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STRONG GROUND MOTION PREDICTION FOR NEW SOURCE FAULT MODELS OF FUTAGAWA AND HINAGU ACTIVE FAULT ZONES, JAPAN

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Abstract

The Comprehensive Research Project for the Major Active Faults Related to the 2016 Kumamoto Earthquake funded by MEXT (PI: Prof. Hiroshi Shimizu, Kyushu Univ.) has been conducted between FY 2016 and FY 2018. It was an integrated research on long-term evaluation of earthquake occurrence on active faults (Sub-theme 1), seismic activity and crustal structure (Sub-theme 2), strong ground motion prediction (Sub-theme 3) and outreach (Sub-theme 4). The research group of Sub-theme 3 developed a three-dimensional underground seismic velocity structure model in and around the source area and predicted strong ground motions for future earthquakes along the Futagawa fault zone and the Hinagu fault zone as there are still un-ruptured segments remained on these two fault zones after the 2016 Kumamoto earthquake. In the research activity in Sub-theme 3, we developed a three-dimensional (3D) velocity structure model including superficial layers. We also constructed new source fault models for the Futagawa fault zone (Uto and Uto-hanto-hokugan segments) and for the Hinagu fault zone (Takano-Shirahata, Northern Hinagu, Southern Hinagu, Northern Yatsushiro Sea, and Southern Yatsushiro Sea segments) from new information compiled by Sub-themes 1 and 2. We used "The Recipe" (Strong ground motion prediction for earthquakes with specified source model) by the Headquater of Earthquake Research Promotion of MEXT [1] for strong ground motion prediction. The hybrid (FDM and stochastic Green's function method) method with the cross-over period of 1 sec was used for simulating ground motions at the surface of the layer of Vs = 300m/s. Seismic equivalent linear analysis was applied to the area where the shallower subsurface velocity model exists and JMA seismic intensity was calculated using the simulated waveform data. We discussed source and basin effects on predicted strong ground motion dictribution in the source area.

Keywords: Strong motion prediction, basin velocity model, the 2016 Kumamoto earthquake, source fault model, Futagawa and Hinagu fault zones

1. Introduction

After the 2016 Kumamoto earthquake sequence, including strong shaking of the JMA seismic intensity 7 twice in Mashiki town, the Headquarters of Earthquake Research Promotion (HERP) proposed an comprehensive research project for upgrading long-term evaluation and strong motion prediction of the Futagawa and Hinagu fault zones. It is because that the 2016 Kumamoto events occurred in a part of the Futagawa and Hinagu fault zones and there are still un-ruptured segments remained on these two fault zones. This "Comprehensive Research Project for the Major Active Faults Related to the 2016 Kumamoto Earthquake", funded by MEXT, (PI: Prof. Hiroshi Shimizu, Kyushu Univ.) has been conducted between FY 2016 and FY 2018. It includes the researches on long-term evaluation of earthquake occurrence on active faults (Sub-theme 1), seismic activity and crustal structure (Sub-theme 2), strong ground motion prediction (Sub-theme 3) and outreach (Sub-theme 4). The research group of Sub-theme 3 developed a three-dimensional underground seismic velocity structure model in and around the source area and predicted strong ground motions for future earthquakes along the unruptured segments of the Futagawa and the Hinagu fault zones. This paper briefly introduces some results on developing a three-dimensional basin velocity structure model, setting up source fault models for the anticipated earthquakes, and simulating ground motions using these basin velocity structure model and source fault models. The final reports of this comprehensive research project is available on the web page of HERP [2].

2. Development of the three-dimensional underground velocity structure model

A reliable S-wave velocity structure model is needed for accomplishing to predict strong ground motions. For constructing the nation-wide seismic hazard map, J-SHIS [3, 4] and JIVSM [5], nation-wide three-dimensional velocity structure models for ground motion simulations, have been developed in Japan by compiling available geophysical and geological information. However, after the 2016 Kumamoto earthquake, Senna et al. (2018) [6] conducted dense microtremor array measurements in the damaged area and improved the underground S-wave velocity structure model in the Kumamoto plain. They also confirmed that the improved S-wave velocity structure model can explain the seismic response of the observed seismic ground motions better than the previous model.

For accomplishing more reliable strong ground motion prediction for the scenario earthquake, following the work by Senna et al. (2018) [6], we conducted many kinds of geophysical explorations in the target area so as to improve the S-wave velocity structure model. The observations were as follows. (1) Seismic reflection surveys in the Yatsushiro plain. As there were no seismic reflection survey in the Yatsushiro plain, we have conducted two seismic reflection surveys (Yatsushiro and Uki lines) using P-wave vibrator across the Yatsushiro plain to get the basin depth information and P-wave velocity distribution in the basin. The cross section of the Yatsushiro line is shown in Fig. 1. (2) Microtremor array measurements. In Yatsushiro plain, large-size microtremor array surveys were carried out at 29 sites with a maximum array radius of 0.5–0.6km in the whole area of the plain. Miniature and irregular array microtremor observations were conducted to survey shallow subsurface structure at 32 sites in the southern part of the Yatsushiro plain, where Yatsushiro city is located. Single-station microtremor H/V observations were carried out at 31 sites in the boundary area between the Yatsushiro and the Kumamoto plains. Microtremor array measurements were also conducted at most of permanent strong motion stations in the Amakusa Islands, the Minamata-Ashikita area, the Hitoyoshi basin, the Izumi plain, the Tamana plain, the Kikuka basin, Aso area, and the southern part of the Shimabara peninsula, which consists of 23 Large-size arrays and 76 small-size arrays. Single-station microtremor H/V observations were conducted at 47 sites in the Izumi plain and 44 sites in the Tamana plain to investigate the spatial variation in the bedrock depth. Miniature and irregular array microtremor observations were also conducted at 48 sites in the Hitoyoshi basin. Fig. 2 indicates the microtremor observation sites. (3) Collection of hot-springs boring well-logs. As it is hard to constrain basin depth from only the information of the dispersion curve by the microtremor array measurements, we collected hot-springs boring well-logs in the Yatsushiro, Kumamoto, Hitoyoshi, and Minamata-Ashikita area.

We also used shallow boring database in the Yatsushiro plain for the construction of shallow (above the engineering bedrock surface) subsurface S-wave velocity structure. (4) Temporary strong motions stations were installed at 37 sites covering the whole area of the Yatsushiro plain. As there are still higher seismic activities than the usual, high quality seismic data were recorded. Small-size microtremor array survey was also conducted at these temporary stations. The temporal station sidtribution is indicated in Fig. 3. (5) Collection of strong motion waveform data. We collected strong motion data of seismic intensity stations in the Kumamoto prefecture, together with those at K-NET, KiK-net and JMA stations. Seismic waveform data in (4) and (5) can be used for validating the constructed underground velocity structure model.

The 3D velocity structure above the seismic bedrock was modelled using these survey data and existing information. For the Yatsushiro plain, the Rayleigh wave phase velocity and H/V spectra from the microtremor observations were jointly analyzed to obtain the one-dimensional S-wave velocity profile at each measurement site. When we analyzed microtremor data, we referred to seismic reflection profiles and hot-spring boring well-log as constraint information for bedrock depth. The deep sedimentary layers were modeled by two layers with S-wave velocities (V_S) of 0.6 and 0.9 km/s. Shallow low-velocity sedimentary layers were also considered above the layer of V_S 0.6 km/s, and we assumed a layer of V_S 2.7 km/s at the top of the seismic bedrock (V_S 3.1 km/s). The top depth of V_S 2.7 km/s is correlated well with the bedrock depth from the reflection surveys, and its depth ranges from 0.3 to 0.7 km. The layer of V_S 0.9 km/s is relatively thicker along the Yatsushiro line compared to the Uki line, which is consistent with interval velocity distributions of P-waves along these survey lines. Shallow veloty structure in the Yatsushiro plain is constructed from the multi layer structure assumed from shallower well-log geological information and the dispersion curve of miniature-to-small size microtremor array measurements. The initial velocity model was constructed by the results of microtremor array analysis, and it was revised with H/V spectra at sites where phase-velocity dispersion curve was not available after checking consistency with gravity anomaly and boring well-log data.

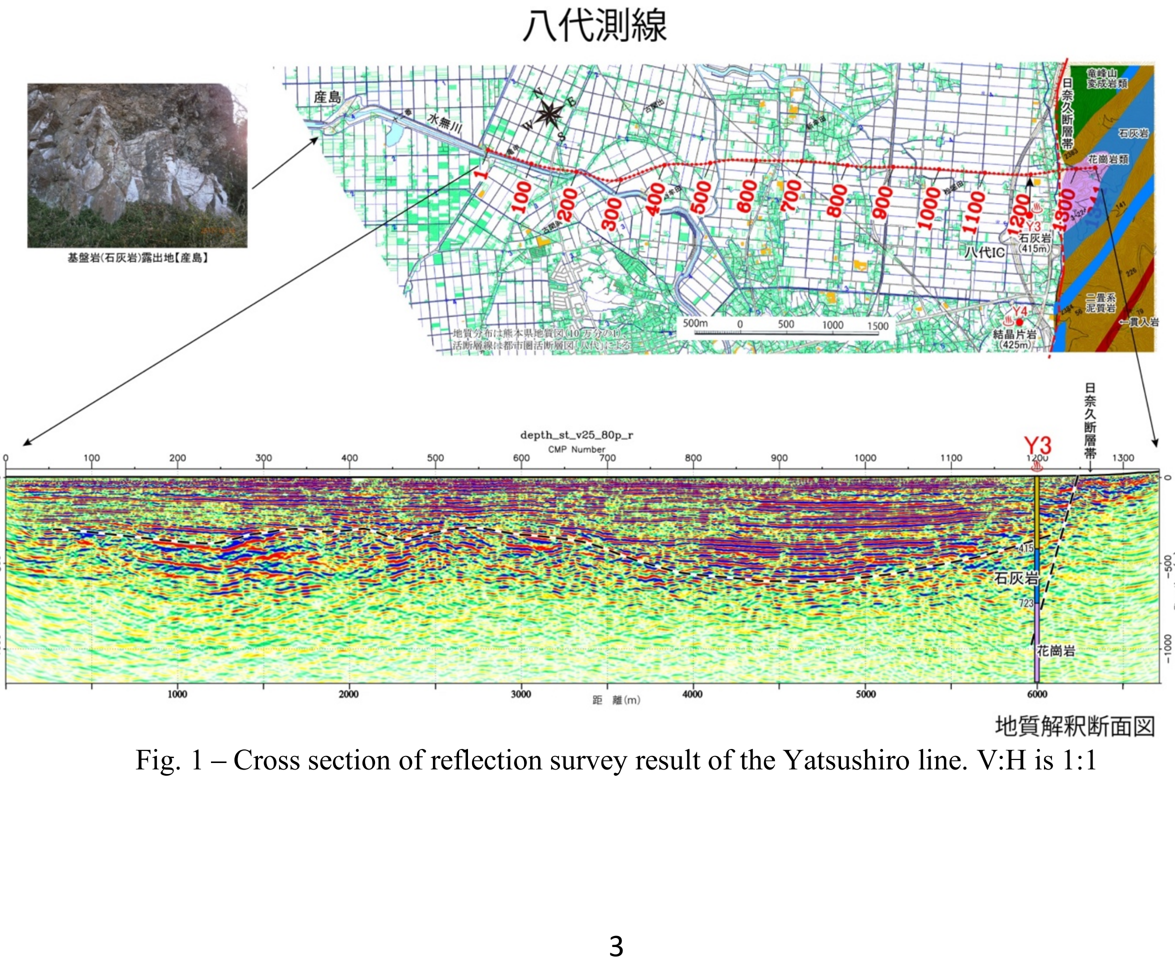

Fig. 1 – Cross section of reflection survey result of the Yatsushiro line. V:H is 1:1

Deep and shallow sedimentary velocity structure models were also constructed in the Hitoyoshi basin, the Amakusa Islands, Izumi plain, Tamana plain, and Kikuka basin using microtremor array surveys. The seismic bedrock depth (V_S 3.1 km/s) is relatively deep in the eastern part of the Hitoyoshi basin (1.0~1.5 km). The top depth of V_S 1.6 km/s is relatively shallow around Amakusa Kamishima Island, which is consistent with high Bouguer anomaly in this area. The bedrock in the Izumi plain deepens toward the coast, and its maximum depth is about 0.9 km.

The final 3D velocity structure model was constructed by integrating the above results and the velocity structure model for the Kumamoto plain by Senna et al. (2018). The performance of our new velocity model has been checked by simulating ground motions from moderate-size events occurring in this region. The synthetic ground motions were improved well in terms of amplitude and duration by the new model compared to existing 3D velocity models.

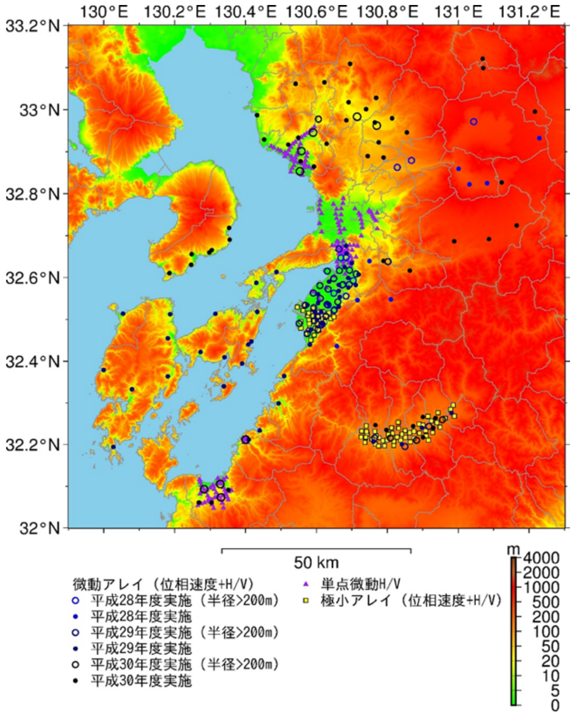

Fig. 2 – Example of microtremor array measurement sites.

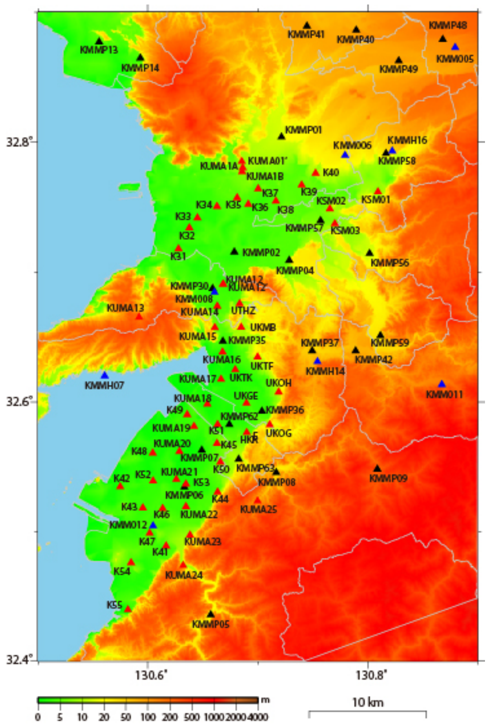

Fig. 3 – Temporal (red) strong motion stations.

3. Strong ground motion prediction for source fault models of Futagawa and Hinagu active fault zones

We conducted strong ground motion simulations from the Futagawa and Hinagu source fault models using the newly developed 3D velocity structure model. Firstly, we constructed source fault models for the Futagawa fault zone (Uto and Uto-hanto-hokugan segments) and the Hinagu fault zone (Takano-Shirahata, Northern Hinagu, Southern Hinagu, Northern Yatsushiro Sea, and Southern Yatsushiro Sea segments). The location of the modeled source fault of the Uto segment is set to about 1 km north from the present one [7] based on the reflection survey result in the Kumamoto basin by Sub-theme 2 of this project. The active fault traces of the Hinagu fault segments are slightly modified in the research results by Sub-theme 1. We assumed two kinds of source models for the dip angle setting of the source fault of the Southern Hinagu segment, 90 deg. and 50 deg. The latter is assumed referring to the microearthquake distribution by Sub-theme 2. The rake angle for each source fault was determined from the stress conditions on the source fault plain by the stress inversion result (Sub-theme 2). The earthquake moment magnitude (Mw) of the future Futagawa and Hinagu fault zones are 7.0 and 7.3–7.4, respectively.

We used “The Recipe” (Strong ground motion prediction for earthquakes with specified source model) [1] for strong ground motion prediction. The rupture starting points were assumed by the implication of the rupture starting point of the 2016 Kumamoto mainshock on the crustal resistivity distribution (Sub-theme 2). The hybrid method (FDM for longer-period range and the stochastic Green’s function method for shorter-period range) with the cross-over period of 1 sec was used for simulating ground motions on the engineering bedrock in the area including Kumamoto and Yatsushiro plains. Seismic equivalent linear analysis was applied to the subsurface velocity model to get the time history of the ground motions at the surface, and JMA seismic intensity was calculated using the simulated waveform data. Additionally, we estimated a JMA seismic intensity distribution in Kumamoto prefecture using PGV values of the engineering bedrock and JMA seismic intensity increments by the geomorphological classification and Vs30 values.

Fig. 4 shows obtained JMA seismic intensity distribution for the scenario event of the Hinagu fault zone in case of rupture propagates from South to North and dip angle of 50 degs. for the South Hinagu segment. Strong shakings of JMA seismic intensity over 6- are expected above the source fault and in the Kumamoto and Yatsushiro plains. There are 5+ observed in the coastal area of the Kumamoto and Yatsushiro plains. There, thick shallower superficial structures above the engineering bedrock surface are set in this velocity model. As we applied the seismic equivalent linear analysis for the seismic response of the shallower structure, the estimation of JMA seismic intensity would be underestimated. Improvement of this kind of evaluation will be the future task.

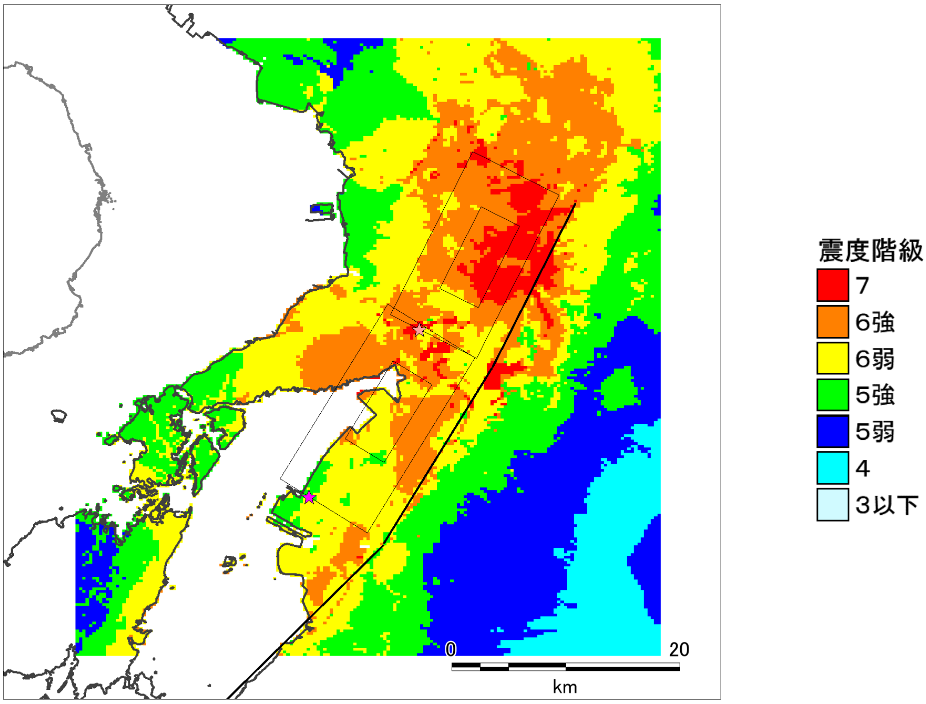

Fig. 4 – JMA seismic intensity distribution for a scenario event of the Hinagu fault zone (in case of rupture propagates from South to North and dip angle of 50 degs. for the Hinagu segment) .

4. Conclusions

The Sub-theme 3 research group of the Comprehensive Research Project for the Major Active Faults Related to the 2016 Kumamoto Earthquake supported by MEXT developed a 3D underground seismic velocity structure model in and around the source area and predicted strong ground motions for future earthquakes along the Futagawa fault zone and the Hinagu fault zone as there are still un-ruptured segments remained on these two fault zones after the 2016 Kumamoto earthquake. The simulation results indicate strong shakings (JMA seismic intensity 6- or more) rock in near-source area including thick sediment area such as Kumamoto and Yatsushiro plains. The obtained sediment model is very useful for seismic disaster reduction for future earthquake. On the contrary, there are strong possibility for the non-linear site responses on the soft sediment area during the strong shaking, that are common situation for big cities or highly populated area all over the world. Dynamic soil tests for obtaining soil response characteristics are also important for earthquake disaster mitigation for reliable strong motion predictions.

5. Acknowledgements

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