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RUN-UP HEIGHTS OF 1983 CENTRAL EAST SEA TSUNAMI ALONG THE KOREAN PENINSULA

Keum-Seok Kang*
Senior Researcher, Korea Electric Power Research Institute. 103-16 Munji-dong, Yusung-gu, Daejon, 305-380, Korea
Phone: 82-42-865-5762, Fax: 82-42-865-5725
E-mail: gldstn@kepri.re.kr

So-Beom Jin
Senior Researcher, Korea Institute of Nuclear Safety, P.O. Box 114, Yusung-gu, Daejon, 305-600, Korea

Yong-Sik Cho
Professor, Dept. of Civil Eng., Hanyang University, 17 Haengdang-dong, Seongdong-gu, Seoul, 133-791, Korea

Chong-Hak Kim
Manager, Korea Hydro & Nuclear Power Co., Ltd, 103-16 Munji-dong, Yusung-gu, Daejon, 305-380, Korea

ABSTRACT

The East Sea is one of the most vulnerable regions to unexpected tsunami attacks in the world. Many catastrophic tsunamis have been occurred in this region. Among them, the Central East Sea tsunami occurred in 1983 has been recorded as the most devastating tsunami in modern Korean history. By employing a combined numerical model, the run-up heights of the tsunami are estimated along the Eastern coastline of the Korean Peninsula. The computed results are compared with available field measurements. A very reasonable agreement is observed.

Keywords: tsunami, run-up heights, nonlinear shallow-water equations, nuclear power plant

1. INTRODUCTION

Tsunamis are huge but long water waves triggered by landslides, submarine volcanic explosions, or sea-bottom deformations associated with large submarine earthquakes. During last decades several devastating tsunamis have been generated around the Pacific Ocean zone. These tsunamis not only killed many human beings but also caused serious property damages. For example, the 1992 Flores tsunami killed more than 264 people in Indonesia and the 1993 Hokkaido tsunami in Japan killed 239 people and caused the huge run-up heights of Babi and Okushiri Islands located near to Flores and Hokkaido Islands, respectively. More recently, the South Asia tsunami occurred in December 26, 2004 have killed approximately 280,000 people along the coastlines of Indonesia, Thailand, India, Sri Lanka and several African countries faced to the Indian Ocean.

As shown in Figure 1, the East Sea surrounded by Korea, Japan and Russia is one of the most susceptible areas to unexpected tsunami attacks. A number of huge tsunamis have been occurred during this century in this region. Among them, the Central East Sea tsunami occurred in May, 1983 and the Hokkaido tsunami occurred in July, 1993 had directly attacked the Korean Peninsula. They had deprived of not only human lives but also property from the coastal communities of Korea.

Several nuclear power plants are located along the Eastern coastline of the Korean Peninsula to get enough amount of cooling water. Furthermore, several more plants are now under construction. Generally, for the safe operation of nuclear power plants, a sea level drop may be more serious than a sea level rise. Once the water intake facilities, especially the bell mouth of a pump, are exposed above a sea water level, it will lead to the shutdown of a nuclear power plant. Sometimes the inhaled air can result in abrupt pressure surging within a mechanical cooling water system. Moreover, the ESWP (Essential Service Water Pump) is related to the safety of reactor. Thus, variation of sea level caused by tsunamis should be conservatively and accurately estimated.

In this study, a second-order upwind finite difference scheme is employed to estimate the run-up heights of tsunamis accurately along the coastline of the Korean Peninsula. A combined numerical model is then employed to simulate 1983 Central East Sea Tsunami event. The combined model consists of propagation and run-up models and is based on the shallow-water theory. A special moving boundary treatment is implemented in the run-up model to track a transient motion of shoreline. The maximum run-up heights along the Eastern coastline of the Korean Peninsula are predicted and compared to available field observed data.

In the following section, the governing equations for propagation and associated run-up of tsunami are given for completeness. Numerically obtained run-up heights of the Central East Sea Tsunami are given in section 3. A comparison with filed measurements is also made. Finally, concluding remarks are drawn in section 4.

2. GOVERNING EQUATIONS

The tsunami in the ocean may be governed by the linear Boussinesq equations, that is, the insignificance of nonlinear effects and the zero viscosity are assumed. Then, the governing equations can be written as

$$\frac{\partial \zeta}{\partial t} + \nabla \cdot \mathrm{M} = 0 \qquad \text{(Eq. 1)}$$

$$\frac{\partial \mathrm{M}}{\partial t} + gh\nabla\zeta + 2\Omega \times \mathrm{M} = \nabla\left[\frac{h^3}{3}\frac{\partial}{\partial t}\nabla \cdot \frac{\mathrm{M}}{h}\right] \qquad \text{(Eq. 2)}$$

in which ζ is the free surface displacement, ∇ is the horizontal operator, h is the still water depth, $\mathrm{M} = (P, Q)$ represents the depth-averaged volume flux vector with $P = u(h+\zeta)$ and $Q = v(h+\zeta)$ being the volume flux components in x and y-axis directions, respectively, g is the gravitational acceleration, and Ω is Earth's angular velocity.

As tsunamis approach the coastal area, the frequency dispersion may not play a significant role. However, the nonlinear convective terms and bottom frictional effects become increasingly significant. Thus, the nonlinear shallow-water equations provide a good approximation for the run-up process of tsunamis along the coastline. To confirm the conservation of the physical quantities the governing equations can be written in the following conserved form

$$\frac{\partial \zeta}{\partial t} + \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} = 0 \qquad \text{(Eq. 3)}$$

$$\frac{\partial P}{\partial t} + \frac{\partial}{\partial x}\left(\frac{P^2}{H}\right) + \frac{\partial}{\partial x}\left(\frac{PQ}{H}\right) + gH\frac{\partial \zeta}{\partial x} + \frac{gn^2}{H^{7/3}}P\left[P^2 + Q^2\right]^{1/2} = 0 \qquad \text{(Eq. 4)}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{PQ}{H}\right) + \frac{\partial}{\partial x}\left(\frac{Q^2}{H}\right) + gH\frac{\partial \zeta}{\partial y} + \frac{gn^2}{H^{7/3}}Q\left[P^2 + Q^2\right]^{1/2} = 0 \qquad \text{(Eq. 5)}$$

in which $H = h + \zeta$ is the total water depth and n is the roughness coefficient.

Detailed descriptions of the numerical techniques solving equations (1)-(2) and equations (3)-(5) are given in Cho and Yoon (1998) and Cho *et al.* (2004), respectively. In Cho *et al.*, a second-order upwind finite difference scheme is employed to discretize the nonlinear convective terms. A moving boundary treatment implemented along the shoreline and a radiation boundary condition for outer boundaries are well described in Liu *et al.* (1995) and are not repeated here. Although the bottom frictional effects are expressed by using the Manning's empirical formula in equations (4) and (5), they may also be written by the Chezy's formula.

3. NUMERICAL COMPUTATIONS

To solve equations (1)-(2) and equations (3)-(5) with the finite difference schemes, a fine grid system, probably less than 5 to 10m, may be needed to get the reliable results to be used in practical purpose. However, it may also be impossible to use a very fine grid system in the total region of a large domain such as the East Sea. Thus, a dynamic linking technique is used to cover the whole area efficiently. In the technique, a coarser grid in deep sea is dynamically linked with a finer grid of a one third of a coarser grid in shallow sea.

In numerical computations, the free surface displacement and volume flux components are exchanged each other and it satisfies a dynamic equilibrium. By repeating the process, a required grid resolution can be obtained, and thus the variation of a local topography can be reproduced.

Figure 1 displays the computational domain covering the total region of the East Sea used in this study. The zone is firstly divided into the 1.1km grid system as an initial grid system. In Figure 1, a dynamic linking is constructed in the boxed area. By performing three times the one third grid refinement, that is, 1.1km to 370m, 370m to 123.3m and 123.3m to 41.1m near the interested zone, the numerical simulation for propagation of tsunami is carried out in the East Sea.

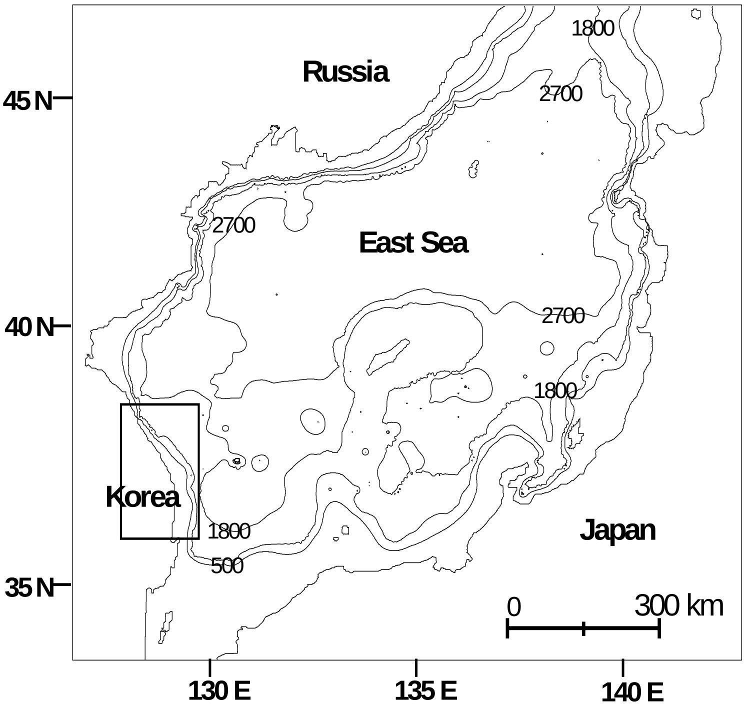

Fig. 1 The computational domain of the Sea

In numerical computations, the propagation model is firstly employed and then the run-up model is then used to compute run-up heights with a smallest grid system of 4.5m. Along the coastline, tsunamis may climb up the land, and run-up may repeatedly occur.

Figure 2 shows distribution of arrival time for leading part of the Central East Sea tsunami event. Although the tsunamis occurred in the near-shore zone of Japan, they traveled across the East Sea and attacked the Korean Peninsula, and thus deprived of three human lives and some property. As shown in the figure 2, about 100 to 120 minutes are taken for the leading tsunami arrival. Thus, the loss of human lives could be minimized by establishing a proper warning system. However, the mitigation of damage on important coastal structures such as nuclear power plants, thermal power plants, harbor facilities and breakwaters is needed. Thus, the effects of unexpected tsunami attacks should be taken into consideration in the design of these coastal structures as well as coastal communities.

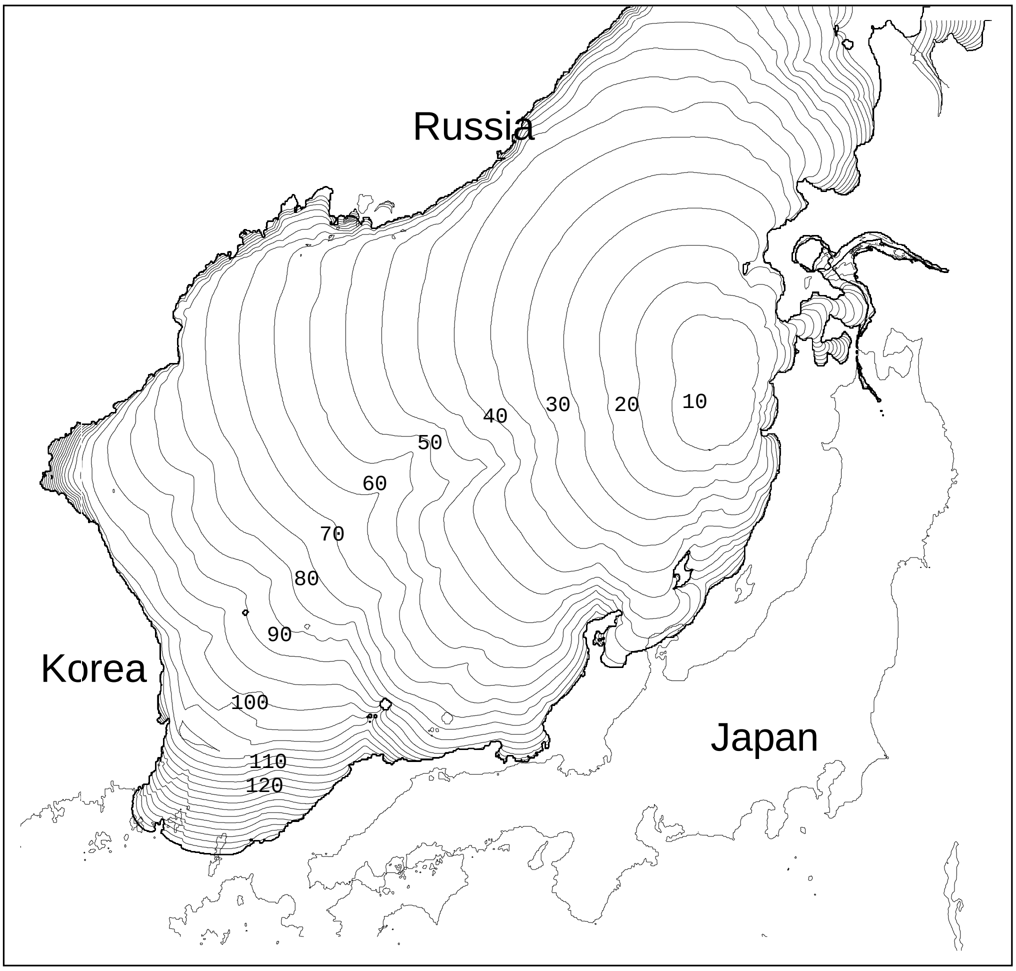

Fig. 2 Contour of arrival time of leading tsunami (unit: minutes)

Figure 3 shows the computed run-up heights of the tsunami along the eastern coastline. Several available measurements are also plotted for comparison. Although a slight discrepancy is observed, the overall agreement is quite reasonable. The computed maximum run-up height is about 5m near Bugoo, a small town.

Finally, the numerically predicted maximum run-up heights at several locations along the coastline of the Korean Peninsula are listed in Table 1. Available field measurements are also tabulated for comparison. The overall agreement between the field measurements and the present study is very good.

In the table, Green's law represents the run-up heights estimated by the Green's law based on the linear shallow-water theory. The law is known to provide approximate run-up height on the beach (Cho, 1995) and is expressed as

$$A = A_o \left[\frac{h_o}{h} \right]^{1/4} \qquad \text{(Eq. 6)}$$

in which A and h denote the wave height and a local water depth, respectively and the subscript represents the deep water quantity.

In the table, the Ulchin nuclear power plant is located at Bugoo. Four units are now under operation, two units are under construction and two more units are scheduled to be built. Thus, it is important to check the safety against possible tsunami attacks.

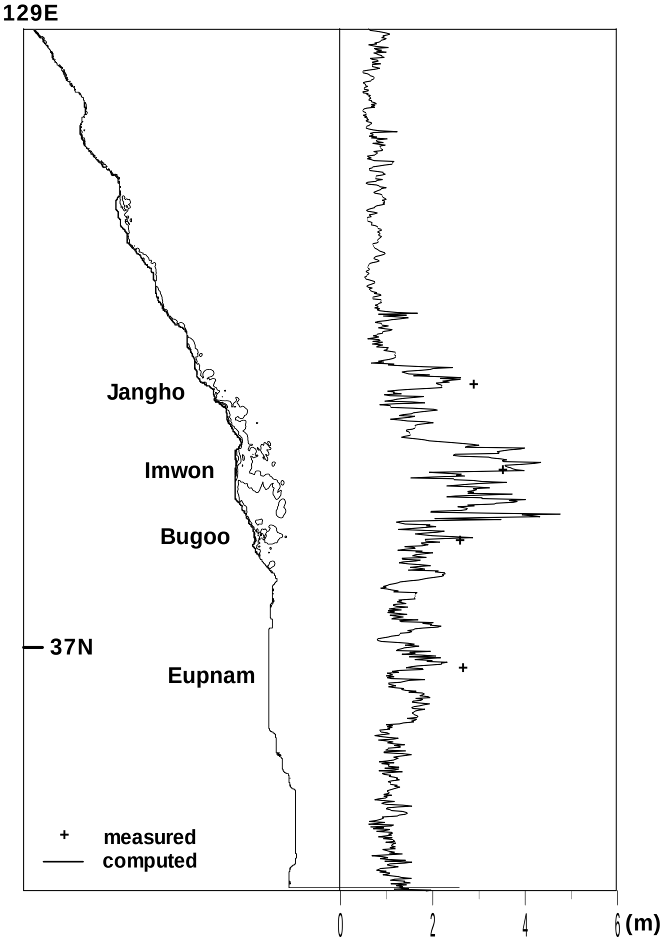

Fig. 3 Comparison of the maximum run-up heights

Table 1 Comparison of run-up heights at several locations along the eastern coastline (unit: m)

Location	Jangho	Imwon	Bugoo	Eupnam
Field Measurements	2.9	3.6	2.5	2.6
Present Study	2.7	4.2	2.6	2.3
Green’s Law	2.2	3.4	3.8	2.0

The study on the safety of intake system at the site of Ulchin Nuclear Power Plant revealed that the circulating water system would not be able to maintain its function in disastrous potential tsunamis of East Sea but the essential service water system related to safety of plants could not have any problem.

4. CONCLUDING REMARKS

The East Sea is one of the most vulnerable regions to unexpected tsunami attacks in the world. The Central East Sea tsunami occurred in 1983 has been recorded as the most devastating tsunami in modern Korean history. By employing a combined numerical model, the run-up heights of the tsunami are estimated along the Eastern coastline of the Korean Peninsula. A second-order upwind finite difference scheme is employed. The computed results are compared with available field measurements. A very reasonable agreement is observed**.**

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