COMBINED GPR AND NON-CONTACT SURFACE WAVE MEASUREMENTS FOR THE INVESTIGATION OF PAVEMENT STRUCTURE

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Abstract

We developed a non-contact surface wave measurement tool using arrayed microphones for the structural investigation of pavements, and tested it on actual pavements. The tool comprises two microphone arrays, each of which is composed of 24 microphones at 5 cm intervals. The microphone arrays are suspended in a sound insulation box cart, 2 cm above the pavement surface. Each microphone is also hooded to reduce direct air wave noises. A PC controlled, 48-channel high-speed data acquisition system is used to observe leaky surface waves. Field measurements demonstrated that the tool could measure leaky surface wave which showed clear dispersion in the frequency range from 150 to 4,000 Hz. S-wave velocity structure of the pavement was successfully reconstructed using the higher modes in dispersion curves. To certify whether the dispersion curves measured by the tool were valid, we conducted comparative surface wave measurements using high-frequency accelerometers pasted on pavement surfaces. In addition, GPR was carried out on the same location to correlate with surface wave measurement results. As a result, 1D S-wave velocity structures reconstructed from the microphone array data were not always concordant with the accelerometer array results. It was presumed that the decrease in S/N of leaky surface waves, caused by surface rough shape and cracks, resulted in inappropriate determination of phase velocities in frequency range from 500 to 900 Hz. Further improvement is planned to enhance the leaky surface wave signals in lower frequency even on damaged pavements.

Introduction

Development and utilization of in-situ inspection methods for aged infrastructures, such as roads and levees, has become a priority issue in Japan, as the matured and twilight economic country. Japan is now forced to continue to use existing aged infrastructures while efficiently maintaining and restoring. We have been researching on the application of high-frequency surface wave method in combination with GPR to paved roads for the maintenance assessment since 2013 (Aoike, et. al., 2013, Aoike, et. al., 2014). Our previous studies have shown the importance of constraint of pavement structure in the inversion process of surface waves. It is required to determine two major unknown parameters, thickness and S-wave velocity, for the following three layers, HMA, base course and subgrade from the observed dispersion curve. Because GPR survey was helpful to estimate each thickness, combination measurements of GPR and high-frequency surface waves are recommended for the assessment of pavement roads. Another finding was the usefulness of piezoelectric type accelerometers for the high-frequency surface wave measurements. Actually, we could obtain clear dispersion curves from 40 to 5,000 Hz when sensors were pasted on the road surface with cohesive clay pads (Inazaki, et. al., 2014). However, it takes much time to set the sensors and it would have a risk of contact with passing vehicles during measurements on the road. Therefore, we developed a non-contact measurement tool to measure
rapidly and safely (Inazaki, et. al., 2015). Previous similar study (Ryden, et. al., 2006), for estimating thickness and stiffness of asphalt or concrete pavements using leaky surface waves measured by non-contact microphone array, treated the measured surface waves as Lamb waves. It would be valid when the surface is covered with concrete. In contrast, we treat and analyze the measured surface waves as Rayleigh waves because 90 percent of the pavements in Japan use hot mixed asphalt (HMA) as the surface course. It means that dispersion in low frequency ranges reflect S-wave velocity structure of pavements, and higher mode inversion analysis is applicable to estimate the S-wave velocity structure of the pavements. In this paper, we show the comparative test results using newly developed non-contact type microphone array (NCMA) tool and surface pasted accelerometer array (SPAA) tool conducted in PWRI Tsukuba site. Next, ambiguity in estimating dispersion curves is discussed in the viewpoint of structural inversion of pavements with aid of GPR survey profiles.

**Non-contact Surface Wave Measurement**

*Figure 1* is a picture of the NCMA surface wave measurement tool. This tool is composed of air knocker as an impulsive source and two microphone arrays incorporated in the sound insulation box. Each microphone array consists of 24 microphones at 5cm spacing, and is suspended in the sound insulation box, 2cm above pavement surface. Each microphone is hooded like funnel to reduce direct air wave noises. The leaky surface wave is recorded by 24 bit A/D, 48 channel data acquisition system at sampling rate of 200 kHz. *Figure 2* shows actual recorded waveforms. It contains not only predominant air waves but also weak leaky surface waves. We use only the leaky surface waves in the first arrival parts and air wave noises are muted before calculating dispersion curves.

To confirm whether the tool could obtain leaky surface waves, we compared the dispersion curve with that obtained using SPAA tool at the same place. *Figure 3* compares the dispersion curves. As shown, two images are basically same in frequency range from 150 to 4,000 Hz. This demonstrates the NCMA tool could correctly acquire the leaky surface waves enough to estimate dispersion curves emulative to the SPAA tool.

*Figure 1*: A schematic illustration of the developed non-contact microphone array surface wave measurement tool (Inazaki, et. al., 2015).
Figure 2: Examples of a raw record (left) and air wave mute data (right).

Figure 3: Phase velocity images in frequency domain (a: SPAA, b: NCMA) and comparison of each dispersion curve (c).

Field Experiment

We tested the developed tool at PWRI Tsukuba site. Figure 4 shows a GPR time section (A) along a survey line, and an image of borehole camera inspection (C). The GPR section imaged an almost homogeneous layered structure beneath the line, and thickness of pavement was about 40cm. The pavement structure revealed by the borehole camera inspection was used to interpret GPR section and for the time to depth conversion. The relative dielectric constant of HMA and base course was calculated and each dielectric constant was estimated as 6.67 for the HMA and 9.81 for the base course. Figure 4 (D) shows estimated structure of HMA and base course at each measuring point using the above values.

In this line, the newly developed tool (NCMA) was applied at 3 points, 5 m interval, and also high-frequency surface wave measurement using accelerometer (SPAA) was carried out at 4 points. Regretfully, NCMA couldn’t acquire emulating data at point 4 due to the influence of surface crack. Figure 5 shows observed dispersion curves. As shown, dispersion curves of SPAA vary in the high frequency range. It was presumed that the pavement structure in S-wave velocity or its thickness...
changed at the shallow part of pavement along the line. Compared with the dispersion curve of SPAA, NCMA curve was plotted on the same line in frequency ranges up to 300 Hz, but that was plotted at different positions in the range higher than 300 Hz. In the inversion analysis, we dealt with these dispersion curves as Rayleigh waves, and used the SeisImager produced by Geometrics. The initial model set three layers, HMA, base course and subgrade. The thickness of HMA and base course for the initial model were estimated based on GPR data and the S-wave velocity set 1500 m/s in HMA, 370 m/s in base course and 150 m/s in subgrade. Generic algorithm (GA) technique proposed by Hayashi (2012) was employed for the inversion. In GA, the search area of S-velocity set ± 20% of the initial model and the condition of constraint sets decreasing of S-velocity with depth.

**Figure 4**: The GPR profile (A) and picture (B) of the survey site. (C) shows the borehole camera image in this site. The borehole inspection was carried out at opposite lane. (D) shows estimated thickness of each survey point.

**Figure 5**: The observed dispersion curves. The solid line is observed by NCMA, and the dashed line is observed by SPAA.
The estimated structures of the pavements are shown in Fig.6. As shown, there is a discrepancy between the estimated pavement S-wave velocity structures as the inversion results. It resulted from the differences in observed dispersion curves especially in frequency range from 400 to 900 Hz. It was considered that strong noises masked the signals when using NCMA under ill surface condition. Additionally, direct air wave noise, generated by surface hitting, still remained in the muted data. This indicated that further improvement should be added to our sound insulation box. In addition, the assumption that observed leaky waves are Rayleigh waves necessitate us to separate signals by setting source at a greater distance.

**Conclusion**

We developed a non-contact surface wave measurement tool for the pavement structure assessment (Inazaki, et. Al., 2015). The tool could record the leaky surface wave, and estimate the phase velocity in frequency range from 150 to 4000 Hz. However, in the field experiment, discrepancies were observed in phase velocity curves with those obtained by surface pasted accelerometer array (SPAA) data especially in frequency range from 400 to 900 Hz. It was presumed that low S/N caused this problem. Then, we are planning to improve the tool to reduce noise more and more. Leaky surface wave measurement tends to be affected by the surface state of the pavements, especially by cracks. Additionally, difficulties in estimating phase velocities close to the air wave velocities should be addressed. Influences on ground or substrata having S-wave velocity lower than 340 m/s are also one of the problems for the practical use of the NCMA tool.
References


