Preliminary source model of the unexpected tsunami in Sendai bay from the 2016 Fukushima earthquake

PANON LATCHAROTE[1], ANAWAT SUPPASRI [1], VOLKER ROEBER [1], FUMIHIKO IMAMURA [1]
[1]*International Research Institute of Disaster Science, Tohoku University, Japan*

1. Introduction: On 22nd November 2016 at 05:59 JST (UTC+09:00), a large earthquake off Fukushima Prefecture struck the east coast of Japan with Mw 6.9 at a depth of 11.4 km. The United State Geological Survey (USGS) provided the earthquake parameters. The 2016 Fukushima earthquake was classified as an aftershock of the 2011 Tohoku earthquake. Although the epicenter was located offshore from Fukushima Prefecture as shown in Fig. 1, the highest tsunami wave was observed in Sendai, Miyagi Prefecture. In addition, the second wave of the tsunami was the highest. While the maximum observed tsunami amplitude in Fukushima Prefecture was only 0.8 m, the maximum amplitude at the tide gauge station in Sendai port was 1.5 m. It was the biggest tsunami event since 2011. In this study, numerical tsunami simulations were performed by a single fault model of the Fukushima earthquake with a length of 30 km and a width of 20 km. The computed waveforms are compared with the observed tide gauge record from Sendai port. Three source models with the same slip but different strike angles are proposed to investigate the tsunami mechanism in Sendai Bay. The strike angle of 238° was one of two nodal planes provided by USGS, whereas the other two strike angles of 90° and 180° (horizontal and vertical planes) were obtained from the tsunami warning system by the Japan Meteorological Agency (JMA).

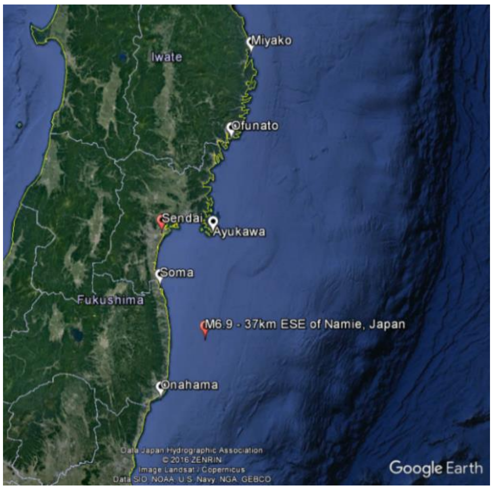

Fig. 1 Epicenter and observed locations (Google Earth)

2. Data and method:

2.1 Fault parameters: The epicenter of the 2016 Fukushima earthquake was located at 37.392°N and 141.403°E. The mechanism can be compared to a small push in the north-west direction and a big pull in the south-west direction. The fault rupture of the three source models was considered as a fault length of 30 km, a fault width of 20 km, and a fault slip of 2.0 m with a dip angle of 42° and a rake angle of -78° as shown in Table 1. The orientation of two nodal planes (238° and 42°) obtained from USGS provided almost identical results, so only the strike angle of 238° is used in this study for Model 1. The results from the strike angles of 90° and 180° for Model 2 and 3 are compared with Model 1 because the JMA database for tsunami warnings is based on numerical results from only purely horizontal and vertical planes. It should be noted that the remaining fault parameters of Model 2 and 3 are identical to those of Model 1 as provided by USGS.

Table 1 Input fault parameters for numerical tsunami simulation

Model	Length (km)	Width (km)	Slip (m)	Depth (km)	Strike (°)	Dip (°)	Rake (°)
1	30	20	2.0	9.0	238	42	-78
2	30	20	2.0	9.0	90	42	-78
3	30	20	2.0	9.0	180	42	-78

2.2 Numerical tsunami simulation: Based on the proposed source models, the nonlinear long wave numerical model TUNAMI was set up with four nested grids of 405 m, 135 m, 45 m, and 15 m and static tide level of MSL + 0.3 m.

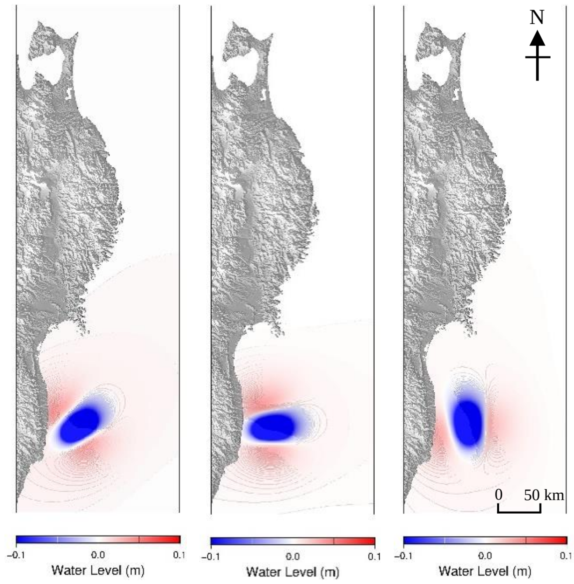

Fig. 2 Initial seafloor deformation of three source models

Fig. 2 shows computed initial seafloor deformation from different orientations of the source models. The fault plane of Model 1 (238°) is perpendicular to Sendai and Soma, while the fault planes of Model 2 (90°) and Model 3 (180°) are orthogonal to each other.

3. Results and discussions:

The observational data from the tide gauge stations along the east coast of Japan show that the maximum tsunami amplitude of 1.5 m was observed at Sendai Port in Miyagi Prefecture. The highest tsunami amplitude at Soma in Fukushima Prefecture was only 0.8 m as shown in Fig. 3. However, the tsunami amplitudes of the first wave in both Sendai and Soma were similar. The second wave was higher in Sendai due to wave amplification. Fig. 3 shows the comparisons between observation data and numerical results of tsunami waveforms at Sendai and Soma. Although the phase of Model 1 was slightly shifted and the tsunami arrival time was slightly earlier than shown in the observation data, the simulated waveforms for Sendai were reproduced with satisfying accuracy. Model 2 shows a maximum tsunami amplitude equal to Model 1, but Model 2 was able to reproduce the first wave more accurately than Model 1. Therefore, the horizontal plane of Model 2 was able to represent the strike plane of Model 1 for the tsunami warning system in Sendai.

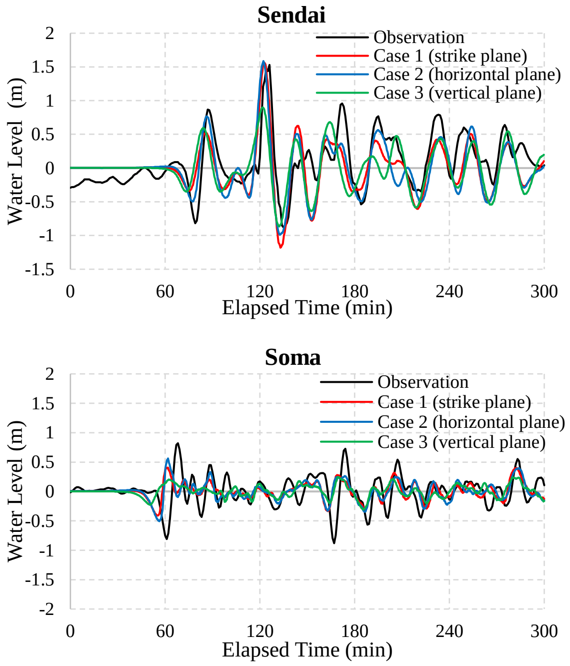

Fig. 3 Comparisons of tsunami waveforms at Sendai and Soma

Fig. 4 shows the tsunami propagation after the earthquake that reached the coasts of Fukushima prefecture within 30 min. Then, while the second tsunami wave traveled to Sendai after about 45 min, the first wave started to reflect from the coast of Fukushima. The reflected wave then propagated along the coasts of Fukushima and finally refracted into Sendai Bay after 1 hour. The subsequent wave processes caused wave attenuation and amplification at Sendai as shown in the Fig 3 after 2 to 3 hours.

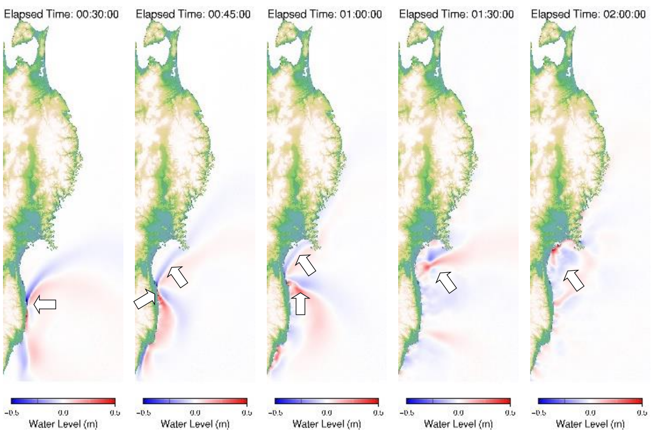

Fig. 4 Snapshots of tsunami propagation at 30 min, 45 min, 1 hour, 1.5 hours, and 2 hours

Fig. 5 shows higher maximum tsunami amplitudes in Sendai Bay because the bulk of the wave energy was released directly towards the coastal area near Sendai. Wave refraction and shoaling are additional factors for the relatively large waves in Sendai Bay. Fig. 6 shows the maximum tsunami amplitude with focus on Sendai Bay. Pushing the reflected wave behind the first wave could cause the concentration on the backside of Sendai Bay.

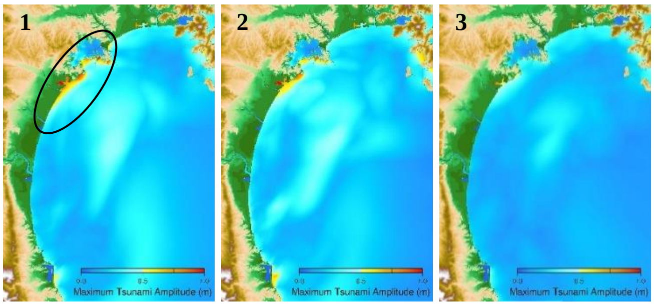

Fig. 5 Distribution of maximum tsunami amplitude in 45-m grid

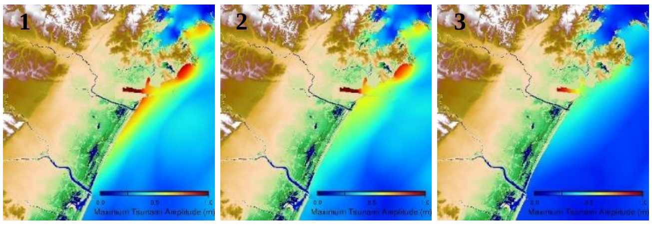

Fig. 6 Distribution of maximum tsunami amplitude in 15-m grid

4. Conclusions and recommendations:

A preliminary source model was proposed using fault mechanisms published soon after the event and verified with tsunami waveforms. The waveform at Sendai was successfully reproduced while needed to be improved for Soma. This shallow earthquake occurred near Fukushima prefecture but caused the unexpected highest tsunami amplitude in Sendai, Miyagi prefecture because of its fault orientation. The simulation results also showed that the second wave was the highest due to wave reflection from Fukushima and refraction into Sendai bay. This study was therefore further test the sensitivity of the fault orientation similar to JMA database by only having purely horizontal and vertical planes. The results showed that the horizontal plane was surprisingly able to explain the tsunami characteristics similar to the case of strike plane. JMA warning message was later upgraded from “advisory” to “warning” because the observed waveform in Sendai was higher than 1 m (upper limit for “advisory”). This study recommends future studies on detailed sensitivity analysis of fault orientation and wave amplification in Sendai bay to improve accuracy of the tsunami warning.

Acknowledgements: This research was funded by the Willis Research Network (WRN) through the International Research Institute of Disaster Science (IRIDeS) at Tohoku University.

References:

Supprasri, A., Leelawat, N., Latcharote, P., Roeber, V., Yamashita, K., Hayashi, A., Ohira, H., Fukui, K., Hisamatsu, A., Nguyen, D., and Imamura, F. (2017) The 2016 Fukushima earthquake and tsunami: Local tsunami behavior and recommendations for tsunami disaster risk reduction, *International Journal of Disaster Risk Reduction*, 2017.