Analysis of Tsunami Run-up near Kori Nuclear Power Plant using Tsunami Analysis Code

Tae Soo Choi and Eung Soo Kim*
Department of Nuclear Engineering, Seoul National University, 559 Gwanak-ro, Gwanak-gu, Seoul, South Korea
**Corresponding author: kes7741@snu.ac.kr*

1. Introduction

After Fukushima accident, Evaluation of the ability to respond to tsunamis and safety checks at domestic nuclear power plants were conducted. The accurate understanding of tsunami characteristics at coast near the nuclear power plant has made it important to predict and analyze the tsunami on the coast.

The behavior of the tsunami occurring in the ocean depends on the fault location, geological characteristics, and the undersea topography in the propagation path. Also, according to previous studies, the effect of global-scale physical phenomena should be taken into account when direction tsunami propagation is simulated in the ocean scale.

In this study, the numerical code to analyze the tsunami propagation in the ocean was selected considering the above characteristics on the ocean scale, the information about the undersea topography and faults was collected, and the coastal area near the domestic Kori nuclear power plant was set as the analysis area. For the candidate fault groups that could affect the domestic nuclear power plant, the faults which could make significant effect was selected. The input data of the oceanic tsunami code was generated using the correlation of the magnitude of the earthquake and the geological characteristics of the faults in the East Asian region.

Analysis of the tsunami height, the propagation velocity and the propagation pattern in the ocean according to the time series near the nuclear power plant was conducted. Through the results of this study, it is expected that a database on tsunami can be constructed, and it will contribute to the construction of a prediction system for the arrival time and reaching wave of tsunami.

2. Numerical Code and Generating Input data

Earth curvature effect in simulating global scale tsunami, dispersion effect and the Coriolis force should be considered.[1][2] If the earth curvature effect is not reflected, the error increases at the high latitude or long distance from the source of tsunami. When the Sumatra tsunami occurred in 2004, the simulation result of the maximum wave height is different from real run up height more than 30%. When the dispersion effect is not taken into consideration, there is a difference of 34% in the maximum height occurrence area. Finally, if the Corilois force is not taken into consideration, the Propagation direction of the tsunami can be distorted due to the effect of the earth rotation.

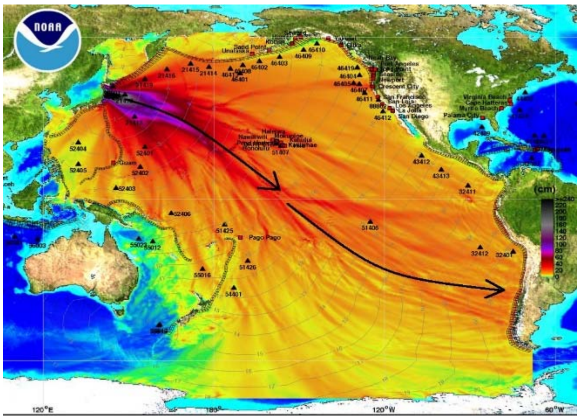


Fig. 1. Tsunami propagation direction affected by Coliori force during the Great East Japan Earthquake in 2011[3]

2.1 Selection of Tsunami Simulation Code

COMCOT v1.7 (Cornell Multi-grid Coupled Tsunami model) was selected as the analysis code for tsunami reaching time and wave height which was verified to be suitable for tsunami analysis through previous studies.[4],[5] COMCOT adopts explicit staggered leap-frog finite difference schemes to solve shallow water equation. It assumes that the fluid is a Newtonian fluid and follows the Boussinesq assumption, and integrates the equations of motion (2), (3), (4) and continuity equations(1) for each coordinate axis to the depth direction.[6]

$$\frac{\partial \eta}{\partial t} + \left\{ \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} \right\} = -\frac{\partial h}{\partial t} \tag{1}$$

$$\frac{\partial P}{\partial t} + gh\frac{\partial \eta}{\partial x} - fQ = 0 \tag{2}$$

$$\frac{\partial Q}{\partial t} + gh\frac{\partial \eta}{\partial y} + fP = 0 \tag{3}$$

$$f = \Omega \sin \phi \tag{4}$$

Where η is the water surface elevation, (P, Q) denote the volume fluxes in X, Y direction. F represents the Coriolis force coefficient and Ω is the rotation rate of the Earth.

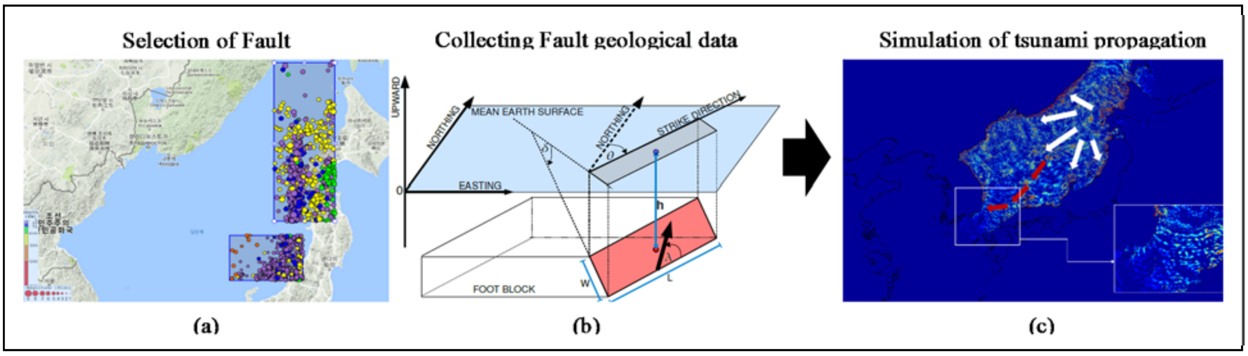


Fig. 2. Code input data formation and code operation

The tsunami propagation can be simulated in the spherical coordinate system and the orthogonal coordinate system for the ocean and the near sea,

and 12 analytical layers are set up, and analysis is carried out through the linear / nonlinear shear equation at each analytical layer.
The Tatehata correlation (4), (5), (6) is used for the size of the faults according to the scale of the earthquake, and the Okada model is used for the correlation between geological size of faults and tsunami. [7]

$$log\, L = 0.5M - 1.9 \quad (4)$$

$$W = 0.5L \quad (5)$$

$$logD = 0.5M - 1.4 \quad (6)$$

Where M is magnitude of earthquake, and L, M represent the length and width of fault. D denotes the dislocation of fault.

2.2 Acquisition of underwater topology information

The underwater topology information used in this report is the depth data of ETOPO format provided by NOAA (National Oceanic and Atmospheric Administration). NOAA's NGDC provides global depth data of 1 minute, 2 minutes, and 5 minutes with modified format for analysis area. In the case of COMCOT, it is necessary to modify the depth value because the sea surface reference depth is recognized as a positive value. [8]

2.3 Acquisition of earthquake geological information

The geological information was collected by dividing the earthquake that may affect the site of the domestic nuclear power plant into the near sea and the oceans according to the location of the earthquake, and the statistical data of the Incorporated Research Institutions for Seismology (IRIS) were used. Among the earthquakes listed in the IRIS, geological information of earthquakes occurred in large-scale fault zones that could affect the Korean peninsula and selected fault zones in previous studies were collected.

Geological information on the historical earthquakes that occurred in the Nankai trench, Northwest fault zone of Japan, and Korea S trait was collected, and geological information about virtual earthquakes assuming extreme conditions in the Northwest fault zone of Japan was generated.

2.4 Selection of faults for analysis

In the case of seismic sources in the ocean, the fault zone in northwest Japan and the south - eastern Nankai Sea in Japan were selected. For an analysis of historical earthquakes occurring in the ocean, conservative assumptions were made that five faults occur simultaneously in the order of magnitude within the analysis area. To account for the extreme situation, an analysis of faults with magnitudes 9.0 was conducted.

In the case of earthquakes that occurred in shallow sea, it was confirmed that the depth of the occurrence area is shallow and does not have a great influence on the coast of peninsula. Therefore, for conservative results, the analysis was conducted on the assumption that three hypothetical scale 7.5 faults occur simultaneously in the Korea strait where faults doesn't exist. Table 1 and 2 shows the geological information of the virtual extreme faults of Northwest Japan and near sea. Table 3 shows the fault information according to the magnitude of the earthquake.

Table 1. Geological information of virtual fault located in Northwest Japan

Geological Feature	
Location	[41.10, 138.52]
Depth of Fault [km]	23.27
Strike angle[˚]	312.4
Dip angled [˚]	30
Rake angle[˚]	30

Table 2. Geological information of virtual faults located in near sea

Location	Depth [km]	Strike Angle	Dip angle	Rake Angle
[35.07, 129.83]	7.2	300 ˚	35 ˚	106 ˚
[34.90, 130.19]	12.0	315 ˚	65 ˚	23 ˚
[35.06, 130.89]	302.2	307 ˚	68 ˚	46 ˚

Table 3. Geological information of fault according to Magnitude of earthquake

Magnitude	Length [km]	Width [km]	Dislocation [cm]
7.5	74.1310	37.0655	223.8721
8.0	131.8257	65.9128	398.1072
8.5	234.4229	117.2114	707.9458
9.0	416.8697	208.4347	1258.900

2.5 Selection of measuring points

The measurement points are set for 12 points on the coast near the Kori Nuclear Power Plant as Fig 3. The time series information of the tsunami waves from each direction can be measured through several measurement points. Also, information about time series sea level and volume flux at every point of analytical layer was obtained by using two analytical layers for understanding the propagation direction of tsunami.

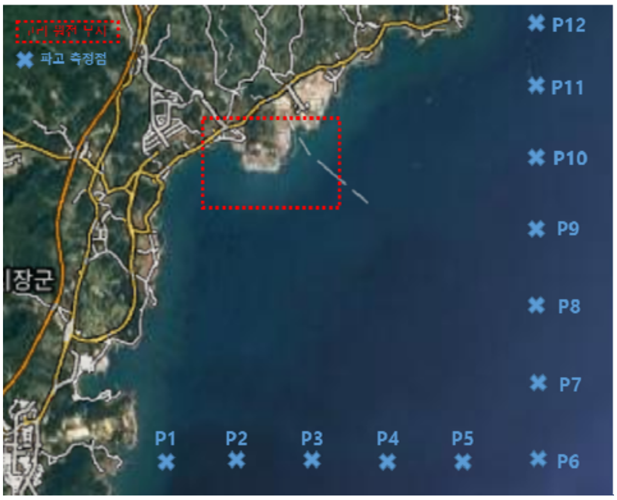


Fig. 3. Wave height measurement point near Kori NPP

3. Result of simulation

For each assumption of historical earthquakes and extreme earthquakes, Simulation using COMCOT 1.7 to acquire time series wave height information at the measurement point and propagation patterns of tsunami at each analytic layers was conducted.

3.1 Tsunami from Nankai trench

In the case of a tsunami assumed to occur in the Nankai trench, it was confirmed that it reached the southern coast of Korea by bypassing the Japanese hon-shu as shown in Fig. 4. The maximum wave height at each measurement point was less than 5 cm. In this case, It is confirmed that Tsunami can't affect the safety of the domestic nuclear power plant by simulation results.

3.2 Tsunami from Northwest Japan fault zone

It is confirmed that the historical earthquakes and extreme earthquakes that occurred at the Northwest Japan Earthquake can affect the domestic nuclear power plants. Assuming that five earthquakes occur simultaneously in the Northwest Japan Earthquake, the wave height near the Kori NPP is shown in Fig. 5. (a), where the maximum wave height is less than 10 cm. Figure 5. (b) shows the wave height information at magnitude 9.0 the earthquake occurred. The maximum wave height at this case was around 2.3 m. The propagation pattern of the tsunami is shown in Fig. 5 (c).

3.3 Tsunami from near sea

In the case of historical earthquakes that occurred between the southern coast of the Korean peninsula and Fukuoka, Japan, Tsunami do not affect domestic nuclear power plants due to shallow water depths of location of faults. Therefore, simulation and analysis of the extreme situation were carried out. The wave height at the measurement points according to the time series is shown in Fig. 6. (a), and the height of the maximum wave is around 3.5m. The tsunami propagation pattern at this time is shown in Figure 6. (b).

5. Summary

In this study, to analyze the propagation patterns of tsunamis in the oceans and near sea and the wave height near domestic nuclear power plants, a grid-based tsunami analysis code suitable for the analysis conditions, Comcot v1.7, was selected. Based on the fault information, the tsunami simulations were carried out, and data on the tsunami propagation patterns from the fault to the analysis area were obtained for the vicinity of the Kori NPP. Because the tsunami caused by the historical earthquake was at a level that could not affect the safety of the domestic nuclear power plant, the event of an extreme virtual earthquake was analyzed. In case of extreme virtual earthquake at Northwest Japan fault zone, maximum wave height at measure point was up to 2.3m Furthermore, In case of extreme virtual earthquake at near sea, maximum wave height at measure point was up to 3.5m. These results are expected to provide a basis for judging the safety of the domestic nuclear power plant against the tsunami and contribute to the construction of the tsunami prediction system by constructing the tsunami database.

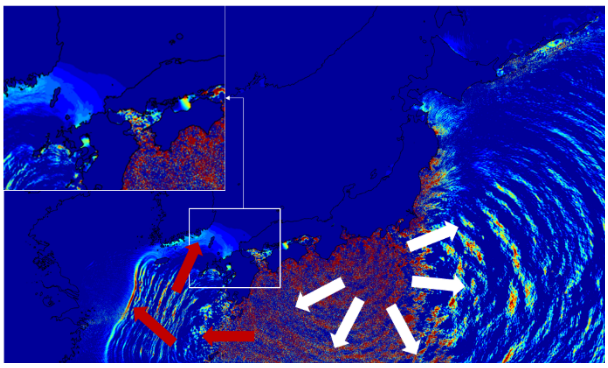
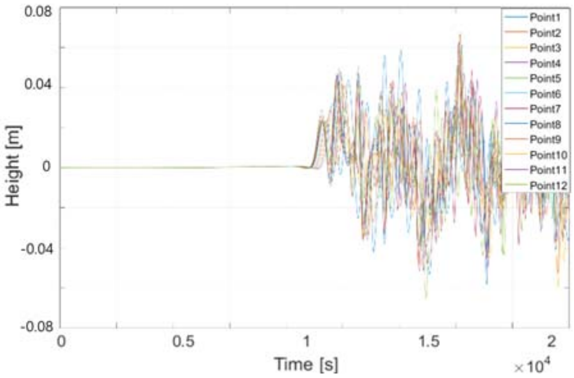
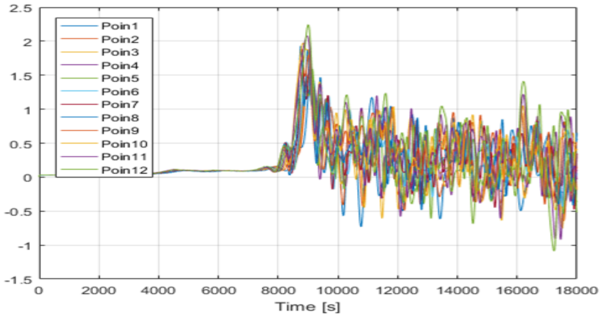


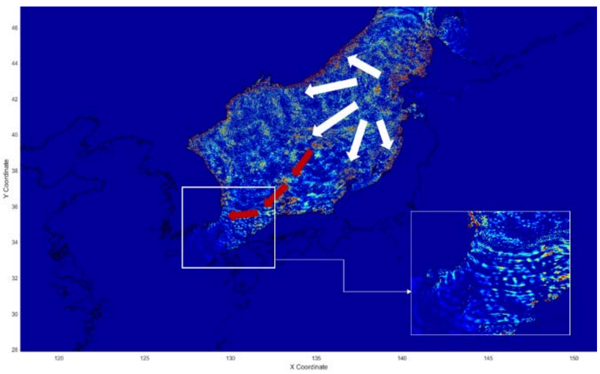
Fig. 4. Propagation pattern of Tsunami Occurred in Nankai trench



(a)

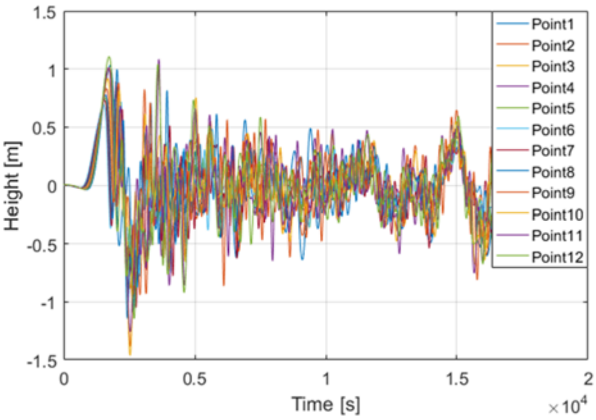


(b)

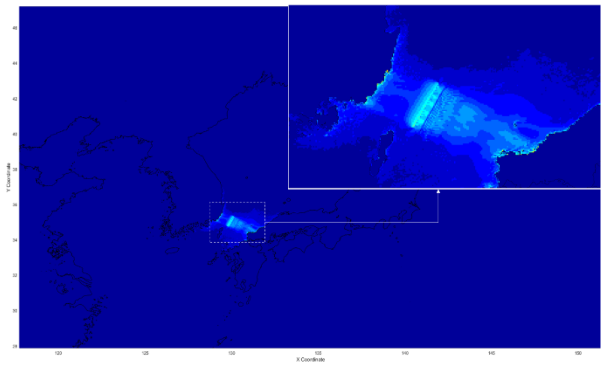


(c)

Fig. 5. Simulation of Northwest Japan Earthquake and Tsunami



(a)



(b)

Fig. 6. Simulation of near sea Earthquake and Tsunami

ACKNOWLEDGEMENTS

This research was supported by the National Nuclear R&D Program through the National Research Foundation of Korea (NRF) funded by MSIP; Ministry of Science ICT & Future Planning (No. NRF-2013M2B2B1075735) and the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety (KoFONS), granted financial resource from the Nuclear Safety and Security Commission(NSSC), Republic of Korea. (NO. 1403005).

REFERENCES

[1] Madsen, O.S., Mei, C.C., 1969. The transformation of a solitary wave over an uneven bottom. Journal of Fluid Mechanics 39 (4), 781–791.

[2] Liu, P.L.F., Cheng, Y., 2001. A numerical study of the evolution of a solitary wave over a shelf. Physics of Fluids 13 (6), 1660–1667

[3] NOAA, Tohoku (East Coast of Honshu) Tsunami, March 11, 2011, Main Event Page, 'http://nctr.pmel.noaa.gov/honshu20110311/'(2017.05.01.)

[4] Lin, Simon C., et al. "Development of a tsunami early warning system for the South China Sea." *Ocean Engineering* 100 (2015): 1-18.

[5] An, Chao, Ignacio Sepúlveda, and Philip L-F. Liu. "Tsunami source and its validation of the 2014 Iquique, Chile, earthquake." *Geophysical Research Letters* 41.11 (2014): 3988-3994.

[6] Hadi, Abdul, et al. "Complete derivation of 2D shallow-water model from the primitive equations governing geophysical flows." (2012): 1-6

[7] Tatehata, H. (1997). The new tsunami warning system of the Japan Meteorological Agency. In Perspectives on tsunami hazard reduction (pp. 175-188). Springer Netherlands.

[8] Wang, X. (2009). User manual for COMCOT version 1.7 (first draft). Cornel University, 65