Evaluation of Road Pavement using Dynamic Cone Penetrometer

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Abstract—
Roads are usually constructed with different layers of thickness on the basis of traffic load repetitions as well as environmental considerations. Durability and longevity of roads are the key factors for the industrial and the economic growth of a country. Hence it is necessary to evaluate the existing roads in terms of their layer thickness and strengths related to California Bearing Ratio (CBR).One of the most popular & simpler device to evaluate the road pavement in terms of their layer thickness and strengths is Dynamic Cone Penetrometer (DCP). DCP maintains ahigher degree of accuracy in theresult. Also, its operation is easier than other expensive &time-consuming devices. This paper reports a laboratory fabrication of DCP using locally available materials and validated for the investigation. The investigation includes the evaluation of existing road pavement performance in terms of their layer thickness and strength. From this investigation, it has been found that most of the existing pavements in the study area do not fulfill the design specifications. Finally, the results have been compared with the specifications given by a standard organization and a computational method.

Keywords - *Road Pavement, California Bearing Ratio (CBR), Dynamic Cone Penetrometer, Pavement Design. Computational method.*

I. INTRODUCTION

Roads are considered as an important factor for the economic growth of a country. Thus a lot of roads are to be constructed in Bangladesh, obviously in a planned manner. Demand for more road mileage is increasing day by day due to rapid industrialization, thegrowth of economic activities and urbanization. As a result, too many new roads have constructed in recent time and many are under construction and some are being planned. These construction processes will be increased more to make remoter land utilization. However, ahuge amount of money is being invested for road construction in Bangladesh.In order to perform as an effective and reliable pavement construction, an accurate and representative material characterization technique is essential. During construction, a quality control program and inspection are usually conducted that proper specifications are followed. After construction, structural evaluation of road pavement is necessary to characterize the nature of rehabilitation strategy. There are many evaluation tools and techniques such as; Falling weight deflectometer (FWD), Dynaflect, Benkelman Beam device, Dynamic Cone Penetrometer, (DCP) etc.[1], [2].The DCP can be useful when the Falling Weight Deflectometer (FWD) back-calculated resilient moduli are not accurate, such as when the asphalt concrete layer thickness is not more than 75 mm or when bedrock is shallow [1], [3]. Falling Weight Deflectometer (FWD) functions as a stop and go (discrete testing) rather than a continuous process. A discrete testing program may not capture all the critical features of the project. In addition, the stop and go measurements become problematic on roads with high traffic densities.The Dynaflect Deflectometer usually used to measure pavement capacity to support the weight of passing vehicles. It also locates deficiencies which affect underlying structures. Measurements are independent of a fixed reference. It is a costly process. The handling and transportation are not easy as well as risky. In the case of Benkleman Beam device, the deflection observations are not easy and approximate corrections must be required. During monsoon season, it is not possible to conduct deflection studies.The Dynamic cone penetrometer (DCP) also known as the Scala penetrometer, was developed in 1956 in South Africa as an in-situ pavement evaluation technique for evaluating pavement layer strength [4]. Since then, this device has been extensively used in South Africa, the United Kingdom, the United States, Australia and many other countries, because of its simplicity in handling and operation, cost-effectiveness and the ability to provide rapid measurement of thein-situ strength of pavement layers and sub-grades. The DCP has also been proven to be useful during pavement design and quality control program.Transport and Road Research Laboratory Research Laboratory prepared a dynamic cone penetrometer with 60-degree cone, 8 kg hammer, 20 kg gross weight which is now widely used all over the world [5]. This equipment is not readily available in Bangladesh. Moreover, it is not economic and also troublesome to procure the equipment from abroad. Hence it has been decided to fabricate such equipment in the Transportation laboratory of Civil Engineering Department, Chittagong University of Engineering and Technology (CUET) with the locally available materials and investigation program of road layers evaluation has to be run using this dynamic cone penetrometer on adifferent type of roads.

II. OBJECTIVES OF THE STUDY

The objectives of the present investigation have been summarized below:

- To fabricate a low-cost DCP for evaluating constructed road layers.
- To evaluate in situ strength (in terms of CBR value) of pavement base, sub-base and sub-grade materials using DCP.
- To determine the thickness of different layers of pavement, using the DCP.
- To compare the obtained results with standard specifications.

III. DYNAMIC CONE PENETROMETER

Development of suitable equipment to determine the thickness of different layers is one of the major objectives of the present investigation. For performing this evaluation, DCP with 60-degree cone is fabricated according to the specifications of TRRL using locally available materials.

A. Components of DCP

The schematic diagram of the dynamic cone penetrometer that has been used to carry the investigation, shown in Fig. 1.

Handle: Length and diameter are respectively 140 mm and 12 mm. It needs to hold by hand for placing the instrument at thevertical position when performing the test.

Upper stop: It is a kind of screw of 16 mm diameter, which retrains the hammer to move out the upper portion of the shaft.

Hammer shaft: Approximate length is 685-695 mm and diameter is 16 mm, which helps the hammer to slide and drop on the anvil.

Hammer: It consists of two parts. The diameter and height of upper part are respectively 118 mm and 64 mm. The diameter and height of lower part are respectively 95mm and 51 mm. Gross weight of hammer is approximately 8 kg. It is used to help the cone for penetrating into the pavement.

Anvil: It also has two parts. Diameter and height of upper part are respectively 77 mm and 30 mm. Diameter and height of lower part are respectively 34 mm and 76 mm. It is used to transfer weight when hammer falling on it from some height that helps the cone to penetrate into the pavement.

Clamp ring: It helps to indicate the depth of penetration value.

Standard shaft: Approximate length is 850-900 mm that penetrates into the pavement. It is used to measure the penetration of the device.

Meter scale: It helps to measure the depth of penetration value

Cone: The cone has 60-degree point and has a base diameter of 20 mm. It is made of mild steel and stainless steel, which helps to penetrate the rod into the pavement.

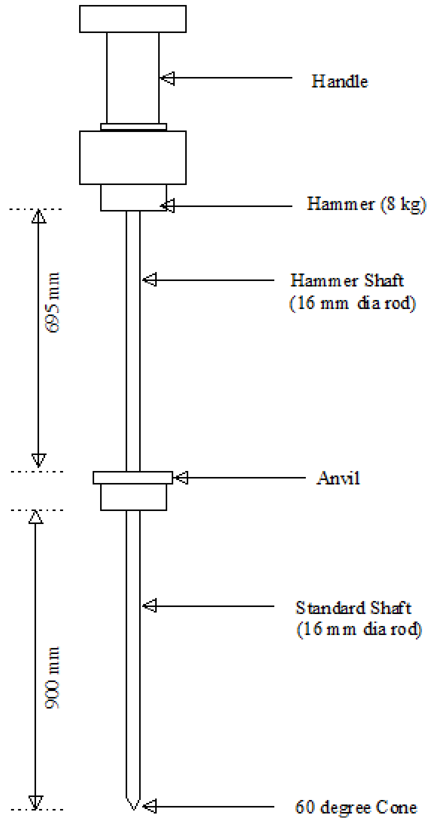

Fig. 1: Schematic Diagram of Dynamic Cone Penetrometer

B. Working Principle

1) Equipment Preparation:

It is important that all the screwed joints be kept tight during testing. The joints should be secured with wrenches before beginning each test. It may be necessary to use a nonhardening thread locking compound. Operating the DCP with loose joints will reduce the life of the instrument.

2) Sample Preparation:

No preparation is necessary if the test is to start from the surface. The instrument is to be held in a vertical position with the weight of the drop hammer on the seat the cone before the beginning of the test. The DCP is capable of penetrating through asphalt and base course materials. After completing the arrangement of the DCP, it is needed to record the zero reading of the instrument.

3) Testing Procedure:

The DCP needs three operators, one to hold the instrument, one to raise and drop the weight and a technician to record the results. The instrument is held vertical and the hammer to be lifted carefully to the handle. Care should be taken to ensure that the weight is touching the handle, but not lifting the instrument before it is allowed to drop. Then the operator let it fall freely and does not lower it with his hands. During the test, if the DCP leaves the vertical, no attempt should be made to correct this as contact between the shaft and the sides of the hole will give rise to erroneous results. If the angle of the instrument becomes worse, causing the weight to slide on the hammer shaft and not fall freely, the test should be abandoned.

It is recommended that a reading should be taken at increments of penetration of about 10mm. However, it is usually easier to take are ading after a set of a number of blows. It is, therefore, necessary to change the number of blows between readings according to the strength of the layer being penetrated. For good quality, granular bases readings every 5 or 10 blows are normally satisfactory but for weaker sub-base layers and subgradesreadings, every 1 or 2 blows may be appropriate. There is no disadvantage in taking too many readings, however, if readings are taken too infrequently, weak spots may be missed and it will be more difficult to identify layer boundaries accurately hence important information will be lost.

After completing the test the DCP is removed by gently tapping the weight upwards against the handle. Care should be taken when doing this as if it is done too vigorously the life of the instrument will be reduced.

Little difficulty is normally experienced with the penetration of most types of granular or lightly stabilized materials. It is more difficult to penetrate strongly stabilized layers, granular materials with large particles and very dense, high quality crushed stone. The TRRL instrument has been designed for strong materials and therefore the operator should persevere with the test. Penetration rates as low as 0.5 mm/ blows are acceptable but if there is no measurable penetration after 20 consecutive blows it can be assumed that the DCP will not penetrate the material. Under this circumstance, a hole can be drilled through the layer using an electric or pneumatic drill or by coning. The lower layers of pavement can then be tested in the normal way. If only occasional difficulties are experienced in penetrating granular materials it is worthwhile repeating any failed tests at a short distance away from the original test point.

4) Relationships Between DCP Value and California Bearing Ratio (CBR):

Extensive research has been performed to develop empirical relationships between DCP penetration resistance and CBR measurements [6]-[12]. Based on the results of past studies, many of the relationships between DCP value and CBR have the form of Equation (1).

$$\log (CBR) = a + b \log (DCPI) \qquad (1)$$

Where:
DCPI = DCP penetration resistance (mm/blow);
a = constant that ranges from 2.44 to 2.60; and
b = constant that ranges from 1.07 to -1.16.

A summary of some of these correlations is presented in TableI and Fig.2.

Table I : DCP-CBR Correlations

Correlation Equation	Material tested	Reference
Log CBR =2.46 - 1.12 Log (DCPI)	Granular and cohesive	Livneh et al. (1987)
Log CBR= 2.14 - 0.69 $(\text{Log DCPI})^{1.5}$	Granular and cohesive	Livneh M. (1989)
Log CBR = 2.20 – 0.71 $(\text{Log DCPI})^{1.5}$	Granular and cohesive	Livneh and Ishia (1987)
Log CBR = 2.70 – 1.12 Log (DCPI)	Granular soil	Harison (1986)
Log CBR = 3.93- 1.47 Log (DCPI)	Weathered sandy soil	Lee et al. (2014)
Log CBR = 2.46 - 1.15 Log (DCPI)	Various types of soil	Webster et al. (1992)
Log CBR = 2.62 - 1.27 Log (DCPI)	Pavement materials	Kleyn (1975)

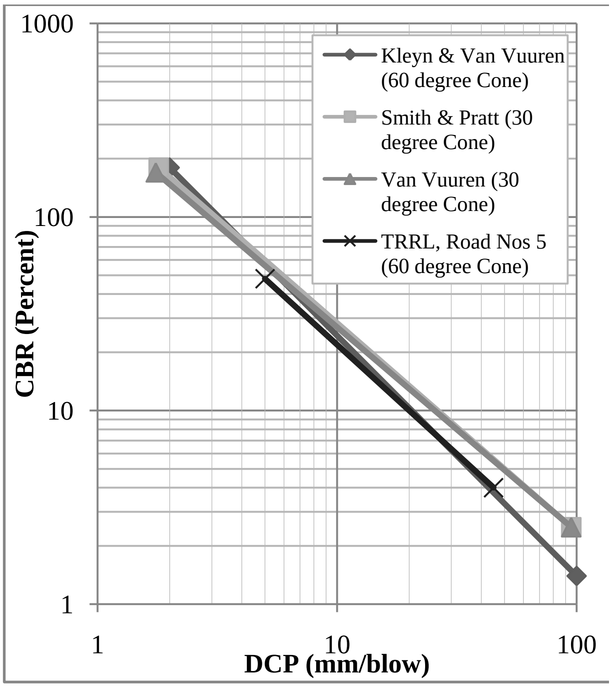

Fig.2: Relationship Between DCP Value & CBR Value

IV. METHODOLOGY

On the basis of traffic volume, the roads are classified as heavy volume, medium volume, and low volume road. These classifications are usually done on the basis of a number of commercial vehicles per day (CVPD). The classification of roads on the basis of CVPD has been presented in Table II. Evaluations of constructed roads using DCP have been conducted on pavements of thedifferentareas on different locations and data for investigation has been taken in three different types of roads (Heavy, Medium, and low volume). On the basis of priority level and general observations, some roads have been assumed to be Heavy, Medium or Low volume and present investigation program has been carried out for the evaluation of these roads. The locations where the investigation program have been carried out, presented in Table III.

Table II : Classification of Roads (Rhd)

Type of road	According to RHD	CVPD (in both directions)
High volume	National Highway	1000
Medium Volume	Regional Highway	700
Low Volume	Feeder road	80

Table III : Different Types of Roads Investigated

Typeof Road	Locations
Heavy volume	Dhaka – Chittagong road
	Chittagong – Cox's Bazar road
	Urban heavy volume road (Chittagong)
Mediu m volume	Chittagong – Kaptai road
	Chittagong – Hathajari road
	Urban medium volume road (Chittagong)
Low volume	Pahartali – Roazan road
	Noapara – Raozan road
	Urban low volume road (Chittagong)

The DCP test has been carried out at different locations at some specific intervals on each road. The results of DCP test have been recorded on field data sheets which have later been used to plot graphs and thus evaluation program is done. Since there is a specific relationship between DCP data and CBR value, thethicknessof different layers and their strength in terms of CBR have been computed.Finally, the evaluation results have been compared with a standard specification and with a computational method.

V. FIELD INVESTIGATION

Investigation abetting DCP had been carried out in the fields in different locations for different traffic volume as per Table III. The evaluated results for different roads, presented in Fig. 3 to Fig. 11 and numerical values have been depicted in Table IV.

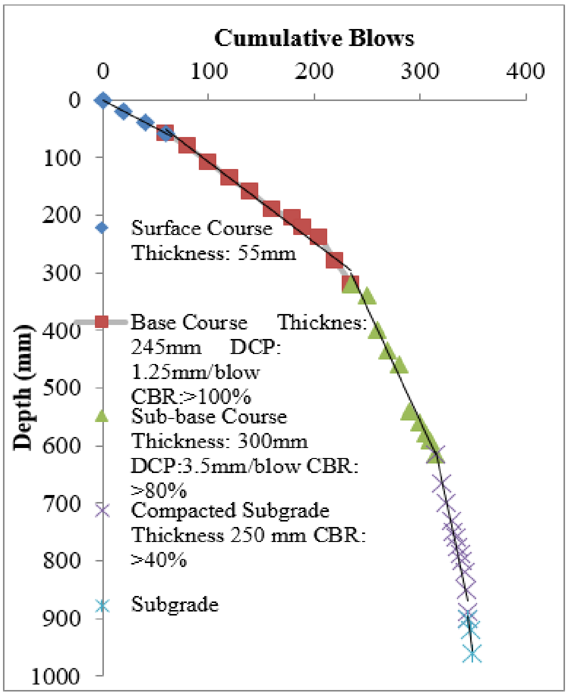

Fig. 3: DCP Test on Heavy Volume Road (Dhaka-Chittagong); Location: Karnelhat

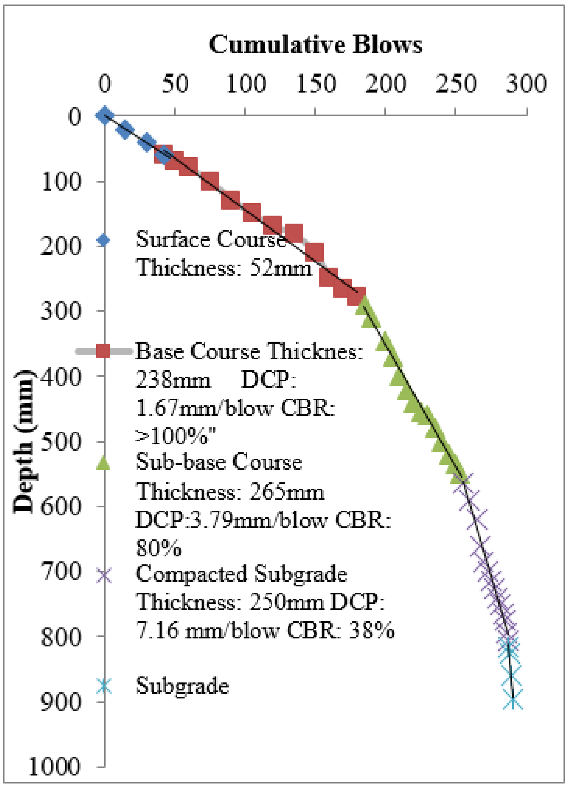

Fig. 4: DCP test on Heavy Volume Road (Dhaka-Cox's Bazar); Location: Anoawara Crossing

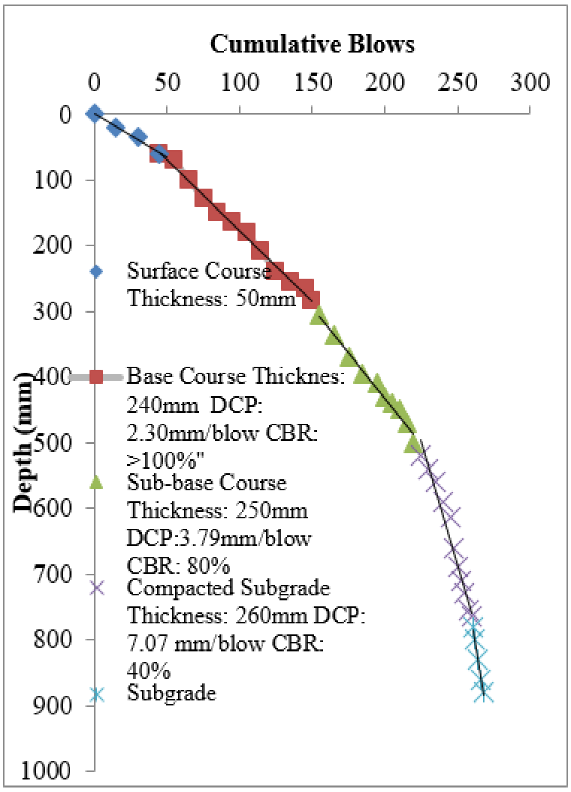

Fig. 5: DCP Test on Heavy Volume Road (Bohoddarhat-GEC); Location: Muradpur

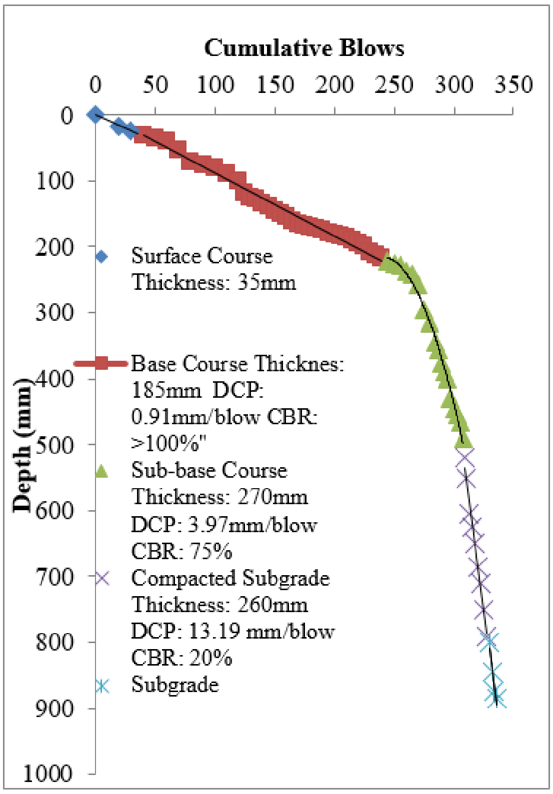

Fig. 7:DCP Test on Medium Volume Road (Chittagong-Hathajari); Location: Chowdhuryhat

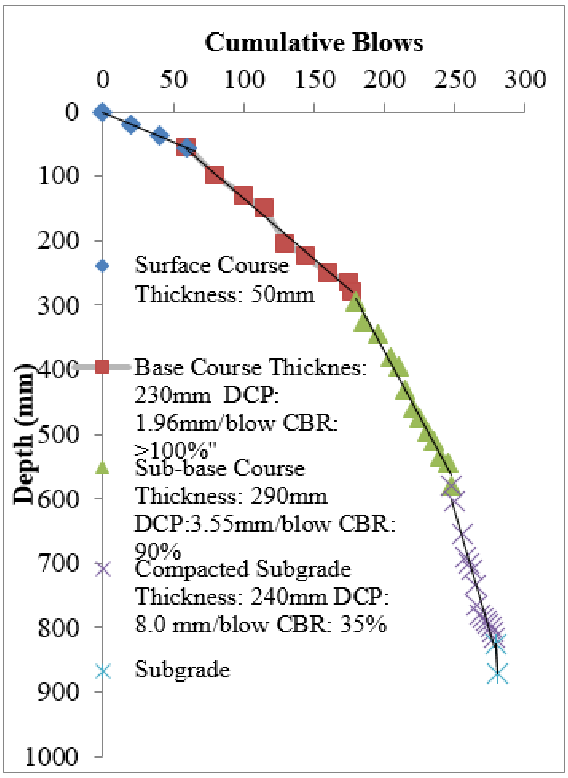

Fig. 6: DCP Test on Medium Volume Road (Chittagong-Kaptai); Location: Noapara

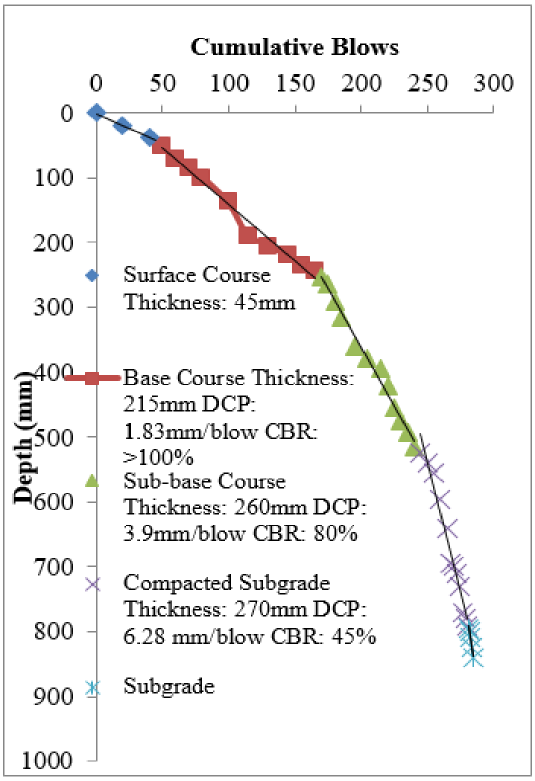

Fig. 8: DCP Test on Medium Volume Road (Bohoddarhat-New Market); Location: Chwakbazaar

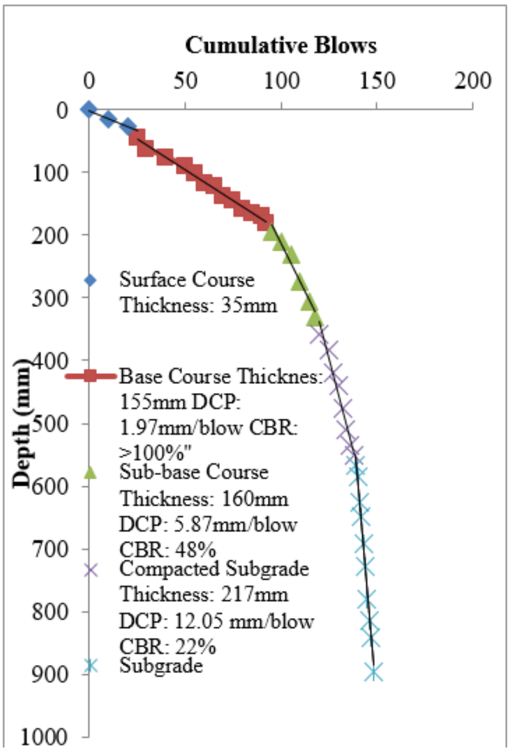

Fig. 9: DCP Test on Low Volume Road (Pahartali-Raojazan); Location: Pahartali

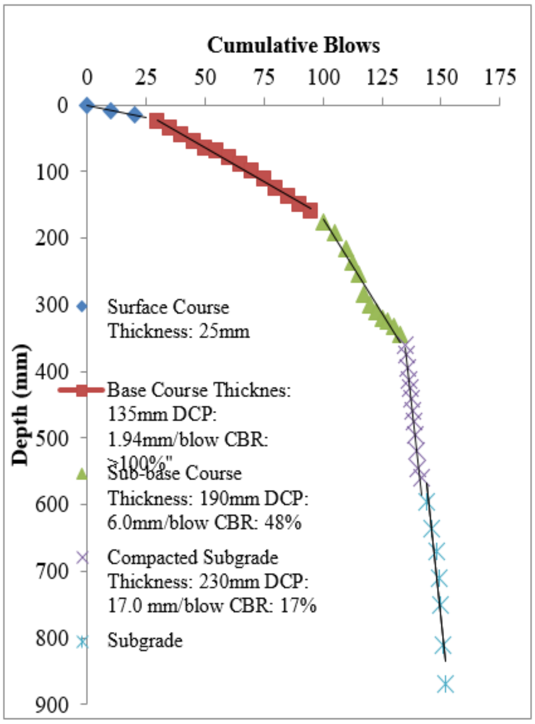

Fig. 11: DCP Test on Low Volume Road (Chandmary Road); Location: Baggona

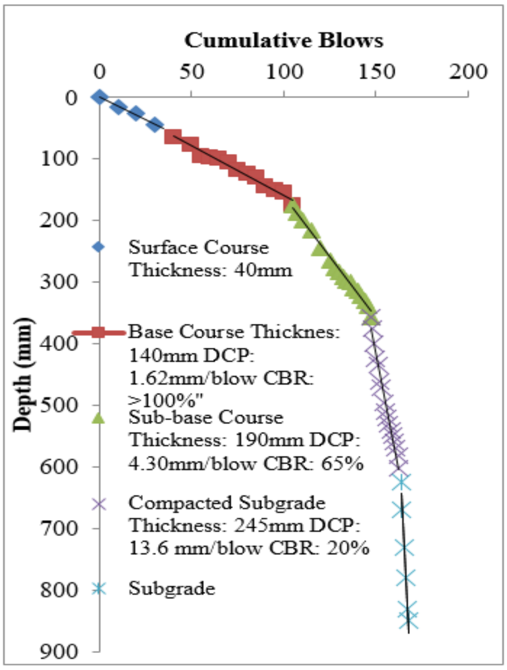

Fig. 10: DCP Test on Low Volume Road (Noapara-Raozan); Location: Noapara

Table Iv : Field Dcp Data for Different Types of Road

Type of road	Surface Course		Base Course (mm)		Sub-base Course (mm)		Total Thickness (mm)
	Thickness (mm)	Avg. Thickness (mm)	Thickness (mm)	Avg. Thickness (mm)	Thickness (mm)	Avg. Thickness (mm)	
Heavy volume	55	52≈50	245	241≈240	300	271≈270	560
	52		238		265		
	50		240		250		
Medium volume	50	45≈40	230	208≈205	290	276≈275	520
	35		185		270		
	45		215		260		
Low volume	35	35≈30	155	143≈140	160	180≈180	350
	40		140		190		
	25		135		190		

The findings from the Table IV it can be summarized below:

- For heavy volume roads, evaluated surface courses and base courses are quite similar. But sub-base courses have been found to have significant variation in different locations.
- For medium volume roads, all evaluated data for sub-base have been found to be almost similar at different locations except large variation observed in surface and base courses.
- For low volume roads, all evaluated data have been found to be almost similar to base and sub-base courses, whereas variation has been found for surface courses.
- The existing roads have been undergone a large number of load repetitions and thus the subgrades have been compacted well and exhibiting higher CBR value i.e. higher strength.

VI. LAYER THICKNESS BY COMPUTATIONAL METHOD

There are several methods for pavement design, of which Indian Road Congress (IRC) method is one of the most familiar [13]. The climatic condition of Bangladesh is quite similar to that of India. So IRC method is quite satisfactory in designing pavements for Bangladesh perspective. Using IRC method, design calculations for different category of roads have been presented in this article. Comparisons of evaluated data with IRC method and specification of Roads and Highway Department, Bangladesh have been made [14].

A) Pavement Design For Heavy Volume Road

Assuming design data for 2 lane single carriageway with Initial Daily Traffic (IDT) 1000 CVPD in both direction, vehicle growth rate 7.5%, design life of road 15 years and Vehicle Damage Factor (VDF) 2.5, cumulative number of standard axle in the design year (N) in MSA (million standard axle) can be calculated from equation (2),

$$N = \frac{365[(1+r)^{n+z}-1]}{r} \times A \times D \times F \qquad (2)$$

Where:
A = Initial traffic in the year of completion in CVPD,
D = Distribution factor of Lane,
F = VDF,
n = Design life in year and
r = Growth rate of traffic

$$N = \frac{365[(1+0.075)^{15}-1]}{0.075} \times 1000 \times 0.75 \times 2.5 = 18\ \text{MSA}$$

From the IRC design catalogswhen N is equal to 18 MSA, the different layers thickness have been presented for different CBR values in Table V.

Table V : Pavement Layer Thickness (Mm) With Variation of CBR Value

CBR	3 %	4 %	5 %	8 %
Surface course	155	145	135	120
Base course	250	250	250	250
Sub base course	380	330	300	200
Total Thickness	785	725	685	570

B) Pavement Design for Medium Volume Road

Assuming design data for 2 lanes single carriageway with IDT 700 CVPD, vehicle growth rate 5%, design life of road 15 years and VDF 2.5, then from equation 2,

$$N = \frac{365[(1+0.05)^{15}-1]}{0.05} \times 700 \times 0.75 \times 2.5$$

= 10.33 MSA ≈ 10.5 MSA

From the IRC design catalogs when N is equal to 10.5 MSA, the different layers thickness have been presented for different CBR values in Table VI.

Table VI : Pavement Layer Thickness (Mm) With Variation Of CBR Value

CBR	3%	4%	5%	8%
Surface course	130	120	110	105
Base course	250	250	250	250
Sub base course	380	330	300	200
Total Thickness	760	700	660	55

C) *Pavement Design For Low Volume Road*

Assuming design data for a1 lane single carriageway with IDT 80 CPVD, vehicle growth rate 4%, design life of road 15 years and VDF 2.5, then from Equation 2,

$$N = \frac{365[(1+0.04)^{15}-1]}{0.04} \times 80 \times 1 \times 2.5$$

$= 1.46$ MSA ≈ 1.5 MSA

From the IRC design catalogs and N is equal to 1.5 MSA, the different layers thickness have been presented for different CBR values in Table VII.

Table VII : Pavement Layer Thickness (Mm) With Variation of CBR Value

CBR	3%	4%	5%	8%
Surface course	60	60	60	60
Base course	225	225	225	225
Sub base course	335	265	215	150
Total Thickness	620	550	500	435

VII. SPECIFICATIONS FROM RHD

Roads and Highway Department, Bangladesh has been proposed some specifications for the structural design of different types of roads [15]. The design specifications for National Highway (heavy volume), Regional Highway (medium volume) and Feeder roads (low volume) have been shown below in Fig.13, Fig. 14 and Fig. 15 respectively.

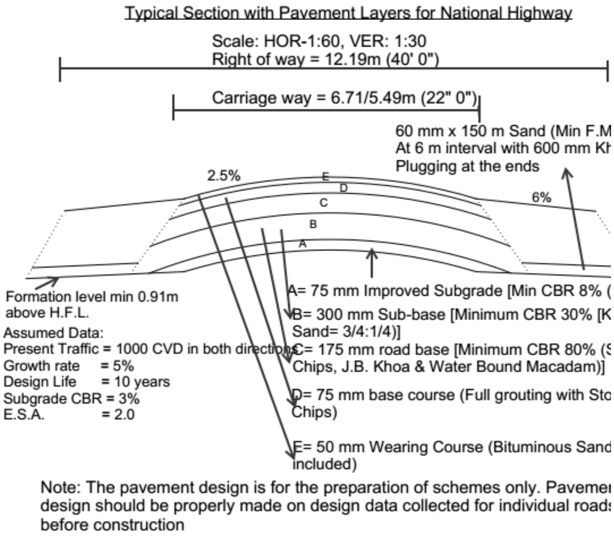

Fig. 13: Design Section of National Highway (Heavy Volume Road) [Source: RHD]

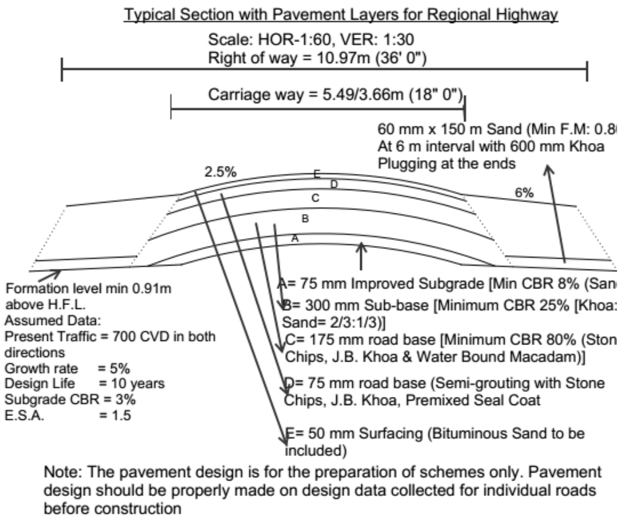

Fig. 14: Design Section of Regional Highway (Medium Volume Road) [Surce: RHD]

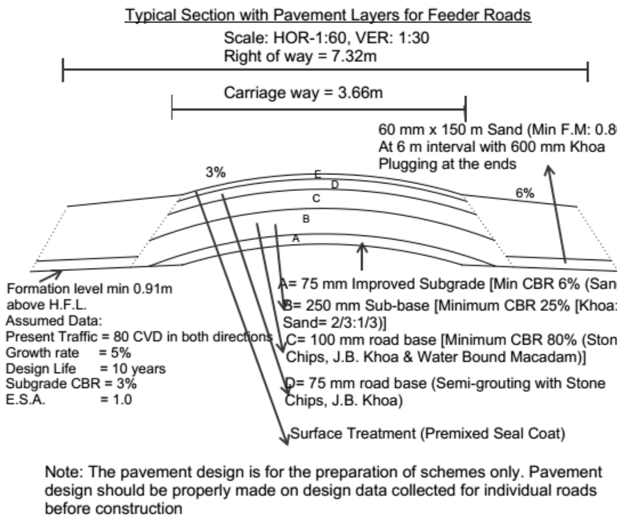

Fig. 15:Design Section of Feeder Road (Low Volume Road) [Source: RHD]

VIII. COMPARISON OF RESULTS

The values obtained from field investigation by DCP tests, computational results by IRC method and values obtained from RHD specification for different pavement layers have been presented in Table VIII.

From Table VIII, it can be found that:

- The thickness of surface courses, found by DCP tests is less than RHD specification for both medium and low volume roads except heavy volume road and significantly lower value from IRC method for heavy, medium volume and low volume roads.
- Base course is quite similar to RHD specification and IRC method for heavy volume roads, but slightly lower from both the case for medium volume roads.
- But base course largely varies from both RHD specification and IRC method for low volume road.
- Sub-base has been found lower from both RHD specification and IRC method.

Table VIII : Evaluated Dcp Results, IRC Design Data and RHD Specifications

Type of road	Thickness (mm) found by DCP test			Thickness (mm) suggested by RHD for 3% CBR			Thickness (mm) found by IRC Method for 3% CBR		
	Surface (mm)	Base (mm)	Sub-base (mm)	Surface (mm)	Base (mm)	Sub-base (mm)	Surface (mm)	Base (mm)	Sub-base (mm)
Heavy Volume	50	240	270	50	250	300	155	250	380
Medium Volume	40	205	275	50	250	300	130	250	380
Low Volume	30	140	180	50	175	250	60	225	335

IX. CONCLUSION

Bangladesh is a developing country. A huge number of pavement constructions are being run, but still, a number of roads are to be constructed. Thus considering the development from theeconomic point of view, pavements are to be constructed according to the design specifications. The present investigation can be summarized as below:

- It has been found that the evaluated data, obtained by DCP test is more or less compatible with the IRC design method and RHD specifications.
- Among the techniques available for post evaluation, the DCP is found to be an important tool for the post evaluation of a constructed road considering its simplicity, accuracy, economyand rapid evaluation techniques.
- Dynamic Cone Penetrometer (DCP)can be used as a useful device during pavement design and quality control program to check whether the design specifications have been maintained properly during the construction.

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