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STUDY ON THE EFFECTS OF RECEIVER DISTANCE, HEIGHT AND MASS OF DROPPING STEEL BALLS ON SASW TEST RESULTS

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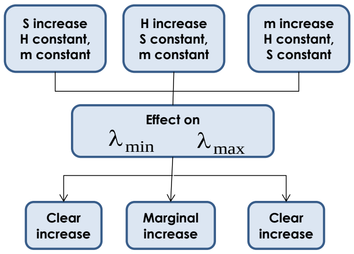
Graphical abstract



Abstract

A series of surface wave tests, namely the Spectral Analysis of Surface Wave (SASW) test, was done on asphalt pavement to study the effect of receiver distance, S; the height of dropping steel balls, H; and the mass of the source, m on the results of SASW evaluation. For each test, four steel balls with different masses, namely0.067kg, 0.228kg, 0.537kg, and 1.805kg, were used as sources, and the balls were dropped from varying heights, 0.25m and 0.50m. This test was conducted with two different configurations, in which the receivers were located 0.15m and 0.30m apart. This paper presents the results of the test in terms of maximum and minimum wavelength. The results proved that larger receiver distance yields large wavelength, and vice versa. The similar trend is observed when the mass of the dropping ball is increased. The height of the falling steel ball, however, did not have significant impact on the results of the SASW evaluation.

Keywords: Asphalt pavement, spectral analysis of surface wave, non-destructive test, surface wave

1.0 INTRODUCTION

The use of surface wave in seismic testing has gained popularity in engineering practice as a method of determining shear wave velocity profile [1, 2]. The surface wave testing in engineering that have been used quite extensively for quite some time is associated with the two-station setup used in the Spectral Analysis of Surface Wave (SASW) method [3-11]. In general, the Spectral Analysis of Surface Wave (SASW) has been widely used as a non-destructive test in the evaluation of subsurface parameters in soils and pavements.

SASW utilizes Rayleigh waves which, at different frequencies, propagate at different velocities. The dispersive characteristics of Rayleigh waves propagating through a layered material are measured and are then used to evaluate the S-wave profile of the material [11, 1]. SASW is a method that is capable of accurately defining the elastic moduli and the thickness of layered systems, such as soil and pavement, with a particular advantage of it being performed entirely on the surface [12].

Generally, waves travel at high velocity (and high frequency) in pavement materials. It is known that the higher frequency waves are associated with shorter wavelength and, as a result, these waves propagate only at shallow depths. On the other hand, lower frequency waves have longer wavelength and travel through deeper layers [13, 4, 5].With regard to asphalt pavement, the ground was excited by using a small impact source to generate waves propagating at shallow depth [14] indicated that (1) an increase in the height of the dropping mass lead to an increase in impact velocity and contact force; and (2)an increase in the dropping mass result in an amplification of the low frequency components of the Fourier Spectrum of the contact force [15].

The systematic introduction of the seismic surface-wave method, namely the Spectral Analysis of Surface Wave (SASW) method, to engineering applications has resulted in an increased use of this non-destructive testing technology [6]. This method is based on the dispersion characteristics of surface waves propagating in a layered medium and could be used to delineate the modulus profile of a pavement section. Dispersion curve is a plot of variation in Rayleigh wave phase velocity against wavelength or frequency [15].

Very recently, a number of studies were conducted to evaluate pavements with the application of SASW method using a spherical mass dropped from different heights [15-21]. The findings of these studies were extended to the condition of asphaltic pavement in Malaysia, with the addition of variation in receiver distance. The effect of maximum and minimum wavelength was observed.

2.0 BACKGROUND OF THE STUDY

2.1 Spectral Analysis of Surface Waves (SASW)

The SASW method is a simple technique that could be easily implemented in the field. It has a source-receiver configuration with multiple sources which have been properly selected for the measured wavelength range for each source-receiver configuration, and therefore provide high-quality results. Phase velocities were calculated from the phase difference. The key feature of SASW method is that it measures apparent velocities, which correspond to the superposed mode of higher-mode surface waves and body waves. Determination of apparent phase velocities incorporates phase unwrapping. The phase unwrapping procedure often requires experienced personnel making the best decision during the unwrapping process. However, the non-systematic nature of unwrapping a phase could be improved with a signal processing technique, such as the impulse-response filtration technique [22] and Gabor spectrum.

2.2 Sources in SASW Testing

Several sources were used in the SASW testing to excite the ground, induce vibration, and produce wave which travel through the layered systems (in this case the asphaltic pavement). Different types of sources could be used, ranging from ordinary hammers to expensive controlled source. The choice of impact source is always made for economic reason. Controlled sources allow the collection of high quality data with high signal to noise ratio. Controlled source could be as small as an electromagnetic shaker or as large as a track-mounted vibrose is.

These sources are typically applied by dropping weights of different sizes [23]. For further source offset which require longer frequency range to penetrate deeper into the ground, an ordinary impact hammer might not be sufficient. Therefore, heavier sources are required. In this test, the sources used were four steel balls with different masses and diameters, as shown in Figure 1.

Figure 1 Steel balls with different diameters and masses, m, used in this test

3.0 METHODOLOGY

A series of field tests were carried out to investigate the effect of receiver distance, height, and mass of dropping balls on SASW evaluation in terms of maximum and minimum wave length. The SASW method makes use of the determination of phase difference between two receivers over a wide range of frequencies.

With regard to data collection for the experiment, the equipment and testing configuration used in this test is closely linked with the scope of the test and the technique to be used in the interpretation of the results. In order to determine the length of the measurement, the desired depth of the investigation must always be taken into account. The relationship between frequency, wavelength, and phase velocity makes the frequency range of interest closely linked to the materials to be investigated, for example deep penetration in soft soils require lower frequency components [23]. Therefore preliminary information, or á-priori' knowledge, regarding the site being investigatedis very helpful.

3.1 Testing Equipments

The basic equipment used in the SASW test comprised of receivers (accelerometers) connected to an acquisition device which digitize and store seismic signals.

The desired depth of penetration will determine the appropriate types and specifications of the receivers required. Typically, on pavements where the frequency range of interest is higher, or for stiffer materials where the desired depth of interest is shallow, accelerometers are used as receivers. Accelerometers could reach operative frequencies in the kHz range.

Various types of recording equipment, the main function of which is to digitize and record analog electric signals generated by the receivers, could be utilized. The use of digital signal analyzer allows signal to be processed in real-time, therefore the quality assessment and preliminary interpretation could be performed instantly on site. In this test, the data was recorded using a Portable Outdoor Laptop with a Customized Compact Analyzer (POLCCA). It is a portable field laptop with built-in dynamic signal analyzer.

Several types of sources, from ordinary hammers to expensive controlled sources, could be used. In this test, which was done on asphalt pavement, steel balls of diameter25.4mm, 38.1mm, 50.8mm, and 76.2mm were used.

3.2 Tests Configuration

For the field test, two accelerometers were located in an array for two types of configurations. In the first configuration the accelerometers were located 0.15m apart, and in the second configuration the accelerometers were located 0.30m apart. Both accelerometers were mounted by weights, as shown in Figure 2, to ensure good coupling between accelerometers and pavement surface.

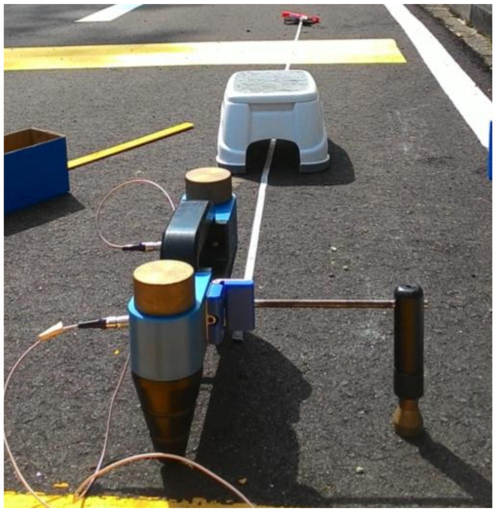


Figure 2 Weight-mounted accelerometers

For the first configuration, three source distances, each0.15m, 0.3m and 0.6m from the first receiver, were applied. For the second configuration, the sources were located 0.30m, 0.6m and 1.2m from the first receiver. Steel balls were used as a source and measurements were recorded for both configurations and for all source distances. The tests were carried out by dropping the steel balls from two different heights, 0.25m and 0.50m. Figure 3 shows the distance layout of the receiver, the distance of the sources, and height of the dropping balls.

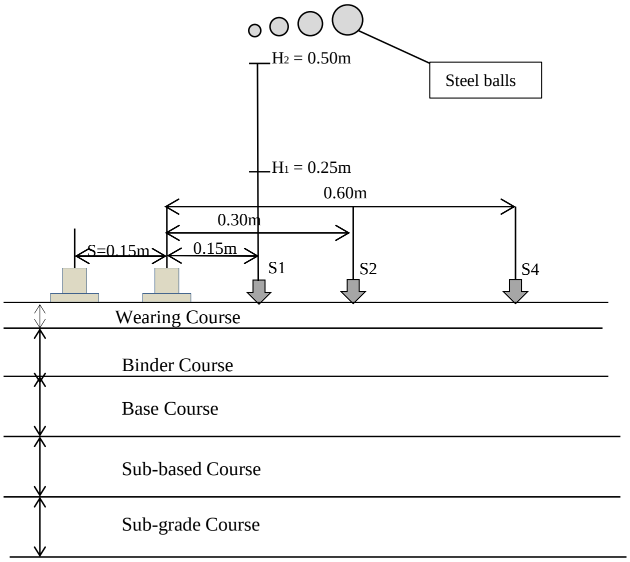


Figure 3 Layout of the SASW test configuration

4.0 RESULTS AND DISCUSSION

4.1 Dispersion Plot

In order to obtain a reliable evaluation of stiffness profile, a single source and receiver set-up is insufficient to determine the phase velocity over a wide range of wavelength. Therefore, several measurement set-ups incorporating several source locations should be used. This source offset concept was employed during field measurement and the result of the experiment is shown in Figure 4. The dispersion curve is a combination of three individual dispersion curves from three locations of source offset. For a receiver distance, S, of 0.30m, the source offset is kept constant at 0.30m, 0.60m, and 1.2m from the first receiver.

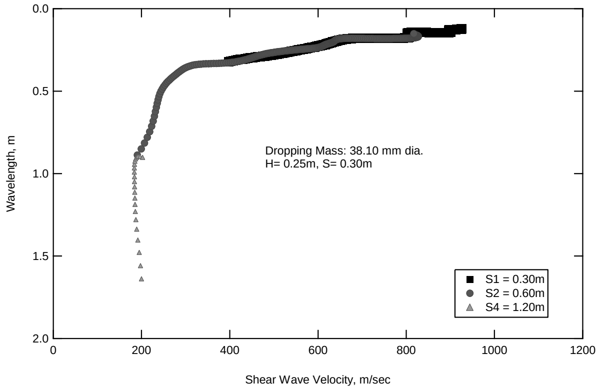


Figure 4 Combination of dispersion curves from all source offset

The dispersion curve obtained by using all four balls as sources with 0.15m receiver distance is shown in Figure 5. Figure 5 (a) shows a composite dispersion curve with the height of dropping ball of 0.25m while Figure 5 (b) shows dispersion curve when height of dropping ball of 0.50m.

It can be seen that for both heights of the dropping ball, the heaviest mass, namely ball number 4, produced the largest value for wavelength, and vice versa. Ball number 4 not only has heaviest mass but is also the largest in diameter, which means larger surface contact between the pavement surface and the steel ball. It therefore resulted in a longer duration of contact time. Previous studies have shown that the duration of impact primarily affect the predominant spectral content of the emerging signal [20, 21, 25, 26]. This has been proven in this research, as evident in the figure which shows that the long duration impacts generate low frequency signals which result in deeper exploration depth. On the other hand, the high frequency signals were generated by smaller balls, which produced shorter duration impacts.

Figure 6 (a) and (b) shows the dispersion curves obtained when the receiver distance was increased to 0.30m and the steel balls were dropped at the height of 0.25m and 0.50m respectively. The receiver distance did have some effect on the characteristics of phase velocities. The velocities could be measured at deeper wavelength region. In this case, we could say that the characteristic of phase velocities is dependent upon the receiver distance.

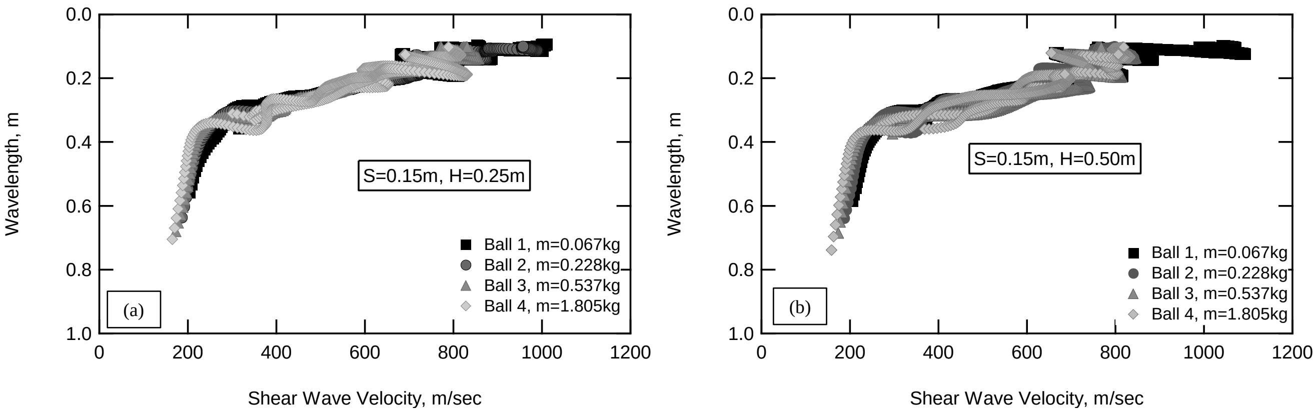


Figure 5 Dispersion curves from SASW measurements with 0.15m receiver distance: (a) Dropping mass at 0.25m, and (b) dropping mass at 0.50m

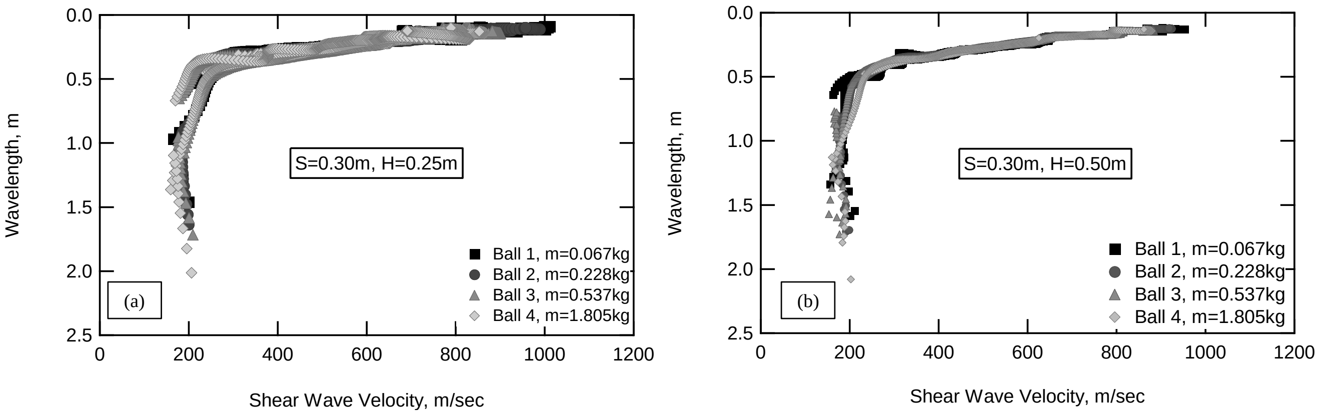


Figure 6 Dispersion curves from SASW measurements with 0.30m receiver distance: (a) Dropping mass at 0.25m, and (b) dropping mass at 0.50m

The values for the minimum wavelength, $\lambda_{\min}$, and the maximum wavelength, $\lambda_{\max}$, were determined from the dispersion plots for all sources and heights. Figures 7 (a) and (b) show the values of $\lambda_{\min}$ and $\lambda_{\max}$ when receiver distance was 0.15m. Both $\lambda_{\min}$ and $\lambda_{\max}$ increase linearly with the increase in the mass of the dropping ball. The figures also show that the difference in the height of the dropping mass did not have significant impact on the values of maximum and minimum wavelengths.

When the receiver distance was increased to 0.30m, the values for $\lambda_{\min}$ and $\lambda_{\max}$ for all sources also increased. In particular, for the maximum wavelength, it was observed that the increase in the wavelength is very significant. This trend can be seen clearly in Figure 8 (a) and (b).

The source offset concept states that the first source is equal to the receiver distance; therefore a longer receiver distance means that the source is located further away from the receiver. Rayleigh surface waves spread cylindrically from a point source and tend to dominate the measured wave-field at large distance. In simpler terms, the large receiver distance allows the wavelength to penetrate deeper and therefore provide information of the subsurface in the lower frequency region. This study could serve as a guide in determining the proper configuration for obtaining data within the depth of interest of the pavement layer.

As with Figure 7, Figures 8 (a) and (b) showthat a difference in the height of the dropping mass did not have any significant impact on the values of λ_{min} and λ_{max}. Also, the increase in mass or diameter of the steel balls yielded higher values of λ_{min} and λ_{max}.

For the different heights of fall of the dropping mass, the values of λ_{min} and λ_{max} were obtained from the dispersion plots and these values are tabulated in Table 1 for a receiver distance of S=0.15m, and in Table 2 for a receiver distance of S=0.30m.

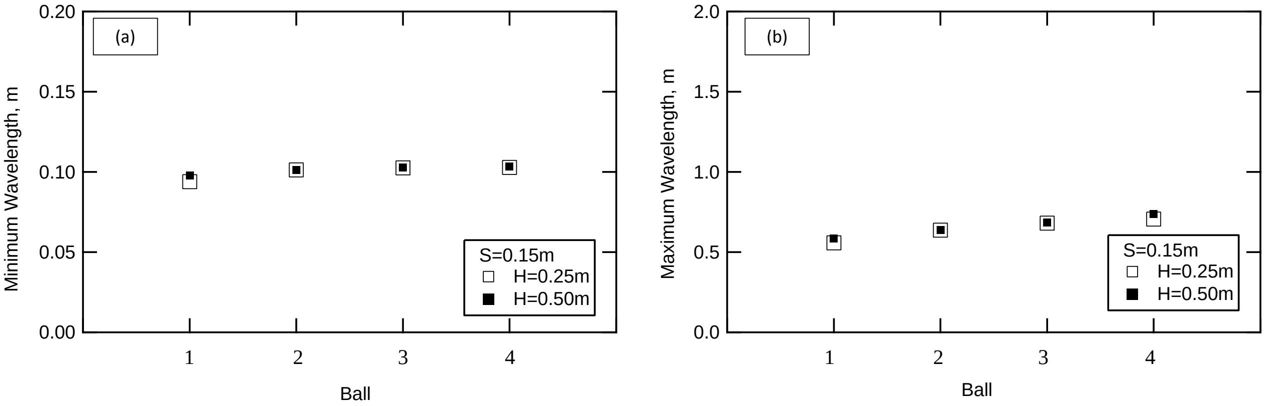


Figure 7 Values of wavelengths obtained from the dispersion plot for a receiver distance of S =0.15m for steel balls with different masses(0.067kg, 0.228kg, 0.537kg, and 1.805kg): (a) Minimum Wavelength, and (b) Maximum Wavelength

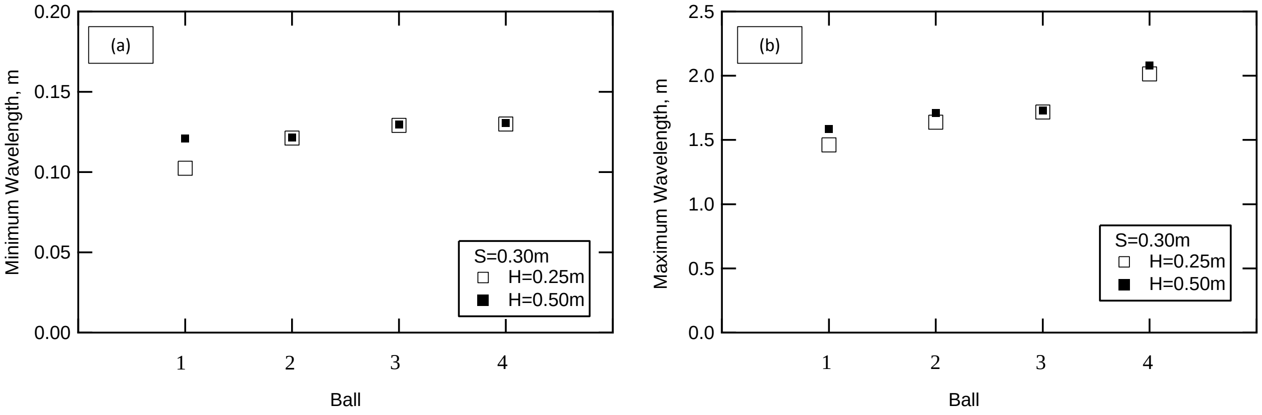


Figure 8 Values of wavelengths obtained from the dispersion plot for a receiver distance of S =0.30m for steel balls with different masses(0.067kg, 0.228kg, 0.537kg, and 1.805kg): (a) Minimum Wavelength, and (b) Maximum Wavelength

Table 1 Comparison of λ_{min} and λ_{max} values for different drop heights of steel balls for a receiver distance of S=0.15m

Ball No	**Ball Diameter (mm)**	**Height of fall, H (m)**			
		0.25		**0.50**	
		λ_{max} (m)	**λ_{min} (m)**	**λ_{max} (m)**	**λ_{min} (m)**
1	25.40	0.5585	0.0939	0.5864	0.0979
2	38.10	0.6371	0.1012	0.6389	0.1013
3	50.80	0.6809	0.1025	0.6856	0.1028
4	76.20	0.7057	0.1029	0.7392	0.1032

Table 2 Comparison of λ_{min} and λ_{max} values for different drop heights of steel balls for a receiver distance of S=0.30m

Ball No	Ball Diameter (mm)	Height of fall, H (m)			
		0.25		0.50	
		λ_{max} (m)	λ_{min} (m)	λ_{max} (m)	λ_{min} (m)
1	25.40	1.4624	0.1024	1.5846	0.1207
2	38.10	1.6389	0.1211	1.7082	0.1215
3	50.80	1.7173	0.1291	1.7297	0.1295
4	76.20	2.0148	0.1300	2.0811	0.1306

As shown in Table 1, the increase in ball diameter (thus the increase in mass) resulted in the increase of minimum and maximum wavelengths. The values of λ_{min} and λ_{max} increased when the height of dropping the mass was increased even though the increase is not significant.

Table 2 shows the variation of the values of λ_{min} and λ_{max} when the configuration of the test was changed and the receiver distance was increase to 0.30m. There was a rapid increase in the value of maximum wavelength when the mass was dropped from a greater height. This observation is convincing because a greater height of fall would lead to a greater magnitude of energy, and this lead to an increase in λ_{max}. It is also worth mentioning that the source/steel balls dropped from a greater height have longer duration and induced more energy. This resulted in the generation of larger wavelength.

5.0 CONCLUSIONS

Based on SASW test done on asphaltic pavement, the following conclusions are drawn:

i. The effect of receiver distance on λ_{min} and λ_{max} was explored. For greater receiver distance (S=0.30m), the values of λ_{max} for all sizes of dropping ball is greater. This means that the phase velocities can be measured at wavelength in deeper region.
ii. The effect of the height of dropping ball on λ_{min} and λ_{max} was also observed. Increasing H from 0.25m to 0.50m resulted in a linear increase in both λ_{min} and λ_{max}, which is reasonable due to the increase in the magnitude of energy. The λ_{max} for the same height but greater receiver distance (S=0.30m) showed a very clear increase in value.
iii. The mass of dropping steel balls (sources) have also been proven to have an impact on λ_{min} and λ_{max}. The dropping ball with larger diameter (thus larger mass) generated longer duration of contact times between the surface of the ball and the surface of the pavement. It therefore generate more low frequency signals which allows the phase velocities to be evaluated in the deeper region. This leads to the increase in values of both λ_{min} and λ_{max}.

This study can be used as a guide for determining the receiver and array configuration in an SASW test on any pavement and at any geological sites as different stiffness of the sites leads to different values of λ_{min} and λ_{max}.

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