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GROUND PENETRATING RADAR'S (GPR) IMAGING AND APPLICATIONS TO PAVEMENT STRUCTURAL ASSESSMENT: A CASE OF MALAYSIA

Nurul Hidayah Muslim[1], Mohamad Ibrahim Mohamed[2], Zulkarnaini Mat Amin[3], Arezou Shafaghat[4], Mohammad Ismail[5], Ali Keyvanfar[6]

[1,2,5] Universiti Teknologi Malaysia, Faculty of Civil Engineering, Johor, Malaysia
[3] Universiti Teknologi Malaysia, Faculty of Science and Geomatic Engineering, Johor, Malaysia
[4,6] Universiti Teknologi Malaysia, Center of Built Environment in the Malays World (KALAM) and Institute Sultan Iskandar (ISI), Faculty of Built Environment, Skudai, Johor, Malaysia
[4,6] Iran University of Science and Technology (IUST), The School of Architecture and Environmental Design, Narmak Street, Tehran, Iran
[6] Universidad Tecnológica Equinoccial, Facultad de Arquitectura y Urbanismo, Calle Rumipamba s/n y Bourgeois, Quito, Ecuador

[4]e-mail: arezou@utm.my
[6]e-mail: akeyvanfar@utm.my

Abstract: *Traditionally, pavement distress evaluations were carried out by visual observation. Traditional practice requires a person to walk along the stretch of the pavement to conduct distress survey, take photo and measure defects occurred at deteriorated surfaces. However, this approach is too subjective, generates inconsistencies of information, less reliable and time-consuming. Due to these shortcomings, the transportation practitioners in pavement maintenance seek for other alternative tools and techniques to arrest incapability of traditional practices. One of the tools available in the market is Ground Penetrating Radar (GPR). GPR is a geophysical tool known by ability to accommodate extensive data in pavement assessment, geotechnical investigation and structural assessment. The application of GPR is such new to most of road maintenance industry in Malaysia. Therefore, this study has been undertaken to evaluate the benefits of using GPR imaging and its application in assessing pavement structures in Malaysia. The GPR survey was conducted in Meranti street located at UTM (Universiti Teknologi Malaysia) campus, and then analyzed using REFLEX 2D simulation software. The finding shows there are three (3) types of information obtained from GPR survey included; identification of raw image and processed image, identification of pavement segments thickness, and identification of GPR response towards surface and subsurface conditions, which illustrated in radargram images. Furthermore, the GPR can perform at high speed and can save time. It is also beneficial for long-term investment due to ability to provide extensive information at a greater depth. The research indicates that interpretation of GPR's radargram images consumes time due to the low resolution. Therefore, selection of GPR system is subject to level of accuracy and clarity of radar images needed in a project.*

Key words: *Pavement, Geophysical tools, Ground Penetrating Radar (GPR), REFLEX 2D software.*

1. Introduction

There are numerous technical definitions of good street pavement by which the utmost comfort level for users to commute without hassle is essential (Lamit et al., 2013; Shafaghat et al., 2016a; Shafaghat et al., 2016b). The pavement upkeep issues became crucial in order to serve public satisfaction which later demands for better and effective pavement distress management. The increasing shift in resource allocation from new pavement construction to pavement rehabilitation highlights the importance of accurate and comprehensive assessment of deteriorating pavements (Colagrande et al., 2011). Traditionally, pavement distress survey has been conducted through human observation, interpretation and effort manually. A person had to walk along a pavement to conduct pavement distress survey,

take photo and measurements of defects occurred at deteriorate surface within the pavement stretch.
In fact, visual survey is a common method conducted by most of transportation engineers; however it leads to significant drawbacks such as; labour intensive and expensive, subjective approach generating inconsistencies and inaccuracies in the determination of pavement condition, inflexible and does not provide an absolute measure of the surface, and long procedure. It has poor repeatability since the assessment of given pavement section may be differ from one survey to the next, and could expose a serious safety hazard to the surveyors due to high speed and high volume traffic (Wang et al., 2016). There are various approaches introduced to arrest above shortcomings. The advancement in technology has applied the geophysical tools into pavement distress evaluation which proven as non-destructive test (NDT) method with extensive amount of data to be obtained and assists remedial works. A variety of remote sensing, surface geophysical, borehole geophysical and other non-destructive methods can be used to determine conditions of bridges and roads (Benson, 2000).

2. Problem statement

There are three (3) identified problems that are vital to initiate this study which are; the current situation of pavement evaluation management, demand of non-destructive methods for pavement distress evaluation and the effectiveness of integrating geophysical tools in pavement distress evaluation. There are numerous types of defects could be found on the pavement such as fatigue cracks, potholes, shoving, depression, rutting and so forth. Above all, fatigue cracks and potholes are the two most popular types of defects can be found on most of the pavement in Malaysia. Several major roads like Jalan Tun Razak, Jalan Pahang heading to Jalan Danau Kota, Jalan Ulu Kelang, Jalan Sultan Ismail, Jalan Taman Desa, along Jalan Ampang and others appear to have potholes, thus, posing serious risks to commuters. Potholes and cracks appear on the road due to surface fatigue. The problem is exacerbated by high traffic volumes and heavy wheel loads (BERNAMA, 2012; Grzyb et al., 2013). Thus, many companies engaged for pavement maintenance are putting their best efforts in managing pavement distress.

Initially, destructive test is preferred for pavement evaluation; however this method has no longer became important as people start to concern on environmental protection, cost and time consumption. That is why, geophysical tools are integrated and optimized in pavement distress evaluation. Most of the countries like; United States, Japan, Australia, and China had integrated geophysical tools into pavement evaluation and currently, India is moving on the same line. The application of Ground Penetrating Radar (GPR) for pavement evaluation is relatively new concept in India due to lack of technical expertise and limitation of financial front (Bala and Jain, 2012). The purpose of tools integration is to promote a non-destructive ways for pavement distress survey process which at the same time provide extensive information that will be useful to assist in decision making and other managerial aspects. The importance of non-destructive test (NDT) for pavement engineering is evident if we consider actual poor condition of road in many countries and the limited financial resources that government plan to spend for maintenance (Benedetto and Blasiis, 2010). In this regards, the current study aimed to evaluate NDT tools, specifically, Ground Penetrating Radar (GPR) in assessing pavement structures because of its effectiveness in cost, time and perseverance of pavement in Malaysia transportation engineering.

3. Pavement structure and types of pavement distress

Pavement structural layers consists of six (6) most common layers which represents different structural capacity, thickness, proportions of materials, CBR values and etc. Pavement is made of bituminous wearing course, bituminous binder course, dense bituminous course, crush aggregate, sub base and sub grade. A flexible pavement structure typically consists of layers of different materials that increase with strength as you move towards the surface (MDOT, 2007) (Figure 1). In other words, pavement structures are divided into surface course, base course, sub base course and sub grade. Surface course is the top layer that comes in contact with traffic. The surface course is the layer in contact with traffic loads and normally contains the highest quality materials (Hausman and Buttlar, 2002). It provides characteristics such as friction, smoothness, noise control, rut and shoving resistance and drainage. In addition, it serves to prevent the entrance of excessive quantities of surface water into the underlying base, sub base and sub grade (NAPA, 2008). While base course, located below the surface course which consists of stabilized or non stabilized crush aggregate and followed by sub base course and sub grade.

Assessing pavement condition starts with collection of distress data (Maintenance Technical Advisory Guides (MTAG), 2003). Collecting distress data consists of type of distress, quantity of distress and level of severity. Distress data collected can tell what type of damage we dealt with. There are various types of pavement distress can be found along the pavement and separate into distinctive groups. Table 1 presents the major distress categories, types and brief definitions.

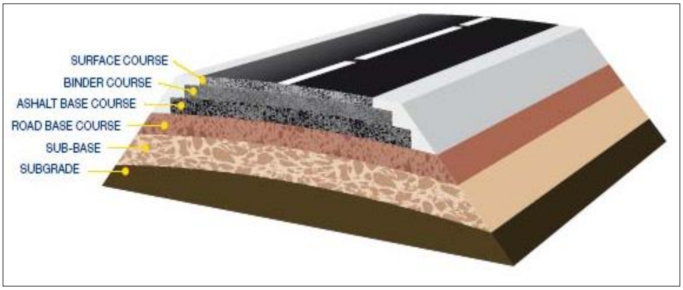

Fig. 1. Typical pavement layers
Source: MDOT (2006).

Table 1. Common distresses on flexible pavement

Categories	Distress Types	Definitions
Crack	Fatigue	Cracks in asphalt layers that are caused by repeated traffic loadings.
	Longitudinal	Cracks that are approximately parallel to pavement centre line.
	Transverse	Cracks that are predominately perpendicular to pavement centre line.
	Reflective	Cracks in HMA overlay surfaces that occur over joints in concrete or over cracks.
	Block	Pattern of cracks that divides the pavement into approximately rectangular pieces.
	Edge	Crescent-shaped cracks or fairly continuous cracks that intersect the pavement edge and are located within 2 feet of the pavement edge, adjacent to the unpaved shoulder
Deformation	Rutting	Longitudinal surface depression that develops in the wheel paths of flexible pavement under traffic.
	Corrugation	Transverse undulations appear at regular intervals due to the unstable surface course caused by stop-and-go traffic.
	Shoving	A longitudinal displacement of a localized area of the pavement surface.
	Depression	Small, localized surface settlement.
	Overlay bumps	Cracks in old pavements were recently filled.
Deterioration	Potholes	Bowl-shaped holes of various sizes in the pavement surface.
	Ravelling	Wearing away of the pavement surface in high-quality hot mix asphalt concrete that may be caused by the dislodging of aggregate particles and loss of asphalt binder.
	Stripping	The loss of the adhesive bond between asphalt cement and aggregate, most often caused by the presence of water.
	Polished Agregate	Surface binder worn away to expose coarse aggregate.
	Pumping	Seeping or ejection of water and fines from beneath the pavement through cracks.
Mat problem	Segregation	Separation of coarse aggregate from fine aggregate.
	Bleeding	Excess bituminous binder occurring on the pavement surface.
Seal Coats	Rock loss	Wearing away of the pavement surface in seal coats.
	Segregation	Separation of coarse aggregate from fine aggregate.
	Bleeding	Excess binder occurring on the surface treated pavements.
	Delamination	Clear separation of the pavement surface from the layer below.

4. Ground Penetrating Radar (GPR) and its application in pavement distress evaluation

The implementation of geophysical methods for pavement, structures, and geotechnical assessments has started few decades ago in most developed countries. Since early 1970's the electromagnetic wave (EM) as geophysical test methods has been use for detection of land mines, evaluation of tunnels, bridge decks, and geological investigation (MDOT, 2006). In early 1980's several commercial Ground Penetrating Radar (GPR) devices were introduced with claims to detect voids beneath pavement and to measure thickness profiles; these are Penetradar, Donohue Remote Sensing, and Gulf Applied Radar Van. Geophysical tools can be used in assessing any structures like bridge, building, pavement, utilities, underground condition, and etc.

A variety of remote sensing, surface geophysical, borehole geophysical and other non-destructive methods can be used to determine conditions of bridges and roads (Benson, 2000; Keyvanfar et al., 2014; Muhammad et al., 2015; Shafaghat et al., 2016c). Geophysical tools provide information about physical properties of the subsurface and are routinely applied to mining related problem of a geotechnical nature (Anderson and Ismail, 2003). Geophysical tools can retrieve information from bottom structural layer without altering or disturbing the soil condition. Traditional investigation methods, such as boreholes and test pits, provide information about the conditions in the immediate vicinity around them. They also can be costly, due to the large amount of testing required to properly characterize a large or complex site using these traditional methods alone.

Ground Penetrating Radar (GPR) is a tool that works on the basic of electromagnetic wave principle. GPR is a non-destructive technique that has been widely used in the world over than 30 years. GPR technique uses discrete pulses of energy with a central frequency varying from 10MHz to 2.5GHz to resolve the locations and dimensions of electrically distinctive layers and objects in materials (Saarenketo, 2006). GPR is a high-resolution electromagnetic technique that is designed primarily to investigate the shallow subsurface of the earth, building materials, roads, and bridges (Saarenketo, 2006). The operation of GPR based on electromagnetic pulses that transmitted into different medium of dielectric properties. So, whenever GPR detects transition of different medium or structural layers the pulses will rebound to the antenna or in other word, reflected. This process will continuously happen through different layers and finally will produce a hyperbolic result. The reflected energy displayed in a hyperbola form on the radar screen. It shows the amplitude and time elapsed between wave transmission and rebound process (Plati and Loizos, 2012). Hyperbolic image is processed based on the dielectric constants of structural layers and its thickness (Maser and Vandre, 2006).

GPR can give extensive information that will be useful for pavement maintenance mostly, rehabilitation, design, forecasting, planning and other managerial aspects. Furthermore, it can be performed under normal driving speed unlike traditional method, which consume much time, limited to certain depth and destructive for pavement. There are multiple methods implemented to assess existing pavement structural capacity, define structural needs and estimate the required asphalt overlay thickness to preserve pavement (Maser and Vandre, 2006). In contrast of traditional method, GPR is able to provide continuous pavement subsurface profile without the need to core and disruption of traffic. The method allow much larger amounts of data to be collected and longer lengths of pavement to be investigated for a given time and cost. GPR is a non-destructive especially when compared to traditional method; coring therefore GPR can be considered as cost effective. As a result the use of GPR has become frequently implemented for structural pavement assessment (Saarenketo and Scullion, 2000; Benedetto and Pensa, 2007).

Furthermore, GPR has high rate of data acquisition, sensitive to water chloride contents, sensitive to environmental conditions and provide a 3-D image construction (Bala and Jain, 2012). GPR has been explored for a variety of road applications with numerous advantages such as; it has been used for measuring air voids content (Saarenketo and Scullion, 2000), detecting presence of moisture in asphalt layers (Grote et al., 2005; Schmitt at al., 2013), detecting location and extent of stripping a moisture related mechanism between bitumen and aggregate (Hammons et al., 2009)], determining localized segregation during paving (Stroup-Gardiner and Brown, 2000), detecting transverse cracking (Saarenketo and Scullion, 2000), rutting observation occurrence, able to locate the same detectable longitudinal dielectric changes with high accuracy repeatedly (Poikajarvi et al., 2012; Holzschuher et al., 2007; Loizos and Plati, 2007), and determination of pavement layer thickness. According to multiple studied, the layer thickness based on GPR data collected is sufficient and effective (Maser and Vendre, 2006; Saarenketo and Scullion, 2000; Plati and Loizos, 2012).

GPR is a method of measurements that able to capture accurate layer thickness data at short intervals at relative high speed (Hartman et al., 2004). As conclusion, GPR offers many advantages such as cost effective, high speed, save time, preserving pavement, safer, highly accurate, exceptionally reliable and understandable procedures (Smith and Scullion, 1993).

5. Methods and materials

5.1. Survey site selection

A GPR survey was conducted at Meranti street, Universiti Teknologi Malaysia (UTM), Skudai, Johor Bahru, Malaysia as illustrated in 11re 2. The significant of selecting this area is due to visibility of pavement distresses and with regard to the safety concern where less traffic distributions and congestion at this route. Aso, the selection of location is based on the lower traffic distributions and visibility of pavement deteriorations in both carriage ways. Thus, it will be easier to conduct GPR survey at this location.

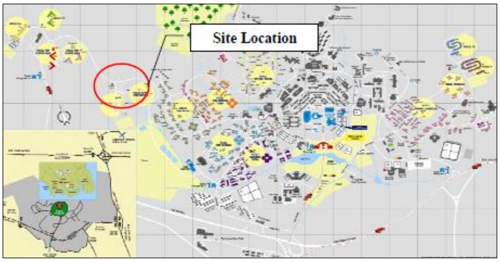

Fig. 2. Site location for GPR survey

5.2. GPR survey

GPR survey was carried out at Meranti street to identify the ability of GPR in assessing pavement structures. Data were collected along 360m street length between College 12 and College 13 as shown in Figure 3. In order to perform the field measurement for GPR tool, site calibration was needed to assist and ease the process of data acquisition as shown in Figure 4. Instruments were setup in transverse and longitudinal directions before commencement of work. The interval between transverse profiles is 20m while 1.5m interval was applied at longitudinal profiles. Calibrated velocity for GPR system was set at 0.15mns-1. The significant of site calibration are to identify visual road conditions, crossings utilities and to ensure GPR collects data in a straight line.

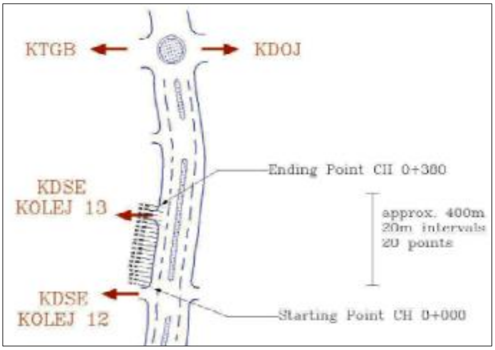

Fig. 3. Data collection points of GPR survey

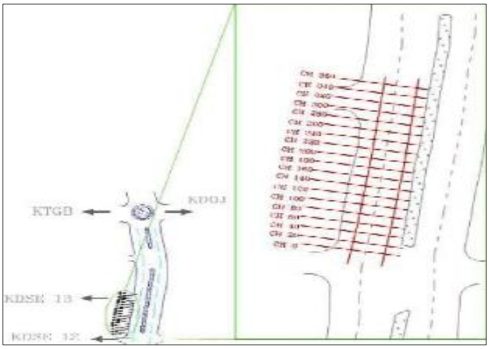

Fig. 4. Detail calibration of GPR survey

6. Analysis and results

6.1. General description

According to the survey, three (3) significant information were obtained; included, identification of raw image and processed image, identification of pavement segments thickness, and identification of GPR response towards surface and sub-surface conditionns.

6.2. Raw image and processed image

Figure 5 i and ii illustrate raw GPR data collected using 750MHz GPR system and the same data that undergo processing, filtering and interfacing. It demonstrates the asphalt layers and the base of asphalt pavement.

6.3. Identification of different structural layers segments

Site measurements were carried out using 750MHz GPR System. The instruments were set in a grid lines form for every 20m intervals along 360m street stretch. Results on each point are presented in Table 2 and Figure 6. According to the results shows in Table 2, it is indicated that GPR has given information about different structural layers thickness of pavement as follows;

i. The first segment varies between 0-220mm
ii. The second segment varies between 140-420mm

The segments of images were observed to be consistent about two distinctive layers as identified in the reflections of different interfaces between regions (see Figure 6). The layers show cross sections consist of asphalt course and base course. The average pavement thickness for first segment is 178mm while for the second segment is 180mm thickness. Figure 7 shows the variations of the obtained GPR thickness

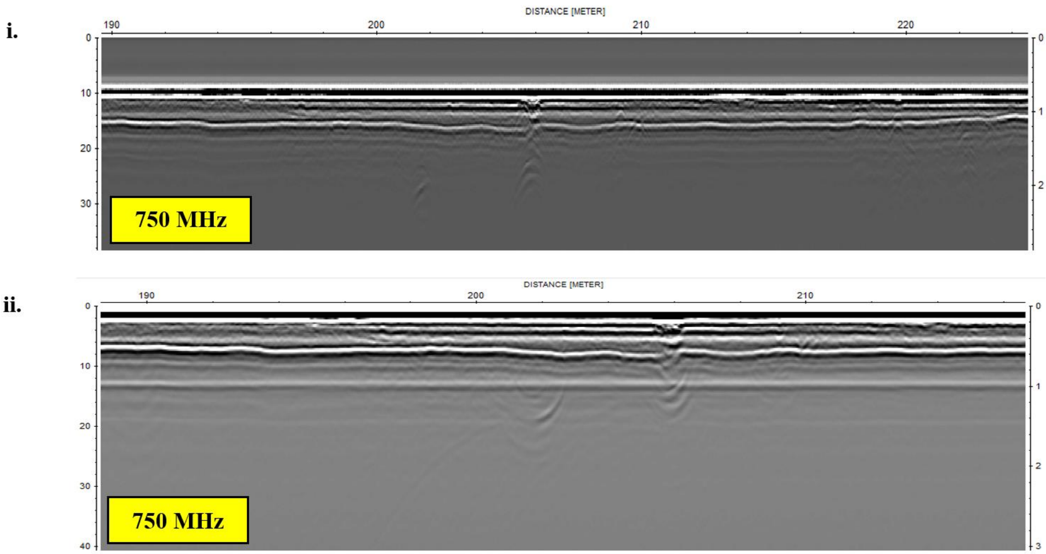

Fig. 5. (i) Raw image, and (ii) Processed image of GPR surveyed data

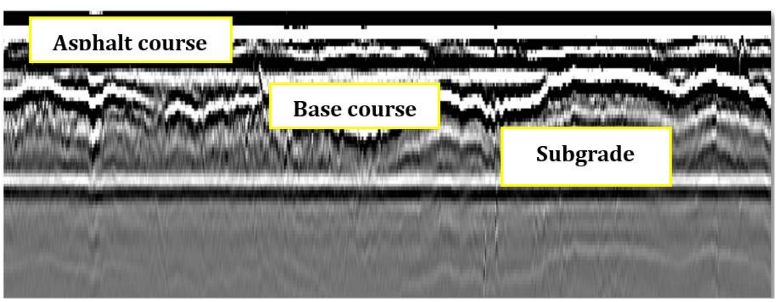

Fig. 6. Diverse GPR thickness

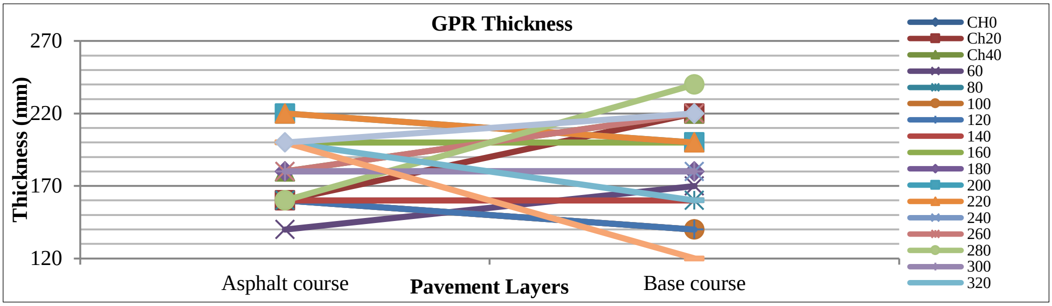

Fig. 7. Variations of the obtained GPR thickness

Table 2. Summary of obtained GPR pavement thickness

CH	Length (m)	GPR Thickness (mm)	
0+000	20	Asphalt course Base course	0- 160 160-300
0+020	20	Asphalt course Base course	0-160 160-380
0+040	20	Asphalt course Base course	0-180 180-400
0+060	20	Asphalt course Base course	0-140 140-300
0+080	20	Asphalt course Base course	0-160 160-320
0+100	20	Asphalt course Base course	0-160 160-300
0+120	20	Asphalt course Base course	0-160 160-300
0+140	20	Asphalt course Base course	0-160 160-320
0+160	20	Asphalt course Base course	0-200 200-400
0+180	20	Asphalt course Base course	0-180 180-360
0+200	20	Asphalt course Base course	0-220 220-420
0+220	20	Asphalt course Base course	0-220 220-420
0+240	20	Asphalt course Base course	0-180 180-360
0+260	20	Asphalt course Base course	0-180 180-400
0+280	20	Asphalt course Base course	0-160 160-400
0+300	20	Asphalt course Base course	0-180 180-360
0+320	20	Asphalt course Base course	0-200 200-360
0+340	20	Asphalt course Base course	0-200 200-320
0+360	20	Asphalt course Base course	0-200 200-420

6.4. Identification of subsurface conditions and existence of underground utilities

Site measurements were carried out using 750MHz GPR System. The instruments were set in a grid lines form for 19 points along 360m street stretch as presented in Table 3 and Figure 8 below. Longitudinal profile of street image is processed and visualised as in Figure 9. Table 3 presents the results for surface and sub-surface deficiency, and existence of underground utility in pavement structure obtained by GPR.

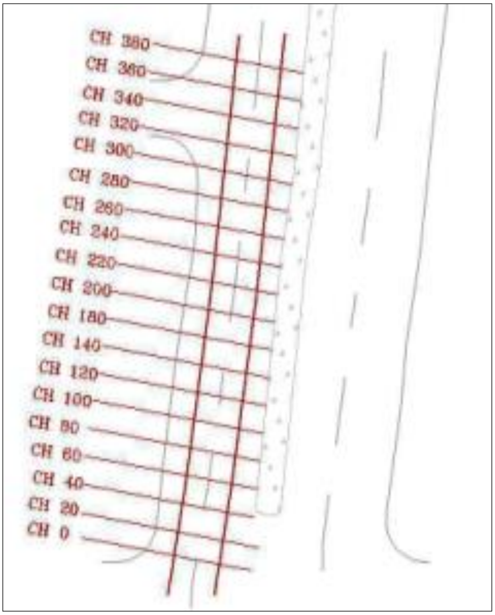

Fig. 8. Instrumentation for Data Acquisition

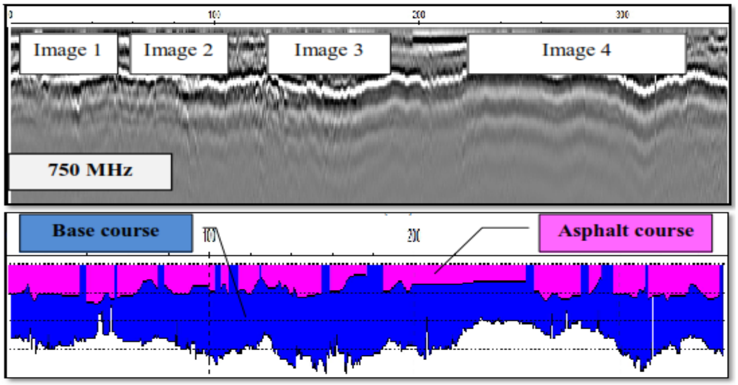

Fig. 9. Longitudinal profile of Meranti street, UTM campus

Table 3. Results for surface and sub-surface deficiency, and existence of underground utility in pavement structure obtained by GPR

CH	Length (m)	Surface and Suspected Subsurface Conditions	GPR Image
0+000	20	Fine cracks and Depression	Image 1
0+020	20	Fine cracks	Image 1
0+040	20	Fine cracks	Image 1
0+080	20	Fine cracks and Delamination	Image 2
0+100	20	Fine cracks and Delamination	Image 2
0+120	20	Fine cracks and Thickness inconsistency	Image 3
0+160	20	Fine cracks and Thickness inconsistency	Image 3
0+200	20	Suspected cable	Image 4
0+220	20	Small cracks	Image 4
0+240	20	Delamination and Patched area	Image 4
0+260	20	Crack and small pothole	Image 4
0+280	20	Delamination and Patched area	Image 4
0+300	20	Delamination and Patched area	Image 4
0+320	20	Operational error	Image 4
0+340	20	Delamination and Patched area	Image 4

7. Findings and discussions

7.1. General introduction

The GPR survey resulted with; i. determination of thickness layer, ii. determination of surface and subsurface conditions; inconsistency of base course thickness layer, deformed layers, and patched sections, and iii. Identification of cracks reflections in subsurface layer and underground utility. But before that, GPR images need to be filtered and interpreted.

7.2. Filtering for processed image

By using filtering analysis, the raw data was prepared for amplifying process of GPR signal, and meanwhile, removing any possible interpolations affect the signal (such as, noises). There are two types of filtering process which are vertical and horizontal filtering. Vertical filtering is used to remove local noise, high frequency noise, signal wowing and interference through a band-pass filter. Thus, it will produce a rapid scan and non smooth lines. So, a horizontal filter was applied in order to remove rapid changes in scan. Another important filtering feature is bandpass butterworth which eliminates the redundant signals from the radar image and obtained clearer image for interpretation. Normally, it requires for upper band cut off and lower band cut off. Upper band cut off inputs the higher frequency of antenna system while lower band cut off inputs the lowest frequency of antenna system incorporate in the GPR system used. Subsequently, the colour transformation takes place to emphasize low amplitude sections and make pavement layers more visible for interpretations (see Figure 10).

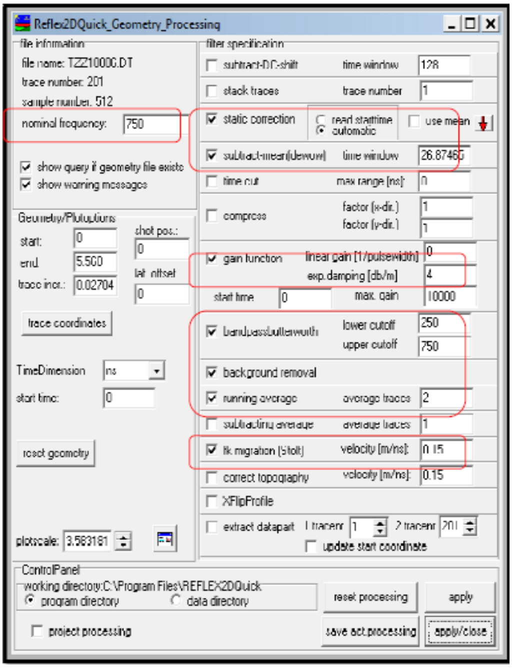

Fig. 10. Basic filtering process for GPR imaging

7.3. GPR thickness

Variations of GPR thickness were plotted as visualized in Figure 7. It was found that most thickness values are within approximate range. There is no deviation of thickness beyond range so far for both segments. In this study, we adopted 750MHz antenna frequency of GPR System in determining pavement thickness. However, the adopted GPR System unable to provide accurate thickness of pavement or in other words, the image resolution is very low. With the capacity of the system, it able to reflect two distinctive pavement layers only which are asphalt course and base course due to the difference in materials conductivity. The principle of GPR system is to penetrate mediums through wave propagation that will rebound or reflect once it hits dissimilar constituent materials and the higher the frequencies the greater their resolutions while lower frequency provides lower image resolution. In real practice, most of the pavement evaluation will be conducted using higher frequency antenna system like; 1.0-2.5GHz to acquire high resolution image at shallower depth. That is why the adopted GPR system unable to provide exact layer thickness. In this situation, the inadequacy of pavement thickness layers identification is affected by the type of antenna frequency adopt in this study.

7.4. GPR interpretations

7.4.1. GPR interpretation Image 1

Based on the assessment carried out, it is found that surface distress like cracks were captured by GPR (Figure 11a). As verified on site, there are finer cracks appeared on the pavement surface. While for the subsurface condition, localised structural deformations was identified. The surface condition does not show any stripping layers or potholes yet light depression. Furthermore, if we compare the reflections of GPR over normal structural layer and deformed layer it shows slight contrast in its amplitude (see Figure 11e). An early guess of this condition might be due to material density problem which related to pavement weak spot however, this requires further verification through material samplings.

7.4.2. GPR interpretation Image 2

Based on the assessment carried out, it was found that surface distress like cracks and delamination occurred (see Figure 11b). As verified on site, there are finer cracks appeared on the pavement surface as well as stripping surface course. The delaminated sections represent inconsistently as shown in figure above. As compared to the real situation, the delamination patterns were successfully outlined by GPR. Delamination happens due to loss of adhesiveforce between asphaltic materials which further results in separation between first layer and second layer materials. This phenomenon occurred due to moisture presence at the respective area. As observed, the delamination section located at the lower point of the road slope. Thus, potential runoff may accumulate at this section before discharge into the side drain. Another assumption that probably aggravates the situation would be material problem where several patches mark can be seen at the delaminated sections. Therefore, further verification should be done at this section to identify whether moisture had penetrated into the subsequent layers or not.

7.4.3. GPR interpretation Image 3

Based on the assessment carried out, it was found that surface distress like cracks occurred on the surface however, the intensity of cracks propagation were less than previous because this is a slope section of the road as illustrated in Figure 11c. Normally, slope sections did not have many problems if proper drainages are constructed along the slope. However, slope could be problematic if water seeps into the surface and further exposed to heavy vehicles continuously. In this situation, inconsistency of thickness may be resulted from the existing ground profile of the section. So, there is no significant structural problem along this section other than functional problem only.

7.4.4. GPR interpretation Image 4

Based on the assessment carried out, it was found that surface distress like small developing potholes, cracks and delamination occurred on the surface. Referring to Figure 11d, the delamination sections were resulted from pothole patching and sectional repair. It is probably caused by wrong selection of materials, workmanship issue during sectional repair work and inadequate compaction. Thus, it leads to severe surface condition where surface course materials leaves the binder course layer. Also, this area is subjected to frequent loading and unloading. Other than that, the pavement condition was aged pavement and requires surface overlays for better performance. Referring to aged pavement condition, there is a possibility where ravelling of surface aggregate occurred. The physical conditions of pavement looks old, and suspected have lost its functional performance. That is why, some areas experiences recurring defects and get lots of patched marks along the road.

The situation have significantly proves that surface overlay is highly recommended for this strret. The subsurface thickness layers shows inconsistency due to the previous sectional repair works. The basic process of sectional repair requires removal of the bituminous course and to be replaced with new materials. Depending on its severity, removal of base course might be possible. However, it is seldom applied over small sectional area as it would be costly, timely ineffective and normally, removal of base course materials are related to strength and structural problems. Lastly, suspicious interference in the first image was captured and it is suspected cause by presence of cables nearby while the third image shows operational error during the data collection stage.

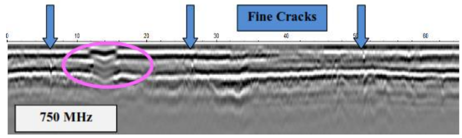

Fig. 11a. Image 1

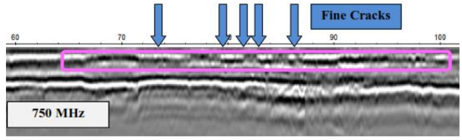

Fig. 11b. Image 2

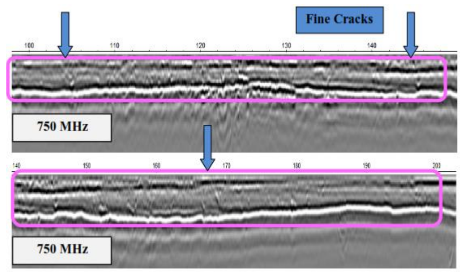

Fig. 11c. Image 3

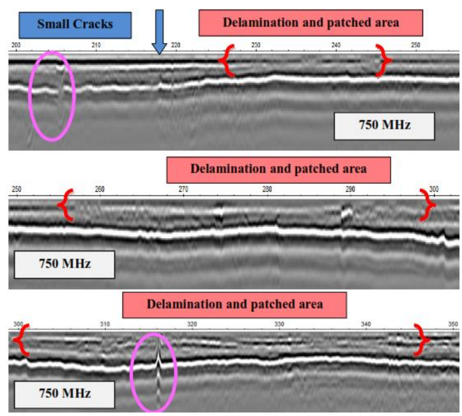

Fig. 11d. Image 4

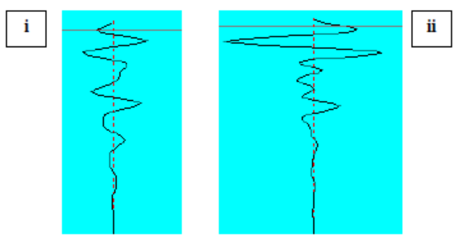

Fig. 11e. Reflection of GPR (i) Normal layer (ii) Deformed layer

7.5. Advantages and disadvantages of GPR system adopted

The types of GPR antenna frequency adopted in this study range from 250MHz and 750MHz. For pavement assessment purpose, 750MHz GPR system is evaluated with due to its performance and image resolutions. Table 4 summarized the advantages and disadvantages of 750MHz GPR System adopt in this study. Thus, it is highly recommended to select higher frequency of GPR system in order to overcome low resolution image which is more suitable in pavement structural assessment. Secondly, to engage expert analyst in image interpretation and pursue in depth analysis of materials conductivity at present layers as to arrest the interpretation phase difficulty.

Table 4. Advantages and disadvantages of the adopted GPR system

Advantages	Disadvantages
▪ Provide many information at one time ▪ Can be completed less than 2 hours thus ▪ considered time effective or fast ▪ Requires less manpower to perform the ▪ test thus consider as cost effective ▪ Non-destructive thus preserve materials from destruction	▪ Time consuming at data interpretation ▪ phase ▪ Low frequency system used thus provide ▪ low image resolution

With respect to the numerous findings, GPR performance also relies on its operating system which depends on its frequency range. Higher frequency is preferable for this kind of study in the future because the required penetration depth is less than 1m which is sufficiently used for typical pavement thickness. Other than that, the image resolution was dissatisfied for data interpretation because there were a lot of noises or unknown disturbances appeared after processing which made it hard for identifying the problems smoothly. The best sides of GPR is in terms of cost time effectiveness proves that GPR survey can be perform less than 2 hours for half kilometre road and in terms of processing image, it is reasonably can be done at faster time except for data interpretation that consumes a little bit time. That is why, in most situation site calibrations is considerably helpful in interpretation process later.
Besides that, GPR can generate information which in real practice needs multiple destructive tests to be performed. This proves GPR can save time, cost and vital for preservation of materials. GPR also can helps to resolve dispute over subsurface problems or problematic roads and prevent wrong selection of remedies onto the matters. Conclusively, GPR has significant benefits and drawbacks in assessing pavement structures as presented in this study.

8. Conclusion and recommendations

This study was initiated based on several issues and problems occur within the scope of road maintenance practices in Malaysia. It was clearly justified the types of GPR system perform important roles to achieve better results in terms of image clarity and accurate penetration depth. Nevertheless, the results obtained still accountable and meaningful for further corrective actions. Numerous benefits of using GPR can be found during the site investigation; however, there is no significant drawback of GPR that affect its operation in assessing pavement structural layers. The only issue to get accurate and reliable information from GPR is to incorporate site calibration, and to use high frequency antenna in GPR System. As shown earlier, huge amount of information collected during assessment. All raw data were processed using REFLEX 2D Quick software and presented in a processed interface.
Indeed, there are few suggestions could be implemented to enhance this study; such as, to incorporate the other techniques to assist the reliability and accuracy of the achieved thickness from GPR tool, for example, by using Dynamic Cone Penetrometer (DCP) or to carry out destructive test by taking a few core samples at a few locations. Secondly, it is needed adopt more high frequency GPR antenna for pavement assessment in order to have a more visible image for interpretation. Thirdly, variations of defects should be incorporate for further pavement investigation, for example, dislodged culverts, cavity or sinkholes, road settlement areas and etc.

to distinguish the differences in pavement structural behaviours. As the future study, integration of GPR and Infrared Thermograph (IR) and Portable Seismic Pavement Analyzer (PSPA) for premature pavement assessment has a room to be investigated.

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References

[1] ANDERSON, N., ISMAIL, A., 2003. A generalized protocol for selecting appropriate geophysical techniques. In Geophysical Technologies for Detecting Underground Coal Mine Voids Forum, 28-30.
[2] BALA, D. C., JAIN, S. S., 2012. Practical Way To Identify The False Target Signatures In Gpr Images Of Ground Profile. i-Manager's Journal on Civil Engineering, 2(2), 28.
[3] BENEDETTO, A., DE BLASIIS, M. R., 2010. Applications of Ground Penetrating Radar to road pavement: state of the art and novelties. In Paving Materials and Pavement Analysis, 412-419.
[4] BENEDETTO, A., PENSA, S., 2007. Indirect diagnosis of pavement structural damages using surface GPR reflection techniques. Journal of Applied geophysics, 62(2), 107-123.
[5] BENSON, R. C., 2000. An overview of geophysical and non-destructive methods for characterization of roads and bridges. In Use of Geophysical Methods in Construction, 1-14.
[6] BERNAMA. 2012. Khazanah istimewa. PM gembira The New York isytihar Melaka destinasi perlu dikunjungi tahun ini. Harian Metro, 12.
[7] COLAGRANDE, S., RANALLI, D., TALLINI, M., 2011. Ground penetrating radar assessment of flexible road pavement degradation. International Journal of Geophysics, 2011.
[8] GROTE, K., HUBBARD, S., HARVEY, J., RUBIN, Y., 2005. Evaluation of infiltration in layered pavements using surface GPR reflection techniques. Journal of Applied Geophysics, 57(2), 129-153.
[9] GRZYB, A., BRYK, K., DUDZIK, M., 2013. Mathematical model for vibrations analysis of the tram wheelset. Archives of Transport, 25 (1-2), 55-68.
[10] HAUSMAN, J., BUTTLAR, W. (2002). Laboratory and field analysis of the TransTech Model 300 Pavement Quality Indicator (PQI) for determining asphalt pavement density. In Proceedings of the 2002 Transportation Research Board Annual Meeting, Washington DC.
[11] HOLZSCHUHER, C., LEE, H. S., GREENE, J., 2007. Accuracy and Repeatability of Ground Penetrating Radar for Surface Layer Thickness Estimation of Florida Roadways. Florida DOT Report FL/DOT/SMO/07-505, Florida.
[12] KEYVANFAR, A., MAJID, M. Z. A., SHAFAGHAT, A., LAMIT, H., TALAIEKHOZAN, A., HUSSIN, M. W., FULAZZAKY, M. A., 2014. Application of a grounded group decision-making (GGDM) model: a case of micro-organism optimal inoculation method in biological self-healing concrete. Desalination and Water Treatment, 52 (19-21), 3594-3599.
[13] LAMIT, H. B., SHAFAGHAT, A., MAJID, M. Z., KEYVANFAR, A., AHMAD, M. H. B., MALIK, T. A., 2013. The Path Walkability Index (PAWDEX) Model: To Measure Built Environment Variables Influencing Residents' Walking Behavior. Advanced Science Letters, 19(10), 3017-3020.
[14] LOIZOS, A., PLATI, C., 2007. Accuracy of pavement thicknesses estimation using different ground penetrating radar analysis approaches. NDT & e International, 40(2), 147-157.
[15] MASER, K., VANDRE, B., 2006. Network-Level Pavement Structure Assessment Using Automated Processing of Ground Penetrating Radar (GPR) Data. In Airfield and Highway Pavement: Meeting Today's Challenges with Emerging Technologies, 719-728.
[16] MDOT (2006). Mississippi Department of Transportation State Study Phase I – GPR Final Report.

[17] MTAG (2003). Common Flexible Pavement Distress. Caltrans Department of Transportation. Maintenance
[18] MUHAMMAD, N. Z., KEYVANFAR, A., MAJID, M. Z. A., SHAFAGHAT, A., MIRZA, J., 2015. Waterproof performance of concrete: A critical review on implemented approaches. Construction and Building Materials, 101, 80-90.
[19] NAPA. 2008. Porous Asphalt Pavements for Stormwater Management: Design, construction and Maintenance Guide, IS-131, National Asphalt Pavement Association.
[20] PLATI, C., LOIZOS, A. 2012. Using ground-penetrating radar for assessing the structural needs of asphalt pavements. Nondestructive Testing and Evaluation, 27(3), 273-284.
[21] POIKAJÄRVI, J., PEISA, K., HERRONEN, T., AURSAND, P. O., MAIJALA, P., NARBRO, A., 2012. GPR in road investigations–equipment tests and quality assurance of new asphalt pavement. Nondestructive Testing and Evaluation, 27(3), 293-303.
[22] SAARENKETO, T., 2006. Electrical properties of road materials and subgrade soils and the use of ground penetrating radar in traffic infrastructure surveys, PhD. Dissertations, Faculty of Science, Department of Geoscience, University of Oulu.
[23] SAARENKETO, T., SCULLION, T., 2000. Road evaluation with ground penetrating radar. Journal of applied geophysics, 43(2), 119-138.
[24] SCHMITT, R. L., FAHEEM, A., AL-QADI, I. L., 2013. Selection of Non-Destructive Testing Technologies for Asphalt Pavement Construction. In Airfield and Highway Pavement 2013: Sustainable and Efficient Pavements, 573-584.
[25] SHAFAGHAT, A., KEYVANFAR, A., MANTEGHI, G., LAMIT, H. B., 2016a. Environmental-conscious factors affecting street microclimate and individuals' respiratory health in tropical coastal cities. Sustainable Cities and Society, 21, 35-50.
[26] SHAFAGHAT, A., MANTEGHI, G., KEYVANFAR, A., BIN LAMIT, H., SAITO, K., OSSEN, D. R., 2016b. Street Geometry Factors Influence Urban Microclimate in Tropical Coastal Cities: A Review. Environmental and Climate Technologies, 17(1), 61-75.
[27] SHAFAGHAT, A., KEYVANFER, A., MUSLIM, N. H. B., 2016c. Drivers' adaptive travel behaviors towards green transportation development: a critical review. Archives of Transport, 38 (2), 49-70.
[28] SMITH, S. S., SCUILLION, T., 1993. Development of ground-penetrating radar equipment for detecting pavement condition for preventive maintenance. NASA STI/Recon Technical Report N, 95, 11904.
[29] STROUP-GARDINER, M., BROWN, E. R., 2000. Segregation in hot-mix asphalt pavements (No. 441). Transportation Research Board.
[30] WANG, S., GUO, Y. C., LI, D. Y., HU, K., 2016. Research of lateral force of pipe conveyor belt's vertical transport section. Archives of Transport, 37 (1), 67-75.