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Application of Ground Penetration Radar and Light Weight Deflectometer for Pavement Quality Control and Quality Assessment

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Abstract**:** ***Pavement evaluation requires the frequent assessment of structural and functional condition. Earlier functional assessment of pavement were rapid and non destructive whereas structural evaluation required destructive testing. With growth in technology the light weight deflectometer (LWD) and ground penetrating radar (GPR) replaced the destructive testing in most part of the world. This paper highlights the use of LWD and GPR as non destructive testing tool in pavement evaluation. LWD and GPR test were conducted on the granular material to investigate the composite modulus of layer for their quality assessment. LWD test results were found to be significantly affected by the base plate diameter, contact between plate and surface layer, whereas drop height does not show significant difference on composite modulus. GPR technology has showed its versatility in pavement layer thickness evaluation, void and crack detection, and sub surface exploration. Ground coupled GPR has been used for subsurface exploration. At project level pavement management system, the combined use of GPR and deflection testing device has resulted in effective monitoring of pavement structural capacity. Hence LWD and GPR had showed its effectiveness for quality control and quality assurance (QC/QA) in PMS.***

Keywords: NDT, GPR, LWD, Stiffness modulus

I. INTRODUCTION

Pavements are built to cater the movement of traffic on them and to transfer the imposed wheel safely on to the subgrade soil. The subgrade soils are compacted up to 98 % of the maximum dry density (MDD) of standard proctor test achieved in laboratory. Due to its simple testing technique the sand cone method is mostly used for the assessment of compaction quality of subgrade and granular layers. The sand cone testing is time consuming, pose difficulty in testing large sized particles and is unsafe for testing in in-situ conditions. Also for QC & QA work the density of material i.e. its compactness and the moisture content can be a poor indicator of pavement performance. In order to overcome this, parameters related to stiffness and strength of material can be used for QC & QA work as they are sensitive to state of stress and moisture content[1].

Non destructive testing such as falling weight deflectometer (FWD), light weight deflectometer (LWD) and ground penetrating radar (GPR) had been used extensively for pavement quality related investigation. LWD a lighter version of conventional FWD has been developed in Germany to assess the stiffness of bound and unbound granular layers. Some researchers made several attempts to establish the correlation between the elastic modulus obtained from light weight deflectometer (LWD) with dynamic cone penetration test, falling weight deflectometer, plate load test, nuclear density gauge and geogauge[2], [3]. In the laboratory, resilient modulus of materials is used to estimate their stiffness parameter. The Indian Road Congress uses several empirical relationships to estimate the resilient modulus (MR) of granular material from the California bearing ratio (CBR) of subgrade soil and the thickness of granular layer. In India very limited researches has been done to address the use of LWD for quality control and quality assessment of bound and unbound granular materials. The stiffness parameters are significantly influenced by temperature and moisture change [4]. India's the seventh largest country by area in world, experiences a wide variation in climate from one part to another. Many researchers [5]–[13] studied the impact of climate change on pavements design and its material properties. MEPDG uses climatic parameters as inputs in design of flexible pavement, as recommended in NCHRP reports.

The climatic parameters (moisture, temperature, wind speed, sunshine hours, precipitation etc) significantly affect the structural responses i.e. stress, strain and deflection of pavements. These responses help to assess the structural strength of pavement as well as predict the pavement remaining service life. Benkelman beam (BB test) has been used as deflection testing and structural evaluation from many years. In recent years falling weight deflectometer (FWD) has widely gained acceptance as deflection testing device, for determining in-situ pavement structural responses. By applying appropriate backcalculation technique the elastic modulus of the pavement layer is determined. Correction for temperature is made in the back calculated elastic modulus. Many researchers used FWD as it had advantages over conventional BB test; the FWD test simulates the actual traffic conditions whereas BB test applies static load. Many researchers used Ground Penetrating Radar for the pavement layer thickness estimation[14]–[19] and FWD for structural strength estimation. The seasonal effect of temperature and moisture variations on pavement strength has been investigated in past also[12], [20]–[22].

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In M-E design the climatic factors should be given due care because the pavement section would be undergoing numerous volumetric changes in different climatic and environmental conditions in various seasons and at various locations.

Hence for weather resistant and durable roads the factors to be considered are, rainfall intensity and duration, cloud coverage, maximum and minimum pavement and air temperature, wind speed, relative humidity, latitude, topography and soil type, drainage conditions, ground water level.

II. IN-SITU TEST

Many in-situ tests were conducted using LWD for the analysis of its effectiveness as QC/QA tool, for compaction control, to correlate the elastic modulus value of LWD with other tests. Some researchers conducted in-situ test to correlate the LWD modulus with modulus of subgrade reaction obtained using plate load test. Tests were carried out on well-compacted subgrade at two different highway construction sites. Three falling heights and weights were used to produce six different levels of dynamic loads. Results showed that there is a reasonable linear correlation between the dynamic deflection modulus and the coefficient of subgrade reaction of well-compacted subgrade. The dynamic deflection modulus is not largely affected by variation of the falling energies. Application of the LWD for compaction control and as an alternative method to the PBLT would lead to significant cost savings[23].

A comparative study was done using LWD and BB on low volume road. The back calculated and composite modulus of subgrade is validated at given moisture content using repeated tri-axial test. Also, validation of static modulus with California bearing ratio (CBR) related subgrade modulus shows moderate correlation of 0.67 to 0.74 whereas dynamic modulus shows good correlation of 0.74 to 0.93 for different types of soils, respectively. Therefore, the comparative analysis shows that LWD provides reliable subgrade modulus values, and it can be used as a quick subgrade strength evaluating tool for low volume roads [24]

Various researchers used FWD for elastic modulus estimation. LWD test were performed on the individual layers of the pavements independently like base course, subbase course and subgrade course. This test was also performed on the parking lot surface but not performed on the existing highways whether it is blacktop or concrete pavement. LWD was used as QC/QA tool for different pavement layers but its use as a tool to determine in-situ elastic modulus incorporating temperature and moisture change was not investigated. However, composite layer modulus was evaluated using the LWD for QA. Measuring a composite layer composed of the material under consideration and underlying base, subbase and subgrade materials.

A. Light Weight Deflectometer (LWD) Testing

The LWD is a simple, portable device with same working principle as FWD. LWD are primarily used for estimating the elastic modulus of bound/unbound layers of pavements. It is mostly used as a quality control and quality assurance (QC/QA) tool for compacted unbound layers.

The general setup of LWD consists of a mass10-20 kg falling freely on the buffer plates. Buffer plate transmits this impact force on to the loading cell. The loading cell transmits the load to steel base plate of diameter 100-300 mm. The steel plates are placed on the rubber mat that acts as a uniform base for efficient load distribution to the ground surface in contact. For surface with too many undulations a thin layer of uniformly graded sand is placed on to the testing location before performing LWD test. The resulting surface deflection (d0) and force of impact (Fpeak) is measured and recorded. The steel base plate and falling weight is designed in such a way that it mimics the actual stress occurring due to moving traffic load on base and subbase layer. For calculating the elastic modulus first three drops are ignored as seating drop and rest of drops are used in the analysis. The linear elastic half space theory is used to calculate the modulus of material. Assuming the layer as homogenous and isotropic the resulting peak stress and deflections are used combined altogether yields elastic deformation modulus (Evd). LWD is generally equipped with quick data collection mechanism; the accuracy of data varies within a range of ± 25% from its mean value. The LWD holds advantage for QC/QA of bound and unbound materials due to its portability, economical viability and self sufficiency in data collection.

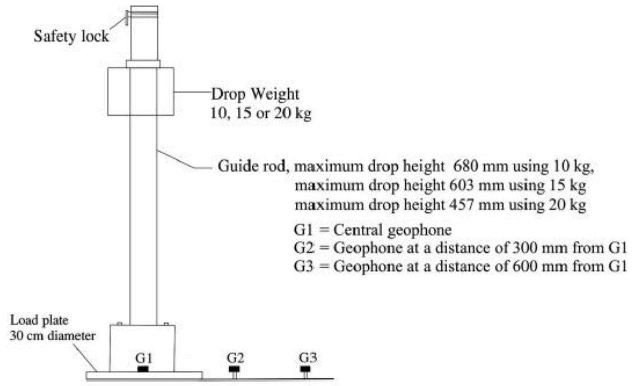

Fig. 1. A typical setup of Light Weight Deflectometer [3]

B. Parameters influencing LWD data

A number of variables such as plate diameter, height of fall, weight of fall, number of geophones and plate-surface interaction may influence the repeatability and reliability of data collected using LWD. The poor contact between plate-surface results in lower value of stiffness this may be due to the early generation of low level of peak force and consequently horizontal movement of instrument due to poor contact with surface. The increase in degree of compaction of pavement layer enables proper plate-surface contact resulting in improved peak stress and peak deflection. For loose and weak materials, the geophone reading raised concerns as punching failure was observed under the foot of geophone and material in contact [25] It is used to predict the in-situ responses i.e. deflection and surface modulus of different layers and structural evaluation.

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In-situ quality assessment of base course, subbase course and subgrade in terms of compaction is very essential. Density estimation of different layers of pavement consumes a lot of time and manpower. Many researchers investigated the utility of LWD as QC/QA tool. [26] conducted in-situ tests to investigate elastic modulus obtained by geogauge and dynamic modulus obtained by LWD.

A good correlation was established between elastic modulus (obtained by geogauge) and dynamic modulus (obtained by LWD) along with elastic modulus (obtained by plate load test) and DCP penetration test data. The results showed that geogauge and LWD can be used to calculate the elastic modulus or elastic characteristics of compacted layers as well as initial modulus of cement - treated clay. The wide scatter diagram and inefficient repeatability makes its use objectionable as QC/QA tools for treated layers.

C. Investigation of factors influencing LWD modulus

The strength related parameters of pavement layers are very sensitive to moisture change. Change in moisture content other than OMC results in volumetric change in compacted base or subgrade layer. Strength parameters like CBR and modulus decreases with increase in moisture content. Since pavement layers are composed of mixes of different materials, so they allow the seepage of water through them. So instead of using annual precipitation data it's more conservative to use intensity and duration of precipitation data for pavement design. Lower intensity and higher duration of precipitation would lead to increased water infiltration in subsequent layers. Influence of in situ moisture content and density of subgrade on elastic modulus values for various falling weights was assessed by correlation analysis [3].

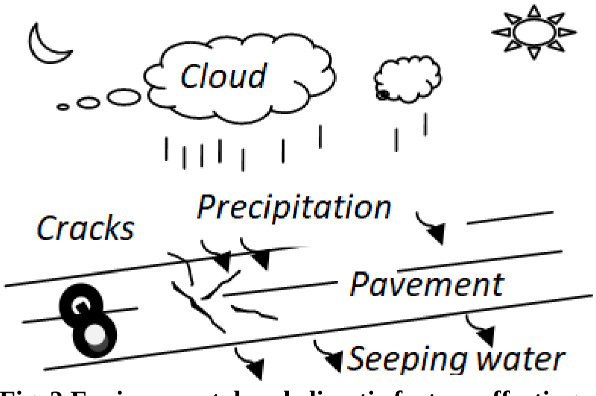

Fig. 2.Environmental and climatic factors affecting pavement

Many investigations on the effect of moisture variation on soils, for use in mechanistic based quality management approach. Results showed weak association between density and modulus of layer. Consistencies in results were found when moisture content and modulus based measurement are taken simultaneously. Significant variations in layer modulus were observed with slight variation in moisture and material indices [27]

D. Ground Penetrating Radar (GPR)

GPR is a ground exploration technique mainly used in pavement for layer thickness estimation, utility detection, for inspection of subgrade soil, crack detection. GPR works on the principle of pulse system using radio waves and mainly used for layer thickness estimation[18]. GPR finds wide application in pavement evaluation, such as finding layer thicknesses, to detect the discontinuities within the layers such as voids and cracks. In this technology, radio signals of high frequency are transmitted through pavement structure, with change in layers properties the signals are reflected back and are detected by receiver GPR. Change in material properties causes change in energy of reflected signals , these signals when intercepted by receivers are combined to visualize the sectional profile of pavement and then an interpretation is done for pavement thickness [28], [29]

E. GPR for thickness estimation of pavement layers

Pavement evaluation requires the elastic/stiffness modulus estimation of in-situ pavement by destructive or non-destructive testing (NDT). Due to time consuming nature only, limited tests are conducted. NDT are most commonly used in road infrastructure by highway authorities for regular monitoring and decision making for scheduling and prioritizing road maintenance rehabilitation (M&R) strategy. GPR being a NDT test helps to estimate the thickness of pavement layer for long stretches. For thickness calibration of the GPR, only four numbers of cores are sufficient[30]. Fig. 3 shows the typical scan profile i.e. radargram image obtained from 400 MHz ground coupled penetrating radar, obtained using the SIR 4000 developed by GSSI Inc. Some researchers made an attempt to predict strain in asphalt pavement using artificial neural network. FWD deflection and GPR thickness data were used as input parameters. Result obtained from analysis showed better efficiency of ANN in strain prediction of asphalt pavement[31].

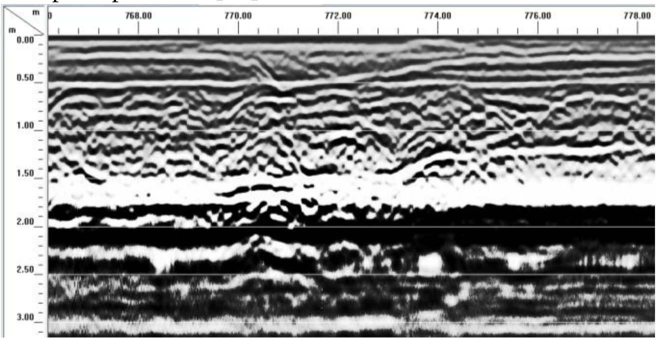

Fig. 3. A radargram image of pavement using 400 MHz GPR

F. Studies on dielectric properties for GPR investigation

The main material property which works behind the GPR is the dielectric property of materials. Materials when comes in interaction with electric and magnetic field the molecules of material get polarized. With increase in dielectric constant, the materials will get more polarized. The dielectric response of hot mixed asphalt was investigated; also the effects of bitumen content, air voids and density on dielectric response were examined. The density and dielectric constant are found to have a linear relationship.

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Higher the density higher the dielectric, but limited effect of bitumen content was observed. For heterogeneous bitumen mixtures, the dielectric mixing model was proposed. A density prediction model was developed to which uses dielectric constant, air voids and bitumen content to estimate density[32]. Further investigation were conducted by [33] on the mechanical properties of materials from their dielectric characteristics. The Young's modulus of elasticity was measured on each grid node using light falling weight deflectometer (LFWD).

The model for predicting strength properties of pavement was developed by comparing the observed elastic modulus and the electromagnetic response of substructure on each grid node. A good agreement between observed and modeled values was found, which shows great promises for large-scale mechanical inspections of pavements using GPR. Some researchers proposed a new methodology to measure the HMA density in terms of dielectric constant variations, known as dielectric sweep test. The dielectric was monitored and the changes were compared to pavement performance data i.e. permanent deformation. Comparison of measured dielectric constant was done with the calculated dielectric constant. Change in bulk specific gravity with change in HMA density was also done. Significant dielectric constant changes are noticed after the primary stage in HMA layer[34].

G. Studies on crack and void detection using GPR

Some researchers investigated the applicability of GPR for crack and void detections. To detect the voids and anomalies in flexible pavement [35] investigated GPR capability of crack detection and characterization in pavement. The cracks were detected due to amplitude variations at the cracking points. The crack depth was found with the hyperbolic curves but a relationship could not be established between the crack depth and measured amplitude in wave. Investigation of pavement shoulders has been done using a GPR as shown in the fig. 4.

Fig. 4. Exploration of pavement shoulder using 400 MHz GPR

III. RESULT AND DISCUSSION

The mean composite modulus at each test point is analyzed using LWDmod program developed by Dynatest. The first three drop at each test point was excluded during calculation of composite modulus. The layer thickness data obtained using the GPR were used as an input. For the initial seed modulus of granular material, the CBR test was conducted on the samples collected from the field. The granular materials collected from the field were oven-dried to determine the moisture content in the field. For initial seed modulus of material, the resilient modulus value was calculated as per the Indian road congress guide [36].

Table 1 presents latitude, longitude, peak force generated, deflection, stiffness of layer and the thickness of bituminous layer and granular layer. The composite modulus measures from the in-situ testing and the normalized composite modulus for 35 ^{o}C pavement surface temperature. With increase in thickness of pavement base layer the composite modulus were found to increase.

IV. CONCLUSION

An application of LWD and GPR in the area of pavement evaluation, maintenance and rehabilitation work are exploring in this paper.

- The large scattering diagram, lower repeatability, inconsistency in measured dynamic modulus at same point causes of LWD interpretation and correlation very difficult. This can be overcome with large set of in-situ test, control lab test, with application of suitable shift factor from laboratory test result to in-situ test result for a particular type of parameter.
- Due to lower amplitude of load levels it can be very efficiently used for the bound/unbound layers of base, subbase and subgrade layers for QC/QA. For asphalt layer its use is very limited due to the level of stress applied and it may result in over prediction of elastic modulus, because the wearing course quality is far more superior to the bound/unbound layers. Since the level of stress applied has significant influence on the LWD stiffness, hence more tests on different layer thickness should be done in conjunction with standard FWD for better correlation between LWD and FWD.
- Investigation of change in layer modulus with the change temperature, moisture content, in different season can help in better estimation / prediction of stiffness modulus of layers. Investigation on layer modulus with the change in moisture content, particle size distribution and maximum dry density can help better QC/QA for different types of layers.
- GPR in pavement evaluation is manly related to the estimation of layer thickness for asphalt and concrete pavements by using horn antennas. GPR with higher frequency can be 16 -36 GHz can be used more efficiently for finding the pavement anomalies such as cracks, voids etc.
- The dielectric of pavement layer material has significant influence on the predicted layer thickness; hence for each type of mixes (as per specifications) the dielectric and its variation with time should be properly investigated.

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Table- I: Composite Modulus of pavement layer at different points

Chain-age (m)	TSur	Latitude	Longitude	P (kN)	δ (μm)	Stiffness (kN/m2)	H1 (mm)	H2 (mm)	Eo (MPa)	Eo, corrected (MPa)	Esub (MPa)
250	36	25°16'22.2"N	85°00'35.7"E	7.1	46	154348	95	667	598	629	128
750	37	25°16'14.4"N	85°00'33.6"E	7.2	48	150000	105	632	536	574	127
1000	36	25°16'06.5"N	85°00'31.6"E	7.2	43	167442	94	695	546	574	123
1250	35	25°15'58.6"N	85°00'29.6"E	7.1	42	169048	136	646	568	588	111
1500	36	25°15'50.7"N	85°00'27.6"E	7.4	57	129825	75	737	504	530	131
1750	40	25°15'42.8"N	85°00'25.7"E	7.1	43	165116	103	478	707	798	109
2000	41	25°15'34.9"N	85°00'23.6"E	7.4	53	139623	136	799	683	785	120
2250	41	25°15'27.0"N	85°00'21.6"E	7.4	49	151020	120	73	512	589	116
2500	42	25°15'19.1"N	85°00'19.6"E	7.3	52	140385	152	695	498	584	118
2750	41	25°15'11.2"N	85°00'17.6"E	7.1	41	173171	128	751	568	653	134
3000	39	25°15'03.4"N	85°00'15.3"E	7.1	47	151064	85	632	512	568	126
3250	38	25°14'55.6"N	85°00'13.2"E	7.1	51	139216	94	639	597	650	129
3500	37	25°14'48.2"N	85°00'10.1"E	7.1	50	142000	94	876	536	574	120
3750	38	25°14'40.5"N	85°00'06.4"E	7.1	42	169048	85	541	579	630	121
4000	40	25°14'33.3"N	85°00'03.3"E	7	41	170732	103	792	557	629	110
4250	39	25°14'25.3"N	85°00'00.7"E	7.2	41	175610	136	639	497	551	94
4500	38	25°14'17.6"N	84°59'57.7"E	7.2	38	189474	52	709	603	657	129
4750	40	25°14'10.8"N	84°59'52.9"E	7.3	56	130357	94	681	514	580	115
5000	39	25°14'04.1"N	84°59'47.9"E	7.3	52	140385	120	695	621	688	102
5250	41	25°13'57.4"N	84°59'42.5"E	7.2	49	146939	64	555	542	623	134
5500	37	25°13'50.6"N	84°59'38.2"E	7.3	48	152083	103	541	590	631	117
5750	36	25°13'43.6"N	84°59'33.6"E	7.2	46	156522	120	555	613	645	131
6000	36	25°13'36.1"N	84°59'30.2"E	7.4	47	157447	152	653	587	618	109
6250	36	25°13'28.4"N	84°59'27.6"E	7.2	49	146939	205	618	565	594	126
6500	36	25°13'20.8"N	84°59'24.7"E	7.2	50	144000	94	604	543	571	105
6750	36	25°13'13.3"N	84°59'21.1"E	7.2	49	146939	228	59	524	551	107
7000	36	25°13'06.1"N	84°59'17.2"E	7.1	50	142000	142	604	562	591	124
7250	37	25°12'58.9"N	84°59'13.1"E	7	48	145833	168	604	547	585	102
7500	36	25°12'51.8"N	84°59'08.9"E	7.1	49	144898	85	632	536	564	93

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