Ground motion waveforms in the epicentral area of the 2011 Tohoku-Oki earthquake with large displacements, retrieved from ocean-bottom dynamic pressure change data

*Tatsuya Kubota[1], Tatsuhiko Saito[1], Hiroaki Tsushima[2], Ryota Hino[3], Yusaku Ohta[3], Syuichi Suzuki[3], Daisuke Inazu[4]

1. National Research Institute for Earth Science and Disaster Resilience, 2. Meteorological Research Institute, Japan Meteorological Agency, 3. Tohoku University, 4. Tokyo University of Marine Science and Technology

Introduction

Recent studies have shown that ocean-bottom pressure gauges (OBPs) can record seismic waves in addition to tsunamis and seafloor permanent displacements. Recently the method to numerically simulate more realistic OBP signals inside the focal area based on the theory of tsunami generation (Saito, 2013; 2019) has been established (e.g., Lotto et al., 2015; Saito et al., 2019; Maeda et al., 2020), although the method to appropriately decompose the OBP signal to the seismic and tsunami signals has not been established well (Saito & Tsushima, 2016). If the seismic waveforms inside the focal area are obtained, our understandings for the source process of earthquakes will be deepened, as well as the seismic wave propagation process inside the focal area. In this study, we develop a method to decompose the in-situ OBP records into the tsunami and seismic motion components based on the theory of tsunami generation and apply the method to the OBP data during the 2011 Tohoku-Oki earthquake.

How to extract ground motions from OBP data

When we focus on the low frequency band ($f <$ ~10^{-1} Hz) where the elasticity of the seawater can be ignored and we can suppose the seawater is incompressible, the ocean bottom pressure change $p(t)$ can be expressed as a sum of the hydrostatic pressure change $p(t) = \rho_0 g_0[\eta(t) - u(t)]$ (ρ_0: seawater density, g_0 : gravity acceleration, $\eta(t)$: sea surface height change, $u(t)$: seafloor vertical displacement) and the dynamic pressure change $p(t) = \rho_0 h_0 \partial^2 u/\partial t^2$ (h_0: seawater depth) (e.g., Saito, 2013). The seafloor pressure change inside the focal area at nth OBP $p_n(t)$ can be expressed as a superposition of the contributions by the Green's functions for the hydrostatic pressure ($G_{i,n}^{hydrostatic}(t)$) and dynamic pressure ($G_{i,n}^{dynamic}(t)$), generated by the seafloor vertical ground motion at ith element: $p_n(t)$ = ∑$_i$ [m_i{$G_{i,n}^{hydrostatic}(t) + G_{i,n}^{dynamic}(t)$}]. By estimating the amplitude of each unit source, m_i, based on this equation, we can obtain the time series of vertical ground motion.

Application to the 2011 Tohoku-Oki earthquake

We apply this method to the in-situ OBP records during the Tohoku-Oki earthquake, installed by Tohoku University and the University of Tokyo (Maeda et al. 2011; Hino et al. 2014). After removing the tidal component, we apply a low-pass filter with a cutoff of 0.05 Hz to remove the high-frequency acoustic component. The vertical displacement waveforms obtained by the analysis show large displacement offsets at stations GJT3, P08, and P09, located in the area where the seafloor displacement was extremely large (e.g., Saito et al. 2011). The final displacement offsets of these stations were in good agreement with the permanent displacements detected by the hydrostatic pressure offset change, indicating the validity of our proposed method. The velocity waveforms at stations P08 and P09 just above the epicenter showed two peaks, which suggests that the two moment releases near the epicenter during the rupture (e.g., Ide et al., 2011). In addition, the waveforms recorded by the nearest coastal seismographs from each station were similar, except for the arrival time delay.

High-sensitivity ocean bottom seismographs, commonly used for the offshore seismic observation, cannot record seismic waveforms correctly because of waveform saturation. Because of the broadband and broad dynamic range observations by the OBPs (Kubota et al., 2020), OBPs can observe high frequency seismic components without saturation. In addition to the tsunami early warning (e.g., Tsushima et al., 2012), the OBP installed inside the focal area is expected to make the important contribution as an instrument to record nearfield strong ground motion.

Keywords: Ocean bottom pressure gauge, Tsunami, Dynamic pressure change, The 2011 Tohoku-Oki earthquake, Seafloor ground motion

