Interrelationship Between CBR and Electrical Resistivity in Gravelly Soil

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Abstract. The Californian Bearing Ratio (CBR) test is used to evaluate the subgrade strength of roads and pavements. However, performing CBR test is laborious and time consuming. Even though the gravelly soils are excellent subbase materials but performing CBR on them have some serious apprehensions. In order to overcome the limitations, it would be appropriate if we have a direct correlation between CBR and one such parameter of soil that can be determined easily and rapidly either on field or in laboratory. Therefore, the objective of this study is to establish an interrelationship between CBR and electrical resistivity in gravelly soils. In this study, four different mixes of subbase materials are prepared. A soil resistivity box in cylindrical shape having dimensions similar to that of compacted soil specimen inside CBR mould is also fabricated to evaluate electrical resistivity of prepared mixes in laboratory. The prepared mixes are first subjected to both soaked and unsoaked CBR test to determine their CBR values. Electrical resistivity tests are then performed on the mixes in both soaked and unsoaked condition to determine their resistivities. Then using the simple linear regression analysis relationship between CBR and electrical resistivity for both soaked and unsoaked condition is established and an equation is also developed to ascertain soaked CBR value using unsoaked CBR and resistivity data by using multiple linear regression analysis. The results obtained show a strong and positive correlation between CBR and electrical resistivity for the prepared mixes. It is also found that the soaked CBR for the prepared subbase mixes can be effectively calculated on the basis of equation developed using the values of unsoaked CBR and resistivity with a great confidence limit.

Keywords: CBR, Electrical resistivity, Subbase.

1 Introduction

The California Bearing Ratio (CBR) test is used to evaluate the strength of soil subgrades of roads and pavements. The thickness of pavements and its component layers are determined using the CBR test results. CBR test is laborious and time consuming. Even though the gravelly soils are excellent subbase materials but performing CBR on them have some apprehensions related to the maximum allowable particle size, amount of energy to be imparted and role of fines present in the mix. In order to overcome all these limitations, researchers in past have tried to correlate CBR with other geotechnical or geophysical properties of soil which could be determined rapidly and more conveniently either on field or in laboratory. Electrical resistivity of soil can be found out either in field or in laboratory in comparatively very less time.

Sebastian et al. studied the correlation of electrical resistivity of non-cohesive soils and the degree of compaction. Based on the results obtained it was asserted that the resistivity survey cannot be used as a direct method for determination of degree of compaction in situ [1]. Ankintorinwa and Oluwole carried out their research to establish a relationship between resistivity and several geotechnical parameters in form of empirical equations. Based on the results obtained it was implied that almost all the geotechnical properties can be estimated using the electrical resistivity measurements from the established empirical equations for each of the parameters [2]. Irfan and Azahar developed simple and multiple regression models for relationship between electrical resistivity and various soil propertied for soil characterization. From the data analysis, significant correlations have been obtained between resistivity and moisture content, friction angle and plasticity index whereas weaker correlation have been observed for cohesion, unit weight of soil and effective size [3]. Mostafa et al. studied the application of electrical resistivity measurement as quality control test for calcareous soils. Resistivity was found to decrease with increase in fines content and degree of compaction on wet of optimum moisture content. However, on the dry of optimum moisture content resistivity was found to increase with degree of compaction [4]. Rabindra et al. studied the effects of maximum particle size, fines content and dust ratio on base and subbase coarse aggregates. The results show that aggregates with larger maximum size particles provide high strength and they are less affected by an increase in fines content. The aggregates with smaller maximum size particles provide lower strength [5].

In the present study, soaked and unsoaked CBR tests are performed on the prepared subbase mixes and their values are interrelated with the electrical resistivity values which are found in laboratory using the fabricated soil resistivity box.

2 Materials

In this study, four different mixes of grade-3 subbase materials are prepared as per the gradations specified by Ministry of Road Transport and Highway (MoRTH) [6]. Two different materials were used for the mix preparation of which one was gravel content which was obtained from river sand and another one was natural soil which was obtained from the college's campus at a depth of 1 m using the auger boring.

2.1 Gravel

Properties of gravel content determined in laboratory as per their respective IS codes are shown in table 1.

Table 1. Properties of gravel content

Test	Symbol	Result	IS Code
Specific Gravity	G	2.68	IS 2386 Part III
Combined Flakiness and Elongation index	FI & EI	25.89%	IS 2386 Part I

2.2 Natural Soil

Properties of natural soil determined in laboratory as per their respective IS codes are shown in table 2.

Table 2. Properties of natural soil

Test	Symbol	Result	IS Code
Specific Gravity	G	2.67	IS 2720 Part III
Grain Size Analysis	Cc & Cu	Cc = 4 Cu = 1.8	IS 2720 Part IV
Soil Classification	-	Poorly graded sand (SP)	IS 1498-1970
Liquid Limit	LL	20%	IS 2720 Part V
Plasticity Index	PI	Non plastic	IS 2720 Part V

2.3 Subbase Mixes

Four mixes are prepared in laboratory as per the MoRTH specifications for grade-3 gradings. Gradation of the mixes are shown in Table 3 and the gradation curves are shown in Fig. 1.

Table 3. Gradation of the prepared subbase mixes

IS Sieve	Percent by weight passing the IS sieve			
Designation	M_1	M_2	M_3	M_4
26.5 mm	100	100	100	100
9.5 mm	65	75	85	95
4.75 mm	50	60	70	80
2.36 mm	40	47	54	60
0.425 mm	20	20	20	20
0.075 mm	3	5	7	10

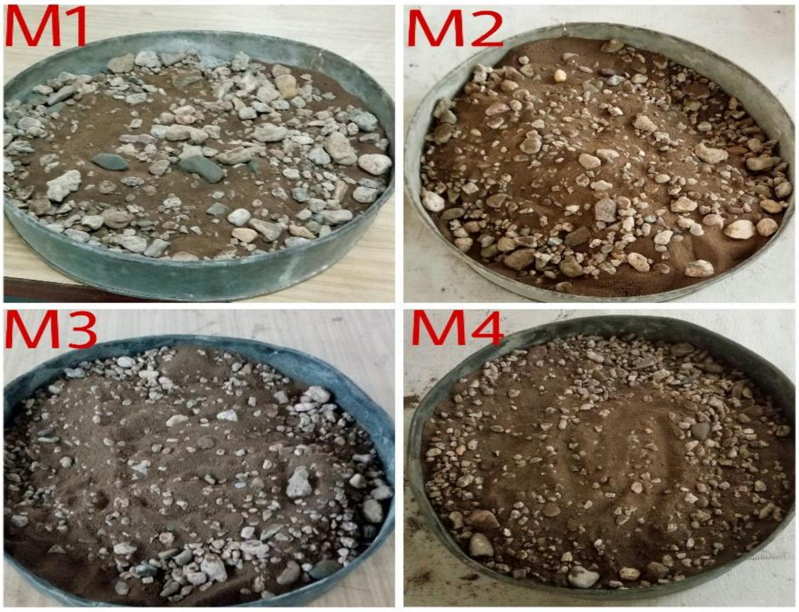

Fig. 1. Prepared mixes of subbase for grade-3

2.4 Subbase Mixes

As per ASTM G187 [8], a soil resistivity box was fabricated in cylindrical shape having dimensions similar to the dimension of compacted soil mass inside the CBR mould (15 cm diameter and 12.8 cm height). Body of the resistivity box was made of acrylic material having significant resistant properties and both the sides of box were fixed with adjustable copper plates of 3 mm thickness to pass the electric current through the compacted soil mass kept inside it.

Fig. 2. Fabricated soil resistivity box

3 Experimental Program

Experimental program of the current study was divided into two steps. First of all, the mixes were subjected to both soaked and unsoaked CBR tests as per IS: 2720 part xvi [8] to determine their CBR values. Then the electrical resistivity tests were performed in laboratory in both soaked and unsoaked conditions to find out their resistivity values.

3.1 CBR Test

CBR test was performed in laboratory as per IS 2720 part xvi [7] in both soaked and unsoaked conditions. For soaked condition, samples were soaked in water for four days (98 hours) prior to their test.

3.2 Electrical Resistivity Test

Electrical resistivity test was performed in laboratory on the prepared mixes in fabricated resistivity box. The soil specimen of a particular mix was compacted inside the mould at its respective OMC and MDD value. Then the resistivity box with compacted soil specimen inside it was connected to the LCR meter as shown in Fig. 3.

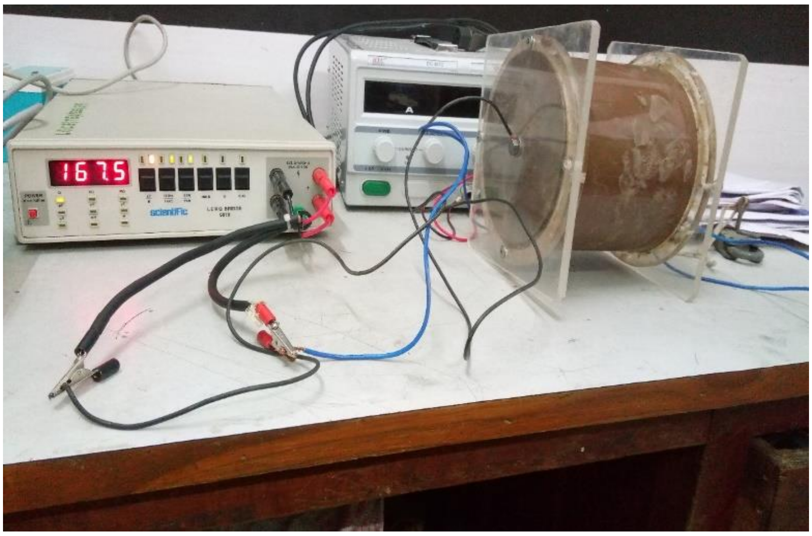

Fig. 3. Electrical resistivity test setup

LCR meter which works on the principal of wheat stone bridge passes current through the compacted soil specimen at a fixed voltage of 12 V and displays the value of resistance of compacted soil specimen as its output. Electrical resistivity was then calculated based on cross sectional dimensions of the resistivity box using equation 1.

$$R = \rho \times \frac{L}{A} \tag{1}$$

Where, R = resistance of the compacted soil mass (Ω)
ρ = resistivity of the compacted soil mass (Ωm)
L = length of the resistivity box (m)
A = Cross sectional area of the resistivity box (m^2)

For performing soaked resistivity test the compacted soil specimen inside the resistivity box was kept submerged in water for four days similar to the soaked condition in CBR test just to maintain the similitude between both the testing condition. After four days of submergence the resistivity was calculated in same way as it was done for the unsoaked condition. The tests were repeated three times and average of the three values was taken as final resistivity value.

4 Results and Discussion

The results of the series of experiments carried out in laboratory are elaborated as follows.

4.1 CBR Test Results

Both soaked and unsoaked CBR test results for the prepared subbase mixes are represented in Table 4.

Table 4. CBR test results of subbase mixes

Mix designation	Soaked CBR value (%)	Unsoaked CBR value (%)
M_1	96.10	109.48
M_2	70.55	82.72
M_3	53.52	60.82
M_4	36.49	43.79

Load vs penetration curves obtained from CBR tests are shown in Fig. 4 and Fig. 5.

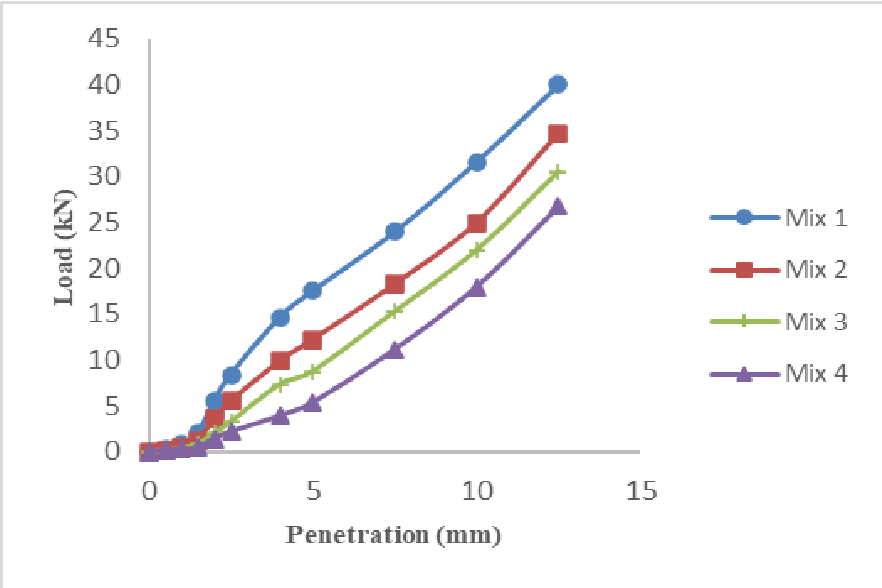

Fig. 4. Load vs penetration curves of subbase mixes in soaked condition

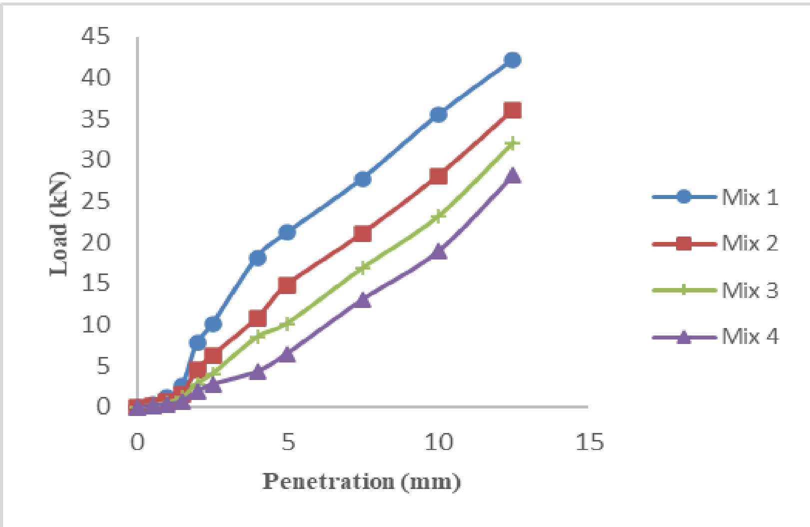

Fig. 5. Load vs penetration curves of subbase mixes in unsoaked condition

4.2 Electrical Resistivity Test Results

Resistance of the subbase mixes compacted inside resistivity box was measured and the resistivity then calculated using equation 1 is listed in Table 5.

Table 5. Electrical resistivity of the subbase mixes

Mix	Soaked electrical resistivity (Ωm)	Unsoaked Electrical resistivity (Ωm)
M_1	149.30	642.88
M_2	135.25	509.31
M_3	95.03	404.85
M_4	58.96	344.97

4.3 Interrelationship Between CBR and Electrical Resistivity

Interrelationship between CBR and electrical resistivity as shown in Fig. 6 and Fig. 7 was developed using simple linear regression analysis.

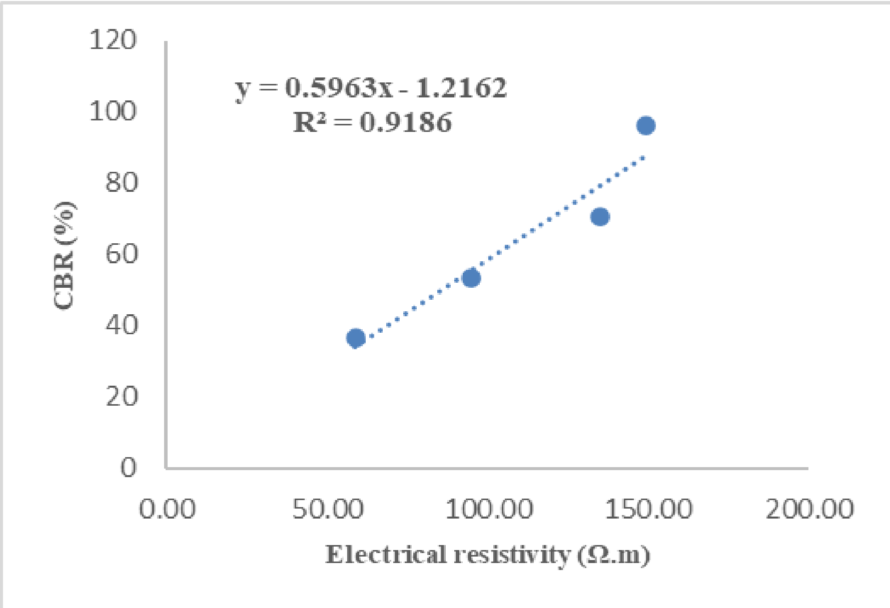

Fig. 6. Interrelationship between CBR & ER in soaked condition

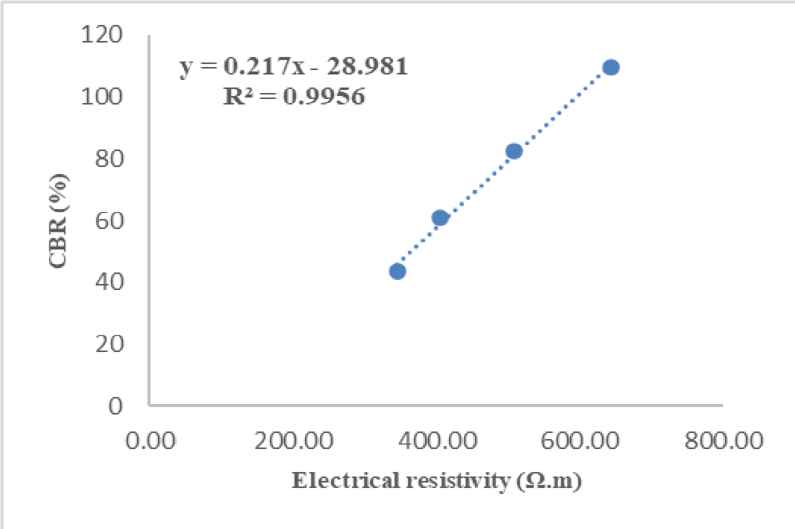

Fig. 7. Interrelationship between CBR & ER in unsoaked condition

Based on the multiple linear regression analysis (MLRA) between Soaked CBR, Unsoaked CBR and unsoaked electrical resistivity values an equation is also developed to ascertain soaked CBR data from unsoaked CBR and electrical resistivity values. The values used for performing MLRA are represented in Table 6 and the equation is shown in Table 7.

Table 6. Values used for MLRA of subbase mixes

Mix	Soaked CBR (%) (Y)	Unsoaked CBR (%) (X_1)	Unsoaked Resistivity (Ω.m) (X_2)
M_1	96.1	109.48	642.89
M_2	70.55	82.72	509.31
M_3	53.52	60.82	404.86
M_4	36.49	43.79	344.97

Table 7. Equation developed for grade-3 subbase mixes using MLRA

Equation	Coefficient of determination (R^2)
$Y = 1.055X_1 – 0.0351X_2 + 2.553$	0.998

5 Conclusions

A series of experiments were conducted in laboratory to determine the interrelationship between CBR and electrical resistivity in gravelly soils. The major findings of the study are enlisted as follows.

1. Both soaked and unsoaked CBR values of grade-3 mixes of subbase materials bear a positive correlation with its electrical resistivity values. As the soaked CBR value of the mixes increase, resistivity also increases and vice versa.
2. Interrelationship between both soaked and unsoaked CBR and electrical resistivity is quite strong as depicted by the coefficient of determination (R^2) value which is quite close to 1 for both the cases.
3. The equation developed for finding out the soaked CBR from unsoaked CBR and resistivity values will also give quite accurate result as depicted by a very strong R^2 value (0.998). Hence, the time and manpower that is required in finding out soaked CBR values of grade-3 subbase mixes can be drastically reduced using this equation.

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