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Non-destructive Method for Asphalt Pavement Evaluation: A Review

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Abstract: This paper presents a simple review of non-destructive test (NDT) method in asphalt pavement evaluation. Three non-destructive testing including ground-penetrating radar (GPR), falling weight deflectometer (FWD) and ultrasonic pulse velocity (UPV) were reviewed. GPR test is to estimate asphaltic concrete density and thickness, FWD test is to check the modulus of resilient and UPV is to estimate the elastic properties. It can be found that small error and good correlation between NDT test and standard test. In the view of literature review, it can be stated that the NDT test method is an interesting technology and able to contribute to the pavement application with acceptable measurement.

Keywords: Non-Destructive Method, Ground Penetration Radar, Falling Weight Deflectometer, Ultrasonic Pulse Velocity

1. Introduction

The pavement is normally used to describe the series of layers that form the structure of the road. Each layer provided important properties that distributed the stress from traffic loading to the sub-base layer. Pavement at the wearing layer constantly undergoes continuous traffic loading, moisture and temperature. The traffic load caused stress on the structure of the pavement and has the potential to contribute to minor defects. As time goes on, these minor defects gradually accumulated and evolved into various types of distress categories. In the meantime, pavement often shows discomfort at various rates of severity [1]. Therefore, destructive testing is always conducted to investigate the mechanical features of failure of structure such as compression strength, tensile strength, ductility and fracture of toughness. However, the destructive testing procedure has a great deal in terms of time and money. The number of tests to be carried out within a time-space is also limited. This testing also does not appropriate for routine evaluation studies [2]. Meanwhile, the non-destructive method can be conducted in many numbers of repeatable, the inspection can detect the surface, subsurface, and volumetric indication using the latest software in a shorter time and thus relatively cheaper cost [2]. Highway transportation is moving toward the use of innovative non-destruction testing (NDT) methods for evaluating the in-situ condition pavement structure. There are various types of NDT methods that have been developed and applied in engineering with varying degrees of success. This

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study was conducted to review the non-destructive (NDT) method used in pavement evaluation. In pavement materials, three non-destructive method involved namely Ground Penetrating Radar (GPR), Falling Weight Deflectometer (FWD) and Ultrasonic Pulse Velocity (UPV).

2. Methods

This study was conducted as a literature review from various database. The articles on non-destructive (NDT) in pavement evaluation used repository databases such as ScienceDirect, ResearchGate, SpringerLink, Scopus, and Google Scholar. Figure 1 presents the numbers of article involved for each screening process. In this review, 13 out of 53 articles were evaluated on the three non-destructive test methods: GPR, FWD and UPV.

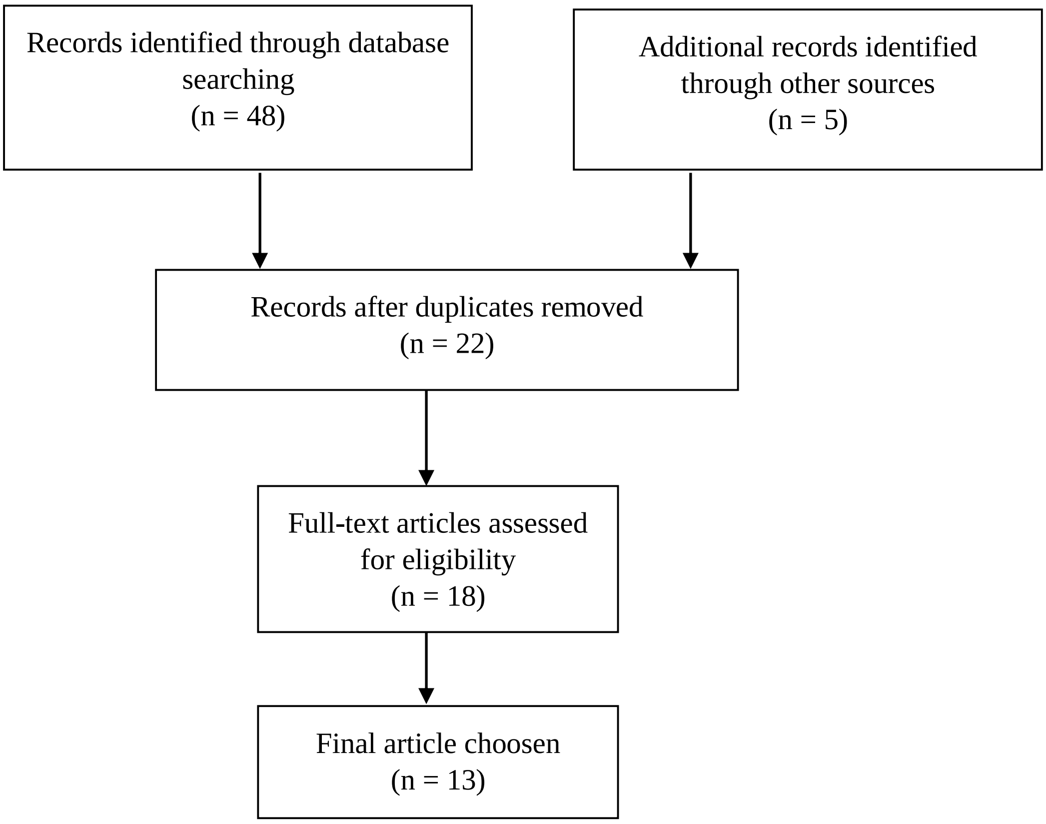

Figure 1: Flow of literature screening

3. Ground Penetrating Radar

Ground-penetrating radar (GPR) is a geophysical locating method that uses radio waves to capture images below the surface of the ground in a minimally invasive way [3]. On the other way, GPR is a method for locating structural objects and assessing, pavement material, layer thickness, and properties of the pavement [4]. Basically, a typical GPR system consists of a transmitter- and receiver-containing antenna. The antenna transmits pulses of the energy microwave (EM) at a specific frequency range (usually between 16 MHz and 2.000 MHz), according to the antenna type used. When the EM signals are released, the antenna receives signal reflections when the dielectric permittivity under the surface switches suddenly [5]. GPR devices record the travel time of the pulses issued from the antenna. This data can be imported into software to digitalize reflections and allow the consumer to decide the reflection depth. The strength and depth of signals under the surface, the digitalized reflections, and resolution depend upon the frequency of the pulses generated by some antenna models. Lower frequency antennas (200MHz to 400MHz) will reach the soil deeper (4 to 9m), but the resolution of the digitized reflections of antennas from 1000 to 2000MHz is substantially smaller because of the large intensity of the transmitted waves [6]. Figure 2 presents the variations in the signal amplitude of different antennas. The low resolution can transfer higher depth of penetration compare to high resolution.

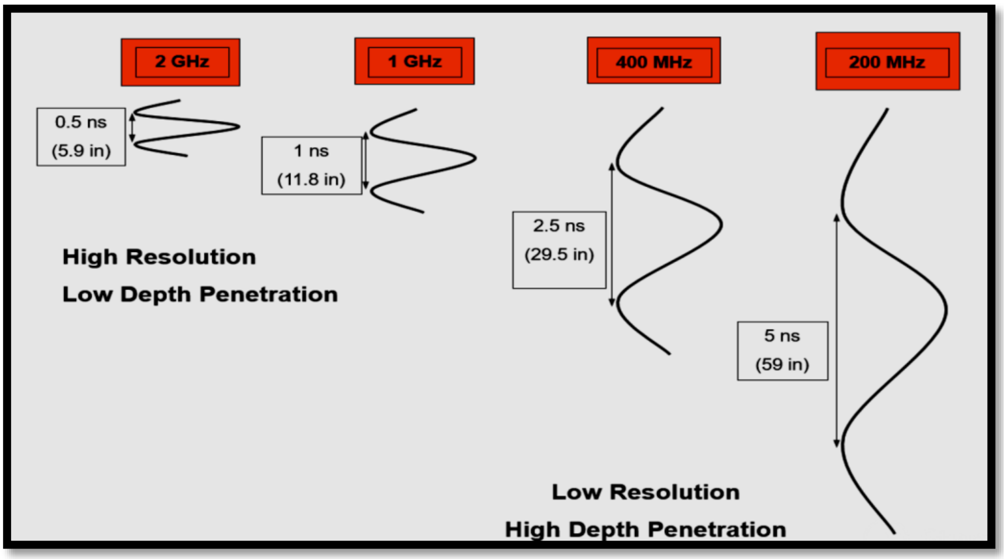

Figure 2: The variations in the signal amplitude of different antennas [6]

A research examined the ongoing measurement of density and thickness of the asphaltic concrete (AC) construction site with GPR [7]. Two types of material transfer vehicles (MTV) used in this study namely for GPR measurements, namely BOMAG and VOGELE. In the first test, for pavement segments installed on two consecutive days, the first measurement compares the AC layer density and thickness. In continuously measuring the AC layer thickness, the GPR program and the proposed truncation algorithm were used. The errors are precisely the absolute differences between core and GPR measurement. Figure 3 shows the difference error for thickness and Figure 4 presents the difference for density for BOMAG dan VOGELE for second test. Based on the results, the difference was found less than 3% for thickness and less than 6% for density.

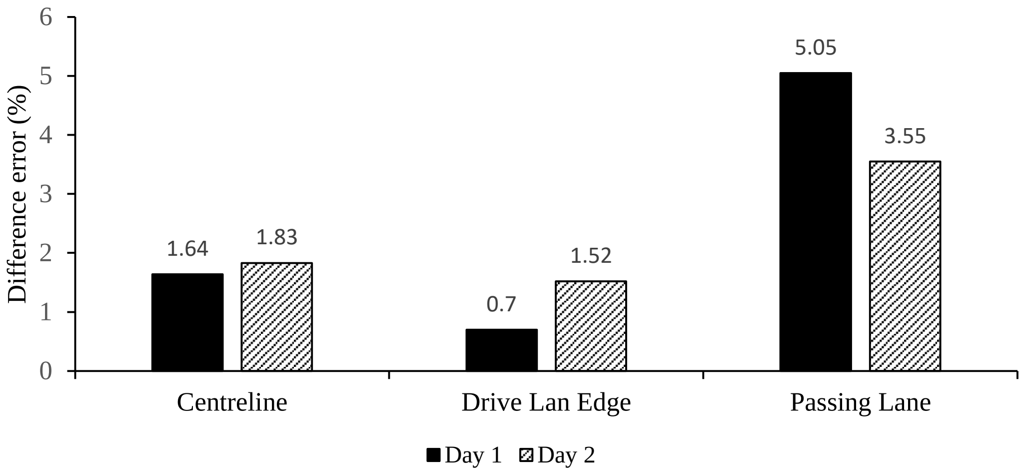

Figure 3: Difference of thickness error of lane [7]

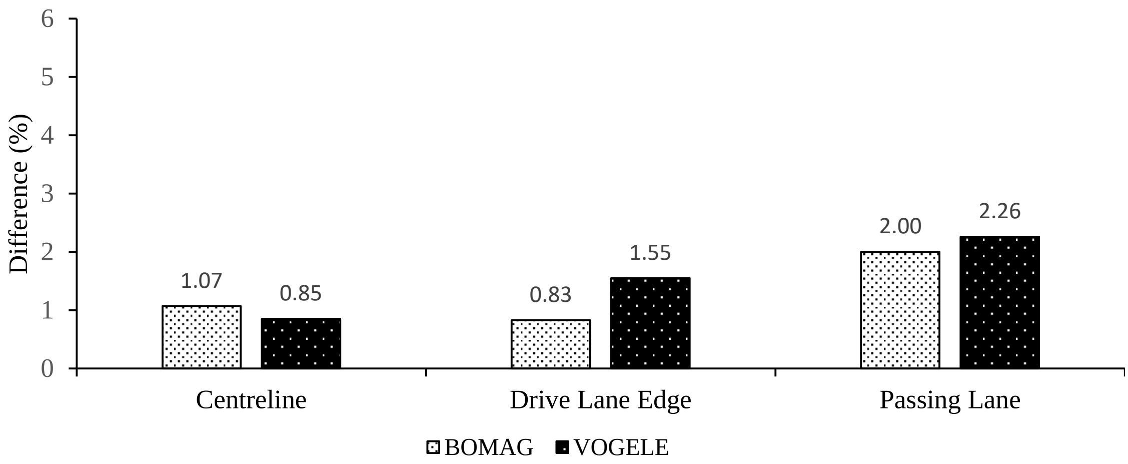

Figure 4: Difference of density error for different MTV [7]

4. Falling Weight Deflectometer

The falling weight deflectometer (FWD) is a NDT method to measure the vertical deflection response of a pavement layer due to an impulse load. The mechanism involves the introduction of a dynamic charge into the paving system in form of a regular "drop weight" and the longitudinal calculation of deflection at different points in the paving to replicate the "deflection bowl" [8]. The use of the FWD is widely spread across the pavement design industry and is used to identify areas of weak pavement, back-calculate layer properties for use in overlay design and estimate the remaining life of the structure. The FWD was used to simulate the various effects of the wheel loading on the concrete, thereby creating the impact force over a range of drop heights. After loading, transducers are counted in the deflected surface basin. Geophones and seismometers for a variety of uses are commonly used in FWD transducers. The bending sensors should be positioned closer to the loaded core than in thicker asphalt flooring for pavements with thin asphalt layers.

A study by Singh et al. [9] compared the resilient modulus (M_R) values for cement stabilized layers using Falling Weight Deflectometer (FWD) and destructive test method through cores. The procedures to measure the M_R of FWD deflection data surface layer material for a load data thickness are called backcalculation. In the study of the pavement design, strength measurement, and overlay thickness design were used M_R value. The same value of the same inputs and have small variations is mainly not accomplished in all backcalculation software. The M_R values were derived for both state highway (SH) and major district road (MDR) from all three program locations. However, the representative graph between MR and distance (chainage) for a single position in SH (Second Location) and MDR (Third Location) have been more detailed to minimize the number of graphs. The M_R values obtained from all the three software (KUAB, MICH-BACK, and ELMOD) have been compared with test pit value are given in Table 1. Based on the results, the range of 7% to 10% value is obtain from the laboratory and field for KUAB and ELMOD. The performance of the measured surface module is tested by comparing the computed module with the laboratories M_R. It shows that the KUAB module values are very near to laboratory than ELMOD and MICH-BACK. The KUAB software is also closer than ELMOD and MICHBACK based on the comparison between back calculated M_r and laboratory value of cement treated base (CTS), cement treated sub-base (CTSB) and bituminous cores. The findings obtained only refer to the ground conditions and materials used on the site. The findings can however vary with different materials and conditions in the field.

Table 1: Percentage difference of resilient modulus values from different FWD software [9]

	% Difference		
FIRST LOCATION	**KUAB**	**ELMOD**	**MICH-BACK**
Bituminous Layer	0.39	2.32	2.77
Cement Treated Base (CTB)	2.54	5.94	6.93
Cement Treated Sub-Base (CTSB)	2.59	5.67	33.36
Sub-grade	0.03	0.08	0.08
SECOND LOCATION	**KUAB**	**ELMOD**	**MICH-BACK**
Bituminous Layer	1.33	4.42	3.20
Cement Treated Base (CTB)	2.3	2.62	6.16
Cement Treated Sub-Base (CTSB)	6.63	9.80	14.52
Sub-grade	0.02	0.10	0.006

5. Ultrasonic Pulse Velocity

Basically, ultrasonic testing uses high frequency energy in the form of waves transmitted through a material. The ultrasound acoustic pulse set point on the specimen is based on acoustic devices, taps with transmitter device and collected by a sensor that can be positioned at various locations. The device is known as Ultrasound if high frequency, above 20 kHz, and sonic oscillations, or acoustic pulses are produced between 20 Hz and 20 kHz. UPV test operates based on through-transmission mode [10]. This refers to the time of the arrival of an ultrasonic pulse from one transducer to another through a solid medium. Typically, two types of ultrasonic pulse can be produced, namely p-wave (or compression wave) and shear (s-wave) [11]. The ultrasonic pulse velocity (UPV) is calculated by dividing the distance between the transducer by the time of arrival using the following equation:

$$V = \frac{L}{t} \quad \text{Eq. 1}$$

where V is ultrasonic speed in (km/s), L is specimen length in meter (m) and t is travel time of ultrasonic through the specimen in microsecond (μs). The application of UPV in pavement evaluation was found for moisture damage evaluation [11], dynamic modulus [10, 12] and modulus elasticity [13]. The main properties from this UPV wave velocities (Eq.1) is Young modulus or dynamic modulus (E). Table 2 presents the formula of E for asphalt mixture.

Table 2: Different formula for Young Modulus and Dynamic Modulus

Author	Parameter	Formula
Birgissison et al. (2005) [11] Arabani et al. (2012) [13]	Young Modulus	$E = \frac{\rho v_s^2 (3v_p^2 - 4v_s^2)}{v_p^2 - v_s^2}$
Contretras et al. (2010) [10]	Dynamic Modulus	$E_u = 1.274 \, x \, 10^9 \, \frac{Wh}{d^2t^2} \frac{(1+v)(1-2v)}{(1-v)}$
Dimter et al. 2016 [12]	Dynamic Modulus	$E_{dyn} = p \, . V^2 \frac{(1+v) \, . (1-2v)}{1-v}$

Where E is Young's modulus in N/m^2 (MPa), ρ or p is density (kg/m^3), V_p is compression wave velocity in m/s, Vs is shear wave velocity in m/s, E_u or E_{dyn} is dynamic modulus (MPa), W is sample mass (kg), h is sample height (mm), ν is Poisson's ratio, d is sample diameter (mm), t is propagation time (μs).

Basically, Young's modulus measures the resistance of pavement mixture to elastic (recoverable) deformation under load. Meanwhile, dynamic modulus is the same definition as Young's modulus but with dynamic loading in the form of vibration is applied. Typically, the pavement layer experience dynamical loading, the term of dynamic modulus is always used in pavement evaluation [10]. According to Birgisson et al [11], the small strain modulus obtained with the ultrasonic pulse wave velocity test is sensitive to changes in mixture integrity due to moisture or pore water effects after conditioning. Arabani et al [13] found that the increasing filler content increased the small strain of Young's modulus for p-wave and s-wave. The stiffness modulus by indirect tensile stiffness modulus test indicate that there is good correlation by the result from UPV test with R^2 is about 0.93. Contreras [10] conducted the comparison for standard (direct) dynamic modulus test and UPV test (indirect dynamic modulus test). The result found that the indirect dynamic modulus test shows a higher magnitude compared with the direct dynamic modulus testing. However, the modulus values obtained from UPV can still be used as indicators of the value of dynamic modulus of low-strain asphalt pavements by conducting the conversion factor. In stabilized mix, the result from the ultrasonic testing showed that ultrasonic velocity is a good indicator of the quality of stabilized mixes [10].

6. Conclusion

Based on the review, the NDT method can be used to obtain various results. GPR can be used to estimate the asphalt mixture density and thickness, FWD is to check the resilient modulus, and UPV to estimate the elastic properties of asphalt mixture. The testing of AC layer density and the thickness by GPR result is about 3% to 6% of the average error. The variation of resilient modulus by FWD on the field and laboratory is 5% to 7%. Then, the correlation of direct measurement of stiffness or dynamic modulus showed good correlation with UPV test. In conclusion, the NDT method will provide faster and accurate results. The most important all these methods would not cause any destruction or damage to the asphalt surface.

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