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# UNSATURATED CBR DESIGN APPROACH OF FLEXIBLE PAVEMENT

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## Abstract

Subgrades in arid and semi-arid regions are often subjected to seasonal moisture variations that trigger volume change. To account for moisture changes in a vadose zone during pavement design, matric suction ($\psi_m$) is unavoidably required. In that context, $\psi_m$ inclusion in CBR design becomes imperative. This study presents two CBR design approaches of flexible pavement, i.e. the conventional CBR design, and unsaturated CBR design methods. To compare these design approaches, subgrade soils were selected and a series of suction tests, CBR, and unsaturated CBR tests were performed to obtain the CBR design values of the subgrade materials. The results illustrate a linear relationship between suction and CBR values of the subgrades. The test results, further revealed that the unsaturated CBR design values are 2 to 2.5 times greater than the conventional CBR values. Based on the experimental results, the design analysis confirmed that the unsaturated CBR design approach is more conservative and rational compare to the conventional CBR design method.

*Keywords: unsaturated CBR, suction, subgrade, design approach, pavement*

## 1 Introduction

The theoretical network that expresses the moisture response of unsaturated subgrades concerning pavement design is demonstrated by [1-2]. The study suggested that variation in moisture content is influenced by the degree of saturation as this in turn affects matric suction. Thus, suction is the stress factor that represents the stress state of unsaturated soil response [3]. Several, attempt has been made to incorporate unsaturated soil mechanics principles in CBR testing and design [4-5] their test results indicated that CBR increases with increasing soil suction, as this lead to ultimate limit design values. Some documented studies have demonstrated the method by which hydraulic hysteresis on subgrade CBR could be evaluated using suction [6]. Whereas, vast studies in the literature have failed to account for suction in CBR testing and pavement design, despite the evidence of seasonally moisture variation with subgrades. This affects suction and in turn, reduces the bearing strength and deformation resistance of the pavement structure.
This study demonstrated the design of flexible pavement, utilizing unsaturated CBR design values. The hydromechanical behavior of the soil was determined by performing a series of unsaturated CBR tests at various dry densities. The CBR dependencies on suction at different gravimetric water content are also presented.

## 2 The material and experimental program

### 2.1 Soils

The collected subgrade soil samples were labeled as Soil A, B, and C respectively. Dry sieving was conducted by firstly passing particles through a 9.5mm sieve and subsequently sieved using 4.75mm and 75µm sieves to separate fines, sand, and gravel. The soils that passed through 75µm sieve were used for the hydrometer test, to further differentiate percentages of silt and clay for the representative subgrade soils following ASTM D1140 and the grading curve of the soils is shown in Fig 1.

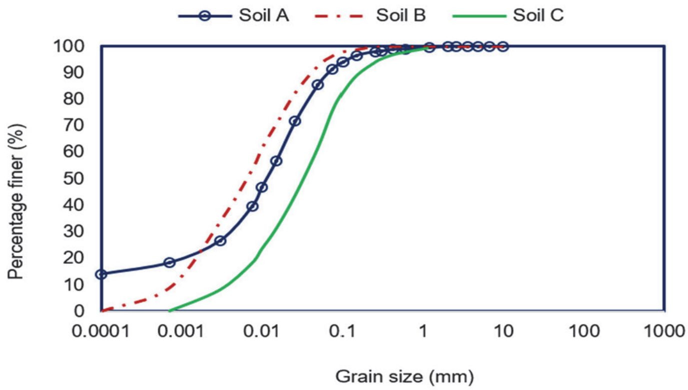


**Figure 1** Grain size distribution curve

Zero swelling tests (ZST) were conducted on the respective soils in conformance to the Indian standard IS: IS 2720 test method, to evaluate the swelling potential of the subgrades. As presented in Table 1, the investigated soils are classified as CH and CL. Thus, it is qualified as an expansive subgrade based on the classification tests.

**Table 1** Properties of soils

| Soil designation | | Soil A | Soil B | Soil C |
|---|---|---|---|---|
| Sampling depth (m) | | 0.5-1.2 | 0.5-1.2 | 0.5-1.2 |
| Specific gravity $G_s$ | | 2.67 | 2.70 | 2.71 |
| ZST (kPa) | | 710 | 650 | 870 |
| Atterberg limit (%) | LL | 62.10 | 68.03 | 57.28 |
| | PL | 28.32 | 29.82 | 34.21 |
| | PI | 33.78 | 38.21 | 23.07 |

* GSA= Grain size analysis, **$C_u$= Coefficient of uniformity ($D_{60}/D_{10}$),
***$C_c$= Coefficient of curvature ($D_{30}^2/D_{60}$ x $D_{10}$)

## 3 Sample preparations

Before sample preparation, the Proctor compaction test was carried on the subgrade soils under ASTM D-698. The soils A, B, and C rendered optimum moisture content (OMC) of 16.12 %, 22.15 % 19.11 % with corresponding maximum dry densities (MDD) 18.15kN/m$^3$, 20.32 kN/m$^3$, and 18.38kN/m$^3$ respectively.

## 4 Experimental testing procedures

Standard laboratory civil engineering testing programs routinely used to measure geotechnical properties of soil were conducted on the subgrade materials. The soil testing programs with their corresponding specifications are as follows, Proctor compaction was conducted following ASTM D-698, 2007 testing procedures, Zero swelling test (ZST) was performed under IS 2720 (Part 41: 1977) protocol, Filter paper test was performed in accordance with ASTM 5298-2018, and CBR test was conducted in line with ASTM D1883-16 testing procedures.

### 4.1 Unsaturated CBR test

The soaked CBR is usually used for pavement design, therefore this study only considered soaked condition. Whereas, CBR values of the subgrades were calculated according to Eq. (1).

$$CBR(\ \%) = T_L/S_L \text{ x } 100 \qquad (1)$$

where CBR is the California bearing ratio in ( %), $T_L$ is the test load, $S_L$ is the standard load The soil-water characteristic curve (SWCC) was established to evaluate the air-entry values (AVE) of the soils. The soaked CBR values corresponding to each matric suction were correlated and the values of the unsaturated CBR were determined using Eq. (2).

$$\frac{CBR_u}{CBR_s} = \left[\frac{\Psi_m}{u_e}\right]^n \qquad (2)$$

Where $CBR_u$ is the unsaturated CBR, $CBR_{us}$ is the soaked CBR obtained from the conventional CBR test, $\Psi_m$ is the matric suction, $u_e$ is the AVE and n is the regression parameter due to suction and dry density obtained from linear interpolation using mathematical software (NCSS 11).

## 5 Result and discussions

### 5.1 Subgrades response to suction

The variation of the total, matric, and osmotic suction at various gravimetric water content is shown in Figs. 2 and 3 for soil A, B, and C respectively. It is noted that the response of the subgrades to suction is approximately linear. Thus, suction decreases with an increase in gravimetric water content. High suction values were evaluated on the dry side of the optimum. Whereas, lower suction values were observed as the gravimetric moisture contents tend to move towards the wet-side of the optimum moisture content [7-8]

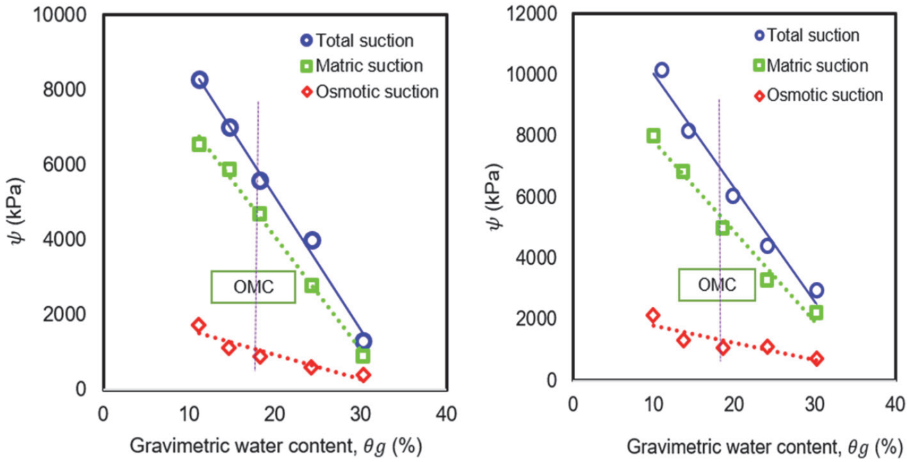


**Figure 2** Suction Ψ versus gravimetric water contents curve for soil A and B

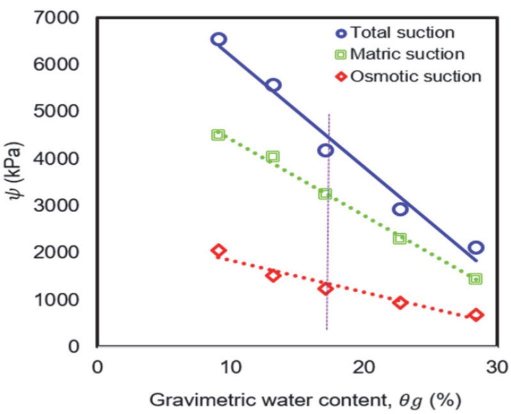


**Figure 3** Suction Ψ versus gravimetric water contents curve for soil C

## 5.2 Soil-$H_20$ retention curves (SWRC)

As shown in Figs 4 and 5, the developed SWRCs were based on the data sets obtained from the filter paper test results and fitted by Fredlund and Xing model. Results show that Fredlund and Xing's [9] equation has the best-fit, and the SWRCs fitted by Fredlund and Xing's equation were used in the following description The dotted legend represents the measured SWRCs for the subgrades and the solid legend line is the Fredlund and Xing fitting curve. The subgrade yielded air-entry values (AEV) of 80 kPa, 300 kPa, and 200 kPa for soils A, B, and C respectively. The AEV for soil B is higher due to larger fine content, this indicates that the initial compaction water contents have no significant influence on the SWRC at high suction. It is noted that soil B possess more capacity to retain water compare to soil A and C. The test result clearly shows that an increase in clay content generally leads to an increase in the amount of water retained at a certain suction level and adsorption governs the high suction value of the SWRC [10]. It is also noted that suction increases as the volumetric water content of the specimens decrease.

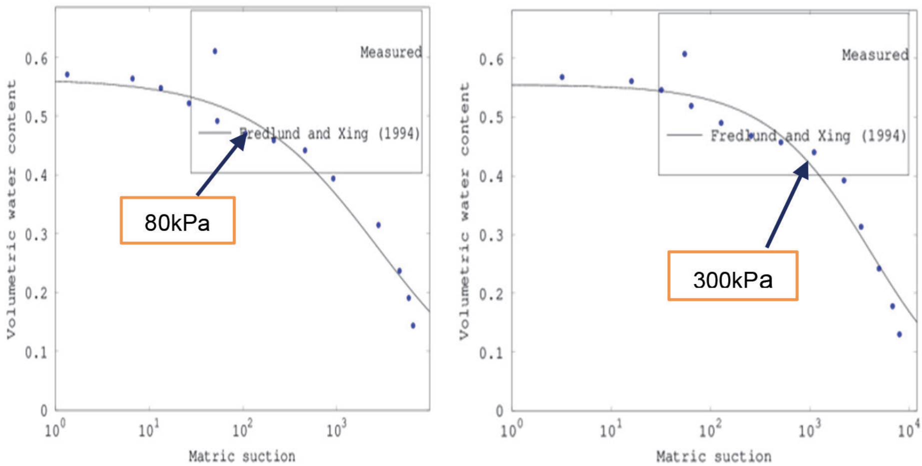


**Figure 4** Soil-water retention curve for soil A and B

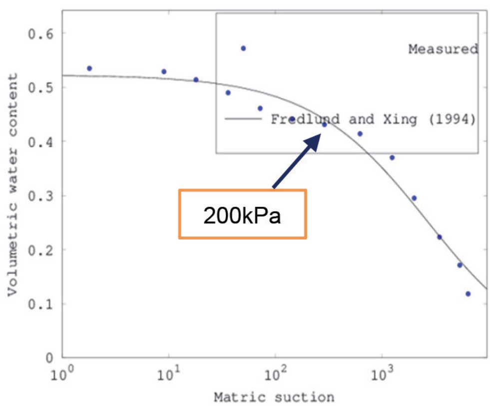


**Figure 5** Soil-water retention curve for soil C

## 5.3 Unsaturated CBR

The values of soaked $CBR_s$ corresponding to each volumetric moisture content and matric suction for the subgrade were determined, as the ratio of $CBR_u$ and $CBR_s$ as presented in Eq. (2). The test results revealed that unsaturated CBR values were 1.5 to 2 times higher compared to the soaked CBR as summarized in Table 2.

**Table 2** Soaked and Unsaturated CBR values

| Soil | C [%] @ 2.5 mm | C [%] @ 5 mm | C [%] @ 7.5 mm | $\Psi_m$ [kPa] | $u_e$ [kPa] | n | $C_u$ [%] | $P_s$ [kPa] | Δ [%] |
|---|---|---|---|---|---|---|---|---|---|
| Soil A | 4.12 | 4.20 | 4.10 | 6541 | 80 | 0.20 | 9.94 | 610 | 7.93 |
| | 3.17 | 3.55 | 3.22 | 5876 | 80 | 0.22 | 8.16 | 284 | 6.30 |
| | 2.25 | 3.18 | 2.89 | 4689 | 80 | 0.24 | 5.88 | 515 | 3.03 |
| | 2.13 | 2.78 | 2.14 | 2793 | 80 | 0.26 | 5.36 | 440 | 2.32 |
| | 2.03 | 2.46 | 1.90 | 921 | 80 | 0.36 | 5.06 | 378.3 | 2.05 |
| Soil B | 3.53 | 3.93 | 3.75 | 8017 | 300 | 0.20 | 6.81 | 840 | 5.04 |
| | 2.10 | 2.72 | 2.73 | 4989 | 300 | 0.25 | 4.83 | 610 | 2.75 |
| | 1.91 | 2.51 | 2.63 | 3295 | 300 | 0.27 | 4.09 | 530 | 2.29 |
| | 1.81 | 2.24 | 2.33 | 2213 | 300 | 0.33 | 3.23 | 450 | 1.85 |
| Soil C | 4.33 | 4.58 | 4.44 | 4498 | 200 | 0.20 | 8.59 | 510 | 6.11 |
| | 3.43 | 3.55 | 3.68 | 4045 | 200 | 0.22 | 6.65 | 395 | 4.85 |
| | 3.05 | 3.36 | 3.34 | 3250 | 200 | 0.24 | 6.28 | 300 | 4.29 |
| | 2.21 | 2.70 | 2.66 | 2298 | 200 | 0.26 | 4.17 | 230 | 2.31 |
| | 2.16 | 2.48 | 1.56 | 1440 | 200 | 0.26 | 3.75 | 200 | 1.91 |

*$C_{soaked}$: CBR* $P_S$: swelling stress*$\Psi_m$: matric suction* Δ: change in C due to $P_S$

## 5.4 The unsaturated approach of flexible pavement design

Though, the basic difference between the two approaches is the incorporation of and AEV in evaluating the CBR values. Based on the CBR result presented in Table 3, Eq. (3) is employed to calculate the required thickness for the investigated pavements, to compare the aforementioned design approaches.

$$A = P(1 + r)^{n+y} \tag{3}$$

Where *A* is the design traffic in commercial vehicles per day (CVPD), *P* is average daily traffic (ADT) and it is taken to be 2500CVPD in this study, r is the annual traffic growth rate =12 %, n is the design period normally 10 year for flexible pavement and 3 years of construction period making it a total nvalue of 13 years.

$$A=P(1+r)^{n+y} = 2500(1+0.12)^{3+10} = 10909 \text{ designe value} = 10{,}100\text{CVPD}$$

According to the design calculation, the pavement falls under the design Index of 'G' as presented in Fig 6.
Based on the CBR design values in Table 3, the calculated thickness corresponding to the required pavement thicknesses without wearing course are presented in Table 4. Based on the CBR design values for $CBR_s$ and $CBR_u$, it is indicated that the investigated subgrades require pavement layer thickness between 600mm to 800 mm when $CBR_s$ design values are utilized. Whereas, $CBR_u$ design values require pavement layer thickness within 400 mm to 530 mm according to the CBR design analysis. It is noted that the design values for unsaturated CBR require lesser thickness compared to that of the conventional CBR values. This implies that the design of flexible pavement using the conventional CBR approach leads to overdesign

of the pavement compared to the unsaturated CBR that is conservative thus requires lesser thickness for the pavement.

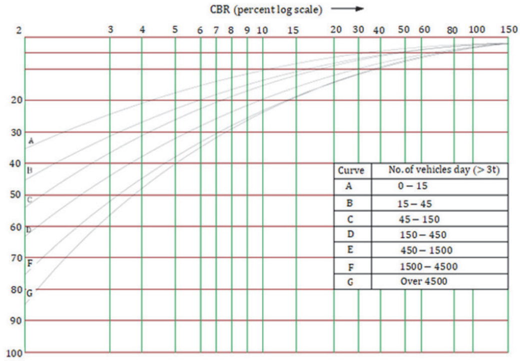


**Figure 6** CBR design chart

**Table 3** Pavement thicknesses

| Design values | Soil A | Soil B | Soil C |
|---|---|---|---|
| $CBR_s$ [%] | 2.25 | 2.10 | 3.05 |
| RPT [mm] | 760 | 788 | 688 |
| $CBR_u$ [%] | 6 | 4.83 | 6.30 |
| RPT [mm] | 480 | 530 | 400 |
| $\Delta CBR_u$ due to $P_s$ [%] | 3.03 | 2.75 | 4.30 |
| RPT [mm] | 680 | 670 | 570 |
| *RPT = required pavement thickness | | | |

## 6 Conclusions

This paper aims to understand the different CBR design approaches, and three different subgrades were investigated. A series of laboratory tests such as the ZST, filter paper tests, CBR, and unsaturated CBR test method was conducted and the following conclusions are drawn:

- Suction increased as the volumetric water content of the specimens decreases, at a low suction within the range of 1 to 50 kPa. The air-entry value (AEV) of the specimens was computed to be 80kPa, 300kPa, and 200kPa for soils A, B, and C respectively. The AEV of soils revealed the degree of pore spaces, absorption capacity, and expansion degree of the soils.
- The highest swelling stress values were obtained at a lower void ratio, and this implies the subgrades possess high water absorption capacity this significantly influences the $CBR_u$ values for pavement design. Averagely, the soaked $CBR_s$ values were considerably 1.5 to 2 times lower than the unsaturated $CBR_u$ values. This implies that pavement design using conventional CBR values could lead to overdesign and require high thickness asphaltic layers. Whereas, $CBR_u$ design values are considered rational and conservative. As expected, strain-softening behavior was observed as the subgrades recorded higher resilient moduli for higher confining stresses and decreased with an increase in the deviatoric stress under identical confinement.

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