# STRUCTURAL EVALUATION OF LOW VOLUME ROAD PAVEMENTS USING PAVEMENT DYNAMIC CONE PENETROMETER

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## Abstract

*Static and dynamic cone penetration tests are widely used in Foundation engineering for measuring the penetration resistance of the ground and for relating it to the degree of compaction and safe bearing capacity of soils. In Highway Engineering, Pavement Dynamic Cone Penetrometer (DCP) is used for rapid in-situ strength evaluation of subgrade and other unbound pavement layers. In the present studies, an attempt has been made to identify the strength and thickness of different pavement layers of newly constructed low volume roads in the State of Karnataka, India using dynamic cone penetration studies and was compared with actual measurements at the site. The evaluation of pavement test stretches was made for a period of two years, and changes in penetration resistance of different pavement layers were measured. A Software was used to analyze the DCP data and to correlate with field observation. The results have favoured the possibility of using dynamic cone penetrometer as a quality control and pavement monitoring tool for low volume roads, eliminating the need for a Benkelman beam or a falling weight deflectometer.*

***Keywords:*** *Pavement Dynamic Cone Penetrometer, CBR, Subgrade, Rural roads*

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## 1. INTRODUCTION

Pavement dynamic cone penetrometer is used for rapid in-situ strength evaluation of subgrade and other unbound pavement layers. It is a simple, economical method, requires minimum maintenance and provides continuous measurements of the in-situ strength of pavement section and the underlying subgrade layers without the need for digging the existing pavement as in the California Bearing Ratio (CBR) test. The dynamic cone penetrometer consist of an upper fixed 575 mm travel rod with 8 kg falling weight, a lower rod containing an anvil, and a replaceable cone with apex angle of 60° and having a diameter of 20 mm. The test is conducted by dropping the weight from 575 mm height and recording the number of blows for any specified penetration. Then the penetration rate, PR (sometimes referred as DCP ratio, or penetration index PI) is calculated. The DCP has the ability to verify both the level and uniformity of compaction, which makes it an excellent tool for quality control during pavement construction. It has been demonstrated that the results from penetration tests correlate well with the in-situ CBR values. There is a strong correlation between CBR and DCP penetration ratio in log-to-log form and CBR-DCP relationship is not significantly affected by changes in moisture content for granular layers. During the past decade, the DCP test has been correlated to many engineering properties such as the CBR, shear strength of granular materials, and most recently, Subgrade Resilient Modulus (MR), Elastic Modulus (E) and the soil classification.

## 2. LITERATURE REVIEW

DCP tests are designed to estimate the structural capacity of pavement layers and embankments. Livneh et al. (1989) demonstrated that the results from penetration tests correlate well with the in-situ CBR values [1]. Livneh and Ishai (1987) conducted a correlative study between the DCP values and the in-situ CBR values [2]. During this study, both CBR and DCP tests were done on a wide range of undisturbed and compacted fine-grained soil samples, with and without saturation in the laboratory. Field tests were performed on natural and compacted layers representing a wide range of potential pavement and subgrade materials. The research resulted in the quantitative relationship between the CBR of the material and its DCP-PR value and is shown in Eqn. 1.

$$\log CBR = 2.2 - 0.71 (\log PR) \quad (1)$$

Harrison (1986) also found that there is a strong correlation between CBR and DCP penetration ratio in log-to- log form. He reported that CBR-DCP relationship is not affected by changes in moisture content and dry density [3]. Kleyn (1975), Smith and Pratt (1983) have suggested the Eqn. 2 and 3 respectively to estimate CBR values [4] based on dynamic cone Penetration values (mm/blow).

$$\log CBR = 2.62 - 1.27 \log PR \quad (2)$$

$$\log CBR = 2.56 - 1.15 \log PR \quad (3)$$

For a wide range of granular and cohesive materials, the US Army Corps of Engineers and Minnesota Department of Transportation [5] have recommended the equations in the form,

$$\log CBR = 2.465 - 1.12 (\log PR) \quad (4)$$

$$CBR = 292/ (PR)^{1.12} \quad (5)$$

Chen et al. (2001) indicated that the DCP can be useful when the Falling Weight Deflectometer (FWD) back-calculated resilient moduli is not accurate, such as when the asphalt concrete layer thickness is less than 75 mm or when bedrock is shallow [6,7]. The subgrade resilient modulus, which is used in design methods based on structural analysis, can be determined either indirectly from relation between subgrade modulus (Es) and CBR or can be predicted directly from the DCP results. The 1993 AASHTO Guide for Design of Pavement Structures has adopted the Eqn. 6 for calculating subgrade resilient modulus (MR), which was proposed by Huekelom and Klomp (1962).

$$MR (MPa) = 10.34 * CBR \quad (6)$$

The resilient modulus from which this correlation was developed is limited to fine-grained soils with a soaked CBR of 10 or less [8]. Powell et al. (1984) suggested relationship between subgrade resilient modulus and CBR as shown in Eqn. 7. Other Equations relate the DCP Penetration Ratio (PR) with the subgrade modulus directly. Pen (1990) suggested the two relationships between the subgrade elastic modulus (Es) in (MPa) and PR in (mm/blow) as defined in Equations 8 and 9 [9].

$$MR (MPa) = 17.58 \times CBR^{0.64} \quad (7)$$

$$\log (Es) = 3.25- 0.89 \log (PR) \quad (8)$$

$$\log (Es) = 3.652-1.17 \log (PR) \quad (9)$$

A number of agencies are using the DCP to assess the strength and uniformity of highway structures. Minnesota Department of Transport (MnDOT) in US specified that the in-situ subgrade CBR based on DCP tests should be at least six to minimize rutting damage to the finished grade (prior to paving) and to provide adequate subgrade support for proper compaction of the base and other layers. In addition, they specified that soils with PR values greater than 25 mm/blow may need remedial procedures, such as sub-cutting, drying and compaction, backfilling with granular borrow or lime treatment. From an investigation of a series of case histories in Herfordshire, U.K., in which the DCP has been used, Huntley (1990) suggested a tentative classification system of soil based on penetration resistance; n in blows per 100 mm. However it has been recommended to use the classification table with considerable caution until a better understanding of the mechanics of skin friction on the upper drive rod is established.

## 3. PRESENT INVESTIGATIONS

To carry out evaluation of low volume road pavements using Pavement Dynamic Cone Penetrometer, newly constructed rural roads (low volume roads) were selected. The roads which were one year old or less than one year were grouped under newly constructed roads. Ten road stretches were selected for pavement evaluation studies. The roads selected have been widely distributed in Karnataka covering different soil types, traffic and environmental condition. Inventory studies were carried out to collect information regarding the width of the pavement, width of the shoulders on both left and right side of the pavement, the condition of drains and thickness and type of the pavement layers. In addition, the data regarding shoulder condition, depth of water table from the pavement surface, type of vegetation on either side of the test stretch etc were collected and recorded. To monitor the structural condition of the selected pavement test stretches for a specified duration dynamic cone penetration studies were planned.

### 3.1 Dynamic Cone Penetration Studies

The DCP tests were carried out on ten selected pavement test stretches, at two locations each, one on left wheel path and another on right wheel path. To carry out DCP test at a location, the equipment was placed above the pavement over a neat and even surface. Initial scale reading was noted and an eight kg hammer was dropped from a height of 575 mm. For every 5 blows, scale reading was recorded. The test was carried out till the penetration cone penetrates to a sufficient depth of subgrade. The readings were recorded in a standard format. After the DCP test; a section of pavement near shoulder was cut open to measure the thickness of different layers of pavement and also to collect the soil sample for laboratory analysis. The same procedure was repeated for all the test sections.

A Software was used to analyze the DCP data and to correlate with field observations. The results of the penetration test were analyzed using software called “UK DCP 3.1”. The pavement layers and thickness of each layer along with CBR values with graphical cross sectional details were the output from the software. The typical outputs for selected pavement section are shown in Table 1 and Fig. 1 respectively. The results were checked with manual method. DCP values for base, sub-base and subgrade along wheel paths for selected pavement test stretches measured during five cycles of field studies are shown in Table 2.

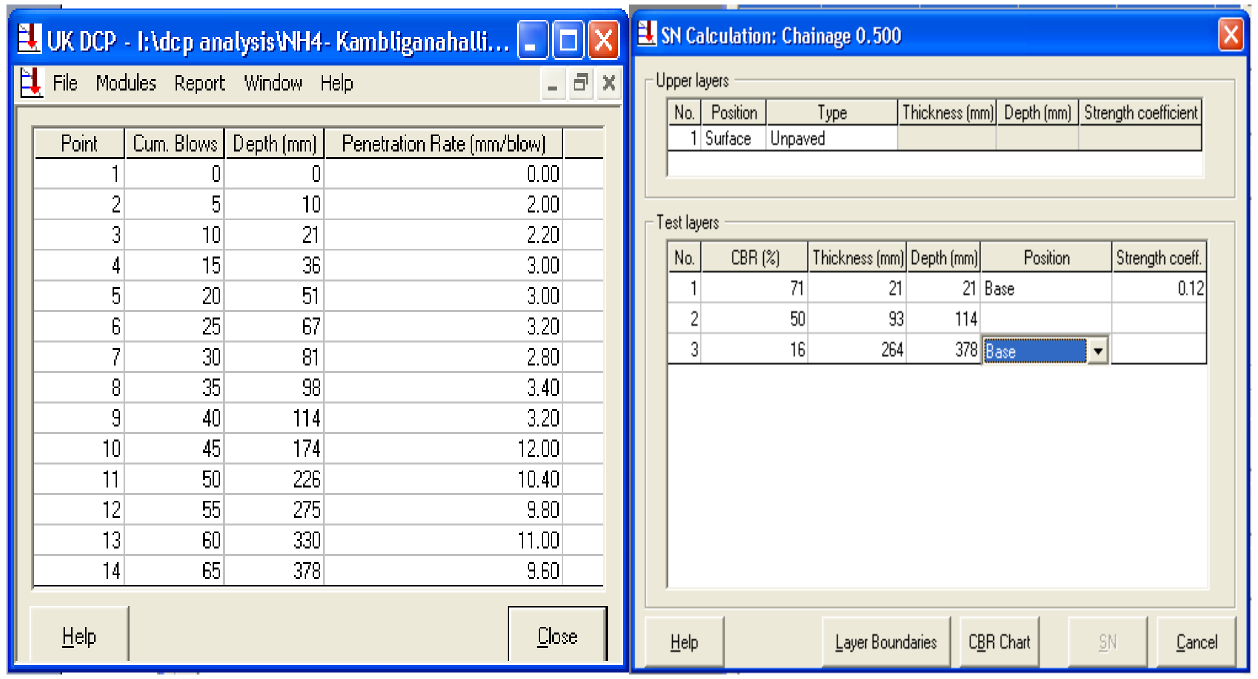
## 4. RESULTS AND DISCUSSION

The strength and thickness of pavement layers of ten newly constructed rural roads in the State of Karnataka, India were measured using Pavement Dynamic Cone Penetrometer. For each pavement test stretch, four layers of different pavement composition were identified. The top layer of thin pre-mix carpet resting over a base course, a granular sub-base course and compacted subgrade have been identified. The thickness of four layers varied in all the pavement test stretches. The thickness of base course varied in the range of 118 mm to 166 mm and the thickness of granular sub-base varied in the range of 76 mm to 175 mm. The compacted thickness of subgrade varied in the range of 100 mm to 210 mm. Although a pavement dynamic cone penetrometer does not directly indicate base or a sub base layer, these layers have to be identified by resistance offered to penetration. During experimental investigations the measured thickness of different pavement layers for different pavement test stretches were found to be different due to changes in constructed thickness.

When pavement layer thickness measured using DCP was compared with actual measurement, the variation in result was less than 10%. A small variation is bound to occur since DCP studies were conducted on wheel paths, but sections were cut open near the edges close to test locations. This clearly indicates the DCP test results are comparable with actual measurements.

The DCP values for base, sub-base and subgrade varied in the range of 2 to 4 mm per blow, 4 to 8 mm per blow and 9 to 15 mm per blow respectively. Using the nomogram given in IRC: SP:72-2007 the corresponding CBR values were in the range of 140 to 70 percent, 70 to 35 percent, 30 to 20 percent for base, sub-base and subgrade respectively. The penetration resistance of chip carpet varied in the range of 4 to 5.2 mm per blow indicating a CBR values in the range value of 70 to 60 percent. The selected pavement test stretches were monitored from May'08 to May'10. During this period, the DCP tests were conducted both during pre-monsoon and post-monsoon seasons on left and right wheel paths of the pavement test stretches and the results were recorded. During this period the DCP values for base courses increased in the range of 20 to 30 percent indicating a significant structural deterioration. A small increase in DCP values were also observed for sub-base layers. The increase in CBR values can be attributed to structural deterioration due to exposure to traffic and weather conditions. The subgrade CBR values measured with DCP for selected pavement test stretches over a period of 2 years have indicated a small increase in CBR values. The increase can be attributed to subgrade compaction due to high wheel loads.

**Table 1** A typical input and out put data of penetration test for a pavement stretch



UK DCP - I:\dcp analysis\NH4- Kambliganahalli...

File Modules Report Window Help

| Point | Cum. Blows | Depth (mm) | Penetration Rate (mm/blow) |
|---|---|---|---|
| 1 | 0 | 0 | 0.00 |
| 2 | 5 | 10 | 2.00 |
| 3 | 10 | 21 | 2.20 |
| 4 | 15 | 36 | 3.00 |
| 5 | 20 | 51 | 3.00 |
| 6 | 25 | 67 | 3.20 |
| 7 | 30 | 81 | 2.80 |
| 8 | 35 | 98 | 3.40 |
| 9 | 40 | 114 | 3.20 |
| 10 | 45 | 174 | 12.00 |
| 11 | 50 | 226 | 10.40 |
| 12 | 55 | 275 | 9.80 |
| 13 | 60 | 330 | 11.00 |
| 14 | 65 | 378 | 9.60 |

Help Close

SN Calculation: Chainage 0.500

Upper layers

| No. | Position | Type | Thickness (mm) | Depth (mm) | Strength coefficient |
|---|---|---|---|---|---|
| 1 | Surface | Unpaved | | | |

Test layers

| No. | CBR (%) | Thickness (mm) | Depth (mm) | Position | Strength coeff. |
|---|---|---|---|---|---|
| 1 | 71 | 21 | 21 | Base | 0.12 |
| 2 | 50 | 93 | 114 | | |
| 3 | 16 | 264 | 378 | Base | |

Help Layer Boundaries CBR Chart SN Cancel

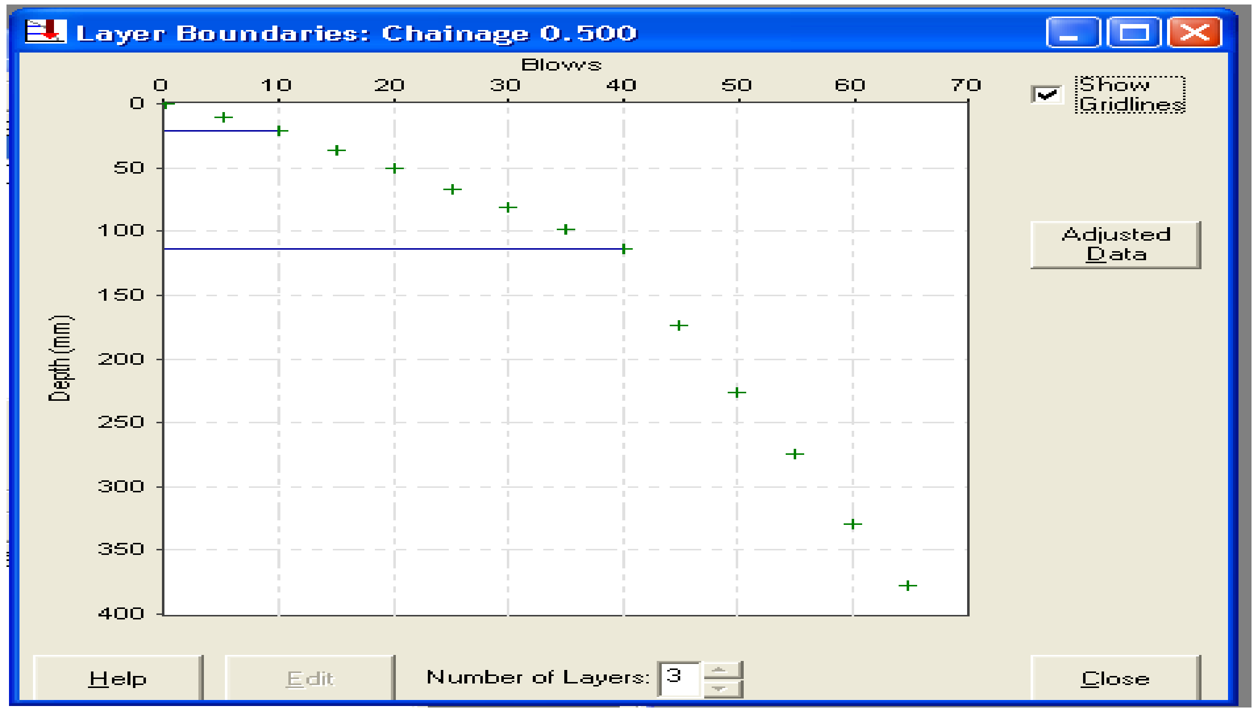



**Fig.1** A typical output for a pavement stretch using UK DCP software

## CONCLUSIONS

1. Dynamic Cone Penetrometer can be effectively used to identify number of pavement layers, thickness of each layer and strength of each layer in terms of CBR for rural roads. The field investigations have indicated that the DCP results and actual measurements vary within 10 percent.

2. Dynamic Cone Penetrometer has the potential to be used as a monitoring tool to evaluate the quality of pavement construction.

3. DCP tests can be used to evaluate the structural condition of the rural road pavements eliminating the need for a Benkelman beam or a falling weight deflectometer.

4. A number of trials are required at each location on a test stretch to get meaningful DCP results. Hence the use of DCP test for evaluating studies will be tedious and suitable for subgrade and pavements free of larger sized aggregates.

5. The DCP test can be conducted only on unbound layers and pavements with thin bituminous surfacing. The test is unsuitable to evaluate the structural condition of bituminous concrete (BC) and semi-dense bituminous concrete (SDBC) surface courses and binder courses.

6. The DCP results have indicated significant structural deterioration (20 to 30 percent) for selected low volume (rural road) test stretches within a period of 2 years. A small increase in penetration resistance of compacted subgrade has been noticed and this can be attributed to further compaction due to exposure to wheel loads.

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**Table 2** Mean DCP values along wheel paths for selected pavement test stretches

| Sl.No | Mean DCP Values, mm/blow | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | May, 2008 | | | Dec., 2008 | | | May, 2009 | | | Dec., 2009 | | | May, 2010 | | |
| | Base | Sub-base | Sub grade | Base | Sub-base | Sub grade | Base | Sub-base | Sub grade | Base | Sub-base | Sub grade | Base | Sub-base | Sub grade |
| 1 | 3.2 | 4.1 | 12.0 | 2.2 | 4.2 | 11.5 | 2.6 | 4.3 | 10.7 | 3.1 | 4.4 | 10.3 | 3.5 | 5.1 | 10.0 |
| 2 | 3.2 | 5.5 | 11.9 | 3.5 | 6.2 | 11.0 | 3.3 | 7.0 | 10.5 | 3.5 | 7.5 | 10.3 | 3.9 | 8.0 | 9.9 |
| 3 | 3.7 | 6.9 | 12.6 | 4.2 | 6.6 | 11.9 | 4.2 | 6.7 | 11.5 | 4.0 | 7.9 | 11.6 | 4.6 | 8.5 | 11.2 |
| 4 | 3.5 | 6.2 | 10.9 | 4.4 | 6.5 | 10.7 | 4.9 | 6.8 | 10.0 | 5.4 | 5.5 | 9.6 | 5.0 | 7.2 | 9.1 |
| 5 | 3.7 | 4.9 | 10.0 | 2.1 | 5.2 | 9.2 | 2.1 | 5.0 | 10.0 | 3.9 | 5.7 | 9.6 | 4.3 | 6.5 | 9.1 |
| 6 | 3.7 | 6.1 | 12.5 | 2.3 | 6.0 | 12.0 | 2.6 | 5.3 | 11.5 | 3.7 | 5.9 | 11.8 | 4.5 | 7.1 | 10.9 |
| 7 | 2.3 | 5.5 | 15.9 | 1.5 | 4.9 | 15.0 | 2.2 | 7.4 | 16.0 | 2.4 | 8.2 | 14.7 | 3.2 | 9.1 | 13.2 |
| 8 | 1.5 | 3.7 | 11.6 | 2.1 | 5.5 | 12.5 | 2.5 | 5.6 | 12.0 | 4.6 | 6.7 | 11.3 | 5.1 | 8.1 | 10.5 |
| 9 | 2.7 | 4.2 | 13.9 | 2.6 | 4.5 | 12.5 | 2.5 | 4.5 | 12.0 | 2.4 | 5.4 | 12.6 | 2.8 | 7.1 | 11.2 |
| 10 | 3.2 | 6.2 | 15.0 | 2.2 | 5.1 | 12.3 | 2.6 | 5.0 | 12.5 | 3.8 | 6.6 | 9.6 | 4.2 | 7.8 | 8.9 |
| Mean | 3.0 | 5.3 | 12.6 | 2.7 | 5.5 | 11.9 | 2.9 | 5.7 | 11.7 | 3.7 | 6.4 | 11.1 | 4.1 | 7.5 | 10.4 |