A study on the characteristics of amplitude and dominant period of long-period ground motions via 3D finite-difference simulation: A case study for the Kanto sedimentary basin

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Introduction

In the Kanto sedimentary basin, long-period ground motions (LPGMs) are frequently observed for shallow local and regional earthquakes. It is reported that, in the Kanto sedimentary basin, the predominant period of LPGMs is mainly controlled by the bedrock depth of sedimentary basin (e.g., Yoshimoto and Takemura, 2014b), but with the exception of the area around the Tokyo Bay where the elongation effect due to low-velocity sedimentary layers is observed (e.g., Kajikawa et al., 2016). It is also found that the excitation of LPGMs is very complex and varies by epicentral direction of earthquakes (e.g., Yuzawa and Nagumo, 2012). For the better seismological understanding of these observations, we conducted 3D finite-difference (FDM) simulations using simplified velocity structure models of sediment-basement system to evaluate the effect of sedimentary structure and basement shape on the characteristics of strength and predominant period of LPGMs.

Simulation method and structure models

We conducted 3D FDM simulations for investigating the characteristics of LPGMs during shallow moderate earthquakes. For the evaluation of LPGMs for periods longer than 4 s, models with a volume of $150\times60\times72$ km^3 discretized by a grid interval of 0.15 km were used for this simulation. Other technical details are same as in Takemura et al. (2015). We used three sedimentary structure models referred from VSP measurements (Yoshimoto and Takemura, 2014a): Yokohama model (Y-model), Chiba model (C-model), and Iwatsuki model (I-model). We adopted four basement topography shapes: flat model (basement depth of 3.5 km) and flat + triangle-shaped hill (height of 2.5, 3.0, and 3.5 km) models. Structure beneath the basement was a stratified layered structure referred from the JIVSM (Koketsu et al., 2012). Pure strike- and reverse-type point source models, which excites Love and Rayleigh waves, respectively, were used in our simulations.

Result of numerical experiments

(1) Characteristics of Love and Rayleigh waves

Single-peak envelope of the fundamental-mode Love wave was found in the simulation using a strike-type source. In contrast to this, for a reverse-type source, multi-peak envelope of LPGMs appeared. These findings indicate that in the case of reverse-type source, LPGMs are constructed by superposition of not only fundamental- but also higher-mode Rayleigh waves. Dominance of horizontal amplitude over vertical amplitude observed for the simulations using a reverse-type source is consistent with this interpretation.

(2) Bedrock topography dependent PGV

Peak ground velocity (PGV) of LPGMs increases with increasing height of a triangle-shaped hill on the basement. This result is interpreted by the strengthening of the Airy phase of Love waves by the constructive interference of short period surface waves that are effectively excited and propagate at shallow depths. This phenomenon may correspond to the strong excitation of Love waves at the northern and western boundary of the Kanto basin.

(3) Local amplification of LPGMs
Local variation of the PGV of LPGMs was detected during surface wave propagation thorough adjacent sediments with different velocity structures. For example, propagation of Love waves from Y-model to C-model showed an amplification of LPGMs at period longer than about 5 s, and especially at about 10 s. This result successfully explains the observed local amplification of Love waves in the western coast of the central Boso Peninsula (Kajikawa et al., 2016).

The characteristics mentioned above were also found in large-scale FDM simulations using JIVSM or SBVSM (Masuda et al., 2016 SSJ). However, these simulations could not sufficiently reproduce the observed LPGMs around the Tokyo Bay and western edge of the Kanto Basin. To overcome this problem, detailed analysis of observed LPGMs, forward modeling and estimation of sedimentary structure via waveform inversion should be required.

Keywords: Long-period ground motion, Kanto sedimentary basin, Sedimentary structure, Surface wave, Maximum amplitude, Predominant period

Quasi-static earthquake cycle simulation based on large-scale viscoelastic finite element analyses

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Earthquake cycle simulation is extensively studied in the field of solid earth science as a tool to explain earthquake generation processes. It is also expected to play an important role in disaster mitigation, such as generation of possible earthquake scenarios as inputs for earthquake damage estimation. An approach combining a boundary element approach based on Green’ s function in an elastic half space and the rate- and state-dependent friction law is widely used for this simulation (e.g. Hori 2009; Barbot et al. 2012). On the other hand, in crustal deformation computation, complex physics such as the mantle rheology and the effect of gravity are not negligible in some cases. To consider extensibility for such effects, it is desirable to develop an earthquake cycle simulation combining crustal deformation computation based on numerical simulation such as finite element (FE) method with the rate- and state-dependent friction law. This approach used to be practically difficult because of the associated computational cost, but the recent development of a fast and scalable FE solver (Ichimura et al. 2016) assuming use of supercomputers is expected to make it feasible. Therefore in this study, we seek to apply the crustal deformation computation using the viscoelastic FE analysis method developed by Ichimura et al. (2016) to earthquake cycle simulation based on the rate- and state-dependent friction law.
We use the equation of motion, the rate- and state-dependent friction law, and a slowness law as the governing equations of the earthquake cycle simulation. However, instead of computing stress changes along the fault plane by superimposing slip response function as in the previous studies, we compute them using the time history calculation of viscoelastic deformation using the FE method. For now, the time integration scheme and other components of the simulation method all follow the approach in Hyodo and Hori (2014).
We are now performing verification of the developed simulation code using a normative three dimensional problem, where a circular-shaped velocity-weakening area is set in a square-shaped fault plane. In the presentation, we will discuss the comparison of our results with those obtained using the previous methods. If possible, we would also like to discuss the change of earthquake generation process due to the introduction of viscoelasticity in the cycle simulation, as an example of the effect by mantle rheology.

Keywords: Earthquake cycle simulation, Finite element method, the rate- and state-dependent friction law, large-scale numerical simulation

Forward simulation of postseismic process after moderate and large interplate earthquakes along the Nankai Trough

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Along the Nankai trough, it has been considered that low seismic activity in the interseismic period is a typical feature there, and that the accumulated strain during the interseismic period is only released by great interplate earthquakes with recurrence intervals of 90-200 years. However, recent observations or studies show that there have occurred several M6~7-class interplate earthquakes within the region of the Nankai Trough earthquake, such as an M6-class earthquake at Kumano-nada (April 1, 2016) and an M7.6 Hyuga-nada earthquake (July, 1498).

Recent two M6~7-class earthquakes occurred within the source area of great interplate earthquakes nearby the Japanese Islands were followed by contracting consequences: the 2016 Kumano-nada earthquake above wasn't followed by the great interplate earthquake, while an M7-class interplate earthquake which occurred at off-Tohoku region in March 9, 2011 was followed by the 2011 Tohoku-oki earthquake, and was regarded as a foreshock of Tohoku-oki earthquake.

Such different consequences are caused by the different urgency of the great interplate earthquake at the timings of occurrences of these M6~7-class earthquakes. Thus, when the occurrence of great earthquake is approaching, postseismic slips after the M6~7-class earthquakes can easily propagate to the surrounding region and can trigger the subsequent great event. While, if the fault is not urgent to the great event, strong coupling on the fault may prevent postsesmic slip from propagating to the surrounding area. These differences in postseismic slip patterns strongly affect the corresponding crustal deformation observed at the earth's surface or the ocean bottom. Hence, from occurrence pattern of the crustal deformation after the M6-7 earthquake in the target source region, it might be possible to narrow down the pattern of afterslip or the subsequent scenario that can occur.

In this study, we focus on the Nankai Trough region, and firstly examine the possible propagation pattern of after slips after the hypothetical occurrence of earthquakes such as M7-class Hyuga-nanda earthquake or M6-class Off-Kumano earthquake in many Nankai Trough earthquake scenarios deduced from numerical simulations. Then, we classify the expected postseismic deformation patterns at the pre-existing observation networks depending on the propagation pattern of particular after slip. Further, we will consider whether the pre-existing network have a distinguishability of after slip propagation pattern or not. If the distinguishability in the existing network isn't enough to distinguish the postseismic slip, we will seek for the better observables or the better observation arrangements. In oder to evaluate realistic crustal deformation, we will evaluate crustal deformation associated after slips not only in a homogeneous elastic half-space but also in FE models with heterogeneous crustal structure and the configuration of bathymetry at the earth's surface.

Keywords: Nankai Trough earthquake, crustal defomation, urgency of the great earthquake

Challenge of Preparing for Careers in Big Data in Geosciences

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In the aftermath of the 2008 financial crisis we have seen the steady encroachment of Big Data into every facets of society, from finances to medical services. Students graduate lacking technological skills despite needing them in the lab and on the field. We believe that putting a stronger emphasis on programming and technology will prepare them for the demands of today’ s modern job market in the geosciences and to use better measurement and analysis technology.

Our curriculum in educating students needs some changes, but universities move too slow. Therefore training centers are sorely needed. For this reason, we have established Mc Data Consult Ltd., based now in Wuhan, but poised to move anywhere.

Our aims are four fold:
(1) To establish training courses at both fundamental and advanced levels, which will be taught with customized software embedded within a affordable data-analytic tool box built with (a) cheap processors such as Raspberries Pi and (b) higher-end Nvidia TX1. Students can learn and perform exercises according to their available time slots.
(2) To provide professional consulting for various Big Data challenges encountered in industries.
(3) To hold workshops and international conferences where we can mix people from various disciplines and engage them in Big Data immersion.
(4) We also see the need to prepare suitable textbooks , focusing on high-performance computing, visualization and data analytics. We maintain that Python holds the key for preparing the students in Big Data analytics.

To be sure, the big data problem is not a new paradigm for geoscience. For instance, Peter Shearer (1991) used a relatively simple 1-dimensional velocity model to stack thousands of long-period body waves, revealing two upper mantle discontinuities, which was the first successful "big data" application: the primary computing happens for data processing, not for artificial modeling. Thus, we believe that geoscientists can be prepared to adapt to the big data era once they master the modern tools: they should master an open programming language suitable for large data, such as Python, and know how to harness parallel and distributed systems. They should learn sound software engineering skills, just as a wet chemist needs to learn to wash glassware. They should learn to produce a reproducible work: all analyses should be scripted and point-and-click tools should be avoided. They should have skills in data visualization and should master the rudiments of nonparametric, computationally based statistical inference, such as permutation tests.

Keywords: Big Data, Machine Learning, High Performance Computing, Python, Education