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Simulation of Tsunami Propagation at East Sea along the Korean Peninsula

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1. Introduction

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**.**

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.

2. Methods and Results

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.

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2.1 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.

2.2 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.

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 1 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.

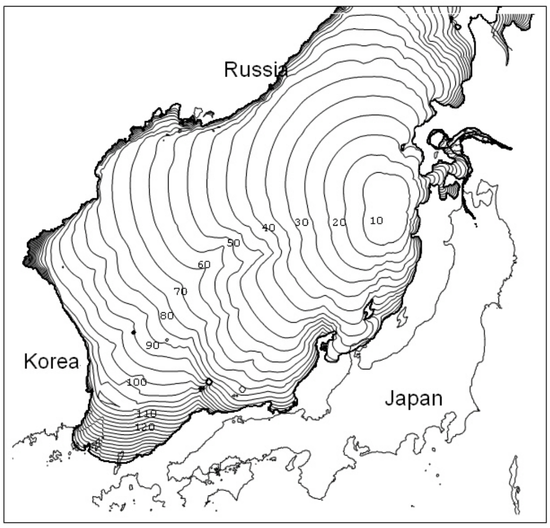

Figure 1. *Contour of arrival time of leading tsunami (unit: minutes)*

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.

3. Conclusion

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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