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SHALLOW REFLECTION METHOD FOR PAVEMENT THICKNESS MEASUREMENT

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ABSTRACT

The seismic reflection technique utilizes the concept of the reflected wave when the media changes its stiffness. Previous studies utilized this technique for deep subsurface profiling in the oil field exploration. The objective of this study is to assess the seismic reflection technique for measuring the shallow profile of the pavement layer and thus able to identify the layer of asphalt thickness. Via applying the non-destructive seismic reflection technique, an early sign of abnormal pavement can be detected, and thus only minimum points for destructive tests can be suggested. The analysis of reflection waves in the time domain can calculate the thickness of the asphalt pavement layer directly on site. An attempt is made to model concrete slabs with different thicknesses. The result shows the sensors arrangement twice of the thickness able to givea lower error of 0.4 % and 15% of the thickness and p-wave velocity, respectively.

Keywords: Seismic reflection; nondestructive test; asphalt pavement; concrete slab.

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1. INTRODUCTION

Over the years, several engineering fields such as mining, archaeology, and environment engineering use geophysics discipline for investigating sites [1]. Detecting buried utilities, exploration of hydrocarbons, and groundwater are some examples of the use of geophysics. The geophysical testing supplements the conventional testing; it can measure the physical properties of the underground soil alongside its thickness after calibration with geotechnical properties as composition, deformability strength, and moisture content of the tested soil. Therefore, geophysical methods can be utilized as a direct testing method after correlation to reach a high level of interpretation accuracy.

The transportation infrastructures enormously rely on pavements while they play an essential part in its economy; thus, the construction and maintenance of pavement systems are expensive [2]. Due to the empirical nature of the state of the are pavement engineering since its purely based on experiment[3], the use of the financial resources are not optimally used, nevertheless current engineering research move toward and focus on introducing analytical methods based on mathematical calculations for substituting the empirical methods [4]

In the last few years, multiple studies evaluate the capability to detect voids in soils using the P wave seismic reflection method [5-11]. Recent studies show that the seismic reflection technique has excellent potentials in detecting deep or shallow voids. Also, this method is considered as cost-effective when investigating soil conditions, and also it can overcome some of the most important limitations that are faced when using the conventional intrusive testing method such as boreholes and soil probe test [12]. A more explicit traces resolution can be achieved by the seismic reflection method since the relatively soft upper layer does not affect the velocity of the deep hard rocks. Therefore, it can map the geological structure of the subsurface while identifying a more explicit thinner layer in a given site [13]. Giving the fact that this method is non-invasive non-destructive, it can provide high resolutions in the information obtained when used in the lateral dimension. Thus, it is recommended when assessing the inconsistency of geotechnical properties like density and thickness[13].

Special equipment for the seismic reflection method is developed in this study for applying a compressional wave seismic source using a ball bearing. When meeting the different stiffnesses of the two layers, the compressional waves are reflected to the surface. An

experimental field study is performed to investigate the time of the first arrival of the reflected wave in the pavement site. An application based on three constructed concrete slabs was conducted with objectives to mimic the pavement site of measuring the thickness and the seismic velocities of the materials. The conventional hot mix asphalt layer was designed at 0.09 m in-thickness [14]. Three constructed concrete slabs thicknesses were 0.15m, 0.1m, and 0.05m in order to investigate the effect of thickness in the testing procedure. Thus, an implementation of a suggested new method to gather the seismic reflection data for investigating the pavement thickness was applied.

2. METHODOLOGY

The reflections of the p-wave in the time domain are used to directly measure the pavement and the concrete slab thickness without introducing any external calibration or needing the material properties. The seismic reflection method depends on identifying the first arrival of the p wave reflected from the interface of the two mediums back to the surface. Fig. 1 shows a schematic configuration of the equipment used for measurement. While working in the time domain, the compressive waves (p-waves) are focused on due to having the highest propagation velocity. The seismic energy is travelled in a hemispherical form in all directions using a seismic source of ball bearing. The generated seismic wave consists of a composite of compressive wave (p-wave), shear wave (s-wave), and surface wave (R-wave). Its worth to note that the p-wave is the fastest wave velocity than the other two types of waves. The seismic sensors are placed on the surface to record the wave movements through the material.
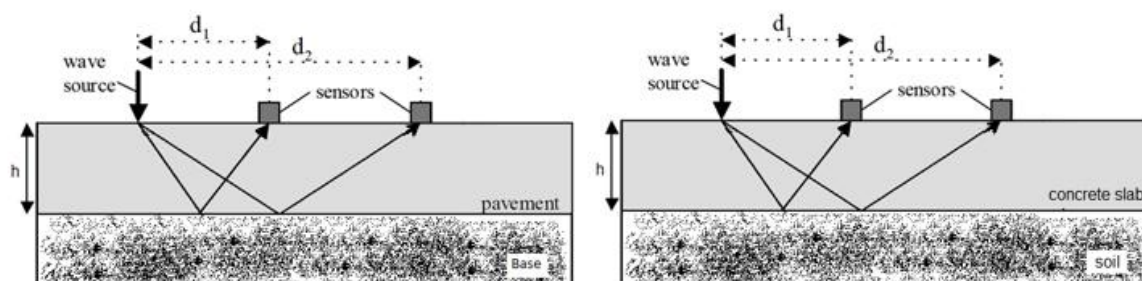

Fig.1. Illustrationof the equipmentsetup

Using the first arrival time of the p-wave and is recorded in a minimum of two sensors at known distance locations. The thickness and the velocity can be calculated when solving the

unknown h and Vp:

$$h = \sqrt{\frac{d2^2 tp1^2 - d1^2 tp2^2}{4tp2^2 - 4tp1^2}} \quad (1)$$

and

$$Vp = \sqrt{\frac{d2^2 - d1^2}{tp2^2 - tp1^2}} \quad (2)$$

Where:

d1 and d2 are the distance between the source and the first and second receiver,

tp1 and tp2 are the arrival time of the P-wave at the first and second receiver,

h is the thickness of the material,

Vp is the velocity of the P-wave of the material.

3. TESTING PROCEDURE

The thickness of the tested pavement is0.9 m, which was obtained via the coring procedure. Meanwhile, the concrete slabs were constructed with three different thicknesses of 0.15, 0.1, and 0.05 m, as shown in Fig 2. In order to suggest the testing procedure for measuring the thickness of the pavement, thus this study was planned to use high-frequency seismic source, and the spacing distance between two sensors is around pavement or concrete slab thickness. Thus the distance between the source and receiver set at 0.1 m, 0.08m, and 0.05m to investigate the optimum source-receiver spacing [10]. Three shot points that gave three readings to average the result. The impact source used of steel ball bearing at a diameter of 5mm and weight 3 gm was released inside a PVC tube of 1 m in length to assure a constant seismic energy. The seismic impact source was given adjacent to the trigger sensor. Thus, receiving seismic energy via trigger sensor and other two sensors able to measure the travelling time of p-wave. All the sensors were connected to the Data acquisition system (DAQ) and displayed by the computer.

Fig.2. (a) preparation of the concrete slab with 0.1m in-depth, (b) pavement coring procedure

The elastic properties and the density of a given material controls its seismic velocity, and these two are related to the strength and the quality of the material. The lab velocity known as the pundit test was solely used to obtain the p-waves velocity of the material by measuring the arrival time of a wave. The test is using ultrasonic seismic wave frequency at 54 MHz. The pundit test is conducted via connecting both ends of the sample towards the sensor, as shown in Fig. 3. Both ends of the sample are required to be smooth surfaces to ensure the sample has good contact between the seismic source and receiver. For this study, the concrete was cast into cube moulds (with 150 x 150 x 150 mm dimension) from each slab, where the internal surfaces were lubricated with oil in prior. The cubes were then left for 24 hours to be hardened. The moulds were dismantled, and the hardened cubes were then submerged into a water-filled tank, and three pavement core samples extracted from the pavement test site to obtain the p-wave velocity presented in Table 01. It worth to note that the typical concrete and pavement velocity in the ranges of 3500 m/s to 4500 m/s [15].

Table 1. results of the ultrasonic seismic wave (Pundit test)

Tested sample	diameter (cm)	P-wave velocity (m/s)			average p-wave (m/s)
pavement core	9	3121	3297	3493	3304
concrete cube	5	3099	3251	3550	3300
	10	3470	3209	3210	3296
	15	3367	3312	3230	3301

The results from the Pundit test show an aviary p-wave velocity of 3300 m/s for all the

samples.

Fig.3. P-wave velocity measurement using the Pundit test.

4. RESULT AND DISCUSSION

The captured waves by the sensors were processed using MATLAB software. Fig. 4 shows an example of a recorded seismic wave on the pavement. Meanwhile, Fig. 5 shows the seismic wave recorded by the sensors on the concrete slab tested at 5 cm thickness. The seismic wave signals were presented in the time-domain. The difference in acoustic impedance between pavement or concrete and the soil base layer.
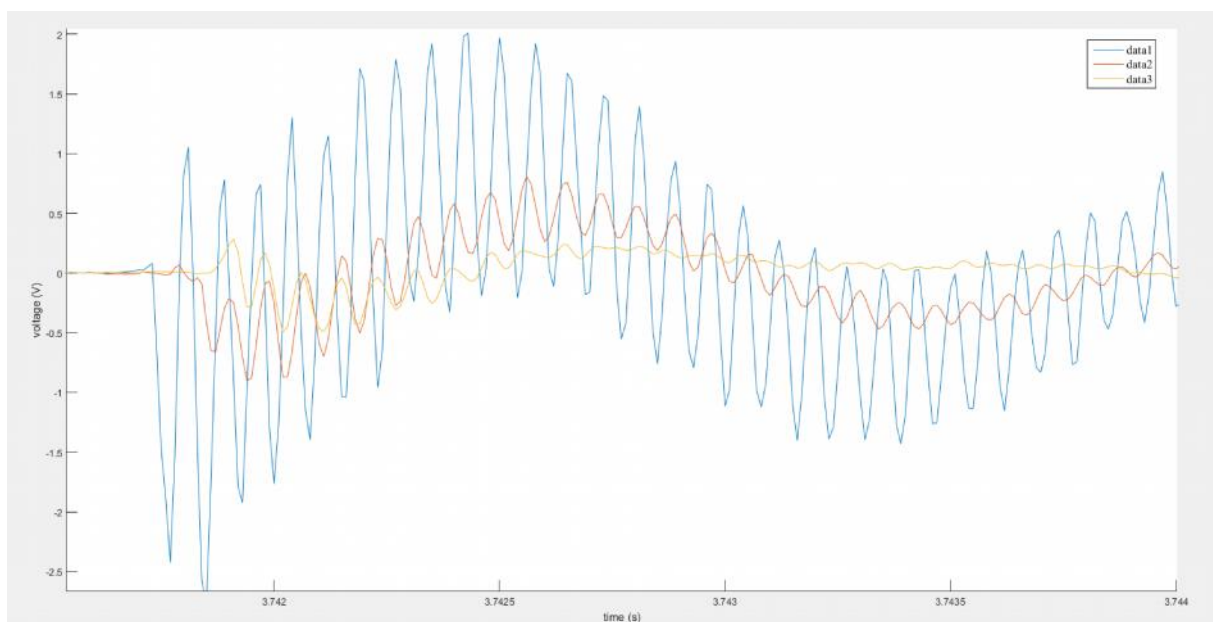

Fig.4. voltage amplitude versus time recording of the p-wave on pavement; first arrival

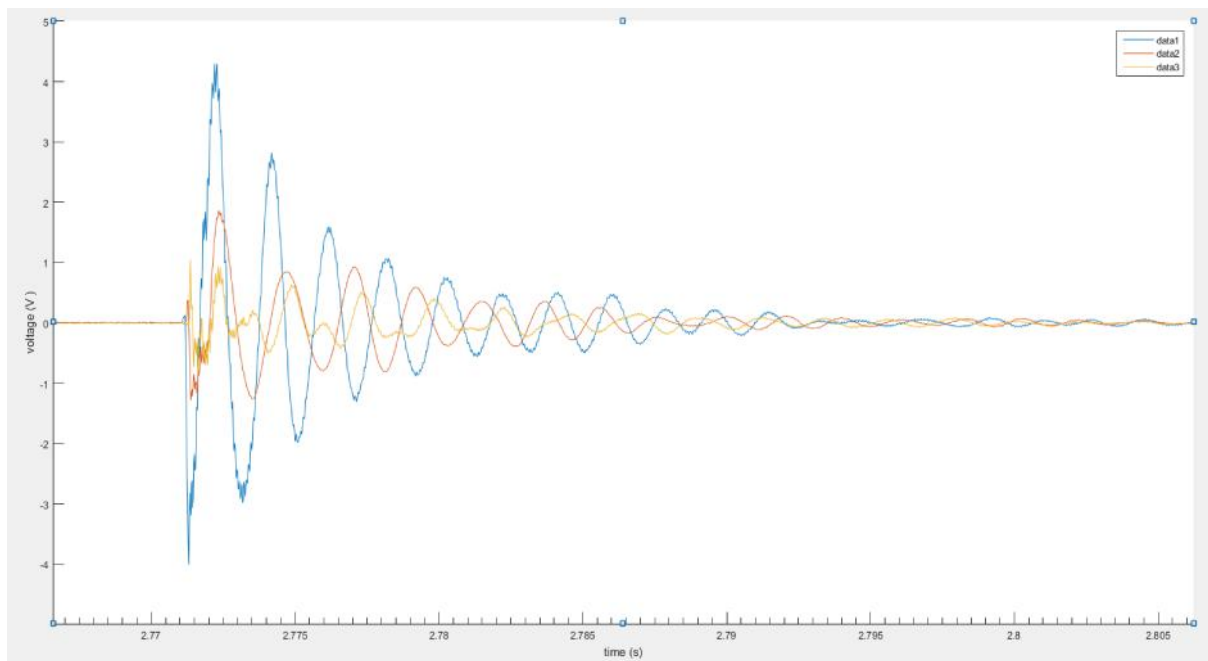detected at 0.09 ms for the first receiver and 0.11 ms for the second receiver.

Fig.5. voltage amplitude versus time recording of the p-wave on 5 cm concrete slab; the first arrival was detected at 0.08 ms for the first receiver and 0.12 ms for the second receiver

The time difference between the trigger sensor (labelled "data1") and the first receiver sensor (labelled "data 2") known as tp1, meanwhile, tp2 is the time difference between the trigger sensor and the second sensor (labelled "data3"). The time tp1 and tp2 are measured from the plot of voltage versus time using the MATLAB platform. Equation 1 and equation 2 is used to calculate the thickness of pavement and concrete slab, as presented in Table 1:

Table 1. results of the seismic reflection test on pavement and concrete

Testing no.	Tested structure	Pavement	Concrete slab		
	Actual thickness (cm)	9	5	10	15
1st test	d1 (cm)	5	10	8	10
	d2 (cm)	10	20	16	20
	t0 (s)	1.30212	2.77106	3.69982	1.68552
	t1 (s)	1.30219	2.77114	3.69989	1.68578
	t2 (s)	1.3022	2.77118	3.69991	1.6858

	tp1 (ms)	0.07	0.08	0.07	0.26
	tp2 (ms)	0.08	0.12	0.09	0.28
	h (cm)	7.42	5.92	7.58	21.08
	Vp (m/s)	2236	1936	2449	1667
2nd test	d1 (cm)	5	10	10	10
	d2 (cm)	10	20	20	20
	t0 (s)	2.608138	2.90894	1.278	1.62066
	t1 (s)	2.608228	2.90898	1.2781	1.62078
	t2 (s)	2.6082355	2.90900	1.27813	1.62080
	tp1 (ms)	0.09	0.04	0.1	0.12
	tp2 (ms)	0.0975	0.06	0.13	0.14
	h (cm)	10.09	5.92	9.15	13.52
	Vp (m/s)	2309	3873	2085	2402.
3rd test	d1 (cm)	5	10	10	10
	d2 (cm)	10	20	20	20
	t0 (s)	3.48665	2.6182	1.3371	2.5503
	t1 (s)	3.48672	2.618245	1.33719	2.5504
	t2 (s)	3.48673	2.61828	1.33722	2.55041
	tp1 (ms)	0.07	0.045	0.09	0.1
	tp2 (ms)	0.08	0.08	0.12	0.11
	h (cm)	7.42	3.12	8.45	18.22
	Vp (m/s)	2236	2619	2182	3780
Average	h (cm)	8.31	4.98	8.39	17.61
	Vp (m/s)	2261	2809	2239	2616
Error	h (%)	8	0.4	16	17
	Vp (%)	31	15	32	21

Table 1 summarizes the measurements from the seismic reflation technique where the calculated thickness of the pavement is 8.31 cm while the actual thickness is 9 cm with an

error of 8% and the seismic velocity is 2260 m/s where the actual velocity is 3300 m/s obtained from the pundit test applied on a sample cored on the same location where the seismic reflection test was conducted with an error of 31%. In the case of the concrete slabs; an average thickness of 4.98 cm and 2809m/s in velocity was obtained on the 5 cm slab, an average thickness of 8.39 cm and 2239m/s in velocity was obtained on the 10 cm slab, and an average thickness of 17.61 cm and 2616m/s in velocity was obtained on the 15 cm slab. The result indicates that the best sensors arrangement when the spacing of the sensors is at the twice of the measured slab thickness. The results of thickness and p-wave velocity show the lowest error compared with the others arrangement of 0.4% and 15% respectively.

5. CONCLUSION

This technique has proved to be a useful tool for pavement investigations as well as a seismic velocity measurement with a relatively low error. This study gives a significant value to overcome the destructive methods used in pavement testing, such as to determine the pavement thickness and stiffness. The results obtained from the concrete slab show the high potentials of seismic reflection to be used in different situations. The estimation of depth and velocity can be achieved more accurately by changing the seismic source and the equipment setup. A full automated data processing technique is suggested using this approach for further research.

6. ACKNOWLEDGEMENTS

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