STRENGTH BEHAVIOUR OF COIR GEOTEXTILE
REINFORCED SUBGRADE

7.1 INTRODUCTION

The behaviour of road surface depends on the strength of the fill material and the subgrade below it. Road construction over soft subgrade soil is a major issue affecting cost and scheduling of highway projects in regions where soft subgrades are common. The strength of the subgrade is most often expressed in terms of California Bearing Ratio (CBR), which is the ratio of test load to standard load at a specified penetration, by a standard plunger. The values of modulus of subgrade reaction and resilient modulus of soil have been correlated with CBR value. In India the design of flexible pavement is primarily on the basis of the subgrade CBR (IRC: 37 - 2001).

The CBR method is one of the earlier empirical methods for pavement design developed during 1928-1929 (Ullidtz, 1986). This method involves determination of CBR value of subgrade for the most critical moisture condition. The design thickness of pavement is read against the CBR value of the subgrade from the design charts, which were developed from experience on pavement performance after noting and analysing a number of failed pavement sections and the corresponding subgrade CBR values. Based on this apparent relationship between the CBR value and thickness of pavement, the US Corps of Engineers in 1940 adopted the CBR method of design for airfield pavements (Horonjeff and Mckelvey, 1983). It may be noted that this attempt at designing pavement did not initially involve the number of load repetitions that a
pavement can sustain and hence later, correction factors related to the number of load repetitions were also introduced.

Many techniques have been evolved to strengthen the highway soil subgrade. Most of them primarily involve stabilisation using chemical admixtures. One of the recent techniques is the use of geotextiles. Geotextiles can be placed within subgrade to strengthen the subgrade and also can be placed at the interface between subgrade and sub base. Since subgrade CBR is taken as the criterion for the design of flexible pavements, the thickness of the component layers (sub base and base course) will be reduced when the subgrade CBR is high. In this section, the results of studies on the performance characteristics of the subgrade with the provision of coir geotextiles are reported.

Two subgrade soils: Red soil (Soil-I) and Clayey silt (Soil-3) and three varieties of coir geotextiles (H2M6, H2M8 and NW) were used in the study. CBR tests were conducted with coir geotextiles at depths of $H/2$, $H/3$ and $H/4$ from the top surface of soil where, $H$ is the depth of CBR specimen. Experiments were also conducted with multiple coir geotextile layers and with aggregate layer above the coir geotextile layer. Using multiple linear regression analysis a mathematical model for modified CBR was obtained in terms of original CBR of the subgrade soil, and properties and depth of placement of coir geotextile. The reduction in the required thickness of the base layer can be computed using US Army method, and IRC method, which is reported elsewhere in this thesis.

**7.2 EXPERIMENTAL PROGRAMME**

The objective of this study was to find out the increase in strength mobilisation in terms of CBR values, by conducting CBR tests on the subgrade soil when reinforced
with coir geotextiles placed at different positions. It was also aimed at in assessing the saving in aggregate thickness due to the use of coir geotextiles in unpaved roads. The details of the experimental programme are given in Table 7.1.

Table 7.1. Parameters varied in laboratory experiments

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgrade material</td>
<td>Clayey silt – with and without aggregate layer</td>
</tr>
<tr>
<td></td>
<td>Red soil – with and without aggregate layer</td>
</tr>
<tr>
<td>Soaking condition</td>
<td>Soaked</td>
</tr>
<tr>
<td></td>
<td>Unsoaked</td>
</tr>
<tr>
<td>Type of coir geotextile</td>
<td>Woven – H2M8</td>
</tr>
<tr>
<td></td>
<td>Woven – H2M6</td>
</tr>
<tr>
<td></td>
<td>Non-woven – AGL C/201</td>
</tr>
<tr>
<td>Position of coir geotextile</td>
<td>No geotextile – Control section</td>
</tr>
<tr>
<td></td>
<td>At H/2 from surface</td>
</tr>
<tr>
<td></td>
<td>At H/3 from surface</td>
</tr>
<tr>
<td></td>
<td>At H/4 from surface</td>
</tr>
<tr>
<td></td>
<td>Multiple layers – at H/3 and H/2</td>
</tr>
</tbody>
</table>

7.2.1 Preparation of Specimen

The experimental set - up consisted of that required for the standard laboratory CBR test. It consists of a cylindrical mould of 150 mm inner diameter and 175mm height and a cylindrical plunger of 50mm diameter. For CBR test on the remoulded sample, soil is compacted in the CBR mould with moisture content corresponding to OMC.

Compaction of the soil sample was done by static method. In this method, a known quantity of air-dried soil passing 20mm sieve was taken and mixed with requisite water to get OMC. Calculated quantity of wet soil was transferred to mould and compacted to the required height statically using hydraulic jack. Top surface was scratched and the coir geotextile specimen, cut to the inside dimension of the CBR mould, was placed over it. Soil was put in the next layer and compacted as in the
previous case. A filter paper was placed on the top of the specimen and then the surcharge disc over it. Schematic representations of the test specimens are shown in Fig. 7.1.

In order to obtain the soaked CBR values, the specimens were soaked for 96 hours before loading the specimen. To soak the specimen, the specimen in the mould and surcharge weight was wrapped in a gunny bag and kept immersed in water. The mould, after four days of soaking is taken out and water is allowed to drain off. The sample, along with the surcharge, is then subjected to loading.

![Fig 7.1 Schematic representation of CBR test samples](image)

7.2.2 Testing

Specimens were tested in a load frame with an electronic outfit, which gives LED display of loads and penetrations. A standard plunger of 50mm diameter was penetrated into the soil at the rate of 1.25mm/minute. The load values corresponding to penetrations of 0.5mm, 1.0mm, 1.5mm, 2.0mm, 2.5mm, 3.0mm, 4.0mm, 5.0mm, 7.5mm, 10mm and 12.5mm were noted. From the load - penetration graphs, CBR
value was calculated as the highest value obtained from the ratio of test load divided by the standard load and expressed in percentage.

\[ CBR\% = \left( \frac{\text{Test load}}{\text{Standard Load}} \right) \times 100 \]  

(7.1)

The standard loads are 13.7kN, 20.55kN, 26.3kN, 31.8kN, and 36.0kN for 2.5mm, 5.0mm, 7.5mm, 10.0mm, and 12.5mm respectively.

7.3 RESULTS AND DISCUSSION

7.3.1 General

CBR values expressed in percentage for different cases are summarised in Table 7.2, in which the initial CBR refers to percentage CBR obtained for soil alone without any coir geotextiles. The experimental results give a clear indication that the presence of coir geotextiles influences the California Bearing Ratio (CBR) of the soil. The improvement in strength of soil due to the placement of coir geotextiles is a function of interaction of coir geotextiles with the soil. It was observed that there exists interaction between soil and coir geotextile in soaked and unsoaked condition.

7.3.2 Type of Soil

Fig.7.2 shows the load penetration curves for unsoaked and soaked conditions for three types of coir geotextiles (H2M8, H2M6 and NW) placed at a depth of H/4 from top surface for two types of soils tested. It can be observed that for both the soils tested, the behaviour was identical when coir geotextiles were placed at H/4 from top in the soil mass and tested in soaked and unsoaked conditions. Penetration of the plunger was more for soil without geotextile in all cases and CBR values were less in soaked condition. Between the two soils, it was found that the percentage increase in
CBR for red soil in unsoaked condition was higher than that for clayey silt. On the contrary, it can be observed that, the coir geotextiles perform much better in clayey soil in soaked condition, the corresponding percentage increase being 100%, 250% and 43% for clayey silt and 36%, 50% and 9% for red soil respectively for Non-woven, H2M8 and H2M6 coir geotextiles.

Table 7.2 Summary of CBR test results

<table>
<thead>
<tr>
<th>Depth of placement from top</th>
<th>Type of Coir Geotextile</th>
<th>1. Clayey Silt Unsoaked: Initial CBR = 2.43%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-woven</td>
<td>Woven H2M8</td>
</tr>
<tr>
<td>H/4</td>
<td>4.25</td>
<td>3.54</td>
</tr>
<tr>
<td>H/3</td>
<td>3.72</td>
<td>3.04</td>
</tr>
<tr>
<td>H/2</td>
<td>3.08</td>
<td>2.93</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth of placement from top</th>
<th>Type of Coir Geotextile</th>
<th>2. Clayey Silt Soaked: Initial CBR = 0.95%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-woven</td>
<td>Woven H2M8</td>
</tr>
<tr>
<td>H/4</td>
<td>1.90</td>
<td>3.35</td>
</tr>
<tr>
<td>H/3</td>
<td>1.56</td>
<td>2.74</td>
</tr>
<tr>
<td>H/2</td>
<td>1.44</td>
<td>2.58</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth of placement from top</th>
<th>Type of Coir Geotextile</th>
<th>3. Red Soil Unsoaked: Initial CBR = 7.98%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-woven</td>
<td>Woven H2M8</td>
</tr>
<tr>
<td>H/4</td>
<td>25.09</td>
<td>14.52</td>
</tr>
<tr>
<td>H/3</td>
<td>14.83</td>
<td>10.65</td>
</tr>
<tr>
<td>H/2</td>
<td>9.89</td>
<td>9.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth of placement from top</th>
<th>Type of Coir Geotextile</th>
<th>4. Red Soil Soaked: Initial CBR = 3.35%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-woven</td>
<td>Woven H2M8</td>
</tr>
<tr>
<td>H/4</td>
<td>4.56</td>
<td>5.02</td>
</tr>
<tr>
<td>H/3</td>
<td>4.11</td>
<td>4.26</td>
</tr>
<tr>
<td>H/2</td>
<td>3.61</td>
<td>3.88</td>
</tr>
</tbody>
</table>
Fig. 7.2 Load - penetration curves with coir geotextiles placed at H/4 from top
Considering different types of coir geotextiles, H2M8 and Non-woven geotextile perform better in both types of soil. Percentage increase of CBR in non-woven coir geotextile reinforced case was found to be more in unsoaked condition. Thus in the case of both soils, maximum CBR was obtained when H2M8 coir geotextiles was placed at H/4 from top. For both the red soil and clayey soil, in soaked conditions, it was observed that the load penetration curves are very close to each other when coir geotextiles are placed at H/2 and H/3 from top irrespective of the type of coir geotextiles.

7.3.3 Type of Coir Geotextiles

The type of coir geotextile used has a role in the performance of CBR of coir geotextile reinforced soil. The properties of coir geotextile viz., its mass density, mesh size and modulus may affect the strength of the soil. Fig.7.3 (a) shows the comparison of load penetration curves for the clayey soil in soaked and unsoaked conditions when the three types of coir geotextiles were placed at H/3 and H/2 from top. The similar behaviour of red soil in soaked and unsoaked conditions can be observed from Fig. 7.3 (b). It can be observed that, in unsoaked condition, non-woven coir geotextile showed maximum penetration resistance indicating greater CBR value whereas, in soaked condition, H2M8 woven geotextile gave higher CBR value. This behaviour was identical for both in clayey soil and in red soil. Clayey silt in soaked condition with geotextiles at H/4 from top, the CBR values obtained were 1.9% and 3.35% for NW and H2M8 respectively. But for the same soil in un-soaked condition, the CBR values were respectively 4.25% and 3.54% for NW and H2M8. Similarly, for red soil, the CBR values with geotextile at H/4 from top were 4.56% and 5.02% for NW and H2M8 respectively in soaked condition and were 25.09% and 14.52% respectively in
un-soaked condition. For all placement depth this behaviour was similar. In all cases it could be seen that the performance of H2M6 in terms of improving the CBR values is only marginal when compared to other types of coir geotextiles. Thus it can be concluded that for the enhancement of CBR, H2M8 will be a better option, as the CBR values were more in soaked condition, which is the condition normally considered for the design purpose. Non-woven coir geotextile can be considered when more or less dry conditions prevail.

Fig. 7.3 (a) Effect of type of coir geotextile for clayey silt
Soil only with H2M8
with NW
Soil only
with H2M8
x
x
△
△

(i) Geotextile at H/3 depth

Fig. 7.3 (b) Effect of type of coir geotextile for red soil
7.3.4 Effect of Soaking

Comparing the load penetration curves for soaked and unsoaked conditions, between reinforced and unreinforced red soil, the percentage increase in CBR value for reinforced soil is lower for soaked condition than percentage increase in the CBR value for unsoaked condition. Whereas for clayey soil, the percentage increase in CBR value is higher for soaked condition than the percentage increase in unsoaked condition when reinforcement was introduced in the soil. It may be noted that the CBR of red soil is 3.3 times greater than that of clayey soil in unsoaked condition and 3.5 times more in soaked condition. The variations of percentage increase in CBR of reinforced soil when compared with the corresponding unreinforced soil are plotted in a chart form in Fig. 7.4. It can be observed that, in the case of red soil, when NW coir geotextile was placed at H/4 depth from the top, the percentage increase in CBR in unsoaked condition was 214% whereas this value in soaked condition was only 36%. But for clayey silt, when NW geotextile was placed at H/4 from top, the percentage increase in CBR was found to be 75% and 100% respectively in unsoaked condition and soaked condition. Hence it can be stated that the coir geotextiles give better results in soaked condition in the case of clayey soil than that of the red soil.

7.3.5 Effect of Placement Depth

Fig.7.5 shows the variation of CBR in soaked and unsoaked conditions with the three coir geotextiles placed at three positions for clayey soil and red soil. The position of geotextile was expressed in terms of depth ratio defined as H/y, where y is the depth of reinforcement from the surface and H is the total depth of the sample in the CBR mould, denoting the depth ratio as zero for unreinforced case for the purpose of comparison. It can be clearly seen from the graph that due to the placement of coir
Fig. 7.4 Effect of soaking on geotextiles placed at H/4 and H/2 from top
Fig. 7.5 Effect of placement depth of coir geotextiles

g geotextiles, the CBR value is increased irrespective of type of coir geotextiles and placement depth, but the quantum of increase depends on type of coir geotextile and placement depth. It is observed that, though the CBR values were increased in all cases, the percentage increase was found to be much higher when Non-woven coir geotextile was placed in the upper one-third region. For example, when coir geotextile
was placed at H/4 depth, the percentage increase in CBR values were 100%, 252% and 43% for Non-woven, H2M8 and H2M6 respectively for soaked conditions. The corresponding values at a depth of H/3 were 64%, 188% and 14% and when it was placed at H/2 depth, it reduces to 51%, 172% and 12%. Similar trend can be observed for unsoaked conditions and also for the cases with red soil. It can be observed that the improvement in CBR when coir geotextiles were placed at the middle height of the mould is only marginal and beyond that level still lesser values are expected. The reason for this could be attributed to the fact that the depth through which the effective pressure bulb passes is a function of the diameter of the plunger and, if the geotextile is inserted at depths greater than the depth of pressure bulb, no significant improvement can be witnessed.

7.3.6 Effect of Multiple Layers

In order to study the effect of additional layer of geotextile in subgrade, CBR tests were conducted with multiple layers of geotextiles. The percentage increases in CBR values with respect to unreinforced cases are tabulated in Table 7.3.

Table 7.3 Increase in CBR due to additional layer of coir geotextile

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Type of geotextile</th>
<th>CBR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without geotextile</td>
<td>With 1 layer at H/3</td>
</tr>
<tr>
<td>Clayey silt Soaked</td>
<td>NW</td>
<td>0.95</td>
</tr>
<tr>
<td>Clayey silt Un-soaked</td>
<td>NW</td>
<td>2.43</td>
</tr>
<tr>
<td>Clayey silt Soaked</td>
<td>H2M8</td>
<td>0.95</td>
</tr>
<tr>
<td>Red Soaked</td>
<td>NW</td>
<td>7.98</td>
</tr>
<tr>
<td>Red Soaked</td>
<td>H2M8</td>
<td>7.98</td>
</tr>
<tr>
<td>Red Soaked</td>
<td>NW</td>
<td>3.35</td>
</tr>
</tbody>
</table>
The effects of multiple layers of coir geotextiles were studied in few cases. The variations in CBR values due to the provision of additional reinforcement are shown in Fig. 7.6 for red soil and clayey silt.

![Graph showing load vs. penetration for clayey silt and red soil with different layers of coir geotextile](image)

**Fig. 7.6 Effect of Multiple Layers of Coir Geotextile**
It can be seen that by providing one additional layer of geotextile the increase in CBR was roughly doubled. For instance, the percentage increase in CBR when Non-woven coir geotextile was placed at a depth of $H/3$ from top in clayey silt was 64%. With one additional layer at $H/2$ from top, the percentage increase in CBR was around 108%. For red soil in soaked condition, this increase was from 27% to 69% when a layer of H2M8 coir geotextile was placed at $H/2$ depth, in addition to the one placed at $H/3$ location.

7.4 SOIL - AGGREGATE SYSTEM

In the case of unpaved roads, the coir geotextiles can perform as a separator if it is placed between the subgrade and the base material. The geotextile prevents the interpenetration of particles between base and subgrade layers keeping the strength and thickness of the base course intact.

A set of experiments was conducted in this study to analyse this performance of coir geotextile in a soil - aggregate system in which a layer of coir geotextile was placed between the soil (representing the existing subgrade) and 20mm nominal aggregate (representing the base material). Two series of experiments using CBR mould, one with clayey silt and other with red soil, were carried out with NW and H2M8 geotextiles placed at $H/4$ from top and putting aggregate over it. Tests were done in soaked and un-soaked conditions. This simulate the situations to arrive at the influence of coir geotextiles as suggested by Koerner (2005), in order to calculate the thickness of pavement by US Army Corps Method.

Experimental results on soil - aggregate system have shown definite increase in strength in terms of CBR value. Fig. 7.7 shows load penetration curves for red soil -
Fig. 7.7 Effect of coir geotextiles in soil - aggregate system

aggregate system and clayey silt - aggregate system with NW and H2M8 coir geotextile placed at interface in soaked and un-soaked conditions. From the figure it
can be seen that in the case of red soil – aggregate system, both NW and H2M8 geotextiles, performed well in increasing the CBR values, the percentage increase was around 41% in soaked condition and around 20% to 25% in unsoaked condition. Similar trend was shown in the case of clayey silt – aggregate system with a variation of 32% to 40% in soaked condition, whereas in un-soaked case, H2M8 coir geotextile gave higher CBR (53% increase) than NW, which showed an increase of only 26%.

Still as a general case, it can be concluded that the modified CBR in the soaked condition for the soil – aggregate system is approximately 35% more than the original CBR.

CBR values and percentage increase in CBR in relation to control section CBR were calculated. These values are summarised in Table 7.4.

### Table 7.4 CBR values for soil – aggregate system

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Soaking Condition</th>
<th>Type of geotextile</th>
<th>CBR (%)</th>
<th>% Increase in CBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clayey silt</td>
<td>Soaked</td>
<td>Nil</td>
<td>4.60</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Un-soaked</td>
<td>Nil</td>
<td>6.12</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Soaked</td>
<td>NW</td>
<td>6.08</td>
<td>32.0</td>
</tr>
<tr>
<td></td>
<td>Un-soaked</td>
<td>NW</td>
<td>7.72</td>
<td>26.0</td>
</tr>
<tr>
<td></td>
<td>Soaked</td>
<td>H2M8</td>
<td>6.16</td>
<td>40.0</td>
</tr>
<tr>
<td></td>
<td>Un-soaked</td>
<td>H2M8</td>
<td>9.36</td>
<td>53.0</td>
</tr>
<tr>
<td>Red soil</td>
<td>Soaked</td>
<td>Nil</td>
<td>4.20</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Un-soaked</td>
<td>Nil</td>
<td>8.20</td>
<td>40.8</td>
</tr>
<tr>
<td></td>
<td>Soaked</td>
<td>NW</td>
<td>7.20</td>
<td>40.8</td>
</tr>
<tr>
<td></td>
<td>Un-soaked</td>
<td>NW</td>
<td>9.90</td>
<td>20.7</td>
</tr>
<tr>
<td></td>
<td>Soaked</td>
<td>H2M8</td>
<td>7.20</td>
<td>40.8</td>
</tr>
<tr>
<td></td>
<td>Un-soaked</td>
<td>H2M8</td>
<td>10.0</td>
<td>22.0</td>
</tr>
</tbody>
</table>

### 7.5 CBR PREDICTION MODEL

#### 7.5.1 General

In India the thickness of flexible pavement is designed on the basis of projected number of standard axle loads during the design life, which is obtained using the
current commercial vehicles per day (CVPD) and its growth rate, along with the subgrade strength in terms of CBR. In rural roads, the top 30cm of the cutting or embankment at the formation level shall be considered as depth of subgrade (IRC: SP: 20-2002).

From the results of the detailed laboratory investigations on the strength behaviour of coir geotextile reinforced subgrade soil, it could be seen that the strength in terms of the CBR of the soil would increase considerably with the positions of geotextile. Also, the strength mobilisation depends on many factors like the inherent strength properties of the soil and also the strength and the placement depth of the geotextile reinforcement. Hence it is advantageous to develop a model to predict the modified CBR of the reinforced subgrade, which would respond to the changes in the properties of the soil and that of the reinforcement.

\[
\text{Modified CBR} = f(\text{Soil characteristics, Reinforcement characteristics, Placement depth})
\]

This can be achieved through the principles of multiple linear regression analysis. The model thus developed can be effectively used for the design of coir reinforced unpaved roads. The details of design procedure are given in Section 10.3.

7.5.2 Multiple Linear Regression Analysis (Johnson, 2001)

Multiple linear regression analysis is a statistical technique frequently used to develop prediction equations to establish the relationship for a variable, which is known to respond to changes in two or more other variables. The variable, which is known to respond (\(y\) variable) is commonly called the dependent variable and the other variables influencing it are called the independent variables (\(x\) variables). The function will be of the following form:
where, \( x_1, x_2, x_3, \ldots, x_m \) = \( m \) independent variables,

\[
a_0 = \text{regression constant, and}
\]

\[
a_1, a_2, \ldots, a_m = \text{regression coefficients of the } m \text{ independent variables.}
\]

The regression coefficients are determined from a given set (n) of observed values of \( x \) and \( x_1, x_2, \ldots, x_m \) by the method of least squares.

The analysis of variance approach is used to test the predictor equation. The total sum of squares of deviations of the ‘n’ observations from the mean is a measure of the degree to which the ‘n’ observations are spread around their average value. Smaller the standard error, the better will be the model.

Coefficient of determination (R^2) is another indicator of the strength of relationship. It is the ratio of regression sum of squares to total sum of squares. R^2 lies between 0 and 1. The closer it is to 1, the better is the equation.

The F ratio gives another indication of the adequacy of the equation. It is the ratio of mean sum of regression squares to mean sum of residual squares. If the F ratio obtained is greater than the values given in the F tables, then the model is significant.

**7.5.3 Development of Model**

The most important property of the subgrade soil considered for the design of pavement is the CBR value. Hence the original CBR for the remoulded soil at OMC and MDD is taken as a property representing the strength of the soil. The different properties of coir reinforcement considered are those which can be evaluated in the
laboratory or supplied by the manufacturers viz., mass / unit area, puncture resistance, strip tensile strength, wide tensile strength, secant modulus and mesh size (picks/dm and ends/dm). CBR tests were conducted by placing coir geotextiles at three depths - H/2, H/3 and H/4, where H is the height of the specimen for CBR test and these heights were taken as the placement characteristics of the geotextile.

Multiple Linear regression analysis was done using SPSS software inputting the laboratory test data obtained. The dependent variable is the modified CBR. The independent variables considered for regression analysis were:

i) Original CBR of the soil,

ii) Mass per unit area of the geotextile,

iii) Puncture resistance of geotextile,

iv) Strip tensile strength in machine direction of the geotextile,

v) Wide tensile strength in machine direction of the geotextile,

vi) Secant modulus of the geotextile,

vii) Picks/dm of the geotextile,

viii) Ends/dm of the geotextile, and

ix) Depth of placement of reinforcement (H/2, H/3 and H/4).

Analyses were done using CBR data separately for soaked and unsoaked conditions and also putting together. During analysis some of the variables representing the properties of geotextiles were found insignificant. The equations for modified CBR values ($\text{CBR}_M$) obtained for different conditions are given below in which,

\[ \text{CBR}_M = \text{Modified CBR in } \% \text{ (reinforced condition)}, \]
\[ CBR = \text{Original CBR in } \% \text{ (unreinforced condition)}, \]
\[ D = \text{Depth of coir geotextiles from surface}, \]

(H/2 = 6.25cm, H/3 = 4.17cm and H/4 = 3.125cm)
\( \sigma_s \) = Strip Tensile Strength of Coir geotextile in kN/m,
\( \sigma_w \) = Wide width tensile strength of Coir geotextile in kN/m, and
\( E_s \) = Secant Modulus of Coir Geotextile in kN.

\( \sigma_s, E_s \) and \( \sigma_w \) being independent variables, are selected as significant variables in the analysis independently, which give rise to the following three sets of equations in each case of analysis:

i) **Both soaked and unsoaked CBR data**

   a) \( CBR_M = 0.550 + 1.249 \ CBR - 0.363 \ D + 0.156 \ \sigma_s \) \hspace{1cm} (7.4)
      \hspace{1cm} (R^2 = 0.936)

   b) \( CBR_M = 0.916 + 1.249 \ CBR - 0.363 \ D + 0.0255 \ E_s \) \hspace{1cm} (7.5)
      \hspace{1cm} (R^2 = 0.936)

   c) \( CBR_M = 0.626 + 1.249 \ CBR - 0.363 \ D + 0.12 \ \sigma_w \) \hspace{1cm} (7.6)
      \hspace{1cm} (R^2 = 0.936)

ii) **Soaked CBR data only**

   a) \( CBR_M = 0.649 + 0.803 \ CBR - 0.178 \ D + 0.162 \ \sigma_s \) \hspace{1cm} (7.7)
      \hspace{1cm} (R^2 = 0.944)

   b) \( CBR_M = 1.029 + 0.803 \ CBR - 0.178 \ D + 0.0264 \ E_s \) \hspace{1cm} (7.8)
      \hspace{1cm} (R^2 = 0.944)

   c) \( CBR_M = 0.728 + 0.803 \ CBR - 0.178 \ D + 0.124 \ \sigma_w \) \hspace{1cm} (7.9)
      \hspace{1cm} (R^2 = 0.944)

iii) **Unsoaked CBR data only**

   a) \( CBR_M = 0.930 + 1.342 \ CBR - 0.549 \ D + 0.150 \ \sigma_s \) \hspace{1cm} (7.10)
      \hspace{1cm} (R^2 = 0.937)

   b) \( CBR_M = 1.284 + 1.342 \ CBR - 0.549 \ D + 0.0246 \ E_s \) \hspace{1cm} (7.11)
      \hspace{1cm} (R^2 = 0.937)

   c) \( CBR_M = 1.005 + 1.342 \ CBR - 0.549 \ D + 0.116 \ \sigma_w \) \hspace{1cm} (7.12)
      \hspace{1cm} (R^2 = 0.937)
Equation 7.8 uses all data and gave higher $F$ values and hence this equation is recommended for the prediction of the modified CBR for design of coir geotextile reinforced unpaved roads. The linear scatter diagram using this equation is shown in Fig. 7.8, which shows that the deviated points lie on the safer side in terms of design consideration.

![Fig. 7.8 Linear scatter diagram for the CBR prediction model](image)

7.6 SUMMARY

Elaborate experimental studies were carried out to understand the strength behaviour of coir geotextile reinforced subgrade in terms of California Bearing Ratio. The CBR values were found to change with the varying location of reinforcement in the subgrade soil and also with respect to the type of soil and type of reinforcement. It was observed that beyond $H/2$ depth, effects of coir geotextiles were nominal. Effects
of multiple layers of coir geotextile reinforcements were also studied and found that with an additional layer, the percentage increase in CBR was very high.

Depending on the type of soil, type of coir geotextile and soaking conditions, the percentage increase in CBR varies. In general, while it can be stated that H2M8 and non-woven coir geotextiles perform better, the performance of latter being found to be better in unsoaked clayey silt soil. In soaked condition, it was found that H2M8 performs better than Non-woven.

With the help of a large number of experimental results, an equation for modified CBR was formulated, which correlated the properties of soil, properties of geotextiles and placement depth of coir geotextiles.