SUPERFICIAL S-WAVE VELOCITY AND DAMPING FACTOR MODEL DETERMINED BY THE MASW MEASUREMENT IN THE GRENOBLE SEDIMENTARY BASIN

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ABSTRACT :

In order to understand and predict earthquake ground motions at high frequencies, it is necessary to evaluate a superficial S-wave velocity structure. In the Grenoble basin, several geotechnical and geophysical surveys have been carried out for estimating the deep velocity structure. However, the superficial velocity profiles have not been obtained in enough detail for allowing reliable numerical predictions of ground motion for frequencies above 1 Hz. Therefore, we have applied the MASW technique using the High-Resolution method to estimate S-wave velocity structure at the uppermost 50 meters of sedimentary layers. The estimated S-wave velocity structure by the genetic inversion algorithm indicates that the soft soil sediment (less than Vs 400-500 m/s) is more deeply deposit in the middle-east of Grenoble than in other areas. Finally, we made a 3D S-wave velocity model for the uppermost layers that will be used for high frequency ground motion predictions in the Grenoble sedimentary basin. Moreover, we proposed a method for determining quality factors of superficial layers by using MASW recording data. The quality factors of S-waves determined by waveform inversion are about 15 within a frequency range from 5 to 50 Hz. We also discuss on the usefulness of joint inversion between a fundamental mode and higher modes.

KEYWORDS: S-wave velocity, Quality factor, The MASW Measurement, The Grenoble Basin and Superficial velocity profile

1. INTRODUCTION

In order to simulate thoroughly earthquake ground motions in a broad band frequency, it is necessary to evaluate site conditions including superficial structural models. In the Grenoble Basin, several geotechnical surveys have already been carried out for understanding the deep velocity structure (Bettig et al., 2001; Nicoud et al., 2002; Vallon, 1999). However, superficial velocity profiles have not been obtained in enough detail, especially for shallower parts than a depth of 50 m. To understand superficial shear-wave velocity structure related critically to the building response by an earthquake input motion, we applied the MASW measurement in the Grenoble sedimentary basin. MASW measurements were carried out at 27 sites within and around the basin. We generally recorded vertical components of surface waves excited by hammer shot at different off-set distances on a 24 geophones linear array. We applied the High-Resolution method to stacked MASW recording data to obtain dispersion curves of Rayleigh waves. This set of dispersion curves was completed by the 22 dispersion curves obtained by BRGM (Bitri et al, 2003) in previous MASW experiments.

2. THE MASW MEASUREMENT

2.1. Observation in Grenoble

The MASW measurements (e.g. Park et al., 1999; Hayashi and Suzuki, 2004) were performed in Grenoble area including rock sites to determine the superficial basin structure. We selected 27 measurement sites especially in the north, the south and the west sides of the Grenoble Basin (Figure 1), because of already having the MASW's results by Bitri et al. (2003) in the east of the Grenoble Basin. We carried out the measurements at 3 rock sites in Chartreuse, Vercors and Belledonne Mountains as well. We generally recorded vertical components of surface waves (Rayleigh waves) excited by hammer shots of different off-set distances in a linear array deploying 24 sensors (4.5 Hz geophone) with an interval pitch of 2 m or 3 m. We mainly retrieved the records by a hammer mass of 5 kg at a sampling frequency of 1000 Hz, except for rock sites by a mass of 3 kg at a sampling of 4000 Hz.

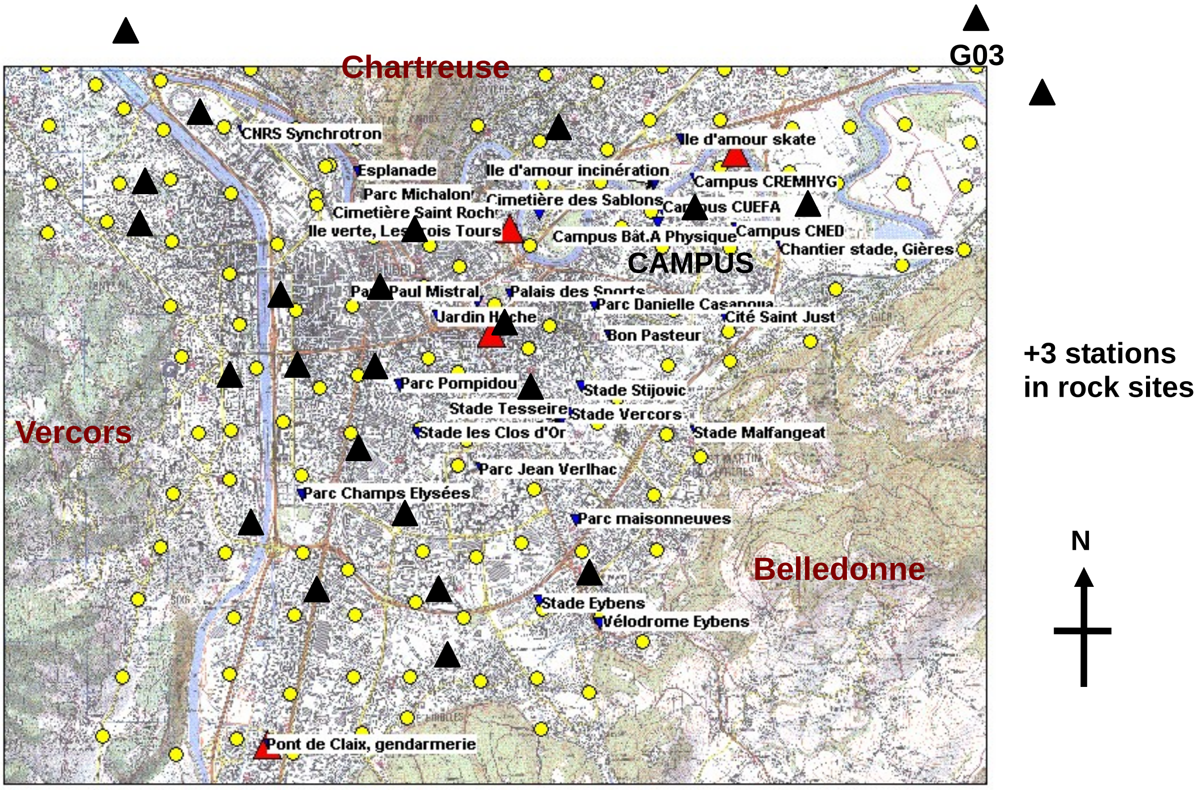

Figure 1. Location map of the MASW measurement in the Grenoble sedimentary basin (Black triangles denote locations of the MASW measurement in this study. Blue inverse triangles and yellow circles denote locations of the MASW measurement performed by Bitri et al. (2003) and H/V measurement performed by Benton (2004) respectively. Permanent seismic stations are shown in red triangles.)

2.2. Phase velocity of Rayleigh waves

We applied the High-Resolution method (Capon, 1969) for stacking data of the MASW records. We finally obtained F-K power spectra (dispersion curves) from a superposition of results calculated by the data of each off-set distance. In these procedures, displacement waveforms were used for emphasizing the lower frequency band of recording data. We show a representative result of F-K analysis at Campus in Figure 2. Dispersions of Rayleigh waves are clearly observed at higher frequencies than 5 Hz. We also confirmed that the phase velocities obtained by the MASW measurement match well those obtained by the Array Microtremors techniques (Figure 3). At rock sites, the larger phase velocities of Rayleigh waves than 2 km/s related to the seismic bedrock are obtained.

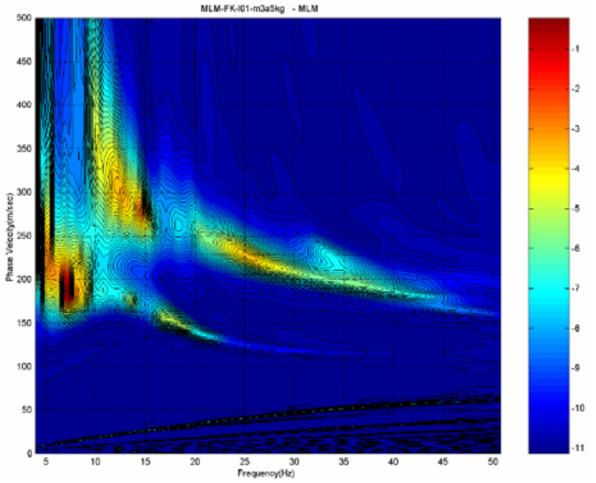

Figure 2. F-K power spectra at Campus (A higher mode of Rayleigh waves is clearly appeared as well as a fundamental mode.)

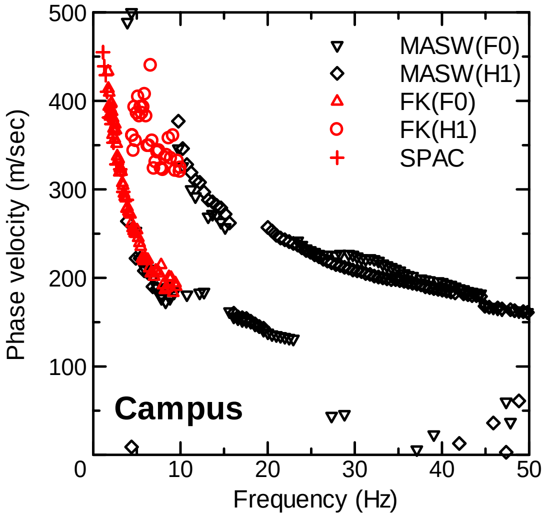

Figure 3. Dispersion curves at Campus (Dispersions by both methods of the MASW measurement and array techniques are in good agreement between 5Hz and 10 Hz.)

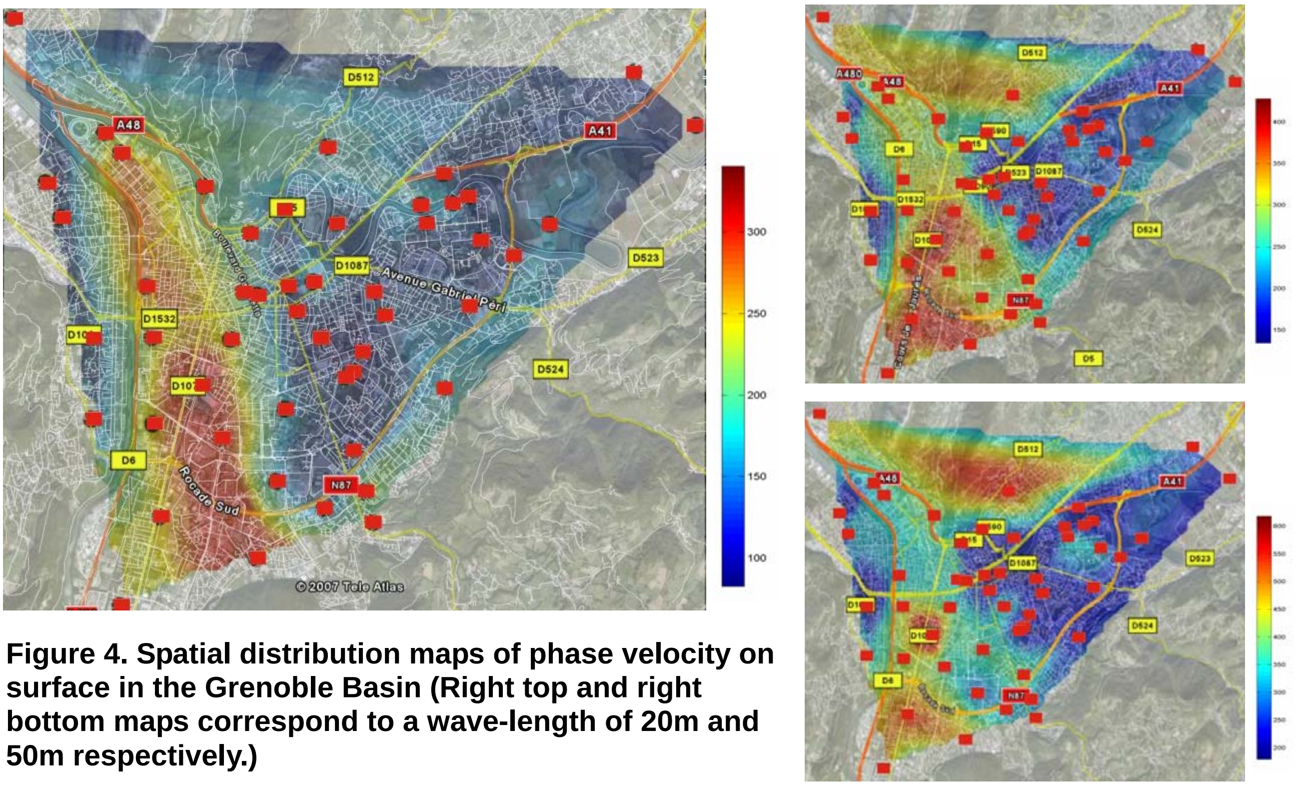

Figure 4. Spatial distribution maps of phase velocity on surface in the Grenoble Basin (Right top and right bottom maps correspond to a wave-length of 20m and 50m respectively.)

A spatial distribution of phase velocity on surface in the Grenoble Basin is shown in Figure 4 (left-top). The minimum phase velocities are larger than 250 m/s in the belt between the northern and the southern areas of the Grenoble Basin. In the eastern area, the minimum phase velocities are less than 150 m/s. Other figures at depths corresponding to wave-lengths of 20 m and 50 m indicate the heterogeneous distribution of superficial structures in the Grenoble Basin.

2.3. Wave-length

Wave-lengths of Rayleigh waves in the Grenoble Basin are shown as a function of phase velocity in Figure 5. Phase velocities obtained are spatially variable, especially for wave-lengths of Rayleigh waves lower than 150 m. In the eastern area of the Grenoble basin, the minimum phase velocities appear at about 100 m/s for higher frequencies than 30 Hz, while the minimum phase velocities are larger than 250 m/s in the belt between the northern and the southern areas of the Grenoble Basin. The wave-length obtained by the MASW measurement for the eastern area of the Grenoble Basin is in good agreement with the ones obtained by the Array Microtremors techniques, such as the SPAC method and the F-K method (Bettig et al., 2001; Kudo et al., 2002; Scherbaum et al., 1999). However, large microtremors array measurements should be performed in the belt between the north and the south of the basin in order to how well MASW measurements would match the microtremors array measurement. Figure 4 and 5 indicate that superficial structures are laterally heterogeneous. Rayleigh wave wave-lengths distribution derived from the ESG velocity model adopted in the numerical benchmark test (Chaljub et al., 2006) within the framework of the third international ESG symposium is also shown in Figure 5. It shows that the velocity structural model of ESG should be revaluated for a lower wave-length than 150 m.

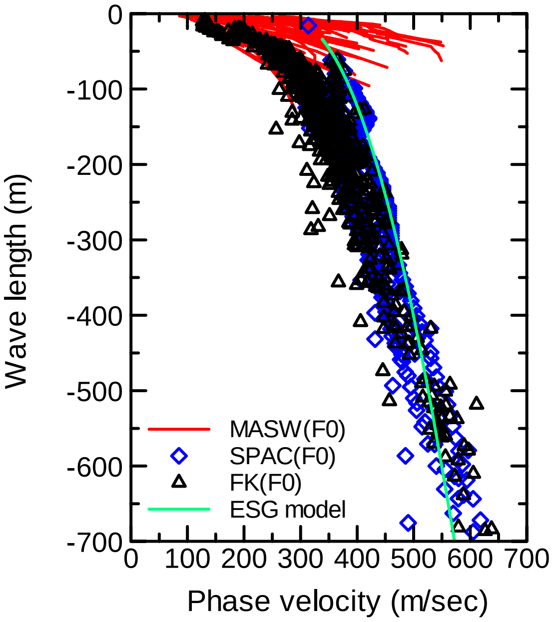

Figure 5. Comparison of wave-lengths of observations with ESG standard model

2.4. S-wave velocity profiles

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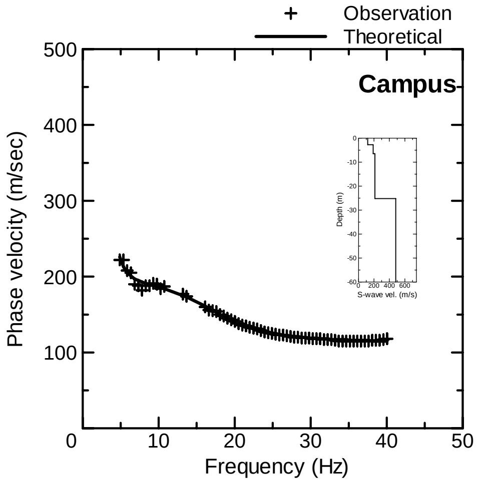


Figure 6. Comparison of dispersion curves between observed and inverted at Campus

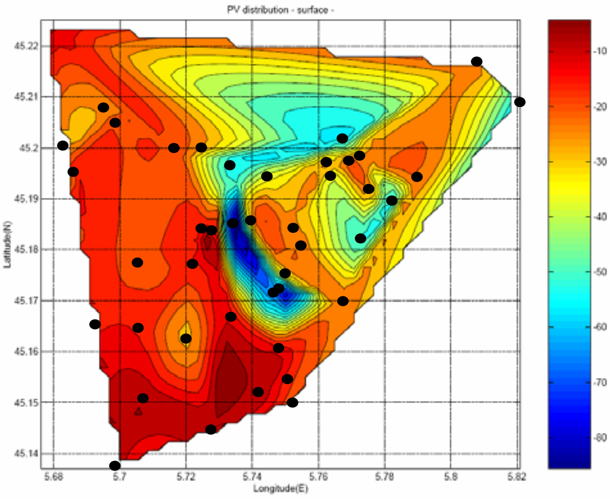


Figure 7. Velocity distribution map of engineering bedrock (Vs 400-500m/s)

We inverted the dispersion curves obtained by the MASW measurement to get S-wave velocity structure by using the Genetic Algorithm (GA) after Yamanaka and Ishida (1996). The theoretical phase velocity inverted by GA at Campus shown in Figure 6 fits well the observed phase velocity. Finally, we found that a soft soil sediment with a S-wave velocity ranging between 400 and 500 m/s is more deeply deposit in the middle-east of Grenoble than in other areas (Figure 7)

4. EVALUATION OF QUALITY FACTORS

We propose a method for determining quality factors in superficial layers by using a waveform inversion procedure on recording data, which are excited by a hammer shot in a linear array. Synthetic waveforms are calculated by the Discrete Wave-Number method (Hisada, 1994; Hisada, 1995) based on the superficial structural models derived in the Grenoble basin (See Figure 7). In this paper, we reproduce synthetic waveforms by the forward modeling to optimize quality factors.

A comparison of theoretical waveforms with observations is shown in Figure 8. The fundamental mode of Rayleigh waves dominating in this wave propagation is in good agreement with the observation. It means that the superficial structural models estimated in this study represent well the realistic site conditions. Moreover, it can be clearly confirmed that synthetics with Q-value of 15 fit better observations than synthetics with Q-value of 50, within a frequency band from 5 Hz to 50 Hz. In this study, we used a constant quality factor with frequencies to reproduce waveforms excited by a point force on surface, which described as a Ricker wavelet with a central frequency of 33Hz.

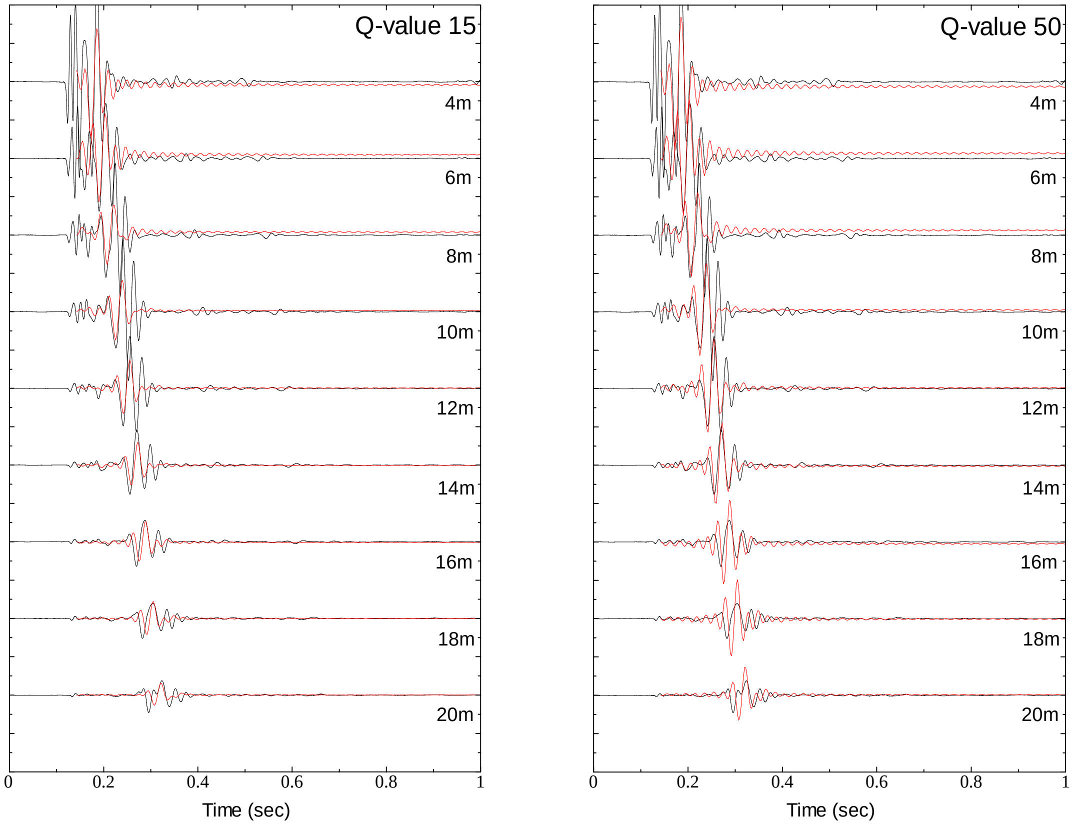


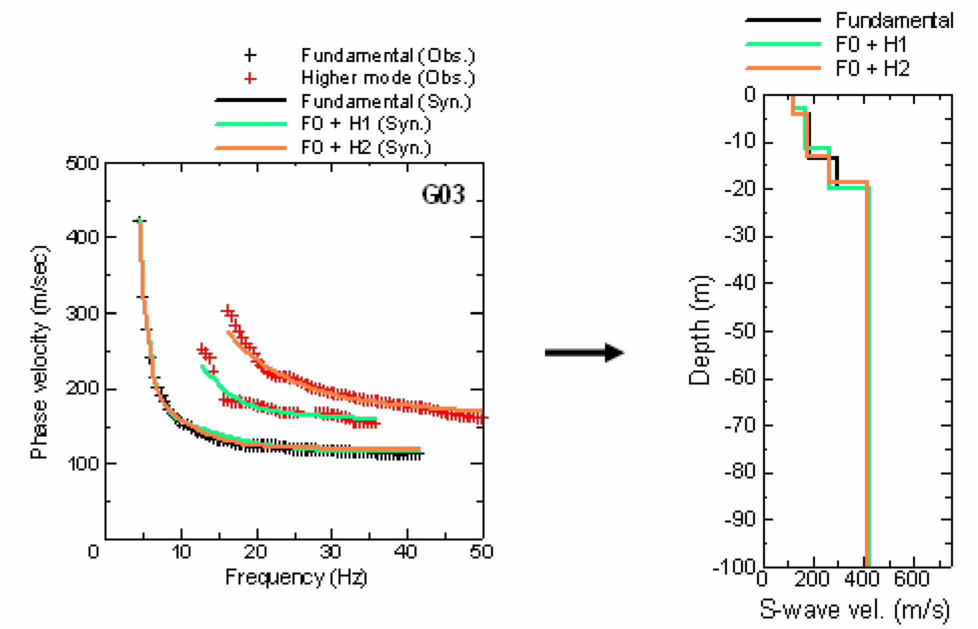
Figure 8. Comparison of theoretical waveforms calculated by DWM with observation recording data generated by hammer shot (Black lines and red lines indicate observation recordings and theoretical waveforms respectively. Theoretical waveforms in left figure are calculated with Q-value of 15, while those in right figure are calculated with Q-value of 50.)

5. DISCUSSION ON HIGHER MODES

We can see higher modes excited during the MASW measurement as well as a fundamental mode (Figure 2). Therefore, we used higher modes to estimate S-wave velocity structures. We confirmed the good fitting of the theoretical higher modes of Rayleigh waves for the observations at 9 sites among 19 sites, while the occurrence of higher modes depends on the site conditions. Here, illustrating two typically observed distributions between fundamental and higher modes, we discuss on the usefulness of higher modes for inverting to S-wave velocity structures.

5.1. Case of higher mode exhibiting lower phase velocity than fundamental mode

A representative comparison of theoretical dispersion curve of Rayleigh waves with observation at G03 site is shown in Figure 9. In this case, the measured maximum phase velocity of fundamental mode is larger than those of higher modes (first and second modes). The good agreement between observed and theoretical dispersion curves for each mode are shown in Figure 9(a); and the estimated S-wave velocity structure shown in Figure 9(b) are slightly changed for the intermediate layer. It indicates that a joint inversion has better constraint of a structural model than an inversion of only fundamental mode.

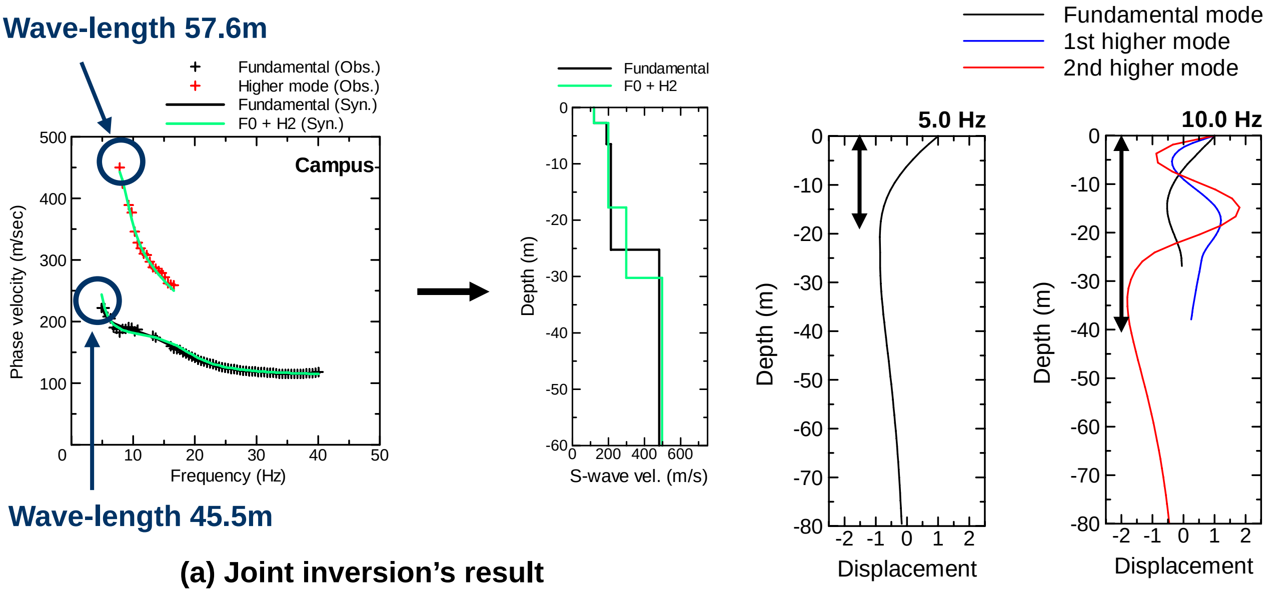


(a) Phase velocities of Rayleigh waves **(b) S-wave velocity profiles by GA**

Figure 9. Joint inversion between a fundamental mode and higher modes at G03 (Marks and lines indicate observed and theoretical dispersion curves respectively. And Black mark and line indicate observation, and colored ones indicate theoretical results.)

5.2. Case of higher mode exhibiting larger phase velocity than fundamental mode

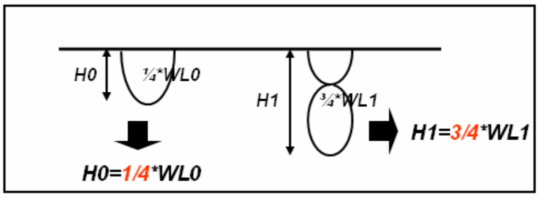
In case of the maximum measured phase velocity of higher mode lager than the velocity of fundamental mode, a comparison of theoretical dispersion curves of Rayleigh waves with observations at Campus site is shown in Figure 10. The joint inversion of fundamental and higher mode is shown in Figure 10(a). The theoretical dispersion curves of fundamental and higher mode are in good agreement with the observation. The S-wave velocity structures estimated by both inversion of fundamental only and of joint inversion are different in terms of the deepest seismic interface depth, which is caused by the contribution of higher mode. The largest wave-lengths between fundamental (wave-length of 45.5 m at 5.4 Hz) and higher mode (wave-length of 57.6 m at 7.8 Hz) doesn't have a large difference, however, the use of higher modes allows detecting a deeper structural model. The eigen function and schematic explanation of modes are shown in Figure 10(b) and (c) respectively. Figure 10(b) indicates that higher modes are excited at a deeper point than a fundamental mode, while the schematic explanation for its reason demonstrates that higher modes have an effect on deeper points than a fundamental mode with the same wave-length.



(a) Joint inversion's result

(b) Eigen functions of modes

Figure 10. Joint inversions between a fundamental mode and higher modes at Campus
(Joint inversion's result is shown at fig(a). Eigen functions of a fundamental mode and higher modes are shown at fig(b). This demonstrates that higher modes can affect a deeper structure than a fundamental mode. Schematic explanation on wave-length of modes called a quarter of wave-length law is simply shown at fig(c).)



(c) Schematic explanation of modes

6. CONCLUSIONS

We performed the MASW measurements in the Grenoble sedimentary basin to determine the superficial S-wave velocity structure and to obtain the S-wave velocity of the seismic bedrock in Alpine valley around the Grenoble Basin. The superficial S-wave velocity profiles in the Grenoble Basin are heterogeneous and especially in the middle-east of Grenoble the soft soil sediment (less than Vs 400-500 m/s) are deeply deposit. Moreover, we proposed a method for determining quality factors using the waveform inversion of MASW recording data. As regards use of higher modes, we showed the possibility of determining a layer with a higher velocity by using joint inversion of fundamental and higher modes.

In future, we will confirm the difference of superficial velocity profiles among the east, the west and the belt of north-south of the Grenoble Basin by analyzing the earthquake recording data obtained by the temporary array seismic observations in the Grenoble Basin.

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