CHAPTER 126

MODEL STUDY OF TRANSFORMATION OF TSUNAMIS IN URADO BAY

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ABSTRACT

For the city and harbour of Kochi, including Urado Bay, facing the Pacific Ocean, an experimental study has been carried out on the problem of protection from tsunami disasters, and future harbour planning; that is, dredging, reclamation and construction of breakwaters against tsunamis. A hydraulic model of horizontal scale 1/250 and vertical 1/100 was used according to Froud's similitude. The transformation of the design tsunami in the bay was studied to find the effect of the tsunami breakwaters, dredging and reclamations by use of the model which was able to reproduce the Chilean Tsunami.

INTRODUCTION

The city and harbour of Kochi, including Urado Bay, located in Shikoku Island facing the Pacific Ocean as shown in Fig.1, have in the past 30 years been severely damaged by several tsunamis, for instance, the one due to the Nankai Earthquake in 1946 and the Chilean Tsunami in 1960. Tsunamis are mainly caused by Japan's position in a sesmic active zone so that a historioal review will show plenty of damage by the tsunamis and their causative earthquakes.

The characteristics of tsunamis have been studied theoretically, experimentally, and through field observations; but they should be studied too from the view point of coastal disaster prevention. A countermeasure has been the construction of seawalls. Recently the development of industries and of the harbour in Urado Bay have been planned, so it is necessary to study the effects of the construction of breakwaters and of the dredging andland reclamation in the bay on the behaviour of tsunamis. It

was decided that the best approach would be conducting hydraulic model studies.

This paper deals to study the transformations of tsunamis in the bay before and after completion of this project.

TSUNAMI GENERATOR

For this study, a tsunami generator of the plunger type was constructed, driven by an oil-hydraulic servo system. The plunger was made of steel, 7 m × 3 m × 0.5 m, located as shown in Fig.2. Power is supplied by an oil-hydraulic controller, shown in Fig.3. Transmission of an input signal is performed by a servo system, schematically given in the block diagram of Fig.1, to drive the plunger. The input signal is given by the cam of acrylite. In order to produce not only simusoidal regular waves but arbitrary waves, cams of various forms were used. According to the radius of the cam, the servo system controls the displacement and phase of the plunger through which the amplitude of the model tsunami wave is produced. By controlling the angular velocity of the cam, the period of the generated wave will be given. The stroke of the plunger is continuously variable and its maximum is ± 100 mm, and the period of the cam for a cycle is variable continuously in the range of 3 to 30 min.

SIMILITUDE AND THE MODEL

First of all, the area of the model should be determined with consideration of tsunamis around the bay mouth.

The tsunamis which attacked this bay were from off Nankaido, Hyuganada, the Aleutian Islands, the Chilean coast, and so on. These tsunamis propagated and attacked the bay after refraction, deflection and rectifying the wave rays to the contours. The propagation maps of the tsunamis show that the fronts of the tsunamis were almost parallel to the contours in the coastal area of 15 to 20 m deep, which was taken as a criterion to limit the model area. The tsunamis which entered the bay should run up the rivers so that the phenomena caused by the tsunamis should be found in the estuarys. The other criterion to limit the model is to find the limit of the tidal and the tsunami influences refering to the field data.

Second, the distortion of the model should be checked in relation to the characteristics of the tsunamis. When the model experiment is carried out by use of a distorted model which has different vertical and horizontal scales, the slope of the bottom is distorted so that the reflection and refraction of the tsunamis might be generally different compared to those in the non-distorted and distorted models. And graphical analysis to give a refraction diagram of the tsunami in the bay shows a little

difference up to the distortion of 2.5 (1/50 of horizontal and 1/100 of vertical) with consideration of recording and processing errors of the data. It was reported that the Hilo harbour tsunami model gave a distortion 3.0 (1/600 of horizontal and 1/200 of vertical) without effect of distortion to refraction and reflection of the tsunamis (Palmer et al., 1965).

In the estuary, saline water contacts fresh river water to mix vertically or to stratify into a stable double layer by the effect of the density difference of the waters. The river discharges flowing into the bay were so small compared to the tidal flushing that there should be prevailed vertical mixing which suggests that the consideration of the density difference might give little errors in the model experiment.

The similitude for the model was derived by the equation of motion and continuity. Froud's similitude was applied to the model experiment; the scale ratios of the prototype to the model are 250 for horizontal length, 100 for vertioal length, 10 for current velocity, 25 for time, 2.5×10^5 for river discharge, and 100 for kinetic energy, respectively.

Generally, the flow regime og the prototype are turbulent so that the friction coefficient may be taken as a certain constant value. And for the model the coefficient is a function of a Reynolds number, therefore it is difficult to hold the similitude mentioned above for a whole period of experiment. Simulation was given for an average of current velocity in the model area.

Roughness of the bottom was simulated by use of Manning's formula for the current velocity as an average. The similitude gives the scale ratio 1.365 of Manning's roughness parameter. An artificial roughness was given in the model for simulation fulfilling the above condition. With the consideration of size distributions of sediments, the roughness parameter is 0.03 in the harbour part which is simulated as 0.022 in the model to give the roughness of 0.2 to 0.3 cm by brushing up the mortar surface. For the river part in the model, the roughness was given by fixing sands of 0.3 to 0.5 cm in size on the river bed mortar. Judging from the result of the experiment, the effect of the roughness was not distinctive compared to topographical influences.

The water level was recorded on the photographic chart continuously and simultaneously. For dynamical understanding, current velocity was obtained from movies tracking floats of 1 cm in diameter in several areas in the model.

The model of Urado Bay is schematically shown in Fig.1 for present topography and is shown in Fig.4 as a bird's eye view.

REPRODUCTION OF CHILEAN TSUNAMI

There are many records of damage caused by tsunamı ınundatıon, there ıs a few records of tsunamıs for Urado Bay. One of the representatıove tsunamıs ın Urado Bay was the Chılean tsunamı of1960, whıch was recorded at three statıons ın the bay: Katsurahama(St.1), Urado(St.3), and Wakamatsu-cho(St.21). The locatıons are shown ın Fıg.1. Trıals were oarrıed out to reproduce thıs tsunamı ın the model basin. Tsunamı records for the fırst four hours were reproduced usıng a cam as ınput under the dynamıcal consıderatıon and repeatıng correctıon of the cam untıl the tsunamı records of the prototype coıncıde wıth the wave records ın the model experıments. One of the records ıs shown ın Fıg.5, ın whıch the scales of elevatıon and tıme are ın prototype according to the sımılıtude. From Fig.5 ıt ıs found that the wave forms ın the model coıncıde well wıth each other ın amplıtude and phase as a whole. Especıally, the wave form at St.1 ıs well reproduced. The detaıls do not perfectly coıncıde at St.3 and St.21. At St.3, the experımental result shıfts about 20 cm hıgh compared to the prototype records. The dıstorted model mıght gıve the shift of the water level. At St.21, the wave heıght ın the experıment ıs up to twıce as large as the tsunamı records ın the mareograms, whıch mıght be caused by the local topography around St.21. The rıver elevatıon ıncreases from the end of the navıgatıon cource to the Kagamı rıver so that the water passing St.21 ıs affected by local topographıcal effects and shoalıng effect. These detaıled dıscrepancıes between the prototype and the experıment should be studıed for more accurate reproductıon of the tsunami ın the model experıment.

DESIGN TSUNAMI AND ITS TRANSFORMATION

Inundatıon from tsunamis ın Kochi Harbour was studıed by numerıcal computatıon (Hamada et al., 1961). Scourıng problems near the tsunamı breakwaters at the entrance of Kochı Harbour were studied experımentally by Shıbayama et al.(1964). The behavıour of tsunamıs at the junctıons of rıvers were studıed numerıcally by Horıguchı (1965). These computatıons and experıments were carrıed out by use of a desıgn ysunamı determıned by the records of the tsunamı of the Nankaido Earthquake and of the Chılean tsunamı. Hamada (1961) gave the desıgn tsunamı at St.1 such as the crest heıght ıs 2.4 m above and the trough 1.5 m below the mean hıgh water level wıth the perıod of 30 mın for the numerıcal computatıon.

Spectral analysıs of the Chilean tsunamı gave the sıgnıfıcant perıod of 30 to 35 mın. For the Hyuganada Earthquake tsunamı ın 1968, the sıgnıfıcant perıod was about 25 mın.

These results suggest that the suitable period of the design tsunami is probably to be 30 min (Iwagaki et al., 1970). In this experiment the same conditions were given for the design tsunami.The initial water level before the tsunami inundation was taken to be the mean high water level (D.L. + 1.89 m).

The design tsunami that entered the bay propagates through the bay mouth; that is, the waves are transformed and their phases are delayed with the progress including the effects of the boundary and topography of the bay. There should be many factors affecting the transformation of the design tsunami, such as: phase velocity as a function of water depth, refraction caused by the bottom slope, deflection around a sharp edge, reflection at the coast and shoaling in the river mouth. The resultant effect of these factors gives the wave transformation. When the design tsunami at the entrance of the bay is given, the transformation of the wave in the model is obtained through the experiment as shown in Fig.6 in model scale. In Fig.6, wave height and time are shown in the model scale. The wave profiles are arranged ordinally for the stations, the locations of which are illustrated by numbers in circles in this figure.

The wave profile at St.1 is a sinusoidal which is found the lowest part of Fig.6. The wave is transformed and decreases its height at the narrow, the fact of which is found by comparison of the wave form at St.1, St.2 and St.3. There should be energy dissipation of the wave at the narrow caused by the confused configulation of the coast lines and to the curved water way. At the inlets, resonance occured by produce higher harmonics of the incidental tsunami. For example, the wave form at St.10 suggests that the third harmonics of the tsunami is amplified in the small rectangular resonator in which the location of St.10 is included.

In the river part, the wave height increases with inundation of the tsunami as found the wave forms of St.22, 23 and 25 in Fig.6. In the Kuma river, the wave height increases from St.23 to St.25. The wave form is transformed to be assymmetry; that is, the steep profile before the crest and the gentle slope after the crest of the wave. These transformed wave profiles differ from the incidental sinusoidal wave at the entrance of the bay.

CREST HEIGHT CHANGE AND TSUNAMI BREAKWATERS

The crest height distributions of the design tsunami were considered for the model of the present topography, the model without the tsunami breakwater for after dredging and reclamations, and the model with the tsunami breakwaters for after dredging and reclamations. The distributions were obtained as

two dimentional or areal distributions which will give understanding about the complexity of the wave characteristics in the bay. In this paper, the distributions are shown only along the navigation course from the entrance to the head of the bay and along the Kagami River and Kokubu River or Kuma River, as shown in Fig.7. In Fig.7, the distances of the stations from the bay mouth are shown in reduced prototype scale in Km and the crest height of the tsunami in meter with reference to the elevation of the mean high water level. The locations of the stations in Fig.7 are shown by the numbers in circles. The dots, the circles and the semi-circles show respectively the case for the present topography, the case for after dredging and reclamations, and the case with the tsunami breakwaters for after dredging and reclamations. The model for the conditions after dredging and reclamations is shown in Fig.8. Tsunami breakwaters are under planning for construction at the narrow point of the entrance of the bay, as shown in Fig.8.

The crest height distributions are shown in Fig.8 along the navigation course and the Kagami River. Comparing to the distribution for the present topography, the distribution for after dredging and reclamations suggests that the tsunami propagates with a little decrease of wave height because of water depth increase. But it is not clear why the crest height at St,2 became anomalously high after dredging. The effect of the reclamations is not so remarcable for the crest height distribution. When the tsunami breakwaters are constructed for the harbour after dredging and reclamations, it is found a remarkable effect of the tsunami-break-waters to diminish the wave height in the bay and to protect the harbour from tsunami inundations around the bay mouth and in the bay. For the crest height distributions, the effect of the tsunami breakwaters is not remarcable at the end of the navigation course. In the Kagami River, there should be found a topographical effect for the tsunami inundations.

About the Kuma River or Kokubu River, the crest height distributions are shown in the up-right part of Fig.7 to compare those to the main profiles of the crest height in the same scale. There are found a little effect of the tsunami breakwater, dredging and reclamations in the profiles of the crest height distributions of the design tsunami.

CONCLUSION

From the results of the model experiment on tsunamis in Urado Bay, the authors obtained the following conclusions.

1) By use of the tsunami generator with consideration of Froude's similitude, the Chilean tsunami was reproduced in the model experimant. This result shows the possibility of studying future problems in the bay.

2) Transformation of the design tsunami and crest height distribution of the tsunami were studied to find the negative effect of dredging of the navigation course and to find the active effect of tsunami breakwaters for protection of the harbour from tsunami inundation. Reclamations gave a little influence on the crest height distribution and on the wave height of the tsunami.

Kochi was attacked directly by the typhoon 7010 on 21, August, 1970 so that they suffered from heavy damages by the storm surge accompanied with the typhoon. This fact suggests that it should be promoted not only to study on tsunami but to investigate on storm surges in Urado Bay. Future plan of the harbour should be refered on the studies mentioned above to protect from coastal disasters.

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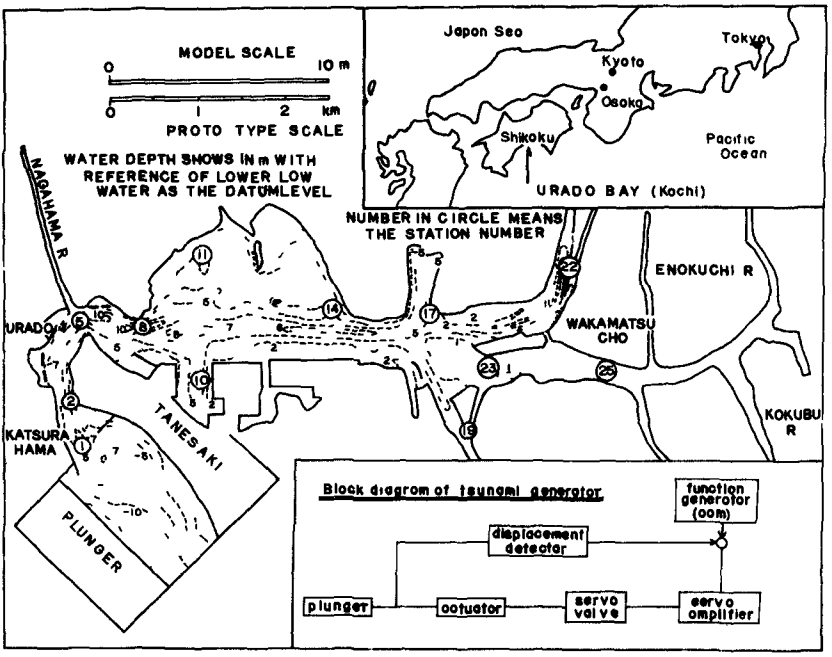

Fig.1 SCHEMATIC PLANE OF THE TSUNAMI MODEL OF URADO BAY (including locations of stations where water levels were recorded in the tsunami model, and tide gauges are located at St.2, St.3, St.7, St.17 and St.21 in the prototype of the harbour)
UP-RIGHT: LOCATION OF URADO BAY
DOWN-RIGHT: BLOCK DIAGRAM OF THE SERVO SYSTEM

Fig.2 PLUNGER OF THE TSUNAMI GENERATOR

Fig.3 OIL-HYDRAULIC CONTROLLER OF THE TSUNAMI GENERATOR

Fig.4 BIRD'S EYE VIEW OF THE TSUNAMI MODEL
(The plunger shown in Fig.2 is at the end of the model. The controller is in the white cottage. The head tank at the center of this photograph supplys river discharges in the model.)

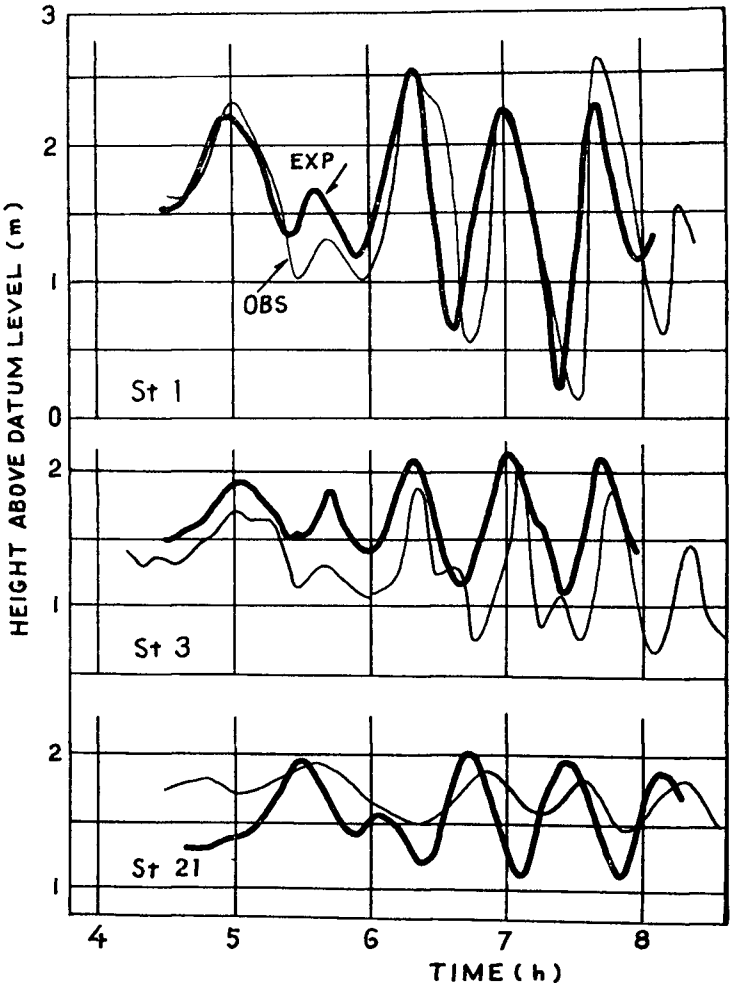

Fig.5 REPRODUCTION OF THE CHILEAN TSUNAMI IN URADO BAY

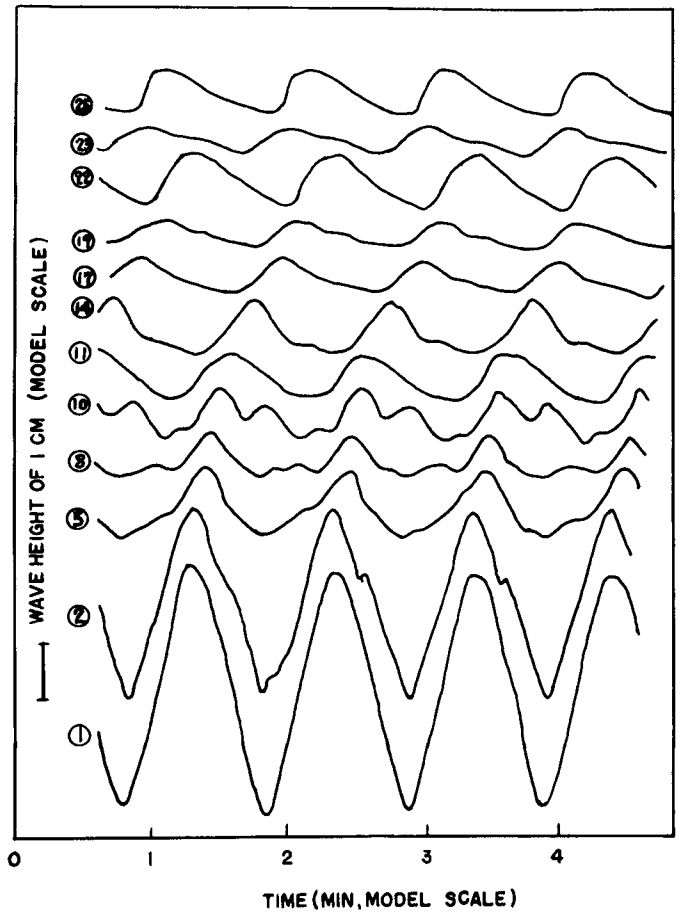

Fig.6 TRANSFORMATION OF A DESIGN TSUNAMI

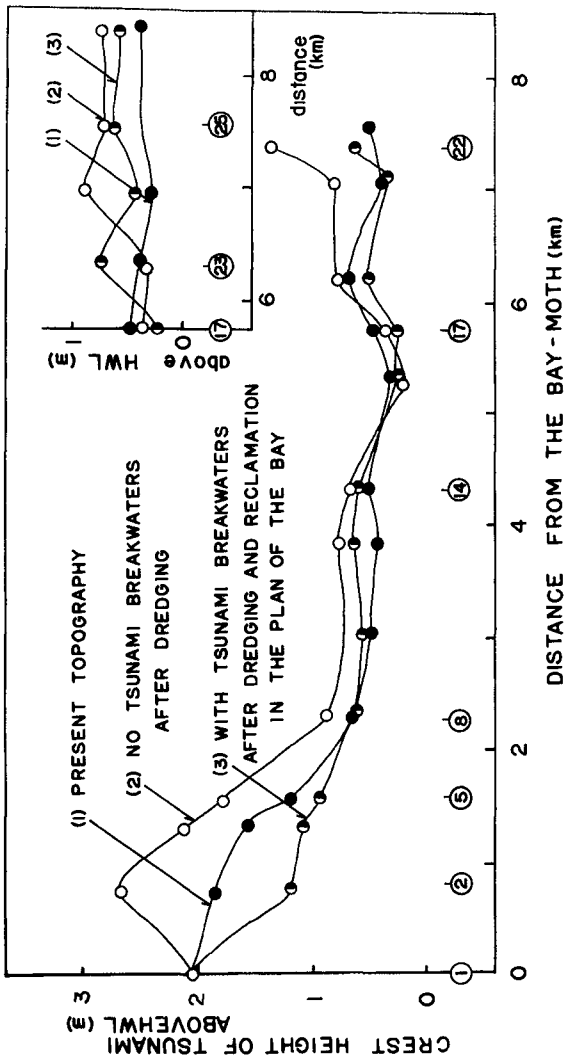

Fig.7 CREST HEIGHT PROFILES OF A DESIGN TSUNAMI

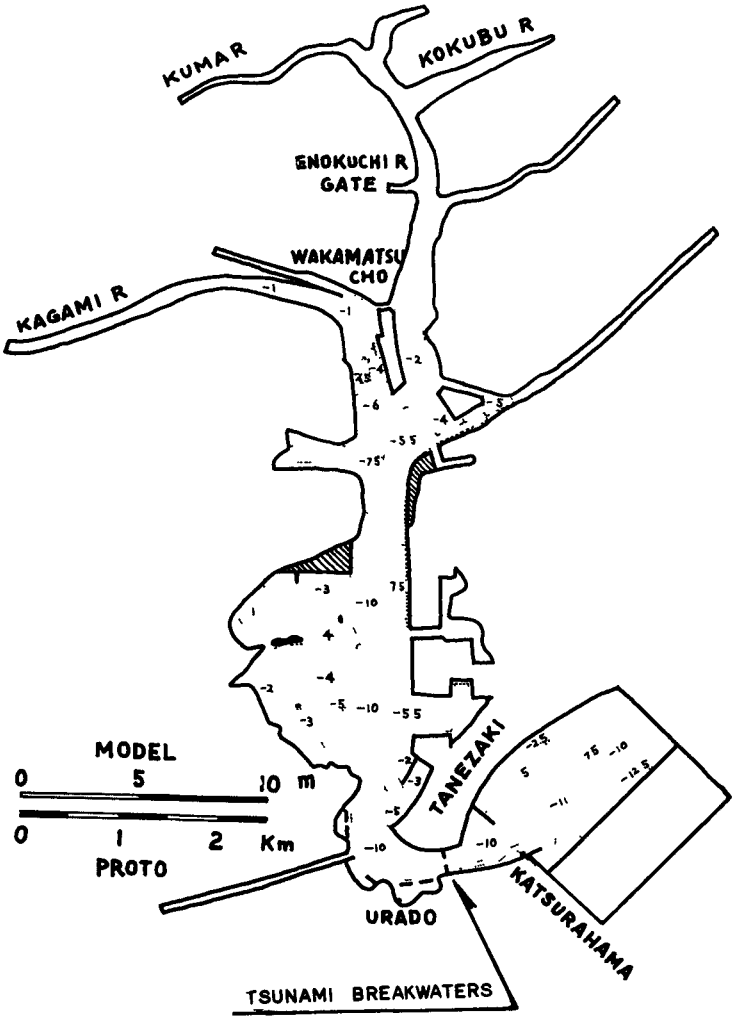

Fig.8 TSUNAMI MODEL AFTER DREDGING AND RECLAMATIONS
(The location of the tsunami breakwaters is indicated by an arrow.)