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To cite this article: Norfarah Nadia Ismail *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **512** 012056

IOP Conf. Series: Materials Science and Engineering **512** (2019) 012056 doi:10.1088/1757-899X/512/1/012056

The application of CAP-SASW method in determination of sub-surface profile of flexible taxiway in the airport

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Abstract. In Malaysia, evaluating and assessing pavement condition always require destructive method such as field-cured cylinders and drilled cores from pavement. Not only these current practices are expensive and labor intensive, they are also may not represent in-place quality of pavement due to the in-situ conditions and site irregularities. In terms of the performance of the flexible pavement, the modulus and thickness of each layer in the pavement are the primary factors that associate with it. In-situ determination of these parameters is crucial, and non-destructive seismic method successfully alleviates the dependency on the destructive method. Utilizing Rayleigh wave propagation as its core element, the technology has proven its ability to obtain important parameters in pavement assessment and delineate the subsurface profile accurately. In this study, a non-destructive seismic method called Common Array Profiling Spectral Analysis of Surface Wave (CAP-SASW) was employed on flexible taxiway at Malaysia airport, as in a new, different configuration compared to the conventional SASW method. This method produces stiffness profile of the flexible pavement at airport taxiway. The inversion procedure is performed to obtain their thickness profile and results were compared with the existing methods such as Heavy Weight Deflectometer (HWD), Ground Penetrating Radar (GPR), Dynamic Cone penetrometer (DCP) and coring data. The pavement moduli are obtained with benefit from equation of Yoder and Witzack, and as for this surface wave technique, the moduli obtained are the small strain modulus. The value of elastic modulus obtained for every layer is also being compared to the modulus obtained from HWD method, which shows good comparison.

1. Introduction

In the management of airport taxiway and runway, the methods or techniques used to measure the pavement condition is very crucial as it will be used to evaluate and monitor the condition of the pavement. Currently the tests used to measure the conditions of the pavements in Malaysian airports are Heavy Weight Deflectometer (HWD), Ground Penetrating Radar (GPR), Single Laser Profile (SLP), coring and Dynamic Cone Penetrometer (DCP).

Nowadays, airports are considered essential in transporting goods and persons, and have been the backbone of economic activities since decades ago. The increasing demand of for air transportation requires greater attention to be given to the overall and continuous assessment of the conditions of runways and taxiways pavement [1,2]. Heavy use of these runways and taxiways has had an impact on the pavement structures, which are either approaching or have exhausted their design life. In view of the deteriorating state of the pavements, airfield management agencies have gradually shifted their emphasis from construction of new pavements to maintenance and rehabilitation (M & R) of existing runways and taxiways [3].

Limited budget is one of the problems in M & R of existing runways and taxiways as monitoring the quality of pavement may take up too much cost, time, and workforce. But some of these limitations might be overcome by adapting geophysical method (such as surface wave method) in civil engineering. These methods are non-destructive and can provide thorough profiling of the subsurface material.

The subsurface profiling was done to evaluate strength and stiffness of the subsurface materials to carry structural load or traffic load. The profiling is also important in the process of quality control, maintenance and rehabilitation so that any distress or failure could be detected at the early stage. The nature of the subsurface materials which varies in terms of characteristics, may make it difficult to obtain the exact parameter value from a test, unless a thorough sampling system is done [4]. However, a thorough sampling system, for example, more drilling hole, will contribute to the increase of cost, time, and workforce.

One of the most important parameters needed for the design of pavement layer system is the shear modulus of the material, which also known as stiffness parameter. Both in-situ measurement and lab measurement could be used to obtain this parameter; however, in-situ measurement give more advantage compare to the later method due to the undisturbed sample material.

The Common Array Profiling of Spectral Analysis of Surface Waves (CAP-SASW), was introduced by Joh et al. [5] and has the advantage in terms of the filtering criteria, to minimize the near-field effect. The measurement technique using CAP-SASW arrangement has been upgraded and allows stiffness evaluation of subsurface being done not only for the whole measurement array, but also at specific subsurface area.

2. Layered System of Airport Taxiway Pavement Design

As for Kuala Lumpur International Airport (KLIA) Sepang, three layers of cement treated base (CTB), each has the thickness of 0.15m were designed and built during the construction. This kind of design may allow crack to happen. To avoid it from happening, the airport pavement was designed and built with another additional layer, called crack relief layer (CRL), with a thickness of 0.10m [6]. The configuration of the layered system is shown in figure 1.

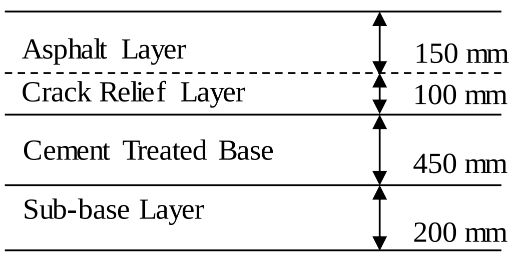

Figure 1. Schematic shows the thickness of pavement design in Kuala Lumpur International Airport.

The asphalt layer in the layered pavement system in Kuala Lumpur International Airport is using polymer modified bitumen as the design material [7]. According to Arahan Teknik Jalan, ATJ 5/85 [8], in the section of Manual of Design of Flexible Pavement, the modulus value of asphalt layer (wearing and binder course) can varies from few hundreds MPa to 3000 MPa. Crack relief layer has lower modulus value compared to typical asphalt mixture, which is around 1380 MPa [9], while cement treated base has the modulus value located in the range of 800 – 3000 MPa [10].

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3. Methodology

This paper presents research and data collected at Taxiway B, Kuala Lumpur International Airport (KLIA) Sepang. Measurements were done utilizing CAP-SASW method. Generally, CAP-SASW method consists of three main phases: 1) Experimental data collection, 2) Determination of dispersion curve from the experiment and 3) Inversion process to the dispersion curve to obtain subsurface profile. Typical configuration for CAP-SASW method is by using 2~4 numbers of receivers (sensors) in an array, with a seismic (instrumented) hammer, or impact source acting at the end of the array. Same receiver distance is employed as standard practice during the measurement. An adequate wavelength range is needed to sample the material in the layered pavement system. The configuration for CAP-SASW measurement is shown in figure 2.

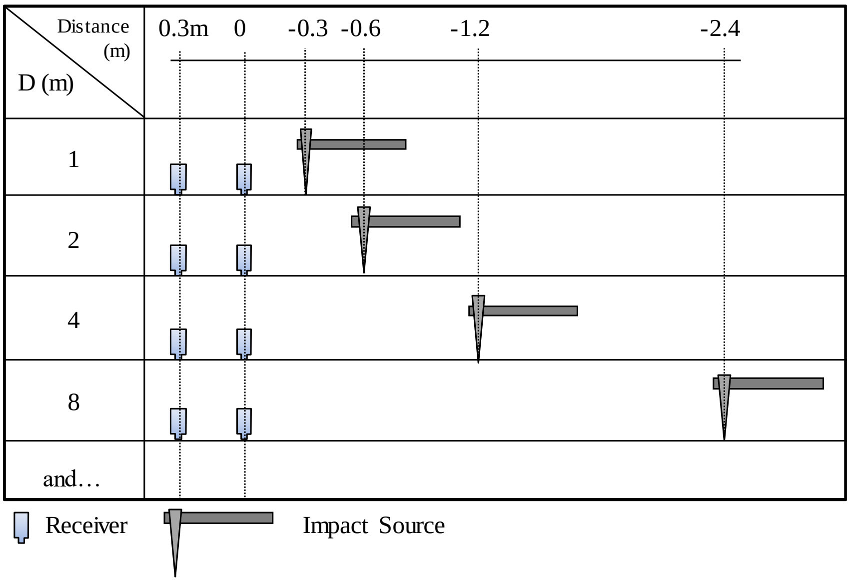

Figure. 2. Configuration of CAP-SASW field measurement.

During field measurement, this research utilizes a dedicated hardware probe called Pavement Integrity Scanner (PiScanner). PiScanner consists of a portable outdoor laptop with customized compact analyzer (POLCCA), and a PiScan probe itself. The PiScan probe is equipped with two receivers (accelerometers), located 0.30m apart and weight to ensure good coupling between the accelerometers and pavement surface. The instrumented hammer is connected to POLCCA so that the impact signal could be recorded. PiScanner is shown in figure 3.

To sample a pavement system with certain depth and evaluation of the stiffness profile, two essential methodologies should be implemented. They are forward modelling process and inversion process. The iteration process for forward modelling is a try-and-error procedure. Based on an initial assumption, a theoretical dispersion curve is computed and then being compared to the experimental dispersion curve. In this analysis, the layer characteristics such as shear wave velocity, layer thickness, Poisson's ratio and density should be assigned. This research is utilizing stiffness matrix method in the forward modelling process. It is better in a way that it creates dispersion curve in superposed mode, in between normal modes and body wave, in which the simulation is more realistic for experimental dispersion curve obtained from field measurement [11].

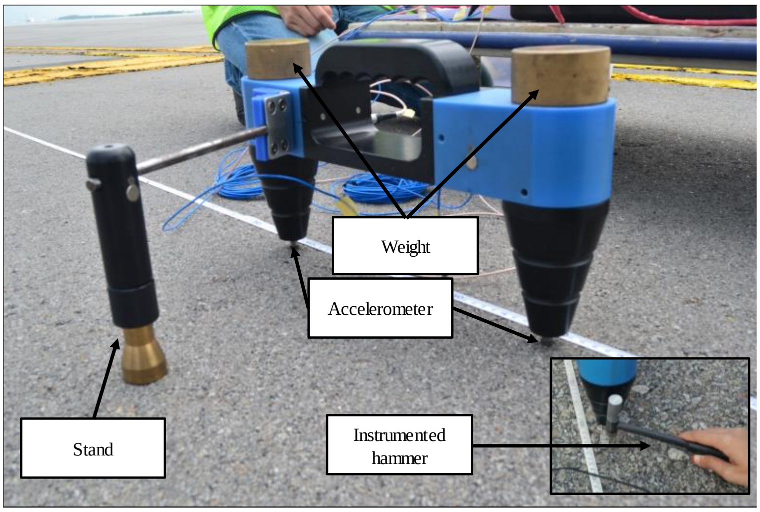

Figure. 3. PiScan probe with weight.

The inversion process on the other hand is the main procedure in characterizing subsurface model from the collected data. It is one of the important parts in using CAP-SASW method in determining the shear wave velocity profile. Simply stated, seismic inversion is a process to determine physical characteristic of rocks or fluids which may be generated from the seismic record that has been obtained. Inversion is the backside of the forward modelling process. The principles of forward modelling and inversion process are illustrated in figure 4.

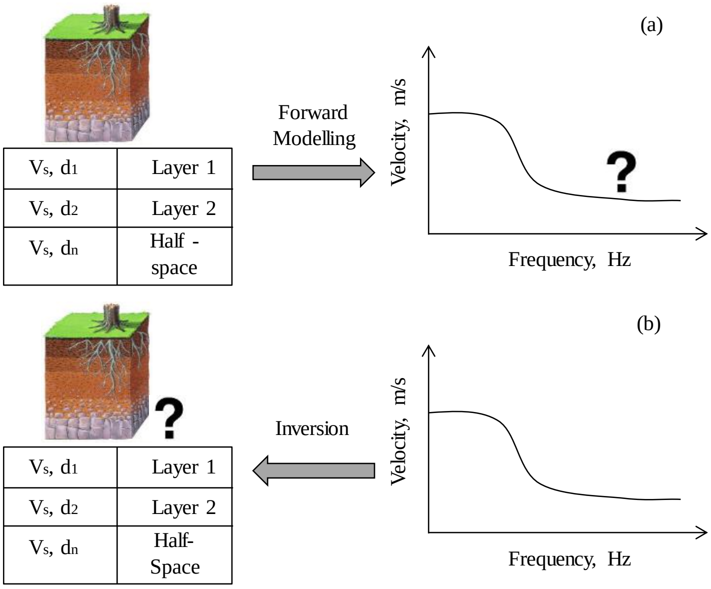

Figure. 4. Principles of: (a) forward modelling process and (b) inversion process.

4. Result and Discussion

The result of this study is presented with comparison to other available methods. This paper presented the outcome of experiment which was done on taxiway B at KLIA Sepang. Taxiway B is located near to the taxiway A, in which both taxiways are connected through series of shorter taxiways. Field measurement using CAP-SASW method has been done to obtain the characteristic of subsurface material, in terms of layer thickness, stiffness (which is represented by the shear wave velocity value), and strength of the layer, which is represented by modulus parameter.

By utilizing CAP-SASW method, there were three measured segments being analyzed. figure 5 shows the outcome of shear wave velocity dispersion curve, plotted against wavelength for all three measured segments. The profiles of pavement layer were also developed and shown in figure 6. These profiles show the stiffness and strength variation of the subsurface materials with depth. figure 5 shows stiffness and strength profile for segment 3 only because this segment is chosen to represent segment 1 and 2 in giving the thickness and modulus of taxiway B.

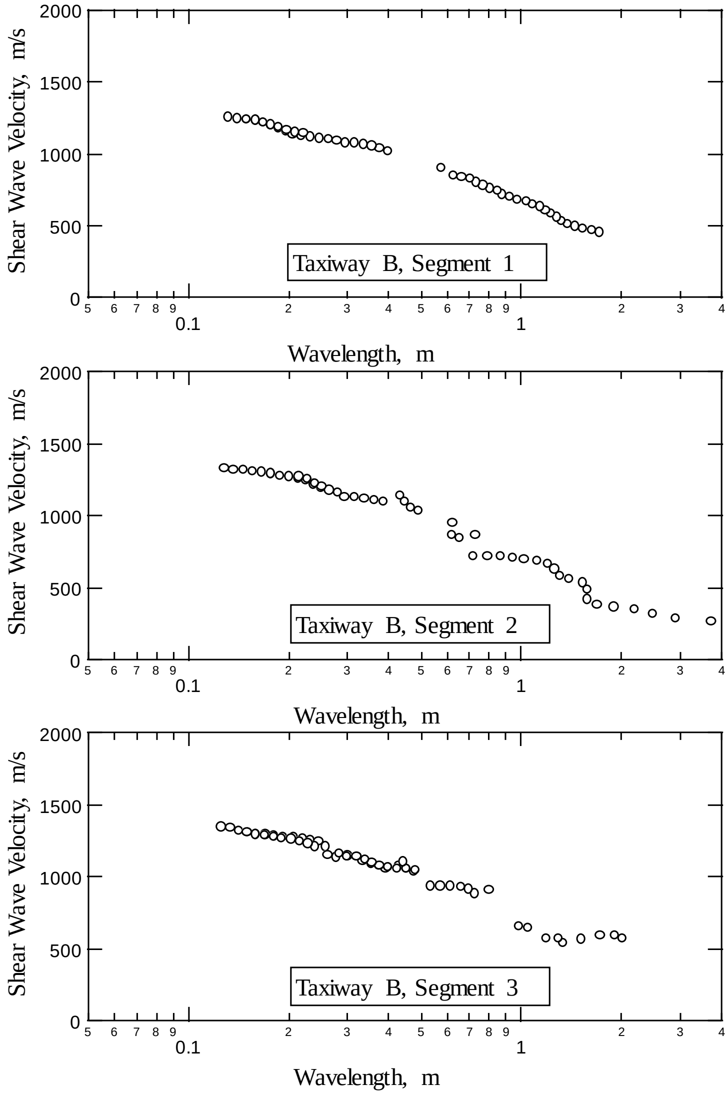

Figure. 5. Shear wave velocity dispersion curve plotted for Taxiway B.

Looking from the general trend of the shear wave velocity dispersion curve (figure 5) and profiles of the pavement structure (figure 6), they are in good terms and reasonable. In terms of value of variation of stiffness and strength with depth, they are also in good and reliable manner. Based on the profiles, it is found that the total depth of asphalt layer and crack relief layer for taxiway B is 0.20m. Based on this CAP-SASW method, the modulus obtained for asphalt layer, crack relief layer and cement treated base for taxiway B are 700 MPa, 950 MPA, and 400 MPa accordingly. These results are reliable up to the depth of 1.0 m.

The output from this study is then used to construct two-dimensional shear wave velocity profile (2-D contour plot). This 2-D contour plot shows shear wave velocity (which represent the material stiffness) variation with depth along the measurement location, 0.30m. The 2-D contour plot for taxiway B is shown in figure 7. The thicker contour line is the boundary between top layer (asphalt layer and crack relief layer) and base layer. The scale on its side shows the value of shear wave velocity which was plotted in this 2-D profile. The higher shear wave velocity represents higher material stiffness.

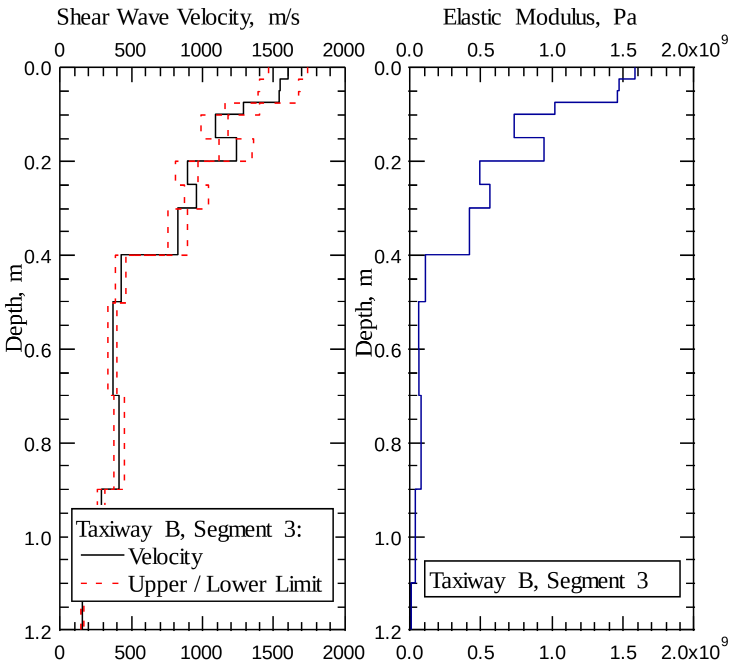

Figure. 6. Stiffness profile and strength profile of subsurface material for taxiway B using CAP- SASW method.

The information synthesized from CAP-SASW method for pavement layer of taxiway B are then being compared to the available information obtained from other measurement methods, as shown in Table 1.

Table 1. Information of pavement layer for Taxiway B.

Method	Thickness (m)			Modulus (MPa)		
	Asphalt	Crack Relief Layer	Cement Treated Base	Asphalt	Crack Relief Layer	Cement Treated Base
CAP-SASW	0.100	0.100	0.300	700	950	400
HWD	0.250	-	0.450	699	6266	259
DCP & Coring	0.140	0.095	0.420	-	-	-
GPR	0.150	0.120	0.451	-	-	-

In the design process of rehabilitation of taxiways at KLIA, asphalt layer and crack relief layer are combined together becoming a top layer with thickness of 0.25m. Seen from Table 1 also, there is no value available for crack relief layer for HWD method. This happened because Taxiway B had undergone rehabilitation process. Extending the research, we found out from Khong (2013) that the thickness of pavement layer obtained from HWD is the design layer thickness, therefore the actual value could not be trusted. It is better to compare the thickness of the layers obtained from DCP & coring with the one obtained from CAP-SASW.

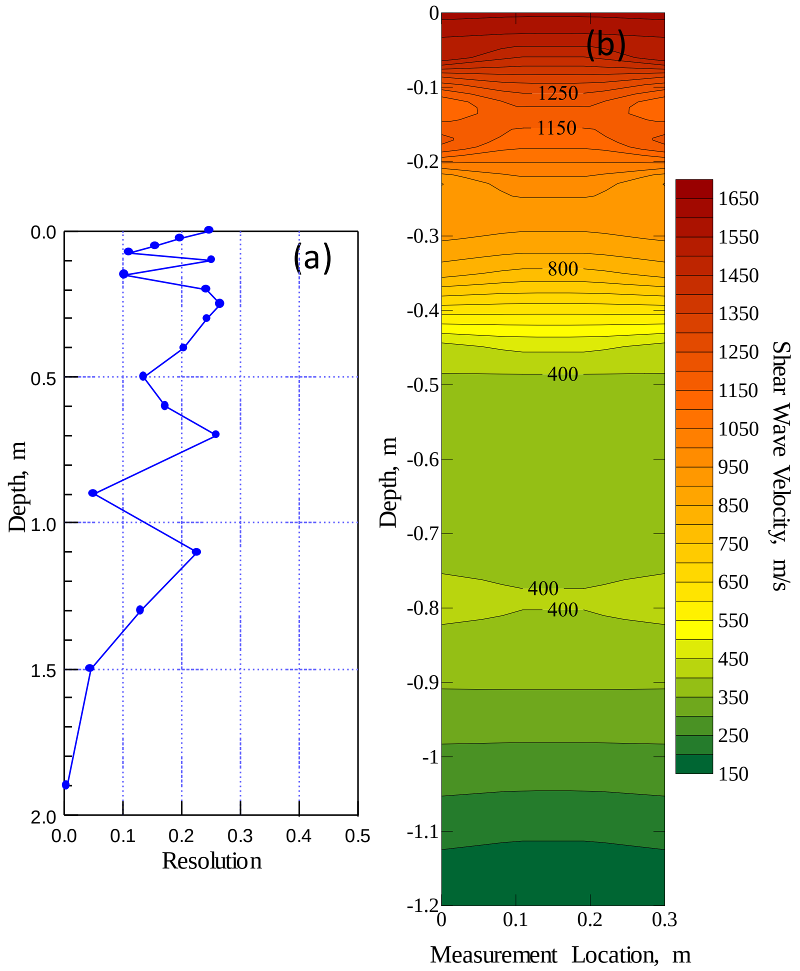

Figure. 7. (a) Parameter model resolution for Segment 3 Taxiway B and (b) 2-D contour plot for Taxiway B.

In terms of strength of the material, the value of asphalt modulus obtained from CAP-SASW method is differ by only 0.1% from the modulus value obtained from HWD method. Therefore, this output is believed to be reasonable and trusted. The modulus value obtained from HWD method for crack relief layer is unfortunately too high and above the assumed value. Hence for crack relief layer, the modulus obtained from CAP-SASW, which is 950 MPa is more trusted. For cement treated base, there is 35% discrepancy in terms of the strength of the materials. Due to the dispute of the layer thickness obtained by HWD method, therefore the modulus obtained from its back-calculation can be doubted and this gives more advantage to CAP-SASW method to provide a more trusted value of modulus.

5. Conclusions

The measurement that has been done on the airport taxiway gave the significant engineering parameters that would be very useful for quality control, maintenance and rehabilitation. The parameters obtained are stiffness which represented by the shear wave velocity, strength of the materials for each layer, represented by the modulus value and lastly is the thickness of each layer. The outcome presented in 2-D contour plot also shows that the thickness values obtained are reliably trusted (0.20m). As for modulus, the CAP-SASW method gives modulus value of 950 MPa, quite in the range of which has been outlined by ATJ 5/85 (2013), which is few hundreds to 3000 MPa.

6. References

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Acknowledgement

The authors would like to thank the Department of Civil & Structural Engineering, Universiti Kebangsaan Malaysia and the Department of Civil Engineering of International Islamic University Malaysia for the financial support and equipment assistance received during conducting this research.