the intensity would have been higher than the 8 assigned and probably large enough to have interferred with their observation and evacuation. The description of each event will be in the "Tsunamis Affecting the West Cost of the United States; 1806 to 1993" volume soon to be published by NOAA.

Prof. Abe: I want to know why you didn't show the 1952 Kamchatka tsunami in the

west coast.

Mr. Lander: Where were some minor damage reports including two log booms in Oregon being broken from their moorings, five small fishing boats being overturned by the currents at Crescent City, California because they were moored fore and aft and a concrete bouy mooring was moved. The wave had a maximum amplitude of about one meter. The total damage was only a few thousand dollars, and the total damage for all tsunamis on the west coast in about \$18 or \$19 million.

Dr. TSUJI

Prof. Yeh: I have a question to Dr. Tsuji and also Dr. Gonzalez. Did anyone a conduct survey on other islands, east of Flores, like Adonara Island and Lomblen Island.

Dr. Tsuji: I have never heard of anyone.

Prof. Yeh: The reason I said that is that the tsunami ran up at Kroko is very high and a little bit more north is also high. There must be some waves propagated further east. Dr. Gonzalez, you did some area survey for those areas. Do you have any idea if there is any sign of tsunami damage on those islands?

Dr. Gonzalez: First of all, we did cover with the aerial survey the north coast of Adonara Island and those photos have not been examined yet. The second thing is, and I'm not sure of this, but I seem to remember that while we were on Flores at Larantuka, we asked if there was any damage on the north coast of Adonara. I got the impression that there was about a 1m high tsunami there, that the wave actually approached but it did not do a lot of damage. But my memory is not very good on that.

Dr. Tsuji: Have you heard about an additional survey team sent to this coast after our survey? Was there another party? No? It is necessary to survey the eastern part of Adonara Island or the Slavatia Island coast.

Mr. Lander: One question, Dr. Tsuji. Did you decide what the total number of fatalities were? They were grossly overestimated in the early reports. It seems to be about 800 now down from 1068 earlier.

Dr. Tsuji: The original source of those numbers is somewhat different. I obtained a copy of the newspaper Compass and I found the number of casualties from each village from the articles and I quoted them on this map.

Mr. Lander: This is a more accurate account then?

Dr. Tsuji: Yes, but changeable. I found out the number of casualties of Babi Island, where first 700 or 800 persons were killed. Then I visited the sheltering camp and found out the total number of the population and the real casualty number was about 160 persons. Many persons living on Babi Island were suddenly lost due to the tsunami and they were first thought killed, but many persons went by swimming or by their own boats to the mainland and after the setting of the sheltering tent, the dead persons appeared again and the statistics suddenly changed one week after the event. And the total number of persons killed suddenly diminished 10 days or 2 weeks after the event. But the number of the statistics at the air force or other places were not changed and we also considered that the number of the casualties at Babi Island was 800 or 700 or so, but it is not exact.

Prof. Shuto: Was there any evidence of the generation of the tsunami by local landslides? The reason why I ask is that during the symposium such a person as Dr. Dawson mentioned many landslides. So just as in the case of the 1964 Alaskan tsunami, maybe they had similar very local tsunami in Flores.

Dr. Tsuji: I saw the coastal line at Buffats. Not plantations. The trees are poor and easily destroyed, easy to make a landslide. And it was possible to have generated a secondary reason for the landslide. But with a height of 20m around that coast, it is difficult to consider that the main reason of such a high wave was due to the secondary happening of a landslide. But partially some landslide may have happened around that coast. Moreover the Lomblen Island event was generated in 1979. Another big landslide tsunami was generated here.

Prof. Abe: In your figure, the maximum point is in Kroko. About this detection have you any idea to explain this?

Dr. Tsuji: Dr. Imamura made the numerical calculations for this event according to the distribution of after shocks and the CMT solutions. It is very difficult to explain about such a high tsunami along this coast. He tried making two separate fault planes and the eastern planes is considered about 3 times the deformation of the western one, but it is very difficult to explain up to this height.

THE REPORT ON THE TSUNAMI DISASTER IN HOKKAIDO

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Abstract

Okushiri Island was devastated by the huge tsunami caused by the Hokkaido-Nansei-Oki earthquake on July 12, 1993. This paper shows the distribution of vertical runup heights and horizontal runup distances from the coastline. It can be thought that a product of a vertical runup height and its horizontal distance, a kind of the magnitude of tsunami energy, gives better explanation of disaster level. It shows ground movements by the earthquake, too. Some ground subsidence was found after the earthquake.

Introduction

The Hokkaido-Nansei-Oki earthquake of magnitude 7.8 rocked the west coast of Hokkaido. Figure 1 shows the earthquake intensity. The earthquake caused devastating tsunami which hit Okushiri Island and the west coast of Hokkaido. The death toll was 200, 33 were still missing, and the property losses were 100 billion yen within Hokkaido as August 16. PWRI surveyed vertical tsunami runup heights along the southwest coast of Hokkaido and Okushiri Island's coast. Geographic Survey Institute, Ministry of Construction, surveyed tsunami inundation area and subsidence of ground of Okushiri Island by using aerial photographs. Many survey teams measured a lot of vertical runup height. First, we show the distribution of vertical runup

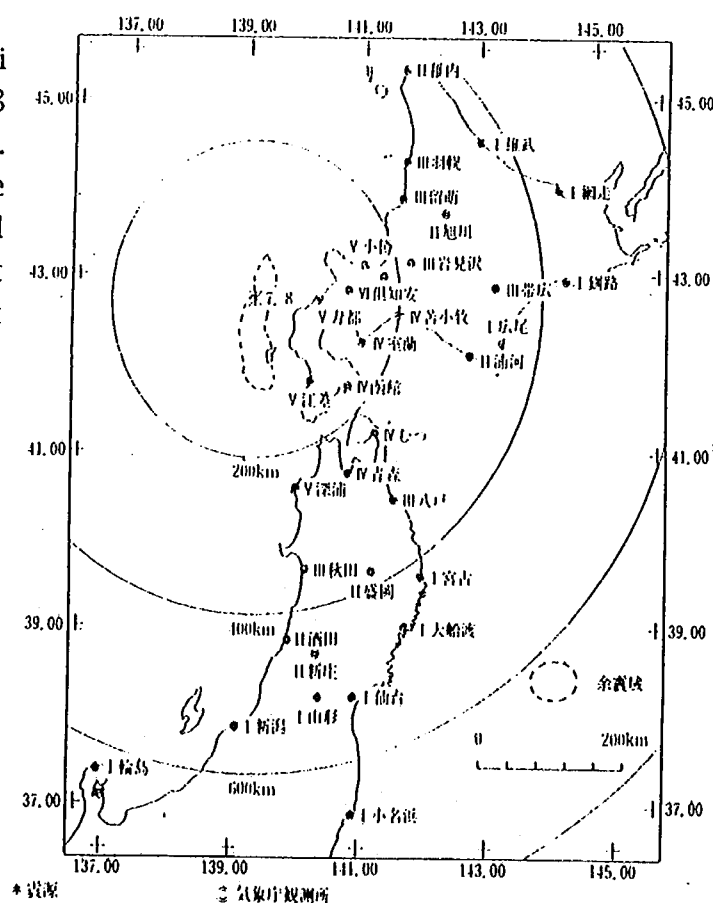


Fig. 1 Distribution of Earthquake Intensity(after Meteorological Agency)

heights along the coast. Next, we show the distribution of horizontal runup distance. Finally, we show the distribution of product of a vertical runup height and its horizontal distance.

Vertical ground movements were also surveyed for Okushirri Island. The result shows greater ground subsidence occurred on the west coast of the island.

Field Surveys

PWRI field survey team, Mr. H. Ito, Mr. K. Yamamoto, Mr. Y. Iwasaki, Mr. K. Sasaki, Mr. A. Hattori, measured vertical runup heights along the southwest coast of Hokkaido and Okushiri Island. They selected local maximum runup points and measured vertical height above sea level of each point using a handlevel and staffs. They also wrote down the time of each measurement and modified the vertical height referring to the tide table of Esashi Port. Figure 2 shows vertical runup heights by PWRI for the southwest coast of Hokkaido. The runup heights are higher in Shimamaki, Setana, Kitahiyama, Taisei. Figure 3 shows the runup height distribution for Okushiri Island. PWRI survey team could not survey some west part of the island. PWRI's highest runup 19.8 m was found at Cape Kuki and the second one 15.9 m was at Hatsumatsumae. The witness near the Miyatsu Fishery Port in Okushiri Island said that he had no time to shut the gate of the slipway.

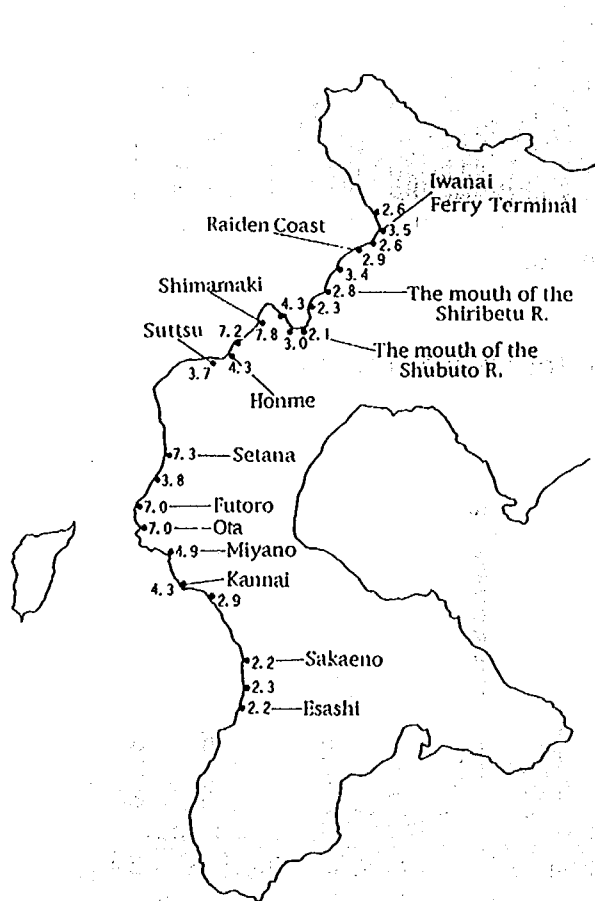


Fig. 2 Tsunami Runup Height for the southwest coast of Hokkaido

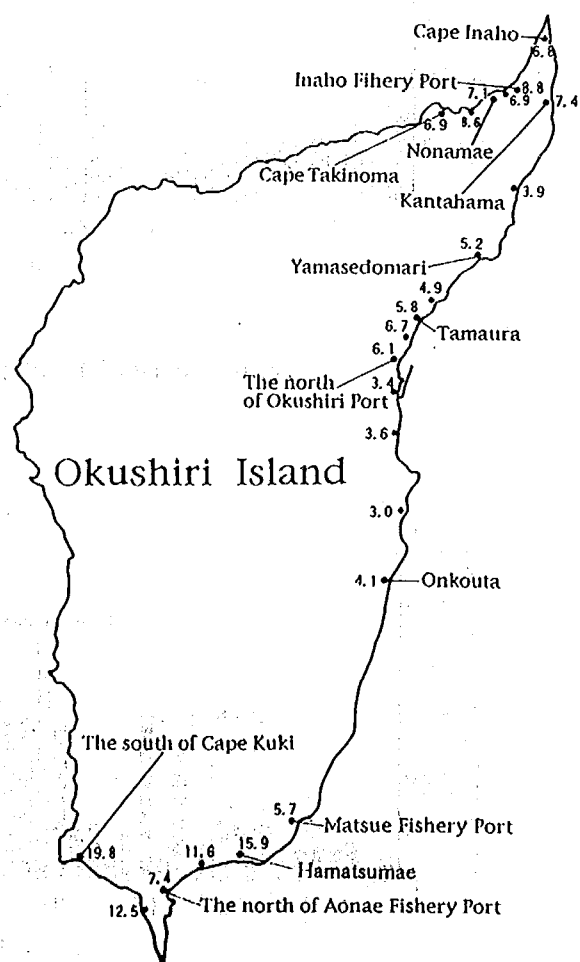


Fig. 3 Tsunami Runup Height for Okushiri Island

Tsunami Runup on Okushiri Island

GSI measured the vertical runup height from the aerial photograph and they also showed tsunami inundation area onto a 1:25,000 map. Figure 4 shows runup heights by field survey and aerial photogrammetry. Horizontal runup distances for those points were measured from the map are shown in Fig. 5. The horizontal axis of these figures indicates survey point in Fig. 6. As one can easily imagine, the vertical runup height distribution is not similar to horizontal runup distance one. It was reported that Aonae to Matsue, Inaho and Monai were heavily damaged. These situations cannot be explained by vertical runup height distribution only nor horizontal runup distance only. It can be thought that a product of vertical height and horizontal distance could eliminate the effect of coastal topography on runup. Figure 7 shows distribution of the product in the same format as Fig. 4 and Fig. 5. The legend indicates source of vertical runup height. One can find from this figure that the product explain disaster level well.

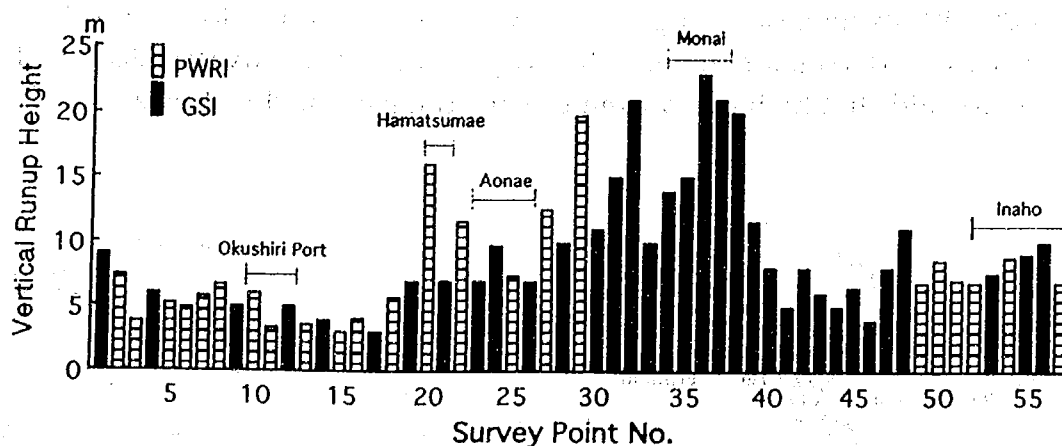


Fig. 4 Vertical Runup Height for Okushiri Island

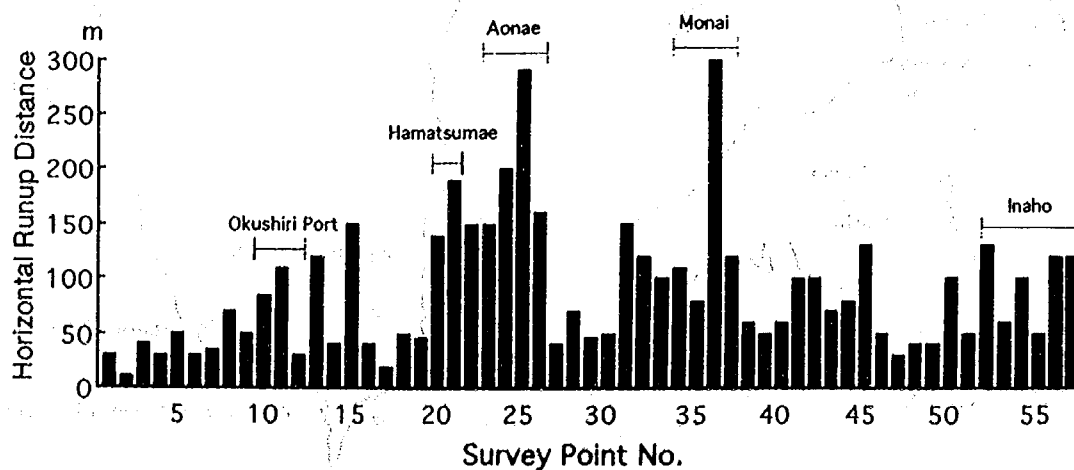


Fig. 5 Horizontal Runup Distance for Okushiri Island

Ground Subsidence

There had been a broad flat rocky shore along west coast of Aonae Peninsula or in front of Senjo, which means thousands of floor mats. The latter is located in the north of Cape Kuki. However, very narrow shore remained after the earthquake. GSI measured ground movements by comparison between aerial photograph in 1976 or 1988 and after the earthquake (July 14). They also carried out the field surveys and GPS observation. Figure 8 shows ground subsidence for Okushiri Island. The contour lines of subsidence run approximately north to south. It can be found that bigger subsidences are on the west coastline and that the maximum subsidence is 80 cm. It must be remember in planning of countermeasure against near-field tsunami that ground subsidence will be possible to take place.

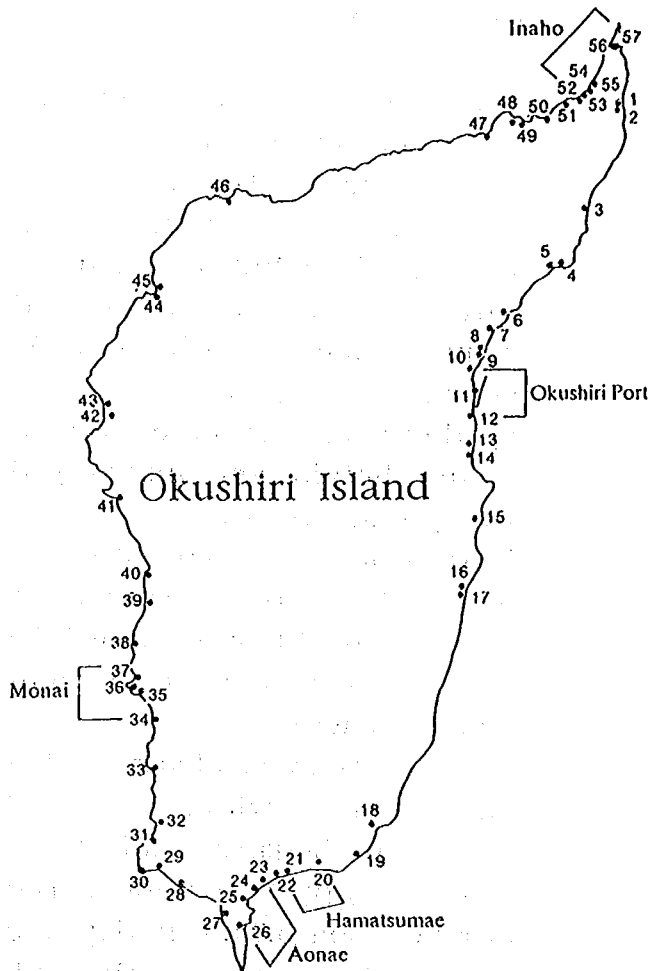


Fig. 6 Survey Point No. in Fig. 4, 5 and 7

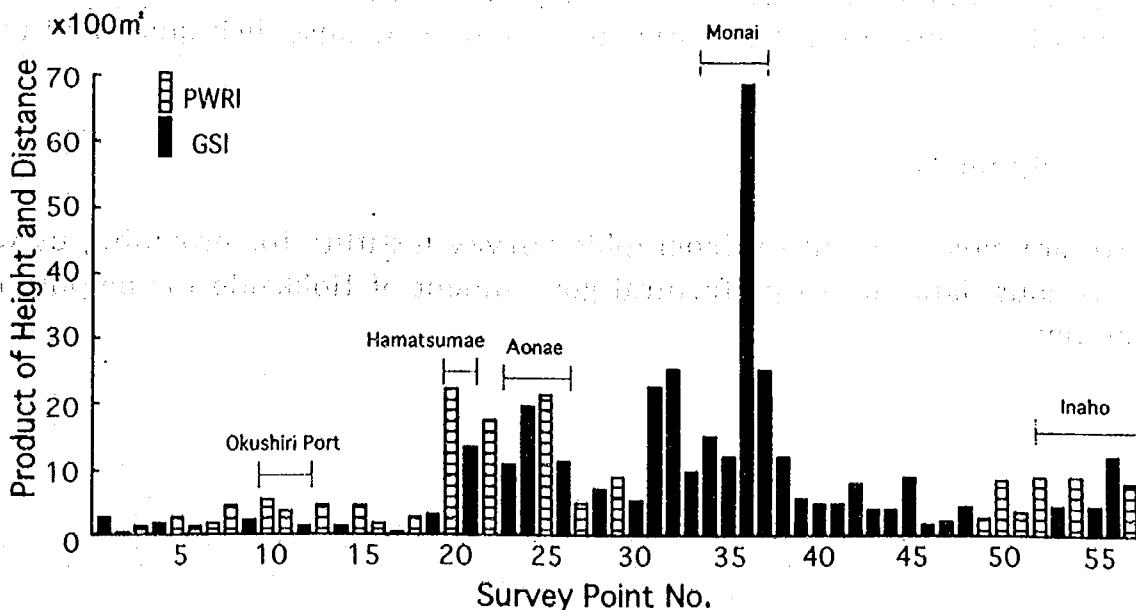


Fig. 7 Product of Vertical and Horizontal Distance for Okushiri Island

Conclusion

The coastal topography has much effect on the tsunami runup against the shoreline. Therefore, the vertical runup height distribution usually differs from the horizontal runup distance distribution. As shown above, however, the synthetic information of vertical runup height and horizontal runup distances can explain the distribution of tsunami disaster level well. So the average value of the product in a region will be useful to evaluate the incident tsunami energy.

By the way, we had another big earthquake which caused tsunami in the Japan Sea in 1983. It was happy that it occurred around noon on a fine day and the death toll was minimized. Unfortunately, on the other hand, Hokkaido-Nansei-Oki earthquake tsunami took place in

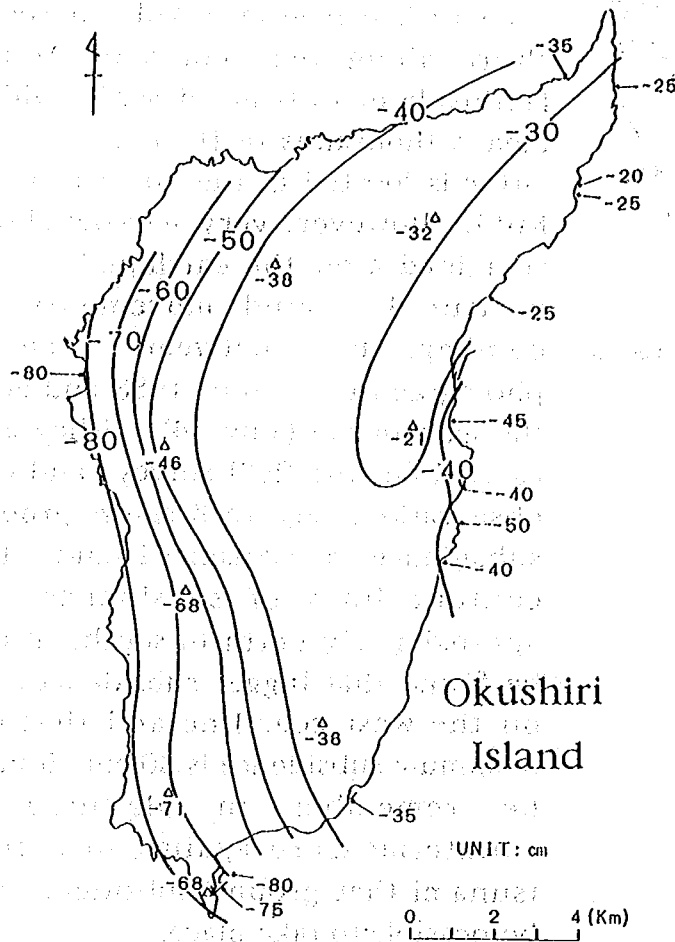


Fig. 8 Ground Movement in Okushiri Island

worse conditions. But the event gave us very instructive information. We realized that bigger tsunamis than planned would occur and we should introduce a comprehensive tsunami disaster mitigation program against such quick and huge tsunami.

Acknowledgement

We are most grateful to Geographic Survey Institute for providing us with many precious data and to prefectural government of Hokkaido for helping our field survey.

Mr. TANAKA

Dr. Gonzalez: You had one plot with PWRI and GSI, yellow and white, and a vertical, I'm sorry what are those numbers?

Mr. Tanaka: This is the product of the vertical height and horizontal distance.

Dr. Gonzalez: So some kind of volume or area?.

Mr. Tanaka: Yes.

Prof. Shuto: Are you going to publish your results in some special issue of your publication? Do you have any idea about the possibility of GSI people also to publish their data as a special issue of this event?

Mr. Tanaka: I think I will make some report.

Prof. Shuto: Especially on tsunami or including every effect of the earthquake too?

Mr. Tanaka: Only tsunami.

Prof. Shuto: That's better. When I belonged to your institute, and when we published the special report about some earthquake and tsunami, everything was included. Therefore the details of the tsunami run-up were not written well, and the accuracy of the data was not good enough to use them afterwards.

Mr. Okada: I have a question. Could you tell me how you measured the inundation distance, such as Cape Aonae?

Mr. Tanaka: In the case of Cape Aonae, it depends on the point of the maximum run-up height. If the point is on the west side, we measure from the west shoreline. But if the point is on the east coast, then we measure from the east.

DAMAGE TO HOUSES CAUSED BY THE 1993 HOKKAIDO NANSEI-OKI TSUNAMI

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Abstract

New data of the degree of damage to individual houses are obtained for the 1993 tsunami and are compared with old data for tsunamis in the past, as a function of tsunami height and structure of houses. A big difference between new and old data is found in case of wooden houses. The reason may be due to increase of floating materials and change of house wall structure.

Introduction

The 1993 Hokkaido Nansei-oki earthquake generated a giant tsunami, which hit Hokkaido mainland and Okushiri Island. Damages to houses reported are as follows; 540 destroyed, 172 partially destroyed, 1,849 slightly damaged, 149 flooded above floor and 194 flooded below floor. The present paper summarizes the result of survey about the degree of damage to houses in relation to tsunami inundation height.

Tsunami in Aonae

Aonae is located at the southern tip of Okushiri Island. It consists of 5 sections; from the 1st section at the north to the 5th section at the south.

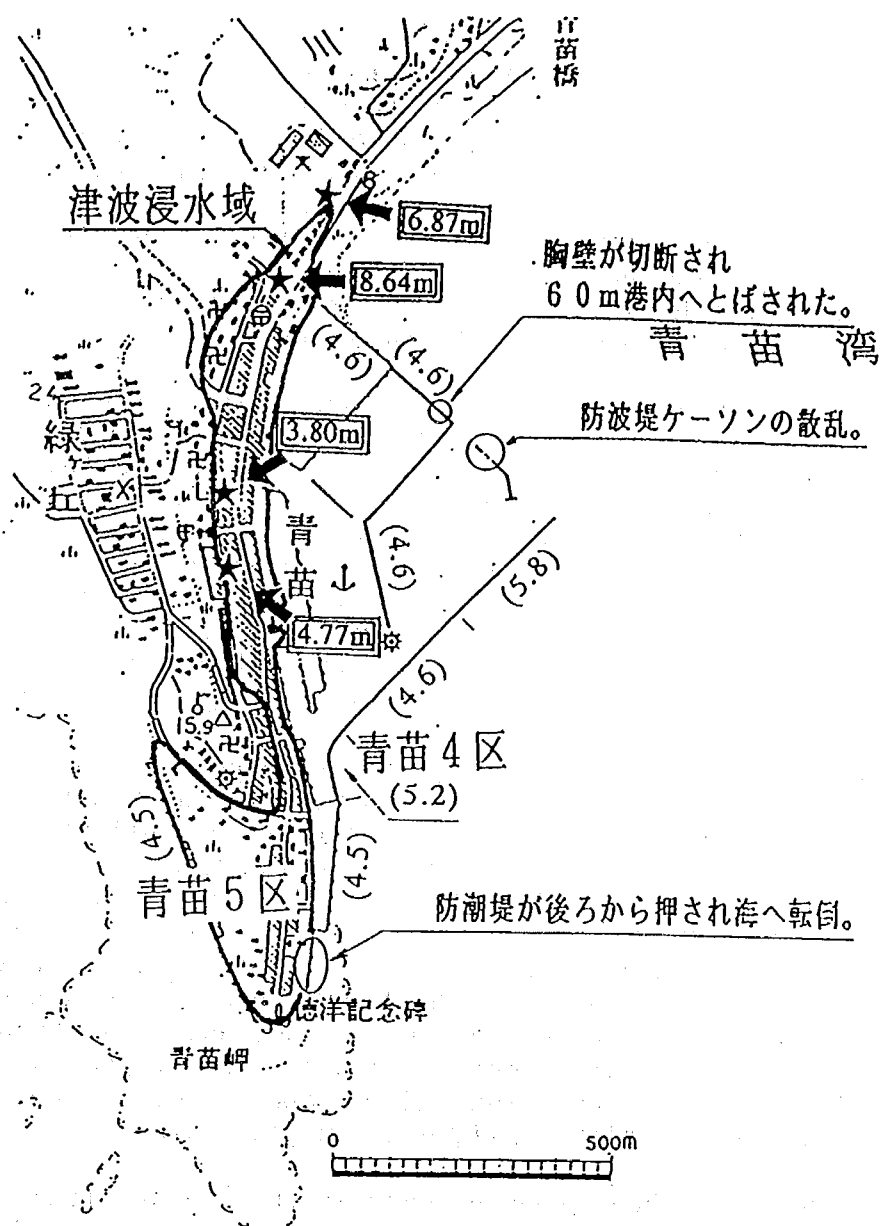
The 1st to 4th sections extend at the eastern foot of a hill 20m high. There is a low sand dune with pine forest on the seaside of the 1st section. The beach in front of the 2nd to 4th sections are recently reclaimed and the Aonae Fishing Harbor has been developed there. From the southern end of the hill, the 5th section of Aonae extends on a sand spit 2 to 3 m high.

Ten years ago, the 1983 Nihonkai-Chubu earthquake tsunami inundated the area and claimed 2 lives. After this experience, a sea wall 4.5 m high was constructed on the western side of the 5th section, and the old sea walls 3 m high on its eastern side was heightened to 4.5 m. Crown heights of breakwaters and sea walls at the time of the present tsunami were shown in Fig.1.

The 1993 tsunami hit the 5th section from the west, overflowed the western sea walls, washed away all the houses in the 5th section, and flowed out over the eastern sea walls by overturning them and scouring the ground in the neighborhood of the overturned walls. Only two things were left; a high strong memorial tower made of massive concrete which was almost intact, and a small public lavatory made of concrete blocks which was severely damaged.

The other sections were hit by the tsunami from the east, the origin of which is not yet known. It might be the extension of the tsunami above stated, which came round the shallows extending the south tip of the island, or the tsunami which came from the north, entrapped by the island. To a corner where the northern breakwater joins the end of the sand dune,

Fig.1. Aonae area. Inundated area is enclosed by solid lines. Stars are points where tsunami trace heights were measured. Numerals in double frame are tsunami trace height. Numerals in parenthesis are crown heights of breakwaters and sea walls. Structures encircled by thin lines are damaged by the tsunami.



the tsunami increased its height to 8.6 m as shown in Fig.1.

The 1st section was hit by the tsunami which overflowed the dune and by the tsunami which entered from the end of the dune. Houses on a higher land could survive. A few houses in low land could also survive if they are behind the higher part of the dune.

The seaside half of the 2nd and 3rd sections were damaged by the tsunami about 4 to 5 m high as shown in Fig.1. The rest was burnt by fires after the tsunami. There were two origins of the fire. The first fire started from a flooded house at 22:40, about 15 minutes after the tsunami attack. The second fire started at 0:45 in the neighborhood of a building in the flooded area after the tsunami already receded. No effective fire fighting was carried out, because no fire engine could enter the area, hindered by debris over the roads.

The tsunami overflowed the breakwaters in front of the 4th section of Aonae, by two meters or so, according to witnesses. First row and a part of second row of houses in the 4th section were damaged, but the rest were not affected by the tsunami and the fire.

Examples

1) House of Watanabe (Wooden house with the first-storey walls made of concrete blocks)

This is a two-storey house in the 1st section of Aonae. It was hit by the tsunami which entered from the southern end of the sand dune. The inundation height was 0.7 m. Although another wooden house in the downstream was damaged seriously, the house of Watanabe could survive only with slight damage. The house in the downstream was damaged mostly by the effect of floated debris, but the first-storey walls of the house of Watanabe were strong enough to resist because they were made of concrete blocks.

2) Warehouse of Nishimoto Store (Reinforced concrete building)

It is an impressive view for every visitors after the tsunami to find a reinforced concrete building in the midst of the totally devastated Aonae. It is a tall warehouse with very small four windows at high position near the roof and a strong iron door on the western side. It was built in 1930's. The door was bent inward with no scratch on its surface, implying that the door was deformed by the effect of water but not by any impact of floating debris. The four windows were broken. A part of the roof was slightly damaged. These facts suggest that this warehouse was inundated up to the roof, and survived. The inundation height was estimated higher than 5 m.

3) Fish Market and Cold-storage Warehouse (Reinforced concrete building)

These two buildings are located at the water front in the Aonae Fishing Harbor. The Fish Market is a two-storey building, the first story of which consists of a wide floor for fish handling, a wall made of concrete blocks at the north end, and a small room at the south end. East and west sides are open without walls. Windows of the small room and the wall at the north side was broken. The tsunami height was 2.7 m above the floor and did not inundate the ceiling of the first floor. The second floor was left intact, and was used as a rescue office. Columns were strong enough to survive.

The cold-storage warehouse has strong thick walls because of its purpose of use. The inundation height was 2.6 m. It stopped three boats and one wooden house, with negligible damages inside.

4) House of Unae (Wooden house in the 4th section)

It is a queer scene that the house of Unae, made of wood, stands intact, at the water front in the Aonae Fishing Harbor, with its right neighbor severely damaged and with its left neighbor washed away by the tsunami. The house of Unae is located near a pier at the bottom of the harbor. The tsunami height inside the harbor was reduced by the breakwaters as is suggested in Fig.1. The pier in front of the house of Unae acted to protect the house from the concentration of the tsunami. Furthermore, the seaside of the house foundation was raised to adjust the uneven ground level with a concrete retaining wall. These conditions acted in favour of this house.

Tsunami Height and Damage to Individual Houses

There are two ways to express the degree of damage to houses as a function of the local intensity of a tsunami. The first expression is the damage percentage of houses in a given village. The second is the degree of damage to individual houses. Here, the second expression is considered. All the data available are summarized in Table 1. Data in frames are obtained by the author for the present tsunami. For other data, see reference [1].

Figure 2 compares the old (open marks) and new (filled marks) data. Notation D. (squares) is for houses destroyed and washed away, P.D. (triangles) for partially destroyed and W. (circles) for withstood and

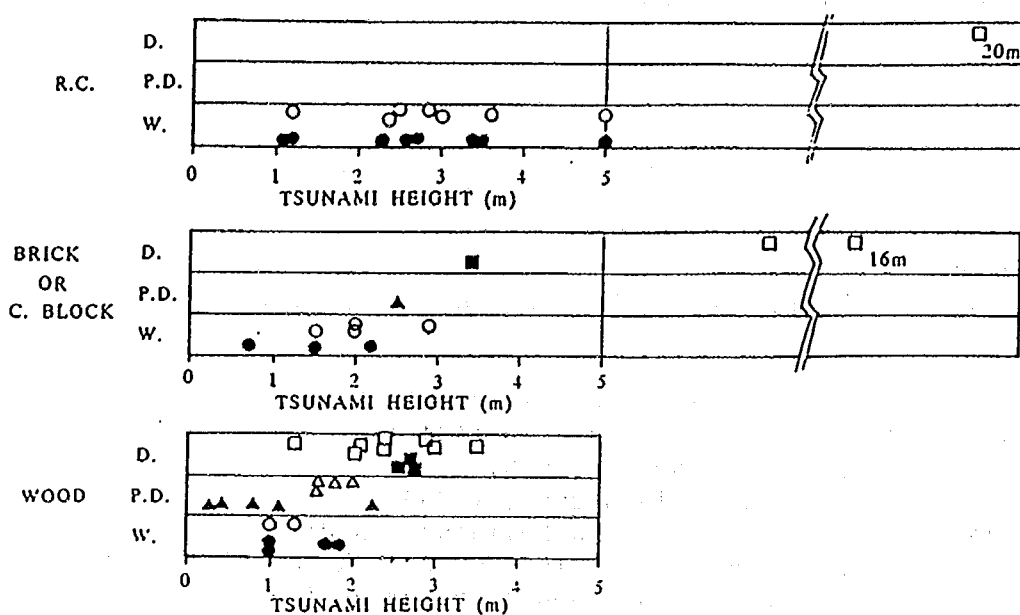


Fig.2 Degree of damage to houses and buildings. Open marks are for tsunamis in the past. Filled marks are for the 1993 Hokkaido Nansei-oki earthquake tsunami. Squares, triangles and circles are for destroyed & washed away, partially destroyed and withstood & slightly damaged.

slightly damaged.

Reinforced concrete buildings can withstand a tsunami inundation height of 5 m, and can not withstand that of 20 m. The boundary between withstood and destroyed is not known due to lack of data.

For houses made of concrete blocks, the boundary between withstood and destroyed seems to be at a tsunami inundation height of 3 m.

In case of partially-destroyed wooden houses, four houses are found partially destroyed by tsunamis less than 1 m high. The smallest inundation height was only 0.25 m, but the impact of floated materials was strong enough to break not only walls but also some columns. Different from olden Japanese houses which had thick walls made of clay, recent new houses have walls made of two thin plates with heat and noise insulating materials in-between. This structure reduces much the resistance of walls against the impact of floated materials. In addition, floated materials such as fishing boats, fishing gears, logs, cars and so on increase in number. These two conditions seems to be effective to change the degree of damage as a function of tsunami height.

Conclusions

From the analysis of measured data, reinforced concrete buildings are found strong enough to resist tsunamis. It is effective as a means of tsunami protection to align such buildings along the shoreline, as was repeatedly recommended just after every tsunamis in the past. For the stability analysis in the design of such substantial buildings, hydrodynamic forces and impact of floated materials should be known through experiments in the near future.

Reference

Shuto, N. (1993): Tsunami intensity and disasters, Tsunamis in the World, edited by S. Tinti, Kluwer Academic Publishers, pp.197-216.

Table 1 Structure of house, degree of damage and tsunami height

Iron Building

Withstood.

H ≤ 15 m. Benkoelen Lighthouse in Sumatra (1883)

Reinforced Concrete Building

Destroyed.

H ≈ 20 m. Scotch Cap Lighthouse in Alaska (1946)

Withstood.

H ≈ 5 m. Puumaile Tuberculosis Hospital in Hilo (1946).

Naniloa Hotel in Hilo (1946)

Hilo Iron Works (1960)

H = 3.6 m. An example in Ofunato (1960)

H ≈ 3~2.4 m. Properly Designed Buildings in Hilo (1960)

H = 2.9 m. Furuminemaru Waiting House in kamaishi (1933)

H = 2.5 m. Matsukuraya Warehouse in Yamada (1933)

H = 1.2 m. Sanriku Kisen Office in Oozuchi (1933)

H ≥ 2.3 m. Rest House at Inaho (1993)

H ≈ 3.5 m. Rest room at Inaho (1993)

H ≈ 3.4 m. Jizo temple at Inaho (1993)

H ≈ 2.7 m. Okushiri Fish Market at Aonae (1993)

H = 2.6 m. Okushiri cold-storage warehouse at Aonae (1993)

H ≈ 5 m. Warehouse of Nishimoto Store at Aonae (1993)

H ≥ 1.2 m. Okushiri Ferry Terminal Building (1993)

H = 1.1 m. Okushiri Fishermen's Cooperative Association (1993)

Stone, Brick or Concrete Block House

Destroyed.

H = 16 m. Nieuwenhuijs's House at Merak (1883)

H = 7 m. Naumann's House at Merak (1883)

H = 3.4 m. Cabin attached to Jizo temple at Inaho (1993)

Weak connection to the foundation

Partially damaged

H ≥ 2.5 m. Rest house at Aonae. A part of wall was broken (1993)

Withstood.

H = 2.9 m. An example in Ofunato (1960)

H = 2 m. Stone houses in Messina (1908)

H = 2~1.5 m. Two warehouses of Someya Sawmill in Miyako (1933)

H = 1.5 m. Okushiri Agricultural Coop. Association at Aonae (1993)

H ≈ 2.2 m. Two-storey house of Nakazawa at Aonae (1993)

H = 0.7 m. House of Watanabe at Aonae (1993)

Table 1 (Continued)

Wooden House

Washed Away

- H = 3.5 m. A house at Takahama (1960)
- H = 3~2.4 m. Light frame buildings and heavy timber structures in Hilo (1960)
- H = 2.9 m. A house at Takahama (1960)
- H = 2.4 m. A house at Tsugaruishi (1960)
- H = 2.1 m. A house at Sekiguchi (1960)
- H $\approx$ 2 m. A house at Origasa (1960)
- H = 1.3 m. A house at Akasaki (1960)

- | | |
|-----------------|---|
| H = 2.7 m. | First floor of the house of Furuya (1993) |
| H = 2.7 m. | First floor of the Aonae Fishermen's Training Center (1993) |
| H $\leq$ 2.6 m. | first floor of Omura Store at Aonae (1993) |

Partially Damaged

- H = 2.0 m. A house at Ofunato (1960)
- H = 1.8 m. A house at Tsugaruishi (1960)
- H = 1.6 m. A house at Origasa (1960)
- H $\approx$ 1.55 m. A house at Origasa (1960)

- | | |
|-------------|---|
| H = 1.1 m. | Office of the Okushiri Kairiku Unyu at Aonae (1993) |
| H = 0.25 m. | House of Kamata (1993) at Aonae (1993) |
| H = 0.4 m. | First floor of the house of Sekiguchi at Aonae (1993) |
| H = 2.25 m. | First floor of the house of Masuda at Aonae (1993) |
| H = 0.8 m. | House of Homma at Aonae (1993) |

Withstood

- H $\approx$ 1.3 m. A house at Yamada (1960)
- H = 1 m. A house at Yamada (1960)

- | | |
|------------|---|
| H = 1.7 m. | First floor of the house of Abe at Aonae (1993) |
| H = 1.8 m. | First floor of the house of K. Furuya at Aonae (1993) |
| H = 0.8 m. | Two-storey house of Matsuzuka at Aonae (1993) |
| H = 1.0 m. | Mantoku-ji and its attached cabin at Aonae (1993) |
| H = 1.0 m. | House of Miura at Aonae (1993) |

Prof. SHUTO

Prof. Abe: I want to know your tsunami height. Is that the tsunami height above the ground?

Prof. Shuto: Yes.

Prof. Abe: Also in the Okushiri area the earthquake intensity is very high, around 6 to 7. What about the effect of that shaking in connection with the damage caused by tsunamis?

Prof. Shuto: For most of the wooden houses, the effect of shaking was not so strong compared with the impact of the fishing boat or others. In the Aonai area no residential houses were overturned by the effect of shaking. The only one example is the lighthouse on this island. It was overturned by the shaking, but the other wooden houses for residential purposes did not suffer that kind of damage.

Prof. Yeh: You showed a photo slide where in one of the two-storey buildings, the upstairs glass was shattered by the wave. Two buildings side by side. On the right-hand side, the glass on the second storey was shattered by the wave, you mentioned. What about the windows in the left-hand side structure, how are those windows?

Prof. Shuto: Smaller surface area.

Prof. Yeh: The window glass is still there, isn't it? That's the one you observed, didn't you? The glass is still intact.

Prof. Shuto: These are intact, but these are broken and also here they are broken very much. It means that the water surface or the piling up of floating material was not the same.

Prof. Yeh: Yes, I have seen lots of places where the glass windows are still intact, even though they have been inundated. I think it is quite interesting.

Prof. Shuto: We shouldn't expect any tsunami to have a uniform effect, if it has these floating materials. Effect is very local.

Dr. Gonzalez: There were actually 2 houses like that, right? With water on the first floor and then broken windows on the top floor. Was there any glass inside or was it all outside? Because I am wondering if internal pressure - if the water came in on the first floor very fast and if it was a warm night and all the windows were closed - I wonder if internal pressure could have blown the windows out.

Prof. Shuto: Once you enter this kind of house, you may find many things in the first floor. I couldn't examine any remains of the glass of this window inside or outside. Anyway, on the second floor, even though the tatami mat was dry, it was a mess due to the material transported from outside.

Dr. Gonzalez: It came in the window from outside.

Prof. Shuto: Yes, I think so.

Dr. Gonzalez: Maybe from the wind.

Prof. Shuto: Yes.

Mr. Sigrist: A couple of comments. One is in reference to the second slide in your presentation. It was the picture of the house with the poured concrete foundation, the newer home. Our survey team investigated the lack of damage to that house, too, and attributed its resilience to the foundation and smooth, firmly attached siding that also appeared to be very resilient. Since the siding is so smooth, possibly it allowed the water to rush by due to minimal resistance. We noticed no damage to the siding on the house at all.

Prof. Shuto: I think we should explain the reason more clearly why this house could survive. This is the detailed map of the area of this house. This is the house. This is Aonai harbor, and this is a pier. I think the pier is longer than the picture shows.

The second tsunami overflows this breakwater by the thickness of about 2m, but the major portion of the tsunami which hit this area came through this entrance of harbour. And then maybe due to the existence of this small barrier, the major energy of the tsunami went in this direction not directly hit the house. So this house was very, very lucky for its position and also for its foundation. So this is a very lucky case.

Mr. Sigrist: One other comment in regard to your observation of the electrical power connection and electric meter where the fallen wires may have caused sparking and subsequent fire. I believe on the Shinkansen rail system power is automatically shut down when an earthquake occurs. I wonder if in situation where there are large earthquakes, shorted electrical circuits are a contributing factor to much of the subsequent destruction and damage and should be shut off. Or would turning off the power immediately following the earthquake create more problems?

Prof. Shuto: No. I think electricity should be supplied so that people do not have a panic. Once you experience a very heavy shock and you recover, and if electricity is supplied, you can base light at night and also you can use the pump for extinguishing fires. The electricity is a very important factor for social life. If we don't have electricity we may feel lack of security.

I had the same experience when we had the earthquake about 15 years ago in Sendai. The earthquake intensity was bigger than 5.5 and almost every houses were very much shaken. We had no electricity due to damage to the electric poles and other apparatus. Suddenly we found that the traffic was very confused because there were no signals. We would like to have hot water, but there were no gas and no electricity, so no water was pumped up and we could not use the water closets or bath. So electricity is very important to stabilize society.

But sometimes it produces this very bad phenomenon effect.

Mr. Hagemeyer: Your comment about electricity. I think I would second that. Your experience sounds like mine in Guam. For 3 days we had no water and no electricity. But I was in a hotel when it happened which had emergency power and although the regular power went out all over the island, the hotel's power kicked in and as people were evacuating, they could at least see where to go. I hate to think what that would have been like if we had

been evacuating the hotel 7 stories in the dark.

Dr. Gonzalez: I heard a rumour that it was possible that at some time during the night there may have been an explosion, because some of the propane gas ...

Prof. Shuto: Yes, they had many, many small explosions.