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Establishment of Correlation between CBR and Resilient Modulus of Subgrade

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Abstract

In the present study, an effort has been made to develop an empirical correlation between Resilient Modulus (M_R) and soaked California Bearing Ratio (CBR) for the subgrade soil. MR is widely used to design pavements instead of the CBR value in recent software like IIT PAVE. M_R is usually determined in the laboratory by conducting tests as per AASHTO T 307-99(2003) (1), using the cyclic triaxial test. Since the repetitive triaxial testing facility is not widely available and is expensive, few generally accepted correlations from IRC: 37-2012 are used in India. As these general correlations are derived based on the American standards, they are not ideal for the Indian design conditions. Thus, it is necessary to determine a suitable empirical correlation that suits the Indian conditions. For this purpose, disturbed soil samples were collected from 5 different locations in and around the Chennai area. Laboratory tests were conducted on the 5 different soil samples to determine its index properties to classify the soil as per the Indian Standard Soil Classification System (ISCS). Soil specimens for soaked CBR test and triaxial test were prepared based on Optimum Moisture Content and Maximum Dry Density values obtained from Modified Proctor Compaction Test. Based on the soaked CBR value and M_R value obtained from the repetitive triaxial test for 5 different soil samples, an empirical correlation was established between the two entities that would suit the Indian design conditions.

Keywords — *Resilient Modulus, CBR, triaxial test, cyclic triaxial test.*

I. INTRODUCTION

Soil is an integral part of any civil engineering structure; either it is used as construction material or used as load-bearing strata to support the structure. If the natural soil present at the site is strong enough to withstand the load coming from the structure, the construction may start immediately without much delay. A number of tests are available to determine the subgrade soil's strength based on which a structure can be designed. Laboratory tests such as direct shear test, unconfined compression test (UCC), triaxial test, California Bearing Ratio (CBR) test, and insitu tests such as plate load test, standard penetration test, cone penetration test can be used to determine the shear strength parameters of the soil and bearing capacity of the soil and also to predict the probable settlement that the soil may undergo in the future. Some of the above tests require less time and are easy to perform, whereas others are laborious and time-consuming, resulting in a delay in completing the project. To overcome this, many researchers have tried to acquire a correlation between soil strength parameters and the various soil index properties, thus reducing the time spent on complex and sophisticated experiments. As per [1], [20], the CBR test is laborious and time-consuming and thus proposed a method for correlating CBR value with the Liquid Limit (LL), Plastic Limit (PL), Shrinkage Limit (SL), Plasticity Index (PI), Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) as these tests are simple and can be completed within less period of time. Reference [1] investigated various linear relationships between index properties and CBR of the samples using simple and multiple linear regression analysis and a predictive equation estimating CBR from the experimental index values.

Another such difficult and time-consuming experiment is the cyclic triaxial test based on which Resilient Modulus (M_R) of soil can be obtained, which is an important parameter in the design of flexible and rigid pavement. M_R is a material measure of subgrade stiffness, and it is an estimate of materials Modulus of Elasticity (E). E is defined as the ratio of stress to strain for a slowly applied load, whereas M_R is the ratio of stress to strain for rapidly applied loads – like those experienced by pavements. The AASHTO guide (1986) for the design of flexible pavements recommends M_R [6]. As per [2], cyclic deformation characteristics such as MR are the key parameter for mechanic-empirical pavements. Also, cyclic deformations can better describe material behavior and can be more useful in road engineering. The M_R is determined from repeated load triaxial apparatus for simulating wheel load. As in [4], the triaxial test apparatus is sophisticated and expensive, and also the realization of the test requires a lot of time and qualified personnel to conduct the test and interpret the results. To reduce the cost, the time required in road projects, and facilitate engineers' work, it is important to predict M_R. By conducting triaxial tests in cyclic load conditions, it is possible to obtain mechanistic factors that better describe subbase behavior than empirical tests and equations [7].

For smaller projects, were costly and complex M_R testing is not affordable, correlation with other simpler tests could be used. In the present experimental work, an effort has been made to correlate the M_R value of soil with soil's CBR value. As in [3], due to the triaxial test's complexity and cost, correlations have been established to predict M_R. CBR is the most used parameter to estimate M_R since it is not expensive and easy to obtain. Correlations have been established based on statistical analysis, and the predicted modulus is used to replace E, representing the base course's stiffness modulus. As per [3], [21], the correlation between M_R and CBR should be used carefully because they tend to ''over-predict'' or ''under predict'' the M_R. In addition, an "under-prediction" of M_R causes an under-design and premature deterioration of roads. Reference [8] believed that the CBR test is one of the most widely used tests for evaluating pavement subgrade competency. Still, there are variations in the procedure followed by different agencies in terms of size of the mould, compaction, and efforts. It was also found that correlations between M_R values and CBR were not statistically significant. As per [6], many researchers can obtain mechanistic factors such as E or M_R by CBR test. M_R is an important parameter that characterizes the subgrade's ability to withstand repetitive stresses under traffic loadings. Factors affecting M_R of base course material in a pavement under repeated traffic loading are the type of material (fine-grained soil or granular soil), loading condition, deviator stress, confining pressure, degree of compaction, method of compaction, moisture content, degree of saturation, density, index properties of soil such as LL, PI, specific gravity, silt content, organic content, etc. As in [16], M_R is influenced by many factors, and the most important of them are stress level and material properties.

Several empirical equations have been suggested by numerous researchers to estimate the M_R and have tried to acquire a correlation between M_R and CBR value of subgrade soil. Since 1960, numerous research efforts have been developed to characterize granular materials' resilient behavior [16]. Reference [12] investigated if a relationship existed between Repeated Load Triaxial (RLT) and CBR test by testing twenty materials with both methods, and the test results were compared. The results indicated that a simple power-law could forecast the stiffness if the CBR-value is known. As per [9], CBR value can be converted to $M_{R,}$ and a strong trend was found to be apparent in the correlation, but there was a lot of scattering. As in [10], CBR can be related, within reasonable limits, to subgrade stiffness. Reference [5] developed an empirical model to estimate M_R based on CBR values using experimental results obtained for 52 remoulded granular samples containing natural aggregates, reclaimed asphalt pavement (RAP), and recycled concrete aggregate (RCA) samples. As per [15], M_R is not a simple CBR function but depends on the soil type and applied deviator stress level. Reference [18] could not find a suitable correlation between CBR and M_R. Reference [19] stated that the CBR does not correlate consistently with either strength or stiffness; As per [13], [14], CBR is not suitable for estimating M_R as CBR is a measure of strength, and thus it cannot be correlated with M_R which is a measure of stiffness, and it is strongly dependent on the stress state. Reference [17] found linear and nonlinear relationships for estimating M_R for fine and coarse-grained soils from physical properties. Reference [2] determined M_R for the lime stabilized clay obtained from the repeated loading CBR tests. As in [4], simple and multiple regression methods are used to establish linear and nonlinear relations to predict MR and are better predicted in a nonlinear relationship.

II. EXPERIMENTAL WORK

To determine whether a correlation exists between soaked CBR value and M_R, laboratory tests were conducted on various soil samples collected from 5 different locations in and around the Chennai area. Tests such as specific gravity test, wet sieve analysis, liquid limit test, and plastic limit test were conducted to determine the soil's index properties to classify the soil as per Indian Standard Soil Classification System (ISCS). Modified Proctor Compaction Test (MPCT), soaked CBR test, and repeated triaxial test were also conducted on the different soil samples, and the results are tabulated below. Remoulded soil specimens for soaked CBR test and triaxial test were prepared at 97% relative compaction based on the OMC & MDD obtained from MPCT. Based on the results obtained from the soaked CBR test and triaxial test wherein cyclic axial loads were applied, a correlation factor was obtained for the 5 different soil samples relating M_R with soaked CBR.

III. RESULTS AND DISCUSSION

The tests such as specific gravity test, wet sieve analysis, liquid limit test, and plastic limit test are listed below. OMC and MDD obtained from MPCT, and the soaked CBR test and repeated triaxial test conducted on 5 different soil samples (S1, S2, S3, S4, and S5) are also tabulated below.

A. Soil Classification

Results of the various index property tests conducted on different soil samples are given below in Table I. Soil samples were classified as per ISCS based on the soil's index properties.

TABLE I
Index property of soil samples

Index Property	S1	S2	S3	S4	S5
Specific Gravity (G)	2.23	2.21	2.26	2.31	2.32
Wet Sieve Analysis					
Percentage of Gravel	0	0	0	0	0
Percentage of Sand	58.17	96.92	95.88	58.92	57.82
Percentage of Fines	41.83	3.08	4.12	41.08	42.18
D_{10} (mm)	-	0.08	0.075	-	-
D_{30} (mm)	-	0.25	0.29	-	-
D_{60} (mm)	0.23	0.6	0.54	0.33	0.26
C_U	-	7.5	7.2	-	-
C_C	-	1.3	2.08	-	-
Atterberg's Limits					
Liquid Limit (%)	20	-	-	32	20
Plastic Limit (%)	12.53	-	-	14.86	17.06
Plasticity Index (%)	7.47	-	-	17.14	2.94
Soil Classified as per ISCS	SC (Clayey Sand)	SW (Well graded sand)	SW (Well graded sand)	SC (Clayey Sand)	SM (Silty Sand)

Fig 1 shows the particle size distribution curve obtained from wet sieve analysis conducted on the 5 different soil samples used in the experimental work.

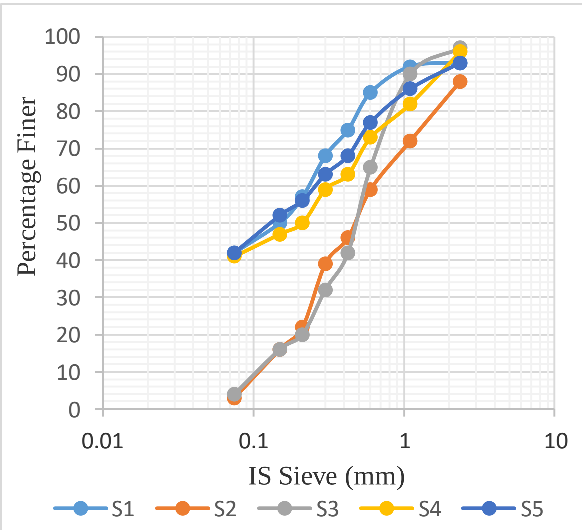

Fig 1: Particle Size Distribution Curve from Wet Sieve Analysis

The particle size distribution curve plotted for the different soil samples shows that S2 and S3 have a similar gradation, whereas S1, S4, and S5 show similar particle size distribution.

B. *Modified Proctor Compaction Test (MPCT)*

OMC and MDD were determined from MPCT for the 5 different soil samples, and the results of the MPCT are tabulated below in Table II. Fig. 2 shows the relation between moisture content (w) and dry density (ρ_d) obtained for the 5 different soil samples from MPCT.

TABLE III
Moisture Content (w) and Dry Density (ρ_d) values from MPCT

S1		S2		S3		S4		S5	
w %	ρ_d g/cc	w %	ρ_d g/cc	w %	ρ_d g/cc	w %	ρ_d g/cc	w %	ρ_d g/cc
5.8	1.81	1.58	1.89	2.26	1.85	2.37	1.87	2.36	1.82
7.56	1.97	3.17	1.94	4.43	1.88	3.83	1.9	3.52	1.91
9.61	2.09	4.87	2.0	5.92	1.92	6.43	1.99	5.62	2.05
12.44	2.07	6.56	2.04	8.19	1.98	9.39	2.04	8.6	2.08
14.21	1.96	8.66	1.96	10.47	1.92	10.79	1.96	10.58	1.92
OMC = 9.61 % MDD = 2.09 g/cc		OMC = 6.56 % MDD = 2.04 g/cc		OMC = 8.19 % MDD = 1.98 g/cc		OMC = 9.39 % MDD = 2.04 g/cc		OMC = 8.6 % MDD = 2.08 g/cc	

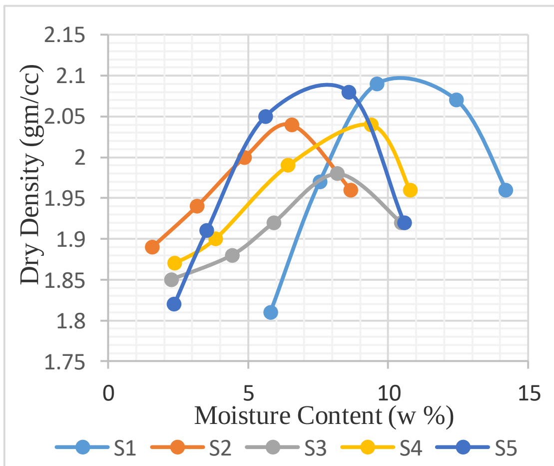

Fig 2: Moisture dry density relation from MPCT

C. *Soaked CBR Test*

The specimen for the soaked CBR test was prepared at 97% relative compaction based on the OMC and MDD obtained for each soil sample from MPCT. The soaked CBR test results are given in Table III, and Fig. 3 shows the load penetration curve obtained from the soaked CBR test for the 5 different soil samples.

TABLE IIIII
Soaked CBR values of the different soil samples

Penetration (mm)	Load (kg)				
	S1	S2	S3	S4	S5
0.5	14.96	74.8	67.32	8.976	14.96
1	29.92	152.59	145.11	17.952	28.424
1.5	40.392	221.41	213.93	25.432	37.4
2	49.368	284.24	281.25	34.408	47.872
2.5	55.352	341.09	339.59	41.888	59.84
4	73.304	466.75	462.26	59.84	76.296
5	82.28	508.64	505.65	68.816	88.264
7.5	100.23	620.84	610.37	85.272	103.22
10	116.69	710.6	704.62	98.736	118.18
12.5	134.64	722.57	-	110.70	137.63
Soaked CBR (%)	4.04	24.9	24.79	3.35	4.37

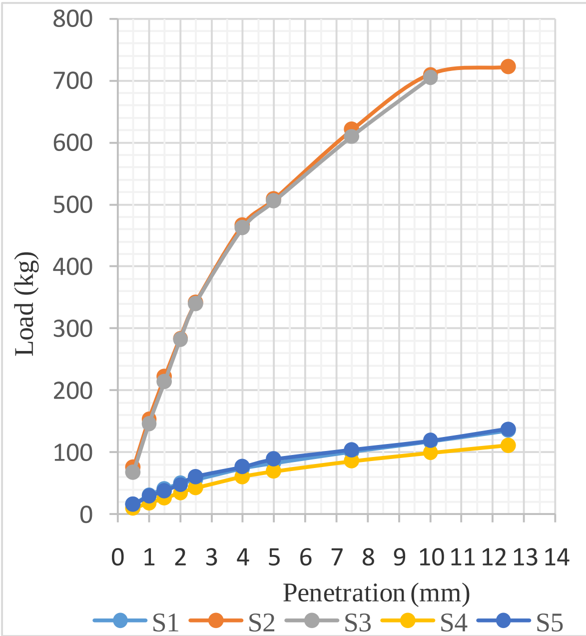

Fig 3: Load Penetration curve obtained from soaked CBR test

From the load penetration curve plotted for the soaked CBR test for the different soil samples, it can be observed that S2 and S3 show a similar curve, whereas S1, S4, and S5 show a similar load penetration curve.

D. Cyclic Triaxial Test

M_R for the subgrade and base material is usually determined in a repeated triaxial test wherein confining pressure and deviator stress can be controlled. The test procedure for determining pavement materials' resilient response is a triaxial compression test in which a cyclic axial load was applied to a cylindrical test specimen prepared from disturbed soil based on the OMC and MDD obtained for the different soil samples from MPCT. The prepared soil specimen, normally 100 mm (4 inches) in diameter and 200 mm (8 inches) in length enclosed within a thin rubber membrane, was placed inside a cell and subjected to all around confining pressure and repeated axial load. After the specimen was subjected to all around confining pressure, measurements were taken of the recoverable axial deformation to calculate resilient strain, and the applied load was measured using a load cell. The deviator stress is the axial stress applied by the testing apparatus minus the confining stress. When the deviator stress was applied, the sample deformed, thus causing a change in length. This change in sample length is directly proportional to the stiffness. The test is usually conducted by applying a number of stress repetitions over a range of deviator stress levels and confining pressure levels representing variation in-depth or location from the point of application of load. The M_R was calculated as

$M_R = \sigma_D / \varepsilon_S$ where σ_D is the axial deviator stress and ε_S is the resilient axial strain

$\sigma_D = P / A$ where P is the applied load and A is the cross-sectional area of the specimen

$\varepsilon_S = \Delta L / L_i$ where ΔL is the recoverable axial deformation and L_i is the original length of the specimen

The cyclic triaxial test was conducted on the 5 different soil samples - S1, S2, S3, S4, S5, and the test results are given below in Table IV, Table V, Table VI, Table VII, and Table VIII, respectively.

TABLE IVV
Cyclic Triaxial Test on S1

Sequence	Cyclic Axial Stress (kPa)	Confining Stress (kPa)	Actuator Resilient Strain	Actuator Resilient Modulus (MPa)
0	5.663921	42.04079	1102.96	5.113827
1	0.866979	42.06368	213.7899	8.755003
2	4.596153	42.00494	1148.474	3.998104
3	22.60046	41.99113	1092.553	20.68706
4	30.88761	42.03793	928.1874	33.27686
5	42.1952	42.0216	1117.241	37.76716
6	0.922057	24.52788	215.5423	18.26471
7	6.985517	24.45816	1847.863	3.66509
8	16.63812	24.43804	2405.334	6.909548
9	37.53697	24.47854	1073.003	34.98583
10	43.07718	24.4804	1090.467	39.50344
11	0.986316	8.815597	239.706	13.94584
12	5.651098	8.790397	1899.898	2.971971
13	12.18856	8.777656	2737.2	4.452673
14	36.5849	8.807091	1084.459	33.74054
15	42.21443	8.801548	1045.561	40.37481

Resilient Modulus of S1 = 39.22 MPa

TABLE V
Cyclic Triaxial Test on S2

Sequence	Cyclic Axial Stress (kPa)	Confining Stress (kPa)	Actuator Resilient Strain	Actuator Resilient Modulus (MPa)
0	7.140553	42.79231	1433.635	4.981285
1	0.647101	42.78415	366.6043	2.800019
2	4.643217	42.81414	1876.318	2.457646
3	20.54448	42.78621	2004.123	10.23599
4	31.4534	42.77388	1473.427	21.34724
5	41.73708	42.71696	1554.048	26.85732
6	1.117601	25.051	352.7164	5.113251
7	4.973543	25.08104	1944.22	2.501063
8	19.34776	25.07023	2034.223	9.509083
9	34.3054	25.04374	1533.294	22.37447
10	42.05619	25.02042	1516.151	27.73898
11	0.944642	9.11784	281.5485	5.078461
12	4.121282	9.130279	1839.888	2.252732
13	18.17508	9.102726	2075.982	8.755108
14	34.38088	9.06863	1524.997	22.5455
15	42.47758	9.0602	1495.647	28.40086

Resilient Modulus of S2 = 27.665 MPa

TABLE VI
Cyclic Triaxial Test on S3

Sequence	Cyclic Axial Stress (kPa)	Confining Stress (kPa)	Actuator Resilient Strain	Actuator Resilient Modulus (MPa)
0	4.774211	42.26987	1452.148	3.287684
1	1.188562	42.27541	755.8346	1.277499
2	3.665353	42.20255	1630.402	2.248331
3	16.41475	42.17999	2313.435	7.088532
4	33.29169	42.20354	1602.471	20.77585
5	45.01514	42.1939	1611.161	27.9408
6	0.863044	24.69519	220.6206	4.323526
7	3.645099	24.64299	1519.907	2.397033
8	18.15381	24.61953	1899.791	9.550022
9	33.36819	24.64634	1511.252	22.08111
10	45.07517	24.63047	1548.707	29.1057
11	0.632384	8.922653	294.0059	2.077791
12	3.580403	8.873367	1384.306	2.58646
13	18.4496	8.859321	1736.462	10.61751
14	32.9857	8.879944	1460.898	22.58071
15	45.00144	8.863857	1505.697	29.88795

Resilient Modulus of S3 = 28.97 MPa

TABLE VII
Cyclic Triaxial Test on S4

Sequence	Cyclic Axial Stress (kPa)	Confining Stress (kPa)	Actuator Resilient Strain	Actuator Resilient Modulus (MPa)
0	10.39937	42.35331	450.7422	23.07426
1	2.730036	42.43435	159.9789	17.11555
2	11.09587	42.52612	478.9948	23.1642
3	19.61135	42.3962	796.2704	24.62875
4	30.19024	42.3627	1186.073	25.45396
5	41.34031	42.45968	1527.572	27.06237
6	0.597851	24.56084	169.5275	78.8627
7	11.44266	24.39795	987.5894	11.58558
8	23.67376	24.47698	1069.868	22.1282
9	31.09321	24.35293	1207.423	25.75179
10	41.45207	24.46646	1506.555	27.51438
11	0.621748	8.49101	177.2761	21.10688
12	9.33889	8.57627	1227.14	7.600386
13	23.73627	8.51913	1109.838	21.38821
14	30.91325	8.49027	1199.698	25.76758
15	41.34978	8.49387	1485.217	27.84091

Resilient Modulus of S4 = 27.47 MPa

TABLE VIII
Cyclic Triaxial Test on S5

Sequence	Cyclic Axial Stress (kPa)	Confining Stress (kPa)	Actuator Resilient Strain	Actuator Resilient Modulus (MPa)
0	8.118563	41.87103	236.1059	34.3894
1	1.398386	41.87174	46.51547	30.14105
2	8.468997	41.82706	242.5671	34.9146
3	18.1643	41.81009	498.7836	36.41667
4	29.62503	41.83777	784.7428	37.75134
5	41.04146	41.83668	1062.071	38.6427
6	1.474009	24.39391	189.0063	7.796889
7	11.7896	24.36142	491.6549	23.98024
8	22.21607	24.34277	698.9598	31.78474
9	29.9826	24.38054	823.0209	36.43013
10	40.52069	24.37015	1034.26	39.1786
11	0.87135	8.76432	223.1598	4.878394
12	11.46947	8.75655	531.0059	21.60113
13	22.87498	8.750561	736.4273	31.06421
14	30.12175	8.773384	829.7801	36.30071
15	40.32413	8.777218	1025.009	39.34039

Resilient Modulus of S5 = 39.05 MPa

Based on soil's index properties, such as particle size distribution curve, plasticity characteristics, and soaked CBR values, 5 types of soil samples utilized in the experimental work were grouped into Group I and Group II. I consisted of S1, S4, and S5 with fine-grained soil such as clay or silt in the sand (SC & SM soil) and Group II consisting of S2 and S3, both being well-graded sand (SW). A correlation was obtained between M_R and soaked CBR value for the two groups of soil, and the correlation factor (C) is given below in Table IX.

TABLE IX
Correlation between M_R and soaked CBR

Group	Soil Sample	Soaked CBR (%)	M_R (MPa)	Correlation between M_R and soaked CBR	C	Avg. C
Group I (SC & SM soil)	S1	4.04	39.22	M_R=(9.71)*CBR	9.71	8.95
	S4	3.35	27.47	M_R=(8.2)*CBR	8.2	
	S5	4.37	39.05	M_R=(8.94)*CBR	8.94	
Group II (SW)	S2	24.9	27.665	M_R=(1.11)*CBR	1.11	1.14
	S3	24.79	28.97	M_R=(1.17)*CBR	1.17	

From the results of the soaked CBR test and cyclic triaxial test, it was observed that for soil samples of Group I having SC soil and SM soil, an average correlation factor of 8.95 could be adopted correlating M_R = (8.95) * CBR between M_R and soaked CBR value. For soil samples of Group II having SW soil, an average correlation factor of 1.14 can be adopted, thus correlating M_R = (1.14) * CBR between M_R and soaked CBR value. Also, the average correlation factor (C) for Group I soil was much higher, about 7.85 times that of Group II soil. It was also observed that, for all the 5 soil samples, the MR value was found to decrease as the confining pressure increased.

IV. CONCLUSION

For soil samples classified as SC and SM, an average correlation factor of 8.95 can be adopted, thus correlating M_R = (8.95) * CBR. For soil samples classified as Well Graded Sand (SW), an average correlation factor of 1.14 can be adopted, thus correlating M_R = (1.14) * CBR. The average correlation factor (C) for SC and SM soil was about 7.85 times that of SW soil. In the cyclic triaxial test, as the confining pressure increased, the M_R value was found to decrease.

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