Short-term Research Visits (Project No.: 28S-02)

Project title: Investigation on Effects of Uncertainty of Velocity Structure Model in Earthquake Source Inversion Study
Principal Investigator: Miroslav HALLÓ
Affiliation: Charles University in Prague, Czech Republic
Name of DPRI collaborative researcher: Kimiyuki ASANO
Name of visitor (Affiliation): Miroslav HALLÓ (Charles University in Prague, Czech Republic)
Period of stay: November 20, 2016 ~ December 5, 2016
Location of stay: Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto, Japan
Number of participants in the collaborative research: 3 DPRI staffs and 2 Non-DPRI participants
- Number of graduate students: 2 students (1 Masters and 1doctoral students) (Included number)
- Participation role of graduate students [Attending Special Seminar]

Anticipated impact for research and education

During the short-time visit of the principal investigator, we had an international seminar on earthquake source inversion study. Graduate students and young researchers from DPRI and others attended the seminar and discussed on this topic.

Research report

(1) Purpose

The seismic waves generated by an earthquake source propagate to the ground surface throughout the rock and soil medium. Assumption of an earthquake source model is then a key factor of ground motion prediction because the assumed source parameters can be directly related to the generation of seismic waves. Large tectonic earthquakes are heterogeneous shear movements on large faults of finite size. Physical description of such sources can be performed by finite source models as space-time distribution of the spatially oriented slip on the fault. The source models are constrained by inversion techniques from observed seismograms, nevertheless they are subject of uncertainty where the major source of it is imprecise knowledge of the velocity structure model of Earth's crust. The consideration of uncertainty is quite important for assessment of model reliability, and also to give better use of earthquake source models. Fully Bayesian earthquake finite source model inversion was not developed yet, as it is difficult to completely describe uncertainties of measured data and especially uncertainties of the method. However, there are recent innovative strategies of Bayesian centroid moment tensor (CMT) inversion in the low frequency point source model approximation. Such earthquake source models allow reliable assessment of inverted point source model uncertainty.

The purpose of the collaborative research was to introduce and apply the innovative earthquake source inversion technique with reliable assessment of their uncertainty. The latter is considered to be due to the uncertainty of the velocity structure model of Earth's crust. The principal investigator participated on development and synthetic benchmarking of such Bayesian CMT inversion, however the technique required enhancements to be applicable on real earthquakes. The source model inversion method was performed and tuned on earthquakes from the Kumamoto earthquake sequence, Kyushu 2016 (平成 28 年熊本地震). The inferred source models and their uncertainties demonstrate the abilities of such a methodology. Moreover, the source models of foreshocks and aftershocks supplemented by the reliable assessment of their uncertainty lead to seismotectonic interpretation of the Kumamoto sequence with demonstrated statistical significance.

(2) Summary of research progress

Active cooperative research started approximately one month prior the planned short-term research visits at DPRI. The principal investigator implemented his previously developed technique for statistical description of velocity model uncertainty in the Bayesian CMT inversion. In particular, he modified the open source Bayesian full-waveform CMT inversion software ISOLA-ObsPy (developed by J. Vackar; http://geo.mff.cuni.cz/users/vackar/isola-obspy/) to be able to account for the uncertainty and work with seismological data from Japanese K-NET, KiK-net, and F-net networks, operated by National Research Institute for Earth Science and Disaster Resilience (NIED). The software modification was tested on synthetic datasets and shown to reliably assess the uncertainty of inverted source parameters.

During the short-term research visits at DPRI, the DPRI collaborative researcher explained the difficulties of analyzing and interpretation of real events from the Kumamoto sequence. The principal investigator got familiar with this earthquake sequence and analyzed selected foreshocks and aftershock in order to infer the source models supplemented by reliable assessment of uncertainty. There were some practical difficulties to overcome in the real earthquake source inversion, therefore the cooperative research was valuable as Czech group has strength in works on theoretical basis and Japanese group has experiences in analyzing real events. The short-term research visits was finished by special seminar where the principal investigator presented theoretical background of the innovative inversion technique and the inferred source models for the selected foreshocks and aftershocks of the Kumamoto earthquake sequence.

After the short-term research visits at DPRI the principal investigator continued with analyzing and summarizing findings about the Kumamoto sequence at his home institution. He extended the set of analyzed events and discussed the possible seismotectonic interpretation with the DPRI collaborative researcher. Finally, they decided to submit abstract with findings about the Kumamoto sequence to IASPEI conference in Kobe (August 2017) and prepare a manuscript to be submitted to an impacted scientific journal.

(3) Summary of research findings

Synthetic benchmarking of the earthquake source inversion involving the velocity model uncertainty show that the present technique can reliably assess the uncertainty of inferred source parameters. Because of the cooperative research and the short-term research visits at DPRI, the principal investigator was able to upgrade this technique on the practical level. He got familiar with the Japanese seismotectonic setting and successfully applied the technique on the real earthquakes from the Kumamoto sequence. The technique and its application was presented on the special seminar on December 1st 2016 to researchers from DPRI and other Japanese seismological institutions. The DPRI collaborative researcher has brought new ideas about future enhancement of the method and supported principal investigator in analysis of real data.

The analysis and the final seismotectonic interpretation of Kumamoto earthquakes has a scientific significance, as the inferred CMTs show a complex temporal and spatial variations. The right-lateral strike-slip events are linked to the NE-SW shear zone and are assumed to be primary phenomena caused by local tectonic regime. The dip-slip events, mostly aftershocks, are connected to the N-S extensional tectonic regime and we consider them as secondary. The assumed fault planes of strike-slip events located close to the intersection of Hinagu and Futagawa fault zone are dipping slightly to east, while those in the southern area (Hinagu fault zone) are dipping to west. The uncertainties of the inferred dip angles are smaller than the difference between east dipping and west dipping zones. Hence, the dip angle difference revealed by the Byesian inversion is statistically significant. Most of the inferred CMT solutions contain a non-shear component of the moment tensor. However, they are statistically insignificant as the method revealed that the uncertainty of non-shear component is relatively large. The non-shear component is statistically significant only for two CMTs, which may reflect complex rupture processes taking place on non-planar faults. Finally, the Bayesian full-waveform inversion of CMTs of the Kumamoto earthquake sequence demonstrates the abilities of such a methodology, and suggests complex tectonic background for this earthquake sequence.

(4) Publication of research findings

The abstract with application of the methodology and the seismotectonic interpretation of the Kumamoto sequence was submitted in February 2017 to the international IAG-IASPEI joint scientific assembly in Kobe. The abstract was accepted as the oral presentation at section “Earthquake source mechanics” and will be presented by the principal investigator on August 4th, 2017 in Kobe International Conference Center. Reference: Hallo, M., Asano, K., Gallovic, F., Bayesian inference of centroid moment tensors of the April 2016, Kumamoto (Kyushu, Japan), earthquake sequence, IAG-IASPEI Joint Scientific Assembly, Kobe, 2017.

The investigators are now in process of preparation of a publication about the scientific findings regarding the Kumamoto earthquake sequence. The manuscript is aimed to be submitted to an impact scientific journal by the end of June.