Real Time Prediction of Tsunami for Early Issue of Accurate Warning for Evacuation

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1. INTRODUCTION

Almost all tsunamis have been generated by submarine earthquakes of large magnitude of M> 7.0. These large earthquakes have occurred in the vicinities of interfaces between different two plates. The deep interface is created by the subduction of a plate under the other with the speed of several cm per year. The subduction accumulates strain energy inside the plate and the emission of the energy due to a sudden destruction of a weak part inside a plate induces an earthquake. The earthquake deforms a wide area of sea bottom and the vertical deformation of the sea bottom similarly deforms the sea surface. The sea surface deformation becomes tsunami when it propagates in all directions due to the action of gravity. Though the tsunami is not so large in the initial stage, it is amplified up to more than 10m in near shore by the phenomena of shoaling, refraction, reflection and resonance related to the sea bottom bathymetry.

A large earthquake of the magnitude M9.0 occurred off the North-West part of Sumatra Island of Indonesia on Dec.28 in 2004. The earthquake had the forth largest magnitude in the world since 1900 and generated huge tsunami. The tsunami drowned nearly 300,000 people in total in the neighboring Asian countries of Indonesia, Thailand, Sri Lanka and India, and even in the remote African countries. The tsunami arrived at these countries except Indonesia more than 2 hours later than the earthquake. If they had received the information of the tsunami and also known the serious hazard of tsunami, the number of victims would have been much decreased because they had enough time to escape.

The earthquake of M7.7 occurred at 200km off Pangangaran in Java Island of Indonesia on July 17 in 2006. The tsunami of 3 to 4m attacked the shore 20 minutes later than the earthquake and drowned more than 500 persons. The engineers who joined the field investigation of this tsunami disaster told us that no persons thought to escape from the tsunami because they did not notice the earthquake. The period of 20 minutes before tsunami arrival would not be too short to escape form the tsunami if the tsunami warning was issued and informed to residents soon after the earthquake occurrence.

These tsunami disasters described above suggest us that early and accurate information of a tsunami is of great importance for early issue of accurate tsunami warning. The prediction system of real time tsunami is developed for early and accurate warning of tsunami. The present paper briefly describes how to predict real time tsunami from tsunami data observed offshore and how accurate the prediction is.

2. REAL TIME PREDICTION OF TSUNAMI

The real time prediction of tsunami can be defined as early and accurate prediction of tsunami in nearshore sea by using tsunami data observed at several offshore points. The prediction is effective on the early issue of accurate tsunami warning. The prediction procedures are planed to be practically executed as follows: 1) The tsunami profiles are observed at several offshore points. 2) Initial vertical deformation of sea surface in the tsunami source is inversely analyzed through the observed data of the tsunami profiles. 3) The tsunami profiles at various points of interest are predicted from the tsunami source information and utilized for early and accurate tsunami warning.

In the real time prediction of tsunami, the possible tsunami source area is covered by small segmented area as shown in Fig.1. The tsunami profiles observed at an offshore point is assumed to be able to be approximately expressed as a linear superimposition of element tsunamis generated by vertical uniform displacements of sea surface in the segmented areas. The vertical displacements in the segmented areas can be estimated inversely by the method of least squares of errors between the observed and superimposed tsunami profiles. Though the longer data of the observed tsunami are more effective on the accuracy of the tsunami prediction, the first prediction of the tsunami should be finished sufficiently before the tsunami arrival to the coasts of interest. The subsequent predictions can improve the estimated values of the vertical displacements in the segmented areas by using longer observed data because the observation is continued. The computation time must be saved to utilize the real time prediction for early issue of tsunami warning. Therefore, it is better to compute in advance the element tsunami generated by each segmented area.

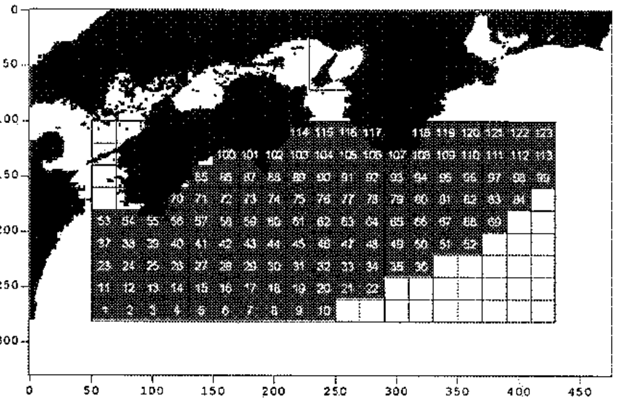

Fig.1 Small segments of tsunami sources

If the value of the vertical displacement in each segmented area is obtained, the necessary tsunami information like arrival time, profiles and maximum height is given at the points of interest by estimating the tsunami profiles as the superimposition of element tsunamis generated by the segmented areas. The accurate information of tsunamis can be utilized for the early issue of tsunami warning, the execution of tsunami measures and so on.

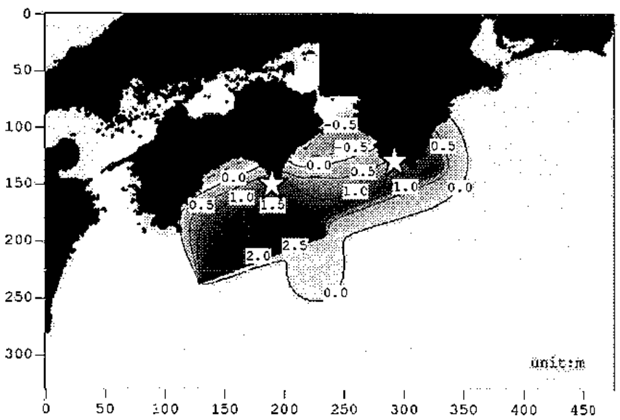

Fig.2 Small segments of tsunami sources

3. EVALUATION OF REAL TIME TSUNAMI PREDICTION

The validity of the real time tsunami prediction model is confirmed by using the past tsunami at Ansei Nankai Earthquake in 1854 (Yasuda et al., 2006). Figure 2 indicates the estimated initial distribution of vertical sea surface displacement in the tsunami source at the earthquake. Two small stars in Fig.2 are the observation points of tsunami. The tsunami profiles observed at two points under the initial distribution of the sea surface is shown by the dotted lines in Fig.3. The initial sea surface displacements in the segmented areas shown in Fig.1 are obtained by the method of least squares from the observed tsunami profiles for initial 30 minutes and the observed tsunami profiles are reproduced as the superimposition of the element tsunamis generated by the initial displacement in the segmented areas. The comparison between the observed and reproduced tsunamis is shown Fig.3. The reproduced tsunami profiles show good agreement with the observed ones for the initial 30 minutes, though the former profiles include short fluctuations, compared with the latter ones, especially at Shionomisaki.

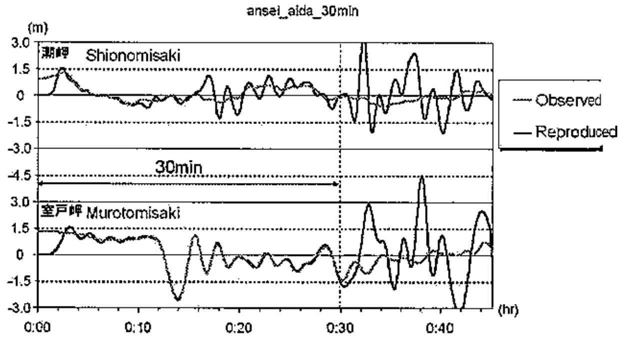

Fig.3 Comparison of tsunami profiles between the prediction and observation for 30 minutes at two observation points

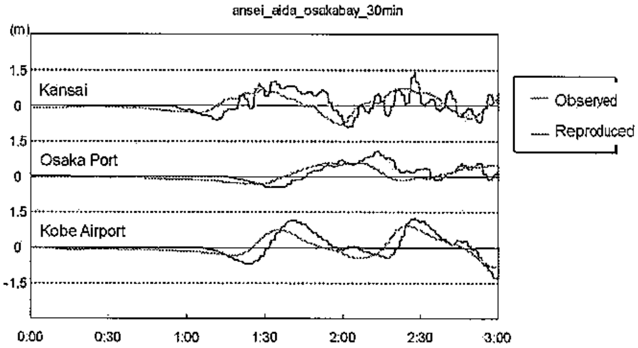

Fig.4 Validity of the real time prediction between the predicted and estimated tsunamis in Osaka Bay

Figure 4 shows the comparison between the predicted and observed tsunami profiles at three different points of Kansai International Air Port, Osaka and Kobe in Osaka Bay. Though the predicted profiles include short fluctuations, especially at Kansai Air Port, they show good agreement with the corresponding ones as a whole. This good agreement suggests the practical applicability of the real time prediction system. The real time prediction of tsunami is expected to become very useful tool for the issue of early and accurate warning.

4. CONCLUDING REMARKS

According to a recent newspaper, Japan Meteorological Agency (JMA) which is responsible for the issue of tsunami warning announced to shorten the forecasting time of tsunami to less than 2 minutes after the earthquake. JMA forecasts the magnitude of tsunami as follows: The results of tsunami computations for 100,000 different seismic conditions have been stored as a database. When an earthquake occurs, the most suitable seismic condition is selected from the database and the magnitude of tsunami corresponding to the seismic condition is announced. The largest tsunami magnitude in a designated coastal area is selected for the announcement.

Though the announced magnitude by JMA is enough for the tsunami warning, more accurate information is necessary for the actual measures and responses to the tsunami because the tsunami magnitudes are quite different from place to place in a coast due to the affection of sea topography. The real time prediction system is effective for the accurate information of tsunami. Therefore it is thought that the system is useful to compensate the JMA information, though the system should be improved for more accurate prediction.

The followings are discussed for the improvement of the real time prediction: 1) The computed tsunami profiles which includes short fluctuations is used as the element tsunami generated by the initial vertical sea surface displacement in a segmented area. The elimination of the short fluctuations may be necessary to increase the prediction accuracy. 2) Though initial sea surface displacements in the segmented areas are obtained under the assumption of their independency, the factor of some dependency or correlation may be necessary to introduce into their estimation.

REFERENCE

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