CORRELATION BETWEEN DYNAMIC CONE PENETROMETER INDEX (DCPI) AND RELATIVE DENSITY OF SOIL FOR A LOCALLY FABRICATED APPARATUS

A dissertation submitted in partial fulfillment of the requirement
for the award of the degree of

MASTER OF TECHNOLOGY
IN
GEOTECHNICAL ENGINEERING

Submitted by:

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CANDIDATE DECLARATION

I, Aman Middha 2k16/GTE/03, student of M.Tech. (Geotechnical Engineering), hereby declare that the project Dissertation titled "Correlation between dynamic cone penetrometer index (DCPI) and relative density of soil for a locally fabricated apparatus" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, in Geotechnical Engineering is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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CERTIFICATE

This is to certify that the work, which is being presented in this dissertation on the title "Correlation between Dynamic Cone Penetrometer Index (DCPI) and Relative Density of Soil for a locally fabricated apparatus", submitted by Mr. Aman Middha (2K16/GTE/03), a student of second year (IV Semester) M.Tech. in Geotechnical Engineering, in partial fulfillment for the award of degree of Master of Technology in Geotechnical Engineering is a record of student's work carried out and found satisfactory for submission.

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If any error comes in the report, I solely take the responsibility of all the errors.

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ABSTRACT

In this dissertation, the analysis of dynamic cone penetration test in relation to various soil parameters and properties has been evaluated. Dynamic cone penetrometer testing can be applied to the characterization of soil properties in many ways. One of the strong points in favor of the dynamic cone penetrometer device is in its ability to give a continuous record of relative soil strength/properties with depth. By plotting a graph of dynamic cone penetration index (DCPI) vs. depth for the testing area, a user can observe a profile with varying layer depths, thicknesses, and strength conditions.

In this study, an attempt is made to develop a relation between DCPI and relative density, degree of compaction, shear strength parameters, namely, angle of internal friction of soil has been obtained. For that dynamic cone penetrometer test is performed in laboratory conditions for sand filled of known relative density in a chamber. An attempt is made to establish a relation between relative density index and CBR is obtained with the help of CBR verses DCPI correlation, given by ASTM D6951/D6951M-09. Performing the dynamic cone penetrometer test and core cutter method of density measurement in field conditions does the verification of correlation.

Keywords: Dynamic cone penetrometer test, California bearing ratio, Relative density and Field density.

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List of abbreviations

Abbreviation	**Extended Form**
DCPI	Dynamic cone penetrometer index
DCP	Dynamic cone penetrometer
D_R	Relative density
E	Modulus of elasticity
G	Shear modulus
D_{10}	Particle size finer than 10%
D_{30}	Particle size finer than 30%
D_{50}	Particle size finer than 50%
D_{60}	Particle size finer than 60%
C_u	Coefficient of uniformity
C_c	Coefficient of curvature
e_{max}	Maximum void ratio
e_{min}	Minimum void ratio
e	Natural void ratio
γ_d	Dry density
$\gamma_{d\,max}$	Maximum dry density
$\gamma_{d\,min}$	Minimum dry density
I_p	Plasticity index

CHAPTER 1

INTRODUCTION

1.1. DYNAMIC CONE PENETROMETER

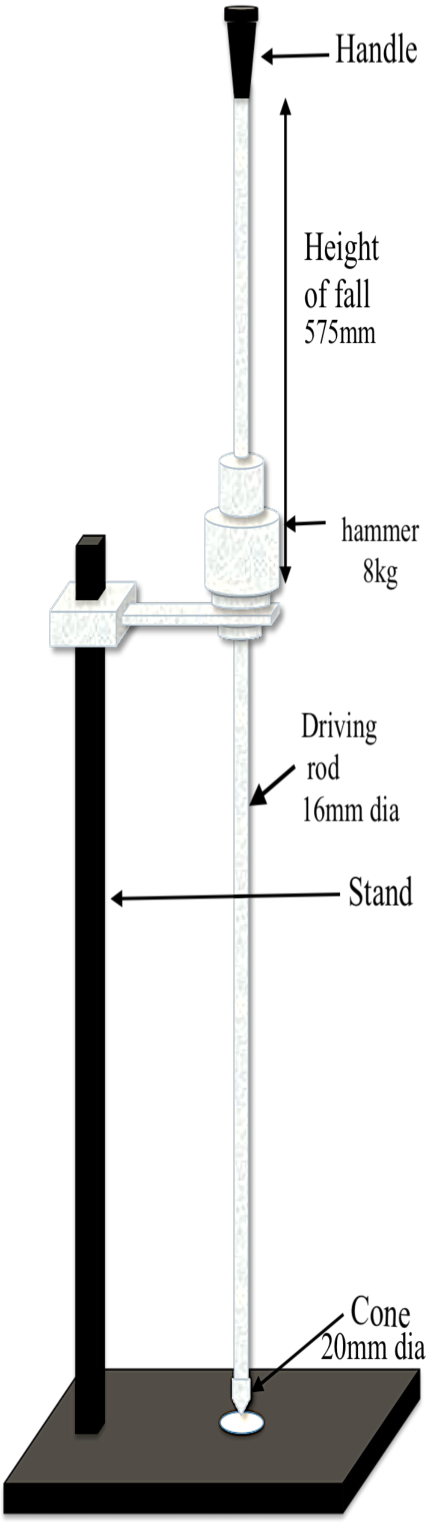
Dynamic Cone Penetrometer was first developed by Scala from Australia in 1959 as an in situ geotechnical assessment technique for evaluating the strength of base and subbase materials of new and existing flexible pavement structures (Scala 1959). This test is also used for quality control of the compaction of some type of soils. Various relationships have been developed between DCPI and other testing methods, for example, CBR and UCS tests (Scala, 1959; De Beer, 1991; Webster *et al.*, 1994 and Chen *et al.*, 1999).

The parameters of the Dynamic Cone Penetrometer, such as, drop mass, the height of fall of hammer and the cone apex angle are varied with the testing method by different investigators and organizations. Its use spreads to many countries. Due mainly to its simplicity its acceptance in the United States grew from the late 1980s (e.g., De Beer and van der Merwe, 1991; Parker, *et.al*, 1998; Burnham and Johnson, 1993, Amini 2003) until in 2003 a standard ASTM D9651- 2003 was developed for its use. There are different types of DCP equipment that have been used as summarized in Table 1.1. The different types of DCP equipment can be categorized as light dynamic cone penetrometer and the heavy-duty dynamic cone penetrometer with impact energy per blow per cone area of the order of $30kNm/m^2$ and $236kNm/m^2$ respectively for harder ground. However, the commonest type is the standard DCP with impact energy per blow per cone area of $144kNm/m^2$.

Table 1.1 Various dynamic cone penetrometer designs

DCP design	Hammer mass (kg)	Height of fall (mm)	Cone diameter (mm)	Potential Energy per drop (J)	Impact energy per blow/cone area (kNm/m^2)
Scala (1956)	8	575	20	45.1	144
Van Vuuren (1969)	10	460	20	45.1	144
ASTM D6951 (2003)	8	575	20	45.1	144
AS 1289.6.3.2 (1997)	9	510	20	45.0	143
Sowers and Hedges (1966)	6.8	508	38	33.9	30
Nguyen and Mohajerani (2012)	2.25	510	20	11.3	36
Cearns and McKenzie (1988)	63	750	44	463.1	236

The dynamic cone penetrometer test apparatus adopted worldwide, given by ASTM D6951 (2003), is locally fabricated for this study at DTU is shown in Fig. 1.1. The specifications of this apparatus are kept according to the design given by ASTM D6951 (2003), those are, a hammer of weight 8kg and height of fall of hammer 575 mm with potential energy per drop of 45.1 J. And cone used in this apparatus is 20 mm in diameter with apex angle of 60 degrees.



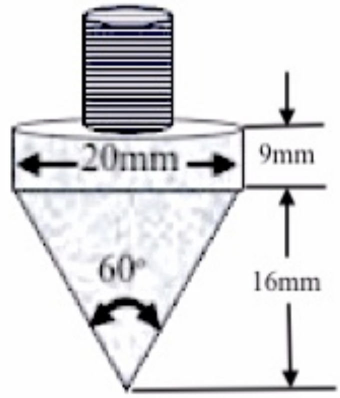


Fig. 1.1. Dynamic cone penetrometer (locally fabricated at DTU)

1.1.1. Applications of dynamic cone penetrometer

Dynamic cone penetrometer test can be used for the characterization of sub-grade and base layer material properties. One of the strong points in favour of the dynamic cone penetrometer device is in its ability to give a continuous record of relative soil strength/properties with depth. By plotting a graph of dynamic cone penetration index (DCPI) versus depth of penetration on the testing surface, layer depths, thicknesses, and strength conditions can be observed. And due to its compact and lightweight design, it can be used in confined areas such as inside buildings to evaluate foundation settlements, or used on congested sites that would prevent larger testing equipment from being used. The DCP is ideal for testing through bore holes in existing pavements. The applications of dynamic cone penetrometer test are as follows:

- Dynamic cone penetrometer test is used for evaluating the strength of base and subbase material for new and existing flexible pavements.

- The relation between dynamic cone penetration index (DCPI) and various soil properties like relative density, moisture content, the angle of internal friction, CBR, UCS, liquefaction potential, liquidity index etc. have been developed. So this test is capable of giving ideal about most of the basic engineering properties of soil.

- Preliminary Soils Surveys - DCP testing can be done during preliminary soil investigations to quickly map out areas of weak material, change in strata, groundwater level.

- Construction Control - The DCP is an ideal too1 for monitoring all aspects of the construction of a pavement sub-grade and base. It can be used to verify the level and uniformity of compaction over a project. It can also be used to define problem areas that develop due to unavoidable soil conditions.

1.1.2. Factors affecting DCPI

- Alignment of dynamic cone penetrometer rod – While testing the rod of the dynamic cone penetrometer should be straight if the penetrating rod is tilted during testing, skin friction will increase for the rod due to which rate of penetration decrease and DCPI will be observed lower than the actual.

- The depth of testing – Dynamic cone penetrometer test results are sensitive to the depth of testing. When the bottom rod of the DCP used is longer than the standard penetrating rod, vertical confinement and skin friction around the rod increases, which leads to the lower value of observed DCPI.

- Damaged cone tip – If the cone tip of the DCP is damaged it will result for higher friction to cone to penetrate in the soil, which gives incorrect test results.

- Hammer weight – If the weight of the hammer is more than the specified weight then the rate of penetration will increase and vice versa.

- Height of fall of hammer – During dynamic cone penetrometer testing, for each blow, the hammer weight should be lifted to the top restraint plate and freely dropped. During testing, if the hammer is not lifted to the standard given height, the impulsive force exerted by the cone to the soil will reduce and the values of penetration decrease.

- Cone apex angle – The penetration rate will be significantly affected by change of the cone apex angle from 30° to 120° since the upward frictional force on a cone surface with a 120° apex angle will be greater than that of with a 30° apex angle cone.

- Moisture content – DCP test results are very sensitive to variations in water content present in the test materials. As the water content increases, the penetration rate of DCP also increases and vice versa.

- Material composition – DCPI varies with test material composition, soil class, the coefficient of curvature and uniformity, density of the layer material and plasticity of the soil.

1.2. RELATIVE DENSITY

Relative density and compaction percentage are commonly used for evaluating the state of compactness of a given soil mass. The engineering properties such as shear strength, compressibility and permeability of a given soil depend on the level of compaction of the soil. Relative density or density index is the ratio of the difference between the void ratios of a cohesionless soil in its loosest state and existing natural state to the difference between its void ratio in the loosest and densest states. The relative density, denoted by D_r, has been presented as a function of the void ratio as,

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \tag{1.1}$$

And presented as a function of the dry density as,

$$D_r = \frac{1/(\gamma_d)_{min} - 1/\gamma_d}{1/(\gamma_d)_{min} - 1/(\gamma_d)_{max}} \tag{1.2}$$

Where, e = void ratio of cohesionless soil in its natural state

e_{min} = void ratio of cohesionless soil in its densest state

e_{max} = void ratio of cohesionless soil in its loosest state

γ_d = density of soil in its natural state

$(\gamma_d)_{max}$ = density of soil in its densest state

$(\gamma_d)_{min}$ = density of soil in its loosest state

1.2.1. Measurement of $(\gamma_d)_{min}$

The density of soil in its loosest state is obtained by light compaction of soil in a mould. Oven dried soil should be placed as loosely as possible in the mould by pouring the soil through the spout in a steady stream. Size of spout and mould is selected as per the Table 1.2, given by IS 2720 part 14. The spout should be adjusted so that the height of free fall of soil is always 25 mm from the top layer of soil in the mould.

Table 1.2 Pouring device to be used

Maximum size of soil particle (mm)	Mass of soil sample required (kg)	Pouring device to be used	Size of mould to be used (mm^2)
75*	45	Shovel	$15*10^5$
37.5*	12	Scoop	$3*10^5$
19*	12	Scoop	$3*10^5$
9.5*	12	25mm diameter spout	$3*10^5$
4.75*	12	12 mm diameter spout	$3*10^5$
4.75**	12	4.75 mm sieve	$3*10^5$

* IS 2720 part 14

** Used in this study

1.2.2. Measurement of $(\gamma_d)_{max}$

The maximum density of sand is obtained by vibrating table method. Oven dried sample of sand is filled in the mould as filled in minimum density test and then mould is fixed on the vibrating deck with nut and bolts. This assembly is allowed to vibrations for 8 minutes with surcharge weight over it.

For maintaining the relative density up to 70% air pulviation method or sand draining method is suitable. For obtaining relative density more than that air pulviation method is not suitable so mechanical vibration is suggested.

CHAPTER 2

LITERATURE REVIEW

- Dynamic Cone Penetrometer was first developed by Scala from Australia in 1959 as an in situ geotechnical assessment technique for evaluating the strength of base and subbase materials of new and existing flexible pavement structures (Scala 1959). This test is also used for quality control of the compaction of some type of soils.

- Kleyn and Savage (1982) investigated the effects of the moisture content of soil, gradation of soil, density and plasticity of soils and they gave the conclusion that all the material properties influence the DCPI.

- Parker *et al.* (1998) proposed an idea for an automated dynamic cone penetrometer. Basically, this penetrometer is a vertical frame with wheels for raising and releasing the hammer. The data of penetration is captured and sent to a computer.

- Fumio *et al.* (2004) also developed an automated data collection system for a portable DCP with a hammer mass of 3 kg. But its use was limited to field surveys only.

- Trivedi *et al.* (2004) studied the cone resistance on compacted ash fills. In this study, the static cone penetration test results analysed at various combinations of stress level and relative density indicated the need for a new scheme for interpretation of the behaviour of ash fills on the basis of relative dilatancy of the ash. The resistance to penetration of the standard cone was interpreted at varying depths on ash fill compacted at varying relative densities. Correlations are suggested to estimate bearing capacity and settlement characteristics of coal ash on the basis of cone penetration test results for direct geotechnical design.

- Mohammadi *et al.* (2008) used the dynamic cone penetrometer for the evaluation of the engineering properties of sandy soil. To validation of results laboratory, direct shear test and plate load test were used as reference tests. The mould used to perform dynamic cone penetrometer is 700 mm in diameter and depth. Based on the experimental results the relationship between dynamic cone penetration index (DCPI), relative density (D_r), modulus of elasticity (E), shear modulus (G), modulus of subgrade reaction (K_s) and the friction angle of soil were obtained.

- Sun *et al.* (2011) done energy based comparison between a dynamic cone penetrometer and a motor operated static cone penetrometer. The base of the study was uncertainty between the simplified Dutch formula and the complete Dutch formula as observed that both formulae considerably extenuated the energy loss arisen from strikes, which was equivalent to an overestimation of the calculated penetration force. On the basis of this study, it was recommended that the shaft vibration should also be taken into account for correcting each formula.

- Bao Thach Nguyen *et al.* (2012) The effects of vertical confinement from the CBR mould on the dynamic cone penetrometer index is studied by Bao Thach Nguyen *et al.* (2012). And the development of a lightweight DCP that can be used in the laboratory as well as in field conditions with similar results.

- Alam *et al.* (2012) developed a correlation between dynamic cone penetrometer and relative density of sand. Sand cone method of field density measurement is used to verify the correlations. And it is concluded that relation developed by them can be used to determine the relative density of sand fills.

- Nguyen and Mohajerani (2012) studied the effect of vertical confinement from the CBR mould on the dynamic cone penetrometer index (DCPI) and developed a new lightweight DCP with a hammer mass of 2.25kg that can be used in the laboratory as well as in the field conditions with similar results.

- Paniagua et al. (2013) Laboratory-scale cone penetration tests (CPTs) in silt were performed with x-ray micro tomography and analysed with three-dimensional digital image correlation. During insertion of the instrumented probe, these tools allow the identification of a contractant bulb of silt close to the tip of the probe surrounded by a larger bulb of dilating material. The results obtained (in particular the failure mechanisms observed) shed new light on the mechanics of cone penetration in silt and consequently reflect on the interpretation of in situ CPTs.

- Patel *et al.* (2013) worked for the prediction of subgrade parameters from dynamic cone penetrometer index, modified liquid limit and moisture content. Multiple variable regression analysis (MLR) is used to predict the California bearing ratio (CBR), coefficient of subgrade reaction K- value, unconfined compressive strength (UCS), field dry density from dynamic cone penetrometer, modified liquid limit and moisture content of subgrade. The empirical correlations developed from multiple variable regression analysis from test results obtained from experimental investigation of the soil sample taken from different locations of Gujarat region in India. The formulations are validated using other sets of tests data. The developed empirical correlations may be useful in the quick determination of strength parameters of subgrade from physical properties of subgrade and Dynamic Cone Penetrometer. Results obtained from validation of these developed empirical correlations proves their reliability and accuracy to perform subgrade strength evaluation for both rigid and flexible pavement.

- Lee *et al.* (2013) estimated the engineering properties of weathered sandy soils in Korea by soil stiffness gauge (SSG) and dynamic cone penetrometer (DCP) tests. Laboratory tests were conducted by nondestructive and penetration methods for in-situ estimation of the engineering properties. Soil Stiffness Gauge (SSG), Dynamic Cone Penetrometer (DCP), Plate Load Test (PLT), and California Bearing Ratio (CBR) are performed with three uncemented soil groups, poorly graded sand (SP), silty sand (SM), and well-graded sand with silt (SW-SM), that were compacted in a large container. Effect of water content is observed on dynamic cone penetration index (DCPI) and the modulus of elasticity obtained from the SSG test (E_{SSG}) for SM and SW-SM soils, whereon effect is observed on the SP sample. The relationship obtained between CBR and DCPI showed a similar trend although at a given DCPI as compared with literature. Elastic moduli, E_{SSG} is linearly proportional to E_{PLT} and is 1.7 times larger than E_{PLT}. For all three soils considered, the void ratio (e) is linearly proportional to the DCPI divided by the median particle size (DCPI / D_{50}) while the angle of internal friction is inversely proportional to DCPI / D_{50}. The dry density of compacted soil appears to increase nonlinearly with the increase in $E_{SSG} \cdot D_{50}/e$. It is, therefore, concluded that E_{SSG}, DCPI, and D_{50} can provide complementary information for the estimation of void ratio and dry density.

- Nguyen and Mohajerani (2014) used a lightweight cone penetrometer with a hammer mass of 2.25 kg in a CBR mould in the laboratory as well as in the field to evaluate the CBR of fine-grained subgrade soils. And given a relation between CBR values and dynamic lightweight cone penetrometer index. There is a consistent and strong log-log correlation between the CBR and the dynamic lightweight cone penetration index (DLPI) for each experimental soil with the coefficient of determination, R^2 =0.85. And the relation is given as,

  $$\log[CBR] = 1.684 - 1.050 \times \log\,[DLPI]. \qquad (2.1)$$

  The results show that the CBR values drop and DLPI values increase with increase in moisture content from optimum to soaked conditions.

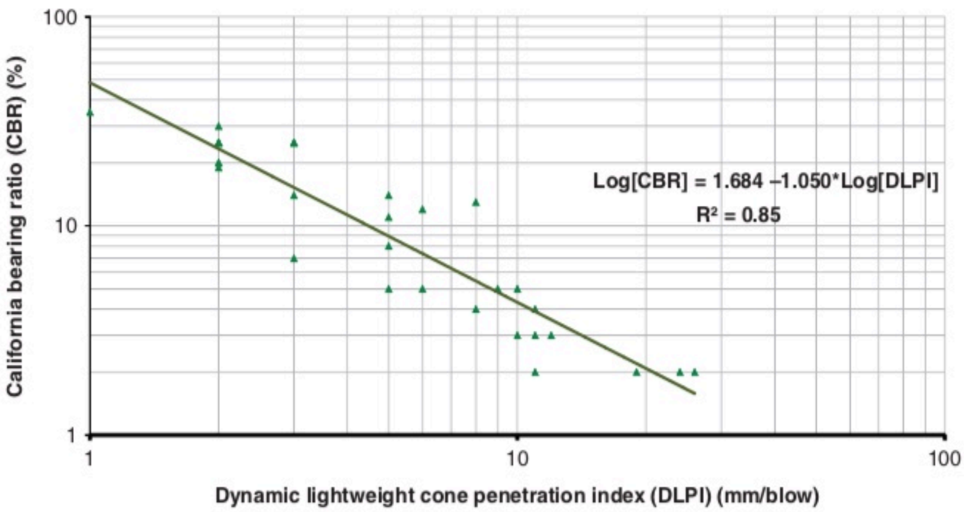


Fig.2.1 CBR vs. DLPI (Nguyen and Mohajerani 2014)

- D6951/D6951M – 09 (2015) Standard test methods for use of the dynamic cone penetrometer in shallow pavement applications, had given the specification for the dynamic cone penetrometer test apparatus and procedure to perform the test in the field and also the relation between in-situ CBR and DCPI as,

$$CBR = 292/(DCP^{1.12})\ \text{mm/blow} \quad (2.2)$$

$$CBR = 1/(0.017019 \times DCP)^2\ \text{mm/blow} \quad (2.3)$$

$$CBR = 1/(0.002871 \times DCP) \quad (2.4)$$

Equation 2.2 is used for all soils except for CL soils below CBR 10 and CH soils. Equation 2.3 is used for CL soils with CBR < 10 and equation 2.4 is used for CH soils.

Extensive research work has been done on the in-situ DCPI and CBR and a strong relation in both is reported by various researchers (e.g., Van Vuuren 1969, Kleyn 1975, Smith and Pratt 1983, Livnch 1987, Harison 1989, Livench *et al.* 1992, Coonse 1999, Gabr *et al.* 2000) as follows:

Table 2.1 CBR vs DCPI

References	Correlation equation	Testing conditions	Coefficient of determination
Kleyn (1975)	log(CBR) = 2.620 − 1.270 × log(DCPI)	CBR: Lab, DCP: Field	Not available
Smith and Pratt (1983)	log(CBR) = 2.555 − 1.145 × log(DCPI)	CBR: Lab, DCP: Field	0.85
Harison (1989)	log(CBR) = 2.560 − 1.160 × log(DCPI)	CBR: Lab, DCP: Field	0.97
Livneh (1987)	log(CBR) = 2.560 − 1.160 × log(DCPI)	CBR: Lab, DCP: Field	0.93
Livneh *et al.* (1992)	log(CBR) = 2.450 − 1.120 × log(DCPI)	CBR: Lab & Field, DCP: Field	Not available
Coonse (1999)	log(CBR) = 2.530 − 1.140 × log(DCPI)	CBR: Lab, DCP: Field	Not available
Gabr *et al.* (2000)	log(CBR) = 1.550 − 0.550 × log(DCPI)	CBR: Lab, DCP: Field	Not available

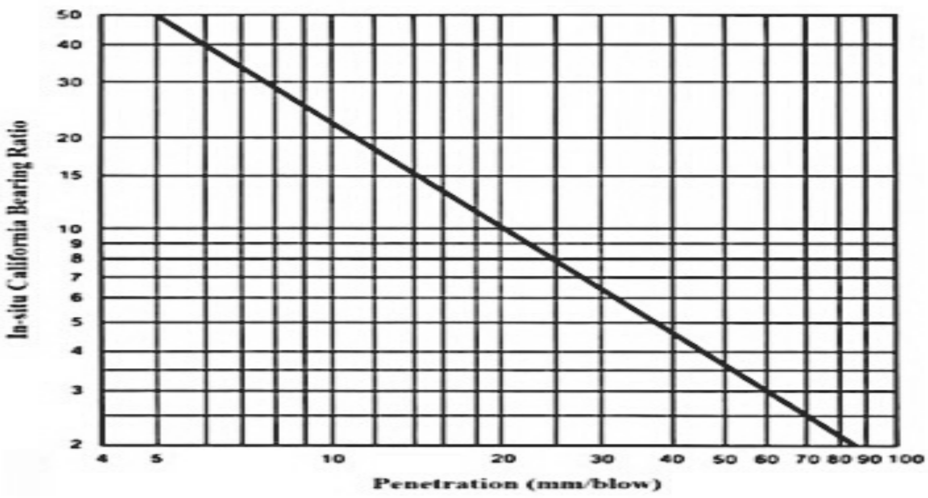


Fig. 2.2 In-situ CBR vs Penetration (mm/blow) (Nguyen and Mohajerani 2014)

Based on previous studies, tabulated as above a better correlation is given as,

$$\log[CBR] = a + b \times \log[DCPI] \quad (2.5)$$

where CBR is measured in percentage, DCPI is measured in mm/blow, constant 'a' varies from 1.55 to 2.70 and constant 'b' various from -1.27 to -0.55.

- Hashemi et al. (2016) presented a new method for the assessment of liquefaction potential, using in-situ dynamic cone penetrometer test. In this study liquefaction potential of soil from six different sites was investigated using dynamic cone penetrometer test and standard penetration test. The results of DCP test to evaluate the liquefaction potential index (LPI), as a new method, is compared with the standard penetration test results. The results showed that the DCP is equally capable as the standard penetration test in the evaluation the liquefaction potential.

- Ampadu *et al.* (2016) studied the effect of horizontal confinement of mould on DCPI during the DCP test determined at the optimum moisture content for the lateritic-clayey sand. In this study, seven moulds 100 mm to 600 mm diameter are used at compaction level of 80%, 90% and 100% of modified Proctor maximum dry density. This study represents the correlation parameter for the ratio of mould to cone diameter varying from 5 to 30. Based on the results, the study proposed a preliminary procedure to drive the in-situ correlation equation from in-mould laboratory test.

- Hrubesova et al. (2016) described the experimental work in the field of evaluation of liquid limit. Two basic methods were used for the evaluation of the liquid limit – Casagrande percussion (cup) method and cone penetrometer method. Two approaches were applied to the evaluation of liquid limit based on cone penetrometer test (30 °/80 g cone) – standard method assuming 20 mm penetration at the liquid limit and new calibration line for the cone penetrometer liquid limit - NCCLL (Mohajerani). Experimentally obtained calibration line assumes the influence of depth of cone penetration at the liquid limit on undrained shear strength, which is not unique for all types of soils. Presented results of laboratory tests show, that bentonite liquid limit based on the standard cone penetration test (using 20 mm penetration) is significantly lower in comparison with Casagrande liquid limit. On the other hand, it verified very significant consistency of Casagrande liquid limit and liquid limit based on NCCLL (evaluated depth of penetration 29 mm).

- Beckett *et al.* (2017) evaluated the dynamic cone penetrometer to detect compaction in ripped soils. In this study evaluation of ability of the "PANDA 2" dynamic cone penetrometer (90° cone angle, projected cone area 200 mm^2, Φ16 mm head, Φ14 mm shaft) to detect compaction in ripped soils after the passage of a Massey Ferguson 4 tonne tractor, which was typical of vehicles used at the test site. In this study two sites of contrasting soil types were identified which had previously been ripped and left fallow and untrafficked for several years. Penetration resistance was measured along a high-resolution grid prior to trafficking and after one and five vehicle passes and compared to results from trial pits. Based on the results of the study, dynamic cone penetrometer is not recommended to monitor compaction in ripped soils for the weight of vehicles used in this study but the device may give better results when examined for the passage of heavier vehicles.

CHAPTER 3

MATERIALS AND METHODS

3.1. SOIL SAMPLE

Two soil samples are used in this study, properties of which are tabulated as,

Table 3.1 Properties of soil used in study

Properties	**Soil A**	**Soil B**
Specific gravity	2.597	2.63
Color	Light brown	Grey
D_{10} mm	0.104	0.276
D_{30} mm	0.175	0.614
D_{50} mm	0.254	0.782
D_{60} mm	0.291	0.865
Maximum void ratio, e_{max}	0.790	0.708
Minimum void ratio, e_{min}	0.633	0.548
Maximum density, γ_{dmax} (kN/m^3)	15.60	16.45
Minimum density, $\gamma_{d\,min}$ (kN/m^3)	14.23	14.91
Classification	SP $C_U = 2.798$ $C_C = 1.012$	SP $C_U = 3.134$ $C_C = 1.579$

Table 3.2 Particle size distribution of soil A

Sieve Size	Weight retained (gm)	% weight retained	% cumulative weight retained	% finer
4.75mm	0	0	0	100
2.36mm	9	0.45	0.45	99.55
1.18mm	29	1.45	1.9	98.1
600 µ	26	1.3	3.2	96.8
425 µ	13	0.65	3.85	96.15
212 µ	1150	57.5	61.35	38.65
150 µ	288	14.4	75.75	24.25
75 µ	460	23	98.75	1.25
Pan	25	1.25	100	0

Table 3.3 Particle size distribution of soil B

Sieve Size	Weight retained (gm)	% weight retained	% cumulative weight retained	% finer
4.75mm	0	0	0	100
2.36mm	19	0.95	0.95	99.05
1.18mm	31	1.55	2.5	97.5
600 µ	1383	69.15	71.65	28.35
425 µ	57	2.85	74.5	25.5
212 µ	443	22.15	96.65	3.35
150 µ	26	1.3	97.95	2.05
75 µ	34	1.7	99.65	0.35
Pan	7	0.35	100	0

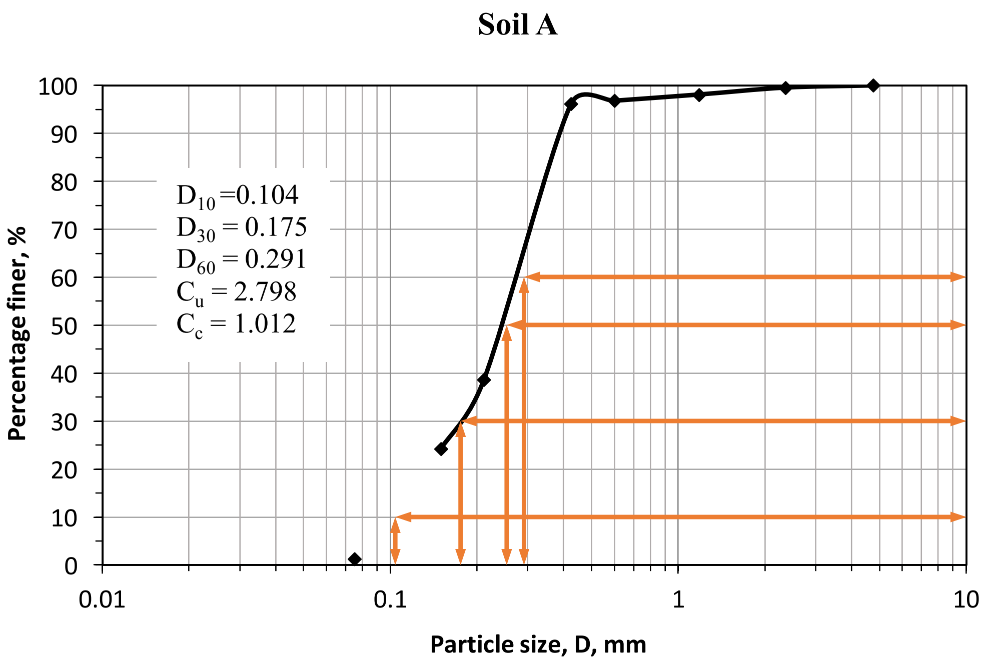


Fig. 3.1 Particle size distribution curve of soil A

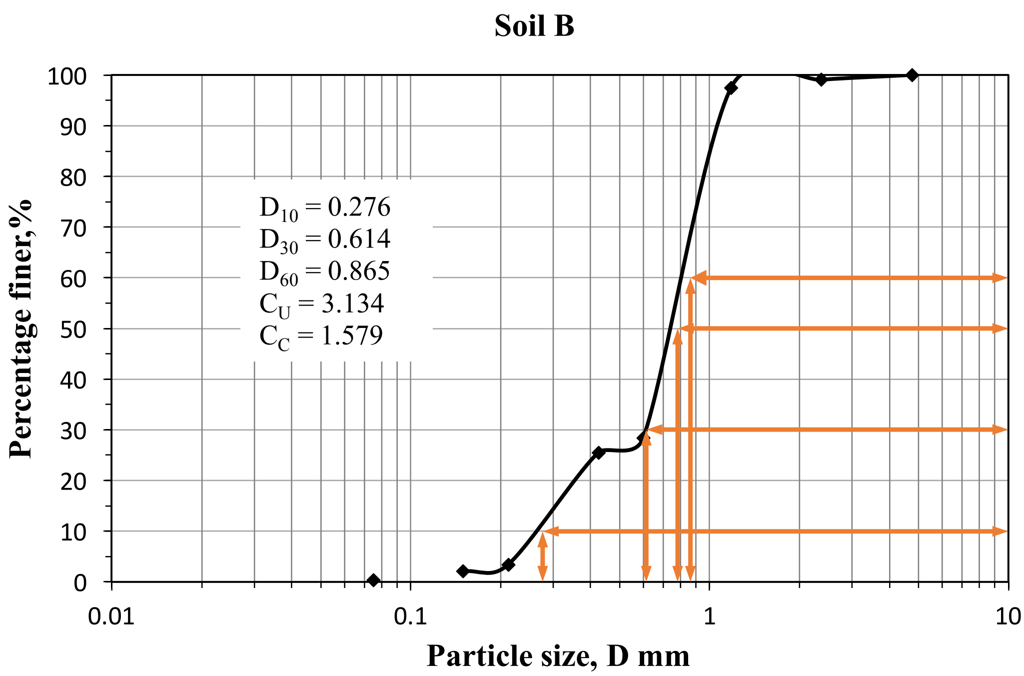


Fig. 3.2 Particle size distribution curve of soil B

3.2. AIR PLUVIATION

Air pulviation method is widely adopted for the preparation of large and uniform sand beds of required densities for laboratory studies to simulate in-situ conditions. The relative density obtained by air pulviation depends on deposition intensity uniformity of the sand rain, the height of fall of sand and particle size characteristics. Deposition intensity is the mass of soil falling in the mould per unit area per unit time. Air pluviation method is used to find the relation between height of fall and relative density of sand. Sand samples are allowed to fall into the mould of size 3000 cm^3 through a sieve of 4.75mm size from different heights. The density of sand in each case is measured with respect to the height of fall of sand. The relation between the height of fall of sand and relative density is shown in Fig. 3.3, which is used to maintain required relative density in the mould for testing.

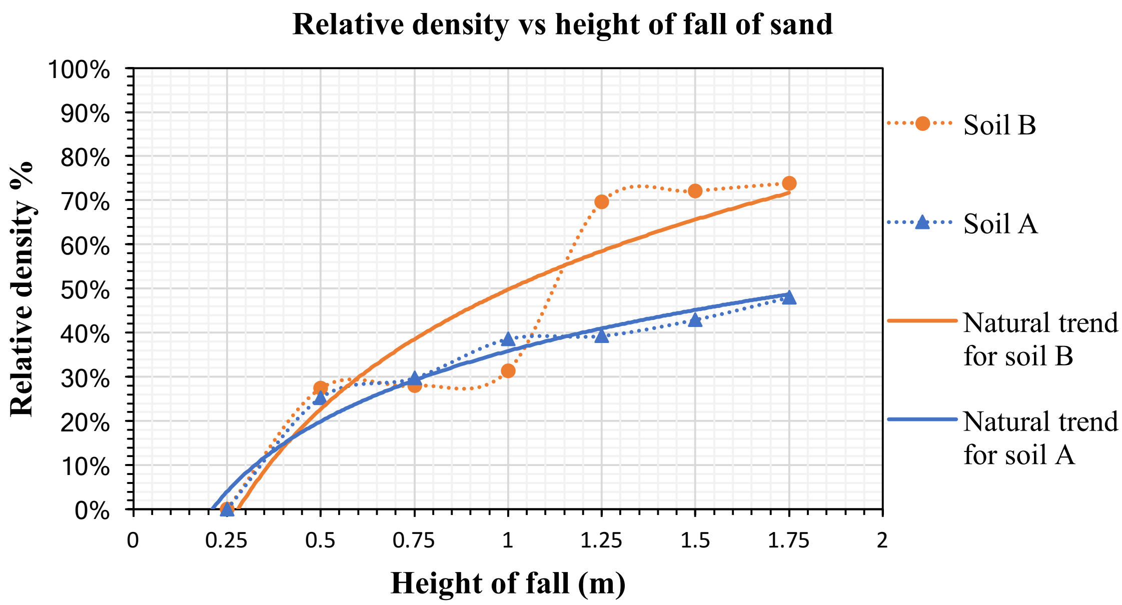


Fig. 3.3 Height of fall vs relative density

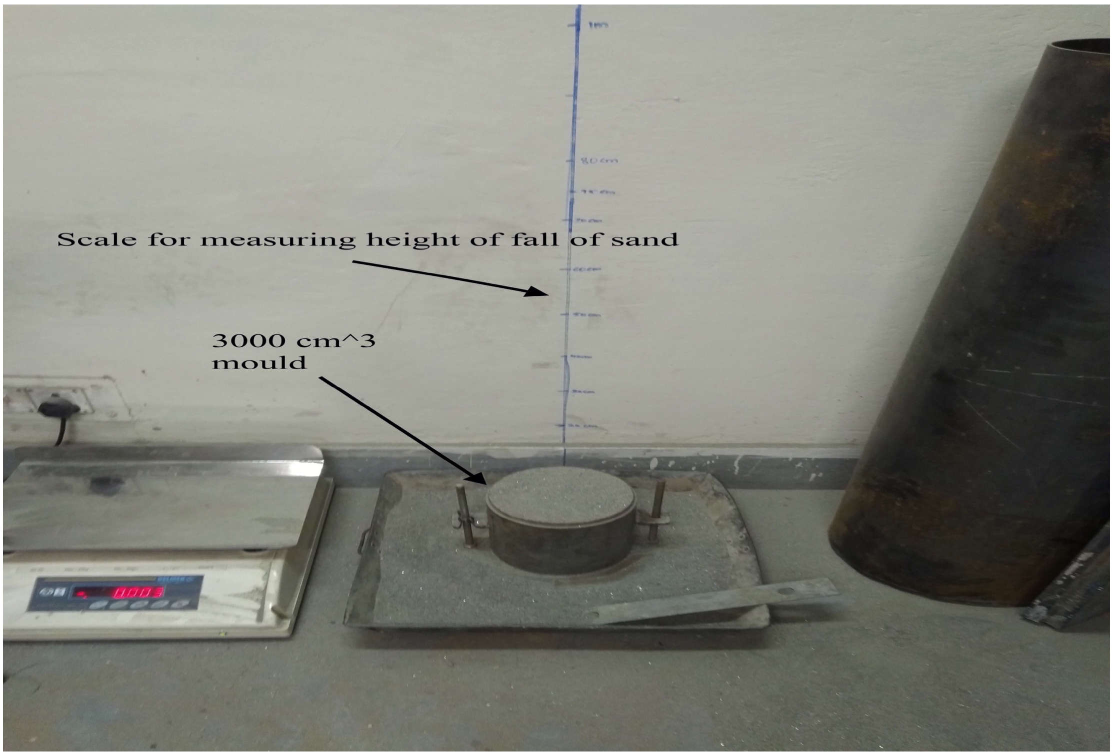


Fig. 3.4 Apparatus for the height of fall vs relative density

3.3. IN MOULD SAMPLE PREPARATIONS

In this study for developing a relationship between relative density and dynamic cone penetrometer index, a mould of size 300 mm diameter and 1000 mm depth is used. Soil samples are filled in this mould at different relative densities and DCP test is performed at different density for both the samples. Density for both the samples in this mould is maintained by air pulviation technique and manual compaction and vibration method. The relationship of the height of fall of soil with the relative density is developed which is shown in fig. 3.3. For soil A relative density up to 50% and for soil B relative density up to 75% can be maintained by air pulviation technique.

For maintaining relative density more than that in the mould, height of mould is divided into five equal parts and marked on the inner side of mould. The soil is weighted according to the density required and filled in the layers uniformly and compacted using rammer. The number of blows required to fill the first portion is counted and other four layers are filled accordingly to maintain the required density in the mould.

3.4. DYNAMIC CONE PENETRATION TESTING

After preparing the sample of required density in the mould top surface of the soil is levelled and dynamic cone penetration apparatus assembly is placed over the centre of the mould. The penetration reading for self-weight of the apparatus is recorded as zero-error reading. The rod is held vertical and the 8kg hammer is raised over the full height of 575 mm and allowed to fall freely onto the anvil to drive the 20mm diameter cone through the compacted sample. The penetration is recorded for each blow. To obtain the dynamic cone penetration index the cumulative penetration values are plotted against the number of blows, the gradient of which gives the DCPI, or it can be calculated by the ratio of total penetration due to dynamic action of the hammer (minus zero error reading) and total no of blows (Mukesh A. Patel 2013). The test is repeated on both the soil samples for different compactions levels and a relation between DCPI vs relative density is observed.

$$\mathrm{DCPI} = \frac{\text{Total penetration}}{\text{no.of blows}} \tag{3.1}$$

At relative-density less than 50% penetration resistance offered by the sand to the dynamic cone penetrometer is negligible. The levels of compaction used to develop the relation are taken more than 50%. And achieving relative density of 100% in the mould by manual compaction is difficult. Considering all the practical factors, the test is performed on soil samples having a relative density of 70%, 80% and 90%.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. LABORATORY TEST RESULTS FOR DCPI VS RELATIVE DENSITY

4.1.1. DCPI at relative density of 70% for soil A

Table 4.1 DCPT results for soil A at relative density of 70%

No. of blows	Penetration (mm)	Penetration per blow (mm)	Average penetration per 5 blows (mm)
0	62	-	
1	127	65	34.2
2	159	32	
3	185	26	
4	210	25	
5	233	23	
6	254	21	17.4
7	273	19	
8	289	16	
9	305	16	
10	320	15	
11	333	13	12.2
12	346	13	
13	358	12	
14	370	12	
15	381	11	
16	393	12	12
17	405	12	
18	417	12	
$\text{DCPI} = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{355}{20} = 19.72\,\frac{\text{mm}}{\text{blow}}$			

4.1.2. DCPI at relative density of 80% for soil A

Table 4.2 DCPT results for soil A at relative density of 80%

No. of blows	Penetration (mm)	Penetration per blow (mm)	Average penetration per 5 blows (mm)
0	85	-	
1	125	40	27
2	152	27	
3	176	24	
4	199	23	
5	220	21	
6	241	21	18
7	260	19	
8	278	18	
9	295	17	
10	310	15	
11	326	16	13.6
12	340	14	
13	354	14	
14	366	12	
15	378	12	
16	389	11	11.5
17	399	10	
$\mathrm{DCPI} = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{314}{17} = 18.47 \frac{\text{mm}}{\text{blow}}$			

4.1.3. DCPI at relative density of 90% for soil A

Table 4.3 DCPT results for soil A at relative density of 90%

No. of blows	Penetration (mm)	Penetration per blow (mm)	Average penetration per 5 blows (mm)
0	58	-	
1	117	59	27.8
2	138	21	
3	159	21	
4	178	19	
5	197	19	
6	214	17	17.6
7	233	19	
8	250	17	
9	268	18	
10	285	17	
11	300	15	14.2
12	316	16	
13	331	15	
14	344	13	
15	356	12	
16	368	12	9.6
17	378	10	
18	387	9	
19	396	9	
20	404	8	
$\mathrm{DCPI} = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{346}{20} = 17.3\,\frac{\text{mm}}{\text{blow}}$			

4.1.4. DCPI at relative density of 70% for soil B

Table 4.4 DCPT results for soil B at relative density of 70%

No. of blows	Penetration (mm)	Penetration per blow (mm)	Average penetration per 5 blows (mm)
0	73	-	
1	129	56	28.2
2	158	29	
3	183	25	
4	205	22	
5	214	09	
6	240	26	16
7	255	15	
8	268	13	
9	282	14	
10	294	12	
11	307	13	11.6
12	319	12	
13	331	12	
14	341	10	
15	352	11	
16	363	11	11.6
17	376	13	
18	386	10	
19	398	12	
20	410	12	
$\text{DCPI} = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{337}{20} = 16.8\,\frac{\text{mm}}{\text{blow}}$			

4.1.5. DCPI at relative density of 80% for soil B

Table 4.5 DCPT results for soil B at relative density of 80%

No. of blows	Penetration (mm)	Penetration per blow (mm)	Average penetration per 5 blows (mm)
0	63	-	
1	101	38	25.8
2	128	27	
3	151	23	
4	172	21	
5	192	20	
6	210	18	16.2
7	226	16	
8	243	17	
9	258	15	
10	273	15	
11	287	14	13.8
12	303	16	
13	316	13	
14	330	14	
15	342	12	
16	354	12	11
17	366	12	
18	377	11	
19	387	10	
20	397	10	

$$\text{DCPI} = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{334}{20} = 16.7\,\frac{\text{mm}}{\text{blow}}$$

4.1.6. DCPI at relative density of 90% for soil B

Table 4.6 DCPT results for soil B at relative density of 90%

No. of blows	Penetration (mm)	Penetration per blow (mm)	Average penetration per 5 blows (mm)
0	87	-	
1	122	35	24.4
2	147	25	
3	168	21	
4	189	21	
5	209	20	
6	226	17	15.8
7	240	14	
8	258	18	
9	273	15	
10	288	15	
11	303	15	14.4
12	318	15	
13	334	16	
14	347	13	
15	360	13	
16	374	14	11.2
17	386	12	
18	397	11	
19	407	10	
20	416	09	
$\mathrm{DCPI} = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{329}{20} = 16.45\,\frac{\text{mm}}{\text{blow}}$			

4.2. FIELD TEST RESULTS

Dynamic cone penetrometer test is performed at the different locations in Delhi Technological University campus for the verification of experimental results obtained in laboratory. The test locations are selected on basis of availability of soil similar to the soil used in laboratory tests.

Dynamic cone penetrometer test is conducted on two sites and natural density of soil in field for both the sites is measured by core cutter method. Using the relation developed by laboratory test, level of compaction of both the soils is estimated and compared with the field results. Properties of soil at site-I are similar to that of Soil A and of soil at site-II are similar to Soil B used in this study.

4.2.1. DCP test results for Site I (kabaddi court)

Table 4.7 DCP test results for site-I

No. of blows	Penetration (mm)	Penetration per blow (mm)	Penetration per 5 blows (mm)
0	19	-	
1	54	35	44.6
2	89	35	
3	128	39	
4	179	51	
5	242	63	
6	275	33	28
7	300	25	
8	326	26	
9	354	28	
10	382	28	
11	405	23	17.8
12	423	18	
13	439	16	

14	454	15	
15	471	17	
16	487	16	14.8
17	504	17	
18	519	15	
19	533	14	
20	545	12	
$DCPI = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{526}{20} = 26.3\ \frac{mm}{blow}$			

4.2.2. DCP test result at site-II (near Kalpana Chawla girls hostel)

Table 4.8 DCP test results at site-II

No. of blows	**Penetration (mm)**	**Penetration per blow (mm)**	**Penetration per 5 blows (mm)**
0	50	-	
1	120	70	38
2	164	44	
3	190	26	
4	211	21	
5	240	29	
6	266	26	24.84
7	290	24	
8	312	22	
9	337	27	
10	365	28	
11	387	22	
$DCPI = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{337}{10} = 33.7\ \frac{mm}{blow}$			

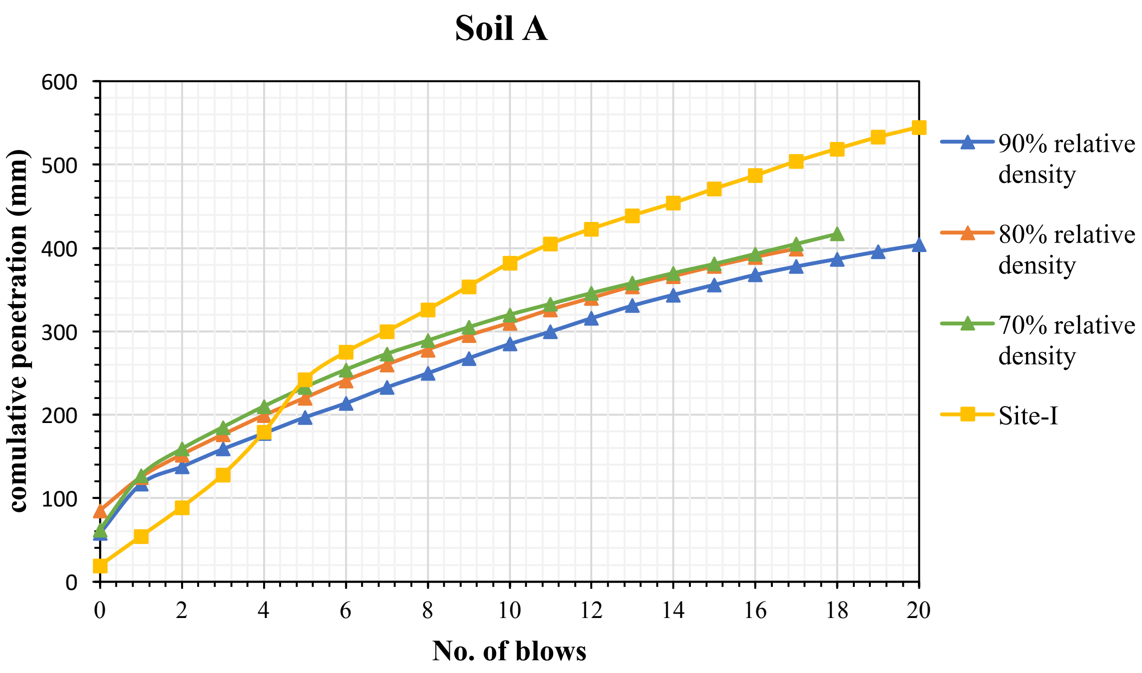


Fig. 4.1 Cumulative penetration vs no. of blows for soil A

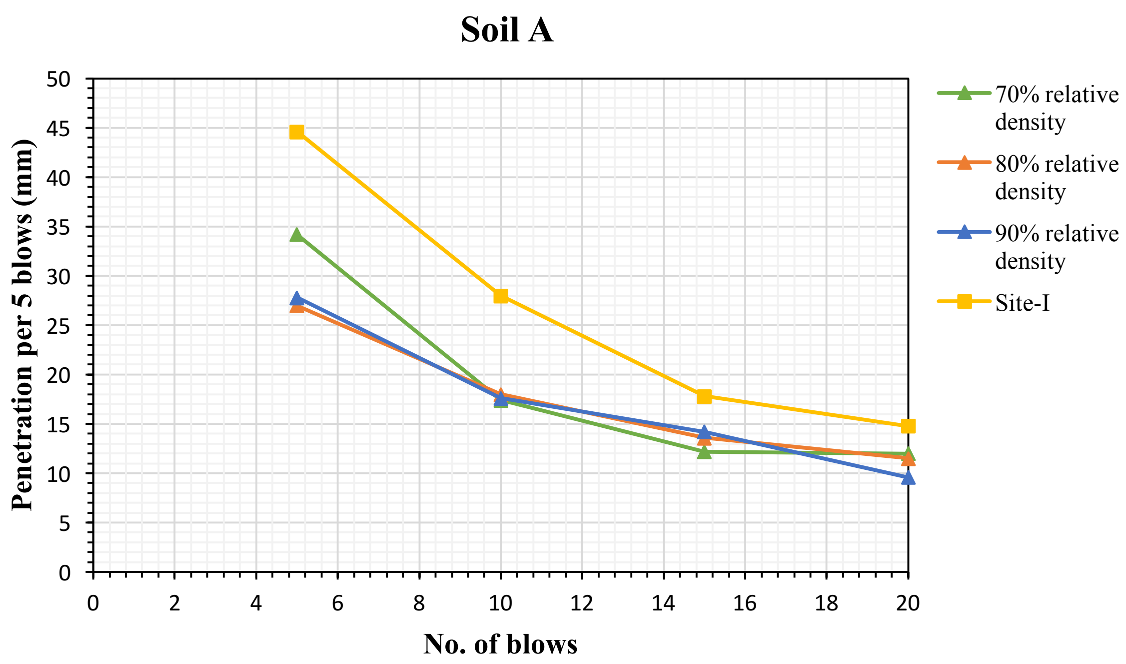


Fig. 4.2 Penetration per 5 blows for soil A

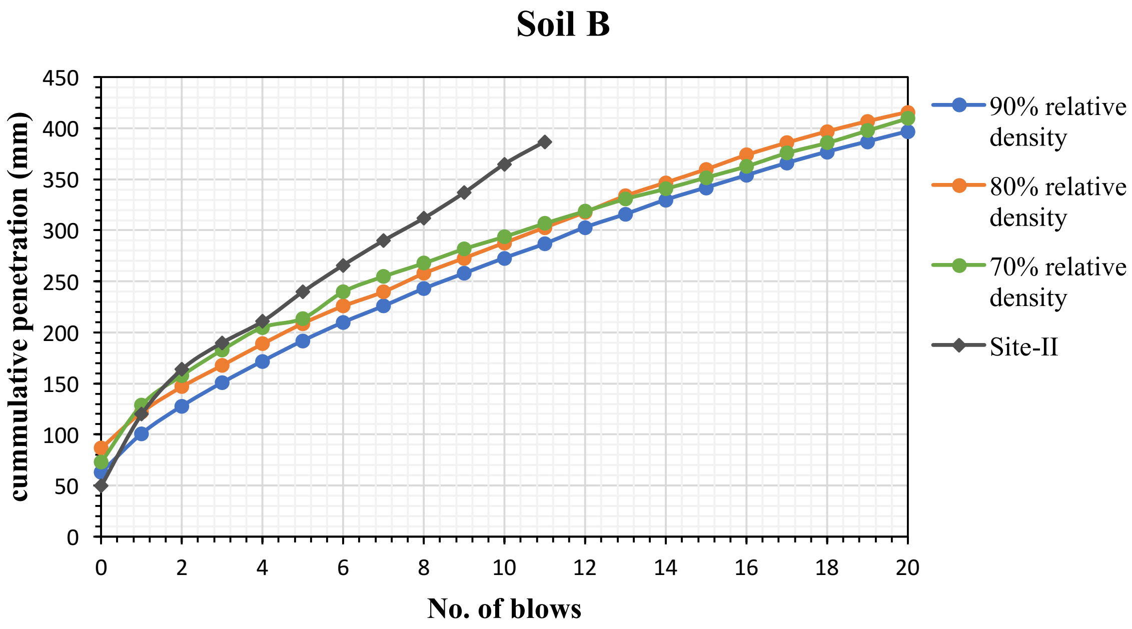


Fig. 4.3 Cumulative penetration vs no. of blows

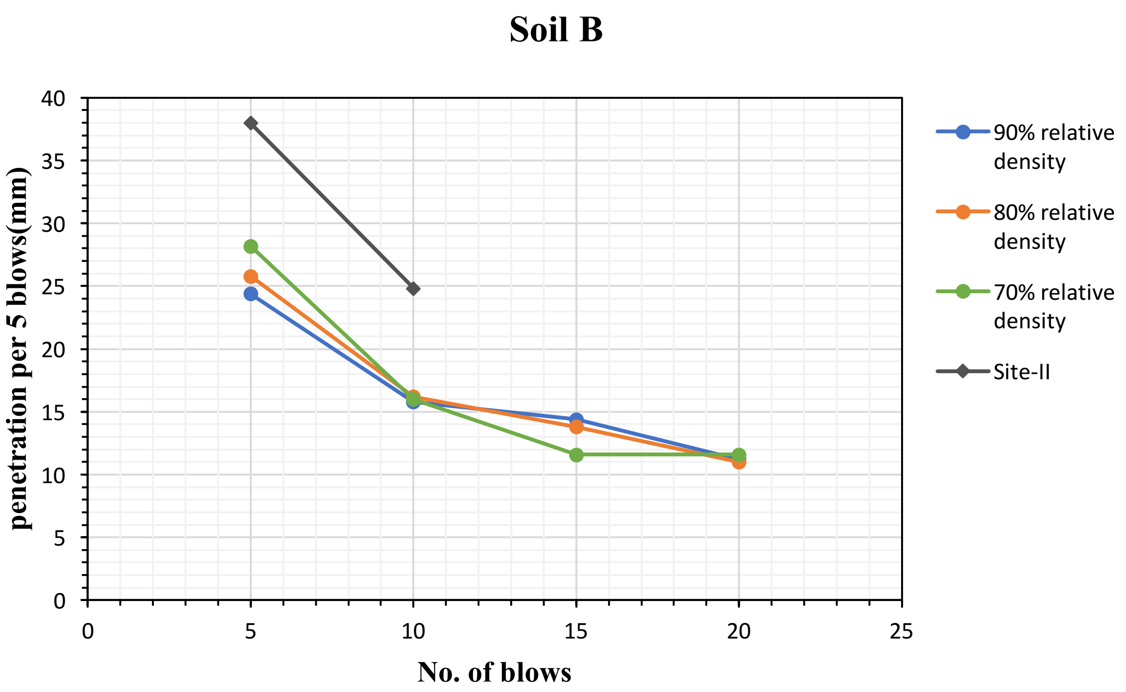


Fig. 4.4 Penetration per 5 blows for soil B

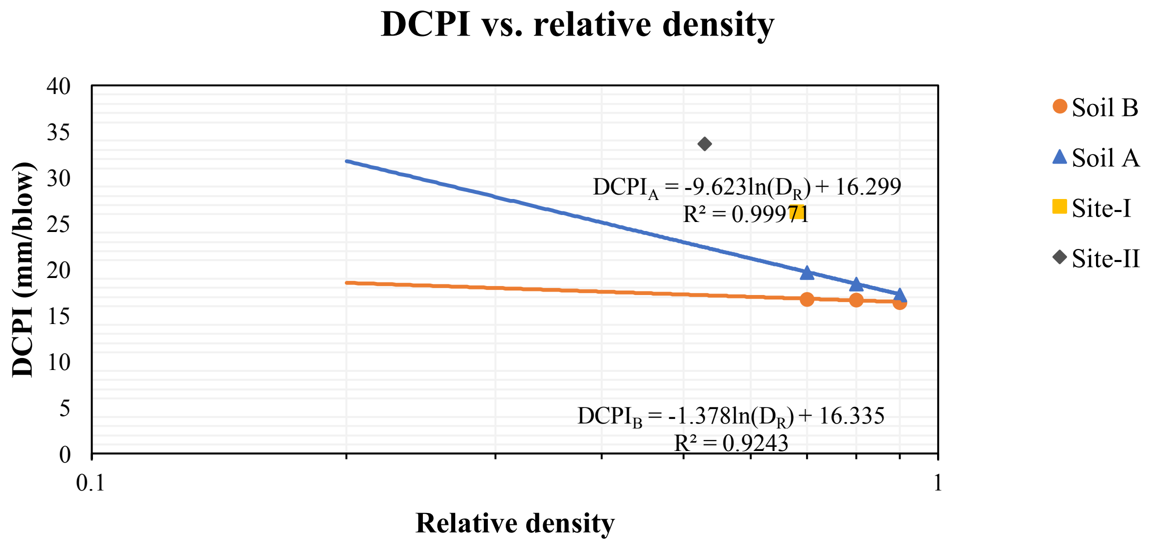


Fig. 4.5 DCPI vs relative density

For soil at site-I relative density is estimated using equation $DCPI_A = -9.623 \ln D_r + 16.299$ with coefficient of determination $R^2 = 0.99971$ and for soil at site-II equation used is $DCPI_B = -1.378 \ln D_r + 16.335$ with coefficient of determination $R^2 = 0.9243$.

From the field test at site-I value obtained for DCPI is 26.3 mm/blow and density of soil by core cutter obtained is 15.134 kN/mm^2 which give the relative density of 68%. The values obtained at site-I is plotted in graph of DCPI vs. relative density.

From the field test at site-II value obtained for DCPI is 33.7 mm/blow and density of soil by core cutter obtained is 15.69 kN/mm^2 which give the relative density of 53%. The values obtained at site-II is plotted in graph of DCPI vs. relative density.

CHAPTER 5

CONCLUSION

- Results obtained for the dynamic cone penetrometer test in the laboratory at relative density of 70%, 80% and 90% gives the relations as follow for both the type of soils as,
  - $DCPI_A = A_A \ln D_R \; + \; B_A,$ $R^2 = 0.99971$ (5.1)
  - $DCPI_B = A_B \ln D_R \; + \; B_B,$ $R^2 = 0.9243$ (5.2)
- The value of coefficients A_A, A_B, B_A and B_B are -9.623, -1.378, 16.299 and 16.335 respectively as observed by the laboratory tests.
- Effect of vertical confinement is also observed from the graph of penetration per five blows. As the average penetration keeps on decreasing with increase in depth of cone.
- Effect of vertical confinement is almost similar at the different level of compaction for both type of soils. From this, it is concluded that effect of overburden pressure and vertical confinement is independent of the type of soil.
- Variation in results of DCPT performed in laboratory and at the field, are observed. The deviation of the field results from the obtained equation is due to the effect of horizontal confinement of the mould.
- To neglect the effect of confinement of mould the equations can be rewritten as,
  - $DCPI_A = \alpha \ln D_R + \beta$ (5.3)

  The value of α and β depends on the physical and engineering properties of soil like mean particle size for sands (D_{50}), plasticity index (I_p) for clays, undrained shear strength, void ratio etc.

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CORRELATION BETWEEN DYNAMIC CONE PENETROMETER INDEX (DCPI) AND RELATIVE DENSITY OF SOIL FOR A LOCALLY FABRICATED APPARATUS

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CORRELATION BETWEEN DYNAMIC CONE PENETROMETER INDEX (DCPI) AND RELATIVE DENSITY OF SOIL FOR A LOCALLY FABRICATED APPARATUS

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CHAPTER 1

INTRODUCTION

1.1. DYNAMIC CONE PENETROMETER

Dynamic Cone Penetrometer was first developed by Scala from Australia in 1959 as an in situ geotechnical assessment technique for evaluating the strength of base and subbase materials of new and existing flexible pavement structures (Scala 1959). This test is also used for quality control of the compaction of some type of soils. Various relationships have been developed between DCPI and other testing methods, for example, CBR and UCS tests (Scala, 1959; De Beer, 1991; Webster *et al.*, 1994 and Chen *et al.*, 1999).

The parameters of the Dynamic Cone Penetrometer, such as, drop mass, the height of fall of hammer and the cone apex angle are varied with the testing method by different investigators and organizations. Its use spreads to many countries. Due mainly to its simplicity its acceptance in the United States grew from the late 1980s (e.g., De Beer and van der Merwe, 1991; Parker, *et.al*, 1998; Burnham and Johnson, 1993, Amini 2003) until in 2003 a standard ASTM D9651- 2003 was developed for its use. There are different types of DCP equipment that have been used as summarized in Table 1.1. The different types of DCP equipment can be categorized as light dynamic cone penetrometer and the heavy-duty dynamic cone penetrometer with impact energy per blow per cone area of the order of 30kNm/m^2 and 236kNm/m^2 respectively for harder ground. However, the commonest type is the standard DCP with impact energy per blow per cone area of 144kNm/m^2.

Table 1.1 Various dynamic cone penetrometer designs

DCP design	Hammer mass (kg)	Height of fall (mm)	Cone diameter (mm)	Potential Energy per drop (J)	Impact energy per blow/cone area (kNm/m^2)
Scala (1956)	8	575	20	45.1	144
Van Vuuren (1969)	10	460	20	45.1	144
ASTM D6951 (2003)	8	575	20	45.1	144
AS 1289.6.3.2 (1997)	9	510	20	45.0	143
Sowers and Hedges (1966)	6.8	508	38	33.9	30
Nguyen and Mohajerani (2012)	2.25	510	20	11.3	36
Cearns and McKenzie (1988)	63	750	44	463.1	236

The dynamic cone penetrometer test apparatus adopted worldwide, given by ASTM D6951 (2003), is locally fabricated for this study at DTU is shown in Fig. 1.1. The specifications of this apparatus are kept according to the design given by ASTM D6951 (2003), those are, a hammer of weight 8kg and height of fall of hammer 575 mm with potential energy per drop of 45.1 J. And cone used in this apparatus is 20 mm in diameter with apex angle of 60 degrees.

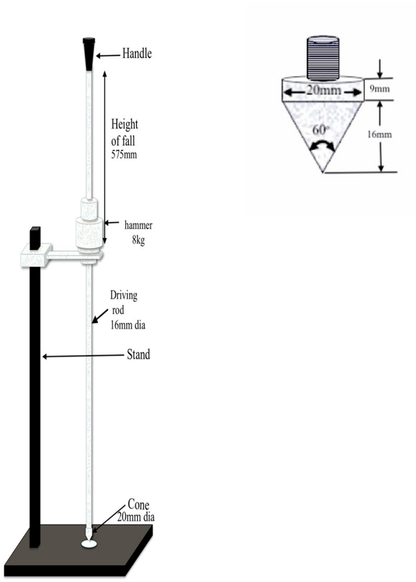

Fig. 1.1. Dynamic cone penetrometer (locally fabricated at DTU)

1.1.1. Applications of dynamic cone penetrometer

Dynamic cone penetrometer test can be used for the characterization of sub-grade and base layer material properties. One of the strong points in favour of the dynamic cone penetrometer device is in its ability to give a continuous record of relative soil strength/properties with depth. By plotting a graph of dynamic cone penetration index (DCPI) versus depth of penetration on the testing surface, layer depths, thicknesses, and strength conditions can be observed. And due to its compact and lightweight design, it can be used in confined areas such as inside buildings to evaluate foundation settlements, or used on congested sites that would prevent larger testing equipment from being used. The DCP is ideal for testing through bore holes in existing pavements. The applications of dynamic cone penetrometer test are as follows:

- Dynamic cone penetrometer test is used for evaluating the strength of base and subbase material for new and existing flexible pavements.

- The relation between dynamic cone penetration index (DCPI) and various soil properties like relative density, moisture content, the angle of internal friction, CBR, UCS, liquefaction potential, liquidity index etc. have been developed. So this test is capable of giving ideal about most of the basic engineering properties of soil.

- Preliminary Soils Surveys - DCP testing can be done during preliminary soil investigations to quickly map out areas of weak material, change in strata, groundwater level.

- Construction Control - The DCP is an ideal too1 for monitoring all aspects of the construction of a pavement sub-grade and base. It can be used to verify the level and uniformity of compaction over a project. It can also be used to define problem areas that develop due to unavoidable soil conditions.

1.1.2. Factors affecting DCPI

- Alignment of dynamic cone penetrometer rod – While testing the rod of the dynamic cone penetrometer should be straight if the penetrating rod is tilted during testing, skin friction will increase for the rod due to which rate of penetration decrease and DCPI will be observed lower than the actual.
- The depth of testing – Dynamic cone penetrometer test results are sensitive to the depth of testing. When the bottom rod of the DCP used is longer than the standard penetrating rod, vertical confinement and skin friction around the rod increases, which leads to the lower value of observed DCPI.
- Damaged cone tip – If the cone tip of the DCP is damaged it will result for higher friction to cone to penetrate in the soil, which gives incorrect test results.
- Hammer weight – If the weight of the hammer is more than the specified weight then the rate of penetration will increase and vice versa.
- Height of fall of hammer – During dynamic cone penetrometer testing, for each blow, the hammer weight should be lifted to the top restraint plate and freely dropped. During testing, if the hammer is not lifted to the standard given height, the impulsive force exerted by the cone to the soil will reduce and the values of penetration decrease.
- Cone apex angle – The penetration rate will be significantly affected by change of the cone apex angle from 30° to 120° since the upward frictional force on a cone surface with a 120° apex angle will be greater than that of with a 30° apex angle cone.
- Moisture content – DCP test results are very sensitive to variations in water content present in the test materials. As the water content increases, the penetration rate of DCP also increases and vice versa.
- Material composition – DCPI varies with test material composition, soil class, the coefficient of curvature and uniformity, density of the layer material and plasticity of the soil.

1.2. RELATIVE DENSITY

Relative density and compaction percentage are commonly used for evaluating the state of compactness of a given soil mass. The engineering properties such as shear

strength, compressibility and permeability of a given soil depend on the level of compaction of the soil. Relative density or density index is the ratio of the difference between the void ratios of a cohesion-less soil in its loosest state and existing natural state to the difference between its void ratio in the loosest and densest states. The relative density, denoted by D_r, has been presented as a function of the void ratio as,

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \qquad (1.1)$$

And presented as a function of the dry density as,

$$D_r = \frac{1/(\gamma_d)min - 1/\gamma_d}{1/(\gamma_d)min - 1/(\gamma_d)max} \qquad (1.2)$$

Where, e = void ratio of cohesion-less soil in its natural state

e_{min} = void ratio of cohesion-less soil in its densest state

e_{max} = void ratio of cohesion-less soil in its loosest state

γ_d = density of soil in its natural state

$(\gamma_d)_{max}$ = density of soil in its densest state

$(\gamma_d)_{min}$ = density of soil in its loosest state

1.2.1. Measurement of $(\gamma_d)_{min}$

The density of soil in its loosest state is obtained by light compaction of soil in a mould. Oven dried soil should be placed as loosely as possible in the mould by pouring the soil through the spout in a steady stream. Size of spout and mould is selected as per the Table 1.2, given by IS 2720 part 14. The spout should be adjusted so that the height of free fall of soil is always 25 mm from the top layer of soil in the mould.

Table 1.2 Pouring device to be used

Maximum size of soil particle mm	Mass of soil sample required kg	Pouring device to be used	Size of mould to be used mm^2
75*	45	Shovel	$15*10^5$
37.5*	12	Scoop	$3*10^5$
19*	12	Scoop	$3*10^5$
9.5*	12	25mm diameter spout	$3*10^5$
4.75*	12	12 mm diameter spout	$3*10^5$
4.75**	12	4.75 mm sieve	$3*10^5$

* IS 2720 part 14

** Used in this study

1.2.2. Measurement of $(\gamma_d)_{max}$

The maximum density of sand is obtained by vibrating table method. Oven dried sample of sand is filled in the mould as filled in minimum density test and then mould is fixed on the vibrating deck with nut and bolts. This assembly is allowed to vibrations for 8 minutes with surcharge weight over it.

For maintaining the relative density up to 70% air pulviation method or sand draining method is suitable. For obtaining relative density more than that air pulviation method is not suitable so mechanical vibration is suggested.

CHAPTER 3

MATERIALS AND METHODS

3.1. SOIL SAMPLE

Two soil samples are used in this study, properties of which are tabulated as,

Table 3.1 Properties of soil used in study

Properties	Soil A	Soil B
Specific gravity	2.597	2.63
Color	Light brown	Grey
D_{10} mm	0.104	0.276
D_{30} mm	0.175	0.614
D_{50} mm	0.254	0.782
D_{60} mm	0.291	0.865
Maximum void ratio, e_{max}	0.790	0.708
Minimum void ratio, e_{min}	0.633	0.548
Maximum density, γ_{dmax} (kN/m^3)	15.60	16.45
Minimum density, $\gamma_{d\,min}$ (kN/m^3)	14.23	14.91
Classification	SP $C_U = 2.798$ $C_C = 1.012$	SP $C_U = 3.134$ $C_C = 1.579$

Table 3.2 Particle size distribution of soil A

Sieve Size	Weight retained (gm)	% weight retained	% cumulative weight retained	% finer
4.75mm	0	0	0	100
2.36mm	9	0.45	0.45	99.55

1.18mm	29	1.45	1.9	98.1
600 µ	26	1.3	3.2	96.8
425 µ	13	0.65	3.85	96.15
212 µ	1150	57.5	61.35	38.65
150 µ	288	14.4	75.75	24.25
75 µ	460	23	98.75	1.25
Pan	25	1.25	100	0

Table 3.3 Particle size distribution of soil B

Sieve Size	Weight retained (gm)	% weight retained	% cumulative weight retained	% finer
4.75mm	0	0	0	100
2.36mm	19	0.95	0.95	99.05
1.18mm	31	1.55	2.5	97.5
600 µ	1383	69.15	71.65	28.35
425 µ	57	2.85	74.5	25.5
212 µ	443	22.15	96.65	3.35
150 µ	26	1.3	97.95	2.05
75 µ	34	1.7	99.65	0.35
Pan	7	0.35	100	0

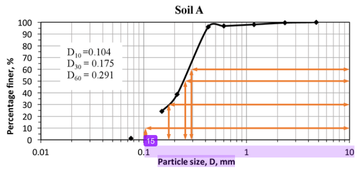

Fig. 3.1 Particle size distribution curve of soil A

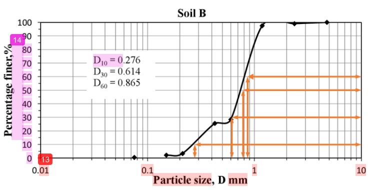

Fig. 3.2 Particle size distribution curve of soil B

3.2. AIR PLUVIATION

Air pulviation method is widely adopted for the preparation of large and uniform sand beds of required densities for laboratory studies to simulate in-situ conditions. The relative density obtained by air pulviation depends on deposition intensity uniformity of the sand rain, the height of fall of sand and particle size characteristics. Deposition intensity is the mass of soil falling in the mould per unit area per unit time. Air pluviation method is used to find the relation between height of fall and relative density of sand. Sand samples are allowed to fall into the mould of size 3000 cm^3 through a sieve of 4.75mm size from different heights. The density of sand in each case is measured with respect to the height of fall of sand. The relation between the height of fall of sand and relative density is shown in Fig. 3.3, which is used to maintain required relative density in the mould for testing.

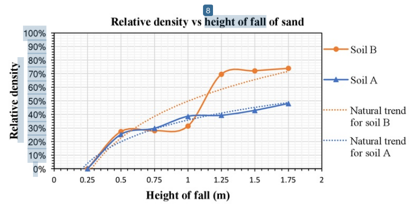

Fig. 3.3 Height of fall vs relative density

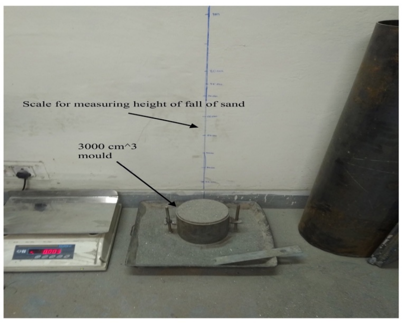

Fig. 3.4 Apparatus for the height of fall vs relative density

3.3. IN MOULD SAMPLE PREPARATIONS

In this study for developing a relationship between relative density and dynamic cone penetrometer index, a mould of size 300 mm diameter and 1000 mm depth is used. Soil samples are filled in this mould at different relative densities and DCP test is performed at different density for both the samples. Density for both the samples in this mould is maintained by air pulviation technique and manual compaction and vibration method. The relationship of the height of fall of soil with the relative density is developed which is shown in fig. 3.3. For soil A relative density up to 50% and for soil B relative density up to 75% can be maintained by air pulviation technique.

For maintaining relative density more than that in the mould, height of mould is divided into five equal parts and marked on the inner side of mould. The soil is weighted according to the density required and filled in the layers uniformly and compacted using rammer. The number of blows required to fill the first portion is counted and other four layers are filled accordingly to maintain the required density in the mould.

3.4. DYNAMIC CONE PENETRATION TESTING

After preparing the sample of required density in the mould top surface of the soil is levelled and dynamic cone penetration apparatus assembly is placed over the centre of the mould. The penetration reading for self-weight of the apparatus is recorded as zero-error reading. The rod is held vertical and the 8kg hammer is raised over the full height of 575 mm and allowed to fall freely onto the anvil to drive the 20mm diameter cone through the compacted sample. The penetration is recorded for each blow. To obtain the dynamic cone penetration index the cumulative penetration values are plotted against the number of blows, the gradient of which gives the DCPI, or it can be calculated by the ratio of total penetration due to dynamic action of the hammer (minus zero error reading) and total no of blows (Mukesh A. Patel 2013). The test is repeated on both the soil samples for different compactions levels and a relation between DCPI vs relative density is observed.

$$\mathrm{DCPI} = \frac{\text{Total penetration}}{\text{no.of blows}} \qquad (3.1)$$

At relative-density less than 50% penetration resistance offered by the sand to the dynamic cone penetrometer is negligible. The levels of compaction used to develop the relation are taken more than 50%. And achieving relative density of 100% in the mould by manual compaction is difficult. Considering all the practical factors, the test is performed on soil samples having a relative density of 70%, 80% and 90%.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. LABORATORY TEST RESULTS FOR DCPI VS RELATIVE DENSITY

4.1.1. DCPI at relative density of 70% for soil A

Table 4.1 DCPT results for soil A at relative density of 70%

No. of blows	Penetration (mm)	Penetration per blow (mm)	Average penetration per 5 blows (mm)
0	62	-	
1	127	65	34.2
2	159	32	
3	185	26	
4	210	25	
5	233	23	
6	254	21	17.4
7	273	19	
8	289	16	
9	305	16	
10	320	15	
11	333	13	12.2
12	346	13	
13	358	12	
14	370	12	
15	381	11	
16	393	12	12
17	405	12	
18	417	12	
$\mathrm{DCPI} = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{355}{20} = 19.72\,\frac{\text{mm}}{\text{blow}}$			

4.1.2. DCPI at relative density of 80% for soil A

Table 4.2 DCPT results for soil A at relative density of 80%

No. of blows	Penetration (mm)	Penetration per blow (mm)	Average penetration per 5 blows (mm)
0	85	-	
1	125	40	27
2	152	27	
3	176	24	
4	199	23	
5	220	21	
6	241	21	18
7	260	19	
8	278	18	
9	295	17	
10	310	15	
11	326	16	13.6
12	340	14	
13	354	14	
14	366	12	
15	378	12	
16	389	11	11.5
17	399	10	
$\mathrm{DCPI} = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{314}{17} = 18.47\,\frac{\text{mm}}{\text{blow}}$			

4.1.3. DCPI at relative density of 90% for soil A

Table 4.3 DCPT results for soil A at relative density of 90%

No. of blows	Penetration (mm)	Penetration per blow (mm)	Average penetration per 5 blows (mm)
0	58	-	
1	117	59	
2	138	21	
3	159	21	27.8
4	178	19	
5	197	19	
6	214	17	
7	233	19	
8	250	17	17.6
9	268	18	
10	285	17	
11	300	15	
12	316	16	
13	331	15	14.2
14	344	13	
15	356	12	
16	368	12	
17	378	10	
18	387	9	9.6
19	396	9	
20	404	8	
$DCPI = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{346}{20} = 17.3 \frac{mm}{blow}$			

4.1.4. DCPI at relative density of 70% for soil B

Table 4.4 DCPT results for soil B at relative density of 70%

No. of blows	Penetration (mm)	Penetration per blow (mm)	Average penetration per 5 blows (mm)
0	73	-	
1	129	56	
2	158	29	
3	183	25	28.2
4	205	22	
5	214	09	
6	240	26	
7	255	15	
8	268	13	16
9	282	14	
10	294	12	
11	307	13	
12	319	12	
13	331	12	11.6
14	341	10	
15	352	11	
16	363	11	
17	376	13	
18	386	10	11.6
19	398	12	
20	410	12	
$DCPI = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{337}{20} = 16.8 \frac{mm}{blow}$			

4.1.5. DCPI at relative density of 80% for soil B

Table 4.5 DCPT results for soil B at relative density of 80%

No. of blows	Penetration (mm)	Penetration per blow (mm)	Average penetration per 5 blows (mm)
0	63	-	
1	101	38	
2	128	27	
3	151	23	25.8
4	172	21	
5	192	20	
6	210	18	
7	226	16	
8	243	17	16.2
9	258	15	
10	273	15	
11	287	14	
12	303	16	
13	316	13	13.8
14	330	14	
15	342	12	
16	354	12	
17	366	12	
18	377	11	11
19	387	10	
20	397	10	
$DCPI = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{334}{20} = 16.7 \frac{mm}{blow}$			

4.1.6. DCPI at relative density of 90% for soil B

Table 4.6 DCPT results for soil B at relative density of 90%

No. of blows	Penetration (mm)	Penetration per blow (mm)	Average penetration per 5 blows (mm)
0	87	-	
1	122	35	
2	147	25	
3	168	21	24.4
4	189	21	
5	209	20	
6	226	17	
7	240	14	
8	258	18	15.8
9	273	15	
10	288	15	
11	303	15	
12	318	15	
13	334	16	14.4
14	347	13	
15	360	13	
16	374	14	
17	386	12	
18	397	11	11.2
19	407	10	
20	416	09	
$DCPI = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{329}{20} = 16.45 \frac{mm}{blow}$			

4.2. FIELD TEST RESULTS

Dynamic cone penetrometer test is performed at the different locations in Delhi Technological University campus for the verification of experimental results obtained in laboratory. The test locations are selected on basis of availability of soil similar to the soil used in laboratory tests.

Dynamic cone penetrometer test is conducted on two sites and natural density of soil in field for both the sites is measured by core cutter method. Using the relation developed by laboratory test, level of compaction of both the soils is estimated and compared with the field results. Properties of soil at site-I are similar to that of Soil A and of soil at site-II are similar to Soil B used in this study.

4.2.1. DCP test results for Site I (kabaddi court)

Table 4.7 DCP test results for site-I

No. of blows	Penetration (mm)	Penetration per blow (mm)	Penetration per 5 blows (mm)
0	19	-	
1	54	35	44.6
2	89	35	
3	128	39	
4	179	51	
5	242	63	
6	275	33	28
7	300	25	
8	326	26	
9	354	28	
10	382	28	
11	405	23	17.8
12	423	18	
13	439	16	
14	454	15	

15	471	17	
16	487	16	14.8
17	504	17	
18	519	15	
19	533	14	
20	545	12	

$$DCPI = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{526}{20} = 26.3\ \frac{\text{mm}}{\text{blow}}$$

4.2.2. DCP test result at site-II (near Kalpana Chawla girls hostel)

Table 4.8 DCP test results at site-II

No. of blows	Penetration (mm)	Penetration per blow (mm)	Penetration per 5 blows (mm)
0	50	-	
1	120	70	38
2	164	44	
3	190	26	
4	211	21	
5	240	29	
6	266	26	24.84
7	290	24	
8	312	22	
9	337	27	
10	365	28	
11	387	22	

$$DCPI = \frac{\text{Total penetration}}{\text{No. of blows}} = \frac{337}{10} = 33.7\ \frac{\text{mm}}{\text{blow}}$$

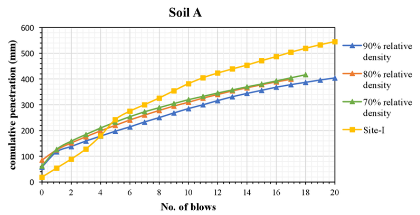

Fig. 4.1 Cumulative penetration vs no. of blows for soil A

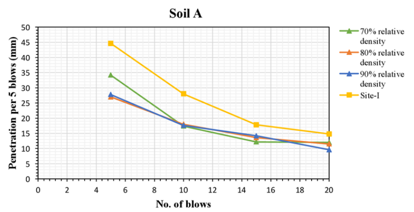

Fig. 4.2 Penetration per 5 blows for soil A

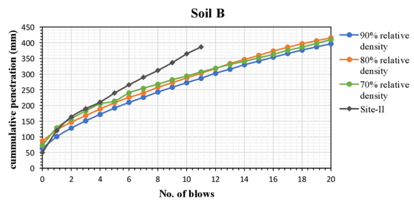

Fig. 4.3 Cumulative penetration vs no. of blows

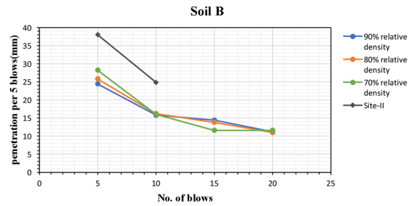

Fig. 4.4 Penetration per 5 blows for soil B

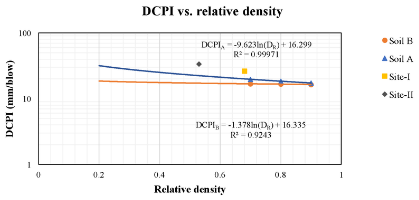

Fig. 4.5 DCPI vs relative density

For soil at site-I relative density is estimated using equation $DCPI_A = -9.623 \ln D_r + 16.299$ with coefficient of determination $R^2 = 0.99971$ and for soil at site-II equation used is $DCPI_B = -1.378 \ln D_r + 16.335$ with coefficient of determination $R^2 = 0.9243$.

From the field test value obtained for DCPI at site-I is 26.3 mm/blow and density of soil by core cutter obtained is 15.134 kN/mm^2 which give the relative density of 68%. The values obtained at site-I is plotted in graph of DCPI vs. relative density.

From the field test value obtained for DCPI at site-II is 33.7 mm/blow and density of soil by core cutter obtained is 15.69 kN/mm^2 which give the relative density of 53%. The values obtained at site-II is plotted in graph of DCPI vs. relative density.

CHAPTER 5

CONCLUSION

- Results obtained for the dynamic cone penetrometer test in the laboratory at relative density of 70%, 80% and 90% gives the relations as follow for both the type of soils as,
  - $DCPI_A = -9.623 \ln D_R + 16.299$, $R^2 = 0.99971$ (5.1)
  - $DCPI_B = -1.378 \ln D_R + 16.335$, $R^2 = 0.9243$ (5.2)
- Effect of vertical confinement is also observed from the graph of penetration per 5 blows. As the average penetration keeps on decreasing with increase in depth of cone.
- Effect of vertical confinement is almost similar at the different level of compaction for both type of soils. From this, it is concluded that effect of overburden pressure and vertical confinement is independent of the type of soil.
- Variation in results of DCPT performed in laboratory and at the field are observed. The deviation of the field results from the obtained equation is due to the effect of horizontal confinement of the mould.
- To neglect the effect of confinement of mould the equations can be rewritten as,
  - $DCPI_A = \alpha(-9.623 \ln D_R) + 16.299$ (5.3)
  - $DCPI_B = \beta(-1.378 \ln D_R) + 16.335$ (5.4)

  The value of α and β depends on the physical and engineering properties of soil like mean particle size for sands (D_{50}), plasticity index (I_p) for clays, undrained shear strength, void ratio etc.

CORRELATION BETWEEN DYNAMIC CONE PENETROMETER INDEX (DCPI) AND RELATIVE DENSITY OF SOIL FOR A LOCALLY FABRICATED APPARATUS

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