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Tsunami Heights and Period Distribution of Tokyo Bay and Characteristic Oscillation of Tokyo and Sagami Bays

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Coastal areas in Tokyo Bay have experienced earthquake tsunamis several times, and there is large difference in wave height distribution inside and outside the bay for tsunamis generated by near earthquakes (e.g. 1923 Kanto earthquake) and for those by far-field earthquakes (e.g. 2011 Tohoku earthquake). Significant attenuation of tsunamis results that wave heights at the inner part of Tokyo Bay were much smaller than those outside for the Kanto earthquake (Hatori et al., 1973), while less attenuation of the Tohoku earthquake tsunamis yielded similar tsunami heights inside and outside Tokyo Bay (Sasaki et al., 2012). Wave heights in a bay strongly depend on the period relation between incident wave and characteristic oscillation of the bay, so it is important to know about these. In this research, we conducted tsunami frequency analysis and calculation of characteristic oscillation for Tokyo Bay and surrounding area.

First, we conducted spectral analysis of observed and numerically reproduced waveforms and estimated the dominant periods. As a result, we found that dominant periods were different between two earthquakes, and that they were also different between inside Tokyo bay and outside Tokyo Bay (around Sagami Bay) even for the same earthquake. For example, the dominant periods were 70 and 30-40 min inside, and 110 min outside for the Kanto earthquake, while they were 60-70 min inside, 60-70 and 110 min outside for the Tohoku earthquake. These dominant period strongly affected wave heights in each area. In particular, for the Kanto earthquake, the shorter period (<40 min) component that was included in the first wave is responsible for the attenuation of tsunami heights around the mouth of Tokyo Bay, especially at the border connecting from Kurihama in Kanagawa Prefecture and Kanaya in Chiba Prefecture. The border is where the water depth becomes abruptly shallow when tsunamis enter the bay.

Second, we calculated characteristic oscillation of an area around Tokyo and Sagami Bays. Characteristic oscillations of Tokyo Bay have been calculated by Aida (1996) as solutions of the eigenvalue problem, but those of Sagami Bay have not. From tsunami numerical simulations, Imai et al. (2014) found the oscillation of Sagami Bay and its effects on tsunami behavior in Tokyo Bay. We consider wide areas including Tokyo and Sagami Bays, and solved an eigenvalue problem composed of linear shallow-water wave equation to obtain normal modes by the same method as Loomis (1975). As a result, we found that most modes were characterized by only inside Tokyo Bay (e.g. 112 min mode), but that several modes are characterized by outside or by both inside and outside (e.g. 72 min). Comparing these modes with dominant periods by frequency analysis, we found that dominant periods around 110 and 70 min periods could be explained by normal modes. However, 30 to 40 min periods that were detected outside for the Kanto earthquake could not be explained by normal modes, because there were no obtained modes correspond to them.

From above analyses and calculations, we consider the cause of the difference of attenuation. For the Kanto earthquake, shorter period (<40 min) components affected large wave amplitudes outside Tokyo Bay, but at the mouth of the bay they were weakened, and wave heights were accordingly attenuated from there. This could not be explained by characteristic oscillations, but Watanabe (1970) suggested that the wave reflection should have occurred and affected the attenuation, because of the abrupt decrease of water depth. On the other hand, for the Tohoku earthquake, the dominant period outside the bay was around 70 min that was close to the period of the coupled (inside and outside) mode of characteristic oscillation (72 min), so the oscillation could be transported to the inner part of the bay.

Keywords: Tsunami spectral analysis, Characteristic oscillation, Tokyo Bay, Sagami Bay, 1923 Kanto earthquake, 2011 Tohoku earthquake