# EXPERIMENTAL STUDY OF MOISTURE CONTENT ON STABILITY OF STONE COLUMN

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

## MASTER OF TECHNOLOGY

**IN**

## GEOTECHNICAL ENGINEERING

**BY**

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## CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report entitled "**EXPERIMENTAL STUDY OF MOISTURE CONTENT ON STABILITY OF STONE COLUMN**" in the partial fulfillment of the requirements for the award of the degree of "Master of Engineering" in geotechnical engineering submitted in the Department of Civil Engineering , Delhi Technological University, is an authentic record of our own work carried out from DECEMBER 2016 to JUNE 2017 under the supervision of **PROFESSOR KONGAN ARYAN** , Department of Civil Engineering.

I have not submitted the matter embodied in the report for the award of any other degree or diploma .

Avineesh kumar Singh

Date: 30 JUNE 2017 (2K15/GTE/07)

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## CERTIFICATE

This is to certify that above statement made by the candidate is correct to best of my knowledge .

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## ABSTRACT

Stone column is a ground improvement method for shallow foundation structures and is a popular method now days. Diameter of stone column can vary from 300 mm to 1000 mm and length can be up to 10m. Stone aggregates of particle size 10mm to 70 mm are used for stone column construction. Stability of stone column depends on so many factors such as relative compaction of stone column material, confining pressure offered by surrounding soil, stress concentration ratio, loading condition, stress history of soil, gradation of stone column material, spacing of stone column, dimensions of stone column etc. In this paper, we have discussed the variation in stability of stone column with the confining pressure of surrounding soil. By stability, we are actually dealing with the load carrying capacity of stone column. Confining pressure offered by the surrounding soil depends on the shear strength of the soil. And shear strength of soil is a function of its moisture content.

Here, we have changed the shear strength of soil by changing its moisture content and then computed the load carrying capacity of stone column experimentally.

A graph has also been given which shows the relationship between shear strength of confining soil and load carrying capacity of stone column.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Preamble

Stone column is a ground improvement technique which is now a days using widely due to its economical and easier construction. They are also known as granular columns or granular piles. Stone column can be thought of as a combination of concrete pile and sand drain. Like concrete piles, stone columns increases the bearing capacity of the soil, reduces the settlement and like sand drains, stone columns provide a drainage path for to water which is not possible in concrete piles. This property of stone column leads to accelerated consolidation in fine grained soil. Unlike concrete piles, stone columns needs no settling time and can be loaded just after their installation. Stone columns generally are of diameter 0.6m to 1m and depth can be 5m to 20m. Factors affecting stone column's efficiency are: - stress concentration ratio, angle of internal friction of column material, shear strength of surrounding soil, elastic modulus of the stone column, area ratio etc. Stone columns can be end bearing or friction type. The modes of failure of stone columns under compressive loads are: - bulging, general shear failure and sliding. Critical length of a stone column is about 4 times its diameter. A long stone column having a length greater than its critical length fails due to bulging irrespective of whether it is end bearing or floating (IS 15284 part I : 2003). As we go below the ground surface, confining pressure increases, so their chances of bulging is less .Stone column bulge somewhere near the top.

## 1.2. Functions of Stone Column

Stone column becomes a very popular ground improvement technique. Functions of stone column which makes it that much popular are as follows.

1. Installation of stone column improves ground by reducing soil settlement. Due to its higher modulus of elasticity than that of soil, it absorbs more load than soil and reduces overall settlement.

2. Since applied load distributes in between soil and stone column in the ratio of their stiffness ratios, load carrying capacity of soil also increases.
3. Stone aggregates are used to fill stone column. Water can easily pass into the stone column. So, stone column helps in excess pore water pressure mitigation and accelerates the consolidation process.
4. Stone columns provide stability to structure under rapid loading condition such as earthquake. Since excess pore water pressure mitigates easily, chances of failure under earthquake condition reduces.

## 1.3. Installation Techniques

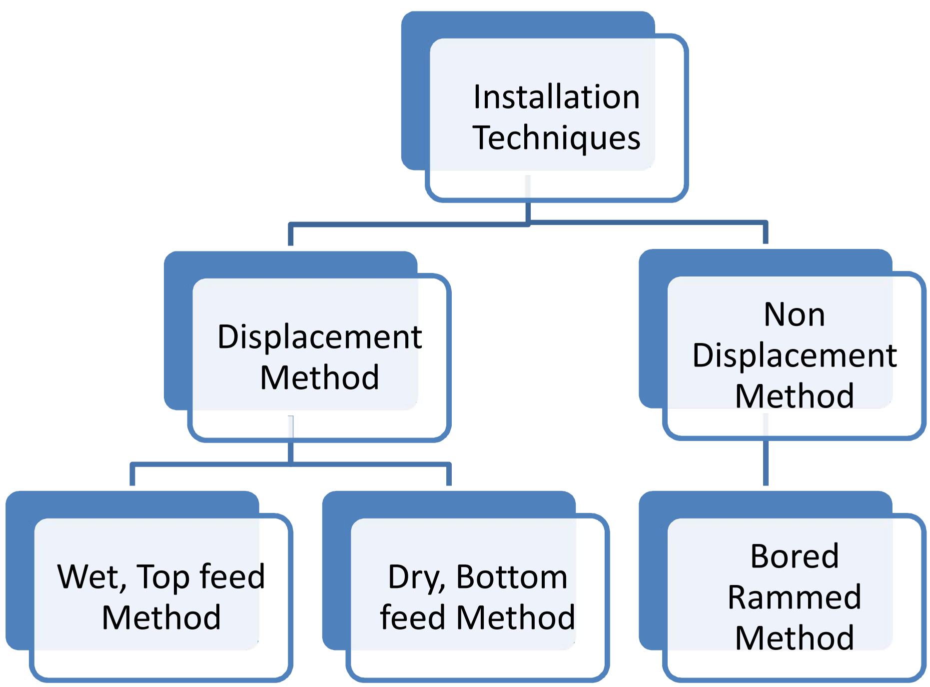


**Figure 1.1 Installation Techniques**

### 1.3.1. Displacement Method:-

In displacement method, boring is done by displacing the nearby soil. Soil is displaced laterally, due to which engineering property of soil may change. Hole can be made by driving casing or tube into the ground. Best example of displacement method is vibrofloat method which is using widely now. Vibroflotation can be done by following two ways.

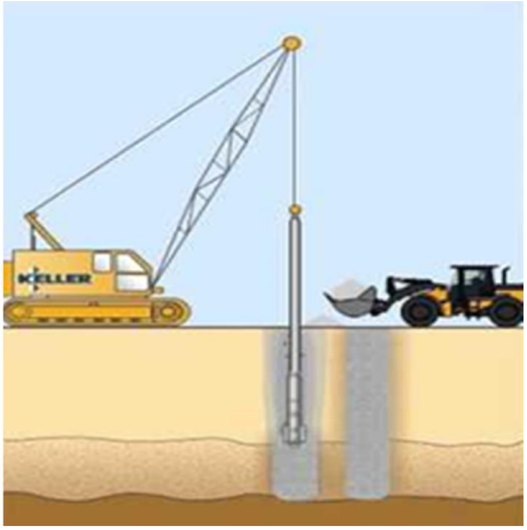


Figure 1.2. Vibroflotation Method (Ambily A.P. and Gandhi Shailesh R. (2007))

#### 1.3.1.1. Wet, Top Feed Method:

This method is used for soft soil in which bore hole is not stable. This method can also be used if water table is very high. In this method, vibrofloat is inserted into the soil by its own weight. After full depth penetration, stone aggregate is poured from the top

.

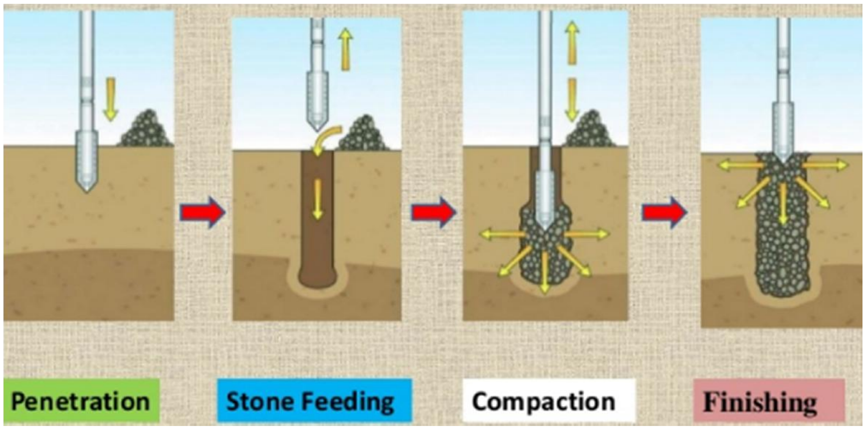


Figure 1.3. Wet, Top Feed Vibroflotation Method (Ambily A.P. and Gandhi Shailesh R. (2007))

#### 1.3.1.2. Dry, Bottom Feed Method:

In this method, feeding of aggregate is done at the bottom with help of a pipe which connects top and bottom of vibrofloat. This method is used at low water table condition, for soil having high shear strength, in which bore can stand on its own.

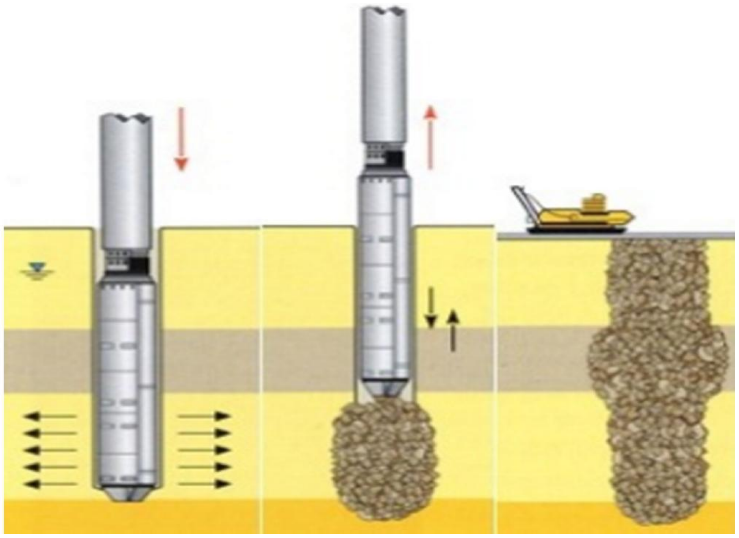

**Figure 1.4. Dry, Bottom Feed Vibroflotation Method (Ambily A.P. and Gandhi Shailesh R. (2007))**

**1.3.2. Non Displacement Method:**

In this method, boring is done without displacing nearby soil. Although there will be some displacement buy can be neglected. Ex:- bored rammed method.

**1.3.2.1. Bored Rammed Method**:

This method consists of a casing and a hammer. Casing is driven into the soil by mean of external pushing force given by hammer. After formation of bore hole, stone aggregate is poured into the bore hole and compacted by hammer. Stone column derives its strength from the lateral confinement provided by the surrounding soil. So soil should have more shear strength and low sensitivity.

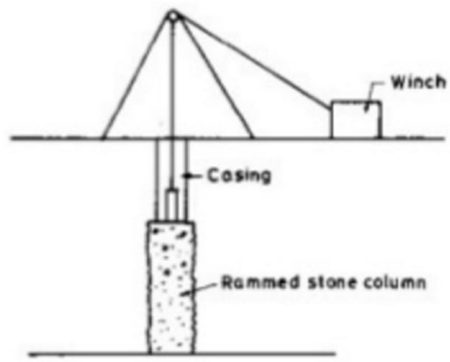


**Figure 1.5. Bored Rammed Method (IS 15289 part I : 2003)**

## 1.4. Factors Affecting Strength of Stone Column

To know about the strength of stone column, first we should know the factors which can affect the strength of stone column. There are so many factors which can affect the stability of stone column such as stress history of soil, rate of loading, loading condition, engineering properties of soil, physical properties of stone column etc. But only important factors are explained below.

### 1.4.1. Diameter of Stone Column

Diameter is the basic parameter of stone column. Increase in diameter will increase the cross section of the stone column and hence load carrying capacity of the stone column will also increase.

### 1.4.2. Spacing

Spacing plays an important role in stability of stone column. Spacing should be sufficient so that there should be no overlapping in the stress bulb of adjacent stone columns. Spacing is broadly computed by loading condition and plan area. Spacing value of 2m to 3m is desirable.

### 1.4.3. Pattern

Pattern of the stone column also affects stone column stability. It affects the unit cell area of stone column. Available patterns are triangular and square pattern. Most dense packing is achieved in equilateral triangular packing.

### 1.4.4. Stress Concentration Ratio

Stress concentration ratio is the ratio of stresses applied at stone column and surrounding soil. Whenever an external load is applied on treated ground, stress is divided in stone column and surrounding soil in the ratio of their stiffness factors. Higher the stress concentration ratio, higher will be the load shared by stone column, lesser will be the overall ground ettlement. Stress concentration ratio can be given as

$$n = \frac{\sigma_c}{\sigma_g} \quad .... \qquad (1)$$

Where $\sigma_c$ = stress in stone column

$\sigma_g$ = stress in surrounding soil

## 1.5. Failure of Stone Column

There are three types of failure by which the stone column can fail. They are given below.

- Bulging failure
- Shear failure
- Punching failure

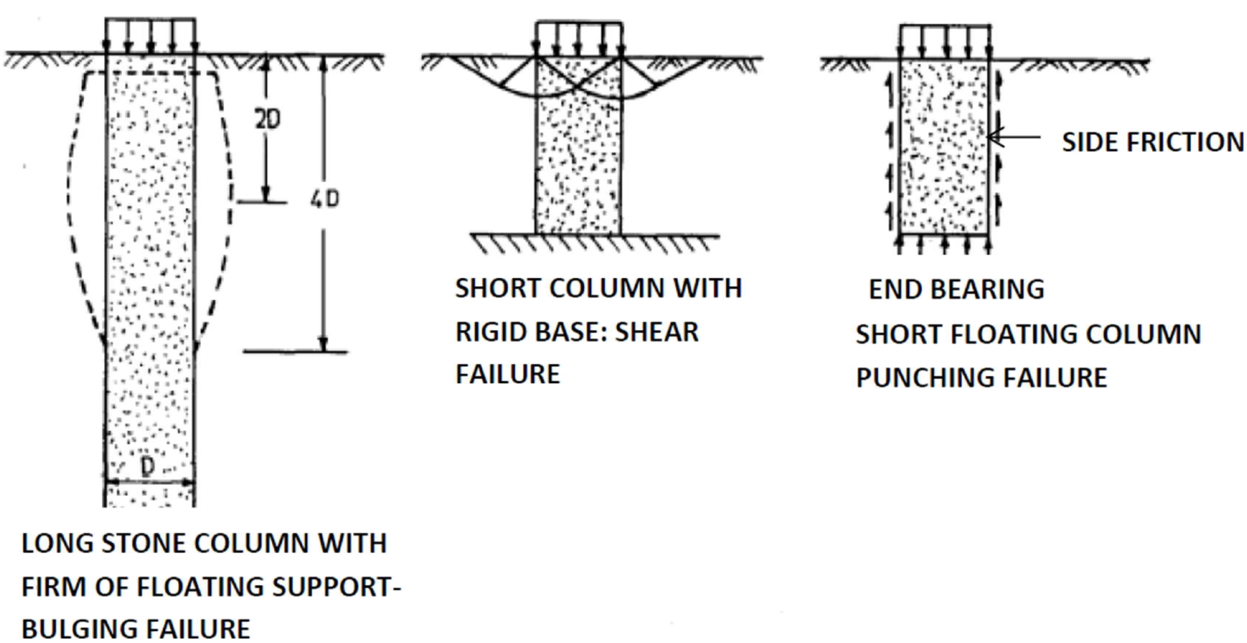


**Figure 1.6. Failure Mechanism of Stone Column (IS 15289 part I : 2003)**

### 1.5.1. Bulging failure

As per IS 15289 PART 1, bulging failure occurs when length of the column is more than its critical length and column is floating. Critical length of stone column is four times its diameter. This failure happens due to lack of confinement.

### 1.5.2. Shear failure

Shear failure happens in short column with rigid base. In this failure, stone column fails due to lack in shear strength. Soil nearby the stone column heaves at failure.

### 1.5.3. Punching failure

This failure occurs due to lack of side friction between stone column and surrounding soil. It generally occurs in floating and short column. No heaving of soil takes place at failure. Large settlement occurs at failure.

## 1.6 Advantages

Weak soil, having very low shear strength and high compressibility requires ground improvement. For efficient use of stone columns, shear strength of soil should be between 7 kpa to 50 kpa. Stone column has following advantages which makes it better than any other ground improvement technique.

1. It reduces total and differential settlement.
2. It reduces chances of liquefaction in cohesion less soils by mitigating excess pore water pressure quickly.
3. It increase the bearing capacity of a site to make it possible to use shallow foundation on that soil hence, saving lot of money and time.
4. It increases the stiffness of foundation.
5. It improves the drainage conditions and can be helpful in environment control.
6. It accelerates the rate of consolidation in cohesive soil by providing drainage path to water.

## 1.7. Limitations

Stone column, when used in sensitive clays have certain limitations. There is increase in the settlement of the bed because of the absence of the lateral restraint. The clay particles get clogged around the stone column thereby reducing radial drainage. To overcome these limitations and to improve the efficiency of the stone columns with respect to the strength and the compressibility, stone columns are encased (reinforced) using geogrids/geocomposites.

## 1.8. Objective

There are so many factors which affects the stability of stone column such as loading condition, confining pressure offered by surrounding soil, stress concentration ratio, dimensions of stone column, spacing etc. The objective of this project is

1. To study the variation in shear strength of soil with its moisture content and obtain a relationship between them.
2. To study the effect of confining pressure of surrounding soil on the load carrying capacity of stone column.
3. To check whether moisture content at maximum load carrying capacity is related with optimum moisture content of that soil.
4. Then finally, to prepare a curve showing relationship between load carrying capacity of stone column and shear strength of the surrounding soil.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1. Previous Researches

Priebe (1995) proposed a method to estimate the settlement of soil reinforced with end-bearing stone columns. He introduced a "settlement improvement factor "and found that on increasing this improvement factor, deformation modulus of the composite system was increased and the foundation settlement was reduced.

The overall performance of a stone column is controlled by the lateral support provided by the soil around the column. Because this lateral support by the surrounding soil typically increases with depth, then bulging to failure near the top of the column is the most common failure mechanism for the column (Mckelvey et al. 2004; Sivakumar et al. 2007; Black et al. 2007).

The bulging length 'h' can be determined by the equation developed by Brauns (1978):

$$h = 2\, r_p \tan\left(\frac{\pi}{4} + \frac{\varphi_p}{2}\right) \;.... \qquad (2)$$

where $r_p$ is the radius of the column and $\varphi_p$ is the internal friction angle of the column material.

Lee et al. (2007), Khabbazian et al. (2009), and Murugesan and Rajagopal (2010) investigated that under a vertical load at the top of a stone column, an axial compression deformation is generated and is often accompanied by a lateral expansion near the top of the column. The volume of the column will not remain constant and the lateral deformation of the stone column will not be uniform under vertical loads.

Castro and Sagaseta (2011) and Pulko et al. (2011) proposed analytical solutions to the study the total settlement at the tops of stone columns using unit cell concept. They also assumed the soft soil as an elastic material throughout the range of applied stress, the column was treated as an elastic-plastic material using the Mohr-Coulomb yield criterion with constant dilation angle, and no shear stress between the columns and the soil along the column length was taken into account.

Ling Zhang,Minghua Zhao, Caijun Shi and Heng(2013) Zhao performed experiments on the foundation resting on soft soil and reinforced with stone columns. They found out that settlement and deformation behavior of stone column depends on many factors. Such as : - stress concentration ratio, shear strength(cohesion and angle of internal friction both) of surrounding soil, elastic modulus of stone column material etc. These factors also affect bearing capacity of stone columns.

There are so many theories available to study the behavior of stone column. Some of them are explained below.

## 2.2. Heinz J. Priebes Method (1976)

Distribution of load between stone column and surrounding soil and lateral support by surrounding soil improves the stability of ground. This improvement can be calculated by introducing an improvement factor.

Load distribution and lateral support from the stone column & surrounding stiffened ground on an area basis are considered to give an improvement factor.

Settlement 's' of the reinforced soil of thickness ' $D_s$' can be written as

$$S = \frac{Pd}{D_S n_2} \ldots\ldots \quad (3)$$

Where, $n_2$ = improvement factor

& $n_2 = F_d * n_1$

$F_d$ = depth factor

P = foundation load

Improvement factor, $n_1$ can be written as

$$n_1 = 1 + \frac{\overline{A_C}}{A} \cdot \left[ \frac{1/2 + f(\mu_S, \overline{A_C/A})}{K_{aC} \cdot f(\mu_S, A_C/A)} - 1 \right] \ldots \quad (4)$$

$$f(\mu_S, A_C/A) = \frac{(1-\mu_S)\cdot(1-A_C/A)}{1-2\mu_S + A_C/A}$$

$$K_{aC} = \tan^2(45° - \varphi_C/2) \quad \ldots\ldots \quad (5)$$

Depth factor $F_d$ can be given as

$$f_d = \frac{1}{1 + \frac{K_{0C} - W_S/W_C}{K_{0C}} \cdot \frac{W_C}{p_C}}$$

$$p_C = \frac{p}{\frac{A_C}{A} + \frac{1-\overline{A_C/A}}{p_C/p_S}}$$

$$\frac{p_C}{p_S} = \frac{1/2 + f(\mu_S, \overline{A_C/A})}{K_{aC} \cdot f(\mu_S, \overline{A_C/A})}$$

$$W_C = \Sigma(\gamma_C \cdot \Delta d), \qquad W_S = \Sigma(\gamma_S \cdot \Delta d)$$

$$K_{oC} = 1 - \sin\varphi_C$$

## 2.3. Elastic approach

This theory was given by Aboshi et al (1979). He assumed soil to be an elastic material. He said that area nearby a stone column which is influencing by it is known as unit cell. He then divided this unit cell into N number of elements as shown in fig below. Each element of the unit cell is experiencing following forces:- shear resistance $\tau_{p,i}$ , radial stress $\sigma_{rp,i}$ at the column-soil interface, and uniform vertical stress $\sigma_{zp,i}$ and $\sigma_{zp,i+1}$ on the top and bottom of the column element, respectively.

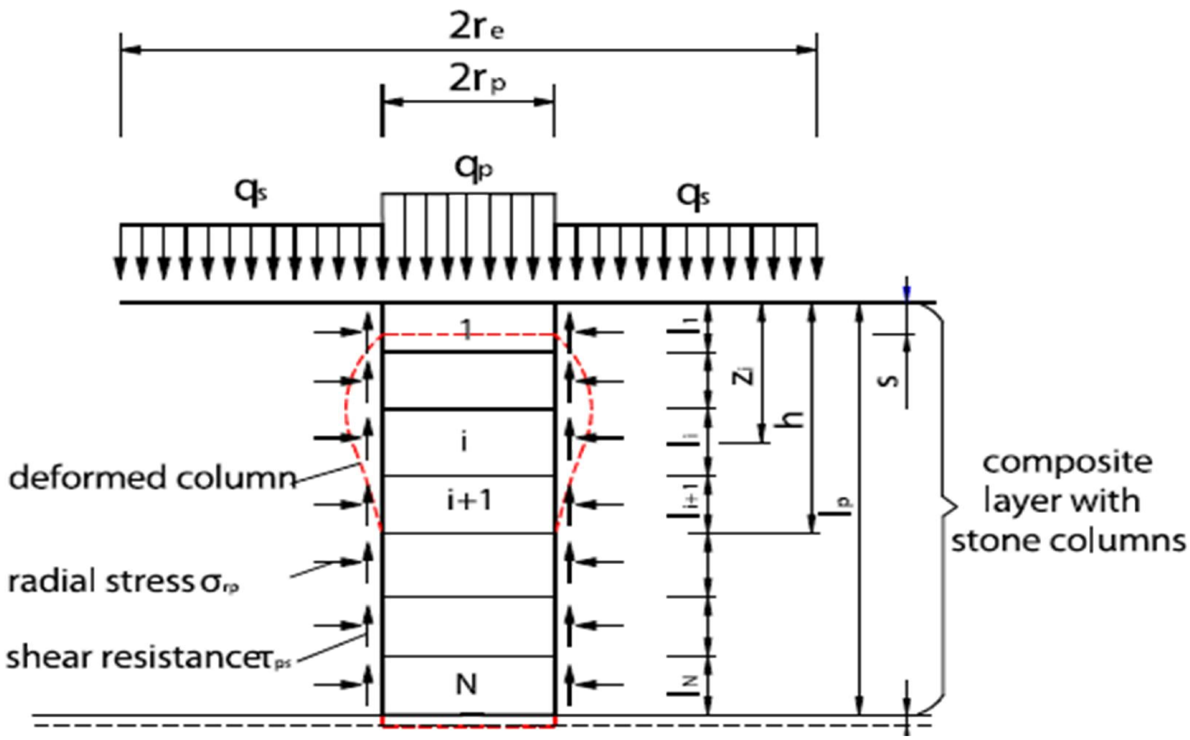


**Figure 2.1 Schematic Diagram of Unit Cell (Ling Zhang; Minghua Zhao; Caijun Shi; and Heng Zhao (2013))**

With the help of generalized Hookr aw, the stress-strain relationships for the ith segment in the elastic situation is given by

$$\Delta s_{p,i} = l_i \times \frac{\sigma_{zp,i}}{E_p} \times \frac{1-\mu_p-2\mu_p^2}{(1-\mu_p)-2\mu_p k_i}$$

$$\Delta r_{p,i} = -r_p \times \frac{\sigma_{zp,i}}{E_p} \times \frac{1-\mu_p-2\mu_p^2}{2\mu_p - \dfrac{(1-\mu_p)}{k_i}}$$

…….(6)

Where , $\Delta s_{p,i}$ = vertical compression

$\Delta r_{p,i}$ = lateral bulging

## 2.4. IS Method (IS 15284 part I ,2003)

Based on the stress concentration factor n and the replacement ratio, $a$ ,using the reduced stress method ,settlement of the treated ground can be easily calculated as

$$S= \beta\, \Delta\sigma\, m_v H \quad ..... \qquad (7)$$

Where, $m_v$ = coefficient of volume compressibility

$\beta$ = settlement reduction ratio

Settlement reduction ratio can be given as

$$\beta = \frac{1}{(1+(n-1)a} \quad ...... \qquad ...... \quad (8)$$

Where n= stress concentration ratio = $\frac{\sigma_s}{\sigma_c}$

$$\sigma_c = \frac{\sigma}{[1+(n-1)a]}$$

$$\sigma_s = \frac{n\sigma}{[1+(n-1)a]}$$

Where a = area ratio = $\frac{A_s}{A_s+A_c}$

Load carrying capacity of stone column can be computed by using following formulas.

Let $\sigma_v$ = Limiting axial stress in the column when it approaches shear failure due to

bulging

$$\sigma_v = (\sigma_{ro} + 4C_u) \times K_{pcol} \qquad .......(9)$$

where $\sigma_{ro}$ = limiting radial stress

$= K_0 \times 2\Upsilon D$

$K_o$ = earth pressure coefficient at rest = 1-sin $\phi$

D = diameter of stone column

$C_u$ = undisturbed undrained shear strength of surrounding soil.

$K_{pcol}$ = passive earth pressure coefficient of stone column material

$= [\tan\left(45 + \frac{\varphi_c}{2}\right)]^2$

$\varphi_c$ = angle of frictional resistance of stone column material

Load carrying capacity = $\sigma_v \times \frac{\pi D^2}{4}$ ……………..(10)

# CHAPTER 3

# EXPERIMENTAL INVESTIGATION

There are two types of materials which has been used in this experiment. One is the surrounding soil and the other is stone column material. To find the engineering and index properties, Tests have been conducted on these two materials and are listed below.

## 3.1. Surrounding Soil

The soil which is to be used to prepare the test tank has been taken from the campus of Delhi Technological University. To achieve cohesive soil free from grasses and other impurities, it was sieved through 425 micron sieve. The properties of soil used are given below:-

### 3.1.1. Atterberg's Limits & Specific Gravity

Liquid limit = 42.27 % ( IS : 2720 ( Part 5 ) – 1985)

Plastic limit = 21.56% ( IS : 2720 ( Part 5 ) – 1985)

Plasticity index = 20.71%,

Specific gravity= 2.72 ( IS : 2720 (Part 3) - 1980)

### 3.1.2. Classification of Soil

Soil was sieved through 75 microns sieve and 56% soil passed through that sieve. i.e.
Fines fraction = 56%
Since %age fines are more than 50%, it is fine grained soil.
Equation of A-Line is, $I_p = 0.73\ (W_l – 20)$ …………(11)
Here, $W_l$ = 42.27%, which implies, $I_p = 0.73\ (42.27 – 20) = 16.25\%$.

Since plasticity index of soil is more than 16.25%. It lies above A-Line. That means it is clay. Liquid limit is more than 35% and less than 50%. So it is intermediate compressible soil.
So as per IS standards, soil can be classified as CI.

### 3.1.3. Standard Proctor Compaction Test ( IS : 2720 (Part 7) – 1980)

To find the optimum moisture content (OMC) and maximum dry density of soil used, standard proctor compaction was performed. Soil was filled in three layer in proctor compaction mould and each layer was given 25 blows by proctor compaction hammer weighing 2.6 kg. The observations are as follows.

**Table 3.1. Standard Proctor Compaction Table**

| S.No. | Moisture content, w (%) | Weight of soil in mould (gms) | Volume of mould (cc) | Bulk density (gm/cc) | Dry density = (bulk density) / (1+w), (gm/cc) |
|---|---|---|---|---|---|
| 1. | 6.20 | 1625 | 1000 | 1.625 | 1.53 |
| 2. | 8.32 | 1710 | 1000 | 1.71 | 1.58 |
| 3. | 10.34 | 1787 | 1000 | 1.787 | 1.62 |
| 4. | 13.85 | 1810 | 1000 | 1.81 | 1.59 |

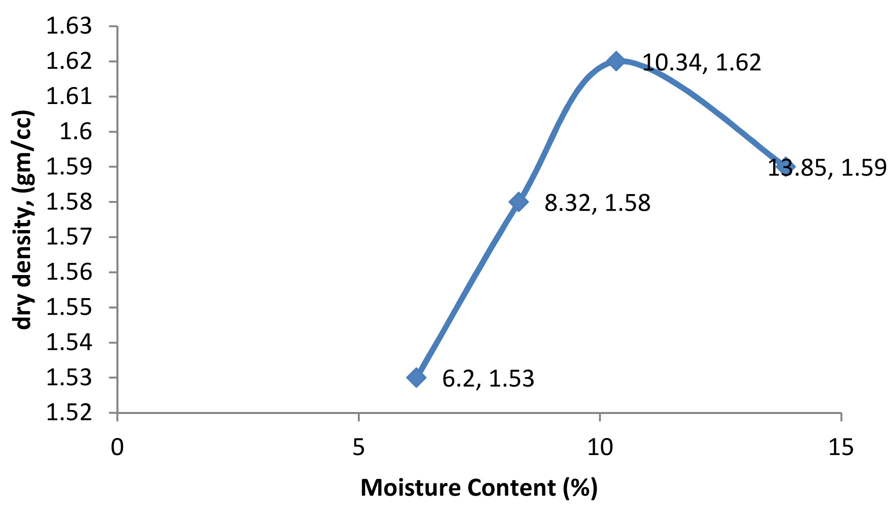


**Figure 3.1 Standard Proctor Compaction Curve of surrounding soil**

From the compaction graph shown above, we can say that

Optimum moisture content,OMC = 10.34% and Maximum dry density = 1.62 gm/cc

## 3.2. Stone Column Material

Aggregates of size 2mm to 10mm were used to fill the stone column. Strength of stone column also depends on compaction of stone column, and maximum compaction can be achieved for well graded soil.

### 3.2.1. Grain Size Distribution

Grain size distribution of stone column material was conducted as per the specifications of IS : 2720 Part 4: 1985 and is as follows.

Total wt. of material taken = 1000 gms

**Table 3.2. Grain Size Distribution of Stone Column Material**

| Sieve size | Wt. retained(gms) | Cumm. Wt. retained (gms) | % wt. retained | % wt. finer |
|---|---|---|---|---|
| 10 mm | 85 | 85 | 8.50 | 91.50 % |
| 4.75mm | 560 | 645 | 64.50 | 35.50 % |
| 2mm | 290 | 935 | 93.50 | 6.50 % |
| 1mm | 65 | 1000 | 100 | 0 % |
| pan | | | | |

$D_{60}$= 7.1 mm, $D_{30}$=4.2 mm, $D_{10}$=2.3 mm

Coefficient of uniformity, $C_u = \frac{D_{60}}{D_{10}} = 3.02$

Coefficient of curvature, $C_c = \frac{{D_{30}}^2}{D_{60} \times D_{10}} = 1.9$

For gravel to be well graded, Cu > 4 and 1< Cc < 3. So this is poorly graded gravel (GP).

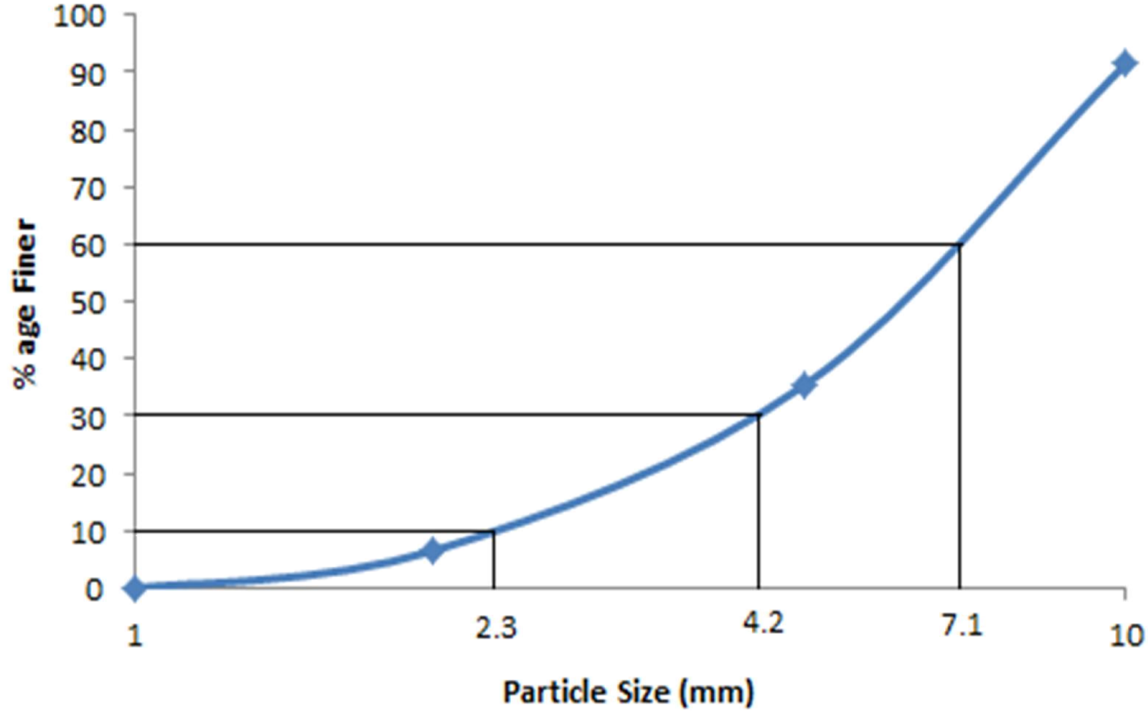


**Figure 3.2  Grain Size Distribution of Stone Column Material.**

### 3.2.2. Specific Gravity

As per IS : 2386 (Part 3) – 1963 clause 2.4, for aggregate size less than 10 mm, pycnometer method can be used to determine the specific gravity of gravel. Specific gravity can be determined by:

$$G = \frac{(W2-W1)}{(W2 - W1)-(W3- W4)}$$

Where,

W1 = weight of empty pycnometer

W2 = weight of pycnometer + gravel

W3 = weight of pycnometer + gravel + water

W4 = weight of pycnometer filled completely with water

**Table 3.3. Specific Gravity Calculation**

| | **Sample 1** | **Sample 2** | **Sample 3** |
|---|---|---|---|
| **W1 (gm)** | 694.32 | 694.32 | 694.32 |
| **W2 (gm)** | 786.43 | 850.43 | 890.23 |
| **W3 (gm)** | 1686.43 | 1697.95 | 1744.34 |
| **W4 (gm)** | 1549.32 | 1549.32 | 1549.32 |
| **Specific Gravity, G** | 2.69 | 2.70 | 2.68 |

Average value of Specific gravity is 2.69.

# CHAPTER 4

# METHODOLOGY

## 4.1. Test Tank Preparation

A tank with dimensions 35cm*35cm*35cm was used to conduct this experiment. Greasing was done on the inner walls of the tank so that the effects due to friction between soil and tank's wall can be neglected. Soil was sieved through 425 microns size in order to get desirable cohesive soil free from grass and coarse aggregates. Some amount of water was added to the soil and it is make sure that water should mix with the soil homogeneously. Then, tank was filled with soil in five layers and each layer was given 25 blows of standard proctor hammer. After preparation of tank, a sample of soil was taken to find moisture content, bulk density and shear strength of the soil. This procedure was repeated three times with different moisture content.

## 4.2. Stone Column Installation

Stone column prepared has a diameter of 3 inches (7.62 cm) and depth of 30cm and is a floating stone column. As per IS 15284 (Part 1): 2003, "to ensure bulging failure, length of stone column should be more than its critical length (= 4 times its diameter)". That is why to ensure bulging failure, length of stone column is taken 30 cm. A steel casing of outer diameter 3 inches and length 15 inches was used to make a bore hole in the soil. After making the bore hole, aggregate was poured into the hole and compacted to achieve sufficient stiffness. Pouring of aggregates and pulling out of casing was done simultaneously.

Figure 4.1. Stone Column Installed in Tank

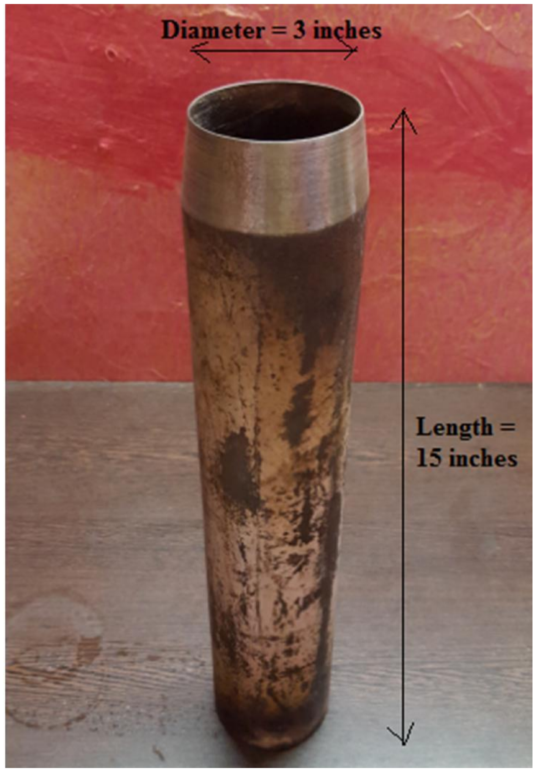


Figure 4.2. Steel Casing

## 4.3. Load application

A rectangular metal plate of dimensions 20cm*15cm*1cm was placed over the stone column and two dial gauges were fixed at the two diagonal corners of the plate. Thickness of metal plate should be sufficient so that it can handle the load which it will going to experience. Loading was applied gravimetrically through the metal plate on the stone column. As per IS 15284 part 1, if stone column settles more than 10 mm, it is assumed as failure of stone column and load experienced by the stone column at 10 mm settlement is said to be Load Carrying Capacity of stone column. Loading was applied until the settlement exceeds 15 mm. Values of settlement and corresponding load were noted and are given in the observation below.

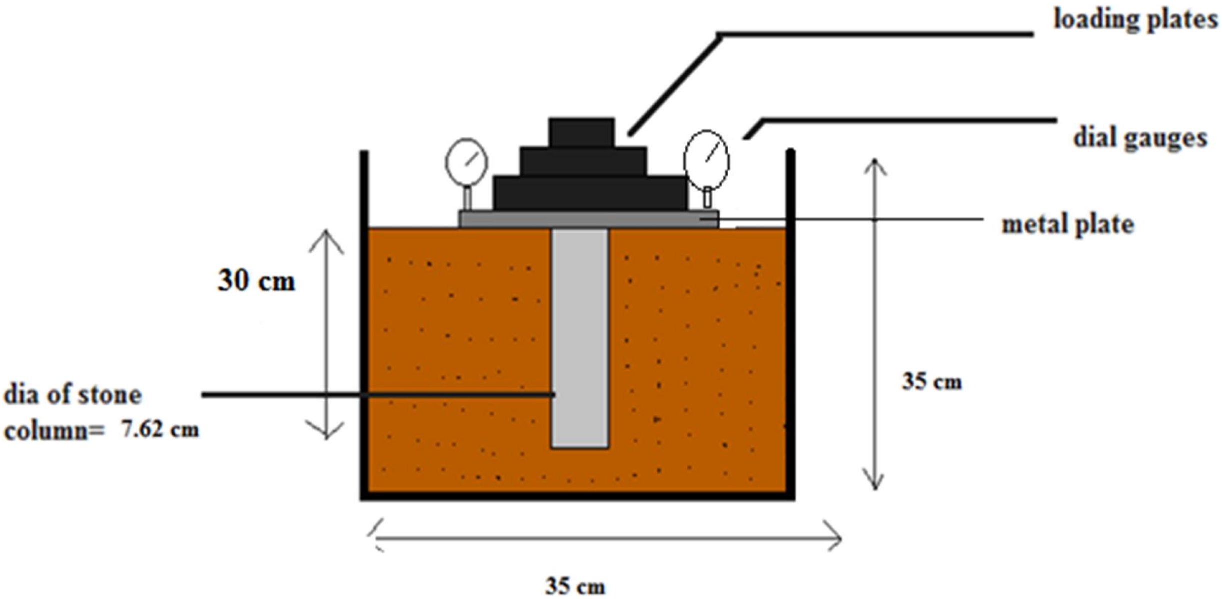


**Figure 4.4. Schematic Diagram of Experimental Setup**

## 4.4. Experimental procedure

First of all, test tank was prepared as per the directions given above. One sample of soil was taken for determination of moisture content, bulk unit weight and shear strength as well. Shear strength was calculated using direct shear test due to its easy and less time consuming procedure. After that, stone column was installed as per the instructions given above. A rectangular metal plate of sufficient thickness was put over the stone column. This rectangular plate represents the footing at actual site and used to distribute the loading between stone column and surrounding soil. Loading was applied gravimetrically by putting metal plates and concrete cubes of known weight on the metal plate. Settlement was recorded by the two dial gauges placed diagonally on the metal plate. Average value of dial gauges was used as settlement value. Loading was applied till 15 mm settlement. Load at 10 mm settlement is known as load carrying capacity of the stone column. This entire procedure was repeated three times with different moisture contents and the observations are given below.

**Figure 4.5. Gravimetric Loading on Stone Column**

## 4.5. Observations

The confining pressure or shear strength of the soil can be changed by changing its moisture content. We have conducted this experiment 3 times with different shear strength and stability of stone column has observed. As per IS 15284 part 1, settlement value more than 10 mm is considered as failure of stone column and load applied on stone column at 10 mm settlement is known as load carrying capacity of the stone column.

Direct shear test was conducted to determine the shear strength of soil. Although there are so many methods for shear strength determination but direct shear direct shear test has been conducted on three samples with varying moisture content and graphs are shown below.

After preparing experimental setup, loading was applied gravimetrically in the form of weighing plates. Settlement was calculated using two dial gauges. Average value of two dial gauges has been taken. Loading was applied for not less than 10 mm settlement, say 14mm to 15mm settlement.

### 4.5.1. Surrounding Soil Sample 1 (moisture content = 11%)

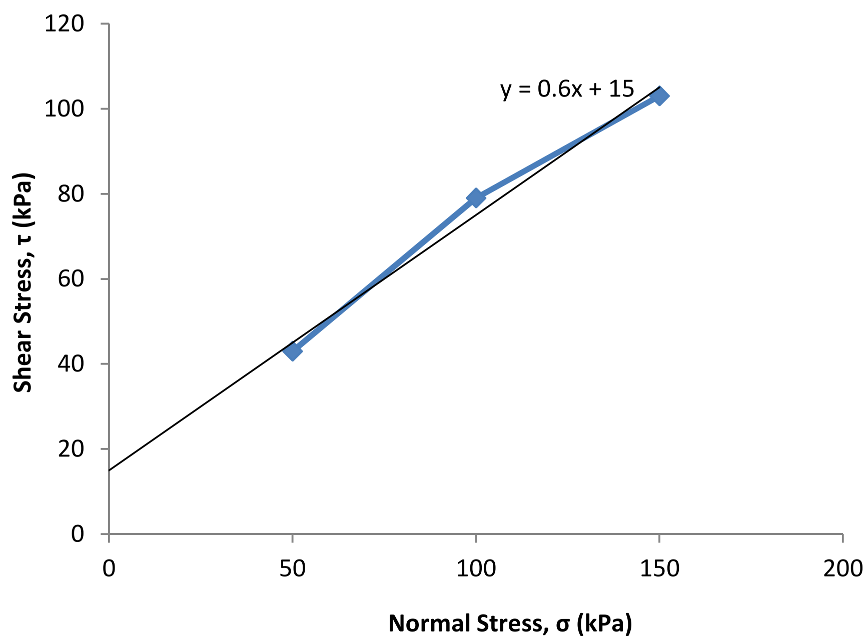


**Figure 4.6. Direct Shear Test for Surrounding Soil Sample 1**

From direct shear test, cohesion, $c = 15$ kPa

Angle of Internal Friction, $\varphi = 30.9^{o}$

Load settlement table is given below.

**Table 4.1. Load Settlement Table for Surrounding Soil Sample 1**

| Load (N) | Settlement (mm) |
|---|---|
| 0 | 0 |
| 176.58 | 2.4 |
| 353.16 | 4.2 |
| 529.74 | 7.1 |
| 706.32 | 8.9 |
| 882.9 | 10.3 |
| 1059.48 | 11.5 |
| 1236.06 | 12.8 |
| 1412.62 | 13.4 |

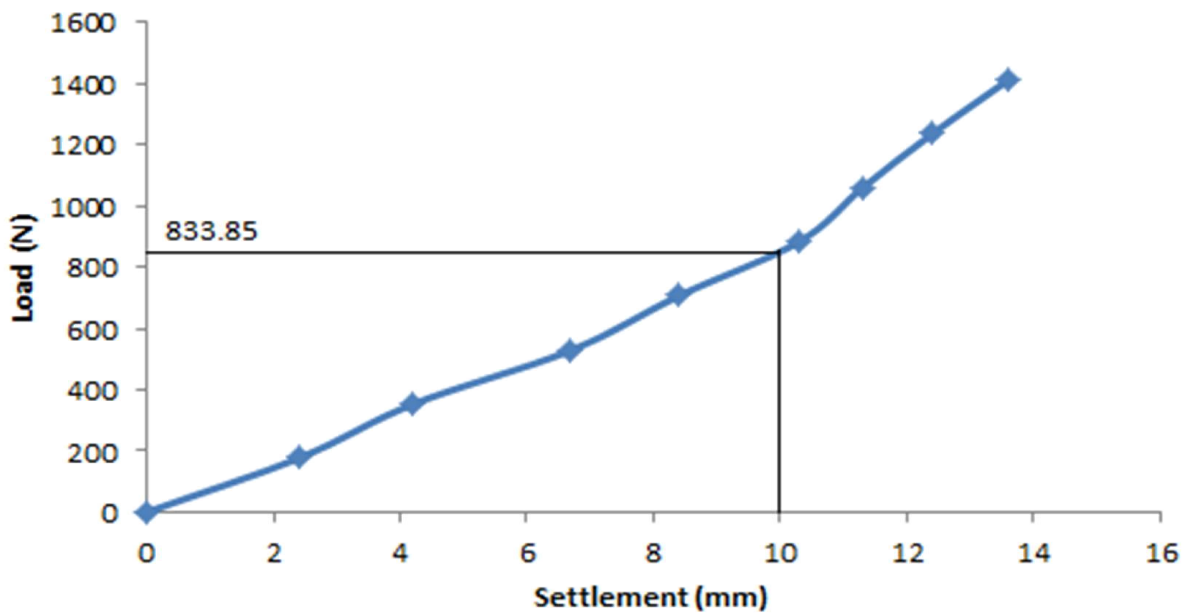


**Figure 4.7. Load Settlement Curve for Surrounding Soil Sample 1**

From the load settlement curve drawn above, load at 10 mm settlement = 833.85 N

### 4.5.2. Surrounding Soil Sample 2 (moisture content = 20%)

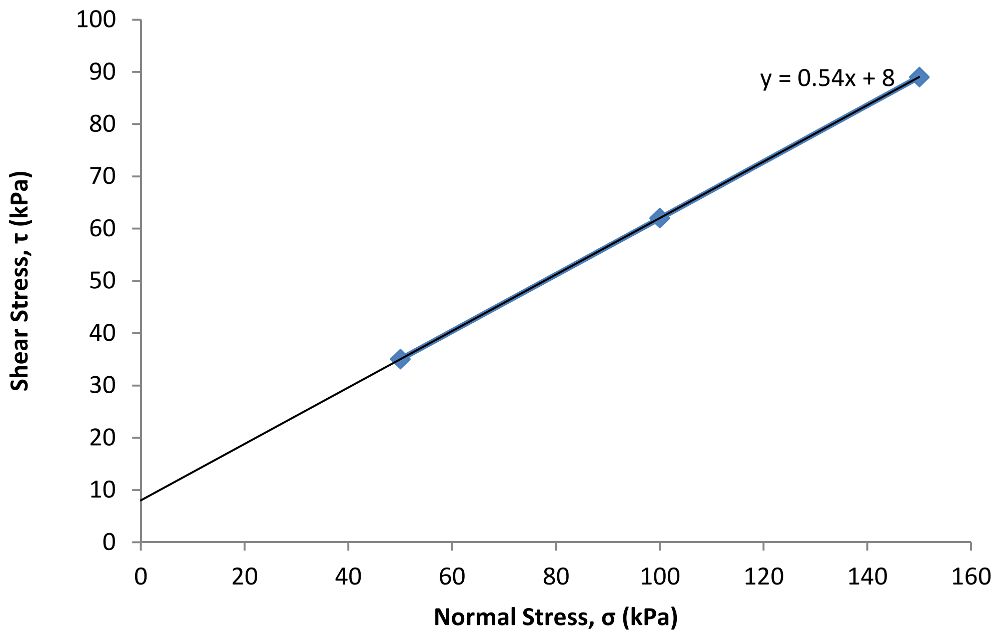


**Figure 4.8. Direct Shear Test for Surrounding Soil Sample 2**

From direct shear test, cohesion, c = 8kPa

Angle of Internal Friction, $\varphi = 28.37^{o}$

Load settlement table is given below.

**Table 4.2. Load Settlement Table for Surrounding Soil Sample 2**

| Load (N) | Settlement (mm) |
|---|---|
| 0 | 0 |
| 176.58 | 2.8 |
| 264.87 | 4.7 |
| 353.16 | 6.9 |
| 441.45 | 8.4 |
| 529.74 | 10.4 |
| 618.03 | 11.5 |
| 706.32 | 12.3 |
| 882.9 | 13.6 |

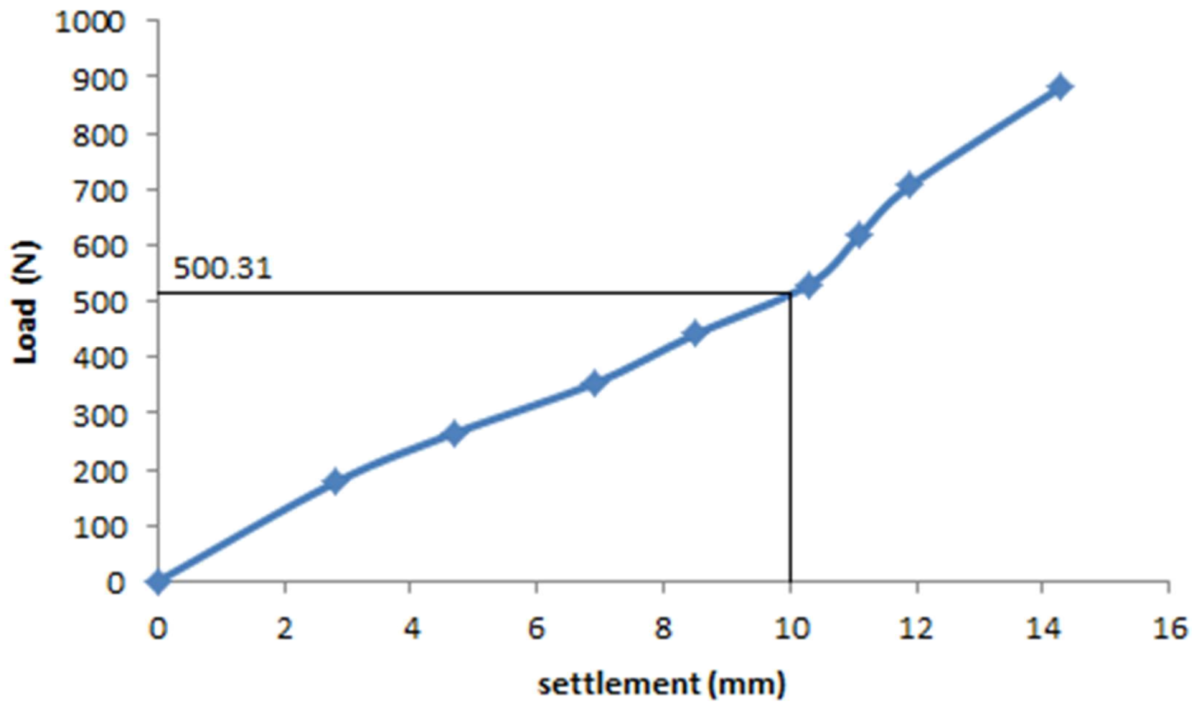


**Figure 4.9. Load Settlement Curve for Surrounding Soil Sample 2**

From the load settlement curve drawn above, load at 10 mm settlement = 500.31 N

### 4.5.3. Surrounding Soil Sample 3 (moisture content = 32%)

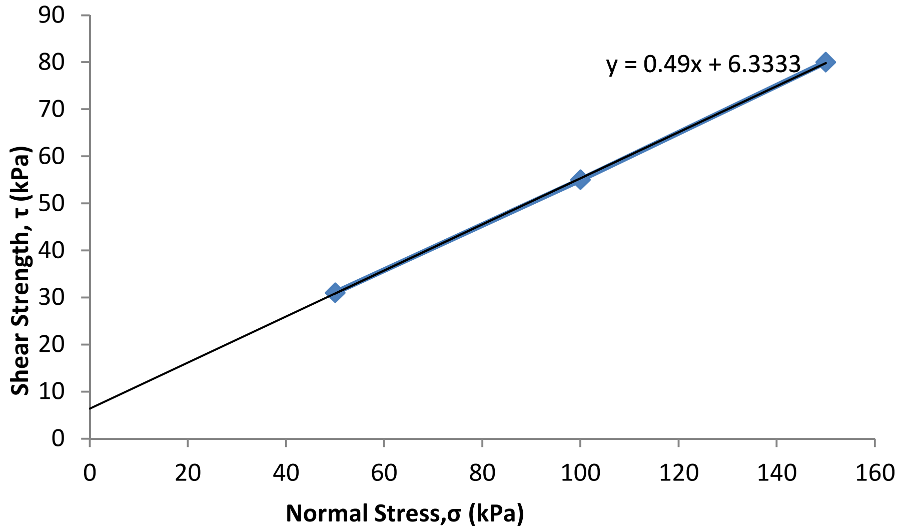


**Figure 4.10.Direct Shear Test for Surrounding Soil Sample 3**

From direc

Angle of Internal Friction, $\varphi = 26.1\,^{o}$

Load settlement table is given below.

**Table 4.3. Load Settlement Table for Surrounding Soil Sample 3**

| Load (N) | Settlement (mm) |
|---|---|
| 0 | 0 |
| 49.05 | 2.5 |
| 137.37 | 4.6 |
| 225.63 | 6.7 |
| 313.92 | 8.7 |
| 402.21 | 10.1 |
| 490.5 | 11.9 |
| 667.08 | 12.6 |
| 843.66 | 13.6 |

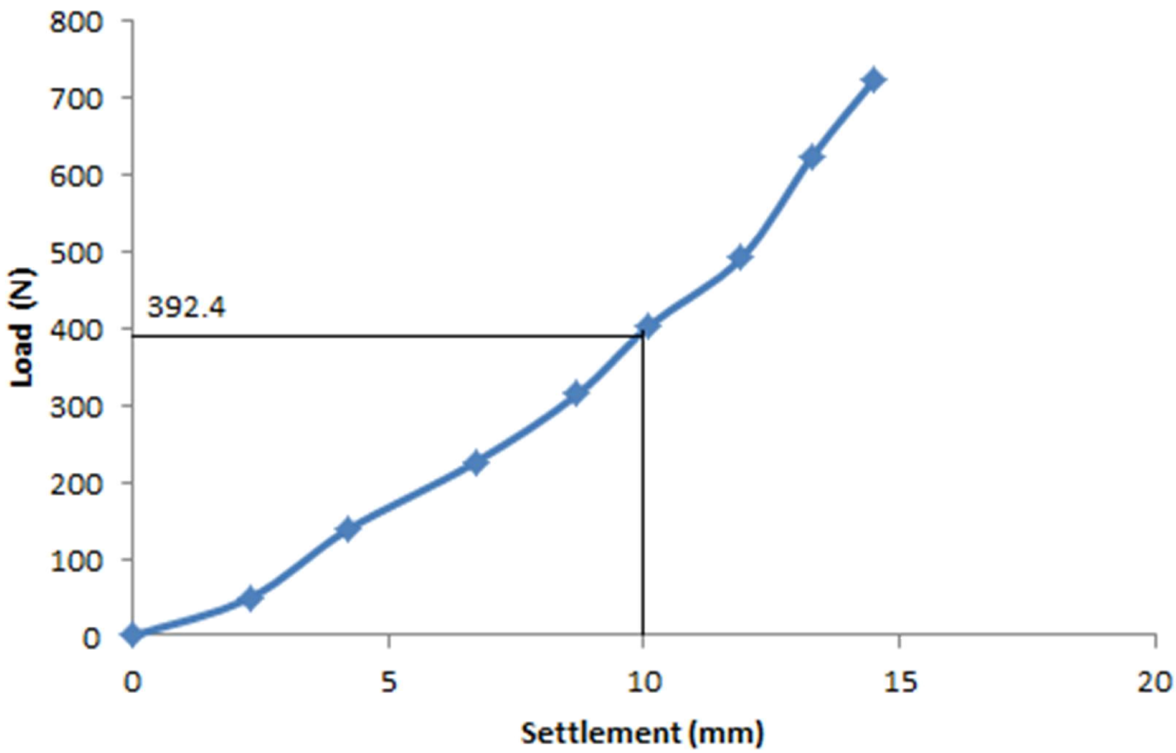


**Figure 4.11. Load Settlement Curve for Surrounding Soil Sample 3**

From the load settlement curve drawn above, load at 10 mm settlement = 392.4 N

# CHAPTER 5

## RESULT AND DISCUSSION

To determine the shear strength of surrounding soil at specific moisture content, direct shear test was performed on the undisturbed sample taken from the test tank. The values obtained are shown below in tabular form.

**Table 5.1. Direct Shear Test Table**

| | Moisture content | Cohesion (kPa) | angle of internal friction, $\varphi$ | Bulk unit wt., $\gamma_t$ (kN/m$^3$) | Dry unit wt., $\gamma_d$ (kN/m$^3$) |
|---|---|---|---|---|---|
| **Surrounding Soil Sample 1** | 11% | 15 | 30.9 $^o$ | 17.76 | 16.00 |
| **Surrounding Soil Sample 2** | 20% | 8 | 28.37 $^o$ | 18.95 | 15.80 |
| **Surrounding Soil Sample 3** | 32% | 6.3 | 26.1 $^o$ | 19.78 | 14.98 |

Shear strength is not the inherent property of soil. It depends on various factors such as loading conditions, rate of loading, moisture content of soil, stress history etc. Here, we have derived a relationship between shear strength and moisture content of soil keeping other factors constant. A graph has been plotted between shear strength and moisture content as shown in figure 4.1. From this graph, we can see that as moisture content of soil is increasing, shear strength of soil is decreasing.

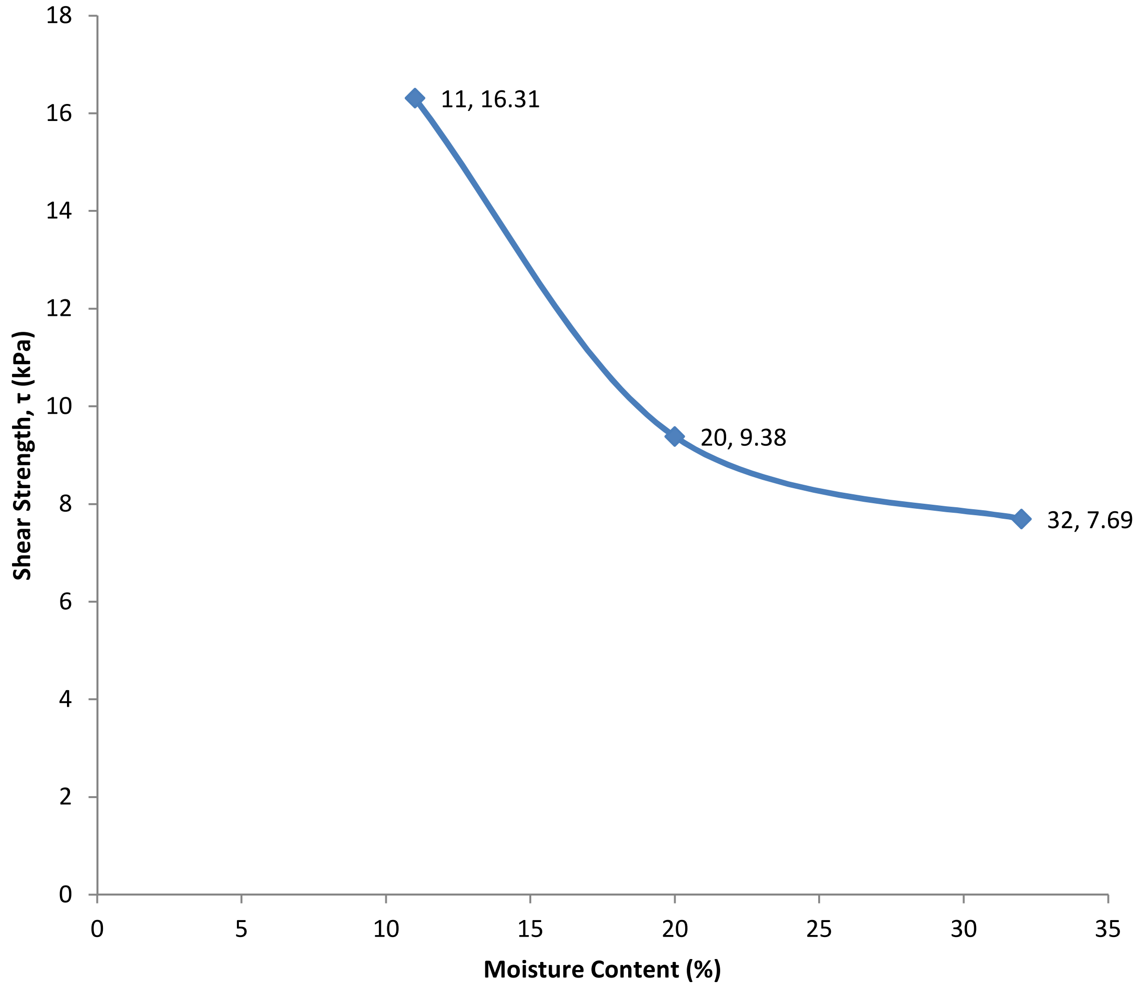


Figure 5.1. Variation of Shear Strength with Moisture Content

Load carrying capacity of stone column depends on many factors such as confining pressure of surrounding soil, diameter of stone column, length of stone column, stone column material, stress concentration ratio, stress history of soil, relative compaction of stones in stone column etc. confining pressure offered by soil is directly proportional to the shear strength of soil. A graph between load and settlement has been already shown above. Variation of load carrying capacity due to change in shear strength is shown in the graph shown below. Influence of shear strength of soil on the load carrying capacity can be predicted from the graph.

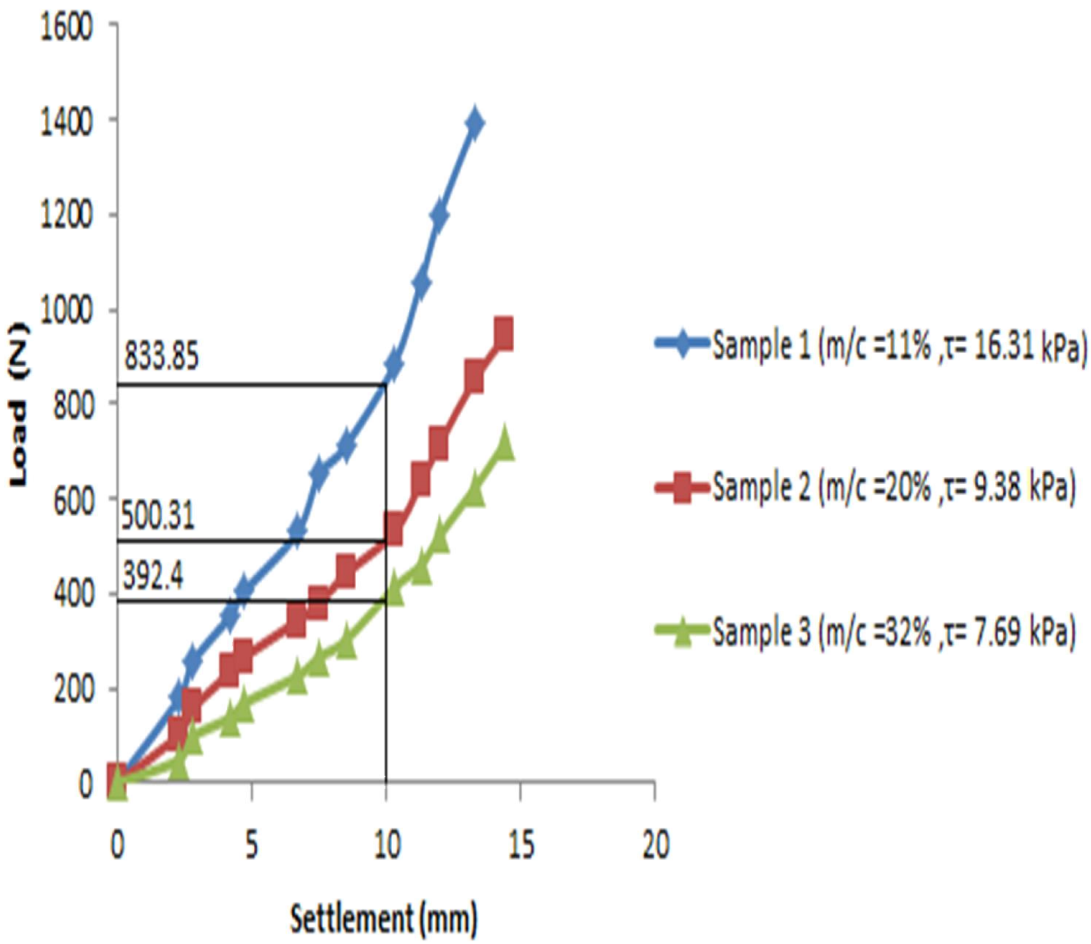


**Figure 5.2. Load Settlement Curve at various Moisture Contents**

Variation in shear strength and load carrying capacity of stone column with the moi sture content of soil is shown below in tabular form. As per IS 15289 part 1, load carrying capacity of stone column is the load required for 10 mm settlement. Load carrying capacity is calculated in the above graph. Test has been conducted on three samples with moisture content 11%, 20% and 32% and shear strength , load experienced by stone column at 10 mm settlement is given below. It can be seen from the table that load carrying capacity as well as shear strength both decreases if moisture content of soil increseas.

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**Table 5.2. Relationship between Moisture Content, Shear Strength and Load Carrying Capacity**

| | **Surrounding Soil Sample 1** | **Surrounding Soil Sample 2** | **Surrounding Soil sample 3** |
|---|---|---|---|
| **Moisture content** | 11% | 20% | 32% |
| **Shear strength(kPa)** | 16.31 | 9.38 | 7.69 |
| **Load at 10 mm settlement(N)** | 833.85 | 500.31 | 392.4 |

With the help of experiments conducted and the graphs given above, a relationship between load carrying capacity and shear strength is shown below in the form of graph. From the graph it can be predicted that load carrying capacity of the stone column decreases by decreasing the shear strength of soil.

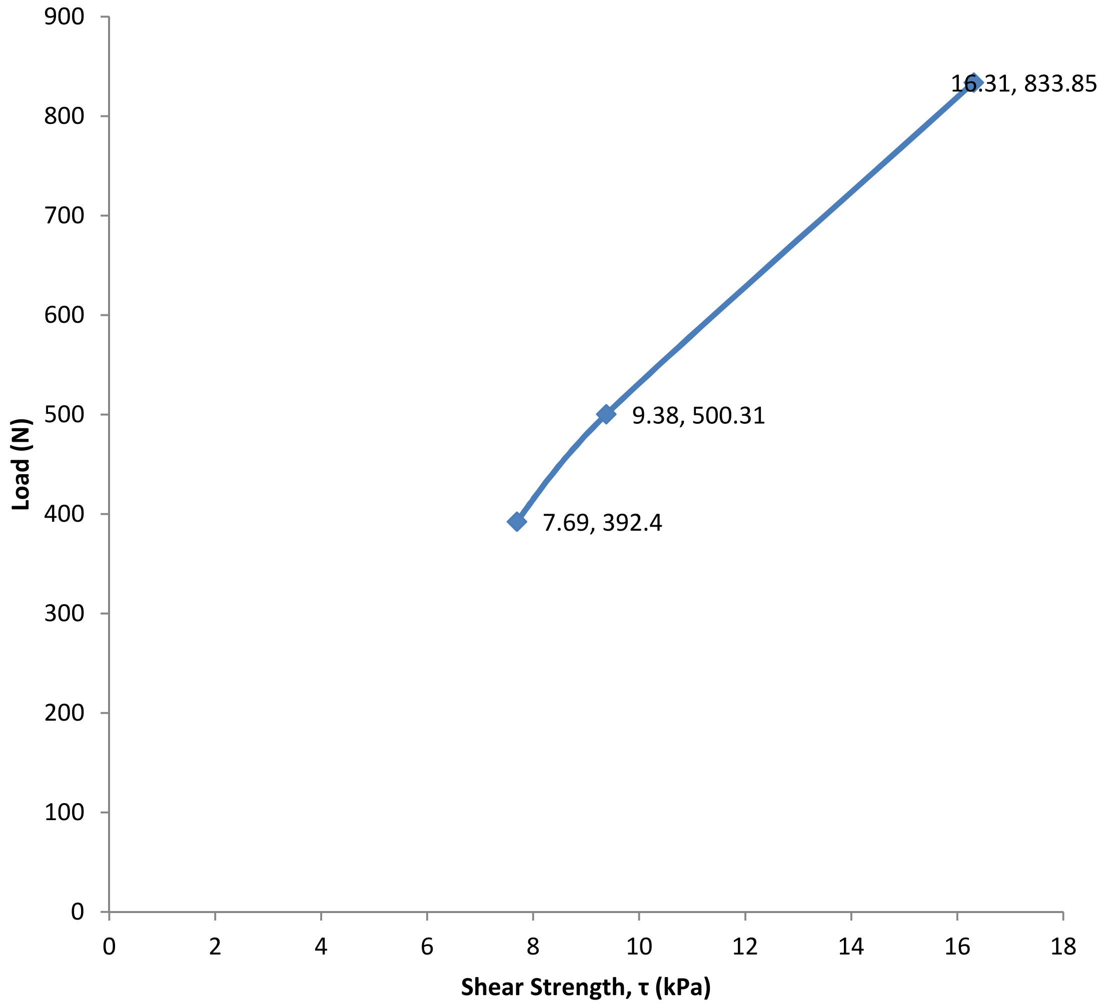


**Figure 5.3. Relationship between Load Carrying Capacity and Shear Strength of Soil**

# CHAPTER 6

# CONCLUSIONS

From the experiments conducted and the graphs shown above, following conclusion can be made.

1. Shear strength of soil depends on so many factors such as normal stress at that point, rate of loading, loading condition, stress history of soil. Moisture content also affects the shear strength of the soil. Shear strength of soil decreases as the moisture content increases.

2. Although cohesion is said to be the inherent property of the soil but it is not always constant for the same soil. It depends on loading condition and rate of loading. It also changes with moisture content and affects the shear strength of the soil.

3. Confining pressure provided by the surrounding soil to the stone column depends on the shear strength of the surrounding soil and is directly proportional to the shear strength of the soil.

4. Confining pressure offered by surrounding soil has a great influence on the Load carrying capacity of the stone column. Load carrying capacity of the stone column decreases as the confining pressure of the surrounding soil decreases.

5. Moisture content at which Load Carrying Capacity is maximum (11%) is approximately equal to the optimum moisture content (10.34%).

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