CHAPTER 194

Tsunami Threat Evaluation by Historical Documents, Numerical Model and Stochastic Model

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An evaluation of local tsunami threat was studied first refering to the historical documents and the catalogs. Secondly, an example of a numerical model of a finite difference method was discussed in relation to problems for reproducing the past local tsunamis and predicting a forthcoming tsunami. Lastly, a stochastic model was utilized in order to evaluate an exceedance probability of tsunami occurrencein an interested time period at an interesting local area where the concerened information or prediction was in need. The evaluation of a local tsunami threat is useful to get a more effective measure for the tsunami warning system and for protection works.

Introduction

In the coastal area, especially around the circum-Pacific seismic zone, they have had severe tsunami hazards repeatedly for thousands years. With recent higher utilization of the coastal area, they have felt it an urgent need to evaluate the nest tsunami threat of the interested location on the coast by an appropriate scientific techniques. Of cause, they have had learned well theirown way to reduce their loss and mitigate their damage with their experiences. If an evaluation of the threat is obtained properly, it can be a basic information for tsunami warning and protection.

As generally well known, the tsunami threat has locality. The author now wish to extend some concept about tsunami threat evaluation by historical documents, numerical model and stochastic model. With these, evaluation of local tsunami threat can be a more effective measure for establishing the tsunami warning system and for improving the concerned protection works.

Sources of Historical Tsunami Data

In order to get a glance of local tsunami threat, it is essential to refer to a tsunami catalog first. Such a catalog has been well composed afer compilation and reconfirmation of the historical documents. Iida, Cox and Pararas-Carayannis(1967) completed a preliminary catalog of tsunamis in the Pacific. Soloviev and Gao have published the russian editions for the western(1974) and eastern(1976) Pacific respectively. The most recent Japanese edition was published by Watanabe(1986). A more convenient tsunami hazard map was issued by NOAA and it seems very useful.

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The first step to compose these tsunami catalogs was to find out the old descriptions which included all of what was concerned the tsunamis and which were mostly kept in form of hand-written. So that, it has been necessary to confirm whether the descriptions are reliable or not at any step of compiling and/or composing them. Even at present, successive effort has been continued to search and reveal the fact out of the historical documents.

These documents are in form of a part of personal diaries, official documents, religious notes kept in Shinto-Shrines, Buddism Temples, Local Office of the Government or simple personal description. Occasionally, some specific merchants left vivid memories. Nakamura (1984a,b, 1985) has been continuing to find out yet any historical description which includes notes concerning the past significant tsunamis in order to get a more precise revision for the local forthcoming hazardous tsunami warning and protection.

As an example, the author take now a local tsunami problem in the coastal area of Tanabe and Shirahama(to the details, refer to the work by Nakamura, 1987, in Bull.DPRI,Kyoto Univ.). Tanabe and Shirahama have had suffered repeatedly from the past hazardous tsunamis accompanied by the big earthquakes, as well known. Tanabe and Shirahama are facing the northwestern Pacific and there are yet many of unpublished materials which inform us the facts which have been left as they have been without any aware of the importance(Nakamura,1984, 1987). A local tsunami catalog can be composed referring to the catalogs introduced above and adding the recently revealed facts out of the unpublished materials. With these additional local documents, a more detailed local tsunami catalog for Tanabe and Shirahama has been composed by Nakamura, 1984).

A brief list is shown as follows referring to the catalog. The significant events are chronologically listed following a format which includes the items of the date in AD or in Japanese era, estimated location of the epicenter taken from Watanabe's recent catalog, the magnitude of the earthquake denoted by M, the tsunami magnitude denoted by S(Nakamura, 1986a) and a brief note about the event.

(1) 684AD Nov.29(Temmu 2) A big earthquake, land falls, destroyed the government offices, warehouses, shrines and temples. Rice fields were drowneded by the tsunami flood. Hot spring ceased at Iyo(Ehime). Tsunami hits Kumano area. Hot spring at Muro also ceased. This is the oldest event confirmed and found in "Nihon-Shoki" and cited everywhere.
(2) 887AD Aug.26 16h(Ninna 9) 135.3E,33.0N, M=8.6, S=3. Big earthquake. Tsunami hits on the coast and lost many lives.
(3) 922AD(Engi 22) 137.7E,33.8N, M=7.0, S=1. A strong earthquake with tsunami.
(4) 1360 Nov.23 Oh(Shohei 15) 136.2E,33.4N, M=7.0, S=2. Repeated shocks of the earthquake. On the next day also a big shock felt. Tsunami hits in morning the day after the next day.
(5) 1361 Aug.3(Shohei 16) 135.0E,33.0E, M=8.4, S=3. Description says an earthquake around Kii and tsunami hits Settsu(Osaka).

(6) 1403(Ouei 10) 136.5E,33.7N, M=7.0, S=1. Strong earthquake in Kumano district and tsunami hits.
(7) 1408 Jan.21 18h(Ouei 14) 136.9E,33.8N, M=7.0, S=1. Strong earthquake in Kumano. Possibly tsunami hits.
(8) 1498(Meio 7) High water caused hazards on the coast of Kii.
(9) 1510 Sep.21 4h(Eisho 7) 135.7E,34.6N, M=6.7, S=1. Estimated epicenter is located in Osaka Bay. Tsunami hits.
(10) 1520 Apr.4 18h(Eisho 17) 136.3E,33.6N, M=7.0, S=1. Temple's buildings destroyed by the earthquake. Houses drawnded.
(11) 1605 Feb.3(Keicho 9) 134.9E,33.0N, M=7.9, S=3. Big waves at Kumano. Hiro(1700 families) lost 700 families at the tsunami.
(12) 1707 Oct.28 12h30m(Hoei 4) 135.9E,33.5N, M=8.4, S=4. Details have been kept as the memory to give warning for their successors. Official reports described the damage and the fast-aid request for foods and living materials. After identifying the location appeared in these descriptions, an illustration was completed as a local hazard map which was shown in Fig.1.
(13) 1854 Dec.24 16h(Kaei 7 or Anse 1) 135.6E,33.2E, M=8.4, S=4. The more detailed descriptions of the earthquake and tsunami has been found to make the tsunami hazard map as in Fig.2. At a glance, there are little difference between the two maps of Figs.1 and 2 except learning what were written in the descriptions in 1707 and in 1854.
(14) 1944 Dec.7 13h35m(Showa 19) 136.2E,33.7N(depth 30 km), M=8.0, S=3. On the coast of Kii Peninsula facing the Pacific, houses washed away by the tsunami. No record was kept except only a limitted number of the mareograms which includede the tsunami.
(15) 1946 Dec.21 4h19m(showa 21) 135.6E,33.0N(depth 30 km), M=8.1, S=3. Several scientific records have been kept. With the local descriptions and hearings the tsunami hazard map was made as found in Fig.3 for the event of 1946. This map shows a successful protection works around the mouths of the Rivers, though the protection works have done against the flood of the river discharge. The illustration of Fig.3 shows the other new areas and coasts had the tsunami hit. This means that these areas had never used or lived by the end of the Second World War.
(16) 1960 May 22 19h11mGMT(Showa 35) 73.5W,41.0S, M=8.25, S=4. The Japanese Islands had hit by the tsunami on 24 May 1960 without any seismic shock in advance. The tsunami was highest at Isla Mocha in Chile(20 to 25 m) and it crossed the Pacific to hit the Japan Islands as well as the Chilean coaat. In Chile, 909 persons died, 834 persons lost, 667 persons injured and many buildings had severe damage. Even in Japan, 119 persons died, 29 persons lost, 872 persons injured, 2830 houses destroyed, 19,863 houses drownded and the unexpected damage of boats.

Even when we are aware of the difference between the epicenters of 1707 event, 1854 event, 1946 event and 1960 event, the author cannot deny the active effect of the protection works completed by that time looking at and comparing the illustrations in Fig .1 for 1707, Fig.2 for 1854, Fig.3 for 1946 and Fig.4 for 1960. Adding to that, we have to be aware of any type of unexperienced tsunami damage.

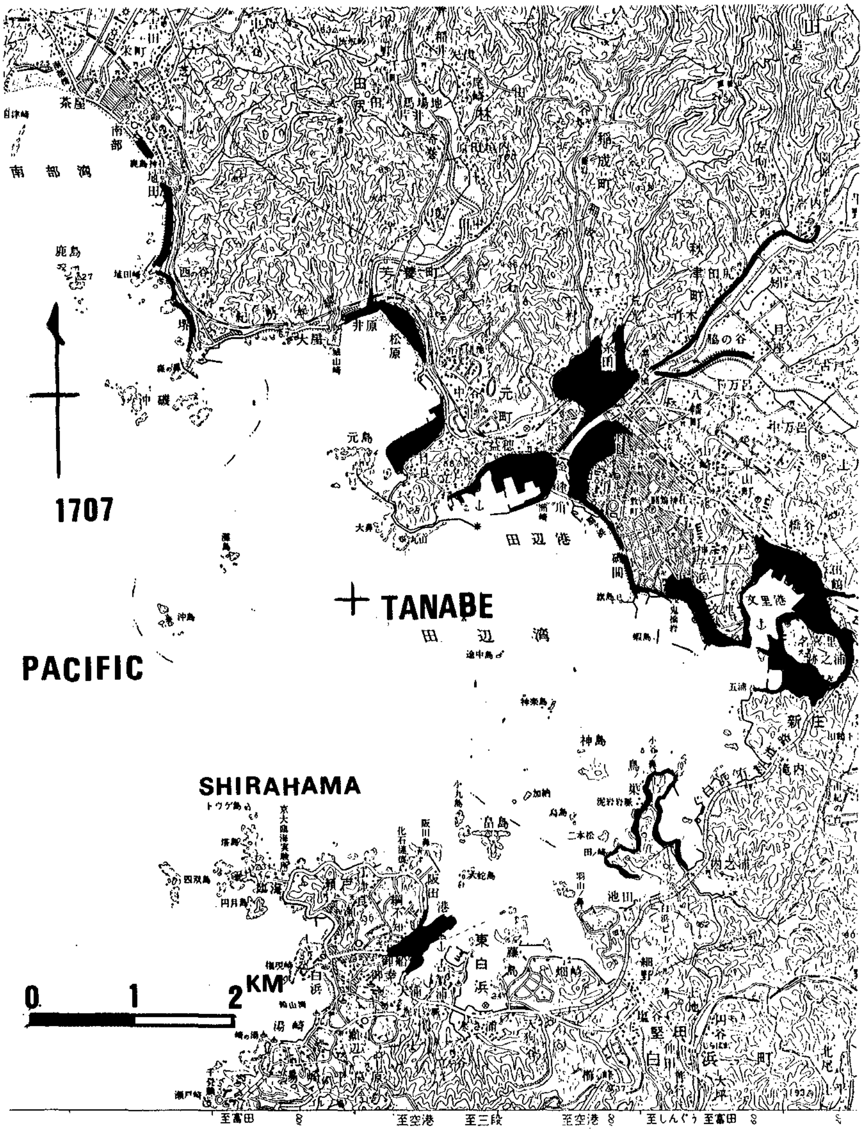

FIG. 1.— Hazard Map of 1707 Hoei Tsunami; Note: The Suffered Area by the Tsunami Flood Was Shown by a Black Coloured Patch or Black Lines along the Coast or along the River Levee and River Bank. (Location of the cross is 135°21'E, 33°43'N)

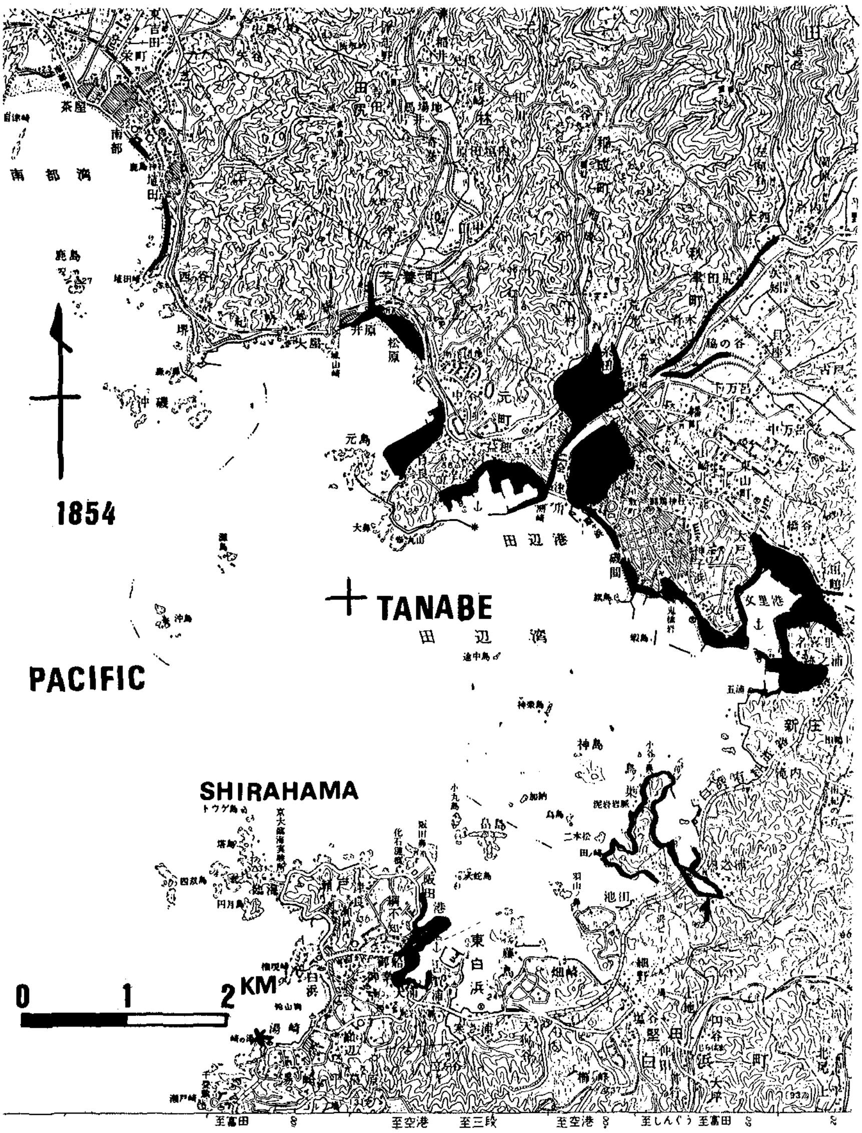

FIG. 2.— Hazard Map of 1854 Ansei Tsunami; Note: The Suffered Area by the Tsunami Flood Was Shown by a Black Coloured Patch or a Black Lines along the Coast or along the River Levee and River Bank. (Location of the cross is 135°21'E, 33°43'N)

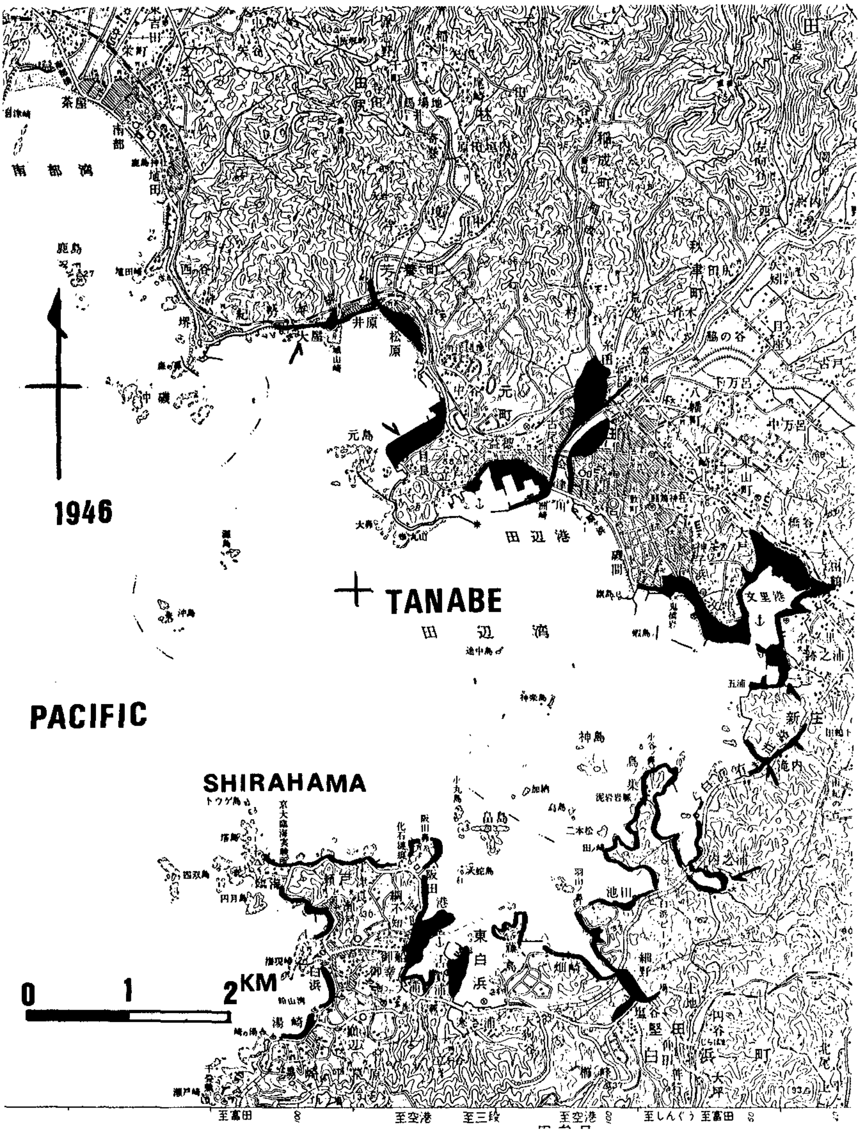

FIG. 3.— Hazard Map of 1946 Nankaido Tsunami; Note: The Suffered Area by the Tsunami Flood Was Shown by a Black Coloured Patch or Black Lines along the Coast or along the River Levee and River Bank (Location of the cross is 135°21'E, 33°43'N)

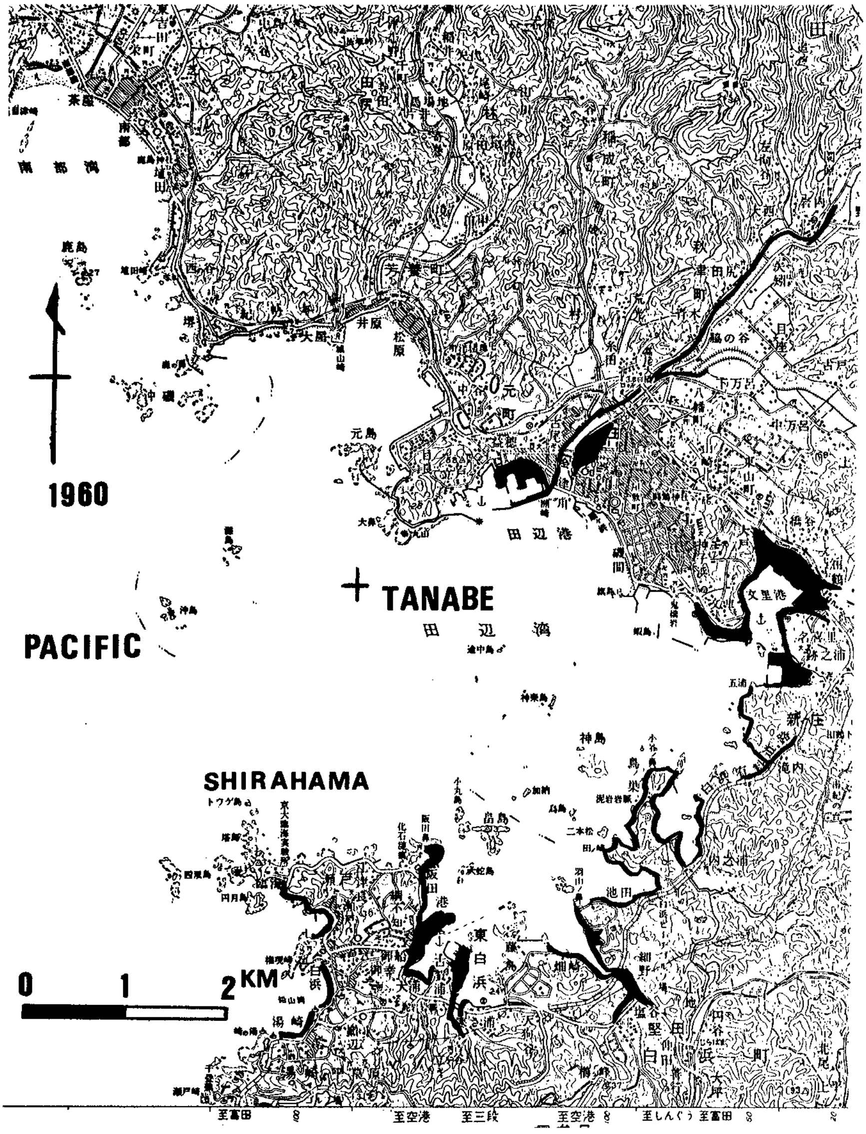

FIG. 4.— Hazard Map of Chilean Tsunami; Note: The Suffered Area by the Tsunami Flood Was Shown by a Black Coloured Patch or Black Lines along the Coast or along the River Levee and River Bank (Location of the cross is 135°21'E, 33°43'N)

Numerical Modelling

Techniques for numerical model has been accepted as a convenient to simulate any local tsunami and to reproduce the forthcoming one. This helpe us to establish an improvement of the present tsunami warning and protection worke. The author feels himself it hard to count up the tsunami model published by thie time. Here, the author introduces only the Japaneee recent works, i.e., by Hatori(1974), Aida(1983), Iwasaki(1983) and Iida et al.(1983). Ando(1982) has tried to reconstruct a fault formed by the main shock of the 1946 earthquake by using the available tsunami data. Nakamura(1983) has ueed and improved Loomis(1972)'s technique for long water waves in a finite difference scheme.

At the author's feeling, the most of the numerical scientists or engineere seem truet that the differential equation is equivalent to a difference equation. When a function u is given as a function of a variable t, it ie correct mathematically that

$$u' = du/dt = \lim_{\Delta t \to 0} \Delta u/\Delta t. \quad (1)$$

However, this does not mean that

$$u' = du/dt = \Delta u/\Delta t, \quad (2)$$

generally. The necessary condition is that the value of Δt is small enough for the given continuoue function, and the limit of (1) have to converge to a certain finite value.

Let ue consider a function $u(t;x,y,z)$ and write it u for our convenience. The first derivative is u'. As for a differential equation $u'=f$,

$$u(t+\Delta t) = u(t) + f\cdot\Delta t, \text{ and } f = f(t;x,y,z), \quad (3)$$

there is no promis to get a finite value of $u(t+\Delta t)$ mathematically if the function f is not continuous or has a specific property. For our convenience, we have to consider a case for

$$f = -u\frac{du}{dx} - v\frac{du}{dy} - \frac{1}{\rho}\cdot\frac{d\zeta}{dx} + [\frac{d}{dz}(K\frac{du}{dz})], \text{ etc.} \quad (4)$$

The differential equation $u'=f$ has a quite similar form to that used for numerical computations of gravitational water waves in a shallow water, i.e., the equation of motion in hydrodynamics. There must bemany of worke not appeared to us as a erroneous solution or ae a simply unexpected solution without any consideration in the scope of mathematics,even if it is reasonable mathematically.

Some other engineer must consider a way to get only for his expected solution using the higher terms of the Taylor's power series expansion of the function u around its variable t. That is,

$$\frac{\Delta u}{\Delta t} = u' + \frac{\Delta t}{2!}u''. \quad (5)$$

Now, consider again similar way as that for (3) and (4), and take $\frac{\Delta u}{\Delta t} = f$, then we have

$$u'' + (\frac{2}{\Delta t})\, u' - f = 0. \qquad (6)$$

As for an expected periodical solution in form of $u=u_0 \exp(ipt)$, The following relation should be satisfyed in (6).

$$p^2 - \frac{2i}{\Delta t}\, p + f = 0. \qquad (7)$$

From (7),

$$p = \frac{i}{\Delta t} \pm [\, f - (\frac{1}{\Delta t})^2 \,]^{1/2} . \qquad (8)$$

Hence, the first term in (8) shows that any disturbance decreases monotonously in the model. The second term controls the property of the solution u satisfying (6). If

$$f - (\frac{1}{\Delta t})^2 > 0 , \qquad (9)$$

the solution u of (6) has a part of an oscillatory solution. If not, this solution must be a monotonous increasing or decreasing function. When the function f is known apriori, it is easy to distinguish whether the solution is oscillatory or not referring to (8) or (9). Although, for example as in case of the function f given by (4) or as a case of an unpredictable function f, we can only control it by a choice of the value of Δt. The necessary condition is that the value of Δt is preferable as small as possible.

This is a remark for a numerical model of a finite difference method which occasionally gives a troublesome unexpected solution or a divergent solution even when so-called"Neumann's criteria" for obtaining a stable solution is well satisfyed. Although, this remark is not neccessarilly exact in the scope of mathematics.

As far as we concern the tsunami researches by this time, one of the tasks for the coastal engineers at present must be to utilize well the numerical model for their successful purposes. When the tsunami source condition is given, we can now utilize a numerical model to simulate and predict a local tsunami only for satisfying given condition. We have to be careful pioneers to introduce some other improved techniques to know when the next tsunami occurs in our interested area in the expected time period. One of them must be that appearing in the next section where the tsunami catalogs are fully utilized as a reference data source.

Stochastic Model

Probability of tsunami occurrence frequency on the coast of California was evaluated first by Wiegel(1970). Rascon and Villareal (1975) worked a stochastic evaluation of possibility of tsunami hit on the Pacific coast of Mexico. Successively, similar studies has been undertaken to know the local property of the tsunami occurrence frequency. Even in Japan, the coastal area in the northwestern Pacific, a simple statistical evaluation about the forthcoming big earthquake and big tsunami. However, it cannot be given as any scientific value for a long time. Only documentation had been the focus to spend their effort, which is at present highly evaluated in the field of coastal engineering for the basic data of tsunami warning and protection works. Almost all of the studies on tsunami occurrence frequency belongs to a stochastic problem. For example, Nakamura(1986a) has considered to introduce an extensive or modified Poisson process in order to get a better fit to the exceedance probability of local tsunami.

Referring to the tsunami catalogs, we can prepare to make a sequence of annual tsunami occurrence for an interested local area. If we take the tsunami event to be annual or the biggest tsunami in every year, then the annual exceedance frequency of tsunami occurrence in the interested area can be evaluated as a Poisson process or an extended Poisson process. Nakamura(for example, 1986a) has expressed exceedance probability P of tsunami occurrence as a function of an interested time interval t, i.e.,

$$P = 1 - \exp(-\Lambda t), \tag{10}$$

with

$$\Lambda = \Lambda_0 \exp[-\beta(h-h_0)^n], \tag{11}$$

where h is tsunami height and reference tsunami height h_0 is taken to be 1 m in this case. And the value of $\Lambda(=1/378)$ or $\Lambda_0(=58/378)$ is inverse of annual return period for h and h_0 respectively. The specific values of $\beta(=0.34)$ and $n(=1.0)$ characterize locality of the exceedance probability of tsunami occurrence. The above expression corresponds to the case of so-called "Poisson process" if n=1. The author uses tsunami scale S(or m) in the other cases instead of tsunami height h for a convenience. As a result, the author could obtain an exceedance probability of 25 % for a tsunami occurrence of the 1707 class(the local maximum of h was 13 m) at least once in a time period of 100 years.

Lastly, the author wishes to remark that a numerical model and a stochastic model are complementary each other as far as we refer to the historical tsunami descriptions and to the tsunami catalogs.

Conclusions

Evaluation of local tsunami threat was studied (i) using and referring to the historical descriptions and documents compiled by the author with an adjustment of what is written in the tsunami catalogs, (ii) using a numerical model of a finite difference method the author discussed what should be remarked mathematically in a simplified form, and a probability of local tsunami threat was evaluated using a stochastic model for an extended Poisson process. As seen above, evaluation of local tsunami threat is useful to establish a more effective measure for the tsunami warning or protection works.

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