FABRICATION OF A DIGITAL STATIC CONE PENETROMETER WITH USB OUTPUT

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CANDIDATE'S DECLARATION

I, Tarun Kumar, Roll No. 2K16/GTE/19 student of M.Tech. (Geotechnical Engineering), hereby declare that the project Dissertation titled "Fabrication of a Digital Static Cone Penetrometer with USB Output" 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, 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 Association, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "Fabrication of a Portable Static Cone Penetrometer with USB Output" which is submitted by [Tarun kumar], Roll No. 2K16/GTE/19 [Department of Civil Engineering], Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi
Date:

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I would like to express my sincere thanks of gratitude for the assistance, guidance and support that I have received during major project. I take immense pleasure in thanking **Prof. A. Trivedi**, for permitting me to carry out this work and for his invaluable encouragement, suggestions and support from an early stage of this project. Above all, his priceless and meticulous supervision at each and every phase of work inspired me in innumerable ways. This report could not have been accomplished without the splendid support and cooperation of the Civil Engineering Department of Delhi Technological University.

If any errors come in the report, I solely take the responsibility of all any and all errors.

Tarun Kumar
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ABSTRACT

Humans have been probing ground since they could hold sticks, but only in recent times have their probes been scientific. Researchers interested in studying soil stratification probed the ground with pointed rods during early 1900s. A more refined instrument called a cone penetrometer was invented in Netherlands during the mid-1930s to measure soil strength. Cone penetrometers measure soil penetration resistance or soil strength encountered at various depths as the cone shaped object is pushed steadily into the ground.

Until recently, penetrometers were comprised of a dial indicator with a stress ring connected to a round rod with scaled depth markings. The rod has a cone-shaped tip at one end and a handle for pushing the cone into the ground on the other end. Using these penetrometers was a cumbersome operation best completed by two people; one to push the penetrometer into the ground and read the force on the dial indicator, and the other to record probe depth and force.

In this thesis, a Digital static cone penetrometer has been designed which can record the output with fixed time intervals automatically. The result will be shown in a table format comprising serial number, load and displacement. For the load output, a load cell has been used. In this, four strain gauges are used in a Wheatstone bridge configuration. For displacement, Linear Potentiometer has been used which measures the total distance between the initial ground level and the final position of the rod. The result is then transferred to output device using a sensor. Finally all the data is simultaneously gathered for a fixed time interval providing the final table comprising serial number, load and displacement. This data is then recorded and saved in the output device i.e. pen drive.

Keywords: Load cell, Linear Potentiometer, Strain gauges, USB Output, Digital static cone penetrometer, Wheatstone bridge.

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List of Abbreviations

CPT	Cone Penetration Test
DSML	Delft Soil Mechanics Laboratory
SCPT	Static Cone Penetration Test
DCPT	Dynamic Cone Penetration Test
LVDT	Linear Variable Differential Transformer
RVDT	Rotary Variable Differential Transformer
LCD	Liquid Crystal Display
ADC	Analog to Digital Convertor
HV	High Voltage
LV	Low Voltage
AC	Alternating Current
DC	Direct Current

Chapter 1

INTRODUCTION

1.1. Introduction

Cone Penetration Test (CPT) is used to find out the geotechnical properties of soils and precisely portray soil stratigraphy. Stratigraphy is a subdivision of geology which is related to the study of rock layers (strata) and stratification.

The two types of penetrometers that are being used to investigate soil by performing cone penetrometer tests are

1. Static Cone Penetrometer
2. Dynamic Cone Penetrometer

In the static cone penetrometer, the cone is pushed into the soil a specific distance at a constant rate of penetration. While in dynamic cone penetrometer, the cone is pounded through a specific distance in the soil by the means of hammer. Different blows of hammer are required for different types of soil.

The static cone penetrometer is the focus of this thesis and many modifications have been done in order to make the experimental procedure much simpler and less energy and time consuming. This thesis is based on the fabrication of digital static cone penetrometer that can record the data (readings) of load and displacement in a USB device and the format of the output would be a table comprising of 5 columns i.e. serial number, load, unit, displacement and unit. Each reading is taken in a fixed time interval. This digital static cone penetrometer reduces the time and effort that was required to perform the test earlier.

Table 1.1: Static Cone Penetration Test

STATIC CONE PENETRATION TEST	
Scope/Purpose	Investigation of soil stratigraphy through Cone Resistance.
Description	The cone along with friction jacket is assembled at the point to be tested. The cone is penetrated using the inner sounding rod while the friction jacket remains in the same position. The gauge reading during this penetration is noted and termed as Cone Resistance. Then the friction jacket along with cone is pushed in to the soil which determines the total resistance of the soil which includes the frictional resistance.
Results	Type of soil, Depth of different layers, Natural Water Table, Consistency of the soil.
Application	Obtain cone resistance, friction ratio, undrained shear strength and cohesion.
Suitable Soil Types	Soft Clayey Soil, Loose Sandy Soil and all easily permeable soil.
IS Codes	IS 4968.3.1976

1.2. Development of Cone Penetration Test (CPT)

The pioneer of the CPT was fabricated and tests were ripened in Holland from 1932 to 1937 by Barentsen. What he did was to make a sleeve-type machinery which comprised of a conical head, sounding rods and covering. The resistance is calculated by using a hydraulic gauge that has a manometer placed at the last part of the rod which was placed near the handles of the static cone penetrometer.

In the United States of America, a static penetration device was designed by Terzaghi in 1929 and that was the foremost mechanized static penetrometer. This device comprised a conical head, sounding rods and covering. It would be pushed into the soil using hydraulic jack upto the distance required to be investigated.

Busiman brought his static penetrating device in Holland in 1940. This penetrating device comprised a cone of 60º apex angle and a $10cm^2$ area of base of the cone, where the diameter of the base is same as the diameter of the covering. This penetrometer device was afterwards modified by DSML (Delft Soil Mechanics Laboratory) by installing a hydraulic piston in place of the mechanical piston.
In 1945, Delft Soil Mechanics Laboratory with the help of Gaudsche Machine Fabric produced 2500 kg capacity penetrometers. In 1947, Delft Soil Mechanics Laboratory with the help of Gaudsche Machine Fabric were able to make a 10000 kg capacity manual penetrometer. Both machine were fabricated to calculate the resistance of cone and total friction of the soil.

To prevent soil particles from going into annular space between covering and sounding rods, the veil developed by DSML (Vermeidin 1948). Since 1948, a large variety of Cone Penetration Test equipment have been produced across the world and it has been used for various purposes across the world.

1.3. Description of Humboldt Static Cone Penetrometer.

A company named Humboldt designed a Digital Static cone penetrometer which can give the data (readings) on the screen. It also gave correlations between various other tests also. Following are the description of the Digital Static cone penetrometer made by Humboldt:

The Digital Static cone penetrometer comprises of a big display that is very simple to read, manifold selection able units, two handles, two rods - starter rod and extension rod that is available with an extra length and a $150mm^2$ cone with apex angle 60º.

1.3.1. Testing Sequence

1) Tare Display: Press this when the Digital Static cone penetrometer is set at horizontal level .

2) Apply Force: The penetrometer device is held in position i.e. perpendicular to the soil. Now a constant pressure is applied to the padded handle so that the cone will drive through

soil. The friction on the outside rod will not affect the reading of penetrometer. Then the load applied will be read directly via the rod on to the load cell and then the reading will be displayed on the screen.

3) Depth of Penetration: The penetration depth will be different for different application.

4) Refusal: If there is existence of any rock layer, then one of the two things will happen:

- Penetration will be stopped
- Cone will be deflected

Forced penetration must not be done as it would result in wrong reading and in the worst case it could damage the cone or load cell that is being used.

1.3.2. Correlations:

Some correlation with other tests have been made by Humboldt. Some of these tests are:

- Standard Penetration (Blow counts)
- California bearing ratio (CBR)
- Reading of cone index (Q_c) and soil constants are not absolute.

All the calculations must be done using $kgcm^{-2}$ for cone index reading.

Standard Penetration (for Humboldt SCPT)

- Uniform clay and silty clay.
  $Q_c = 4$ "N",
  $Q_c = 5\ Q_u$,
  $Q_c = 10\ c$

- Clayey Silts
  $Q_c = (10\text{-}20)\ Q_u$,
  $Q_c = (20\text{-}40)\ c$

- CBR Value (%)

Where,

N- Number of blows.

Q_c – Cone Index.

c – Cohesion (kg/cm^2)

Q_u – Unconfined Compression (kg/cm^2)

These correlations are not for my Digital Static cone penetrometer. These are given by manufacturing company which is Humboldt and can be used for that device only.

Table 1.2: Correlations of Humboldt's Digital Static Cone Penetrometer

Standard Penetration	**Strength and Cohesion**	**CBR Value (1%)**
Test "N" Value Q_c = 4 "N"	Q_u – Unconfined Compression (Kg/cm^2) c - Cohesion (Kg/cm^2) Uniform Silt and Silty Clays: $Q_c = 5\ Q_u$ $Q_c = 10$ c Clayey Silts: Q_c = (10 to 20) Q_u Q_c = (20 to 40) c	Q_c = (2.5 to 3.3) CBR

CHAPTER 2

LITERATURE REVIEW

2.1.Load Cell

Load cell is used in this project to measure the load applied. Basically load cells are tools that converts the applied load to electrical signal. The more the load applied, the more will be the value of electrical signal generated. Load cells are basically of 3 kinds:

- Hydraulic
- Pneumatic
- Strain Gauge

Table 2.1: Load Cell comparison

Type	Weight Range	Accuracy (FS)	Applications	Strength
Mechanical Load Cells				
Hydraulic Load Cells	10 Million lbs.	0.25%	Tanks, bins and hoppers.	Takes high impact.
Pneumatic Load Cells	Wide	High	Food industry.	Contains no fluids.
Strain Gauge Load Cells				
Bending Beam Load Cells	10-5k lbs.	0.03%	Tanks, platform scales.	Low cost, simple.
Shear Beam Load Cells	10-5k lbs.	0.03 %	Tanks, platform scales.	High side load rejection.
Canister Load Cells	500k lbs.	0.05%	Truck, tank, track.	Handles load movements.
Ring and Pancake Load Cells	5-500k lbs.		Tanks, bins, scales.	All stainless steel.
Button and Washer Load Cells	0-50k lbs. 0-200 lbs.	1%	Small scales.	Small, inexpensive.
Other Load Cells				
Helical	0-40k lbs.	0.2%	Platform, forklift.	Handles off-axis loads, shocks
Piezo-resistive		0.03%		Extremely sensitive

For this project, a strain gauge load cell has been used, whose resistance is directly proportion to the applied load. With the help of Wheatstone bridge, the voltage can be measured easily.

The load cell that has been chosen for this project is a single point load cell in which four strain-gauges have been placed in a Wheatstone bridge formation. It is placed by fixing one corner of load cell with the wires, and then a force is applied perpendicularly on the other corner of the load cell that has an arrow. The load cell has been placed in a cantilever beam position. When the load is applied, the tensions and compressions are calculated by the 4 strain gauges.

Fig. 2.1 Load Cell (Source: Present Study)

Shape specific load cell:

- Pancake Load Cell
- Button Load Cell
- Thru-Hole/Ring Load Cell
- Load Beam Cell
- S-Type Load Cell
- Rod-Type Load Cell

2.2.Linear Potentiometer

Linear potentiometers produce a resistance output that varies according to the displacement or position of a slider or wiper. They are variable resistors with three leads. Two leads connect to the ends of the resistor, so the resistance between them is fixed. The third lead connects to a slider that travels along the resistor varying the resistance between it and the other two connections. The resistance element is excited by either DC or AC voltage. This video discusses potentiometers in general and compares linear and logarithmic tapers.

One of the most common application is measuring of displacement. To measure the displacement of the body, which is movable, is connected to the sliding element located on the potentiometer. As the body moves, the position of the slider also changes accordingly so the resistance between the fixed point and the slider changes. Due to this the voltage across these points also changes.

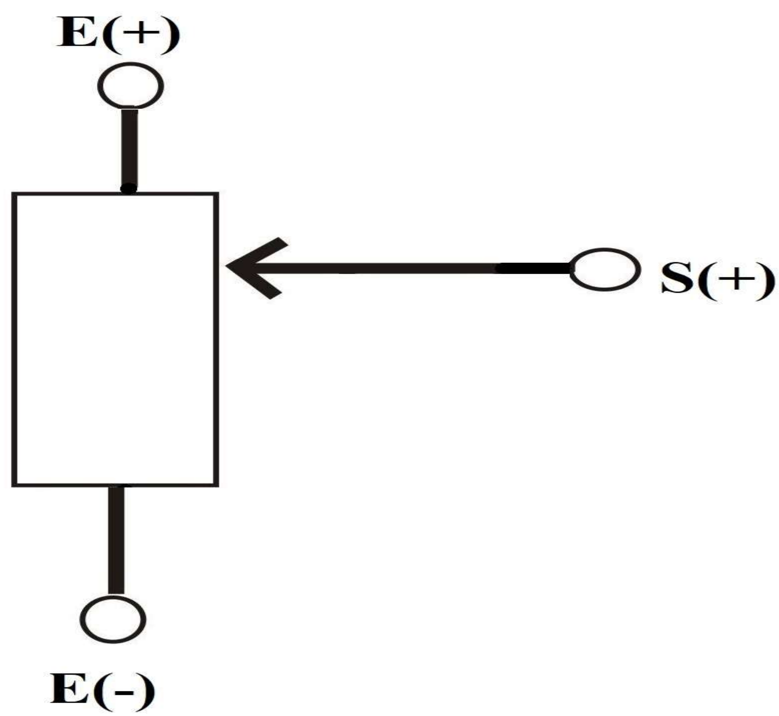


Fig. 2.2 Linear Potentiometer wire drawing.(Source: Present Study)

The change in resistance or the voltage is proportional to the change in the displacement of the body. Thus the voltage change indicates the displacement of the body. This can be used for the measurement of translational as well as well rotational displacement. Since these potentiometers work on the principle of resistance, they are also called as the resistive potentiometers.

CHAPTER 3

FABRICATION OF DIGITAL STATIC CONE PENETROMETER

3.1.Components of Digital Static Cone Penetrometer.

The Digital Cone Penetrometer comprises:

A measuring body with 2 push handles.
1 outer rod (D = 16 mm, L = 498 mm)
1 stainless steel inner rod (D = 19 mm, L = 210 mm)
4 conical tips, i.e. 30º, 45º, 60º, 75º.
1 Linear Potentiometer with a displacement range of 200mm
1 Data Acquisition System with USB output
1 Load cell with a capacity of 300 kg

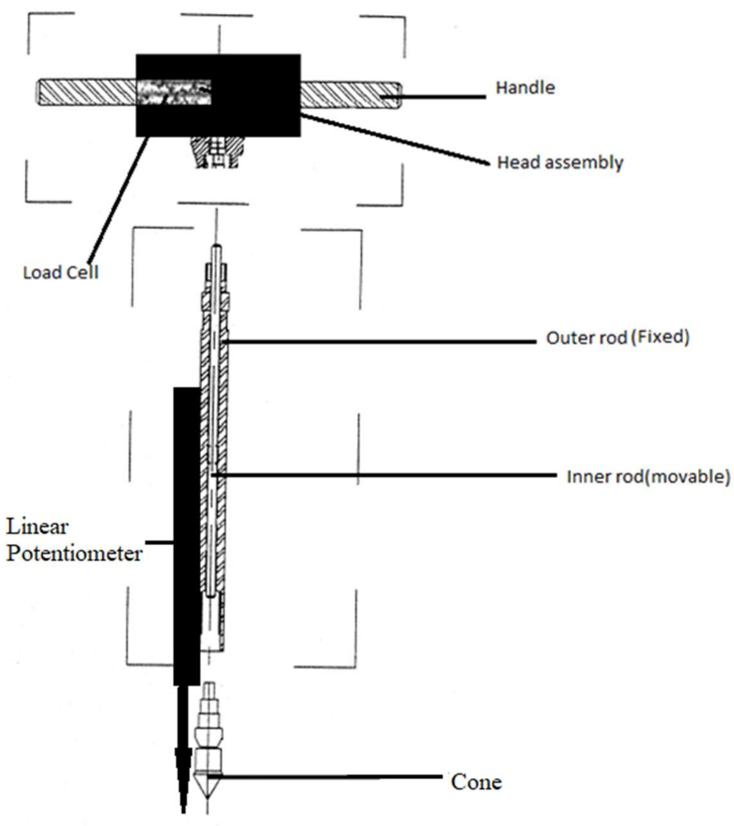
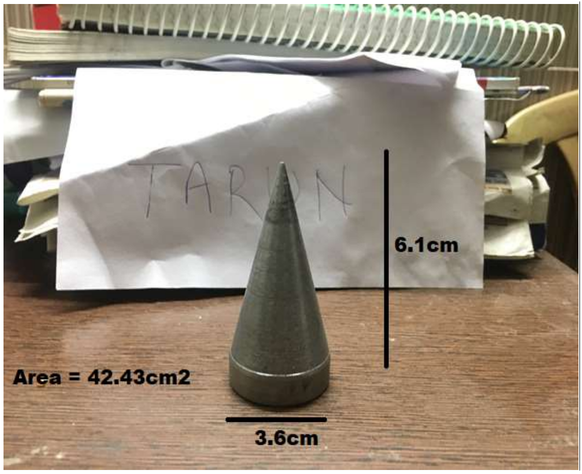


Fig. 3.1 Components of Digital Static Cone Penetrometer.
(Source: https://geotechnicaldesign.info/fotobank/cone-penetration-test.html and edited in paint.)



a) 30º cone

b) 45º cone

c) Rod (length = 49.8cm and diameter = 16mm)

d) 60º cone

e) 75º cone

Fig. 3.2 Dimensions of Cones and Rod

a) 30º cone – Depth = 6.1cm, Diameter = 3.6cm, Area = 42.43cm^2.

b) 45º cone – Depth = 4.1cm, Diameter = 3.6cm, Area = 31.68cm^2;

c) Rod - Length = 49.8cm, Diameter = 16mm;

d) 60º cone – Depth = 2.8cm, Diameter = 3.6cm, Area = 25.46cm^2;

e) 75º cone - Depth = 2.3cm, Diameter = 3.6cm, Area = 22.63cm^2;

(Source: Present Study)

Table 3.1: Dimensions of Cones

Degree of Cone(º)	Depth(cm)	Diameter (cm)	Area (cm^2)
30 º	6.1	3.6	42.43
45 º	4.1	3.6	31.68
60 º	2.8	3.6	25.46
75 º	2.3	3.6	22.63

Fig. 3.3 Digital Static cone Penetrometer (Source: Present Study)

3.2.Specification of Digital Static Cone Penetrometer:

3.2.1. Linear Potentiometer

Range of Displacement – 0 to 200mm

Least Count – 0.1mm

Port Used – 0-2V

3.2.2. Load Cell

Range of Load – 0 to 300kg

Least count – 0.05kg

Port Used – 2mV/V

3.2.3. Data Acquisition System

LCD display - 16 x 2 LINE DOT MATRIX DISPLAY

Motherboard - PIC18FH6K80

ADC (Analog to Digital Convertor) – ADS1232

CHAPTER 4

WORKING OF DIGITAL STATIC CONE PENETROMETER

4.1.Working Procedure:

To use the Digital static cone penetrometer, a consistent load has to be applied on the handle bars provided at the head assembly of the penetrometer. The applied load will push the rod and cone into the ground. The Digital static cone penetrometer must be held perpendicular to the ground. The load that is being applied will be measured by the load cell mounted at the end of rod. The load cell will send the electrical signal to the Data acquisition system which will convert the electrical or analog signal to digital. This will be shown on the screen and then will be transferred to a USB. Jerking pushes should be evaded as they will give data that will be too high and it will not represent the soil.

As the rod and cone are pushed into the ground, Linear Potentiometer will also be working along with load cell. Linear Potentiometer is used here to determine the displacement or penetration of the Digital static cone penetrometer. As for how it works, Linear Potentiometer also sends an electrical signal to transmit data. Linear Potentiometer is calibrated at the initial ground level and that position shows the reading of Linear Potentiometer as zero. As the rod and cone are pushed into the ground, Linear Potentiometer will start to read the difference in position and will start sending electrical data for different location after fixed interval of time. This data will then be converted from electrical signal to digital and the result will be shown on the screen. Afterwards, it will be stored in a USB.

The essential component for the working of this Digital static cone penetrometer is Data Acquisition System. It contains:

- Motherboard
- LCD Display
- Storage device point
- Keyboard
- Stepdown Transformer
- ADC (Analog to Digital Convertor)
- 1 Linear Potentiometer port
- 1 Load cell port

Both the data from Load cell and Linear Potentiometer came in the form of electrical signal. The ADC in this system converts the electrical signals to digital, thus enabling it to be displayed on the screen to make the task shorter, simpler and less energy taking. To make it effortless and even simpler, it has been provided with output recorder. The output storage point is a USB.

To measure the resistance to penetration (kg/cm²) of the soil, divide the value of load measured by the surface area of conical tip. The value of this resistance is used to determine the surface of the conical tip to be used i.e. *for higher reading of this resistance, a conical tip with smaller area has to be applied and for lower reading of this resistance, a conical tip with larger area has to be used.*

4.2.Working of Data Acquisition System:

In Data Acquisition System, the voltage of domestic household supply (220V) is reduced by using stepdown transformer. The stepdown transformer changes the high voltage (HV) and low current from primary side to low voltage (LV) and high current value to secondary side.

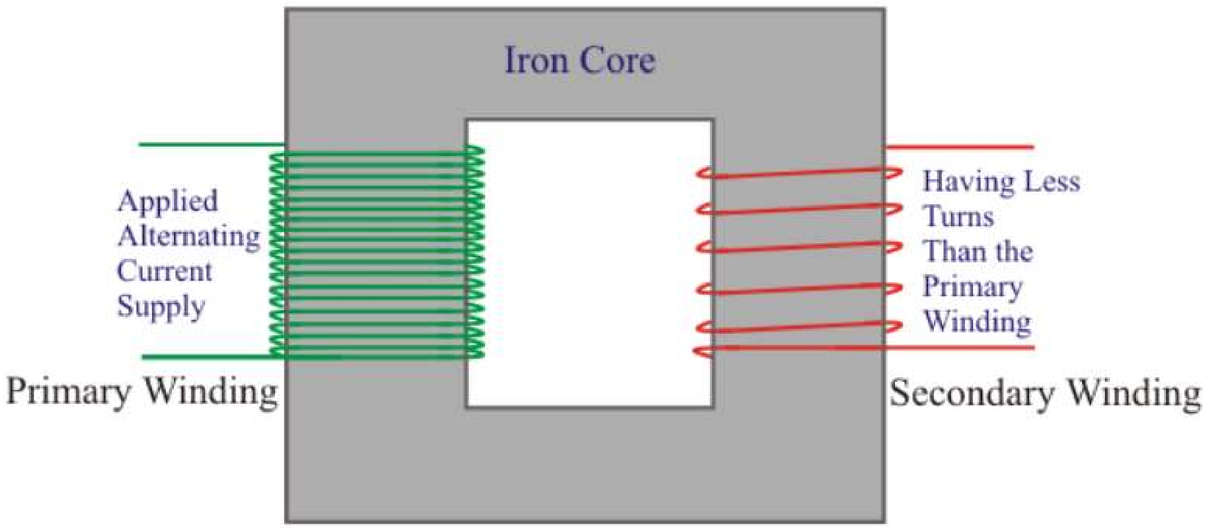


Fig. 4.1 Stepdown Transformer (Source: https://www.electrical4u.com/step-down-transformers/)

Then the alternating current is converted to direct current with the use of a rectifier. Then the current is passed on to the motherboard which is connected to every other part of the data acquisition system i.e. key panel, LCD display, storage device port, ADC. Now the mother board will transmit the data accordingly.

When the experimental procedure is started, Load cell and Linear Potentiometer starts sending electrical signals to their respective port i.e. 4 wire port and 3 wire port. The data received by the sensors is forwarded to ADC (Analog to Digital Convertor). The digital data is now sent to the LCD display via the motherboard. And the data will be shown on the display below their respective title. Now the data sent to LCD display will also be sent to USB output where the data will be transferred and stored in a table format comprising – S. No., Load, Unit, Displacement, Unit. It takes a large number of readings within a minute.

The circuit of the Data acqusition system is given below. The wiring is also shown in the circuit diagram. It is labelled and brief depiction of the circuit used in the Data acquisition system.

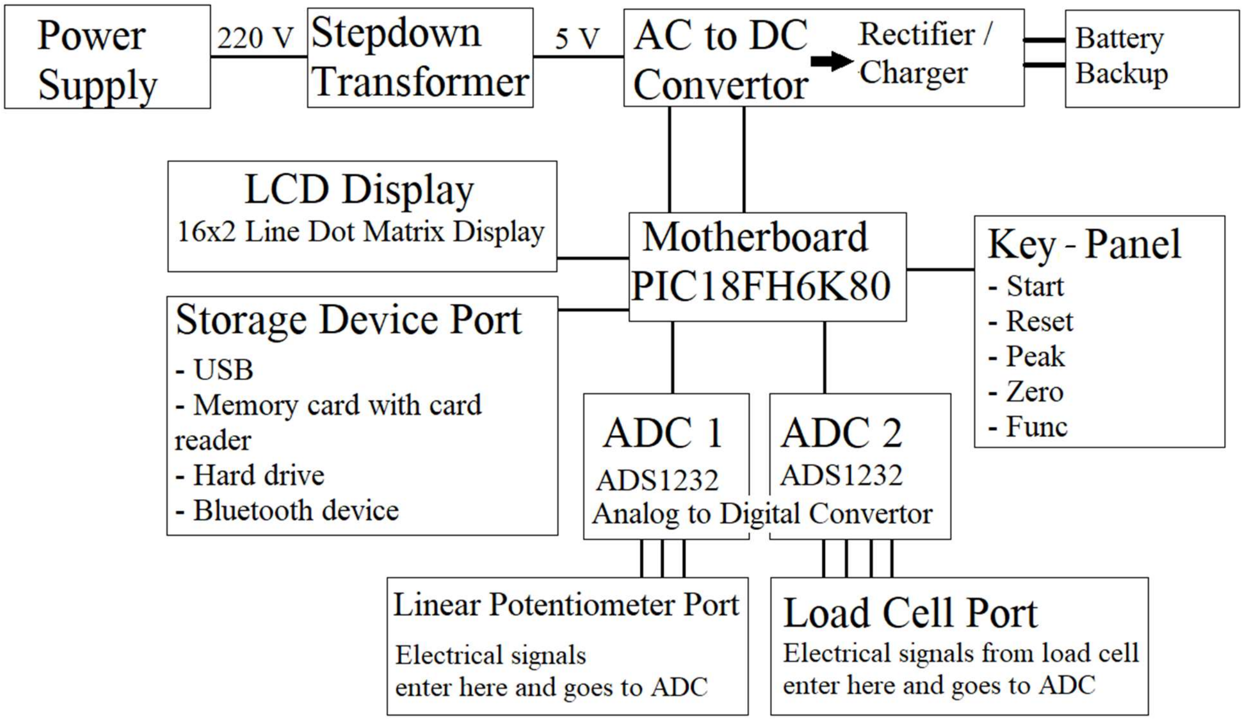


Fig. 4.2 Circuit of Data Acquisition System (Source: Present Study)

Fig. 4.3 Data Acquisition System (Source: Present Study)

The Specifications of the data acquisition system are given below and all the parts are explained as well. The Parts are:

a) LCD display: 16 x 2 LINE DOT MATRIX DISPLAY

It contain 16 columns and 2 rows. In the first row, the title appears - i) Linear Potentiometer and ii) Load. In the second row the readings of Load and Displacement is displayed.

b) Motherboard: PIC18FH6K80

A motherboard is the main printed circuit board (PCB) mostly found in microprocessor. It acts like a connector for other peripherals.

c) ADC: ADS1232

ADC is basically an Analog to Digital Convertor. It converts analog signal such as sound, light or electrical signal into digital signal.

d) Linear Potentiometer: 200mm range and 0-2V port
e) Load Cell: 300kg capacity and 2 mV/V port

2mV/V sensitivity means if an excitation voltage of 1V is provided then output voltage produced will be 2mV i.e. if 6V excitation voltage is provided the output voltage produced will be 12mV.

f) Key Panel: Five keys are provided namely start, reset, peak, zero and func. It is used for calibration and recording the output of the experiment.

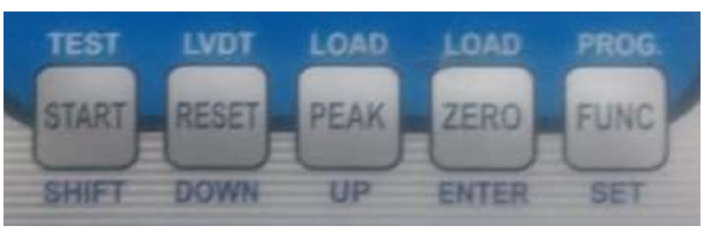


Fig. 4.4 Key Panel (Source: Present Study)

2mV/V sensitivity means if an excitation voltage of 1V is provided then output voltage produced will be 2mV i.e. if 6V excitation voltage is provided the output voltage produced will be 12mV.

4.3.Keys and Function of Data Acquisition System

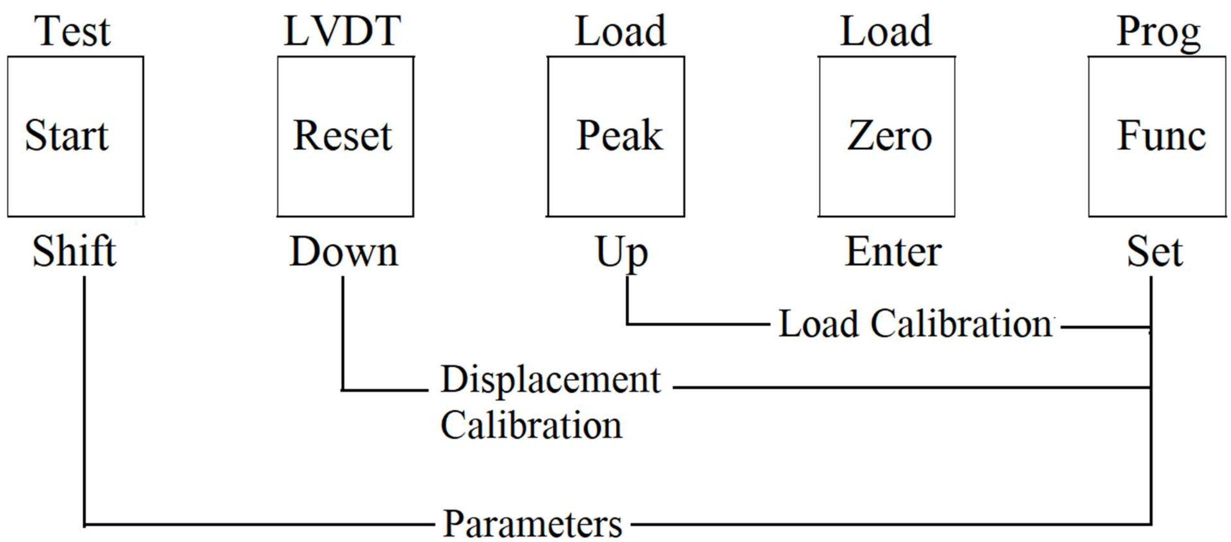


Fig. 4.5 Keys and their Functions (Source: Present Study)

4.4.Calibration:

4.4.1. Load

Load – Func +Peak

To calibrate load, press Func + Peak after that a dialog box will appear that will ask for a password. There is no need to insert any password. All that has to be done is to press Enter. Then it will ask for the values that need to be calibrated. Input the values using Peak and Zero keys that are equivalent to up and down. To insert the value the cursor can be toggled between unit digit, tens digit and hundreds digit, after that just use Peak and Zero to insert the desired value.

4.4.2. Displacement

Displacement – Func + Reset

To calibrate displacement, press Func + Reset after that a dialog box will appear that will ask for a password. There is no need to insert any password. All that has to be done is to press Enter. Then it will ask for the values that need to be calibrated. Input the values using Peak and Zero keys that are equivalent to up and down. To insert the value the cursor can be toggled between unit digit, tens digit and hundreds digit, after that just use Peak and Zero to insert the desired value.

4.5.Storage

For storage of data, Start key has to be pressed before performing the experiment the data storage will begin only after pressing Start button. Now as the rod and cone are pushed into the ground, the data will be simultaneously store in a table format. To end the storage, Reset button has to be pressed. The data will automatically store in the pen drive.

CHAPTER 5

EXPERIMENTAL WORK

This experiment can be performed only on these types of soil: Soft clayey soil, loose sandy soil and all easily permeable soils.

Scope: The purpose of this is to investigate soil stratigraphy through cone resistance.

5.1.Load Cell

Load cell is used in this project to measure the load applied. Basically load cells are tools that converts the applied load to electrical signal. The more the load applied, the more will be the value of electrical signal generated. Load cells are basically of 3 kinds:

- Hydraulic
- Pneumatic
- Strain Gauge

For this project, a strain gauge load cell has been used, whose resistance is directly proportion to the applied load. With the help of Wheatstone bridge, the voltage can be measured easily.

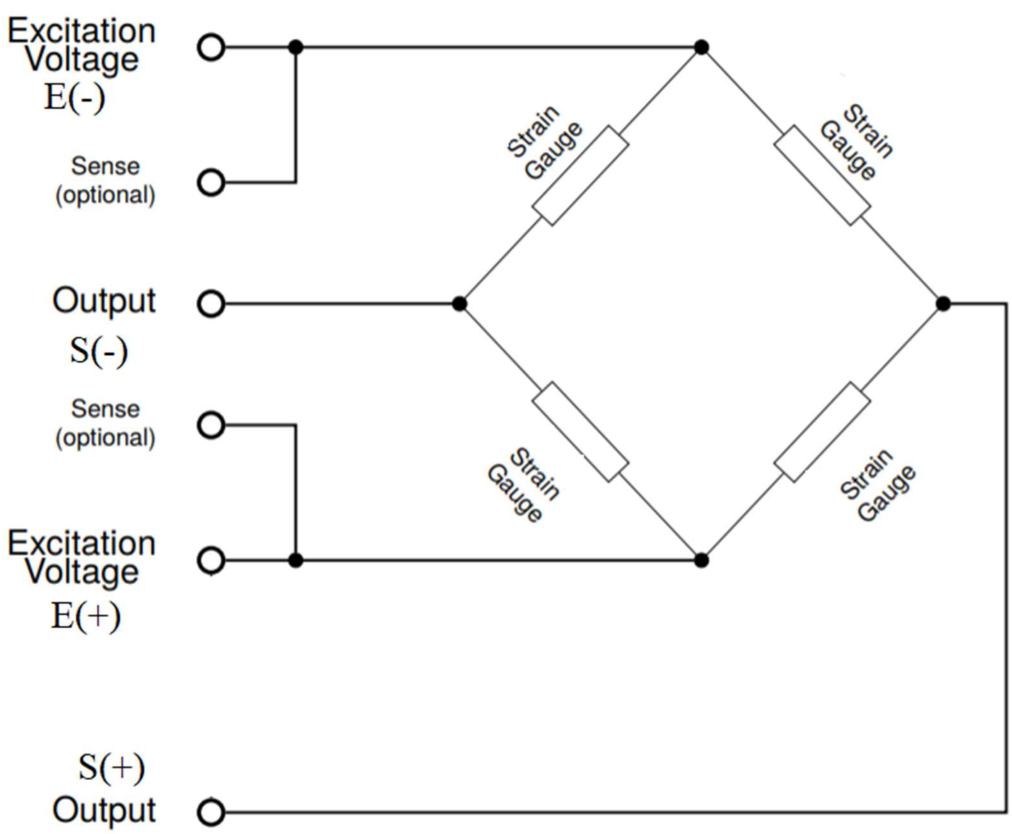


Fig. 5.1 Basic arrangement of four or six strain gauges in a load cell (Source: Present Study)

The load cell that has been chosen for this project is a single point load cell in which four strain-gauges have been placed in a Wheatstone bridge formation. It is placed by fixing one corner of load cell with the wires, and then a force is applied perpendicularly on the other corner of the load cell that has an arrow. The load cell has been placed in a cantilever beam position. When the load is applied, the tensions and compressions are calculated by the 4 strain gauges.

Shape specific Load Cell:

- Pancake Load Cell
- Button Load Cell
- Thru-Hole/Ring Load Cell
- Load Beam Cell
- S-Type Load Cell
- Rod-Type Load Cell

5.2. Linear Potentiometer

Linear potentiometers produce a resistance output that varies according to the displacement or position of a slider or wiper. They are variable resistors with three leads. Two leads connect to the ends of the resistor, so the resistance between them is fixed. The third lead connects to a slider that travels along the resistor varying the resistance between it and the other two connections. The resistance element is excited by either DC or AC voltage. This video discusses potentiometers in general and compares linear and logarithmic tapers.

One of the most common application is measuring of displacement. To measure the displacement of the body, which is movable, is connected to the sliding element located on the potentiometer. As the body moves, the position of the slider also changes accordingly so the resistance between the fixed point and the slider changes. Due to this the voltage across these points also changes.

The change in resistance or the voltage is proportional to the change in the displacement of the body. Thus the voltage change indicates the displacement of the body. This can be used for the measurement of translational as well as well rotational displacement. Since these potentiometers work on the principle of resistance, they are also called as the resistive potentiometers. Range can vary upto 50 inches.

Fig. 5.2 Linear Potentiometer (Source: Present Study)

5.3.Experimental Procedure:

1) Calibrate both the load and displacement using the keys as mentioned above.
2) Place the digital static cone penetrometer perpendicular to the ground.
3) Check the readings in the display. If it shows value other than zero, then change it to zero.
4) Press the start button on the data acquisition system.
5) Start pushing the digital static cone penetrometer into the ground with a consistent force.
6) There must not be any jerked pushes as it will affect the readings also.
7) After hitting the end, press reset button and pull the rod out of the ground.

The reading will automatically be taken by Digital Static Cone Penetrometer. It will be shown in the form of a table. The file is either in the form of excel file.

Fig. 5.3 Experiment using Digital Static Cone Penetrometer. (Source: Present Study)

CHAPTER 6

RESULT AND DISCUSSIONS

6.1.Reading before implementation of Linear Potentiometer

Tests were done on OAT soil and following results were calculated:
These tests are done before the implementation of Linear Potentiometer i.e. Major Project I

6.1.1. Readings for Load and Displacement using 30º cone

Table 6.1: Readings for 30º Cone before the implementation of Linear Potentiometer.

For 30º cone (Area = 42.43cm^2 , length = 6.1cm)		
Load(kg)	**Penetration(cm)**	**Cone index(kg/cm^2)**
20	0.5	0.786
25	0.8	0.983
30	2.1	1.180
35	2.5	1.376
40	3.1	1.573
45	3.9	1.770
50	4.2	1.967

6.1.2. Readings for Load and Displacement using 45º cone

Table 6.2: Readings for 45º Cone before the implementation of Linear Potentiometer.

For 45º cone (Area = 31.68cm^2 , length = 4.1cm)		
Load(kg)	**Penetration(cm)**	**Cone index(kg/cm^2)**
20	-	0.63
25	-	0.79
30	0	0.94
35	0.5	1.10
40	1.9	1.26
45	3	1.42
50	3.6	1.57

6.2.Readings using Digital Static Cone Penetrometer

Soil for this experiment is taken from **Kabaddi ground** (Sports Complex) and it is performed using Digital Static Cone Penetrometer with USB Output.

6.2.1. Readings for Load and Displacement using 60º cone

Table 6.3: Load and Displacement using 60º cone.

Sl. No.	Load	Unit	Disp.	Unit
1	0	kg	0	mm
2	0.95	kg	4.1	mm
3	2.1	kg	6.4	mm
4	5.45	kg	8.9	mm
5	6.4	kg	15.6	mm
6	12.25	kg	19.6	mm
7	19.2	kg	21.3	mm
8	21.45	kg	27.5	mm
9	31.5	kg	35.8	mm
10	35.75	kg	38.9	mm
11	37.95	kg	44.4	mm
12	43.85	kg	50.1	mm
13	49.05	kg	52.8	mm
14	54.95	kg	54.7	mm
15	59.05	kg	59	mm
16	62.8	kg	61.8	mm
17	68.85	kg	64.4	mm
18	74.1	kg	67.6	mm
19	79.4	kg	69.6	mm
20	82.35	kg	72.4	mm
21	86.8	kg	78.8	mm
22	91.35	kg	81.1	mm
23	93.7	kg	86.6	mm
24	98.2	kg	92.6	mm
25	102.05	kg	94.5	mm
26	103.7	kg	98.7	mm
27	110.1	kg	102.1	mm
28	111.75	kg	105.8	mm
29	112.6	kg	111.4	mm
30	115.3	kg	117.9	mm

6.2.2. Readings for Load and Displacement using 45º cone

Table 6.4: Load and Displacement using 45º cone.

Sl. No.	Load	Unit	Disp.	Unit
1	0	kg	0	mm
2	1.2	kg	5.6	mm
3	4.2	kg	11.4	mm
4	6.4	kg	14.3	mm
5	12.4	kg	17	mm
6	15.8	kg	20.6	mm
7	21.2	kg	28.8	mm
8	25.9	kg	33.4	mm
9	30.4	kg	41.8	mm
10	35.25	kg	45	mm
11	42.5	kg	50.6	mm
12	47.8	kg	59	mm
13	50.95	kg	62.2	mm
14	57.7	kg	66.8	mm
15	67.65	kg	71	mm
16	73.25	kg	74.7	mm
17	81	kg	78.3	mm
18	88.65	kg	83.5	mm
19	93.35	kg	88.4	mm
20	98.8	kg	93.1	mm
21	100.3	kg	94.8	mm
22	105.9	kg	98.7	mm
23	111	kg	100.7	mm
24	115.65	kg	102.4	mm
25	118.95	kg	104.6	mm
26	125.65	kg	107.7	mm
27	127.4	kg	108.4	mm
28	131.05	kg	110.2	mm

6.2.3. Readings for Load and Displacement using 75º cone

Table 6.5: Load and Displacement using 75º cone.

Sl. No.	Load	Unit	Disp.	Unit
1	0	kg	0	mm
2	1.4	kg	4.5	mm
3	4.8	kg	10.8	mm
4	8.2	kg	13	mm
5	11.95	kg	22.2	mm
6	14.55	kg	26.1	mm
7	19.8	kg	30.2	mm
8	22.6	kg	34.6	mm
9	24.85	kg	39.6	mm
10	29.8	kg	40.25	mm
11	32.6	kg	47.8	mm
12	38.85	kg	50.6	mm
13	42.2	kg	54.1	mm
14	48.5	kg	58.7	mm
15	53.6	kg	63.8	mm
16	65.25	kg	70.3	mm
17	70.2	kg	76.4	mm
18	80.6	kg	83.6	mm
19	85.15	kg	87.9	mm
20	92.4	kg	91.4	mm
21	94.9	kg	98.8	mm
22	99.1	kg	102.4	mm
23	104.5	kg	106.3	mm
24	109.95	kg	109.6	mm
25	112.2	kg	110.9	mm
26	112.6	kg	111.5	mm
27	119.6	kg	118.7	mm
28	125.9	kg	119.3	mm
29	127.6	kg	119.7	mm
30	128.75	kg	120.5	mm

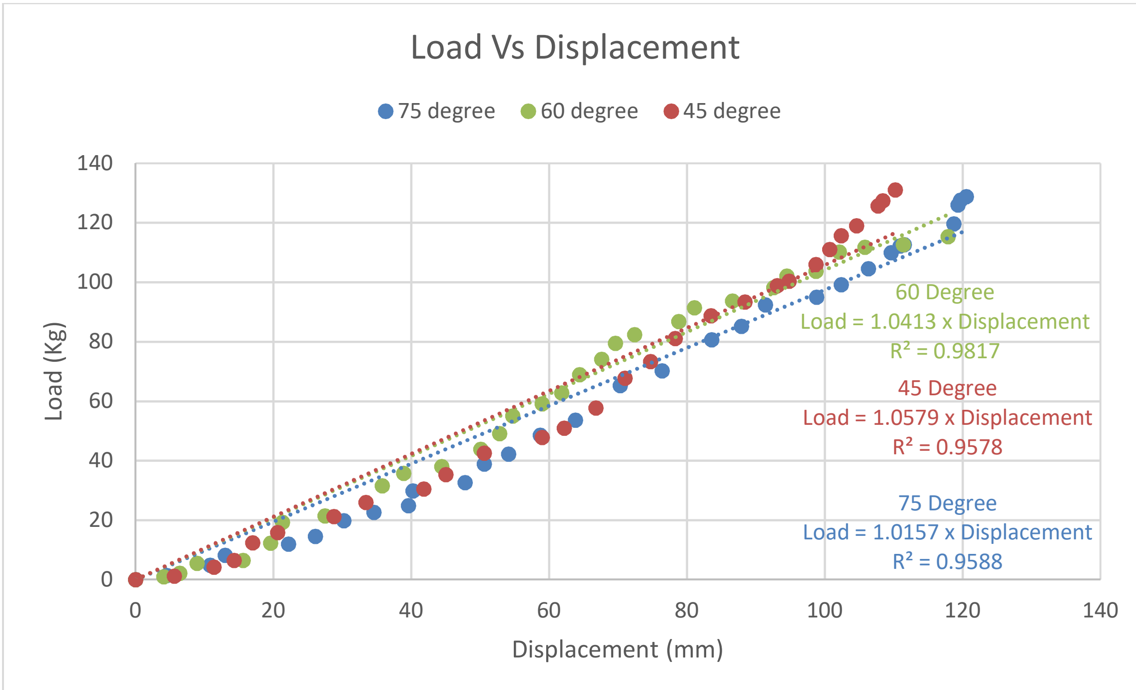


Fig. 6.1 Plot between Load and Displacement using 75º, 60º and 45º cone. (Source: Present Study)

6.3.Result and Discussions:

From above Plot between Load and Displacement, trendline is added for 75º, 60º and 45º plot. Using MS Office, following equations of trendline are added.

For 75º Curve: Load = 1.0157 x Displacement
For 60º Curve: Load = 1.0413 x Displacement
For 45º Curve: Load = 1.0579 x Displacement

Load = m x Displacement

Where,
m is a constant that depends upon angle of cone, material of cone and soil type.

To verify the reliability of a trendline, the R- Squared value is checked. The nearer R-Squared value is to one, the more reliable a trendline is. Following are the R- Squared values for 75º, 60º and 45º plot.

For 75º Curve: R^2 = 0.9588
For 60º Curve: R^2 = 0.9817

For 45º Curve: $R^2 = 0.9578$

From the Curves and trendlines, we found that for 60º trendline we get the most reliable data having $R^2 = 0.9817$

6.4.Future Scope

1. The output can be transferred using Bluetooth Technology. After this, readings can be directly sent to a person’s mobile or computer.
2. It can also be used for cyclic loading.
3. It can use real time data to take three variable into account.
   Time.
   Load
   Displacement.

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by Tarun Kumar

Submission date: 12-Jul-2018 04:00PM (UTC+0530)

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A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

MASTERS OF TECHNOLOGY

IN

GEOTECHNICAL ENGINEERING

Submitted by

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2K16/GTE/19

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MAY, 2018

Chapter 1

INTRODUCTION

1.1. Introduction

Cone Penetration Test (CPT) is used to find out the geotechnical properties of soils and precisely portray soil stratigraphy. Stratigraphy is a subdivision of geology which is related to the study of rock layers (strata) and stratification.

The two types of penetrometers that are being used to investigate soil by performing cone penetrometer tests are

1. Static Cone Penetrometer
2. Dynamic Cone Penetrometer

In the static cone penetrometer, the cone is pushed into the soil a specific distance at a constant rate of penetration. While in dynamic cone penetrometer, the cone is pounded through a specific distance in the soil by the means of hammer. Different blows of hammer are required for different types of soil.

The static cone penetrometer is the focus of this thesis and many modifications have been done in order to make the experimental procedure much simpler and less energy and time consuming. This thesis is based on the fabrication of digital static cone penetrometer that can record the data (readings) of load and displacement in a USB device and the format of the output would be a table comprising of 5 columns i.e. serial number, load, unit, displacement and unit. Each reading is taken in a fixed time interval. This digital static cone penetrometer reduces the time and effort that was required to perform the test earlier.

Table 1: Static Cone Penetration Test

STATIC CONE PENETRATION TEST	
Scope/Purpose	Investigation of soil stratigraphy through Cone Resistance
Description	The cone along with friction jacket is assembled at the point to be tested. The cone is penetrated using the inner sounding rod while the friction jacket remains in the same position. The gauge reading during this penetration is noted and termed as Cone Resistance. Then the friction jacket along with cone is pushed in to the soil which determines the total resistance of the soil which includes the frictional resistance.
Results	Type of soil, Depth of different layers, Natural Water Table, Consistency of the soil.
Application	Obtain cone resistance, friction ratio, undrained shear strength and cohesion
Suitable Soil Types	Soft Clayey Soil, Loose Sandy Soil and all easily permeable soil.
IS Codes	IS 4968.3.1976

1.2. Development of Cone Penetration Test (CPT)

The pioneer of the CPT was fabricated and tests were ripened in Holland from 1932 to 1937 by Barentsen. What he did was to make a sleeve-type machinery which comprised of a conical head, sounding rods and covering. The resistance is calculated by using a hydraulic gauge that has a manometer placed at the last part of the rod which was placed near the handles of the static cone penetrometer.

In the United States of America, a static penetration device was designed by Terzaghi in 1929 and that was the foremost mechanized static penetrometer. This device comprised a conical head, sounding rods and covering. It would be pushed into the soil using hydraulic jack upto the distance required to be investigated.

Busiman brought his static penetrating device in Holland in 1940. This penetrating device comprised a cone of 60^o apex angle and a $10cm^2$ area of base of the cone, where the diameter of the base is same as the diameter of the covering. This penetrometer device was afterwards modified by DSML (Delft Soil Mechanics Laboratory) by installing a hydraulic piston in place of the mechanical piston.
In 1945, Delft Soil Mechanics Laboratory with the help of Gaudsche Machine Fabric produced 2500 kg capacity penetrometers. In 1947, Delft Soil Mechanics Laboratory with the help of Gaudsche Machine Fabric were able to make a 10000 kg capacity manual penetrometer. Both machine were fabricated to calculate the resistance of cone and total friction of the soil.

To prevent soil particles from going into annular space between covering and sounding rods, the veil developed by DSML (Vermeidin 1948). Since 1948, a large variety of Cone Penetration Test equipment have been produced across the world and it has been used for various purposes across the world.

1.3. Description of Humboldt Static Cone Penetrometer.

A company named Humboldt designed a Digital Static cone penetrometer which can give the data (readings) on the screen. It also gave correlations between various other tests also. Following are the description of the Digital Static cone penetrometer made by Humboldt:

The Digital Static cone penetrometer comprises of a big display that is very simple to read, manifold selection able units, two handles, two rods - starter rod and extension rod that is available with an extra length and a $150mm^2$ cone with apex angle 60^o.

1.3.1. Testing Sequence

1) Tare Display: Press this when the Digital Static cone penetrometeris set at horizontal level.

2) Apply Force: The penetrometer device is held in position i.e. perpendicular to the soil. Now a constant pressure is applied to the padded handle so that the cone will drive through soil. The friction on the outside rod will not affect the reading of penetrometer. Then the load applied will be read directly via the rod on to the load cell and then the reading will be displayed on the screen.

3) Depth of Penetration: The penetration depth will be different for different application.

4) Refusal: If there is existence of any rock layer, then one of the two things will happen:

- Penetration will be stopped
- Cone will be deflected

Forced penetration must not be done as it would result in wrong reading and in the worst case it could damage the cone or load cell that is being used.

1.3.2. Correlations:

Some correlation with other tests have been made by Humboldt. Some of these tests are:

- Standard Penetration (Blow counts)
- California bearing ratio (CBR)
- Reading of cone index (Q_c) and soil constants are not absolute

All the calculations must be done using $kgcm^{-2}$ for cone index reading.

Standard Penetration (for Humboldt SCPT)

- Uniform clay and silty clay.
  $Q_c = 4$ "N".

$Q_c = 5\ Q_u$
$Q_c = 10\ c$

- Clayey Silts
  $Q_c = (10\text{-}20)\ Q_u$
  $Q_c = (20\text{-}40)\ c$

- CBR Value (%)
  $Q_c = (2.5\text{-}3.3)$ CBR

Where,

N- Number of blows.

Q_c – Cone Index.

c – Cohesion (kg/cm^2)

Q_u – Unconfined Compression (kg/cm^2)

These correlations are not for my Digital Static cone penetrometer. These are given by manufacturing company which is Humboldt and can be used for that device only.

Table 2: Correlations of Humboldt's Digital Static Cone Penetrometer

Standard Penetration	Strength and Cohesion	CBR Value (1%)
Test "N" Value Q_c = 4 "N"	Q_u – Unconfined Compression (Kg/cm^2) c - Cohesion (Kg/cm^2) Uniform Silt and Silty Clays: $Q_c = 5\ Q_u$ $Q_c = 10$ c Clayey Silts: Q_c = (10 to 20) Q_u Q_c = (20 to 40) c	Q_c = (2.5 to 3.3) CBR

CHAPTER 3

FABRICATION OF DIGITAL STATIC CONE PENETROMETER

3.1.Components of Digital Static Cone Penetrometer.

The Digital Cone Penetrometer comprises:

A measuring body with 2 push handles.
1 stainless steel sounding rods (D = 16 mm, L = 498 mm)
1 stainless steel sounding rods (D = 19 mm, L = 210 mm)
4 conical tips, i.e. 30°, 45°, 60°, 75°.
1 LVDT with a displacement range of 200mm
1 Data Acquisition System with USB output
1 Load cell with a capacity of 300 kg

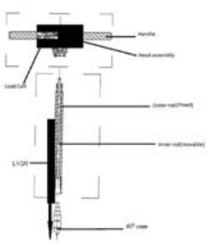
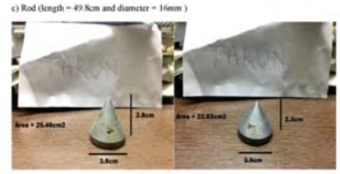


Fig. 1 Components of Digital Static Cone Penetrometer.
(Source: https://geotechnicaldesign.info/fotobank/cone-penetration-test.html and edited in paint.)

a) 30°cone b) 45° cone

c) Rod (length = 49.8cm and diameter = 16mm)



d) 60° cone e) 75°cone

Fig. 2 Dimensions of Cones and Rod

a) 30° cone – Depth = 6.1cm, Diameter = 3.6cm, Area = 42.43cm^2.

b) 45° cone – Depth = 4.1cm, Diameter = 3.6cm, Area = 31.68cm^2;

c) Rod - Length = 49.8cm, Diameter = 16mm;

d) 60° cone – Depth = 2.8cm, Diameter = 3.6cm, Area = 25.46cm^2;

e) 75° cone - Depth = 2.3cm, Diameter = 3.6cm, Area = 22.63cm^2;

(Source: Present Study)

Table 4: Dimensions of Cones

Degree of Cone(°)	Depth(cm)	Diameter (cm)	Area (cm^2)
30 °	6.1	3.6	42.43
45 °	4.1	3.6	31.68
60 °	2.8	3.6	25.46
75 °	2.3	3.6	22.63

Fig. 5 Digital Static cone Penetrometer (Source: Present Study)

3.2.Specification of Digital Static Cone Penetrometer:

3.2.1. Linear Variable Differential Transformer (LVDT)

Range of Displacement–0 to 200mm

Least Count –0.1mm

Port Used - 2mV/V

3.2.2. Load Cell

Range of Load – 0 to 300kg

Least count – 0.05kg

Port Used – 2mV/V

3.2.3. Data Acquisition System

LCD display - 16 x 2 LINE DOT MATRIX DISPLAY

Motherboard - PIC18FH6K80

ADC (Analog to Digital Convertor) – ADS1232

CHAPTER 4

WORKING OF DIGITAL STATIC CONE PENETROMETER

4.1.Working Procedure:

To use the Digital static cone penetrometer, a consistent load has to be applied on the handle bars provided at the head assembly of the penetrometer. The applied load will push the rod and cone into the ground. The Digital static cone penetrometer must be held perpendicular to the ground. The load that is being applied will be measured by the load cell mounted at the end of rod. The load cell will send the electrical signal to the Data acquisition system which will convert the electrical or analog signal to digital. This will be shown on the screen and then will be transferred to a USB. Jerking pushes should be evaded as they will give data that will be too high and it will not represent the soil.

As the rod and cone are pushed into the ground, LVDT will also be working along with load cell. LVDT is used here to determine the displacement or penetration of the Digital static cone penetrometer. As for how it works, LVDT also sends an electrical signal to transmit data. LVDT is calibrated at the initial ground level and that position shows the reading of LVDT as zero. As the rod and cone are pushed into the ground, LVDT will start to read the difference in position and will start sending electrical data for different location after fixed interval of time. This data will then be converted from electrical signal to digital and the result will be shown on the screen. Afterwards, it will be stored in a USB.

The essential component for the working of this Digital static cone penetrometer is Data Acquisition System. It contains:

- Motherboard
- LCD Display
- Storage device point
- Keyboard
- Stepdown Transformer
- ADC (Analog to Digital Convertor)
- 1 LVDT port
- 1 Load cell port

Both the data from Load cell and LVDT came in the form of electrical signal. The ADC in this system converts the electrical signals to digital, thus enabling it to be displayed on the screen to make the task shorter, simpler and less energy taking. To make it effortless and even simpler, it has been provided with output recorder. The output storage point is a USB. The data which is displayed on the screen is also stored in the USB in a table format. The table consists of 5 columns – serial number, load, unit, displacement and unit.

To measure the resistance to penetration (kg/cm^3) of the soil,divide the value of load measured by the surface area of conical tip. The value of this resistance is used to determine the surface of the conical tip to be used i.e. *for higher reading of this resistance, a conical tip with smaller area has to be applied and for lower reading of this resistance, a conical tip with larger area has to be used.*

4.2.Working of Data Acquisition System:

In Data Acquisition System, the voltage of domestic household supply (220V) is reduced by using stepdown transformer. The stepdown transformer changes the high voltage (HV) and low current from primary side to low voltage (LV) and high current value to secondary side.

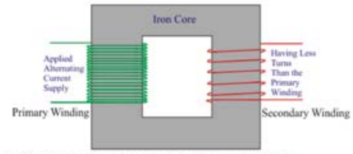


Fig. 6 Stepdown Transformer (Source: https://www.electrical4u.com/step-down-transformers/)

Then the alternating current is converted to direct current with the use of a rectifier. Then the current is passed on to the motherboard which is connected to every other part of the data acquisition system i.e. key panel, LCD display, storage device port, ADC. Now the mother board will transmit the data accordingly.

When the experimental procedure is started, Load cell and LVDT starts sending electrical signals to their respective port i.e. 4 wire port and 3 wire port. The data received by the sensors is forwarded to ADC (Analog to Digital Convertor). The digital data is now sent to the LCD display via the motherboard. And the data will be shown on the display below their respective title. Now the data sent to LCD display will also be sent to USB output where the data will be transferred and stored in a table format comprising – S. No., Load, Unit, Displacement, Unit. It takes a large number of readings within a minute.

The circuit of the Data acqusition system is given below. The wiring is also shown in the circuit diagram. It is labelled and brief depiction of the circuit used in the Data acquisition system.

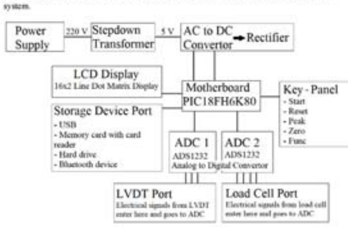


Fig. 7 Circuit of Data Acquisition System(Source: Present Study)

Fig. 8 Data Acquisition System (Source: Present Study)

The Specifications of the data acquisition system are given below and all the parts are explained as well. The Parts are:

a) LCD display: 16 x 2 LINE DOT MATRIX DISPLAY

It contain 16 columns and 2 rows. In the first row, the title appears - i) LVDT and ii) Load. In the second row the readings of Load and Displacement is displayed.

b) Motherboard: PIC18FH6K80

A motherboard is the main printed circuit board (PCB) mostly found in microprocessor. It acts like a connector for other peripherals.

c) ADC: ADS1232

ADC is basically an Analog to Digital Convertor. It converts analog signal such as sound, light or electrical signal into digital signal.

d) LVDT: 200mm range and 2 mV/V port
e) Load Cell: 300kg capacity and 2 mV/V port

2mV/V sensitivity means if an excitation voltage of 1V is provided then output voltage produced will be 2mV i.e. if 6V excitation voltage is provided the output voltage produced will be 12mV.

f) Key Panel: Five keys are provided namely start, reset, peak, zero and func. It is used for calibration and recording the output of the experiment.

Fig. 9 Key Panel (Source: Present Study)

2mV/V sensitivity means if an excitation voltage of 1V is provided then output voltage produced will be 2mV i.e. if 6V excitation voltage is provided the output voltage produced will be 12mV.

4.3.Keys and Function of Data Acquisition System

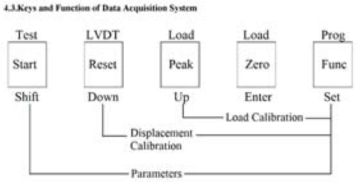


Fig. 10 Keys and their Functions (Source: Present Study)

4.4.Calibration:

4.4.1. Load

Load – Func +Peak

To calibrate load, press Func + Peak after that a dialog box will appear that will ask for a password. There is no need to insert any password. All that has to be done is to press Enter. Then it will ask for the values that need to be calibrated. Input the values using Peak and Zero keys that are equivalent to up and down. To insert the value the cursor can be toggled between unit digit, tens digit and hundreds digit, after that just use Peak and Zero to insert the desired value.

4.4.2. Displacement

Displacement – Func + Reset

To calibrate displacement, press Func + Reset after that a dialog box will appear that will ask for a password. There is no need to insert any password. All that has to be done is to press Enter. Then it will ask for the values that need to be calibrated. Input the values using Peak and Zero keys that are equivalent to up and down. To insert the value the cursor can be toggled between unit digit, tens digit and hundreds digit, after that just use Peak and Zero to insert the desired value.

4.5.Storage

For storage of data, Start key has to be pressed before performing the experiment the data storage will begin only after pressing Start button. Now as the rod and cone are pushed into the ground, the data will be simultaneously store in a table format. To end the storage, Reset button has to be pressed. The data will automatically store in the pen drive.

CHAPTER 5

EXPERIMENTAL WORK

This experiment can be performed only on these types of soil: Soft clayey soil, loose sandy soil and all easily permeable soils.

Scope: The purpose of this is to investigate soil stratigraphy through cone resistance.

5.1.Load Cell

Load cell is used in this project to measure the load applied. Basically load cells are tools that converts the applied load to electrical signal. The more the load applied, the more will be the value of electrical signal generated. Load cells are basically of 3 kinds:

- Hydraulic
- Pneumatic
- Strain Gauge

For this project, a strain gauge load cell has been used, whose resistance is directly proportion to the applied load. With the help of Wheatstone bridge, the voltage can be measured easily.

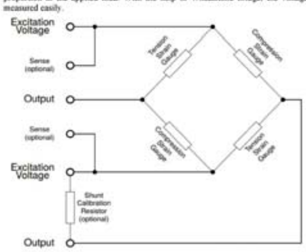


Fig. 11 Basic arrangement of four or six strain gauges in a load cell
(Source: https://www.omega.com/techref/pdf/StrainGage_Measurement.pdf)

The load cell that has been chosen for this project is a single point load cell in which four strain-gauges have been placed in a Wheatstone bridge formation. It is placed by fixing one corner of load cell with the wires, and then a force is applied perpendicularly on the other corner of the load cell that has an arrow. The load cell has been placed in a cantilever beam position. When the load is applied, the tensions and compressions are calculated by the 4 strain gauges.

Shape specific load cell:

- Pancake Load Cell
- Button Load Cell
- Thru-Hole/Ring Load Cell
- Load Beam Cell
- S-Type Load Cell
- Rod-Type Load Cell

5.2.Linear Variable Differential Transformer (LVDT)

LVDT is an abbreviation for Linear Variable Differential Transformer. It is also known as Linear Variable Displacement Transformer and Linear Variable Displacement Transducer or to put it simply it is said differential transformer also. LVDT is a type of electrical transformer which is used to calculate displacement. An equivalent device to LVDT that is used to calculate rotary displacement is known as Rotary Variable Differential Transformer (RVDT).

The LVDT converts a deformation from a point into a proportional electrical signal which contains phase that is used for direction and amplitude that is used to record distance information. The LVDT operation depends on electromagnetic coupling so it need no contact of moving part and coil assembly. The Linear Variable Displacement Transformer consists of 3 coils of solenoid that are placed end to end around a tube. The coil at the center is known as primary and the other 2 coils are secondary coils placed at top and bottom. An AC starts the primary coil and due to the primary coil, voltage is induced in both the secondary coil (top and bottom). The voltage induced will be directly proportion to the length of the primary that has been linked with the secondary.

Fig. 12 Linear Variable Differential Transformer (LVDT)(Source: Present Study)

It is a transducer that changes the linear motion to corresponding electrical signal. Linear variable differential transformer can calculate positions upto a few millionths of one inch but LVDT can also calculate movement upto ±30 inches (±762 mm).

5.3.Experimental Procedure:

1) Calibrate both the load and displacement using the keys as mentioned above.
2) Place the digital static cone penetrometer perpendicular to the ground.
3) Check the readings in the display. If it shows value other than zero, then change it to zero.
4) Press the start button on the data acquisition system.
5) Start pushing the digital static cone penetrometer into the ground with a consistent force.

6) There must not be any jerked pushes as it will affect the readings also.
7) After hitting the end, press reset button and pull the rod out of the ground.

The reading will automatically be taken by Digital Static Cone Penetrometer. It will be shown in the form of a table. The file is either in the form of excel file or pdf.

Fig. 13 Experiment using Digital Static Cone Penetrometer. (Source: Present Study)

CHAPTER 6

RESULT AND CALCULATIONS

6.1.Reading before implementation of LVDT

Tests were done on OAT soil and following results were calculated:
These tests are done before the implementation of LVDT i.e. Major Project I

6.1.1. Readings for Load and Displacement using 30° cone

Table 5: Readings for 30° Cone before the implementation of LVDT.

For 30° cone (Area = 42.43cm², length = 6.1cm)		
Load(kg)	**Penetration(cm)**	**Cone index(kg/cm²)**
20	0.5	0.786
25	0.8	0.983
30	2.1	1.180
35	2.5	1.376
40	3.1	1.573
45	3.9	1.770
50	4.2	1.967

6.1.2. Readings for Load and Displacement using 45° cone

Table 6: Readings for 45° Cone before the implementation of LVDT.

For 45° cone (Area = 31.68cm², length = 4.1cm)		
Load(kg)	**Penetration(cm)**	**Cone index(kg/cm²)**
20	-	0.63
25	-	0.79
30	0	0.94
35	0.5	1.10
40	1.9	1.26
45	3	1.42
50	3.6	1.57

6.2.Readings using Digital Static Cone Penetrometer

Soil for this experiment is taken from **Kabaddi ground** (Sports Complex) and it is performed using Digital Static Cone Penetrometer with USB Output.

6.2.Readings using Digital Static Cone Penetrometer

Soil for this experiment is taken from **Kabaddi ground** (Sports Complex) and it is performed using Digital Static Cone Penetrometer with USB Output.

6.2.1. Readings for Load and Displacement using 60º cone

Table 6.3: Load and Displacement using 60º cone.

Sl.No.	Load	Unit	Disp.	Unit
1	0	kg	0	mm
2	0.95	kg	4.1	mm
3	2.1	kg	6.4	mm
4	5.45	kg	8.9	mm
5	6.4	kg	15.6	mm
6	12.25	kg	19.6	mm
7	19.2	kg	21.3	mm
8	21.45	kg	27.5	mm
9	31.5	kg	35.8	mm
10	35.75	kg	38.9	mm
11	37.95	kg	44.4	mm
12	43.85	kg	50.1	mm
13	49.05	kg	52.8	mm
14	54.95	kg	54.7	mm
15	59.05	kg	59	mm
16	62.8	kg	61.8	mm
17	68.85	kg	64.4	mm
18	74.1	kg	67.6	mm
19	79.4	kg	69.6	mm
20	82.35	kg	72.4	mm
21	86.8	kg	78.8	mm
22	91.35	kg	81.1	mm
23	93.7	kg	86.6	mm
24	98.2	kg	92.6	mm
25	102.05	kg	94.5	mm
26	103.7	kg	98.7	mm
27	110.1	kg	102.1	mm
28	111.75	kg	105.8	mm
29	112.6	kg	111.4	mm
30	115.3	kg	117.9	mm

6.2.2. Readings for Load and Displacement using 45º cone

Table 6.4: Load and Displacement using 45º cone.

Sl.No.	Load	Unit	Disp.	Unit
1	0	kg	0	mm
2	1.2	kg	5.6	mm
3	4.2	kg	11.4	mm
4	6.4	kg	14.3	mm
5	12.4	kg	17	mm
6	15.8	kg	20.6	mm
7	21.2	kg	28.8	mm
8	25.9	kg	33.4	mm
9	30.4	kg	41.8	mm
10	35.25	kg	45	mm
11	42.5	kg	50.6	mm
12	47.8	kg	59	mm
13	50.95	kg	62.2	mm
14	57.7	kg	66.8	mm
15	67.65	kg	71	mm
16	73.25	kg	74.7	mm
17	81	kg	78.3	mm
18	88.65	kg	83.5	mm
19	93.35	kg	88.4	mm
20	98.8	kg	93.1	mm
21	100.3	kg	94.8	mm
22	105.9	kg	98.7	mm
23	111	kg	100.7	mm
24	115.65	kg	102.4	mm
25	118.95	kg	104.6	mm
26	125.65	kg	107.7	mm
27	127.4	kg	108.4	mm
28	131.05	kg	110.2	mm

6.2.3. Readings for Load and Displacement using 75º cone

Table 6.5: Load and Displacement using 75º cone.

Sl.No.	Load	Unit	Disp.	Unit
1	0	kg	0	mm
2	1.4	kg	4.5	mm
3	4.8	kg	10.8	mm
4	8.2	kg	13	mm
5	11.95	kg	22.2	mm
6	14.55	kg	26.1	mm
7	19.8	kg	30.2	mm
8	22.6	kg	34.6	mm
9	24.85	kg	39.6	mm
10	29.8	kg	40.25	mm
11	32.6	kg	47.8	mm
12	38.85	kg	50.6	mm
13	42.2	kg	54.1	mm
14	48.5	kg	58.7	mm
15	53.6	kg	63.8	mm
16	65.25	kg	70.3	mm
17	70.2	kg	76.4	mm
18	80.6	kg	83.6	mm
19	85.15	kg	87.9	mm
20	92.4	kg	91.4	mm
21	94.9	kg	98.8	mm
22	99.1	kg	102.4	mm
23	104.5	kg	106.3	mm
24	109.95	kg	109.6	mm
25	112.2	kg	110.9	mm
26	112.6	kg	111.5	mm
27	119.6	kg	118.7	mm
28	125.9	kg	119.3	mm
29	127.6	kg	119.7	mm
30	128.75	kg	120.5	mm

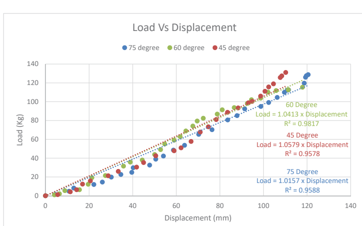


Fig. 6.1 Plot between Load and Displacement using 75º, 60º and 45º cone. (Source: Present Study)

6.3.dFuture Scope

The output can be transferred using Bluetooth Technology. After this, readings can be directly sent to a person's mobile or computer.

FABRICATION OF A DIGITAL STATIC CONE PENETROMETER WITH USB OUTPUT

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