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Relation-Ship between Dynamic Deformation Modulus (E_{vd}) and CBR for Common and Granular Materials

M. A. Kamal[1], M.U. Arshid[2], M.I. Sha[3], E.A. Khan[4]

[1]Civil and Environmental Engineering Department, University of Engineering& Technology, Taxila, Pakistan
[2,3,4]Civil Engineering Department, University of Engineering & Technology, Taxila, Pakistan
[2]usman.arshid@uettaxila.edu.pk

Abstract- California bearing ratio (CBR) is the reliable and direct measure of the sub grade but it takes a considerable time for its evaluation strength. As a result of the enormous work being carried out in the field of Transportation Engineering, there has been a shift from empirical to mechanistic-empirical pavement design. Consequently, there need arises to evaluate the modulus value of the subgrade, sub-base and base at a speed consistent with modern construction apparatus and the building pace of the construction industry at design and construction stages. The objective of this study was to correlate the results of one of the state of the art Non Destructive Testing Devices (NDT), the Light Falling Weight Deflectometer (LFWD) with the traditional CBR. LFWD tests were conducted on each sample at 9 locations i.e. middle, corners and sides ofthe samples having various densities. The CBR test following the standard procedure were done on the identical sample used for the LFWD tests. Consequently, an extensive experimental work was carried out and as a result statistical correlations have been developed between Dynamic Deformation Modulus (E_{vd}) and CBR for Granular (A-1-b) and common (A-4) soil. The coefficient of determination for both types of materials shows a strong relationship between Evd and CBR.

Keywords- Dynamic Deformation Modulus, California Bearing Ratio, Stiffness/Strength, Subgrade, Non Destructive Testing, Light Falling Weight Deflectometer,

I. Introduction

Keeping in mind the significance of soil stiffness and potency in material evaluation, a mutual effort has been made during the last decade to develop methods which can help to measure the stiffness and strength before and during the pavement construction. Advancement of pavement design from empirical to mechanistic-empirical procedure has emphasized the importance of direct monitoring of stiffness and strength. (i-v).For obtaining a qualitative assessment of the subgrade, the traditional Field-density test, visual inception and observation of construction equipment are required. Usually, the achievement of minimum stiffness/strength cannot be ensured adopting these methods until/unless stiffness and strength are related to moisture-density in a two-step process (vi).

There are unconventional construction practices and materials which include recycled and reclaimed materials that are money saving/cheap and eco-friendly. Methods of quantitative evaluation of alternative construction practices and material would be facilitated if their strength and stiffness are directly monitored(vii).The particular motives are summarized below:-

- To enhance the strength/stiffness of subgrade/ embankment soils using the LFWD.
- To initiate and develop co-relations among Dynamics Deformation Modulus (Evd) and California Bearing Ratio.
- To suggest methods that can become criteria for controlling construction of pavement layer and embankments using in-situ stiffness.

II. Literature Review

The most challenging task in road construction is soil compaction; usually the drill is to acquire sufficient field density as compared to a maximum dry density achieved in laboratory using standard or modified enhanced proctor tests. The general techniques to find out the strength of component layers and sub-grades include CBR, R-V value etc. The above mentioned methods are accurate but consume a lot of time and space (not usually though), laboratory testing and co-relations. During the last few years road engineers prefer simpler, faster and more reliable techniques of evaluating pavements, such that the obtained results can be corrected with the CBR test(viii), similar study has been conducted to compare the results of clegg impact hammer and California-bearing ratio (CBR) by (ix). Accordingly, it is mandatory to co-relate the results achieved through CBR method and the Falling Weight Deflectometer (FWD) or Light Falling Weight

Deflectometer (LFWD) (x-xi). Structural testing and evaluation of pavements (STEP) provides an estimate of pavement configuration, and subsequently remaining structural life, using analysis of falling weight Deflectometer pavement deflection data (xii)

One of the recent and most advanced device is LWD (Light Weight Deflectometer), its readings determine the appropriate stiffness of pavement foundations (modulus value). Such methods help the engineers to design pavements using analytical methods and procedures such as AASHTO method 1993.

The basic motive of this research, which was held under controlled laboratory condition for example moisture content and degree of compaction, was to propose a relation between Dynamic Deformation Modulus (Evd) and CBR for common and granular materials. Common material is the term that is used repeatedly in this study, it refers to the local material used in permanent subgrade whose CBR is greater than 5% passing more than 35% from a 0.075 mm (#200) sieve and thus is 'silt-clay material" as per AASHTO grading whereas granular material have classified as less than 35% material passing (# 200) Sieve as per AASHTO.

A. Performance Based Comparison of Various NDT

The most important factor which effects the design thickness of a flexible pavement is the subgrade soil strength in relation with the given traffic, materials and environment conditions. For usual flexible pavement structure, the subgrade specifically contributes towards the total deflection of the pavement system. The predominantly acknowledged relationship between the CBR value and modulus of the subgrade was introduced by [xi]

$$M_R = 17.58 \text{ x } CBR^{0.64} \qquad (Mpa)$$

Correlation model proposed by [xii] has been adopted by AASHTO guide (1993) to determine resilient modulus of subgrade based on CBR of fine grained soils having a soaked CBR of 10% or less.

$$Mr = 10.34 \text{ x } CBR \qquad (Mpa)$$

Fleming has reported a consistent correlation of 0.6 between the stiffness moduli of the German Dynamic Plate Tester (GDPT) and FWD. Realizing the limitation of FWD in terms of its mobility and financial aspects, Fleming conducted a series of field of tests using the LFWD (TFT, GDP, and Prima 100) & FWD. They reported the following relationship between FWD & Prima 100 [xii].

$$M\text{FWD} = 1.031 \text{ ELFWD (Prima 100)}$$

Fleming further reported that variation of transducer type, software analysis and mass also effect the measured stiffness. [xiii]

A comparative study on German light drop weight (LDW) and Dynamic Cone Penetration (DCP) tests has been carried out by [xiv]. The relationship between the modulus measured by the LDW (ELDW) and the in situ CBR values obtained from the DCP was expressed as follows for clayey and sandy soils.

$$E_{LDW} = 600 \times \text{In} \frac{300}{300 - 6.019 \times \text{CBR}^{(1/1.41)}} \qquad \text{(Clayey Soils)}$$

$$E_{LDW} = 600 \times \text{In} \frac{300}{300 - 4.035 \times \text{CBR}^{(1/1.41)}} \qquad \text{(Sandy Soils)}$$

Where; ELDW is in MPaand CBR are in percentage.

The relationship between elastic moduli estimated using LFWD and back-calculated resilient modulus values (M_{FWD}) using FWD has also been worked out by [xv]

$$M_{FDW} = 0.97(\text{E}_{\text{lfwd)}}$$

A direct relationship between the penetration rate (DCPI) for DCP tests measured in mm per blow, and the layer-moduli (calculated in MPa) was proposed by Chen [xvi]

$$E_s = 664.67 \text{ x DC} PI^{-071.68}$$

Some of the recent technologies introduced for the estimation of pavement's resilient modulus, include, the free resonant column, Impulse-echo test, artificial neural networks, ground penetrating radar and surface waves. The subgrade resistance modulus (k_{30}, E_{v2}, and E_{vd}) also get influence of the granite gravel content, and the resistance modulus increases significantly beyond granite gravel content of 50% [xvii]. Mechanical parameters such as the moduli of track-bed layers, their damping ratios, thicknesses as well as the average track surface wave velocity are major parameters governing the performance of railway tracks [xviii]. Correlations between several soil parameters including the Evd and performance of the surface layers of soil have been evaluated by [xix].

III. EXPERIMENTAL WORK

Following tests were carried out in the laboratory (xx to xvii)

a. Sieve Analysis and Soil Classification (AASHTO T-27)
b. Moisture Density Relation Ship (AASHTO T-180)
c. Density Test by Sand Cone Method (AASHTO

T-191)

d. California Bearing Ratio Test (AASHTO T-193)

e. Dynamic Deformation Modulus, Evd (German TP BF – StB part. B 8.3/1997)

For granular and common materials results have been summarized in Table I.

TABLE I

PROPERTIES OF GRANULAR AND COMMON MATERIALS

<table>
<tr><td colspan="12">Sieve Analysis & Soil Classification (AASHTO T-27)</td></tr>
<tr><td colspan="6">Granular Materials</td><td colspan="6">Common Materials
(81 % passing # 200 (Silt-Clay)</td></tr>
<tr><td colspan="3">Passing # 200</td><td colspan="3">3 %</td><td colspan="4">Liquid Limit (AASHTO T-89)</td><td colspan="2">21.60</td></tr>
<tr><td colspan="3">Passing # 10</td><td colspan="3">54 %</td><td colspan="4">Plastic Limit (AASHTO T-90)</td><td colspan="2">17.20</td></tr>
<tr><td colspan="3">Soil Group</td><td colspan="3">A-1-b</td><td colspan="4">Plasticity Index</td><td colspan="2">4.40</td></tr>
<tr><td colspan="6"></td><td colspan="4">Soil Group</td><td colspan="2">A-4</td></tr>
<tr><td colspan="12">Moisture Density Relation (AASHTO T-180)</td></tr>
<tr><td colspan="4"></td><td colspan="4">Granular Materials</td><td colspan="4">Common Materials</td></tr>
<tr><td colspan="4">Maximum Dry Density (MDD)</td><td colspan="4">143.5 lbs/cft</td><td colspan="4">125 lbs/cft</td></tr>
<tr><td colspan="4">Optimum Moisture Content (OMC)</td><td colspan="4">5.8 %</td><td colspan="4">11.20 %</td></tr>
<tr><td colspan="12">3- Point CBR Test (AASHTO T-193)
Density achieved (lbs/ft^3) with corresponding CBR (%)</td></tr>
<tr><td colspan="6">Granular Materials</td><td colspan="6">Common Materials</td></tr>
<tr><td colspan="2">131.95</td><td colspan="2">137.60</td><td colspan="2">143.50</td><td colspan="2">110.75</td><td colspan="2">118.10</td><td colspan="2">125</td></tr>
<tr><td colspan="2">32.00</td><td colspan="2">50.50</td><td colspan="2">80.55</td><td colspan="2">4.60</td><td colspan="2">7.10</td><td colspan="2">8.30</td></tr>
<tr><td colspan="12">Sand Cone Method for Density (AASHTO T-191)
Relative Density (%)</td></tr>
<tr><td colspan="6">Granular Materials</td><td colspan="6">Common Materials</td></tr>
<tr><td colspan="2">85.70</td><td colspan="2">90.80</td><td>94.55</td><td>99.60</td><td colspan="2">81.15</td><td>85.05</td><td>89.55</td><td>94.40</td><td>99.85</td></tr>
<tr><td colspan="12">Corresponding LFWD E_{vd} (MPa)</td></tr>
<tr><td colspan="6">Granular Materials</td><td colspan="6">Common Materials</td></tr>
<tr><td colspan="2">36.00</td><td colspan="2">38.00</td><td>40.20</td><td>44.25</td><td colspan="2">26.35</td><td colspan="2">28.25</td><td>30.40</td><td>31.60</td></tr>
</table>

A. Determination of Dynamic Modulus.

The LFWD used in the current study is a portable FWD, an alternative in-situ testing device to the plate load test. To determine the soil bearing capacity and the compaction or consolidation of soils and non-cohesive subbases, primarily for earthwork and road construction the dynamic plate load test employing the Light drop-weight tester is used over and above for soil improvement applications. The test method may be used to determine the dynamic modulus of deformation (Evd) of soil in the range of 15 – 80 MN/m^2.

The device consists of free falling drop weight of 10 kg onto the loading plate (300 mm diameter) producing a load pulse, of maximum input force of 7.07kN and one geophone sensor to measure the centre surface deflection. To hold and then release the drop weight from a certain drop height, a mechanism is mounted on top of the rod as shown in Fig. 1

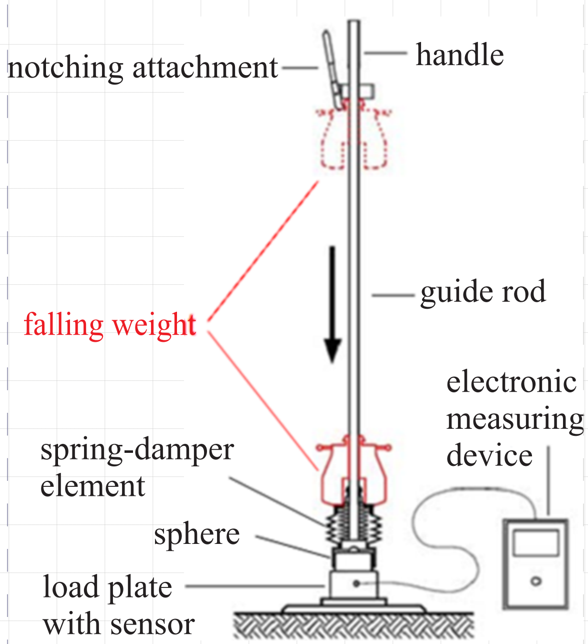

Fig. 1 Schematic Diagram of LFWD showing Different Components.

B. Wooden Box/Mould Fabricated for the Proposed Study

Apart from the consideration of the size of the test box/mould, it should have been strong, durable and allow compaction of the sample, whilst permitting some flexure to simulate suitable confinement.

It is important to limit boundary effects caused by the test box/mould in order to avoid its influence on the behaviour of the sample during testing. Laboratory tests conducted to determine the influence depth of the LFWD have indicated that the LFWD influence depth ranges from 270 to 280 mm. As suggested by and convenience to use the equipment, a wooden box was fabricated having a size of (3ft x 3ft x 2ft).

LFWD tests were conducted on 5 samples at different densities in the box and the results have been presented in the following sections.

C. LFWD Tests

LFWD Tests were conducted on each sample at 9 locations i.e. middle, corners and sides as shown in Fig. 2 at various densities.

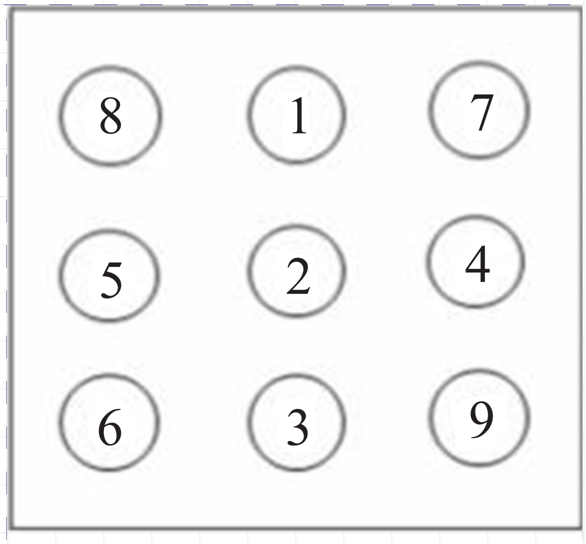

Fig. 2. Lay out of the box with test positions shown

IV. Results and Discussions

The results for granular and common materials have been tabulated in Table II.

TABLE II
RESULTS OF CBR AND EVD AT VARIOUS DEGREE OF COMPACTION OF GRANULAR MATERIALS AND COMMON MATERIALS

Sr. No.	Description	Granular Materials				Common Materials			
1	Dry Density achieved in the box (lbs / cft)	123.00	130.50	135.70	143.00	106.30	111.90	118.00	124.80
2	Compaction %	85.70	90.80	94.50	99.60	85.00	89.50	94.40	99.85
3	CBR %	13.60	27.20	45.00	82.00	2.45	5.00	7.00	8.25
4	Evd (MPa)	36.00	38.00	40.20	44.25	26.35	28.25	30.00	31.60

Statistical analysis was carried out and correlations between CBR and Evd at the same compaction and density have been developed for granular & common materials shown in Fig. 3 & 4 respectively.

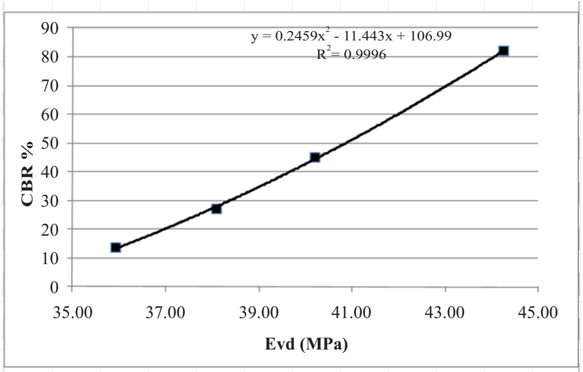

Fig. 3. Evd vs CBR (Granular Materials)

- The following correlation has been developed for A-1-b soil as a result of the study based on polynomial trend of the Evd and CBR.

  $CBR = 0.2459\,(Evd)^2 - 11.443\,Evd + 106.99$

  The above relationship can reliably be used for maximum grain size, not exceeding 63 mm.
- The following correlation has been developed for A-4 soil as a result of the study based on linear trend of the Evd and CBR.

$CBR = 1.0925 \times E_{VD} - 26.117$ ($R^2 = 0.9948$) and ($E_{vd} > 26 MPa$)

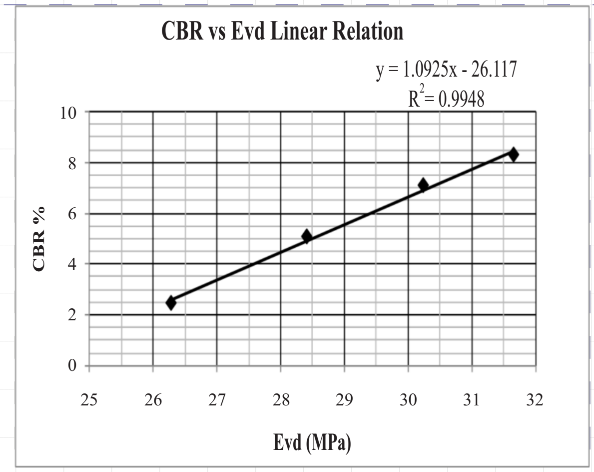

Fig. 4. Evd versus CBR (Common Materials)

IV. CONCLUSIONS

The following conclusions have been drawn as a result of this study;

- Correlations have been developed for A-1-b and A-4 soils which can reliably be used with a reasonable level of determination (R2=0.9996 and R2= 0.9948)
- The Light Falling Weight Deflectometer can effectively and reliably be used as a measuring tool to determine the Dynamic Deformation Modulus (Evd) as well as compaction subject to the condition that the layer thickness should not be more than 30 cm as the influence depth of the equipment is 27 – 28 cm.

The Evd can be measured very quickly as compared to the CBR

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