Comparative Studies of Field and Laboratory CBR Results

By

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Introduction

California Bearing Ratio (*CBR*) is the representative test to know load-penetration characteristic of soil. In India, the design of flexible pavements is guided by the criterion of *CBR* tests conducted mostly in the laboratory on soil samples. The *in-situ* field *CBR* tests conducted on natural subgrade can only provide the correct representation regarding load-penetration characteristics of soil. Although, much of the work is available on laboratory *CBR*, very little work has been done pertaining to field *CBR*. With this in view, present studies were planned.

The tests were carried out in the field to obtain *in-situ CBR* of natural subgrade soil. Undisturbed samples were collected from the field. Laboratory *CBR* tests were carried out on these undisturbed samples. Herein, an attempt is made to compare the results of *CBR* thus obtained in the field and laboratory.

In addition, supplementary tests were performed to obtain geotechnical engineering properties of these soils. Herein, an attempt has also been made to correlate field *CBR* with these properties.

Experimental Programme

The selection of test locations, experimental set-up used and procedures adopted for carrying out *CBR* tests aregiven briefly.

Field CBR Tests

(a) Test Locations

The field tests were conducted in Chandrapur district of Maharashtra State. On the basis of the available knowledge about geology and pedology of the area suitable test locations were selected. These locations were distributed in area of around 1500 sq. km.

(b) Test Procedure

Afer selecting test location, the area of about 1 m×0.4 m was cleaned and allowed to saturate for 48 hours. The experimental set-up consisting of loading frame, dead weights, loading jack, proving ring, loading plunger, dial gauge, magnetic base, guide weight etc. assembled as shown in Figure 1 was placed in position such that the test portion comes exactly

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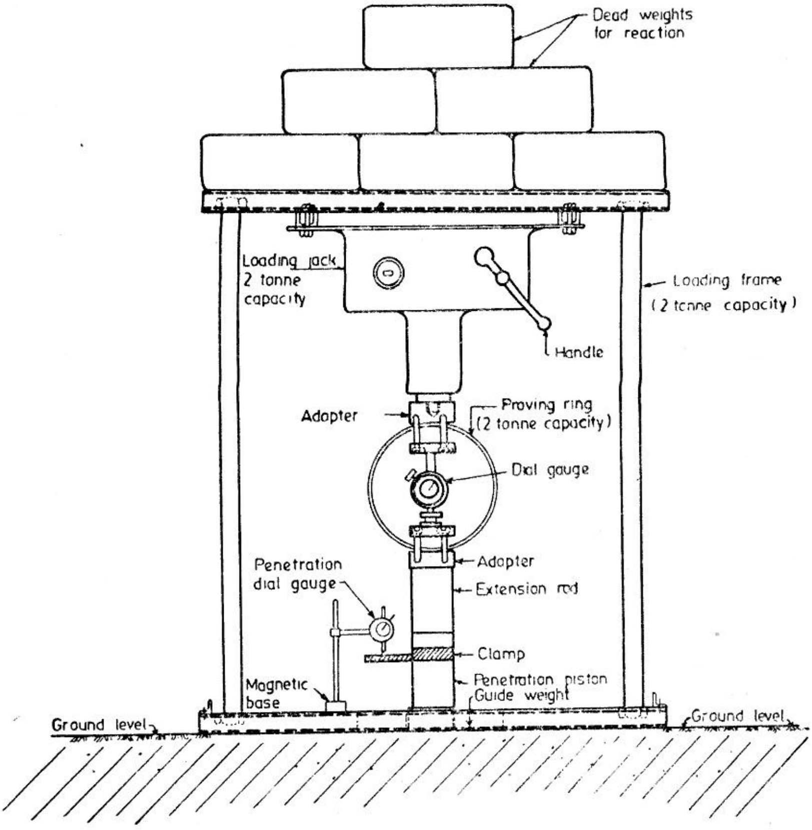

FIGURE 1 Experimental set-up for *in-situ CBR* test.

below the centre of the loading frame. It was ensured that entire assembly was in plumb. The excess water and slush were carefully removed before starting the test. The load was applied on penetration plunger by operating the loading jack and load readings were recorded on proving ring for the dial gauge readings corresponding to penetrations of 0, 0.5, 1.0, 1,5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0 and 12.5 mm.

After completion of *CBR* test, a penetration resistance of the soil was obtained by means of pocket penetrometer having 5 mm needle diameter. Undisturbed soil samples needed for the determination of laboratory *CBR* were collected from the field by adopting the procedure given in IS (1965). While taking out the sample proper precautions were exercised to minimize the friction between mould and specimen. Samples required for obtaining geotechnical engineering properties of soils were also collected from the field.

Laboratory Experiments

Laboratory *CBR* tests were carried out on the undisturbed soil specimen brought from the field, under fully saturated condition. The procedure adopted to obtain laboratory *CBR* was as specified by Indian

Standard code of practice. In addition, the tests such as determination of grain size distribution curve, consistancy limits, unconfined compressive strength, shear parameters, standard proctor density, optimum moisture content and coefficient of permeability were performed.

Results and Discussions

(*a*) *CBR test results*

The *CBR* values for 2.5 mm and 5.0 mm penetrations for both the field and laboratory tests are given in Table 1. For the area studied,

TABLE 1

Results of *CBR* Tests at Full Saturation

Test No.	Location	*CBR*(%)			
		Field		Laboratory	
		2.5 mm	5.0 mm	2.5 mm	5.0 mm
1	*A*/3, 1	2.35	2.31	2.85	2.67
2	*A*/4, 1	7.20	6.92	9.23	9.12
3	*A*/4, 2	4.50	4.01	6.47	5.72
4	*A*/4, 3	6.65	6.58	8.95	8.77
5	*A*/4, 4	2.40	2.26	3.60	3.45
6	*A*/4, 5	3.24	3.04	4.85	4.62
7	*A*/4, 6	3.85	3.72	4.90	4.81
8	*B*/1, 1	4.43	4.02	6.06	5.12
9	*B*/1, 2	5.85	5.66	7.42	7.18
10	*B*/1, 3	2.78	2.70	4.10	3.98
11	*B*/1, 4	3.42	3.29	4,30	4.22
12	*B*/1, 5	5.03	4.64	6.55	6.46
13	*B*/1, 6	1.72	1.65	2.62	2.49
14	*B*/1, 7	2.85	2.83	3.74	3.60
15	*B*/2, 1	2.94	2.81	4.22	4.05
16	*B*/2, 2	3.65	3.60	5.22	4.65
17	*B*/2, 3	4.27	4.14	5.60	5.55
18	*B*/2, 4	4.07	3.98	5.34	5.25
19	*M*/16, 1	6.15	5.77	8.82	8.16
20	*M*/16, 2	5.24	5.12	7.60	7.44

the field *CBR* values are ranging from 1.72 percent to 7.20 percent for 2.5 mm penetration and from 1.65 percent to 6.92 percent for 5.0 mm penetration. The corresponding laboratory *CBR* ranges from 2.62 percent to 9.23 percent for 2.5 mm penetration and from 2.49 percent to 9.12 percent for 5.0 mm penetration. It may be noted that the samples collected for the determination of moisture content, after *CBR* tests, indicated 100 percent degree of saturation for both field and laboratory experiments.

The variation between field *CBR* and laboratory *CBR* is shown in Figure 2. The laboratory *CBR* increases with increase in field *CBR*. On an average, this relationship is linear. A 45° line, which represents 1:1 ratio between laboratory *CBR* and field *CBR*, is drawn on Figure 2. It

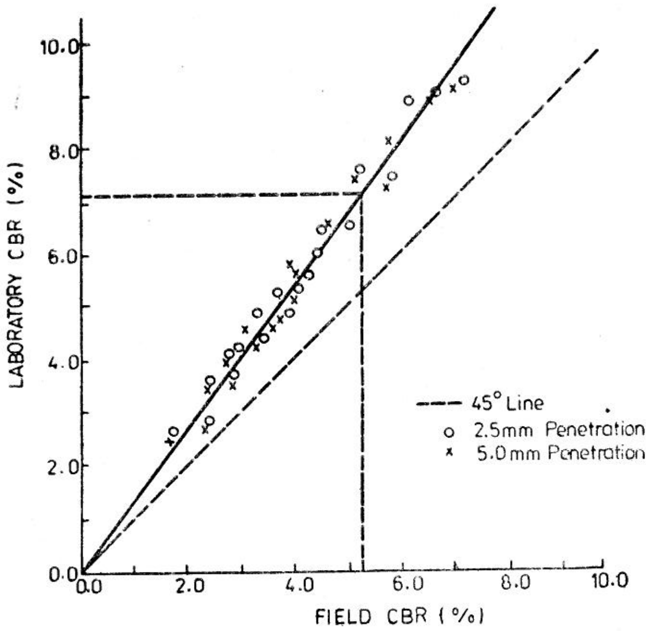

FIGURE 2 Variation between field and laboratory *CBR*.

may be seen that the actual plot points are always lying above the 45° line thus indicating that laboratory *CBR* values are always higher than the corresponding *in-situ* *CBR* values. The ratio between the laboratory *CBR* and field *CBR* as obtained from the average line is 1.35:1.

During laboratory *CBR* the soil mass is contained in *CBR* mould. The *CBR* plunger (50 mm dia) may be visualized as a footing resting on soil mass contained in *CBR* mould (150 mm dia.). The application of load on *CBR* plunger gives rise to the development of failures into the soil mass. The extent to which these failure planes spread depends upon the angle of internal friction (ϕ) of the soil. The angle of internal friction of the soils tested in the present work ranges from 12°-10′ to 25°-05′. By using Terzaghi's bearing capacity analysis, the extent of failure planes for this system have been obtained. Table 2 shows the computations for various quantities needed for obtaining the conceptual failure surface. The conceptual failure surfaces thus obtained for a minimum value of ϕ equal

TABLE 2

Computations For Conceptual Rupture Surfaces

ϕ	$\left(\frac{\pi}{4}+\frac{\phi}{2}\right)$	$\left(\frac{\pi}{4}-\frac{\phi}{2}\right)$	r_o mm	$r = r_o.e^{\frac{\pi}{2}\tan\phi}$ mm
12°—10′	51°—05′	38°—55′	38	53
25°—05′	57°—32′	32°—58′	45	93

to 12°-10′ and a maximum value of ϕ equal to 25°-05' are shown in Figure 3. It can be seen that the conceptual failure surfaces in both the case extends beyond the walls of the mould. Which means the walls of the *CBR* mould provides to some extent confinement of soils. For the field *CBR* the soil surface is semiinfinite. Thus the higher values of laboratory *CBR* may be attributed to the lateral confinement of soils due to the walls of the *CBR* mould. Thus the results obtained by carrying out a laboratory *CBR* overestimates the actual strength of the soil.

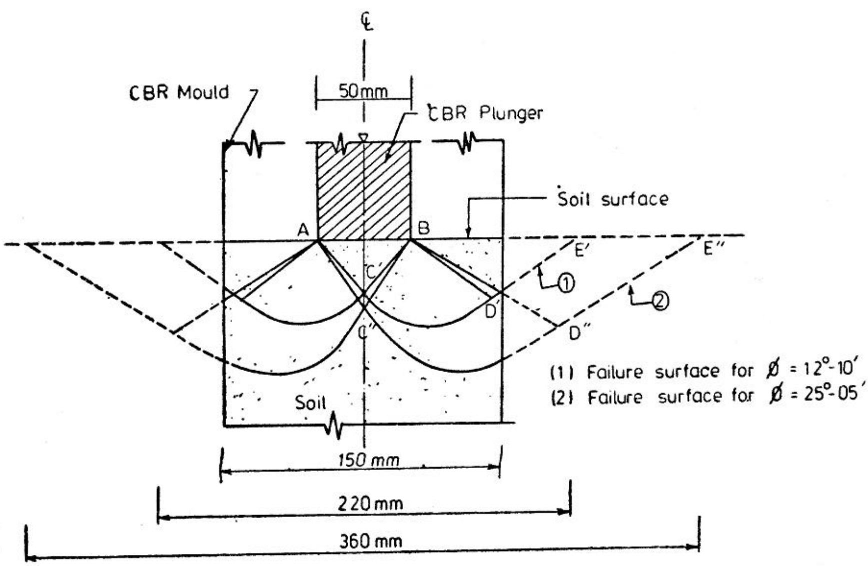

FIGURE 3 Conceptual failure surfaces for different angles of internal friction

(b) In-situ test results

The results of various geotechnical engineering properties of soils tested are given in Table 3. The values of penetration resistance recorded with pocket penetrometer for 5 mm penetration for fully saturated soils at different test locations are ranging from 2.01 kg/cm² to 5.85 kg/cm².

The variation benween penetration resistance obtained by pocket

TABLE 3

Geotechnical Engineering Properties of Soils

Test No.	Location	Penetrometer resistance (kg/cm²)	Field dry density (g/cc)	Standard Proctor density (g/cc)	Optimum moisture content (%)	U.C.S. Strength (kg/cm²)	Direct shear test result		Coefficient of permeability (cm/sec)
							c (kg/cm²)	ϕ	
1.	A/3,1	3.42	1.45	1.39	30.8	0.53	0.24	14°—25′	7.2×10^{-5}
2.	A/4,1	5.85	1.69	1.62	21.8	0.29	0.07	25°—05′	9.8×10^{-4}
3.	A/4,2	4.76	1.60	1.65	19.5	0.33	0.11	19°—05′	5.6×10^{-4}
4.	A/4,3	5.76	1.67	1.59	22.7	0.29	0.09	24°—50′	7.9×10^{-4}
5.	A/4,4	3.24	1.46	1.71	18.3	0.50	0.23	12°—55′	8.7×10^{-5}
6.	A/4,5	4.03	1.52	1.67	17.9	0.45	0.23	17°—10′	9.4×10^{-5}
7.	A/4,6	4.63	1.56	1.61	23.6	0.37	0.19	17°—45′	2.7×10^{-4}
8.	B/1,1	4.85	1,58	1.65	20.7	0.35	0.14	17°—45′	5.7×10^{-4}
9.	B/1,2	5.45	1.65	1.58	17.7	0.30	0.11	21°—15′	6.9×10^{-4}
10.	B/1,3	3.76	1.50	1.64	21.6	0.47	0.18	15°—40′	9.8×10^{-5}
11.	B/1,4	4.21	1.53	1.58	23.1	0.43	0.21	15°—35′	6.6×10^{-4}
12.	B/1,5	5.22	1.63	1.63	21.6	0.34	0.10	21°—05′	6.1×10^{-4}
13.	B/1,6	2.01	1.38	1.48	26.2	0.68	0.29	12°—10′	4.6×10^{-6}
14.	B/1,7	3.95	1.51	1.73	19.4	0.44	0.19	13°—50′	9.1×10^{-5}
15.	B/2,1	4.09	1.52	1.69	21.2	0.46	0.20	15°—10′	1.2×10^{-4}
16.	B/2,2	4.37	1.54	1.58	24.6	0.38	0.21	16°—05′	$1\,9\times10^{-4}$
17.	B/2,3	4.92	1.59	1.64	20.3	0.38	0.14	19°—10′	4.1×10^{-4}
18.	B/2,4	4.71	1.57	1.54	24.1	0.35	0.14	18°—35′	3.6×10^{-4}
19.	M/16,1	5.49	1.67	1.52	17.6	0.32	0.11	21°—40′	7.1×10^{-4}
20.	M/16,2	5.28	1.61	1.55	19.2	0.31	0.13	18°—25′	6.4×10^{-4}

penetrometer and field *CBR* at 100 percent degree of saturation is shown in Figure 4. The penetration resistance increases with increase in field *CBR*, initially, it increases nonlinearly and subsequently it becomes linear. A dotted line, indicating the pressure exerted by *CBR* plunger on soil for 5 mm penetration, is shown in the figure. The penetration resistance obtained by pocket penetrometer when compared with the pressure exerted by *CBR* plunger, indicates that upto a field *CBR* value of roundabout 5 percent the former is higher than the later and subsequently it becomes lower. The difference in their magnitude may be due to scale effect and rate of penetration. This indicates that the pocket penetrometer has to be used with caution since it does not represent the true penetration resistance.

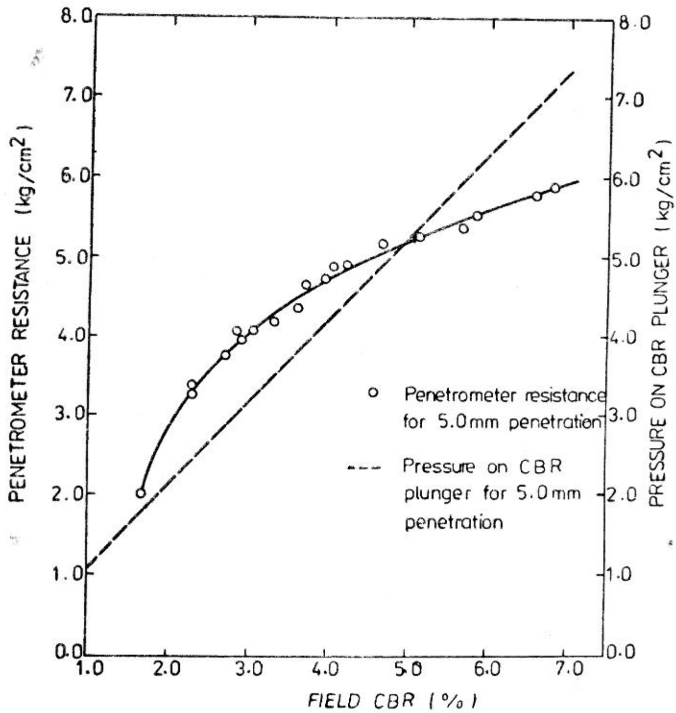

FIGURE 4 Variation between field *CBR* and penetrometer resistance.

(c) Geotechnical engineering properties

The results of various geotechnical engineering properties of these soils are given in Table 3. Field dry densities indicate the range from 1.38 g/cc to 1.69 g/cc. The unconfined compressive strength (*UCS*) on fully saturated samples exhibits the strength ranging from 0.29 kg/cm² to 0.68 kg/cm².

The relationship between field dry density, *UCS* and field *CBR* is shown on Figure 5. The variation between field dry density and field *CBR* indicates a nonlinear increase in field *CBR* with increase in dry density. Whereas, it is interesting to note that field *CBR* decreases with increase in *UCS*. This may be due to the presence of coarse grained partieles in a soil matrix.

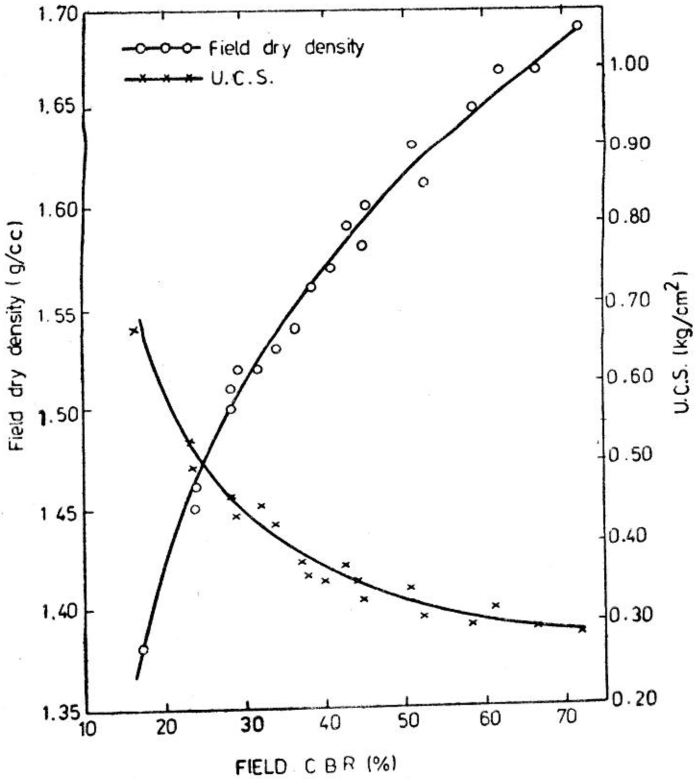

FIGURE 5 **Relationship between field dry density,** ***UCS*** **and field** ***CBR.***

The results of undrained direct shear test indicate the ranges of angle of internal friction from 12°-10′ to 25°-05′ and cohesion from 0.07 kg/cm² to 0.29 kg/cm². The plot between angle of internal friction and field *CBR* shown in Figure 6, indicates on an average a linear relationship. Field *CBR* increases with increase in angle of internal friction.

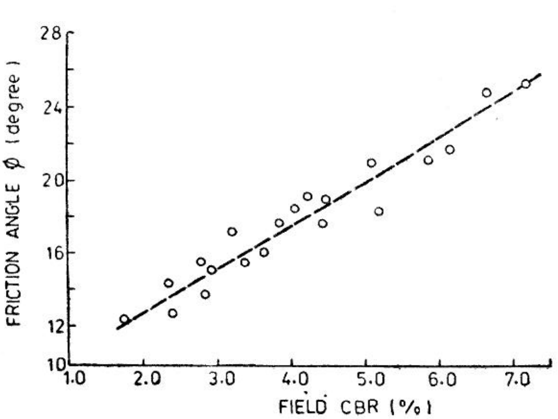

FIGURE 6 **Field** ***CBR*** **Variation with angle of internal friction.**

TABLE 4

Summary of the Results of Classification Tests

Test No.	Location	Textural					Consistancy			
		Clay ($\leqslant$ 2 μ m) (%)	Silt (0.002 mm to 0.06 mm) (%)	Sand (0.06 mm to 2 mm) (%)	Gravel (> 2 mm) (%)	Classification	*L.L.* (%)	*P.L.* (%)	*P.I.* (%)	Classification
1.	*A*/3,1	25.9	43.6	28.1	2.4	Silty clay	50.2	32.3	17.9	*MH*
2.	*A*/4,1	12.4	48.7	35.3	3.6	Silt	18.8	13.7	5.1	*ML*
3.	*A*/4,2	22.1	38.4	37.2	2.3	Clay loam	28.6	24.4	4.2	*ML*
4.	*A*/4,3	14.2	52.3	28.4	5.1	Silt	21.7	15.4	6.3	*ML*
5.	*A*/4,4	25.2	40.6	30.7	3.5	Silty clay	41.2	23.9	17.3	*CL*
6.	*A*/4,5	24.6	34.9	36.2	4.3	Silty clay Loam	35.8	26.9	8.9	*ML*
7.	*A*/4,6	24.5	36.1	33.6	5.8	,,	32.3	25.4	6.9	*ML*
8.	*B*/1,1	22.8	33.7	39.6	3.9	,,	29.4	24.6	4.8	*ML*
9.	*B*/1,2	18.1	53.2	27.1	1.6	Silt	22.5	16.8	5.7	*ML*
10.	*B*/1,3	24.9	35.9	32.4	6.8	Silty clay loam	37.6	26.4	11.2	*ML*
11.	*B*/1,4	24.1	33.6	34.9	7.4	,,	34.7	26.0	8.7	*ML*
12.	*B*/1,5	21.1	36.8	38.6	4.5	Silty loam	27.4	21.1	6.3	*ML*
13.	*B*/1,6	27.3	36.2	31.9	4.6	Clay	52.1	30.8	21.3	*CH*
14.	*B*/1,7	25.1	44.7	23.7	6.5	Silty clay	36.2	22.1	14.1	*CL*
15.	*B*/2,1	24.4	44.2	26.5	4.9	Silty clay	37.7	24.5	13.2	*CL*
16.	*B*/2,2	24.3	39.1	35.7	2.9	Slity clay loam	34.1	26.9	7.2	*ML*
17.	*B*/2,3	23.3	42.1	33.4	1.2	,,	28.3	23.5	4.8	*ML*
18.	*B*/2.4	23.6	37.8	36.7	1.9	,,	31.7	24.3	7.4	*ML*
19.	*M*/16,1	17.5	45.7	27.7	9.1	Silt	22.4	18.6	3.8	*OL*
20.	*M*/16,2	20.1	41.8	30.8	7.3	Silt	25.1	19.8	5.3	*OL*

Coefficients of permeability determined by variable head permeameter ranges from 4.6 x 10^{-6} cm/ sec. to 1.2 x 10^{-4} cm/sec. indicating that the soils fall within medium permeable range.

(d) Classification test results

Table 4 shows the results of classification tests of these soils. The grain size analysis, in general shows the percentages range of clay (< 2 micron), silt (2 micron to 0.06 mm), sand (0.06 mm to 2.0 mm) and gravel (> 2 mm) are 12.4 percent to 27.3 percent, 33.6 percent to 53.2 percent, 23.7 percent to 39.6 percent and 1.6 percent to 9.1 percent respectively. The textural classification in general shows majority of soils are silt and silty clay loam.

The liquid limit, plastic limit and plasticity indices range from 18.8 to 50.2, 13.7 to 32.3 and 3.8 to 21.3 respectively. A-line classification indicated that these soils fall within *ML* and *MH* groups. The relationship between liquid limit, 2 micron clay content and field *CBR* is shown in Figure 7. The variation between liquid limit and field *CBR* shows a curvilinear decrease in field *CBR* with increase in liquid limit. Similarly, field *CBR* decreases with increase in clay contents. The curve upto around 24 percent of clay shows convexity upwards and beyond this it shows convexity downwards.

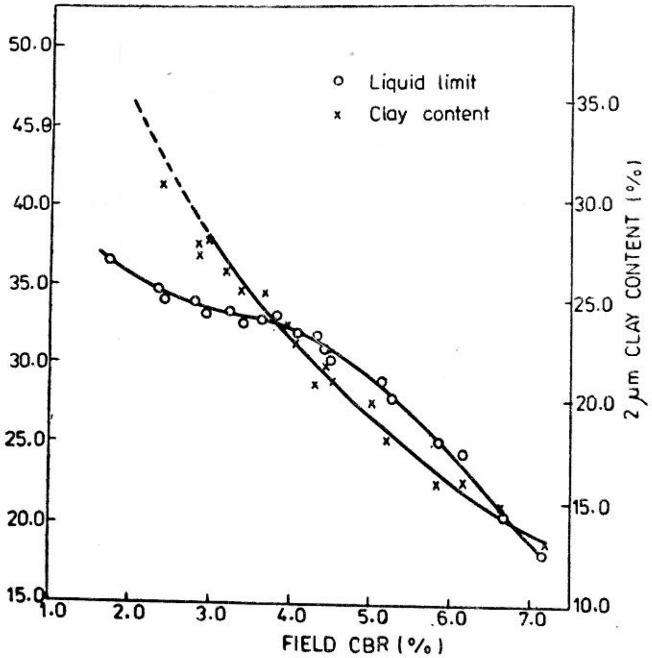

FIGURE 7 Relationship between liquid limit, 2 micron clay content and field *CBR*.

Conclusions

On the basis of the studies conducted, the conclusions arrived at are summerised below.

1. The laboratory *CBR* values are always higher than the field *CBR* thus over estimating the behaviour of soil. The higher values of laboratory *CBR* may be due to confinement of soils in the mould. For the soils studied in the present investigation, the ratio between laboratory *CBR* and field *CBR*, on an average is 1.35.

2. The values of penetration resistance obtained by pocket penetrometer have to be used with caution since those do not represent the true values.

3. The field *CBR* values increase with increase in dry density whereas these decrease with increase in *UCS*. Field *CBR* increases linearly with increase in angle of internal friction. A non linear decrease in field *CBR* is observed with increase both in liquid limit as well as clay contents.

The results of these studies may prove to be useful while designing the flexible pavements.

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Notations

CBR = California Bearing Ratio

c = Cohesion

e = Base of Naperian Logarithm (2.718)

L.L. = Liquid Limit

P.I. = Plasticity index

P.L. = Plastic limit

r = Distance between the spiral pole and spiral point separating plastic flow and passive state zones.

r_0 = Face length of triangular wedge

UCS = Unconfined compressive strength.

π = 3.142

ϕ = Angle of internal friction.