S-wave velocity structure modeling around the Fujikawa-kako fault zone using array microtremor exploration and seismic interferometry

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Abstract

In order to upgrade the strong motion prediction around the Fujikawa-kako fault zone, it is necessary to validate and reconstruct the 3D S-wave velocity structure model in the area. We thus perform array microtremor exploration and also we apply seismic interferometry to the microtremor record continuously observed at the temporary ground motion station network. For array microtremor exploration, we performed array microtremor measurement with the array size of about 1 m to 1 km to estimate 1D S-wave velocity structure of shallow and deep sedimentary layers at the measurement site. The vertical component of microtremos is used for SPAC analysis and phase velocity dispersion curve of Rayleigh wave is estimated. The inversion analysis of dispersion curve provides 1D S-wave velocity profile. However, only 1D S-wave velocity structure is not sufficient for the strong motion prediction in whole area. We therefore use seismic interferometry to validate existing 3D S-wave velocity structure model in the region. The crosscorrelation functions between the station pairs are calculated using several months of records observed at the strong motion temporary stations. Not only vertical but also horizontal component of mictoremors are used for crosscorrelation. Multiple filter analysis is used to observe group velocity dispersion curves of Rayleigh and Love wave from the peak amplitude in the crosscorrelation function. We perform tomographic analysis for both Rayleigh and Love wave slowness to obtain the spatial distribution of group velocity around the fault zone. We then compare the dispersion curve estimated from the tomography with theoretical curve that can be calculated from the subsurface structure model at each cell. In the northern part of the fault zone, the estimated curve was lower than the calculated curve. The calculated dispersion curve was lower than that estimated in the low-frequency range in wide area of the fault zone. When we compare the dispersion curve of surface wave with the theoretical dispersion curve calculated using the extracted 1D model from the existing model with the estimated model from array microtremor exploration in this study, the theoretical dispersion curve from the estimated model better evaluates the dispersion curve observed using seismic interferometry. The ground motion simulation using modified 3D model is performed to confirm the accuracy of the model.

Keywords: Seismic interferometry, Array microtremor, S-wave velocity structure, Fujikawa-kako fault zone

1. Introduction

In order to upgrade the subsurface structure model for strong motion prediction around the Fujikawa-kako fault zone, we perform array microtremor exploration and we also apply seismic interferometry to the microtremor record continuously observed at the temporary ground motion station network to validate the S-wave (*Vs*) velocity structure model. The vertical array microtremor records are used for SPAC analysis to estimate phase velocity dispersion curve of Rayleigh wave. The *Vs* structure model is modified using these results. The crosscorrelation function between the station pair is calculated using several months of records observed at the temporary strong motion stations. Multiple filter analysis is used to observe group velocity dispersion curve of Rayleigh wave and Love wave. We perform tomographic analysis to obtain the spatial distribution of group velocity around the fault zone. We then compare the dispersion curve estimated from the tomography with theoretical curve that can be calculated from the subsurface structure model at each cell.

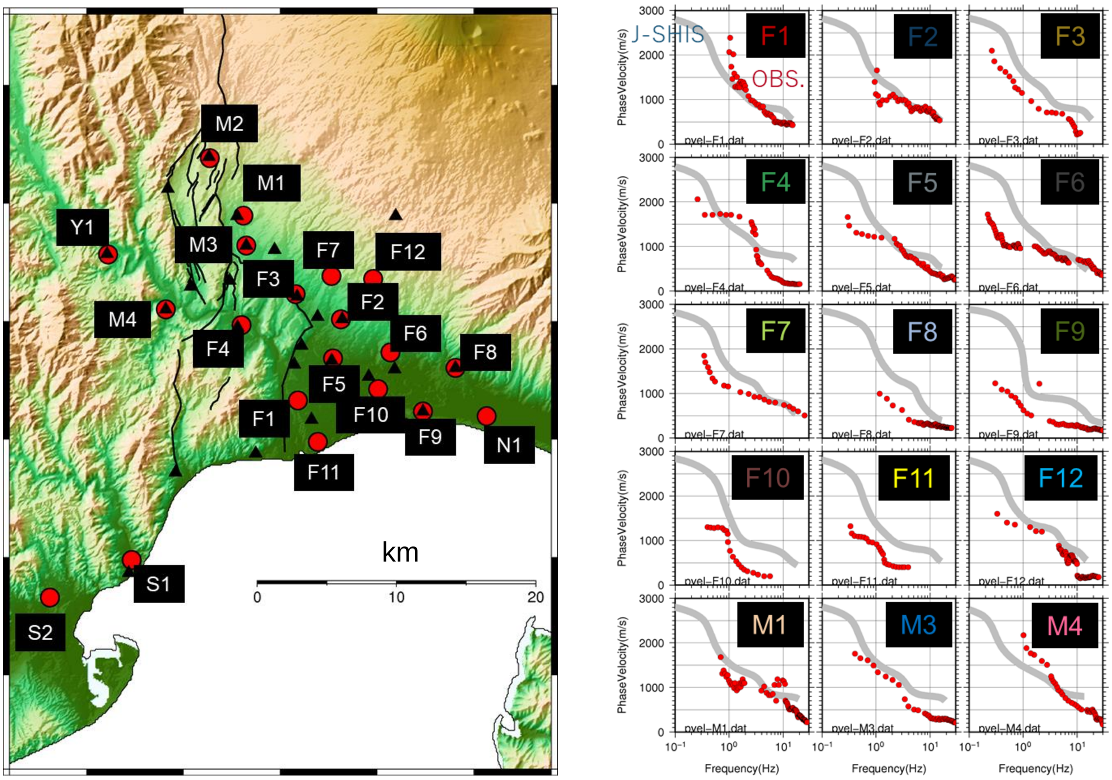

Fig. 1 – Location of the array microtremor measurements (left) and dispersion curve (right). The faults of fujikawa-kako fault zone are indicatd by bold line. The array microtremor measurement was conducted at red circle, and the temporary ground motion observation station is denoted by triangle. Observed phase velocity is plotted by red circle and the theoretical phase velocity dispersion curve for fundamental mode of Rayleigh-wave calculated by using J-SHIS [3] subsurface structure model is shown by gray.

2. Array Microtremor Method

For the purpose of estimating the deep *Vs* structure model, microtremor array observations with a maximum array radius of about 500 m were performed at 20 locations around the fault zone (Fig. 1, left). We used the seven instruments of VSE15D6 or JEP6A3 (10V/G) for the sensor and LS7000XT for data logger to make double triangular array [1]. The phase velocity of Rayleigh wave was estimated by SPAC analysis [1, 2] of the vertical component of microtremor. Fig. 1 right shows part of the results. The gray is the fundamental mode phase velocity dispersion curve of the Rayleigh wave calculated from the subsurface structure model

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of J-SHIS version 2 (National Research Institute for Earth Science and Disaster Resilience, NIED, 2019) [3], and the red circle is the estimated dispersion curve of phase velocity. In the high frequency range, there are many similarities, but in the low frequency range, the observed values are generally smaller than the theoretical values, suggesting that the sedimentary layers are more likely to be deeper. A one-dimensional (1D) *Vs* structure model of each array observation point was estimated by the inversion technique of the dispersion curve using a hybrid heuristic search method of GA and SA (Yamanaka, 2007) [4]. Fig. 2 shows the estimated *Vs* structure.

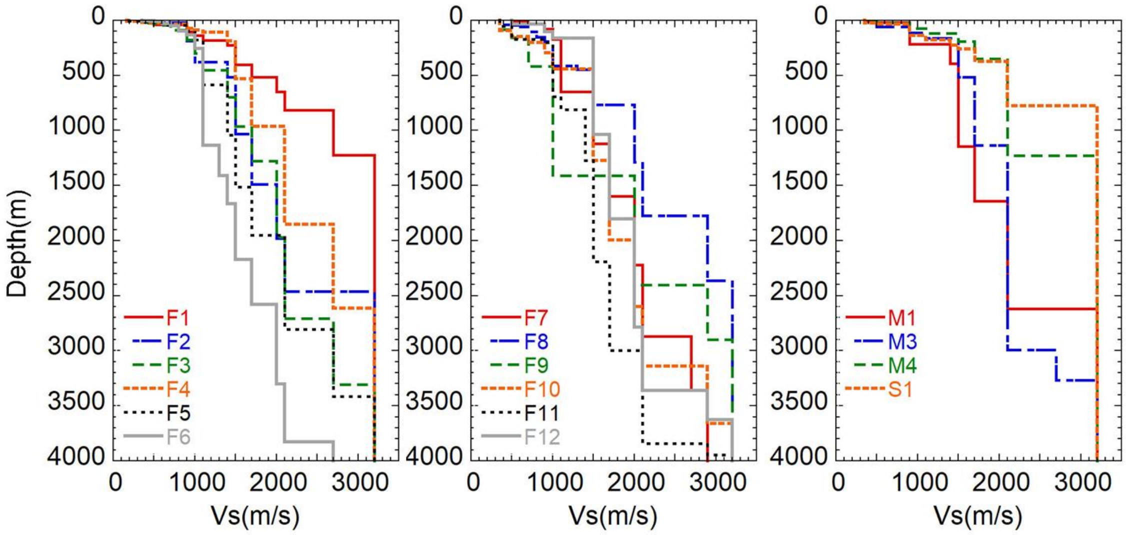

Fig. 2 – S-wave velocity structure model estimated by inversion of dispersion curve.

3. Seismic Interfoerometry

Temporary seismic observation stations were established sequentially from March 2018, and a temporary seismic observation network of 32 points has been constructed. In this study, seismic interferometry [5] is applied using the 29 observation records shown in Fig. 1. At each temporary observation point, a Mitutoyo sensor JEP6A3 (2V/G) and Hakusan data logger LS8800 or LS7000XT are used. Since the seismic observation is performed continuously, small and medium earthquakes and microtremors can be used. In this study, we use the observed microtremor records for about 4 months. The crosscorrelation analysis performed the same data processing by following Chimoto and Yamanaka (2014) [6]. First, the continuous microtremor recording was divided every hour, the spectrum was calculated by FFT analysis, and the cross-coherence type crosscorrelation was calculated in the frequency domain. Chimoto and Yamanaka (2014) [6] do not perform 1-bit normalization, bandpass filtering, and data selection. Average the hourly cross coherence and obtain the time-domain crosscorrelation function by inverse FFT. The group velocity dispersion curve is estimated by multiple filter analysis of the crosscorrelation function. The vertical component of the microtremor recording correspond to Rayleigh wave, and the horizontal component is converted to the transverse component and corresponds to Love wave.

Fig. 3 shows the crosscorrelation function calculated for all observation point pairs. A bandpass filter with a period of 1 to 5 seconds is applied to the crosscorrelation function. Since the crosscorrelation for the station located on the southern side of the observation point pair is calculated, the large signal appearing at the positive delay time indicates that the surface wave propagating from south to north is dominating. In addition, it can be seen that the signal propagates at the velocity of about 1 km/s from the travel time of the clear signal in the crosscorrelation functions.

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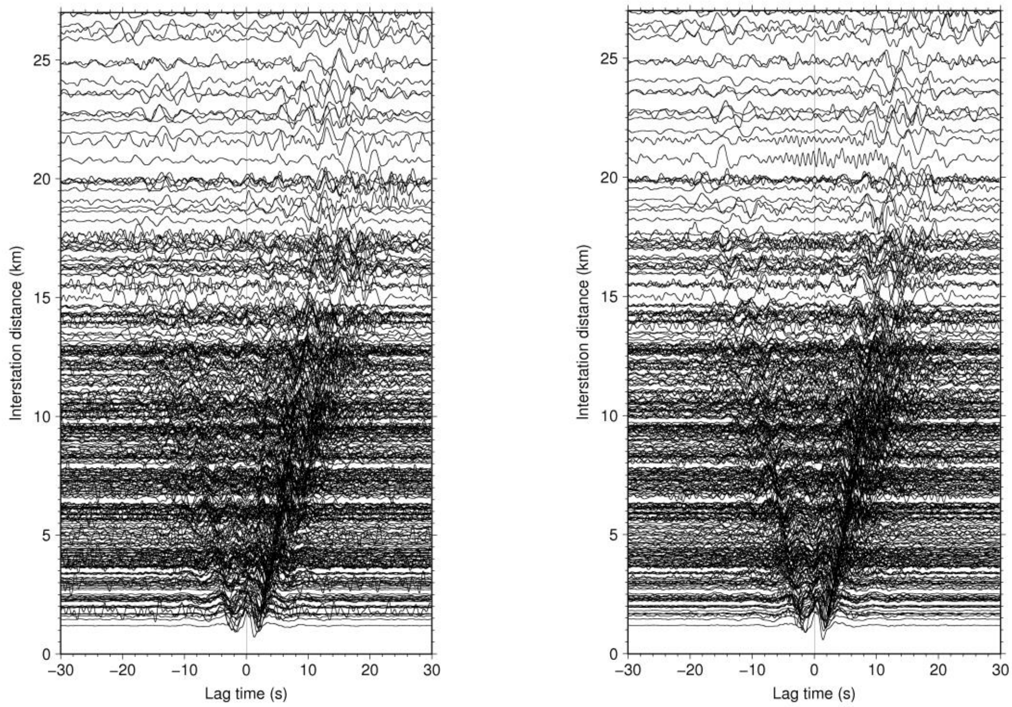

Fig. 3 – Crosscorrelation functions of the vertical component (left) and the transverse component (right).

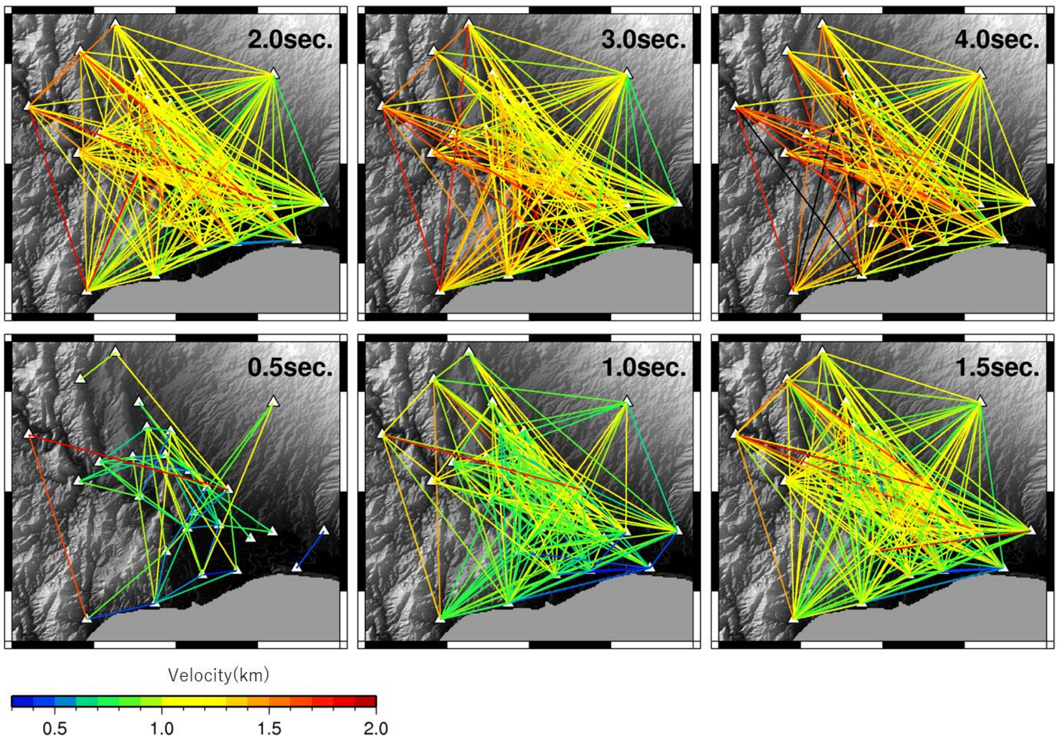

Fig. 4 – Distribution of group velocity of Love wave at the periods from 0.5 to 4.0 seconds observed from multiple filter analysis of the crosscorrelation function of the transverse component.

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The multiple filter analysis was performed to the crosscorrelation function to estimate the dispersion curve of surface waves. We extracted group velocity at each period by choosing the arrival time of large packets of surface wave with some criteria. The criteria are that the SN beyond 5000 and the wavelength less than half of station pair. The determined velocity of Love wave is plotted in Fig. 4. It is observed that the velocity is higher at longer period and it is smaller at shorter period. It is also observed that the velocity at mountain area is higher than the lowland area.

The slowness tomography analysis is performed based on the estimated group velocity dispersion curves of Rayleigh and Love waves. The tomography cells were divided into 0.015625 ° squares, and analyzed in each period to determine the slowness of each cell. The analysis was performed using a simultaneous iterative method based on backprojection (Chimoto and Yamanaka, 2011) [7].

Fig. 5 shows Love wave group velocities determined by tomographic analysis at periods from 0.5 to 4.0 seconds. It is observed that the velocity is higher at longer period and it is smaller at shorter period. It is also high in the western mountains and small in the southern plains.

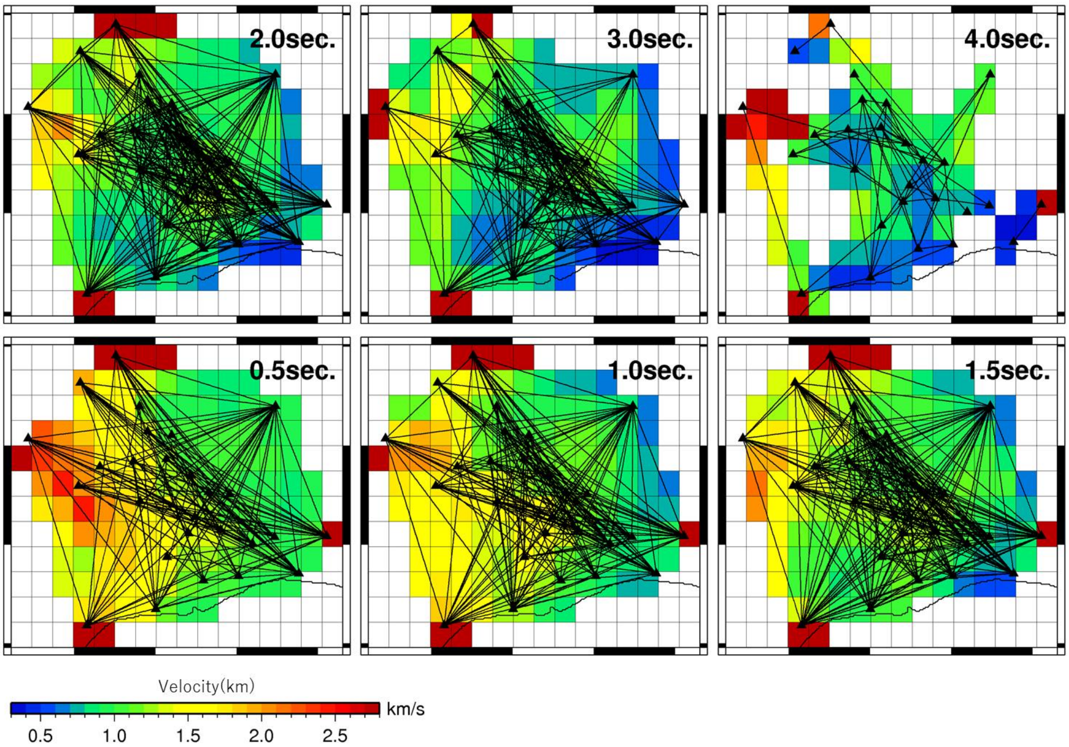

Fig. 5 – Group velocity of Love wave at the periods from 0.5 to 4.0 seconds calculated by the tomographic analysis.

Fig. 6 shows the dispersion curve of Love wave group velocity in each cell based on the group velocity determined at each period. The figure also shows the fault location, but there is no significant difference in the dispersion curve due to the fault. In the south-western part, e.g. No. 102 cell, the observed and the theoretical dispersion curves fit well. However, in the north-eastern part, e.g. No.135, the theoretical curve shows difference with oberved curve. The dispersion curve by the model made by the microtremor array exploration fit well to the observed dispersion curve. In the same way, we examined Rayleigh wave and found that they showed a similar tendency.

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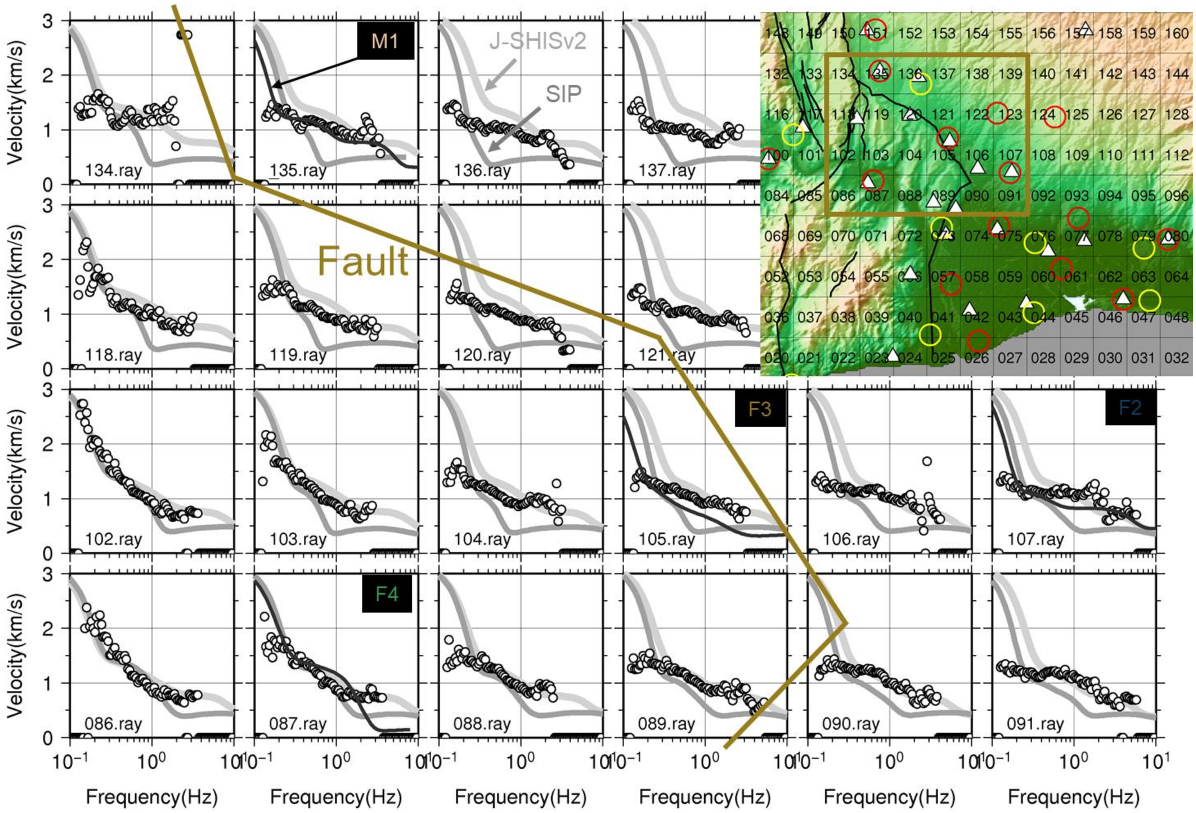

Fig. 6 – Dispersion curve of group velocity at the cells shown by rectangular in the top right panel. Circle indicates the estimated group velocity of Love wave by tomographic analysis. Gray line shows the theoretical dispersion curve of Love wave group velocity calculated using the J-SHIS [3] (light gray) and Wakai et al. (2019) [8] (gray). Black is theoretical dispersion curve for the model estimated by array microtremor exploration.

4. Vs Structure Modeling

We then modify the existing *Vs* structure model of J-SHIS (National Research Institute for Earth Science and Disaster Resilience, 2019) [3]. First, the land area of Shizuoka Prefecture was replaced by the *Vs* structure model by Wakai et al. (2019) [8]. Then, the array microtremor measurement site was replaced by the model estimated from the array microtremor exploration. The final *Vs* structure model is shown in Fig. 7. The depth to the seismic bedrock is modified especially around the fault zone where many microtremor exploration was conducted.

For the validation of the model, we compare the theoretical dispersion curves of group velocity for the fundamental mode of Rayleigh wave with the observed dispersion curve (Fig. 8). The theoretical dispersion curves are larger than the observed dispersion curve in the low frequency range. The curve for the modified model shows good comparison in the eastern area. The same comparison for Love wave can also be done.

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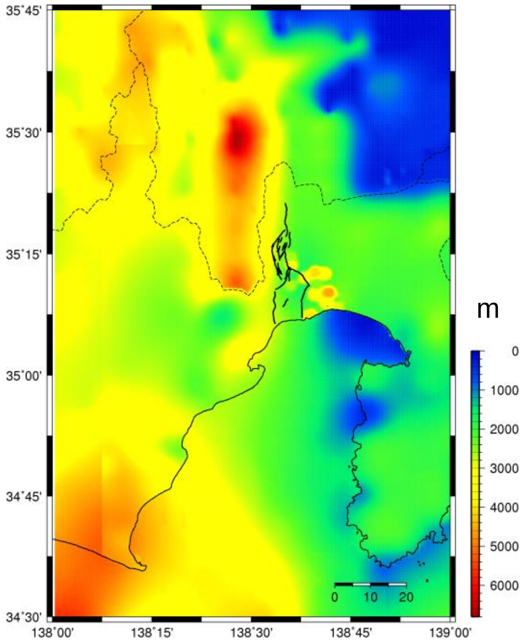

Fig. 7 – Depth to the seismic bedrock with the *Vs* of 3.2 km/s.

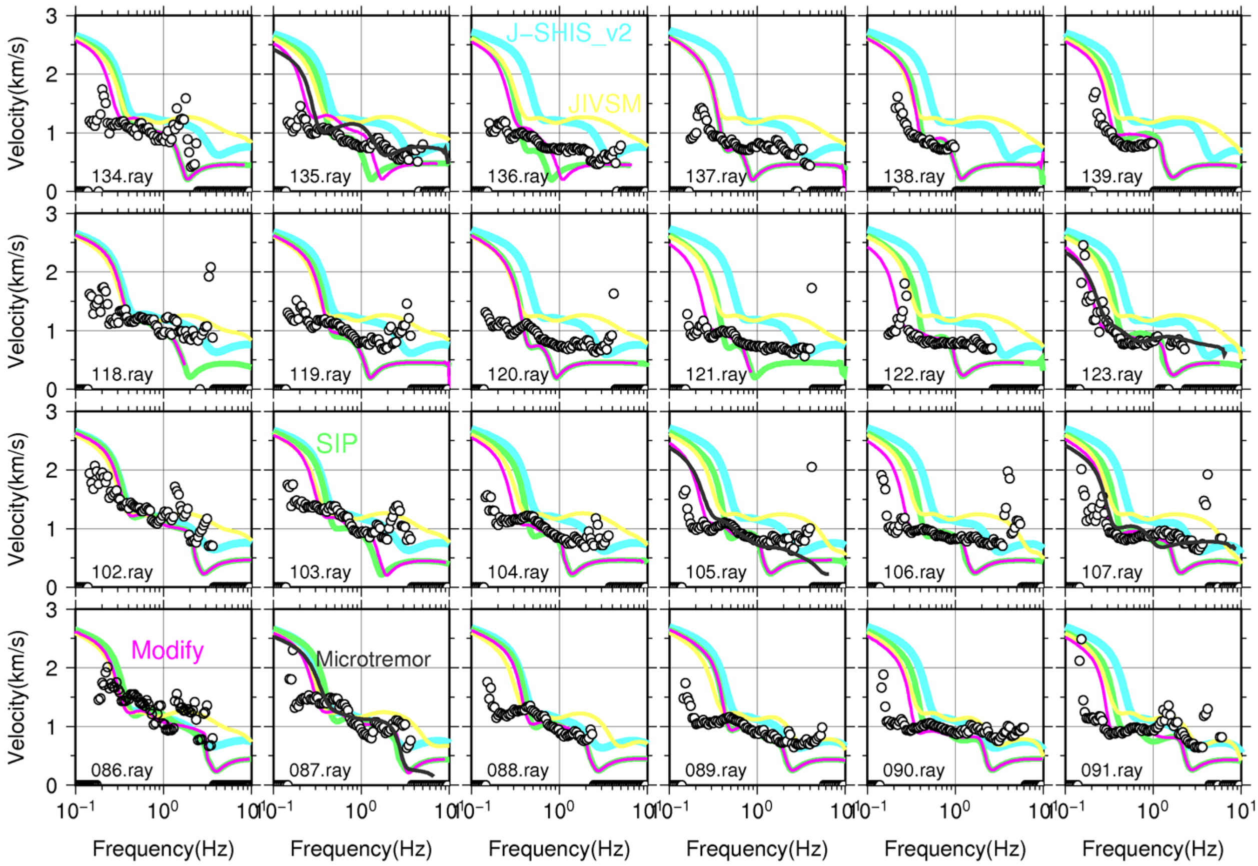

Fig. 8 – Comparison of the dispersion curves among observed and theoretical group velocity of fundamental mode of Rayleigh wave. These cells are corresponding to Fig. 6.

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5. Conclusions

In order to improve the subsurface structure model for the prediction of strong ground motion around the Fujikawa-kako fault zone, the ground motion was observed by a temporary seismic network around the fault zone to verify the existing subsurface structure model. Seismic interferometry was applied using continuous ground motion recording. A microtremor array observation of a large array size was performed for a deep ground structure model near the temporary observation point. The Rayleigh wave phase velocity dispersion curve was estimated by analysing the microtremor array record by SPAC method. A one-dimensional S-wave velocity structure model was estimated by the inversion technique. A clear signal appeared in the crosscorrelation function calculated from the microtremor records for about 4 months. The group velocity dispersion curve of Rayleigh wave and Love wave over a wide band was estimated by the multiple filter analysis. The group velocity distribution around the fault zone divided by cell was determined by the tomography analysis, and the validity of the models was verified by comparing observed dispersion curve with the theoretical dispersion curve. As a result, the group velocity is slow in the north side of the fault zone.

Acknowledgement

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