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Origin of the surface vibrations of the Sea of Japan generated by the 2011 off the Pacific coast of Tohoku Earthquake

IWAI, Maki[1*], MUROTANI, Satoko[1], TSURUOKA, Hiroshi[1], SHINOHARA, Masanao[1], SATAKE, Kenji[1]

[1]ERI, the Univ. of Tokyo

Just after the Tohoku earthquake on March 11, 2011, sea surface vibrations were observed at some tide stations along the coast of the Sea of Japan. In this study, we made numerical computation to generate these vibrations from a source model based on observed data of the Pacific Ocean - such as tide stations (JMA, JCG), ocean bottom tsunami sensors (ERI), offshore GPS wave gauges (NOWPHAS). As a result, we could successfully reproduce the observed vibrations of the Sea of Japan with the initial condition of not only the vertical but also of the horizontal displacement of ocean bottom.

This earthquake caused tsunami. About 30 minuates after the earthquake, tsunami attacked the Pacific coast of Tohoku with more than 9 m height according to the records of many costal tide gages.

Immediately following the earthquake, some vibrations were observed at several tide stations of the Sea of Japan. Judging from the records, the wave frequencies were rather high (the periods were about several minutes) with the amplitudes about 10 cm. Inferred from the observed data, tsunami passed the Tsugaru cannel 2 hours after this earthquake. It indicates that these vibrations were different from the tsunami that passed the Tsugaru channel.

In general, tsunamis are assumed to be long waves and the vertical deformation of ocean bottom is assumed to be instantaneous. Under these assumptions, the initial condition of numerical computation of tsunami, that is, the displacement of water surface is equal to the vertical displacement of ocean bottom. The effect of the horizontal deformation is usually neglected. This is valid as long as the ocean bottom is flat or shallowly-dipping. However, according to Tanioka and Satake (1996), if the ocean bottom contains steep slopes or steps, the effect of the horizontal displacement of ocean bottom cannot be neglected. In this study, we computed the water level of the Sea of Japan including the effect of the bathymetry and horizontal displacement of ocean bottom.

For the computation a 30s-interval grid bathymetry data (JTOPO30) was used for 128-148E longitude and 39-46 N latitude. WThe fault model, which consists of 40 rectangular subfaults, was inverted from the observed waves (Fujii et al., 2011). Then static deformation of the seafloor was calculated by using formula of Okada (1985). To calculate tsunami propagation, the linear shallow-water, or long wave, equations are numerically solved by using a finite-difference method. Finally we compared the observed and computed waveforms at every observed station.

The result indicates that only vertical displacement of ocean bottom cannot explain the vibrations of the Sea of Japan just after the earthquake, although the long-period waves were computed. Adding horizontal displacement of ocean bottom generated the vibrations similar to the observed. The horizontal displacement slightly increased the computed tsunami amplitudes at the stations along the Pacific Ocean though the waves themselves were almost the same of those from only vertical displacement.

Although the slopes of ocean bottom are located many places in the Sea of Japan, vibrations with larger amplitudes were especially observed from Akita to Sado coasts. One reason is that there exist some steep slopes or steps parallel to the fault. Another reasonis that the above regions are nearer to the fault so that ocean bottom deformation is relatively larger. There are very few changes along the Pacific Ocean because the effect of vertical displacement of ocean bottom is much more dominant than that of the horizontal one.

We computed the vibrations of the Sea of Japan just after this earthquake. However, the waveforms themselves are not so similar to the observed. This is because we ignored the effect of the non-linear terms of equations near the coast and we computed with 30s grid-interval (about 1km-interval) so that the coast topography near the tide stations is very rough.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, tsunami, the Sea of Japan, horizontal displacement of ocean bottom