Structural evaluation and quality assurance of flexible pavement using Light Weight Deflectometer
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ABSTRACT

India is rapidly growing country and many road structures are in constructing phase. It is required to be compliance with quality assurance for prevent failure and long performance. Quality assurance work involves the compaction parameter but from recent years, it is moving to a modulus - based method. The aim of this paper is to evaluate the elastic modulus of flexible pavement using portable light weight deflectometer and develop a relation with density and moisture content for quality assurance. In situ test measurements are taken on 40 test locations, the LWD used for determine elastic modulus, core cutter method used for density and samples are tested for moisture content in a laboratory. Elastic modulus is back-calculated using LWDmod software. The multiple linear regression relation shows a coefficient of determination ($R^2$) of 0.491 and trend line of elastic modulus increases with an increase in bulk density and decrease in water content.

Keywords: Light weight deflectometer (LWD), quality assurance, elastic modulus, density and moisture content.

1. Introduction

India is rapidly growing country and road networks are one of the key components of contributing roles in economy. Nowadays, many road works are at stage of distortion due to many causes of failure. A pavement performance calls for accurately designed pavement layers and a strict quality control and quality assurance program during construction. Design of pavement involves selection of proper material, which would suffice the strength to sustain the given traffic growth and also rehabilitated work compliances with quality assurance. To identify causes of failure a pavement evaluation study is required and based on its maintenance measure strategies are bordered.

Traditionally in India, quality assurance works of highways are confirmed by density and degree of compaction. MORTH guidelines (2004) suggest measurement of density at every 500 sq.m of work and one density measurement is the average value of six readings. Each reading requires about half hour. Therefore, it is laborious and time consuming. For rapid work, empirical relations are required. Nowadays, shift around the world from the empirical approach to mechanistic-empirical approach of pavement layer design and quality assurance work. AASHTO (1993), the IAN 73 of UK (2009) and IRC 37- 2012 guidelines design guidelines of flexible pavements incorporated modulus based mechanistic empirical approach for design. Therefore, it is important to know mechanistic behavior of material for pavement design and also for quality assurance works. Assessment of modulus does not part of quality assurance, although it is the most important parameter in mechanistic pavement design as studied by Gurp et al. (2010). The importance of evaluation a sub grade modulus for structural design of pavement is absolute necessity due to appreciation of semi- mechanistic design
approach. Conventional methods are laborious and time consuming as studied by Erlingsson (2007).

2. Literature review

In this section, correlation between modulus with density and factors influencing the LWD reading is briefly reviewed. Sulewska (2004) found dynamic modulus of deformation obtained by the light drop-weight tester increase with the increase in degree compaction. Erlingsson (2007) found an increase in trend of CBR with increasing trend in dry density and also increased in modulus but relationships are not significant. Moreover, a significant correlation may be developed when moisture content is considered. George et al. (2009) found a positive effect of dry density and negative effect of liquid limit, plasticity index and moisture content on modulus value and on CBR values, where modulus values is obtained through PFWD, the observed coefficient of determination $R^2$ of 0.83 and 0.85 respectively. Tehrani (2014) developed regression models between NDG obtained dry unit weight with LWD obtained modulus and DCP obtained modulus value with the coefficient of determination $R^2$ of 0.475 and 0.58 respectively. Moreover, dry unit weight has positive and water content has negative influence. Post compaction due to LWD drops causes the increase in the surface modulus with increasing in drop numbers.

The higher the degree of compaction lower will be the increase in the surface modulus as found by Gurp et al. (2010). Sing et al. (2010) suggest, the adequate correlation between the dry density of material and its dynamic moduli obtained from the LWD to be used for compaction control. According to Kavussi et al. (2010), the dynamic moduli increase with the increase in weight but remained the same with the drop height variations. The results of the statistical analysis show a good correlation do exist between CBR and PFWD obtained elastic moduli for CBR within the range of 20% to 80%. Rathje et al. (2006) encourage modulus values as a quality control test.

According to Sing et al. (2010), the depth of influence of the LWD is 1.5 to 2 times the plate diameter. Lin et al. (2006) found the important factor affecting the surface modulus is the loading plate size. The surface moduli from the 100 mm loading plate were about 1.5 times higher than those from the 300 mm loading plate. For loading plates 100 mm and 300 mm, the effects of drop height on PFWD moduli not play a role in variation measurement, as different drop heights yield similar moduli. The effects of drop height on PFWD moduli were small. The test results illustrated, the moduli remained about the same regardless of the drop heights. Mooney and Miller (2009) found measurement depths agree with reported values of 1.0 D but are less than other reported values ranging from 1.25 to 2.0 D. The depth to which different contact stress distributions affect in situ stress is approximately 1.0 D–1.5 D, covering the entire influence depth of the LWD test, where D is a diameter of loading plate.

3. Overview of light weight deflectometer (LWD)

There are many in-situ tools available for measure elastic modulus for structural evaluation but out of many tools, LWD emerges as very high convincing and acceptable tool. In this work, LWD produced by dynatest is used. The LWD consists of a loading device that produced a defined load pulse, a loading plate, and one center geophone sensor (deflection data device) to measure the center surface deflection. This test method is a type of plate bearing test. The load is force pulse generated by a falling weight (mass) dropped on a buffer
system that transmits the load pulse through a plate resting on the material to be tested. The resulting force and velocity time histories are measured, respectively below the center of the corresponding displacement time histories are automatically obtained by means of integration (internal to the device) of the recorded velocity. The instrument is connected to a personal digital assistantship (PDA) equipped with software for recording, data interpretation, and visualization. An estimated value of the surface moduli is obtained by equation (1) expressed by Egorov (1965), where $E_0$ is the surface modulus (MPa), $\sigma_0$ is contact pressure at load (kPa), $a$ is a radius of the load (mm), $d_0$ is deflection at the centre of load ($\mu$m) and $\nu$ is poisson’s ratio.

$$E_0 = 2(1-\nu^2)\frac{a\sigma_0}{d_0}$$

The LWD is similar to the falling weight deflectometer (FWD), used for road works but is portable with a weight of 15 kg to 25 kg, can be operated with a one person and test can be done in 1 to 2 minutes as use by Lin et al.(2006), Fleming et al. (2007), Gurp et al.(2010) and Singh, et al.(2010)

3.1 Site description

The selected stretch is a construction site of road of kutch district, where strengthening is in progress. The stretch caters heavy traffic of shipping, cement, salt and fishing industry. The road was 12 m wide with 10 m of carriageway and 1 m of unpaved shoulders on each side. Entire stretch is passing through plain terrain and marshy land zone, have sufficient drainage condition and also observed rain cuts at some places on the embankment beyond the paved shoulder.

3.2 In-situ test methodology

The test was conducted according to the procedure given in ASTM E2583-07 (2011) and at every point, where LWD was conducted, at a same point the density was also determined as per IS 2720 Part XXIX. Samples were collected for determine moisture content in a laboratory. The 10 kg drop weight was allowed to fall from a height of 850 mm. The diameter of loading plate was 300 mm. The generated impact force was in the range of 7.0 - 8.0kN. The stress distribution factor and the poisson’s ratio were set to 2 and 0.4 respectively. The LWD test readings were taken at a definite intervals of 20 m on either side in staggered pattern in 10 m. Total 40 readings taken using LWD and also dry density measurement at the same point. Sand pad was used to level up the surface and to ensure contact of the loading plate. The sand used was uniformly graded passing 1 mm and retaining 600 micron. The results namely, the force, pressure, deflection, pulse duration and the surface modulus evaluated were stored in the PDA through the data collection software as shown in Figure 1.

![Figure 1: Data collected in PAD](image)
3.4 Data analysis

For data analysis LWDmod, a back calculation programme developed by the dynatet is used. It can carry out analysis up to three layers. The software uses odemark-boussinesq method for analysis.

3.5 Drop quality

It is important, which and how many drops (i.e. drop quality) are considering as input in LWDmod for analysis. Deflection-time history gives idea about it. The drops are assessed based on the emerging patterns of deflection time histories. Some of the original field recordings of PAD are shown in Figure 2. Figure 2 (a) shows normal deflection time histories and it is acceptable for analysis. Herein deflection-time pulse (D1) almost returning to starting or initial level with a less value of offset or no offset, the difference between start and end level for the deflection curve is called the offset. This condition represents a good contact between loading plate and material layer. Generally, such good drops are used for analysis. In Figure 2 (b) the deflection time pulse (D1) shows irregular pattern and not returning to starting level and also comparatively high value of offset. It is due to equipment moving out of position, while conducting test and is considered as bad drops, all such bad drops are omitted in analysis because such drop leads to wrong elastic modulus calculation.

3.6 Seating drops

Seating drops are for proper contact between circular loading plate and material under test. It is recommended that the first 3 to 4 drops are considered as seating drops and neglected in analysis of stiffness modulus Steinert et al. (2006). First three drops a deflection time histories are shown in Figure 3.
In case of first drop of deflection-time histories, it is clearly observed a deflection-time pulse not returning to its initial or starting level and has high value of offset, this is indicative of poorly compacted material or shearing on weak materials. In second drop, offset is progressively reduced and in third drop, it almost reaches to initial or starting level and neglected value of offset. Effect of compaction under testing showing reduced in deflection with a number of blows and a ‘permanent’ element of the deflection-time pulse. It is suggested that use sand pad of uniformly graded passing 1 mm and retaining 600 micron for better contact between loading plate and material layer for uniform distribution of stress.

4. Result and discussion

Elastic modulus is back calculated using LWDmod, bulk density is obtained by core cutter method and water content determined in a laboratory. Density is a key component for quality assurance work and high value of density indicative of good compaction and in this work, its range between 1.4 to 2 gm/cc with coefficient of variation 0.435 and water content ranges between 7 to 33 percent with coefficient of variation 0.376. Elastic modulus ranges between 30 to 199 Mpa with coefficient of variation 0.092. Therefore, increase in value of bulk density and decrease in value of water content with increase in elastic modulus, it is indicative of good compliance with quality assurance.

**Table 1: Model Summary**

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
<th>Change Statistics</th>
<th>Sig. F Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R Square Change</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>F Change</td>
<td>df1</td>
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<tr>
<td>1</td>
<td>.700</td>
<td>.491</td>
<td>.463</td>
<td>33.05667</td>
<td>.491</td>
<td>17.821</td>
</tr>
</tbody>
</table>

**Table 2: Coefficients**

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>-103.167</td>
<td>100.453</td>
<td>-1.027</td>
<td>.311</td>
</tr>
<tr>
<td>1 Bulk Density (gm/cc)</td>
<td>138.501</td>
<td>48.967</td>
<td>.484</td>
<td>2.828</td>
</tr>
<tr>
<td>Water Content (%)</td>
<td>-1.507</td>
<td>.978</td>
<td>-.264</td>
<td>-1.541</td>
</tr>
</tbody>
</table>

The multiple linear regression method is used for developing relation of independent elastic modulus with dependent bulk density and water content. Coefficient of determination (R²) of 0.491 is observed. The regression equation is significant (F (2, 3723) = 17.821, p <.001) shown in Table 1.

From Table 2 coefficients, it is observed a predictor have significant standardized regression weights of bulk density is (Beta = 0.484, t = 2.828, p = 0.008) and for a water content (Beta = -0.264, t = -1.541, p = 0.132). The sign of the regression weights is in the predicted direction.
with elastic modulus is positively associated with bulk density but negatively associated with water content. Regression standardized residual is normally distributed with standard deviation 0.974 as shown in Figure 4. The scatter plot of bulk density with elastic modulus and water content with elastic modulus are shown in Figure 5 and Figure 6 respectively.

A trend line shows elastic modulus increases with an increase in bulk density and decrease in water content. A very large scatter in the data with low correlation factors of linear trend line is observed. It may be due to material gradation, environment and device factor, which are not included in this study. It may be possible to get good relationship by reduce some of the outlier point.
5. Conclusion

LWD is found to be a very useful tool for evaluating the in-situ strength of materials, where conventional methods being laborious. It was found to be a less time consuming as it took 5 - 10 minutes for its operation per test for data recording. Less but skilled personnel are required for operation LWD since it is very sensitive equipment.

Following conclusion derived from this study:

1. Initial seating drops are required since surface modulus increases with increases in drops up to 3rd - 4th drop after which a constant surface modulus is achieved if the pavement layer is properly compacted.

2. Bulk density range between 1.4 to 2 gm/cc with coefficient of variation 0.435 and water content ranges between 7 to 33 percent with coefficient of variation 0.376. Elastic modulus ranges between 30 to 199 Mpa with coefficient of variation 0.092.

3. The multiple linear regression relation have a coefficient of determination (R²) of 0.491 and trend line shows elastic modulus increases with an increase in bulk density and decrease in water content.

4. The high scatter seen is due to variability of the material, which was site specific. The relationship between elastic moduli and density will improve with more homogenous material.

Acknowledgment

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6. References


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