ADDIS ABABA INSTITUTE OF TECHNOLOGY
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ADDIS ABABA INSTITUTE OF TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING

Exhaustive Literature Review Dealing with the Relationship between CBR, Ks, and Resilient Modulus

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November 2015

DECLARATION

I certify that this project work title "**Exhaustive Literature Review dealing with the relationship between CBR, Ks, and Resilient Modulus"** is my own work has not been presented elsewhere for assessment and awarded of any degree or diploma. Where material has been used from, other sources it has been properly acknowledged (referred).

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Fekadu Eshetu

An independent project submitted to the school of graduate Studies of Addis Ababa University in Partial Fulfilment of the Requirements for the Degree of Master of Engineering in Geotechnical Engineering

Approved by Board of Examiners

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Abstract

In high way formation the sub grade layer, where acts as a pavement foundation should be well designed. In order to provide a suitable design input for identifying the bearing capacity and stiffness/strength of sub grade materials, it is very important to conduct laboratory and field tests like CBR, MR and Ks.

However, in the current practice it is too difficult to carry out cyclic tri axial tests for determining resilient modulus and filed plate load test for modulus of sub grade reaction, due to the unavailability of the testing apparatus widely, time consuming conducting the test and requires very high cost performing the test.

This paper presents an exhaustive literature review to evaluate the suitability and reliability of different correlation equations used to calculating MR and Ks, so far developed by many writers on the relationship of CBR, MR and Ks. The work has begins with referring different papers and selecting the correlation equations studied for different type of soil natures. Then with a known CBR value calculating the value of MR and Ks for all equations on the table and plotting them on the graph. After plotting all equations on the graph, explain the behaviour and the similarity between the equations and identify which equations are better useful for predicting the values of MR and Ks.

From this literature review one can have the information of how to predict the values of modulus of sub grade reaction and resilient modulus from the correlation equations without performing filed plate load test and cyclic tri axil laboratory tests.

Table of Contents

List of Figures

Figure **Page**

List of Tables

Table **Page**

List of Abbreviations

- ✓ **CBR** – California Bearing Ratio
- ✓ **MR** – Resilient Modulus
- ✓ **MRSG** - Resilient Modulus Sub Grade Reaction
- ✓ **Ks -** Modulus of Sub Grade Reaction
- ✓ **AASHTO** – American Association of State Highway & Transportation Office
- ✓ **MnDOT** – Minnesota Department of Transport
- ✓ **PCC** – Plain Concrete
- ✓ **OMC** – Optimum Moisture Content
- ✓ **LL** – Liquid Limit
- ✓ **U.S. Army** – United State of Army Corps of Engineers
- ✓ **CSIR** - South African Council on Scientific and Industrial Research
- ✓ **TRRL -** Transportation and Road Research Laboratory
- ✓ **NAASRA -** National Association of Australian State Road Authorities
- ✓ **GDoT –** Georgia Department of Transport
- ✓ **NCHRP**- National Cooperative Highway Research Program
- ✓ **LVDT -** Linear Variable Differential Transforms

1. Introduction

1.1 Back Ground

When designing pavements, the characteristic of each layer is an essential design parameter that needs to be considered. Sub grade materials are typically characterized by their resistance to deformation under load, which can be either a measure of their strength /stiffness.

In highway formations the sub grade layer, where acts as a pavement foundation should be well designed. In order to evaluate the sub grade strength it is important to conduct sub grade strength tests of CBR, MR and Ks during design stage and construction.

A basic sub grade stiffness/strength characterization is **resilient modulus (MR).** Resilient modulus is a measurement of the elastic property of soil recognizing certain nonlinear characteristics, and is defined as the ratio of the axial deviator stress to the recoverable axial strain. Both the AASHTO Guide for Design of Pavement Structures (AASHTO, 1993) and the mechanistic based design methods (AASHTO, 2008) use the resilient modulus of each layer in the design process.

The modulus of sub grade reaction (k) is a required parameter for the design of rigid pavements. It estimates the support of the layers below a rigid pavement surface course. The modulus of sub grade reaction is determined from field plate bearing load tests (Huang, 1993). However, the field plate bearing load test is elaborate and time-consuming. Recently, resilient modulus has been commonly applied for both flexible and rigid pavement in the design guide (AASHTO, 1993).

The California Bearing Ratio (CBR) Test

It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material. This test method is used to evaluate the potential strength of sub grade, sub base, and base course materials, including recycled materials for use in the design of road and airfield pavements. The CBR value obtained in this test forms an integral part of several flexible pavement design methods.

Field plate load test is commonly used to predict the deformations and failure characteristics of the soil/sub grade and modulus of sub grade reaction (ks). Modulus of sub grade reaction (ks) is used in foundation design, soil-structure interaction studies and design of highway pavement (flexible and rigid pavements). One of the parameters obtained from the field plate load test is the spring constant/ modulus of sub grade reaction, ks-value. The ks-value is used as a primary input in pavement design models, and is based on Minnesota Department of Transport (MnDot) pavement design. It can be measured using a field plate load test conducted on top of the sub grade (Kameswara Rao, 2000; MnDoT, 2007).

However, performing modulus of sub grade reaction using filed plate load test is costly besides being time consuming. Also it is difficult to conduct a plate load test at depths beyond 1 or 2 m below Ground Level (GL).

The resilient modules (M_R) of sub grade and sub base soils are very important properties in the analysis and design of a flexible pavement system. However, the difficulties and complexities in performing cyclic M_R test are require higher cost in performing the test and time consuming. Moreover, it is tedious on performing the test in the laboratory and the unavailability of the testing equipment widely has prevented the cyclic M_R test from becoming a routine test.

Hence, it is necessary to develop a correlation equation for the relationship between the modulus of sub grade reaction (k), CBR and the sub grade soil resilient modulus (MR). This allows the designer to treat the seasonal variation of the sub grade soil k-value by simply converting the same seasonal resilient modulus that would be used for flexible pavement design.

1.2 Objective of the Study

The objective of this study is to evaluate the suitability of different relationship formulas between CBR and MR, MR and Ks and CBR and Ks that has been presented by different writers.

There are a gap between quality assurance and the design procedure because the laboratory/field dry density is not a direct indication for the material stiffness used in the flexible pavement design. Applying CBR or plate loading test can be a better guide for the pavement layer stiffness during flexible pavement layers construction. Thus, the correlations formula developed between MR and CBR will estimate the resilient modulus of pavement layers during the construction process. There has been considerable discussion on the suitability of using any of these approaches but there are no consistent results.

For example, Thompson and Robnett (1979), Unlike many research, could not find a suitable correlation between CBR and MR where they concluded that the CBR test is a measure of the shear strength of the material and does not necessarily correlate with a measure of stiffness or modulus such as the MR. Since several correlation equations are available from past studies, there is a need to substantiate the predictability of these equations. Those equations, if proved to be valid, could serve a vital role in proposing a preliminary pavement design for budgeting purposes. Final design can await completion of the grading contract, followed by additional in-situ tests.

Therefore, the main target of this study will focus on the following points

- Selecting the most suitable correlation equation for the relationship of CBR and MR, Ks and MR and Ks and CBR by comparing and identifying similarity of different correlation equations which are developed by several writers.
- Discussing on factors affecting the resilient modulus of fine grained soils.
- Discussing on factors affecting the resilient modulus of coarse grained soils.
- Explaining the effect of material type and fines content on MR and Ks

1.3 Scope of Study

In order to provide reliable laboratory and field test results for evaluating the behaviour of sub grade soil for pavement design input, different tests have been required. Those tests are measuring the bearing capacity, stiffness and strength of sub grade soil. As I have explained in the previous chapters the main difficulties of conducting these tests are tedious performing the test, require long time conducting the test and it requires higher cost.

So that, in order to avoid this, this Literature review has prepared for the topic of Exhaustive Literature Review Dealing with the relationship between CBR, MR and Ks for predicting modulus of sub grade reaction and resilient modulus from one of the correlation equations.

Hence, the scope of this paper will be in order to provide supportive information for a continuous study of the topic for the determination of modulus of sub grade reaction and resilient modulus without performing field plate load test and repeated cyclic tri axial tests.

2. Description of Tests

2.1 Definition, Use and Significance of CBR

It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material. The California Bearing Ratio Test (CBR Test) is a penetration test developed by California State Highway Department (U.S.A.) for evaluating the bearing capacity of sub grade soil for design of flexible pavement.

This test method is used to evaluate the potential strength of sub grade, sub base, and base course materials, including recycled materials for use in the design of road and airfield pavements. The CBR value obtained in this test forms an integral part of several flexible pavement design methods.

For applications where the effect of compaction water content on CBR is small, such as cohesion less, coarse-grained materials, or where an allowance is made for the effect of differing compaction water contents in the design procedure, the CBR may be determined at the optimum water content of a specified compaction effort. The specified dry unit weight is normally the minimum percent compaction allowed by using client’s field compaction specification.

The criteria for test specimen preparation of self-cementing (and other) materials which gain strength with time must be based on a geotechnical engineering evaluation. As directed by the client, self-cementing materials shall be properly cured until bearing ratios representing long term service conditions can be measured.

2.2. Definition, Use and Significance of MR

Resilient Modulus (MR) is defined as a ratio of applied axle deviator stress and axle recoverable strain. Resilient Modulus is a measure of the elastic response of a soil (e.g., how well a soil is able to return to its original shape and size after being stressed) under repeated loading.

MR is a fundamental material property used to characterize unbound pavement materials. It is also a measure of material stiffness and provides a mean to analyze stiffness of materials under different conditions, such as moisture, density and stress level. Furthermore, it is a required input parameter to mechanistic-empirical pavement design method.
Resilient Modulus is typically determined through laboratory tests by measuring stiffness of a cylinder specimen subject to a cyclic axle load.

Benefits of MR testing

- ✓ Measure of fundamental material property
- ✓ Dynamic load testing similar to traffic loading
- ✓ Essential input in mechanistic-empirical pavement design

Based on the conversion factors included in NCHRP Report 128, "Evaluation of AASHTO Interim Guide for the Design of Pavement Structures," allow you to quickly estimate the Sub grade Resilient Modulus (MRSG) from either a California Bearing Ratio (CBR) or Resistance Value (R-value) measurement.

The conversion from resilient modulus of the sub grade to k-value was updated in the fall of 2011 to better reflect published test results; the constant conversion factor of 19.4 as suggested in the AASHTO Guide for Design of Pavement Structures 1993 is no longer used.

2.3. Definition, Use and Significance of Ks

Modulus of sub grade reaction (ks) is used in foundation design, soil-structure interaction studies and design of highway pavement (flexible and rigid).

Modulus of sub grade reaction is a spring constant describing the relationship between applied pressure and resulting deflection (settlement) below a structural element founded on grade. In the structural analysis the soil is modelled as an elastic half space, and local supporting pressure is assumed to be directly proportional to settlements.

The sub grade modulus is not a fundamental soil property and its magnitude depends on many factors, among them shape of the foundation, stiffness of foundation slab, shape of loading on the foundation, depth of the loaded area below the ground surface, and time. As such, it is not constant for a given type of soil, which makes the estimation of a single general value for design a challenging task.

In highway formations the sub grade layer, where acts as a pavement foundation should be well designed. To evaluate the sub grade strength it is important during construction and design stage.

3. Laboratory Testing Method and Procedures

3.1 California Bearing Ratio (CBR)

It is the ratio of force/ unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material.

Tests are carried out on natural or compacted soils in water soaked or un-soaked conditions and the results so obtained are compared with the curves of standard test to have an idea of the soil strength of the sub grade soil.

Apparatus Used:

- ✓ Mould
- ✓ Steel Cutting collar
- ✓ Spacer Disc
- ✓ Surcharge weight
- ✓ Dial gauges
- ✓ IS Sieves
- ✓ Penetration Plunger
- ✓ Loading Machine
- ✓ Miscellaneous Apparatus

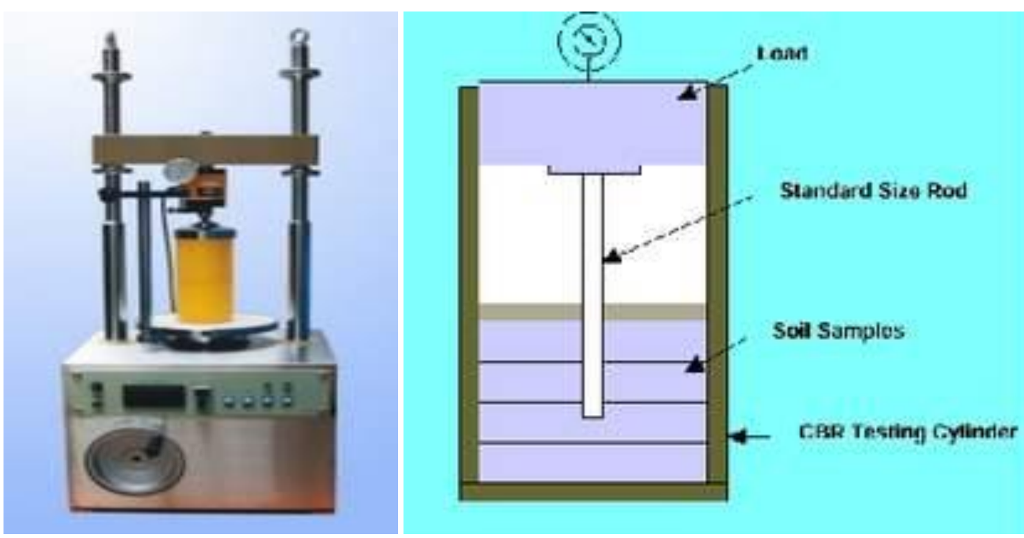

Fig. 01 CBR Testing Apparatus

CBR Test Procedure

- ✓ Normally 3 soil specimens has been prepared for a standard cylinder volume of the mould diameter 156 mm and height 116.43 mm and the compaction is for 10, 30 and 65 blows.
- ✓ Weigh of empty mould
- ✓ Add water to the first specimen (compact it in five layer by giving 10 blows per layer)
- ✓ After compaction, remove the collar and level the surface.
- ✓ Take sample for determination of moisture content.
- ✓ Weight of mould + compacted specimen.
- ✓ Place the mould in the soaking tank for four days (ignore this step in case of un soaked **CBR**).
- ✓ Take other samples and apply different blows and repeat the whole process.
- ✓ After four days, measure the swell reading and find % age swell.
- ✓ Remove the mould from the tank and allow water to drain.
- ✓ Then place the specimen under the penetration piston and place surcharge load of 4.5 kg or 10 lb.
- ✓ Apply the load and note the penetration load values.
- ✓ Draw the graphs between the penetration (mm) and penetration load (kg) and find the value of **CBR**.
- ✓ Draw the graph between the %age **CBR** and Dry Density, and find **CBR** at required degree of compaction.

Methodology

Determination of CBR value.

In order to show sample examples how to determine CBR value after obtaining the laboratory results. For applied penetration load it can be easily read the value from the dial reading. Having this result we can calculate the load and the CBR values as follows.

Table 01 Calculation of CBR Value

Penetration (mm)	10 Blows			30 Blows			65 Blows		
	Dial Reading	Load (KN)	CBR %	Dial Reading	Load (KN)	CBR %	Dial Reading	Load (KN)	CBR %
0.00	0.00	0.00		0.00	0.00		0.00	0.00	
0.64	18.00	1.90		27.00	2.84		36.00	3.79	
1.27	32.00	3.37		51.00	5.37		77.00	8.11	
1.96	41.00	4.32		78.00	8.21		129.00	13.58	
2.54	**52.50**	**5.53**	**41.41**	**101.00**	**10.63**	**79.66**	**174.00**	**18.32**	**137.23**
3.18	63.70	6.71		120.00	12.63		217.00	22.85	
3.81	74.30	7.82		139.50	14.69		256.00	26.95	
4.45	85.10	8.96		155.30	16.35		291.00	30.64	
5.08	**94.60**	**9.96**	**49.80**	**173.00**	**18.22**	**91.08**	**330.00**	**34.75**	**173.73**

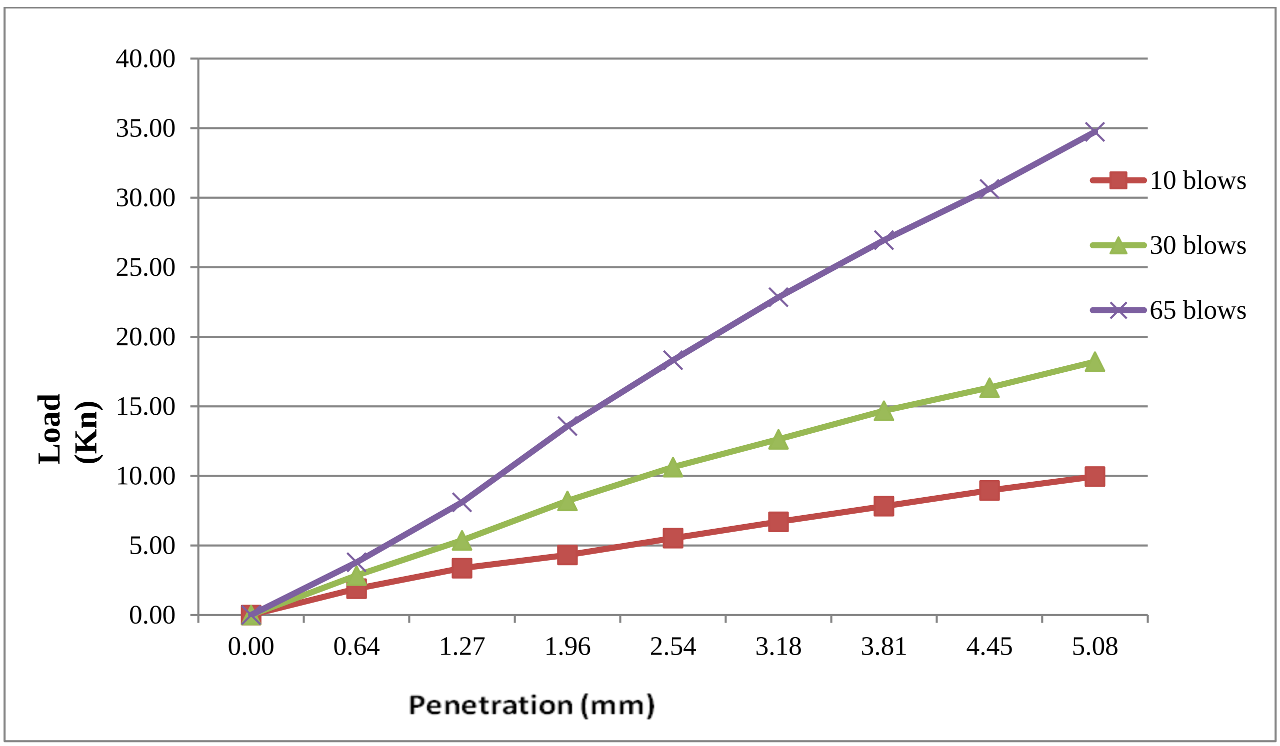

Fig. 02 Penetration Verses Load for Three Blows

In order to calculate the load, use the ring factor (RF) = 105.29 Newton / diversion, which is obtained from the Standard Agency

- Load (KN) = (Ring Factor * Dial Reading)/1000
- The CBR value = Load/area*100, (Dial reading * Ring factor) / area of Piston) From AASHTO standard by converting the pressure 1000 psi which is given for 2.54 mm, 6894.57 KN/m2 and 1500 psi for 5.08mm, 10,842.14 KN/m2, it can be calculating the two standard forces for calculating CBR value.

For calculating the force, P = F/A

Where,

Pressure, P = 6894.57 KN/m2 for 2.54mm and 10,842.14 KN/m2 for 5.08mm Penetration,

Area of piston, $A = \pi r^2$, diameter of piston 4.96 cm or 0.0496 m, R = 0.0248m

A = 3.14 * (0.0248*0.0248) = 0.001932 m2

F_{at} 2.54mm = 6894.57 KN /m2* 0.001932 m2 = 13.35 KN

F_{at} 5.08mm = 10,842.14 KN /m2* 0.001932 m2 = 20.00 KN

Finally, it can be calculate the value of CBR as follows

- CBR = (Load (KN) / 13.35)*100, at 2.54 mm penetration
- CBR = (Load (KN) / 20.00)*100, at 5.05 mm penetration

3.2 Resilient Modulus (Mr)

In a triaxial resilient modulus test a repeated axial cyclic stress of fixed magnitude, load duration and cyclic duration is applied to a cylindrical test specimen. While the specimen is subjected to this dynamic cyclic stress, it is also subjected to a static confining stress provided by a triaxial pressure chamber.

The total resilient (recoverable) axial deformation response of the specimen is measured and used to calculate the resilient modulus using the following equation:

$$M_R \left(or\ E_R\right) = \frac{\sigma_d}{\varepsilon_r}$$

Apparatus Used:

- ✓ Repeated load actuator
- ✓ Load cell
- ✓ Ball seat
- ✓ Steel ball
- ✓ Chamber piston rod
- ✓ LVDT solid bracket
- ✓ Thomson ball bushing
- ✓ Cell pressure inlet
- ✓ Cover plate
- ✓ O - ring seal
- ✓ Sample cap
- ✓ Porous bronze disc
- ✓ Chamber
- ✓ Filter paper
- ✓ Tie rods
- ✓ Base plate
- ✓ Vacuum inlet

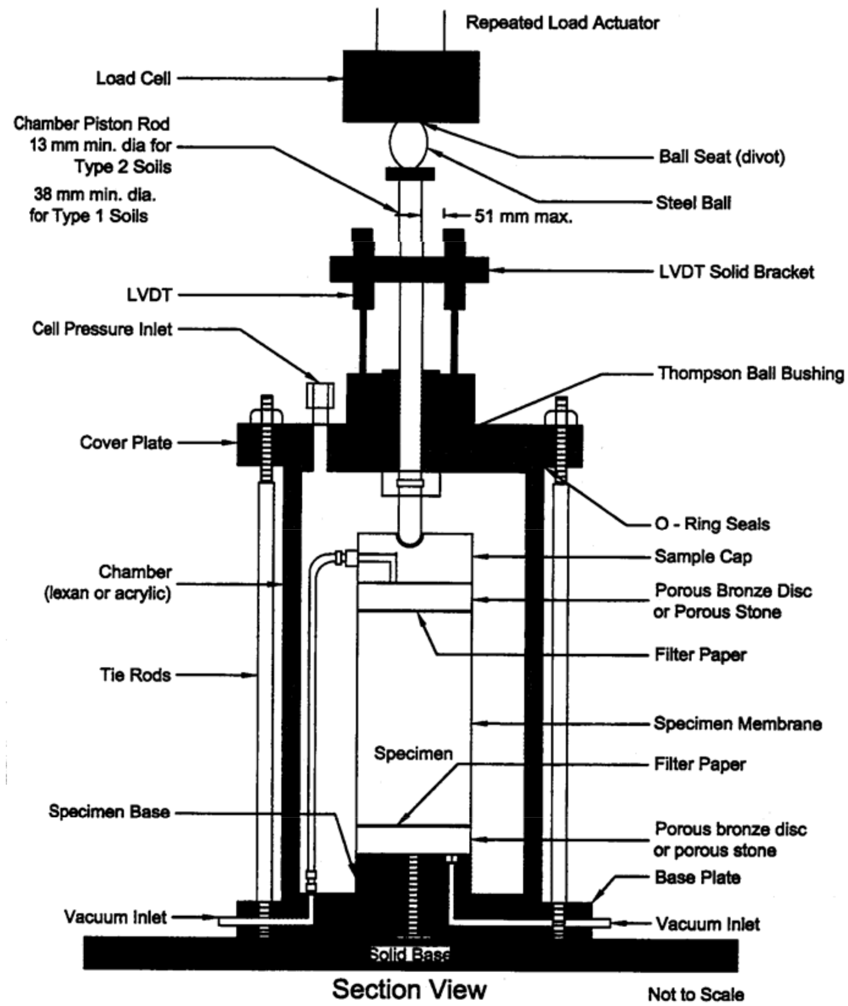

Fig. 03 Tri axial Testing Apparatus

Mr Test Procedure

The following is a basic outline of the triaxial test procedure:

- ✓ The specimen is a cylindrical sample normally 100 mm (4 in.) in diameter by 200 mm (8 in.) high.
- ✓ The sample is generally compacted in the laboratory; however, undisturbed samples are best if available (which is rare).

- ✓ The specimen is enclosed vertically by a thin "rubber" membrane and on both ends by rigid surfaces.
- ✓ The sample is placed in a pressure chamber and a confining pressure is applied (δ3).
- ✓ The deviator stress is the axial stress applied by the testing apparatus (δ1) minus the confining stress (δ3).
- ✓ The resulting strains are calculated over a gauge length, which is designated by "L".
- ✓ Basically, the initial condition of the sample is unloaded (no induced stress). When the deviator stress is applied, the sample deforms, changing in length. This change in sample length is directly proportional to the stiffness.

Methodology

Determination of MR value

In order to show sample examples how to determine MR value after obtaining the laboratory tri axial cyclic test results are as follows.

MR Calculator determined the recoverable axial displacement of each Linear Variable Differential Transforms LVDT (d1, d2, and d3) by subtracting the baseline displacement during the recovery period from the peak displacement.

The recoverable axial strain, (Δεa), was calculated by averaging the three recoverable displacement values and dividing by the gage length (lo):

$$\Delta\varepsilon a = \frac{1/3\ (d1 + d2 + d3)}{lo}$$

Where, εa = the recoverable axial Strain

d1, d2 and d3 = measures the displacement of the load

lo = gage length

The cyclic axial deviatoric stress ($\Delta\sigma_a$), induced in the specimen was the peak load (P_{max}) less the load during the recovery period (P_o) divided by the cross-sectional area of the specimen:

$$\Delta\sigma_a, = \frac{(P_{max} - P_o)}{\pi r^2}$$

Where, P_{max} = the peak load

Po = load during recovery period

r = radius of specimen

Then, MR value was calculated by dividing the cyclic axial stress by the recoverable axial strain

$$MR = \frac{\Delta\sigma_a}{\Delta\varepsilon a}$$

Give values

- d1 = 0.0000358 m
- d1 = 0.0000386 m
- d1 = 0.0000371 m
- lo = 0.1524m
- P_{max}= 1900N
- Po = 217N
- R = 0.0762m

$$\Delta\varepsilon a = \frac{1/3\ (d1 + d2 + d3)}{Lo}$$

$$= \frac{(0.0000358\ m + 0.0000386\ m + 0.0000371\ m)}{3 * 0.1524}$$

$$= \underline{\underline{0.00024}}\ 411$$

$$\Delta\sigma_a, = \frac{(P_{max} - P_o)}{\pi r^2}$$

$$= \frac{(1900N - 217N)}{\pi * (0.0762*0.0762)m2}$$

$$= \underline{92.30\ kpa}$$

$$MR = \frac{\Delta\ \sigma_a}{\Delta\ \varepsilon a} = \frac{92.30\ kpa}{0.00024} = \underline{385}\ Mpa$$

Table 02 Typical Soil Resilient Modulus Test Results of Granular Soil

Confining Pressure	Axial Load	Dev. Stress	Bulk Stress	Middle Strain	External Strain	Middle Modulus	External Modulus
kPa	kN	kPa	kPa			MPa	MPa
20.68	0.155	19.168	81.748	0.00015	0.00021	127.430	89.633
20.68	0.325	40.029	102.609	0.00030	0.00042	134.391	94.998
20.68	0.491	60.588	123.168	0.00042	0.00060	145.494	101.510
34.47	0.268	33.106	136.516	0.00017	0.00026	198.495	128.905
34.47	0.548	67.641	171.051	0.00035	0.00053	193.152	128.282
34.47	0.826	101.903	205.313	0.00055	0.00080	185.181	127.466
68.95	0.547	67.486	274.336	0.00024	0.00038	282.521	176.026
68.95	1.106	136.485	343.335	0.00052	0.00079	264.672	173.296
68.95	1.666	205.452	412.302	0.00080	0.00119	255.427	173.093
103.42	0.548	67.629	377.889	0.00020	0.00033	341.028	207.223
103.42	0.828	102.144	412.404	0.00031	0.00049	333.298	207.409
103.42	1.666	205.442	515.702	0.00063	0.00098	325.283	209.555
137.90	0.829	102.258	515.958	0.00026	0.00044	391.018	234.660
137.90	1.107	136.549	550.249	0.00035	0.00058	387.246	236.780
137.90	2.191	270.277	683.977	0.00073	0.00116	369.183	233.745

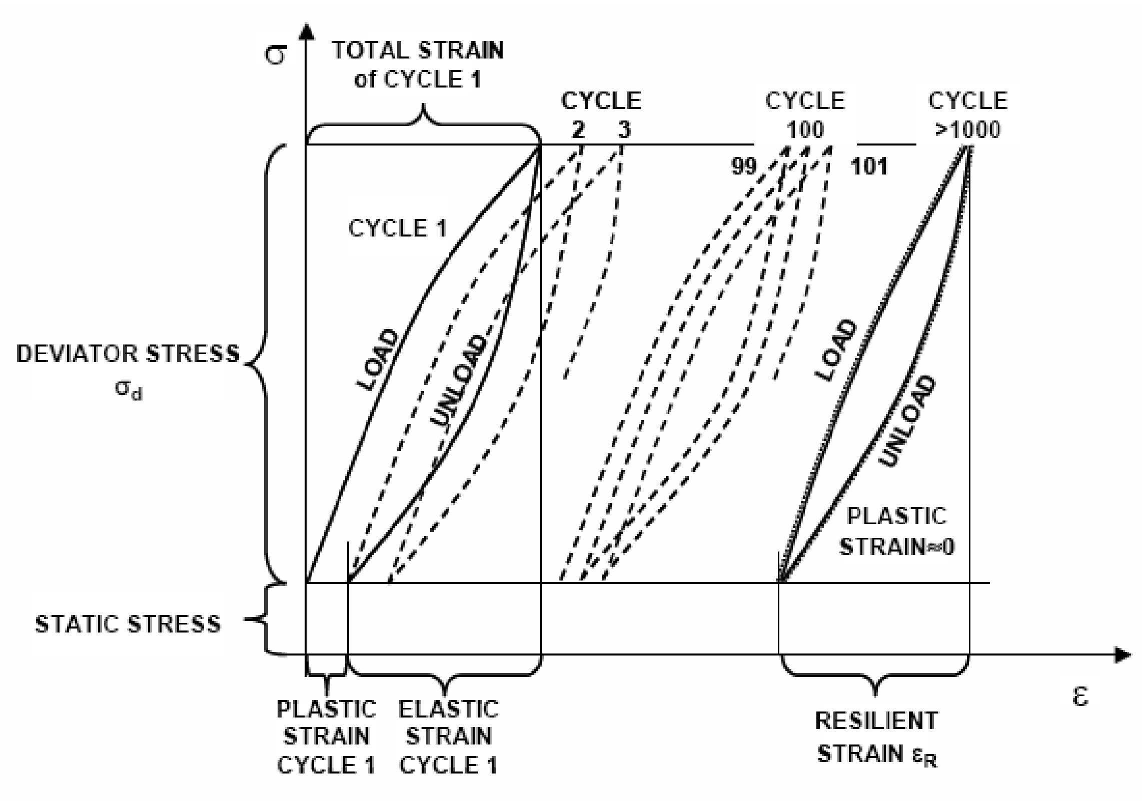

Fig. 04 Concept of Resilient Modulus of Soils

3.3 Modulus of Sub Grade Reaction (Ks)

The modulus of sub grade reaction (k) is used as a primary input for rigid pavement design. It estimates the support of the layers below a rigid pavement surface course (the PCC slab). The k-value can be determined by field tests or by correlation with other tests.

The modulus of sub grade reaction is determined from a plate loading test, in which the size of the plate can be 300 mm to 760 mm in diameter and the shape is square, rectangular, or circular (Jones, 1997; Moayed and Janbaz, 2009)**.** The load is applied at a predetermined rate until a pressure of 10.69 kPa is reached. The pressure is held constant until the deflection increases not more than 0.001 inch per minute for three consecutive minutes.

Ks Test Apparatus

- ✓ **Loading device,** such as a truck, trailer, tractor-trailer, an anchored frame, or other structures loaded with sufficient weight to produce the desired reaction on the surface under test. The supporting points (wheels, in the case of a truck or trailer) should be at least 2.4m (8ft.) from the circumference of the largest diameter bearing plate being used.
- ✓ **Hydraulic jack assembly,** with a spherical bearing attachment, capable of applying and releasing the load in increments. The jack should have sufficient capacity for applying the maximum load required and shall be equipped with an accurately calibrated gauge that will indicate the magnitude of the applied load.
- ✓ **Two or more dial gauges**, graduated in units of 0.03 mm (0.001 in.), capable of recording a maximum settlement of 25.4mm (1 in.)
- ✓ **Deflection beam,** upon which should be mounted: dial gauges; a 63.5 mm (2.5 in.) standard black pipe; and a 76 × 76 × 6 mm (3 × 3 × 1/4 in.) steel angle, or equivalent, at least 4.9m (16 ft.) long, and resting upon supports located at least 2.4m (8 ft.) from the bearing plate or the nearest wheel or supporting leg
- ✓ **Miscellaneous tools**, including a thermometer and spirit level.

- ✓ **Set of circular steel bearing plates**, not less than 25.4 mm (1 in.) in thickness, machined so they can be arranged in pyramid fashion to ensure rigidity, with diameters ranging from 152.4–762.0 mm (6–30 in.)

  Note - A minimum of four different plate sizes are recommended for pavement design or evaluation purposes. For evaluation purposes alone, a single plate may be used, provided its area is equal to the tire contact area corresponding to what may be considered as the most critical combination of conditions of wheel load and tire pressure. For providing data indicative of bearing index (for example, the determination of relative sub grade support throughout a period of a year), a single plate of any selected size may be used.

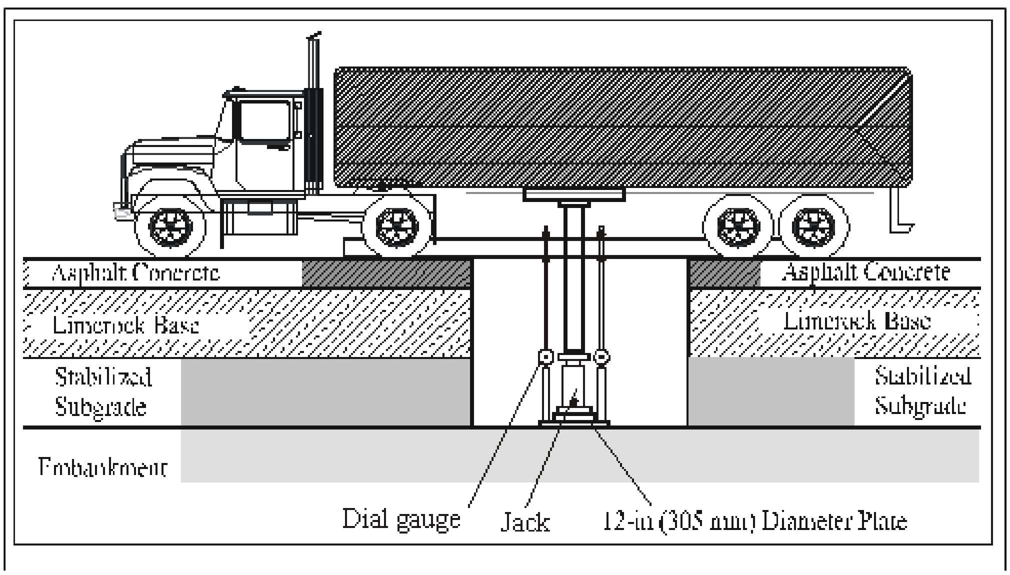

Fig.05 Field Plate Load Test

Ks Test Procedure

- ✓ Carefully centre a bearing plate of the selected diameter under the jack assembly.
- ✓ Set the remaining plates of smaller diameter concentric with, and on top of the bearing plate.

- Set the bearing plate level in a thin bed of a mixture of sand and plaster of Paris, of plaster of Paris alone, or of fine sand, using the least quantity of materials required for uniform bearing.
- Where unconfined load tests are to be made at a depth below the surface, remove the surrounding material to provide a clearance equal to one and one-half bearing plate diameters from the edge of the bearing plate.

  For confined tests, the diameter of the excavated circular area shall be just sufficient to accommodate the selected bearing plate.
- Place a sufficient number of dial gauges, located and fixed in position to indicate the average settlement of the bearing plate.
- After the equipment has been properly arranged with all of the dead load (jack, plates, etc.) in place, quickly seat the bearing plate and assembly and release a load sufficient to produce a settlement of not less than 0.3 mm (0.01 in.) or more than 0.5 mm (0.02 in.), as indicated by the dials.
- When the dial needles come to rest following release of the load, reseat the plate by applying half of the recorded load that produced 0.3 – 0.5 mm or 0.01– 0.02 in Settlement.
- When the dial needles have again come to rest, set each dial accurately at its zero mark.
- Apply loads at moderately rapid rate in uniform increments. The magnitude of each increment should be small enough to permit the recording of a sufficient number of load-settlement points (not less than six) to produce an accurate load-settlement curve.
- After each increment of load, wait until a rate of settlement of not more than 0.03 mm (0.001 in.) per minute has been maintained for three consecutive minutes. Record load and settlement readings for each load increment.
- Continue this procedure until the selected total settlement has been obtained, or until the load capacity of the apparatus has been reached, whichever occurs first. This point, maintain the load until an increased settlement of not more than 0.03 mm (0.001 in.) per minute for three consecutive minutes occurs. Record the total settlement.

- ✓ Release the load to the load at which the dial gauges were set at zero. Maintain this zero-setting load until the rate of recovery does not exceed 0.03 mm (0.001 in.) per minute for three consecutive minutes.
- ✓ Record settlement at the zero-setting load.
- ✓ From a thermometer suspended near the bearing plate, read and record the air temperature at half-hour intervals.

Methodology

Determination of Ks value.

In order to show sample examples how to determine Ks value after obtaining filed plate load test result.

Ks = P/δ **(Winkler methods 1967)**

Where, Ks = Spring constant = Modulus of sub grade reaction

P = Applied pressure (load /the area of 763mm diameter plate)

Δ = Measure deflection of the 762 mm diameter plate

Table – 03 Computation Ks Values

Bearing Pressure (Kpa)	Settlement (mm)	Ks (KN/mm2)
0	0	0.00
23	0.43	53.49
39	0.8	48.75
55	1.1	50.00
72	1.4	51.43
88	1.55	56.77

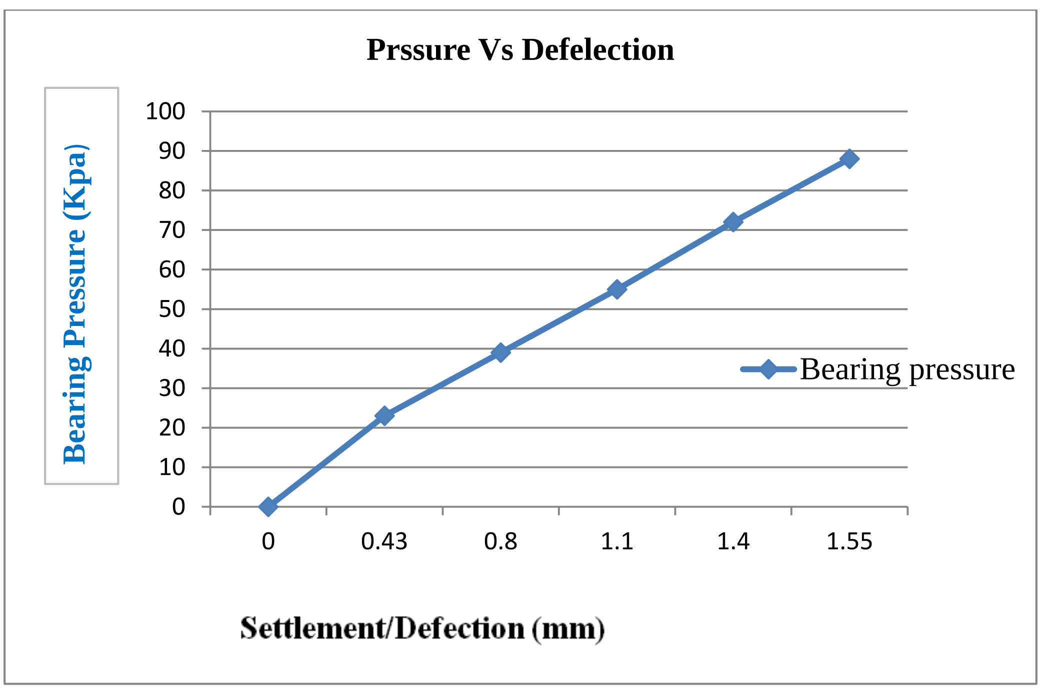

Fig. 06 Bearing Pressure Vs Deflection for Computing Ks Value

4. Review and Comparison on Relationship between CBR,MR and Ks

4.1 Relationship between CBR and Ks

One of the parameters obtained from the field plate load test is the spring constant modulus of sub grade reaction Ks, which used as a primary input in pavement design models. It can be measured using a field plate load test conducted on top of the sub grade. However, this test is costly to perform besides being time consuming. Also it is difficult to conduct a plate load test at depths beyond 1 or 2 m below ground level.

Thus CBR test is expected to simplify the effort in determination of the Ks which is used in Foundation design, soil structure interaction, design of highway formations etc.

One of the correlation equations presented for the relationship between CBR and Ks is the characterization of layered pavement of sub base and sub grade soils for Egypt, by Ahmed Ibrahim 2014, has developed the following,

- **$Ks = 97.142*(CBR)^{0.5842}$**

Where,

- Ks = Modulus of sub grade reaction
- CBR= California bearing Ratio

Another developed correlation equation for the relationship between CBR – Ks is, by Sam. I. Thornton 1983 on Correlation of sub grade reaction for A – 4 and A- 6 soils for Arkansas has been presented as follows,

- **$Ks = 13.8CBR + 80.6$**

Table 04- Comparison of Ks value

CBR value	Ahmed Ibrahim Ks = 97.142 $(CBR)^{0.5842}$	Thornton Ks = 13.8 CBR+80.6
12	414.82	246.2
15	472.58	287.6
19	542.57	342.8
24	621.91	411.8
29	694.61	480.8
34	762.25	549.8

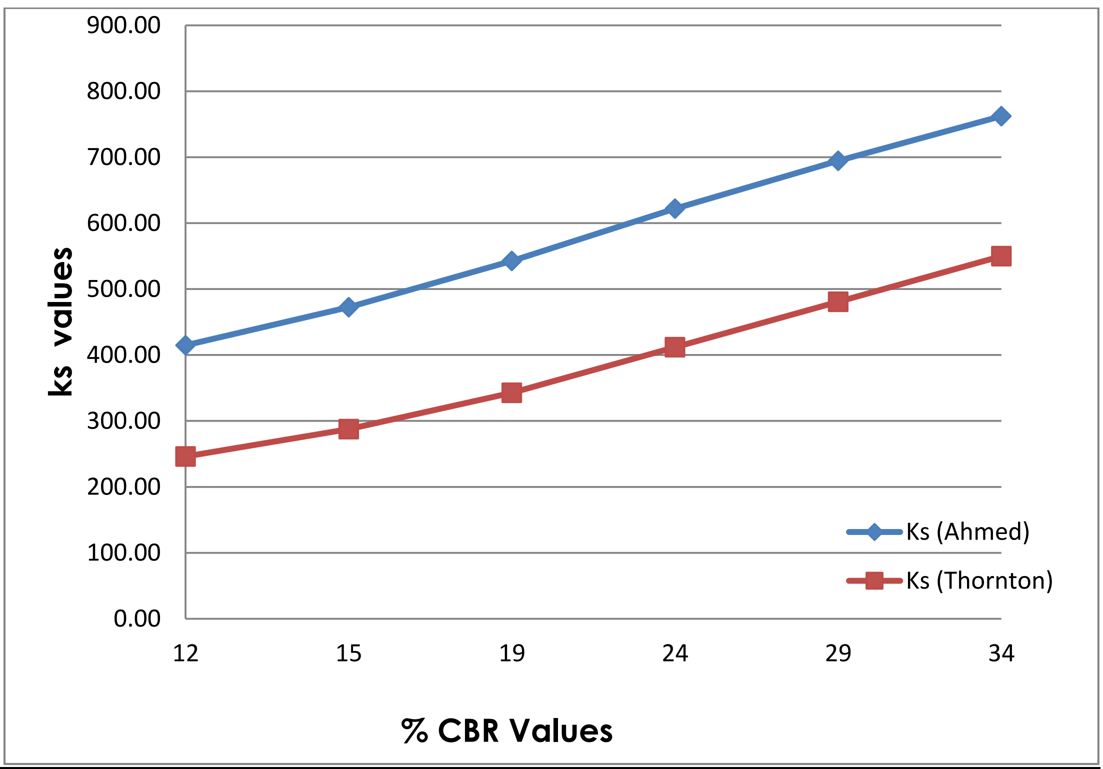

Fig. 07 Relationship of CBR and Ks

As we have seen on the above figure, the result of the two correlation equations on relationship between California bearing ratios (CBR) and modulus of sub grade reaction (Ks), both graphs have different behaviour, because of their nature of equation and they do not have same point for the common CBR value. However, in both cases for a common CBR value, increasing on CBR value, the corresponding Ks value also increases.

In general, the gap between the two graphs is very large; and the difference has reached 59 %. The main reason for such a big gap has created, both correlation equations have a different and the study was carried on a different sub grade soils.

Therefore, in order to minimize the gap and achieve a better correlation equation for predicting Ks value from known CBR, it has to be evaluating the nature of equation and similarity on sub grade soil during comparison.

4.2 Relationship between CBR and MR

Simple correlation equations have been reported to predict M_R from standard CBR, R value, and soil physical properties. A widely used empirical relationship developed by Heukelom and Klomp (1962). This equation is restricted to fine grained materials with soaked CBR values of 10% or less as stated in ECP, 2008 and used in the1993 AASHTO guide is:

- **$M_R = 1500 * CBR$**

Where; - MR, Resilient modulus

CBR, California Bearing Ratio

However, Hossain S.M. (2009) explained that the current practice of converting a CBR value to a resilient modulus value does not provide a reliable estimate of the resilient modulus using Heukelom and Klomp equation.

Thus, some of the various correlations between MR and CBR relationship are used around the world:

- ✓ U.S. Army Corps of Engineers (USACE)(Green and Hall 1975).
  - **$MR = 5409 (CBR)^{0.71}$**
- ✓ South African Council on Scientific and Industrial Research (CSIR)
  - **$M_R = 3000(CBR)^{0.65}$**
- ✓ Transportation and Road Research Laboratory (Powell et al.) (TRRL) (1984)
  - **$M_R = 2555(CBR)^{0.64}$**

The Georgia Department of Transportation (GDoT), 2004 tested a number of granular materials in repeated load triaxial test following the AASHTO procedure to create a database, so that the resilient modulus can be predicted.

A typical equation for stabilized lime stone is as follows.

- **$M_R = 3116(CBR)^{0.49}$**

In addition, NAASRA (1950) developed the following equations.

- **MR = 2350 (CBR) $^{0.70}$ (For CBR less than 5%)**
- **MR = 3250 (CBR) $^{0.50}$ (For CBR more than 5%)**

Çöleri E. (2007) stated that resilient modulus prediction models can be improved by including soil index parameters in order to minimize residual errors. The most effective parameters that have high significance in representing the MR variation are CBR, liquid limit (LL) and optimum moisture content (OMC).

The regression model equation (R^2 = 0.7089) for predicting resilient modulus is as follows.

MR = 228376.7946 – (1479.8978 * LL) – (12381.4217 * OMC) + (689.5*CBR) + (152.9164* LL * OMC).

However, CBR is widely used to calculate resilient modulus empirically due to the easiness of determining CBR value. The fundamental problem with empirical relationships developed to correlate resilient modulus with CBR is that those tests themselves are empirical, whereas resilient modulus is a mechanistic parameter and depends on soil index properties and stress state.

The correlation equation for MR – CBR relationship developed by different writers for various soils has been summarized here.

1. **Restricted to fine grained materials with soaked CBR values of 10% or** less
   MR = 1500 * CBR
2. **For granular materials**

   - **U.S. Army corps of engineers (Green and Hall 1975).**

   MR = 5409 (CBR) $^{0.71}$

- **South African Council on Scientific and Industrial Research (CSIR)**

  $M_R = 3000(CBR)^{0.65}$

- **Transportation and Road Research Laboratory (Powell et al.) (TRRL) (1984)**

  $M_R = 2555(CBR)^{0.64}$

3. **The Georgia Department of Transportation (GDoT)(2004)**
   - **for stabilized lime stone**

     $M_R = 3116(CBR)^{0.49}$

4. **In addition, NAASRA (1950) developed the following equations**

   $MR = 2350\ (CBR)^{0.70}$ (For CBR less than 5%)

   $MR = 3250\ (CBR)^{0.50}$ (For CBR more than 5%)

Table 05 – MR Values for five different Correlation Equations

% CBR Value	MR values				
	US	CSIR	TRRL	GDT	NAASRA
	10^3	10^3	10^3	10^3	10^3
15	37	17	14	12	13
24	45	21	17	14	15
37	74	33	27	19	21
52	99	43	35	23	25
61	121	52	42	27	29
75	142	60	49	30	33
98	162	67	55	33	36
121	181	74	60	35	38
140	199	81	66	37	41

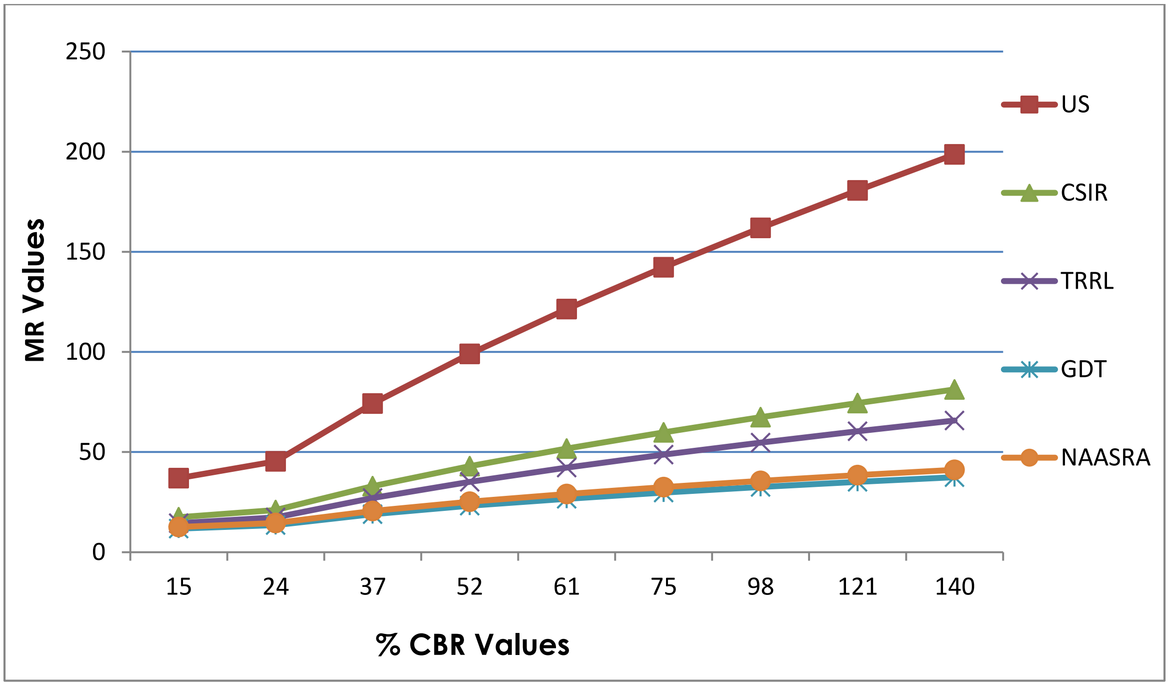

Fig.08 Comparison of Five Correlation Equations of CBR and MR

It was trying to compare the relationship of five correlation equations namely (US Army, CSIR, TRRL, GDT and NAASRA) on the above cited graph. When we see the nature of the graph of NAASRA and GDT equations, the two equations are suited for predicting MR values for a known CBR value due to very close similarity between them. Moreover, both equations have common values at percentage CBR 24 and nearly identical when increasing on CBR value, so that the equation is satisfactory.

Hence, using this two correlation equations (NAASRA and GDT) one can easily predict the value of Resilient Modulus.

On the other hand, the correlation equations by CSIR and TRRL have similar graph nature up to percentage CBR value of 24. But, after passing this CBR value the gap between them becomes large for increasing CBR value. So that in order to say the equations are satisfactory, it must be compared with other correlation equations.

The correlation equation developed by US Army does not agree with the rest four correlation equations as compared on the graph. This is because of the gap between them is very large and the difference also increases for increasing CBR values.

Therefore, concluding the suitability of the five correlation equation developed by different writers, the four correlation equations (CSIR, TRRL, GDT and NAASRA) have nearly identical values for the determination of MR values, but US army equation do not agree with the rest.

On the other hand it was trying to compare that the correlation equation of Heukelom and NAASRA for the determination of MR value from known CBR values on the following table and figures.

Table 06 – Comparison of MR Values

% CBR Value	MR Value	
	Heukelom 10^3	NAASRA 10^3
2.5	4	5
4.5	7	7
6.5	10	8
8.5	13	9
10.5	16	11
12.5	19	11

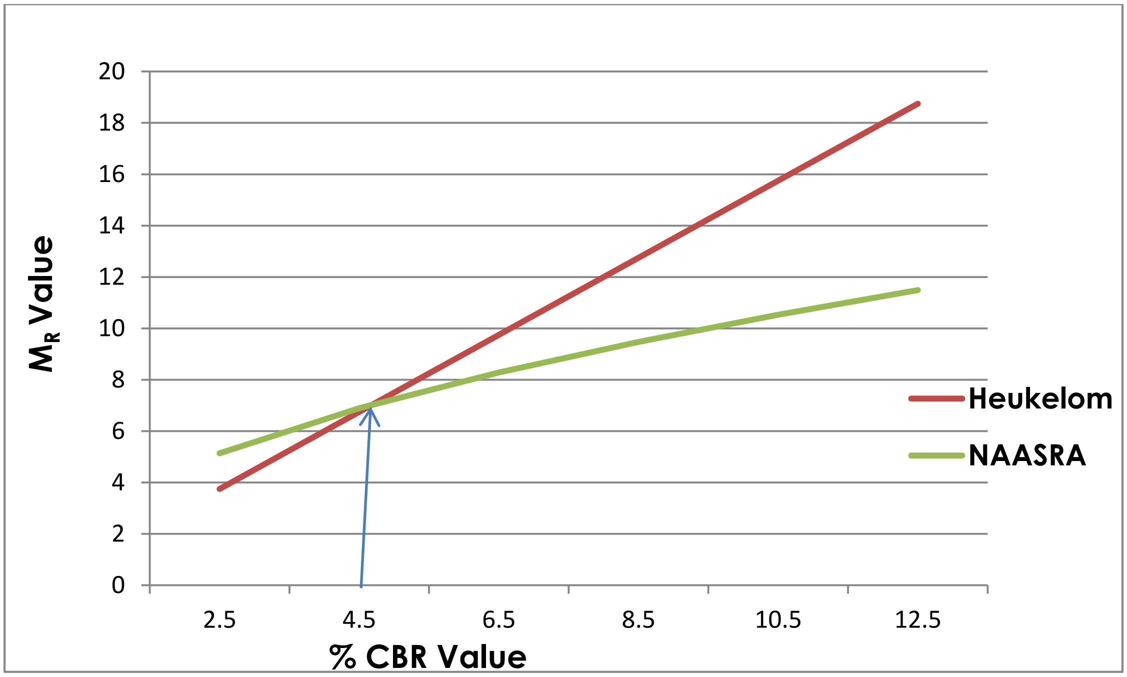

Fig. 09 Relationship between MR and CBR Equations

From the above figure, the NAASRA and Hukelom correlation equations have different graph nature. Even though the two equations have different nature and values, they recorded the same result at CBR 4.5 %. But after passing the common value the gap between them increases for increasing CBR values. Therefore, this two equations are not similar behaviour and not confidential to use it for predicting of Resilient Modulus.

Factors Affecting Resilient Modulus of Cohesive Soils

The resilient modulus of fine-grain soils is not a constant stiffness property but depends upon various factors like load state or stress state, which includes the deviator and confining stress, soil type and its structure. This primarily depends on compaction method and compaction effort. Previous studies showed that the deviator stress is more significant than confining stress for fine-grain soils. However, resilient modulus was found to increase with a decrease in moisture content and an increase in density. It also decreases with an increase in deviator stress.

Factors Affecting Resilient Modulus of Coarse Soils

Since 1960, numerous research efforts have been devoted to characterizing the resilient behaviour of granular materials. It is well known that granular pavement layers show a nonlinear and time-dependent elastoplastic response under traffic loading. To deal with this nonlinearity and to differentiate from the traditional elasticity theories, the resilient response of granular materials is usually defined by resilient modulus and Poisson's ratio.

Alternatively, the use of shear and bulk module has been suggested. For design purposes, it is important to consider how the resilient/ elastic behaviour varies with changes in different influencing factors.

From the studies found in the literature, it appears that the resilient behaviour of unbound granular materials may be affected, with varying degrees of importance, by several factors as described below.

- Effect stress,
- Effect of density,
- Effect of grading, fines content, and maximum grain size,
- Effect of moisture content,
- Effect of stress history and number of load cycles,
- Effect of aggregate type and particle shape,
- Effect of load duration, frequency, and load sequence.

Studies have also indicated that there is a critical degree of saturation near 80-85 percent, above which granular material becomes unstable and undergoes degradation rapidly under repeated loading. Resilient modulus of granular materials increases with increasing confining stress and principal stresses (known as bulk stress (θ)), and slightly increases with deviator stress.

4.3 Relationship between MR and Ks

It is necessary to develop a relationship equation between modulus of sub grade reaction (Ks) and resilient modulus (MR). This allows the designer to predict (MR) that will be used for flexible pavement design by converting the Ks value using a (MR-Ks) model.

The following three correlation equations has been developed By Ahmed Ebrahim,2014 of MR and Ks relationships for Dolomite base layer, Silt sub grade soil and lime stone base layer.

The three equations are as follows

- MR dolomite base = 0.0205 * Ks $^{1.9637}$
- MR limestone sub base = 61.4* Ks $^{0.8529}$
- M R silt sub grade = 189.45* Ks $^{0.6497}$

Table 07 – Comparison of Correlation Equation for MR

Ks Value	MR Value		
	Dolomite	Limestone	Silt
80	112	2,578	3,265
222	830	6,157	6,338
364	2,193	9,387	8,739
506	4,187	12,432	10,824
648	6,805	15,352	12,711
790	10,042	18,178	14,457
932	13,893	20,931	16,096
1074	18,354	23,622	17,650
1216	23,423	26,261	19,133
1358	29,096	28,855	20,556
1500	35,371	31,409	21,928

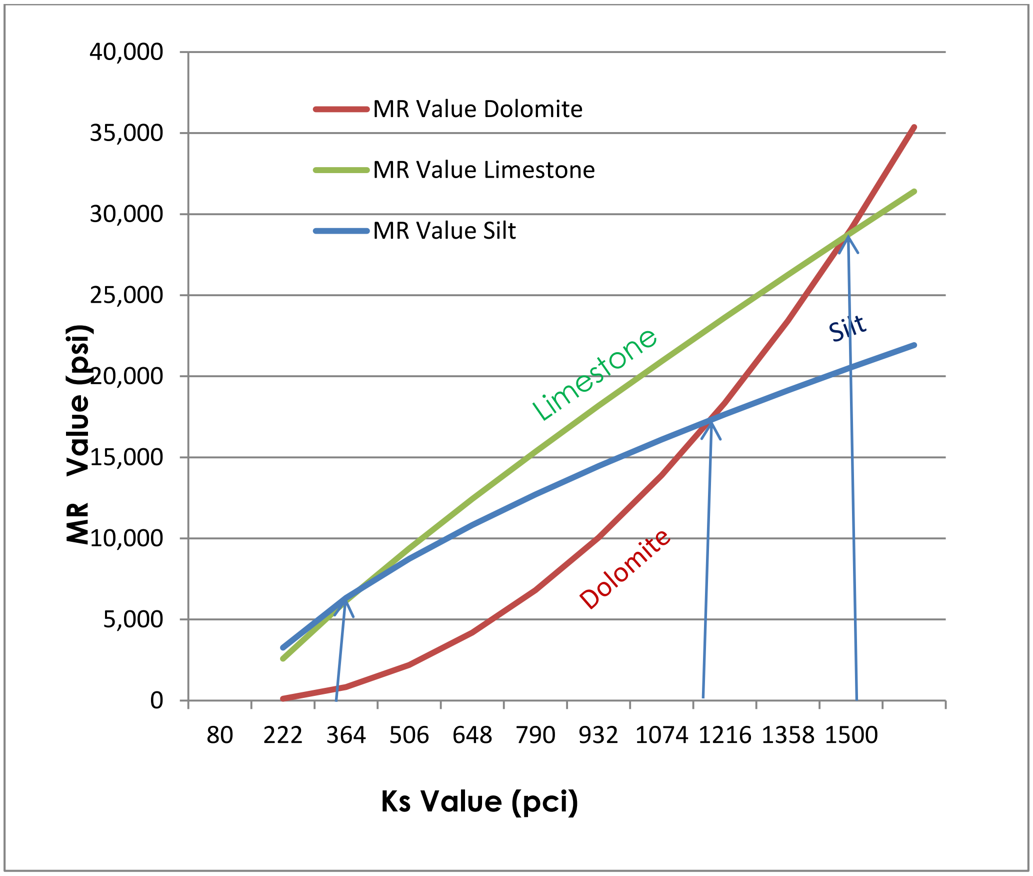

Fig. 10 Relationship between MR and Ks

The above table and figure shows, the relationship of the three correlation formulas for the materials of Dolomite base layer, Silt sub grade soil and lime stone base layer.

Comparing the graphs of Lime stone base layer and silt sub grade soil, both equations have almost similar behaviour up to their common point ks value 300pci. But after this point they totally separate and the gap between them increases. For increasing the ks value for both cases, we get a higher value of MR for lime stone, but not for silt.

On the other hand, the graph of Dolomite base layer is like upward parabolic nature and it is not agreed with the other two.

However, the graph crossing silt sub grade soil at Ks and with lime stone base layer at Ks 1400 (pci). This means that even though it has the same value of MR at the crossing point, gap between them is very large and dolomite is not agreed with the two.

The reason for such not observing similarity between the three different equations may be due to the difference of soil nature.

In general as per the above relationship of the correlation equation it is too difficult predicting resilient modulus. Hence, it has to be compare with other equations of similar soil type.

Effect of material type and Fines content on MR and Ks

The effect of aggregate type (Dolomite and lime stone) provides an obvious effect on MR and Ks, where the dolomite base course gets the highest value due to having angular to sub angular shape particles and rough particle surface that provides better load spreading properties and a higher Resilient Modulus than lime stone aggregate. Granular materials consist of large number particles, normally of different sizes.

Previous research in this area shows that the stiffness of such material is dependent on particle size and its distribution. The literature is not quite clear regarding the impact of fines content on the material stiffness. The base aggregate of 5 % fine content achieves MR higher than sub base aggregate of 9 % fine content. Thus it can be conclude that the Resilient Modulus generally decreases with the amount of fine increases.

This result agrees with many researchers, where a dramatic drop of about 60% in MR when the amount of fines was increased from 0 to 10%. This improvement in stiffness is attributed to increase contacts as pore space is filled.

Gradually, excess fines displace the course particles so that the mechanical performance relies only on the fines, and stiffness decreases.

5. Conclusion

Engineers are always looking for better ways to obtain reliable and suitable pavement design parameters at the lowest cost. On the basis of the study presented in this paper the following conclusions can be summarized.

- ✓ By using different correlation equations, calculating the values on the table and plotting them on the graph. Then identify which equation is not agreed with the other, explaining the similarity and finally selecting those equations suitable for predicting MR and Ks values.
- ✓ It also discussed that, MR of fine-grain soils is not a constant stiffness property but depends upon various factors like load state or stress state, which includes the deviator and confining stress, soil type and its structure.

  The resilient behaviour of unbound granular materials may be affected by several factors like effect of stress, density, grading, fines content, grain size, moisture content, aggregate type and particle shape.

- ✓ The effect of aggregate type (Dolomite and lime stone) provides an obvious effect on MR and Ks, where the dolomite base course gets the highest value due to having angular to sub angular shape particles and rough particle surface that provides better load spreading properties and a higher Resilient Modulus than lime stone aggregate. Granular materials consist of large number particles, normally of different sizes.

The major conclusions resulting from the relationship between the correlation equations of CBR, MR and KS for different soil types are as follows.

- CBR test is expected to simplify the effort in determination of modulus of sub grade reaction and resilient modulus due to the easiness of determines the value.

  As we have seen in the correlation formulas developed for the relationship between CBR and Ks, the difference between the two equations in the graph is very large. This is because of the difference of the nature of equations and the equations are carried out for different sub grade soil.

- Simple correlation equations have been evaluated to predict MR from standard CBR. The most effective parameters that have high significance in representing the MR variation are CBR, liquid limit (LL) and optimum moisture content (OMC).

  Summarizing the five correlation equations for relationship of MR and CBR values by **US Army, CSIR, TRRL, GDT and NAASRA** developed for course soils and fine grained soils, stabilized lime stone and granular materials as follows.

  - US Army equation does not agree with the rest four equations.
  - NAASRA and GDT equations are nearly identical and suited for predicting MR values.
  - TRRL and CSIR they have similar nature up to the same percentage value of CBR 24. But after that they will travel parallel and the gap between them increases.
  - On the other side comparing only NAASRA and Heuokelom equations provides the same result of MR at percentage CBR 4.5. But after this point the gap between them increases for increasing CBR value.

- Here I have seen three correlation equations for the relationship of MR and Ks for soil types of Dolomite base course, Silt sub grade soil and Lime stone sub base layer.

  - In the graph Dolomite base course has a nature of upward parabolic type and it is not agreed with the other two equations of silt and lime stone.
  - The graphs of silt sub grade and lime stone base layer have similar behaviour up to CBR value 300 (Pci). But when increasing CBR value they will differ and the gap between them increases.
  - Comparing the three equations, all have a similar value of MR for common value of Ks for increasing the ks value. But the big difference between them it is difficult to consider the dolomite with the other two.

6. Recommendation

- Since several correlations equations are available from past studies, there is a need to substantiate the predictability of these equations.
- Determination of resilient modulus from laboratory repeated cyclic tests and modulus of sub grade reaction from field plate load test is costly and time consuming. Though, In order to avoid this and provide a reliable and suitable correlation formula for the relationships of CBR, MR and Ks continuous study must be done here in Ethiopia for the different types of soil for predicting MR and Ks values from the correlation equations.

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