CBR Value Estimation Using Dynamic Cone Penetrometer

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ABSTRACT

IRC-37-2001, Indian Standard deals with the design of flexible pavement and recommends the California Bearing Ratio (CBR) as an indicator of subgrade soil strength. The subbase/base thickness of pavement is governed by the CBR value of the subgrade soil along with some other parameters such as traffic intensity, climatic conditions etc. The conventional CBR testing method is expensive, time consuming and its repeatability is low. Additionally it is very difficult to mould the sample at the desired in-situ density in the laboratory CBR test. Values of in-situ density are underestimated due to local dampness of surface water percolation and stress release while taking out the sample. Dynamic cone penetration test (DCPT) value conducted in the field can be used to estimate the CBR value provided a suitable relationship exists between CBR and DCPT value. In the present study an attempt has been made to establish a relationship between DCPT value and CBR.

1. INTRODUCTION

The design of new flexible pavements and rehabilitation of existing pavements needs an accurate estimation of CBR value. In the design of overlays generally Benkelman’s beam method and Falling Weight Deflectometer (FWD) are used but these methods are sophisticated and time consuming. Scala (1956) has successfully used dynamic cone penetrometer (DCP) for estimating the strength of soil. The study was mainly in relation to application in design and strengthening of existing pavements. Some of the work regarding correlation between DCPT and CBR has been reported in literature (Smith and Pratt 1983, Livenh 1989) but the conditions considered is not simulating the actual highway condition. During the design of new pavements or strengthening of existing one worst possible environmental conditions to be faced by the highway during its design life should be simulated. Therefore in situ CBR tests has to be conducted after saturating the existing sub grades fully. However, it is very difficult to conduct a field soaked CBR test and is almost impractical in many situation. On the other hand in case of a laboratory CBR test specimens after being moulded at insitu density tend to give higher values of CBR than those obtained in the field especially for sandy soils (Haison 1987). The difference is due to the confining effect of rigid mould in laboratory tests. Again in field CBR tests, many times misleading values of CBR is obtained, whenever piston tip rests on a small stone particle or pebble. Keeping in view the above stated limitations of field as well as laboratory CBR tests, it was decided to conduct dynamic cone penetration test (DCPT) in place of CBR tests. The DCPT test values can be used to estimate the CBR values provided a suitable relationship exists between the CBR and the DCPT value. Development of any such relationship may become very effective tool for highway engineers. The other benefits of the relationship are the following: (a) It may help enhancing highway construction quality control; (b) It may help ensuring long-term pavement performance and stability; and (c) It may help achieving more uniform structural property. In the present study DCP tests were conducted along the 8 km long stretch of the left bank of Sidhwan canal passing through the southern part of Ludhiana city (Punjab) for widening and strengthening of the existing road. Total 8 locations were earmarked at an interval of one km after visiting the site. The interval was decided based on uniformity of soil available along the whole stretch. The present study describes a series of DCP tests conducted at insitu conditions and soaked in situ condition. In addition to the above field test, laboratory soaked CBR tests moulded at insitu density were also carried out. In the present paper the results obtained from the tests were presented and discussed. It is also important to note that by exercising little extra care some limitations of the DCP test such as blunting of cone due to its repeated use and inadequate fall of hammer were overcome.
2. EXPERIMENTAL WORK

The DCP tests were conducted according to the procedure laid down in ASTM-D6951-3 (2003). The apparatus consists of 16mm diameter steel rod in which a tempered steel cone with a 20 mm base diameter and a 60 degree point angle is attached. The DCP is driven into the soil by a 8kg hammer with a free fall of 575mm. The hammer correction factor is unity for 8kg hammer. Figure 1 shows the dimensions of the dynamic cone penetrometer.

The DCP index or reading is defined as the penetration depth (D) in mm for a single drop of hammer. The cone is driven in to the ground upto the desired depth and average DCP index is calculated for a single blow. Depth of penetration considered in the study was 800mm because the stresses induced due to the wheel load becomes negligible beyond this depth.

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Field and Laboratory Tests

Following tests were conducted during the course of this study:

- Sieve analysis
- Atterberg’s limit test
- Modified Proctor compaction test
- In situ density test (Sand replacement method)
- DCP test (In situ and soaked condition)
- Laboratory CBR test (Soaked condition at in situ density).

Test Procedure and Sample Preparation

The experimental study involved performing a number of field and laboratory tests at different locations. To conduct soaked CBR tests at in situ density, laboratory specimens were prepared at different compaction levels by varying the number of blows. In this case, four compaction levels i.e. 15, 25, 35, and 65 blows were adopted. Density and CBR values were determined for all four cases and a graph between CBR (soaked) and density at various compaction effort were drawn. The CBR values corresponding to the desired in-situ density were calculated from this graph. Figure 2 shows a typical variation between CBR value and dry density. Similar results were obtained for other cases also.

![Fig. 1: Dynamic Cone Penetrometer](image)

![Fig. 2: Relation between Soaked Lab. CBR and Dry Density](image)

Dynamic cone penetration tests (DCPT) were carried out on the existing subgrade surface to determine the DCP based CBR value at field moisture content and in-situ density. The dynamic cone penetrometer was directly placed on the subgrade and the test was started by sliding the hammer. Soil resistance was measured in terms of penetration as mm/blow. For every location three points were tested and average value was considered for the determination of CBR value. Since the imprint area of the cone tip for the first blow is smaller than that of subsequent blows, the penetration of the first blow was discounted. The number of blows were counted for 800mm penetration of the cone and penetration per blow was calculated. To conduct soaked in-situ DCP test, a small area of 3mx3m was flooded with water by making small dykes around that area. As the soil was silty sand, water was kept flooded for 8 hours before conducting the DCP test. Rest of the field and laboratory tests were conducted as per the relevant Indian Standard Codes.

3. RESULTS AND DISCUSSION

The most important parameter to evaluate subgrade/subbase strength for the pavement design is the CBR value. The results of various tests conducted in the field and laboratory are given in Table – 1.
It can be observed from the results that soil is almost uniform for all the 8 locations with sand content varying from 63.5% to 70%. Soil is non plastic in nature with liquid limit ranging between 16.5% to 17.9%. The in-situ density is different for different locations varying from 16.80 kN/m$^3$ to 19.20 kN/m$^3$. In-situ moisture lies between 2.4 to 3.9%. The results in Table-2 further reveals that soaked laboratory CBR value is higher than the DCP based soaked in situ CBR value. This is attributed to the higher confinement pressure of rigid mould in the laboratory.

**Table 2: Soaked Laboratory CBR and In situ CBR Test Values at Different Locations**

<table>
<thead>
<tr>
<th>Chainage (kM)</th>
<th>Insitu Dry Density (kN/m$^3$)</th>
<th>Field Moisture Content (%)</th>
<th>Maximum Dry Density kN/m$^3$</th>
<th>Optimum Moisture Content (%)</th>
<th>Compaction Level (%)</th>
<th>Sand Content (%)</th>
<th>Liquid Limit (%)</th>
<th>Plasticity Index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.25</td>
<td>19.20</td>
<td>2.4</td>
<td>19.70</td>
<td>9.5</td>
<td>97.46</td>
<td>70</td>
<td>16.5</td>
<td>NP</td>
</tr>
<tr>
<td>5.25</td>
<td>18.80</td>
<td>3.2</td>
<td>19.70</td>
<td>9.5</td>
<td>95.43</td>
<td>70</td>
<td>16.5</td>
<td>NP</td>
</tr>
<tr>
<td>6.25</td>
<td>17.55</td>
<td>3.4</td>
<td>19.55</td>
<td>9.6</td>
<td>89.76</td>
<td>68.5</td>
<td>17.0</td>
<td>NP</td>
</tr>
<tr>
<td>7.25</td>
<td>16.95</td>
<td>3.8</td>
<td>19.50</td>
<td>9.6</td>
<td>86.92</td>
<td>68.0</td>
<td>17.0</td>
<td>NP</td>
</tr>
<tr>
<td>8.25</td>
<td>18.50</td>
<td>2.9</td>
<td>19.50</td>
<td>9.6</td>
<td>94.87</td>
<td>66.5</td>
<td>17.2</td>
<td>NP</td>
</tr>
<tr>
<td>9.25</td>
<td>18.00</td>
<td>3.1</td>
<td>19.75</td>
<td>9.4</td>
<td>91.13</td>
<td>64.5</td>
<td>17.7</td>
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<tr>
<td>10.25</td>
<td>16.85</td>
<td>3.9</td>
<td>19.55</td>
<td>9.5</td>
<td>86.18</td>
<td>65.0</td>
<td>17.5</td>
<td>NP</td>
</tr>
<tr>
<td>11.25</td>
<td>16.80</td>
<td>3.9</td>
<td>19.60</td>
<td>9.5</td>
<td>85.71</td>
<td>63.5</td>
<td>17.9</td>
<td>NP</td>
</tr>
</tbody>
</table>

The variation in CBR value under different conditions has been expressed by a dimensionless term California bearing ratio index (CBRI) and has been defined as given below (Choudhary et al. 2010)

\[ CBRI_1 = \frac{CBR_{LS}}{CBR_{DCPS}} \]  
\[ CBRI_2 = \frac{CBR_{DCP}}{CBR_{DCPS}} \]

Where $CBR_{LS}$ is the laboratory soaked CBR value at in situ density, $CBR_{DCPS}$ is DCP based in-situ CBR value at field moisture content and in-situ density and $CBR_{DCPS}$ is the DCP based in situ CBR value under soaked condition.

Figure 3 describes the variation of CBRI and CBRI with respect to compaction level. Compaction level has been defined as the percentage compaction in the field with respect to the maximum dry density. Variation between CBRI and compaction level can be expressed in terms of linear equations as given below for CBRI and CBRI, respectively:

\[ y = 0.0007x + 1.4646 \]  
\[ y = -0.0015x + 2.1465 \]

Where x is the compaction level and y is CBRI.

Results tabulated in Table 1 and 2 also shows the variation of CBR value with respect to dry density and moisture content. In the practical application of the dynamic cone penetration approach for assessing CBR at site, when the soil is different from soil tested in this study, one must use a regression function for data obtained for various conditions of soil type, moisture content and in-situ density.

**4. CONCLUSIONS**

Based on the study, following conclusions can be drawn:

1. The CBR value of uniform soils having similar characteristics can be determined quickly and with adequate accuracy using the DCPT results.

2. Once the correlation is established between CBR index for tests conducted under different conditions and compaction level or in-situ density, the soaked CBR value in the field can be determined very quickly by conducting the in-situ DCPT for existing conditions and using the CBRI value for that particular condition.
3. Similarly laboratory soaked CBR value can be evaluated after establishing a correlation between CBRI (CBR_{LS}/CBR_{DCPS}) and compaction level.

4. For construction of new embankments or strengthening of existing pavements, DCPT will be a very useful tool for evaluating the strength of sub grade in terms of CBR value.

5. It may helpful in enhancing highway construction quality control, ensuring long-term pavement performance, stability and achieving more uniform structural property.

REFERENCES


