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SEISMIC SITE CHARACTERIZATION USING HWAW(HARMONIC WAVELET ANALYSIS OF WAVES) METHOD

Hyung-Choon Park[1], Dong-Soo Kim[2], Eun-Seok Bang[3], Jong-Tae Kim[4]

ABSTRACT

To obtain a shear-wave velocity profile in geotechnical practice, various seismic investigation methods which have their own strength and weakness are being frequently used. In this study, harmonic wavelet analysis of wave (HWAW) method is applied to determination of V_s profile to overcome some of weaknesses in the existing surface wave methods. HWAW method which is based on time-frequency analysis using harmonic wavelet transform have been developed to determine phase and group velocities of waves. Field testing of this method is relatively simple and fast because one experimental setup which consists of one pair of receivers is needed to determine V_s profile of site. The proposed method uses the signal portion of the maximum local signal/noise ratio to evaluate the phase velocity to minimize the effects of noise, and uses single array inversion which considers receiver locations. In order to estimate the applicability of HWAW method, field tests were performed in 4 sites. 2 sites are for evaluating accuracy of test method and others are for estimating the applicability of 2-D imaging by HWAW method. Through field applications and comparison with other test results, the good accuracy and applicability of the proposed method were verified.

Keywords: Harmonic wavelet, HWAW method, time-frequency transform, V_s profile, 2D V_s map

INTRODUCTION

The evaluation of shear modulus (or shear wave velocity) profile of site is very important in the various fields of geotechnical engineering. To obtain shear wave velocity profile, various in-situ seismic methods using surface waves have been developed (Nazarian and Stokoe, 1984; Gabriels et. al, 1987; McMechan and Yedlin, 1981; Park et al, 1999). These surface wave based in-situ seismic methods have their own strength and weakness.

In this study, new seismic site characterization method using the harmonic wavelet analysis of wave (HWAW) was proposed to overcome some of weaknesses in the existing surface wave based seismic site characterization methods. HWAW method which is based on time-frequency analysis using harmonic wavelet transform was developed to determine phase and group velocities of waves. The seismic site characterization method using HWAW method consists of three steps: field testing, evaluation of dispersion curve, and determination of Vs profile by single array inversion process. The field testing of this method is relatively simple and fast because one experimental setup which consists of one pair of receivers is needed to determine the dispersion curve of the whole depth of interest

[1] Assistant Professor, Department of Civil Engineering, ChungNam National University, Korea, Email: civilman@cnu.ac.kr
[2] Professor, Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology, Korea, Email: dskim@kaist.ac.kr
[3] Senior Researcher, Geotechnical Engineering Division, Korea Institute of Geoscience and Mineral Resources, Korea, Email: kesbang@kigam.re.kr
[4] Ph. D Candidate, Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology, Korea, Email: greatrok@hotmail.com

using a short receiver spacing setup which can minimize error caused by lateral variation. The proposed method uses the whole wave field including near and far field, and can sample much deeper part of site than the conventional phase unwrapping method using same source. Moreover, HWAW method mainly uses the signal portion of the maximum local signal/noise ratio to evaluate the phase velocity in order to minimize the effect of noise. This method uses single array inversion which considers the variation of phase velocity with receiver location without increase of calculation time and complexities because the whole dispersion curve is determined from one experimental setup. These characteristics show the good potential of applicability of HWAW method for site characterization.

In this paper, the procedure of proposed method is briefly described. Then, to estimate the applicability of the proposed method, field tests were performed in the 4 sites. In site 1 and 2, the shear wave velocity profiles obtained by HWAW method were compared with those by conventional SASW test and PS-suspension logging test to verify accuracy of method. In site 3 and 4, 2D shear wave velocity maps determined by HWAW method were compared with results of boring, SASW, MASW, Down-hole method.

SITE CHARACTERIZATION USING HWAW

HWAW Method

HWAW method is based on the harmonic wavelet transform to evaluate dispersive phase and group velocities. To apply the harmonic wavelet transform in the evaluation of dispersive velocity, the meaning of harmonic wavelet coefficient is interpreted from a different point of view. Based on these concepts, the step by step procedure to evaluate the dispersive phase and group velocities was proposed. First, harmonic wavelet transform decompose signals obtained at receiver 1 and 2 into frequency components in time domain. And this transform determine energy and phase time-frequency maps which describe instantaneous energy and phase of frequency components with time(Figure 1). Then group and phase delays of each frequency component are determined from instantaneous energy and phase information. The group delay mean time corresponding to maximum energy and the phase delay is time corresponding to certain fixed phase around maximum energy time. If the distance between receiver 1 and receiver 2 is D, then the group velocity V_{gr} and the phase velocity V_{ph} at each frequency are obtained(Figure 2). The HWAW method mainly uses the signal portion of the maximum local signal/noise ratio to evaluate the phase velocity and it can minimize the effects of noise.(Park and Kim, 2001)

Site characterization using HWAW method

For the site characterization, HWAW method can use two test setups; short receiver spacing setup and conventional test setup (Figure 3). In the short receiver spacing setup, source-receiver spacing (D) is 6~12m and receiver spacing (R) is 1~3m. In contrast, at the conventional test setup, source-receiver spacing is over 10m and receiver spacing is same as the source-receiver spacing. For more accurate and detailed result, the short receiver spacing setup is preferable because of the lateral non-homogeneity of soil layer. The proposed method use the whole wave field information including far and near field information to determine dispersion curve of whole depth from one test setup. It has been found that the near field dispersion curve includes long wave length component enough to explore deep layer and is more sensitive to the deep layer material properties than far field dispersion curve. The dispersion curve determined by HWAW method and the theoretical dispersion curve used in the inversion process reflect the near field effect in the same way. Therefore, the whole wave field dispersion curve including near field effect can be used to evaluate deep soil profile. In general, for phase unwrapping method, average signal to noise (S/N) ratio is too low in the near field to determine the correct phase velocities. HWAW method can determine the correct phase velocities in the near field because the HWAW method uses local information where signal energy is dominant (Park and Kim, 2001).

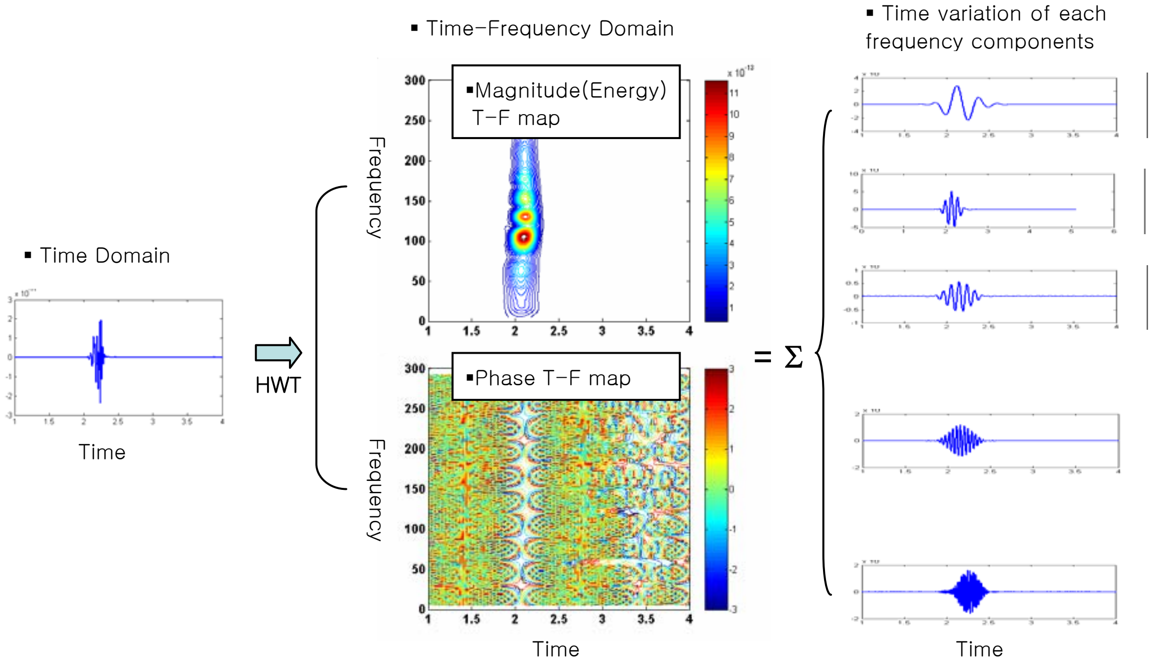
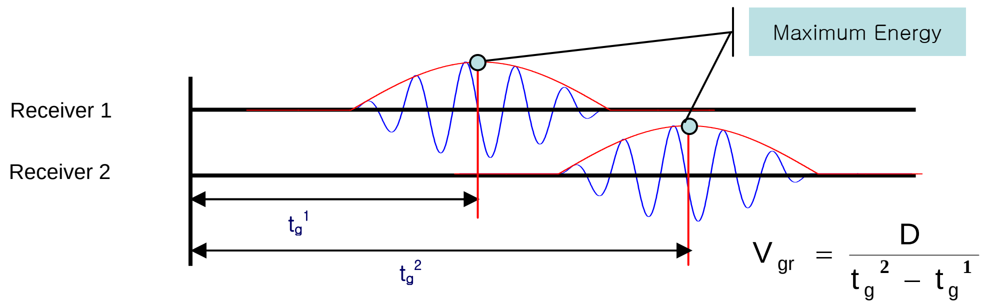
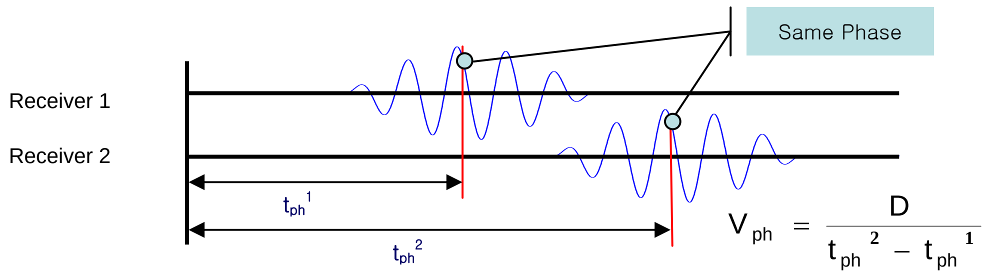


Figure 1. Decomposition of time record by harmonic wavelet transform



(a) Determination of group velocity



(b) Determination of phase velocity

Figure 2. Determination of group and phase velocities of each frequency component

Because the phase velocities vary with receiver location due to different velocities of modes of which surface wave consist, field testing set up should be considered for the inversion process. The array inversion in which the theoretical dispersion curve is generated at receiver locations same as field test setup, was developed to consider testing setup in the inversion process(Joh, 1996). Array inversion show good performance but cause increasing calculation time and complexity in the inversion peocess. In the proposed method, the single array inversion process can be possible without increasing calculation time and any complexity because the proposed method uses just one test setup in the field. Because the proposed method uses short receiver spacing setup, it can minimize the possibility of error due to lateral non-homogeneity and can determine detailed local soil profile. By performing series of tests along testing direction, 2-D subsurface stiffness imaging can be obtained by interpolating all local Vs profiles of interested region. Even though this is not a tomography but a simple interpolation job, this simple interpolation can provide detailed 2-D stiffness contour because receiver spacing is close enough.

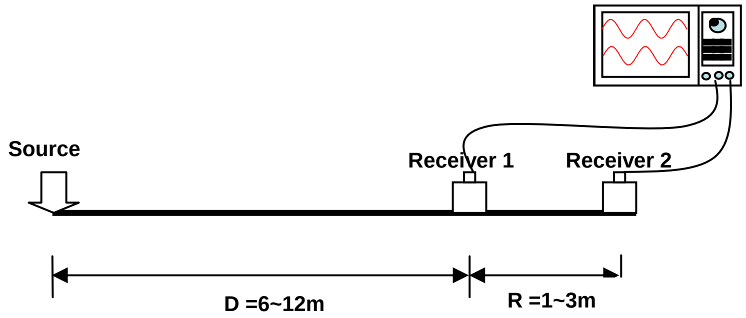


Figure 3. Test setup for HWAW method(short receiver spacing setup)

FIELD APPLICATION

Site 1

The proposed method was applied in the field to verify accuracy of method. The short receiver spacing setup (D=12.9m, R=1.8m) and conventional test setup (D=24m, R=24m) were used to determine dispersion curves and the single array inversion was used to evaluate soil profile. The soil profiles by the proposed method were compared with those by SASW and PS-suspension logging tests. Figure 4 shows the comparison of shear wave velocity profiles determined by the proposed method using short receiver spacing setup, SASW test, and PS-suspension logging test. The result of PS-suspension logging test represent local characteristic of site. In Figure 4, Vs profile by SASW test shows a little difference with those by other methods. This difference can be due to the lateral variation of soil properties of site. SASW test need a long test line to explore deep layer and determine the soil profile between receivers in the average sense when lateral non-homogeneity exists. However, HWAW method uses just one short receiver spacing setup to determine dispersion curve of whole depth of interest. The short receiver spacing setup having receiver spacing of 1~3m can minimize the effect of lateral non-homogeneity and it has potentials to determine the detailed local Vs profile along the lateral direction such as two dimensional Vs map of site. Figure 5 shows comparison of Vs profiles determined by HWAW methods using short receiver spacing and long receiver spacing setup and SASW test. Vs profiles show a little difference at depths of about 20m. These differences between soil profiles may be explained by the variation of phase velocities with receiver locations and lateral non-homogeneity of site. If site has no lateral non-homogeneity, Vs profiles determined by the proposed HWAW methods using short and long receiver spacing setups would be same. At this site, however, test results by HWAW methods using different test setups are different each other, explaining that this site has some lateral non-homogeneity. It is also interesting to notice that Vs profile determined by HWAW method with long test setup is more similar to that by conventional SASW test and the longer the receiver spacing the more averaging the lateral non-homogeneity of site. So, to evaluate detailed local properties of ground and 2-D stiffness image, it is recommended to use short receiver spacing setup.

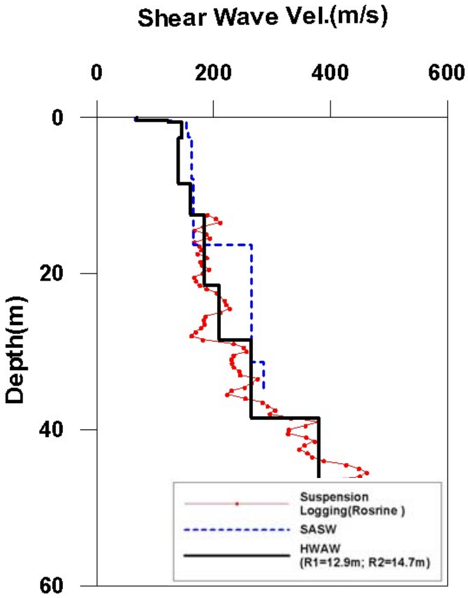


Figure 4. Comparisons of Vs profiles determined by short receiver spacing HWAW, SASW, and PS-suspension logging tests

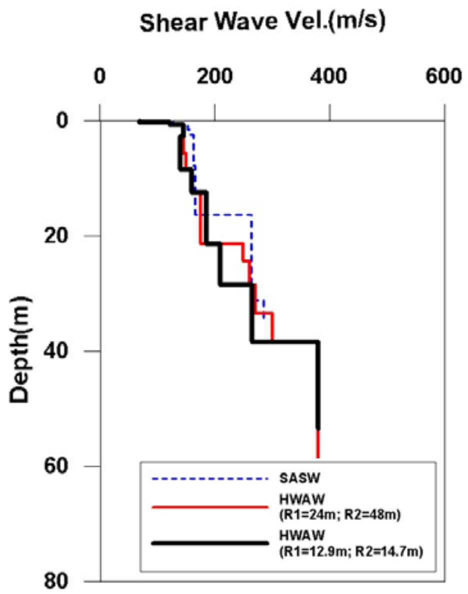


Figure 5. Comparisons of Vs profiles determined by HWAW methods using short and long spacing setup and conventional SASW test

Site 2

For site 2, the short receiver spacing setup (D=6.9m, R=1.8m) was used to determine dispersion curves for the proposed method and the single array inversion was used to evaluate soil profile. The soil profile by the proposed method were compared with those by SASW and PS-suspension logging tests. Figure 6 shows the comparison of shear wave velocity profiles determined by HWAW, SASW and PS-suspension logging methods. In Figure 6, Vs profile by SASW test shows a little difference with those by the other methods. As mentioned above, this difference can be explained by the lateral variation of soil properties of site.

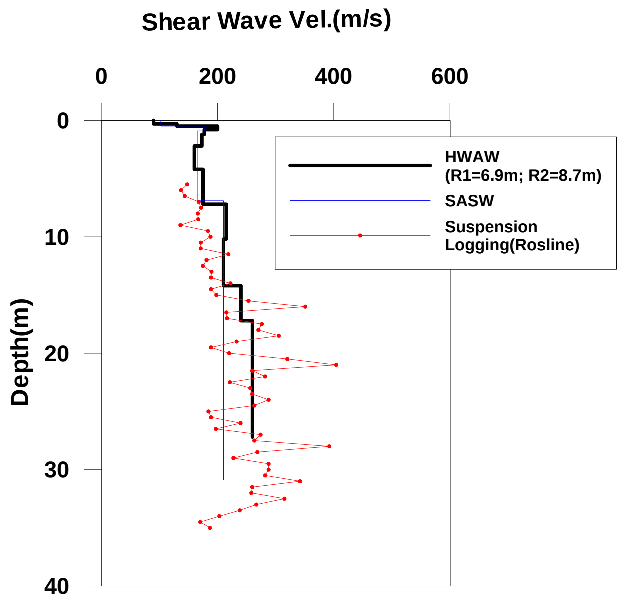


Figure 6. Comparisons of Vs profiles determined by short receiver spacing HWAW, SASW, and PS-suspension logging tests

Site 3

Site 3 is a model testing site which composed of four local layers with size about 16m×26m×8.5m (W×L×H) as shown in Figure 7. 140 vertical and horizontal geophones were embedded at the boundary of each layer to evaluate the dynamic material properties of each layer. Using the interval travel time between embedded geophones, Vs and Vp of each layers were obtained as reference data for evaluation of other seismic tests(Figure 8). In this site, SASW, MASW and HWAW tests were performed along the embedded geophone line. In HWAW method, the 6m of source to receiver spacing (D) and 2m of receiver spacing (R) were used to determine the individual dispersion curve and HWAW tests were repeated quickly by shifting source and receiver setup parallel from 0m to 15m at 7 locations to determine 2D-Vs map.

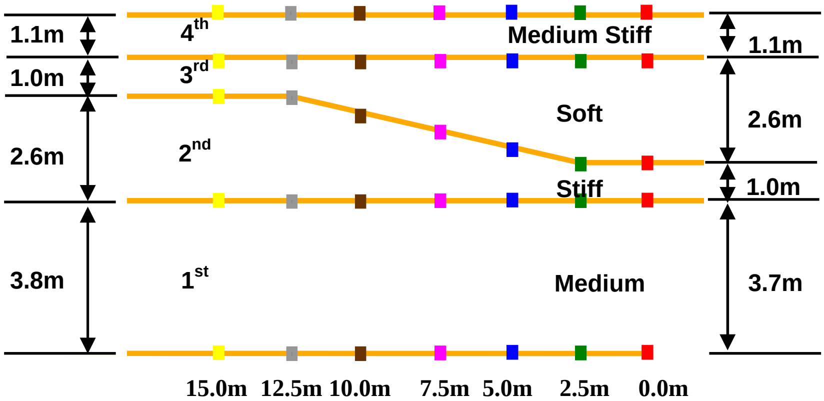


Figure 7. Geometry of model testing site

Figure 9 shows comparison of results of three tests and reference data. Test location is at horizontal coordinate of 10m where centerlines of receivers of HWAW, SASW and MASW methods are located. Vs profile by HWAW method agree well with reference result, but Vs profile by SASW test shows a little difference with those by the other methods. This difference is due to lateral variation of this site because Vs profile of SASW represents the average Vs profile of model site using combination of several receiver spacings.

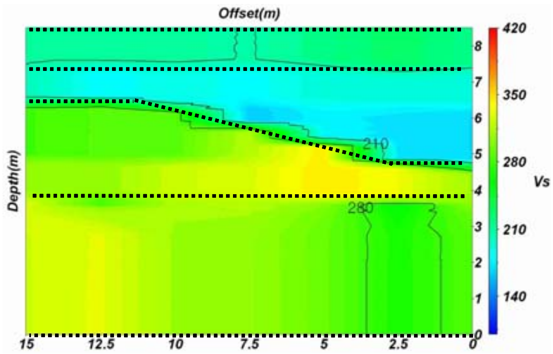


Figure 8. Reference 2D-Vs map of model testing site

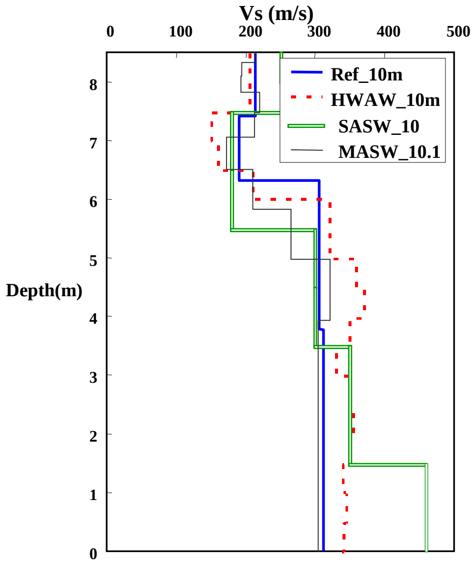
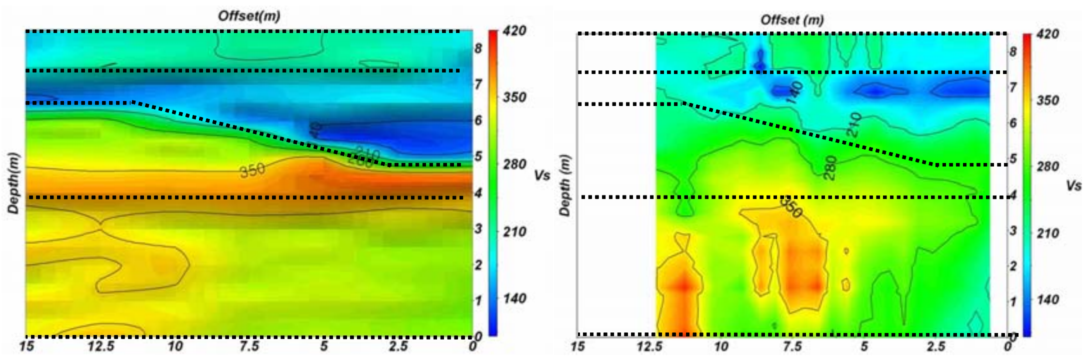


Figure 9. Comparisons of Vs profiles determined by short receiver spacing HWAW, SASW, MASW tests and reference value is at horizontal coordinate of 10m



(a) 2-D Vs map by HWAW **(b) 2-D Vs map by MASW**

Figure 10. Comparison of 2-D Vs map of model site

Figure 10 show 2-D Vs images obtained by HWAW and MASW methods. 2-D Vs profiles by HWAW method match well with detailed geometry and reference value of model site (Figure 10(a)). As shown in Figure 10(b), MASW method also provide 2-D Vs profiles but the 2D image is a little different from reference value. MASW method use 24 receivers(receiver spacing : 0.5m) and determine average Vs profile covering horizontal length of 11.5m. On the contrary, HWAW method uses short receiver spacing(2m) contrary to long multi-channel receiver array of MASW, so it is possible to get locally detailed Vs profile of the entire model site. By comparing 2-D image determined by reference data, the good applicability to develop 2-D Vs profile using HWAW method was verified.

Site 4
In site 4, Down-hole, SASW and HWAW were performed to evaluate applicability of 2-D imaging by HWAW method and three borings(BH-1,BH-2, BH-3) were performed to investigate the subsurface geometry. Figure 11 shows the boring results. It is noted that soil layers are not horizontally uniform from Fig. 6. HWAW method use short receiver spacing setup in which source to receiver spacing was 6m and receiver to receiver spacing was 2m. SASW test used conventional test setup. Down-hole test was performed to about 30m depth at three bore-holes .

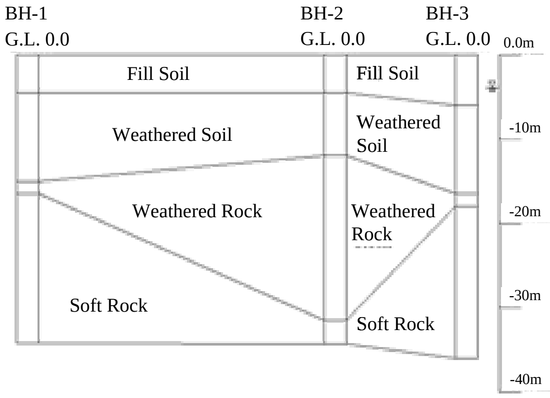


Figure 11. The three boring investigation results

Figure 12 shows comparison of Vs profiles determined by HWAW, SASW, and down-hole test at BH-2. Although there are some differences between three results, it can be said that three Vs profiles are similar over whole depth range. The differences between HWAW and SASW method can be explained by the lateral stiffness variation of site, differences in sampled region and inversion process. And Vs profiles determined by down-hole method are similar to results by surface wave method. Anyways, it can be verified that HWAW can give a reliable Vs profile including deep depth properties with short receiver spacing setup, too

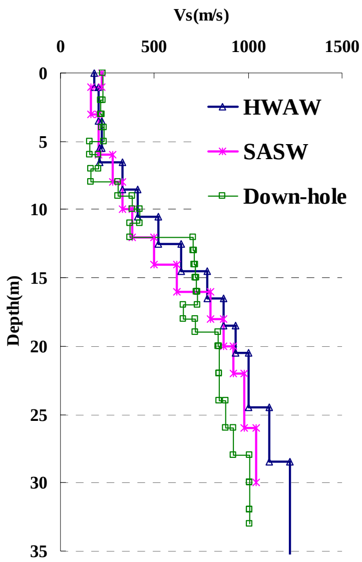


Figure 12. Vs profiles obtained by HWAW, SASW and down-hole test at BH-2

HWAW test was also repeated shifting source and receiver setup parallel at space, and total 14 dispersion curves were evaluated. Figure 13 is the 2-D Vs map which shows the horizontal irregularity, and the boundaries of weathered soil and weathered rock assumed by the shear wave velocity contours of around 250m/s and 600m/s. Boring profiles is also shown in Figure 13 respectively. Thus it is possible to distinguish boundaries of layer by wave velocities. Also, It can be insisted that assumed weathered soil and rock lines in the 2-D Vs image accord well with 2-D boring geology as shown in Figure 13. Therefore, by comparing site geology determined by bore holes, the good applicability to develop 2D V_s profile using HWAW method was verified.

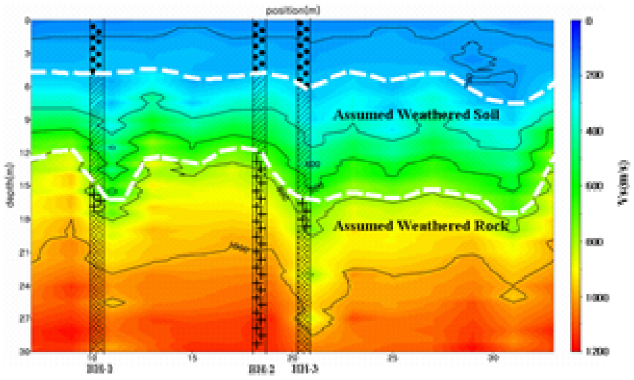


Figure 13. 2-D V_s map by HWAW

CONCLUSION

In this study, the new seismic site characterization method using the harmonic wavelet analysis of wave (HWAW) method and the application of shear wave velocity imaging were proposed. Field testing of this method is relatively simple and fast because one experimental setup which consists of one pair of receivers is needed to determine the dispersion curve of the whole depth. To estimate the applicability of the proposed method, field tests were performed. Through application in site 1 and 2, the shear wave velocity profiles obtained by the proposed method were compared with those by conventional SASW test and PS-suspension logging test and accuracy of HWAW method was verified. In site 3 and 4, 2-D Vs map determined by HWAW method is compared with results of boring, SASW, MASW, Down-hole test. Through field applications, the good applicability of the proposed method is verified. In other words, the proposed method using short receiver spacing setup can determine 2D Vs map by evaluation of the detailed local Vs profile along lateral direction by performing series of tests.

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