EFFECT OF GROUTED GRANULAR COLUMN ON LOAD CARRYING CAPACITY OF EXPANSIVE SOIL

A DISSERTATION REPORT

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I, **PALLAVI VERMA**, **2K17/GTE/13** student of M.Tech (GTE), hereby declare that the dissertation entitled "**EFFECT OF GROUTED GRNULAR COLUMN ON THE LOAD CARRYING CAPACITY OF EXPANSIVE SOIL**" 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 Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the dissertation entitled "**EFFECT OF GROUTED GRNULAR COLUMN ON THE LOAD CARRYING CAPACITY OF EXPANSIVE SOIL** " which is submitted by **PALLAVI VERMA**, **2K17/GTE/13** [Department 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.

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ABSTRACT

In the recent years granular columns have came under the widespread use for increasing the load bearing capacity and reducing the settlement in the expansive soil and loose sand. For the improvement of the stability of large area of foundation granular columns are being widely used. Conventional granular columns are driven into the loose expansive soil and they maintain their stability from lateral confinement due to the reaction from the surrounding stiffened soil. However, this may not be possible in very loose soil and additional lateral support may have to be provided to stabilize it and reduce its settlements. This study attempts to improve this weakness by wrapping the granular column in geotextile layer to enhance the lateral reinforcement.

In the present project the discussion is about the variation in load carrying capacity and settlement characteristics of granular column (made up of cement fly ash and sand in a definite proportion instead of aggregates and stones) and analyzing its effect on the expansive soil by comparing its results with geo textile encased columns. In this process the study investigates the improvement of load carrying capacity of a single granular column encased in geotextile through model test.

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LIST OF ABBREVIATION

C_U	Coefficient of uniformity
C_C	Coefficient of curvature
D_{10}	Effective particle size (m)
D_{30}	Diameter through which 30% of the total soil particles is passing
D_{60}	Diameter through which 60% of the total soil particles is passing
E	Elastic modulus (Pa)
CH	Highly clay
G_s	Specific gravity
OMC	Optimum moisture content
PFA	Pulverized fly ash

CHAPTER 1
INTRODUCTION

Due to the scarcity of land for the construction of industrial, commercial, and transportation structures for development in urban areas, it is very necessary to use the places which have weak strata. This has become very mandatory to use the land which has poor engineering properties due to the unavailability of land. Granular column is a vastly suitable technique to upgrade the poor engineering properties of ground stratum. It is generally designed to carry vertical loads imposed by the structure. Ground improvement techniques are generally used to increase the foundation soils or projected earth structures to provide the modified performance of weak strata under different loading conditions. In new project this is very common to utilize ground which has poor subsurface conditions to render the conditions which are formerly not allowing the project to be economically justifiable and technically feasible to carry on. Granular columns are one of them. Construction of these columns generally consists of water-jetting a vibrofloat into the soft clay layer to make a circular hole that extends through the loose strata to firmer soil. The hole is then filled with an imported gravel or mix to increase the bearing capacity of soil. The granular columns tend to reduce the settlement of foundations at allowable loads. Granular column is being widely used in soil improvement techniques. Stability of these column depends on so many factors such as relative compaction of column material, confining pressure offered by surrounding soil, stress concentration ratio, loading condition, stress history of soil, gradation of column material, spacing between the columns, dimensions of granular column etc. Diameter of granular column can vary from 300 mm to 1000 mm and length can be up to 10m. In the present work, we have discussed the variation in load capacity and the settlement behaviour of granular column with intruding grouting mix inside the column instead of aggregates and stones. By stability, we are actually dealing with the load carrying capacity of the soil by comparing its result by encased column. Confining pressure offered by the soil depends on the strength of the soil.

1.1. FUNCTIONS OF GRANULAR COLUMN

Nowadays granular column is playing a major role in improvement technique of soil. The main functions of the granular column according to its role in the stabilization are as follows:

1. Granular column helps in ground improvement and it also provides foundation to the structure. It is found that grouted granular columns also very effective in improving the bearing capacity and stiffness of the expansive soil. Load carrying capacity of granular column increases because applied load is distributed accordingly between the soil and column depending upon the ratio of their stiffness
2. Under sudden and rapid load conditions such as earthquake granular column impart stability to the structure, since dissipation of settlement in weak strata mitigates the chances of failure of the structure under such conditions.
3. Improvement in the settlement of soil takes place due to the installation of granular column, because as compare to soil granular column have higher modulus of elasticity due to which it is capable of carrying more load than the soil.

1.2. INSTALLATION TECHNIQUES

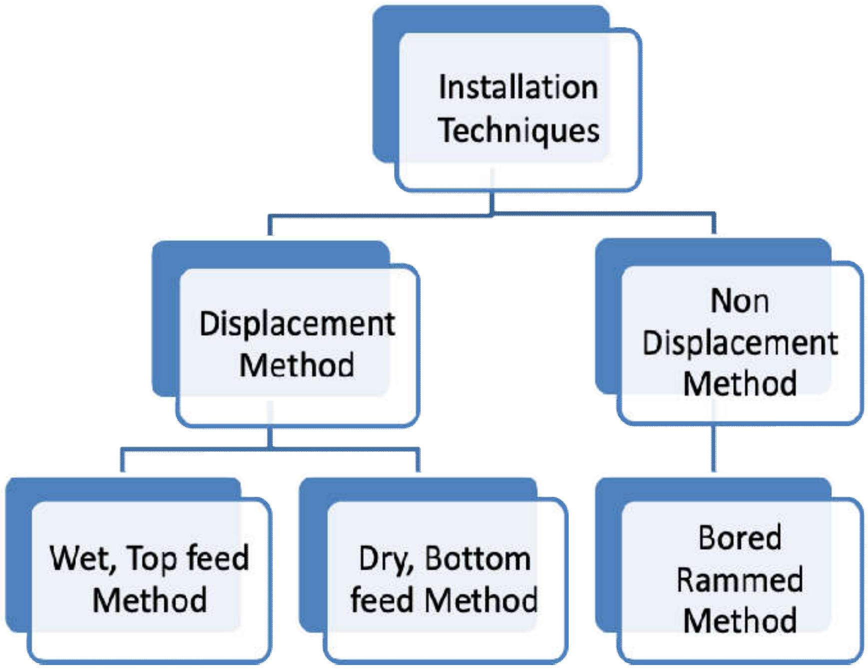

Fig.1.1 Installation Technique

1.2.1. Displacement Method:-

In this process boring is done by displacing the soil by driving a casing or tube inside the soil, due to which it slightly affect the engineering property of the soil. Vibro-floating is the best example of displacement method .which is performed by adopting the given methods:

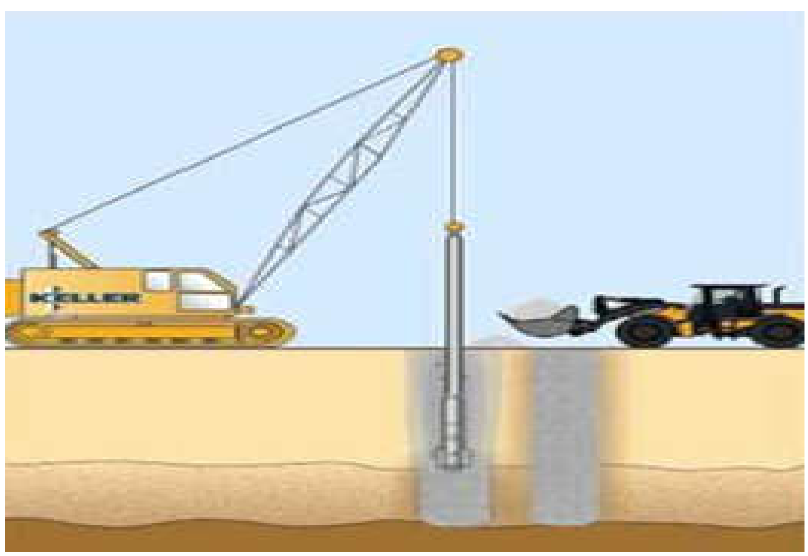

Fig.1.2. Vibro Flotation (Ambily A.P.and Gandhi Shailesh R. (2007))

1.2.1.1. Wet Top Feed Method:

This process is extensively used where the water table is very high and the bore hole is not stable. This type of condition may generally occurs in soft soil .In this process water or air jetting is provided under high pressure with the help of nose of vibrofloat to accommodate its penetration. After penetration to its full depth, mixture is poured from the top.

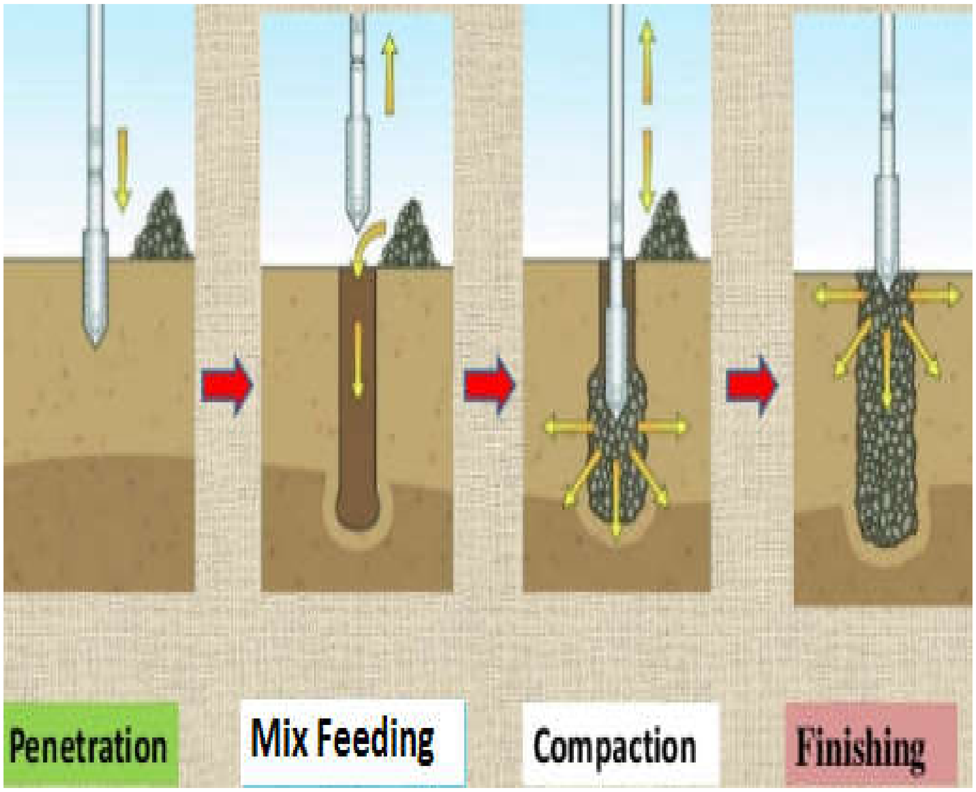

Fig. 1.3.Wet,Top Feed Vibro flotation Method (Ambily A.P.and Gandhi Shailesh R. (2007))

1.2.1.2. Dry Bottom Feed Method:

This is generally used where the stability of bore hole is high as compared to the top feed method, in this method with the help of pipe the feeding of mixture is done from bottom which helps to connect the top and bottom of the vibrofloat. This method is used where the water table condition is low for soil having high shear strength.

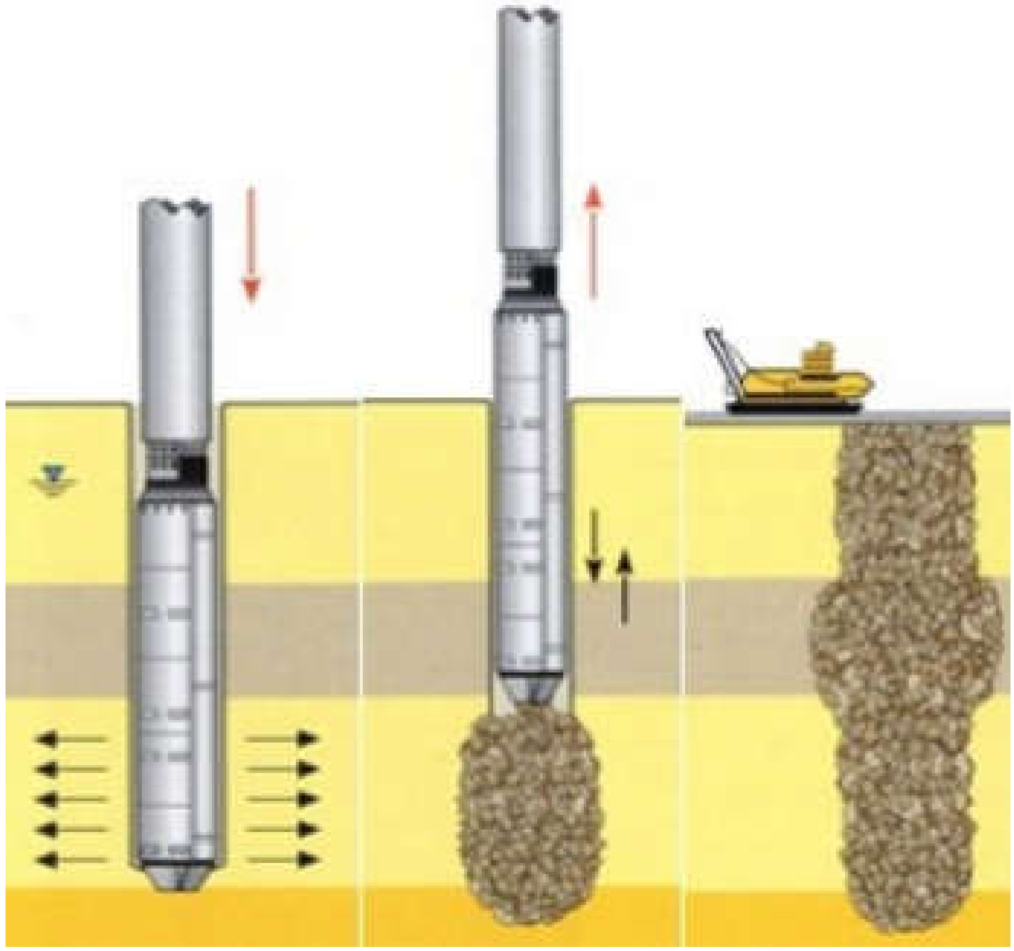

Fig 1.4.Dry,Bottom Feed Vibro flotation Method (Ambily A.P.and Gandhi Shailesh R.(2007))

1.2.2. Non Displacement Method:

In this method, boring is done without displacing the soil and by inserting the stone aggregates or grouting mix with the help of driven casing.

1.2.2.1. Bored Rammed Method:

This method is done with the help of a casing and hammer. Casing is inserted into the soil with the help of external force applied by the hammer and then the material is filled after the formation of hole. In this method the strength driven by the granular column is due to the lateral confinement which is being provided by the surrounding soil. Hence soil should have more shear strength and low sensitivity.

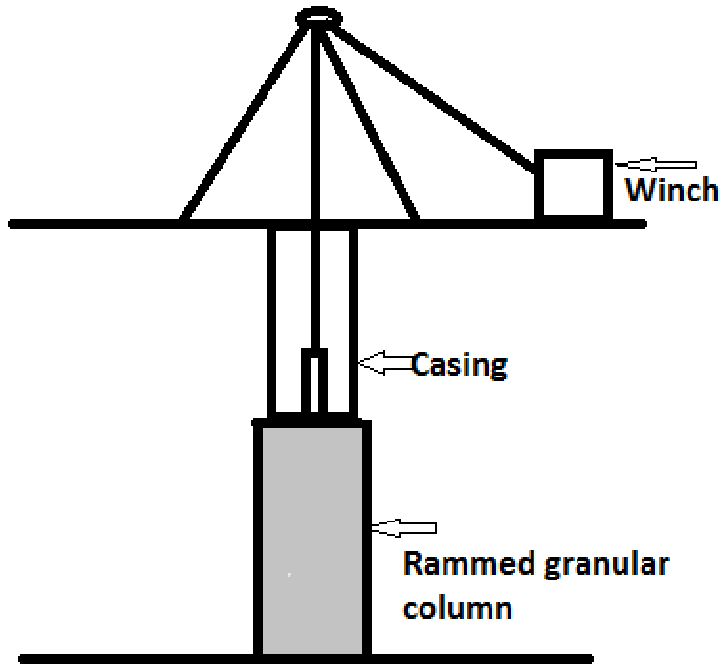

Fig.1.5. Bored Rammed Method

1.3. FACTORS AFFECTING STRENGTH OF GRANULAR COLUMN

Firstly, we should know the factors affecting the load capacity of granular column, to get the idea of the strength of granular column. There are lots of factors which may affect the strength of granular columns such as loading conditions, engineering properties of soil, stress history of soil, physical properties of granular column, properties of mixture used in the column, rate of loading etc. Some important are given below.

1.3.1. Diameter of the Column

Diameter is one of the very basic properties of granular column, increase in the diameter increases the area of granular column as a result the bearing capacity will also increases.

1.3.2. Spacing

To counter the stability of granular column spacing plays a very important role, it should be provided in a way such that there should be no overlapping between the stress bulb of adjacent granular columns. Spacing can be broadly determined by the loading conditions and the plan area. The desirable value of spacing is about 2m to 3m.

1.3.3. Pattern

Stability of granular column is also affected by the pattern of column in which it is installed. This mainly affects the unit cell area of granular column. Nowadays the available patterns are triangular and square pattern. Equilateral triangle pattern is the most densely packed pattern.

1.3.4. Stress Concentration Ratio

It is the ratio of stresses applied at column to the stresses of the surrounding soil. Whenever an external load is applied on soil, stress is divided between granular column and nearby soil in the ratio of its stiffness factors. Higher the stress concentration ratio, higher will be the load shared by the granular column, lesser will be the overall ground settlement. It can be given as

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

Where σ_c is stress in the column

σ_g is stress in surrounding soil

1.4. FAILURE OF GRANULAR COLUMN

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

- Failure due to bulging
- Failure due to shear
- Failure due to punching

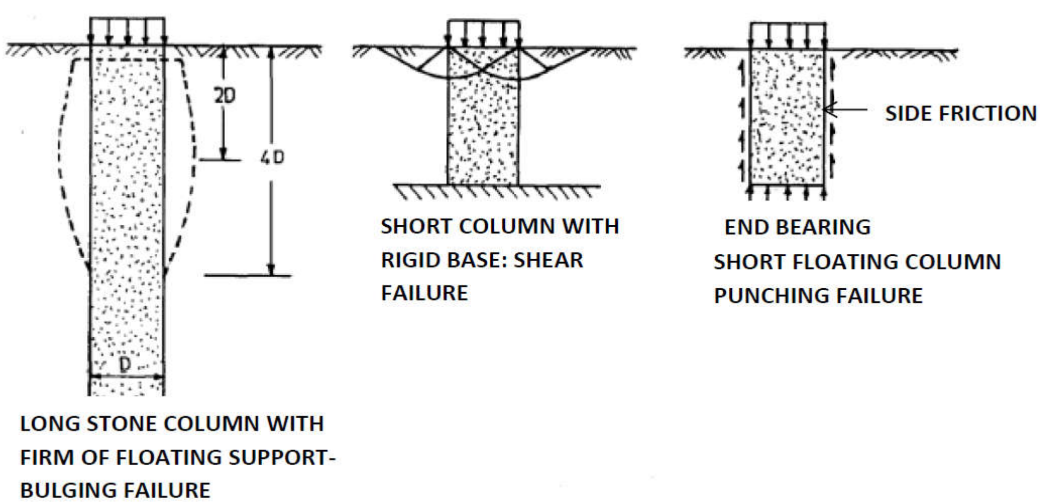

Fig.1.6.Failure of granular column (IS 15284 part I : 2003)

1.4.1. Bulging Failure

As per IS 15284 PART 1, bulging failure happens when length of the column is more than its desirable length and column is floating. Critical length of granular column is four times its diameter. This failure happens due to lack of confinement.

1.4.2. 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.

1.4.3. Punching Failure

This failure occurs due to lack of side friction between granular 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.

1.5 ADVANTAGES

Soil having weak strata generally show very less shear strength, high settlement and very low bearing capacity requires ground improvement. Granular 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 increases the stiffness of foundation.
4. It improves the drainage conditions and can be helpful in environment control.
5. It accelerates the rate of consolidation in cohesive soil by providing drainage path to water.

1.6. LIMITATIONS

Granular column, which used in soft sensitive clay have certain limitations. Due to the absence of lateral restrain in the soil bed there is a increase in the settlement of the soil. The clay particles which are due to very fine nature get choked around the stone column and results in depletion in radial drainage. To remove these limitations and to enhance the efficiency of granular column encasement is provided in the stone columns in form of geo grids and geo membranes.

1.7. OBJECTIVE

There are many factors which affect the stability of granular column such as loading condition, bearing capacity of black cotton soil, stress concentration ratio, dimensions of the column, spacing etc. The objective of this project are:

1. To modify the properties of expansive soil by installing the grouted granular column made up of cement, sand, fly ash..
2. To study the change in bearing capacity of soil by installation of grouted granular column and also to find the variation of its load settlement behaviour if encased with geotextile.
3. To establish a comparison between settlement behaviour of grouted granular column.

In order to perform the study literatures have been surveyed which are reflected in the succeeding chapter.

CHAPTER 2
LITERATURE REVIEW

In this present study the literature on the granular piles/stone columns on weak soil is studied and presented in the following paragraphs. For soil having minimum shear strength,granular columns are not used because soil is not capable of supporting effective confining stress. Hence this problem in soft clay is solved by either skirting in column or by encasing or wrapping the columns with geo-synthetics. In order to increase the stiffness of granular column geo-textile encasement plays a major role ,which prevent loss of mixture in nearby soft soil and it also helps in maintaining the drainage and frictional properties upto the acceptable limit as determined by the various numerical and experimental studies.

Huges and Withers (1974) conducted laboratory experiments to analyse the effect of granular columns in soft soil. The equation given by **Brauns (1978)** is used to calculate the approximate bulging length ‘h’;

$$h = 2\, r_c \tan\left(\frac{\pi}{4} + \frac{\varphi_c}{2}\right) \qquad (1)$$

Where r_c is radius, φ_c is internal friction angle of the column.

They found that bulging failure takes place in both single and multiple stone columns. Other researchers **Balaam and Booker (1981)** also reported same conclusion based on the assumptions that each column combined with the surrounding soil can be treated as a rigid cylindrical wall. As a result unit cell concept is adopted which neglect the horizontal displacement and inter linkage between the column.

Rao and Ranjan (1985) they developed a method for analyzing settlement in foundation of weak sub-soil deposits which are reinforced with granular piles. Four sites were taken to determine the in-situ test of soft soil on full scale consisting of skirted granular piles. A comparison between the proposed analytical procedure and observed values from field is noted. They concluded that granular pile has been extensively used to improve the engineering behaviour of loose sand deposit.

Mitchell and Huber (1985) conducted laboratory test to provide the properties of soil by finite element method and they found that the estimated load settlements were greater than those recorded. Results were analysed that installation of granular column in the soft soil decreases its settlement by 30-40%.

Priebe (1995) suggested a experimental method to determine the settlement in soil reinforced with end-bearing granular columns. He developed a “settlement reduction factor” and observed that on enhancing this improvement factor changes occurred in the composite section that foundation settlement was reduced and deformation modulus was increased. The total performance of granular column is influence by the lateral support provided on the nearby soil which is generally increases by the depth.

Sharma et al. (2004) performed tests to examine the effect of geogrid reinforced on the bearing capacity of granular piles in soft clay**.** They found that there is a improvement in the capacity of geogrid reinforcement and also in the engineering behaviour of the soil with the increase in the geogrids. Bulging length and diameter of the column also decreases due to the reinforcement. This studies estimate that stress required for 3mm settlement is increased by 100 % when soil bed is reinforced with granular pile, bulge length and diameter of the pile also decreases by significant amount.

Dimiter et al. (2005) they provide a method to support the column laterally and which also provide the increased bearing capacity to the soil that is geosynthetic encased column.which confines the compacted granular and stone columns therefore increasing its bearing capacity and compressibility even in extremely weak stratum.

Lee et al. (2007) analysed that when load is applied at the top surface of the granular column this results in deformation which is frequently followed by lateral expansion at the top surface of the column. Thus the volume of column changes and the lateral deformation in the granular column will vary under the effect of the vertical loads. The lateral support which is provided by the soil present around the column influence the total performance of the column. The support provided by the soil surrounding the column increases as the depth increases, but at the top of the column bulging failure is the most general mechanism for column failure**. Khabbazian et al. (2009)** also suggested the same results.

Castro and Sagaseta (2011) and Pulko et al. (2011) used unit cell concept while proposing solutions to study the overall settlement to the top surface of the columns, by assuming soft soil as the elastic material through the entire range in which the stress is applied. They treated the column as an elastic material by using the concept of Mohr-Coulomb yield mechanism and keeping the angle of dilation constant, with zero shear stress in the soil along the column length and the column.

Ling Zhang et al. (2013) experiments have been performed on foundations resting on soft soil and reinforced with stone columns. According to them the factors responsible for the deformation and settlement of column are: - stress concentration ratio, shear strength (cohesion and angle of internal friction) of the surrounding soil, modulus of elasticity of the stone column material etc.

Zhng and Zhao (2013) verified the method of installation of stone column by comparing it with two different solutions. They conducted studies to examine the changes due to effect of applied stress, geo-textile encasement and spacing between the column and diameter. Settlement analysis made by specified procedure was compared by the values observed by field tests in which a good correlation was observed to establish a bond between encased and non-encased columns. They found the result that a reduction in the bulging and settlement of the column due to the high stiffness of geo-textile encasement. Therefore, while designing the granular column stiffness of geo-textile is considered with respect to diameter and spacing of columns because diameter and spacing of column have a huge impact on the settlement reduction**.**

Indraratna et al. (2013): They established a conceptual theory to determine rate of consolidation in soil reinforced with gotextile. This model explains the well resistance and smear effects. Well resistance appears, when flow in the channel drain is decreased and obstruct the flow as a result reduced discharge capacity. They found that decrease in the permeability, stress concentration and smear zone of the stone column reduces the rate at which consolidation is taking place, whereas decrease in the diameter of column, size of smeared zone and thickness of soil will enhance the consolidation rate.

Etezad and Hanna (2014) developed a analytical method to determine the general shear failure in the group of stone columns .This method was effective enough to analyse the load capacity of reinforced soil and model was analysed by the Terzaghi (1943) and the bearing capacity factors. The failure mechanism of the column was analysed by a passive Rankine section and they also concluded that the limit-equilibrium method is a practical method to determine value of reinforced soil with granular columns.

Miranda et al. (2016) conducted three tests first one with non-encased column and rest two with different geo textile encasements. They observed the increased in vertical stress carried by encased column is 1.7 times of the non-encased column. stress concentration factor in encased column is also increased by 2 to 4 times the non-encased column. They also determine settlement reduction factor as 0.58, 0.62 and 0.77 for geo-textile and non-encased column respectively.

Harish et al.(2016) they performed a laboratory model test on the single embedded column with and without encasement of geotextiles on different grades of expansive soil by investigating the variations in the single stone column by simultaneously varying its diameter and length. They studied the number of encasement provided for embedded depths and also the effect of encased reinforced dust. Conclusions were made depending on load improvement ratio and settlement reduction factors, and results obtained support that the intrusion of quarry dust increases the load capacity and also reduces settlement on the basis of which load settlement behaviour is investigated.

Kargar and Hosseini (2016) performed tests on a scale model to improve in the effect of strip footing which was supported by geocell reinforced sand layer. In this model test they used woven geotextile, non woven geotextile and biaxial geogrids and calculated the geocell strength and stiffness. Results shows that the stiffness of geocell enhance the performance of the soil by indicating 1.5 times improvement in the bearing capacity of soil at settlement ratio of 6%.

Sambhaji and Harihar (2017) conducted a study of cemented porus material to improve the soft clay, they considered two cases one is of bulb formation at the bottom of stone column and the other one at an intermediate level of depth which is equal to 5 times its diameter which involves load tests of six unit cells in laboratory which consists of bulb cemented stone columns, they concluded that underreamed cement column were extremely effectual in enhancing the load capacity and soft clay stiffness.

Misir and Laman (2018) developed a empirical design approach by regression analysis for estimating the behaviour of circular footing reinforced with geogrid encased granular fill on a weak clayey soil. In this study a model was developed with a high deformation coefficient R^2 by 0.959, with reference to data obtained by the in-situ test and on the basis which they derive a improvement factor (IF) which consists of dimension less parameters such as thickness of granular fill bed layer (H/D), settlement deformation ratio (s/D) and depth of geotextile layer (u/D) .

For materials used in the granular column like fly ash the mechanism of reaction is totally based on these factors which was determined by **Chaturvedi and Sahu (2017)** based on review they concluded that properties which influence the fly ash mechanism are effect of fine powder, pozzolanic reaction within the mix, effect due to dilution, growth in gel surface area, upgrade in the gel structure For type of fly ash these factor can function either singularly or in combined form depending on the quantity of addition. By substituting the portion of OPC by fly ash reduces the total amount of C_3A present in the mortar mixes. This reduction is termed as the dilution effect and the same become exceptional when addition of fly ash is more than the endurance limit in the technique. And the other mechanism which affects the behaviour of mortar is due to the increase of sulphate resistance by pozzolanic effect. Therefore due to this pozzolanic reaction between $Ca(OH)_2$ (a byproduct of OPC hydration) a C-S-H binder matrix formation takes place as a result mortar becomes denser and stronger in addition.

Kolathayar et al.(2019) they studied the effect of coir geocells and high density polyethylene on the load capacity of sand bed both reinforced and unreinforced with these two materials by conducting a model test tank in the laboratory after performing various plate load tests at the system. They found that the load carrying capacity of coir reinforced system was 2 times more than the high density polyethelene geocell reinforced system. They also obtained a sustainable results for the fill material seashell with respect to sand and estimated that the mixture of 20% seashell with 80% sand gives a maximum bearing capacity.

2.1. ELASTIC APPROACH

This theory was given by **Aboshi.et al. (1979)** He assumed that soil is considered to be an elastic material. He supposed that the area which is nearby the stone column influenced by it is known as unit cell. According to which he decided to classify this unit cell area into N number of components as shown below. Each component of this unit cell is suppose to encounter following forces :- shearing resistance $\tau_{p,i}$, radial stresses $\sigma_{rp,i}$ at the soil-column interface, and uniform vertical stresses $\sigma_{zp,i}$ and $\sigma_{zp,i+1}$ on the above surface and at the lower level of column element respectively.

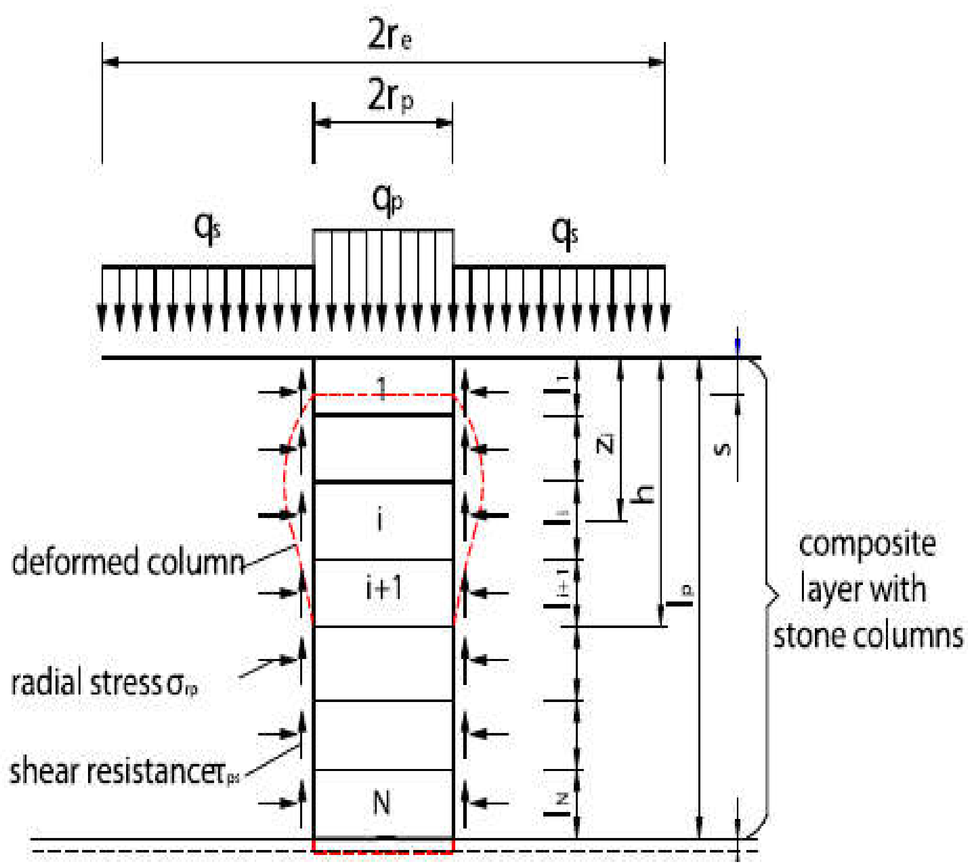

Figure 2.1 Schematic Diagram of Unit Cell (Ling Zhan et al. (2013))

With the help of estimated basic Hook law, stress-strain relationship for the i[th] segment in any situation is determined by

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

$$\Delta r_{p,i} = -r_p * \frac{\sigma_{zp,i}}{E_p} * \frac{1-\mu_p-2{\mu_p}^2}{2\mu_p - \frac{(1-\mu_p)}{k_i}} \quad (6)$$

Where,

E_p = young's modulus

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

$\Delta r_{p,i}$ = lateral bulging μ_p = poison's ratio k_i = segment constant

2.2. IS METHOD (IS 15284 PART I, 2003)

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

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

Where, m_v = coefficient of volume compressibility

β = settlement reduction ratio

Settlement reduction ratio can be given as

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

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

Where,

σ_s is stress in the column

σ_c is stress in surrounding soil

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

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

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

Load bearing capacity in granular column can be computed by using following formulas.

Let σ_v = Limiting axial stress obtained in the column when it proceed towards shear failure due to bulging.

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

where σ_{ro} is the limiting radial stress

$$= K_0 \times 2\Upsilon D$$

K_o is earth pressure coefficient at rest which is equal to 1-sin ϕ

D is diameter of stone column

C_u is undisturbed strength of surrounding soil.

K_{pcol} is coefficient of passive earth pressure of granular column material

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

φ_c is friction angle

Load carrying capacity can be determined by $\sigma_v \times \frac{\pi D^2}{4}$ (10)

CHAPTER 3
MATERIALS AND METHODS

There are three types of materials which have been used in this experiment. Expansive soil, grouting materials (fly ash, sand, cement) and geo textile. To find the engineering and index properties, Tests have been conducted on these materials are listed below.

3.1. SOIL

3.1.1. Procurement

The soil which is used in present work has been transported to DTU laboratory from Obaidullaganj, Raisen district of Bhopal. The soil has been extracted from 100cm from the ground surface to eliminate the surface impurities.

Fig.3.1 Location map of study area

To achieve cohesive soil free from any impurities, it was sieved through IS 4.75mm, sieve. Visually soil can be classified as fine grained soil which is grey in colour and very hard in dry state. Following tests were performed to obtain the properties of soil.

3.1.2. Specific Gravity

As per IS: 2386 (Part 3) – 1963 clause 2.4, for clayey soil pycnometer test is generally used in determination of the specific gravity of soil. With the help of following equation Specific gravity can be determined:

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

Where,

W_1 is weight of empty pycnometer

W_2 is weight of pycnometer with soil

W_3 is weight of pycnometer with soil and water

W_4 isweight of pycnometer filled completely with water

3.1.3. Liquid Limit (W_L)

It is defined as the liquid state at which soil having minimum water content and poses a very less strength against its flowing behaviour, which can be estimated by standard evaluated means.

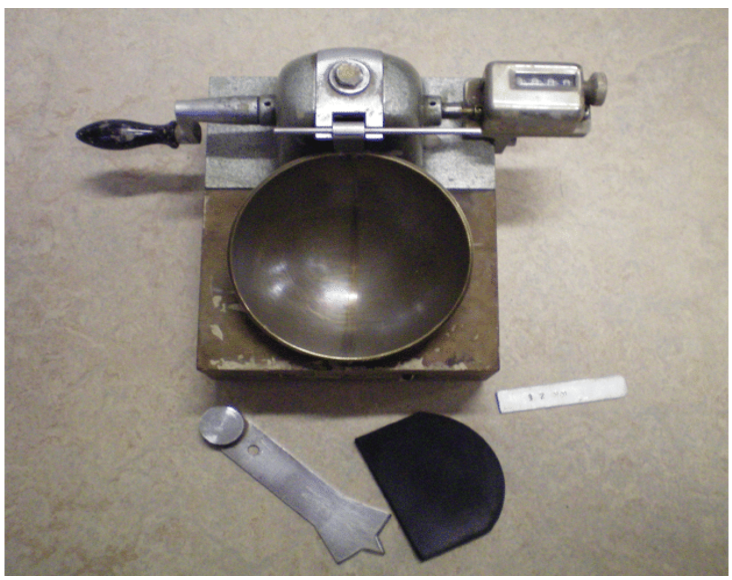

Fig. 3.2 Mechanical liquid limit device

3.1.4 Plastic Limit (W_P) It is the property of the soil which is defined as the lowest water content and can be determined as a weight percentage of dried soil at which it can easily rolled into 3.2mm diameter without breaking into pieces.

3.1.5. Standard Proctor Compaction Test

To determine the optimum moisture content (OMC) and maximum dry density of soil in laboratory, standard proctor compaction was performed. It is defined as the minimum moisture content at which the soil specimen will become highly dense and obtains its maximum value of dry density. In this soil was filled in three layers in proctor compaction mould and each layer was given 25 blows by proctor compaction hammer weighing 2.6 kg.

3.2. CEMENT

3.2.1. Procurement

Cement used in this project is ordinary Portland cement which fulfils the requirement of IS: 122269-53, grade which is obtained from high quality clinker ground with high purity gypsum.

3.2.2. Consistency of Cement

The consistency is defined as the ability of cement to flow when mixed with water. It is measured by Vicat Appratus Test. Consistency of cement was determined as 34.75%.This is Ordinary Portland Cement, as per IS 269:2013 the Initial setting time and Final setting time of cement is 30min and 10hrs respectively.

Fig.3.3 Vicat apparatus

3.2.3 Specific Gravity of Cement

Le-Chatelier flask is used to perform the specific gravity test of the cement.

Specific gravity can be determined:

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

3.3. SAND

3.3.1 Procurement

For this project Yamuna sand was taken which was present in the concrete laboratory of Delhi Technological University at the time of experiment and its properties were evaluated by performing different tests in the laboratory which are given below.

3.3.2 Dry Sieve Analysis

Sieve analysis is a method used to evaluate the grain size distribution of the granular material by allowing them to pass through a number of sieves of continuously smaller size and weighing the material that is retained on each sieve as a fraction of total mass of the material used.

3.4. FLY ASH

3.4.1. Procurement

Fly ash used in this test was obtained from India Mart, all the properties of fly ash given is as per their specification. Fly ash is a byproduct generated in electric power industries from burning of pulverized coal. Fly ash, sand and cement were used to fill the stone column. Strength of stone column also depends on the type of material used.

3.5.GEOTEXTILE

3.5.1.Procurement

Geotextile used in this test is obtained from India Mart, which is black in colour of about 5mm thickness, made up of polypropylene. The texture of geotextile is shown in figure and its basic properties is as per the India Mart norms.

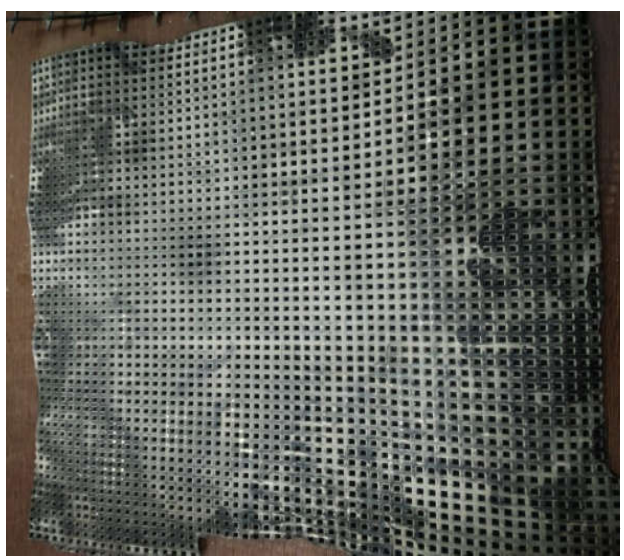

Fig. 3.4 Geotextile used in column

3.6 SAMPLE PREPARATION FOR GRANULAR COLUMN

Three samples of cement, fly ash, and sand were prepared in ratio of 1:3 in total of nine specimen of cube (70.06*70.06*70.06) mm mould. One ratio consists of both cement and fly ash combined and three ratio is sand.

Water content = (P/4 + 3), where P is the consistency of cement. All the above material is mix thoroughly and with the help of vibrating machine all the cube mould was filled with one ratio of cement and fly ash was taken with three ratio of sand along with water to prepare the mould. Fly ash is added in the sample to make the stabilization of soil economical and durable.

Fig 3.5.Prepared samples

After the preparation of granular column samples these cubes are kept for curing for 7 days which almost gives 65% of its total strength and this strength will automatically increase because soil with granular column is having 35% moisture content before its installation. Again after 7 days the cube samples have been tested in compression testing machine and the following data were calculated.

3.7 TEST TANK PREPARATION

A wooden tank with dimensions 45cm*45cm*45cm was used to conduct this experiment. Plastic covering was done on the inner walls of the tank so that the effect due to friction between soil and tank's wall can be neglected. Soil was sieved through IS 4.75mm size in order to get desirable cohesive soil free from grass and coarse aggregates. Some water was added by weight to the soil and it is make sure that water should mix with the soil homogeneously. Then, this tank was filled by soil in 5 layers and each layer was given 25 blows of standard proctor hammer. After preparation of tank, known amount of load was applied on the soil to determine its load settlement behaviour and from the result obtained a graph is plotted to determine the load capacity of expansive soil. This procedure was repeated three times with different conditions.

3.8 GRANULAR COLUMN INSTALLATION

Stone column prepared has a diameter of 3 inches (7.62 cm) and depth of 30cm and is a floating stone column. IS 15284 (Part 1): 2003 recommended that, "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. Test tank was filled with soil sample by maintaining its lowest density. After making the bore hole, sand column material is poured into the hole with the help of a cone made with paper and compacted to achieve sufficient stiffness. Pouring of material and pulling out of casing was done simultaneously. A circular model footing of diameter 225mm was placed exactly on the centre of stone column to avoid eccentric loading. Load was applied on the footing simultaneously with the aid of gravimetric loading in which known amount of load is applied on the footing to calculate the

settlement in the footing. Two dial gauges are fixed on the footing to calculate the settlement by calculating their average settlement for better accuracy. For different column material the above procedure is repeated till the variations in the load vs settlement is calculated.

Fig. 3.6.Steel casing

3.9. LOAD APPLICATION

A circular metal plate of diameter 12cm was placed over the stone column and two dial gauges were fixed at the two diagonal corners of the plate to calculate the average settlement for more accuracy. Thickness of the metal plate should be sufficient so that it can be able to handle the load which it will going to experience. Loading was applied gravimetrically through the metal plate on the granular column. As per IS 15284 part 1, if stone column settles more than 10 mm, it is assumed as failure of granular column and load experienced by the stone column at 10 mm settlement is said to be bearing Capacity of granular column. Loading should be applied until the value of settlement exceeds 15 mm. Values of settlement and corresponding load were noted and are given in the observation below.

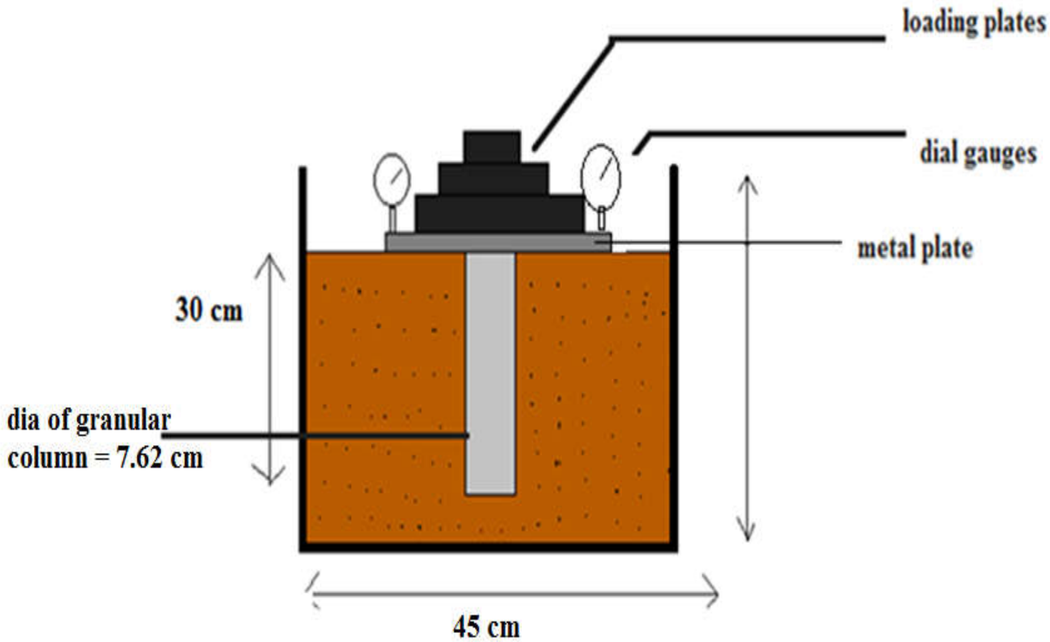

Fig. 3.7. Schemetic diagram of loading arrangement

3.10 EXPERIMENTAL PROCEDURE

First of all, test tank was prepared as per the directions given above. One sample of soil was taken for determination of compressive strength of soil as well. After that, granular column was installed as per the instructions given above. A circular metal plate of sufficient thickness was put over the granular column. This circular plate represents the footing at actual site and used to distribute the loading between granular 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 conditions such as load carrying capacity of soil without column, load carrying capacity of soil with column, bearing capacity of soil with column encased with geotextile and the observations are given below.

Fig. 3.8. Loading weights

3.11. OBSERVATIONS

The settlement and bearing capacity of column is calculated by conducting three experiments on the same soil by changing the fill conditions. As per IS 15284 (part1) settlement value more than 10 mm is considered as failure of granular column and load applied on stone column at 10 mm settlement is known as load carrying capacity of the granular column.

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.

Fig.3.9. Expansive soil with granular column

Fig.3.10. Soil after load application

Settlement is due to the change in the stresses within the soil due to the vertical movement of the footing under the increasing load conditions.

Fig.3.11.Soil after Settlement

Settlement occurs when soil is not able to resist load of the structure above it, which causes heaving and movement in the foundation.

Construction of granular column involves formation of a hole in the soil which is filled with granular mix and compacted with a rod to sufficient strength.

An improvement factor can be determined from the lateral support and load distribution of column and the surrounding soil stiffness on the basis of the area. This improvement in the factor shows an increase in the compression and also in amount to which settlement is decreasing by the installation of column in the soil.

Design method of granular column indicates an improving effect in comparison to the early state of soil because density of the surrounding soil increases due to installation of granular column. This study indicates the improvement in the load carrying capacity of single granular column encased with geotextile through field test made on test samples through a model test tank containing expansive soil by utilizing the gravimetric loading condition through the plate loading test.

Fig. 3.12.Granular column encased with geotextile

Fig.3.13. Overall Setup

The result indicated by the experiment due to the variation of load intensity and settlement are, expansive soil without granular column, expansive soil with granular column, soil with granular column encased with geotextile was plotted simultaneously for diameter 76.20mm and height and 300mm, and the observed variation in load-carrying capacity is given.

CHAPTER 4
EXPERIMENTAL RESULTS AND DISCUSSION

1.1. RESULTS OF TESTS PERFORMED ON SOIL

4.1.1 Specific Gravity of Soil

Table 4.1 Specific Gravity of Soil

	Sample 1	Sample 2	Sample 3
W_1 (gm)	699	700	710
W_2 (gm)	893	900	895
W_3 (gm)	1693	1692	1690
W_4 (gm)	1574	1576	1576
Specific Gravity, G	2.586	2.380	2.605

Average value of Specific gravity is 2.52.which is in normal range as per IS: 2386 (Part 3) – 1963 clause 2.4, for clayey soil.

4.1.2 Liquid Limit

Table.4.2. Liquid Limit of Soil

Number of blows	Water content (%)
24	57.33
28	54.8
33	51

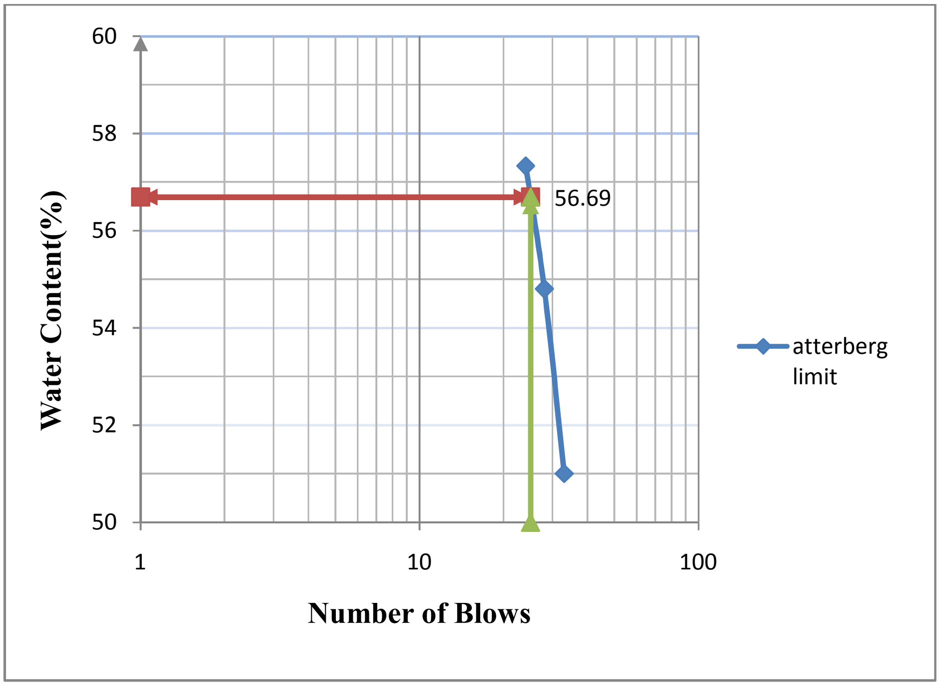

Fig.4.1 Liquid Limit Curve

From this graph the liquid limit of soil obtained was 56.69 %,which is in normal range for expansive soil.

4.1.3 Plastic Limit of Soil (W_P):

Table.4.3 Plastic Limit

Container Number	1	2	3
Weight of container, W_1 (gm)	6.2	6.5	6.6
Weight of container + wet soil sample, W_2(gm)	15.3	14.2	15.21
Weight of container + dry soil sample, W_3(gm)	13.35	12.7	13.2
Water content(%)={(W_2-W_3)/(W_3-W_1)}*100	26.53	24.19	30.45
Plastic Limit (Mean value,%) = 27.06			

4.1.4 Plasticity Index (I_P)

$I_P = W_L - W_P = 56.69-27.06=29.63\%$

Hence soil is highly plastic clay, it can also be determined from plasticity chart.

4.1.5 Liquidity Index (I_L)

$I_L = (W- W_P)/ (W_L- W_P) = (35-27.06)/(56.69-27.06) = 26.79\%$

4.1.6. 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 = 56.69%, which implies, $I_p = 0.73(56.69– 20) = 26.78\%$.

Since plasticity index of soil is more than 26.78%. It lies above A-Line, that means it is belongs to CH or OH groups. Liquid limit is more than 50%. So as per IS standards, soil can be categorised as highly clay or high Plasticity i.e.CH.

4.1.7 Dry Sieve Analysis

Table 4.4.Sieve Analysis of Soil

Sieve Size(mm)	Weight retained (gm)	Cumulative weight retained (gm)	Percentage weight retained %	Percentage weight finer%
4.75	32.440	32.44	6.488	93.512
2.36	60.600	93.04	18.608	81.392
1.18	155.310	248.35	49.67	50.33
0.600	135.210	383.56	76.71	23.29
0.425	15.330	398.89	79.79	20.21
0.300	40.830	439.72	87.94	12.06
0.150	38.440	478.16	95.63	4.37
0.075	21.120	499.28	99.85	0.15
pan	0.72	500	100	0

The % soil weight retained on the each sieve was noted on the reference with the total weight of soil taken during the test. Then cumulative % of soil retained (which gives the %finer when subtracted from 100) on successive sieve is calculated. A log graph is plotted on log scale between the grain size on X axis and percentage finer on Y axis.

Diameters corresponding to 10%, 30%, 60% finer is obtained which can be evaluated as D_{10}, D_{30}, D_{60} respectively.

Generally in case of clayey soil wet sieve analysis is used to fine the particle size distribution curve of soil.

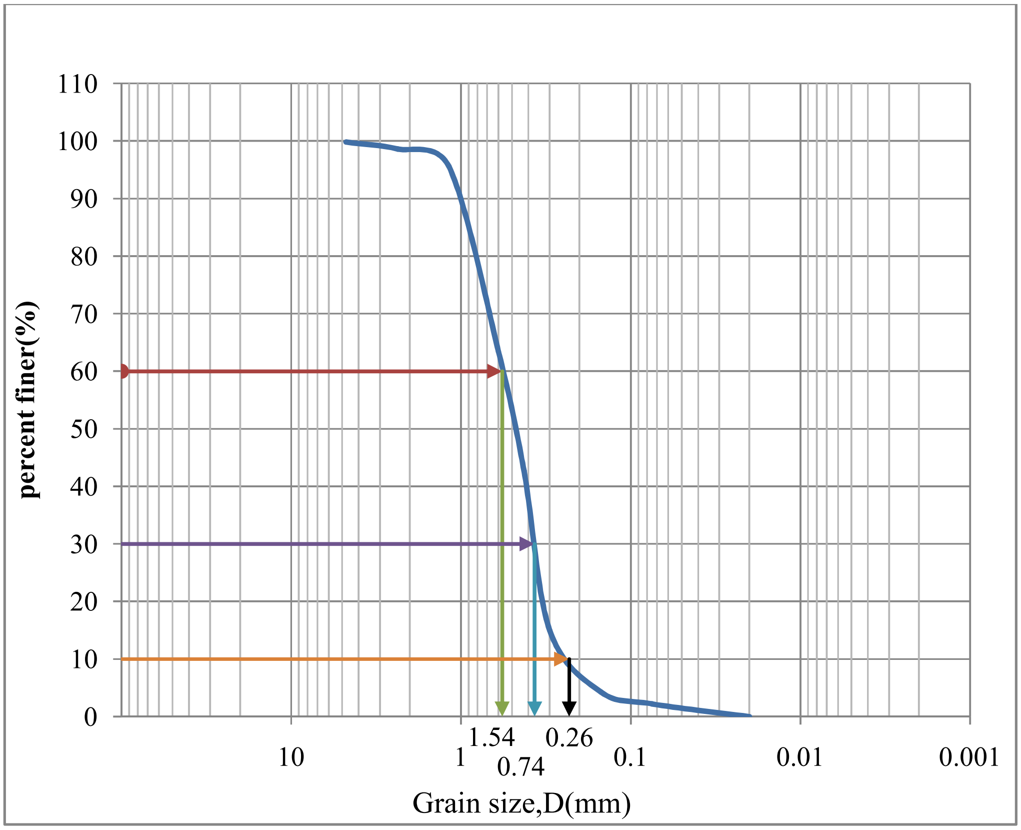

Fig. 4.2 Particle size distribution of soil

D_{60}= 1.54 mm, D_{30}= 0.74 mm, D_{10}= 0.26 mm

Uniformity Coefficient, $C_u = \frac{D_{60}}{D_{10}} = 5.92$

Coefficient of curvature, $C_c = \frac{{D_{30}}^2}{D_{60} \times D_{10}} = 1.36$

For soil to be well graded, Cu > 5 and 1< Cc < 3. So this is well graded soil.

4.1.8 Standard Proctor Test results

The observations are as follows.

Table.4.5 Standard proctor compaction test

S. No.	Moisture content, w (%)	Weight of soil in mould (gm)	Volume of mould (cc)	Bulk density (gm/cc)	Dry density = (bulk density) (KN/m^3)
1.	12	6028	4246	1.80	16.1
2.	16	6113	4246	1.88	16.2
3.	20	6117	4246	1.87	15.6
4.	24	6032	4246	1.79	14.4

A curve is plotted between the water content and dry density, generally the shape of resulting plot have a distinct peak as shown. Such inverted 'V' is obtained for clayey soils and known as compaction curve. Following is the compaction curve of the soil used in this project.

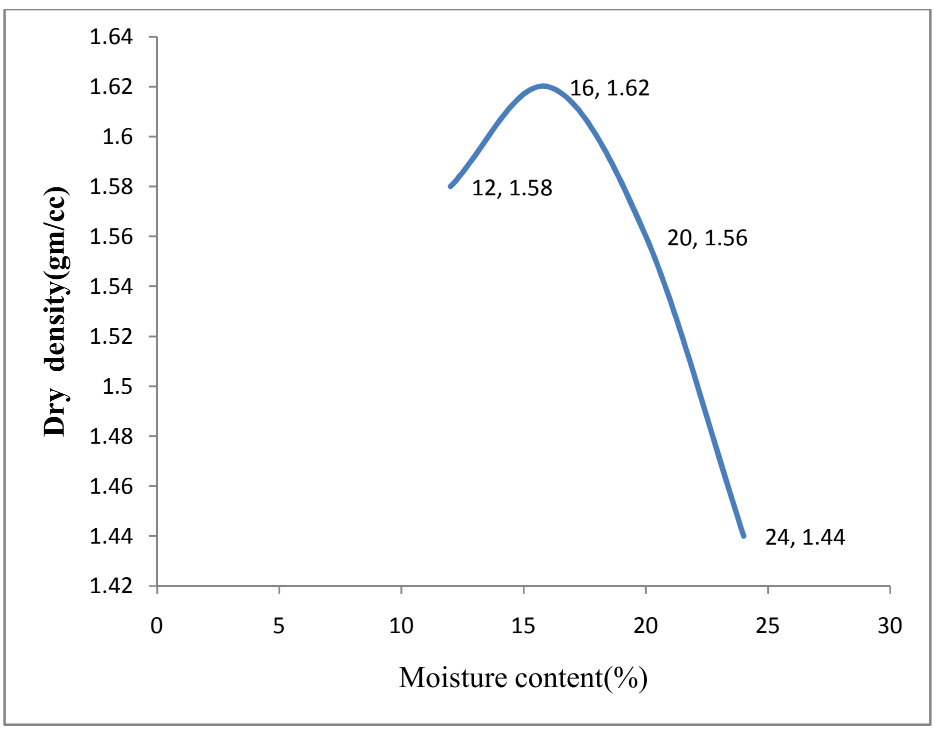

Fig. 4.3. Standard proctor compaction curve of expansive Soil

Optimum Moisture Content, OMC = 16% and Maximum dry density = 16.2 KN/m^3

4.2.RESULTS OF TESTS PERFORMED ON CEMENT

Table 4.6.Properties of cement

Parameter	**Value**
Consistency of cement (%)	34.75
Initial setting time (min)	30
Final setting time (hrs)	10
Compressive Strength (KN/m^2)	33
Specific Gravity	3.15

Cement used in this project is ordinary Portland cement which fulfils the requirement of IS: 122269-53, grade

4.3 RESULTS OF TESTS PERFORMED ON SAND

Grain size distribution of sand was conducted which has been used in granular column. Total weight of sand taken = 1000gms

4.3.1 Grain size distribution of sand

Table 4.7 Sieve analysis of sand

Sieve size (mm)	Weight retained (gm)	Percent retained (%)	Cumulative Percent retained %	Percentage weight finer%
4.75	2	0.2	0.2	99.8
2.36	12	1.2	1.4	98.6
1.18	30	3.0	4.4	95.6
0.600	322	32.2	36.6	63.4
0.425	224	20.8	57.4	42.6
0.300	266	27.6	85.0	15.0
0.150	109	10.7	95.7	4.3
0.075	17	2.1	97.8	2.2
pan	12	2.2	100	0

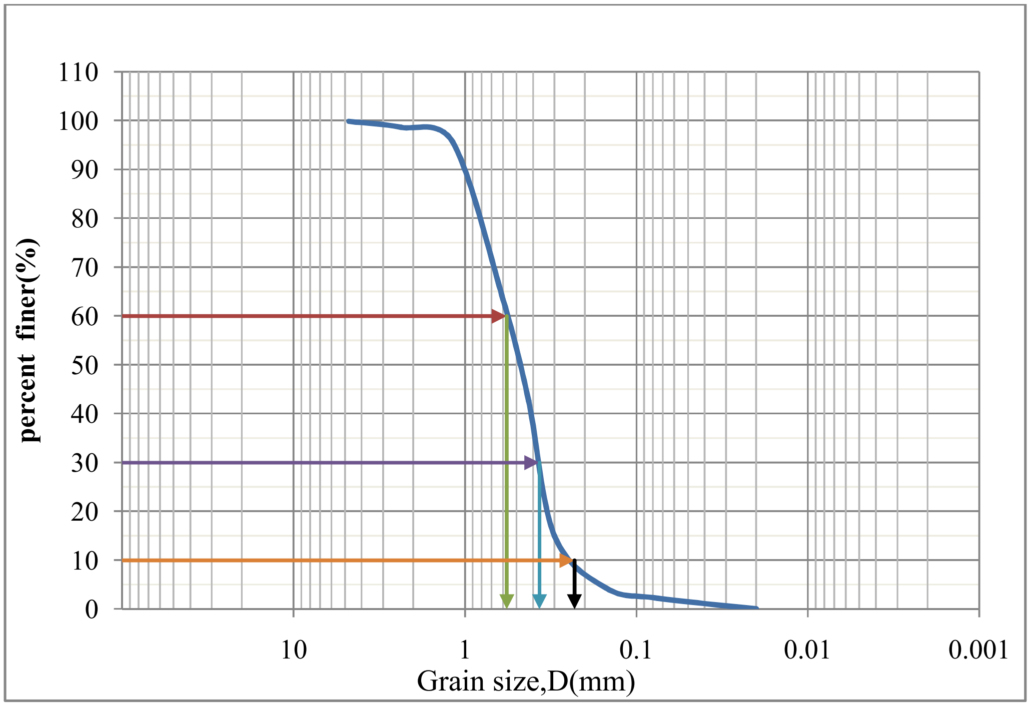

Fig. 4.4 Particle size distribution of sand

D_{60}= 0.57mm, D_{30}= 0.368 mm, D_{10}= 0.23 mm

Uniformity Coefficient, $C_u = \frac{D_{60}}{D_{10}} = 2.48$

Coefficient of curvature, $C_c = \frac{{D_{30}}^2}{D_{60} \times D_{10}} = 1.033$

For Cu < 3 indicates a uniform soil means sand having very narrow particle size and 1< Cc < 3. So this is well graded sand.

Table.4.8.Properties of sand

Properties	**Value**
C_U	2.48
C_C	1.033
Specific Gravity	2.66

4.4.FLY ASH

Table.4.9. Fly ash composition (source: India Mart data)

Constituents of PFA	Value
SiO_2	48%
Al_2O_3	26%
CaO	2.5%
MgO	1.5%
Fe_2O_3	9%
Relative Density	2.2-2.8

These are the properties of fly ash as per the reference taken by India mart.

4.5 GEOTEXTILE

Based on the construction condition to mitigate the problem the use of geotextile varies depending upon its properties and requirement.

Table 4.10 Properties of geotextile (Source: India Mart Data)

Parameter	Value
Tensile modulus of geotextile (J),KN/m	2300
Thickness of geotextile(t_g), mm	5

To determine the actual effect of geotextile on the performance of granular column load is applied on the soil with the aid of gravimetric loading and the load settlement behaviour was estimated through the graph results were found by comparing the stone column without encasement.

4.6 RESULTS OBTAINED FROM DESIGN OF MORTAR MIX

Table 4.11 Granular column sample preparation

S.N.	Proportion(Cement and fly ash)	Load (N)	Area(mm^2)	Compressive strength(KN/mm^2)
Sample 1	40%cement + 60% fly ash	7.92	4900	1.62
Sample 2	50%cement + 50% fly ash	8.67	4900	1.76
Sample 3	60%cement + 40% fly ash	10.75	4900	2.19

In this project we have used sample 2 because its compressive strength was in range and the percentage of cement get also reduced for economy point of view this sample is best suited.

Actual compressive strength of the virgin soil at OMC is = 0.45 KN/mm^2

Combined properties of granular column:

Materials used in granular column are sand, cement, fly ash by percentage 75, 12.5, 12.5 and specific gravity 2.66, 3.15, 2.5 respectively.

Specific gravity of granular column can be calculated by using the formula:

$$G_{sb} = \frac{(P_A + P_B + P_C)}{[P_A/G_A + P_B/G_B + P_C/G_C]}$$

Where: P_A, P_B, P_C = percent by mass of each material used in column

G_A, G_B, G_C = bulk specific gravity of each material

Hence, the combined specific gravity of granular column is coming out to be 2.69

4.7 RESULTS OBTAINED AFTER THE APPLICATION OF LOAD ON THE SOIL

In actual way load is shared between the soil and granular column. These are the results obtained. As the load is increasing settlement in the soil is also increasing. Settlement is recorded upto 15mm but the failure is estimated at 10 mm as per IS standard.

Table 4.12 Soil without granular column

S.N.	Load(N)	Settlement(mm)
1	0	0
2	60.23	-0.5
3	130.74	-1.25
4	180.52	-2.12
5	300	-4.75
6	399.65	-7.2
7	445.2	-8.4
8	481.88	-10.25
9	481.88	-12.0
10	481.88	-15.05

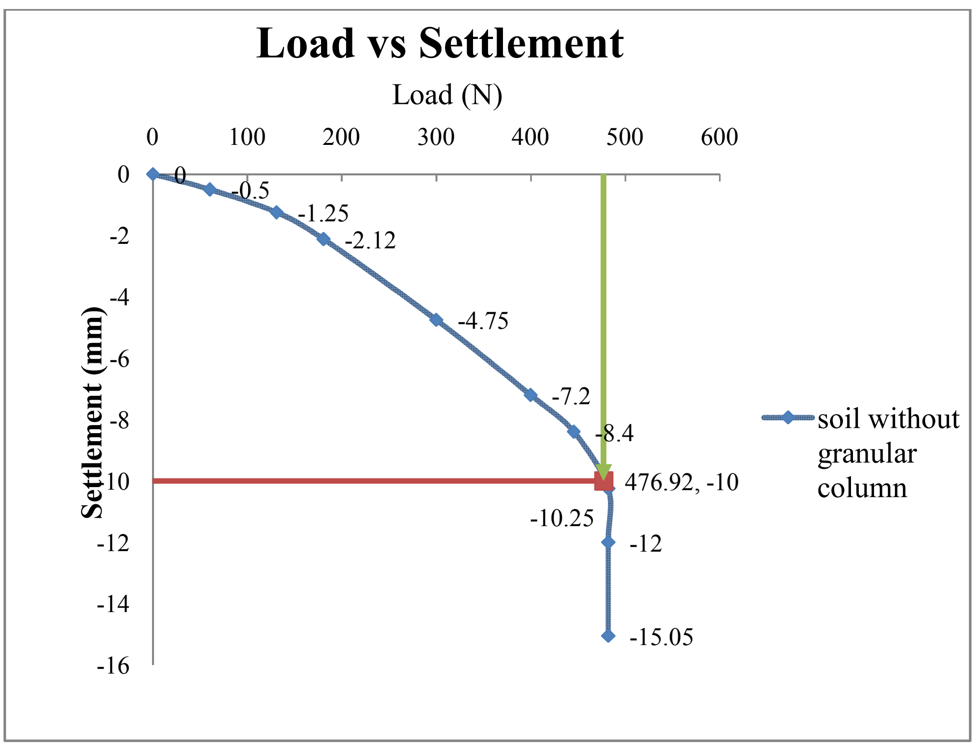

Fig. 4.5 Load Settlement Curve of soil without granular column

Table.4.13.Load settlement calculation of soil with granular column

S.N.	Load(N)	Settlement(mm)
1	0	0
2	60.23	-0.5
3	140.67	-1.27
4	336.87	-3.5
5	552.69	-5.2
6	670.41	-6.47
7	742.41	-7.2
8	870.52	-8.4
9	1006.13	-10.5
10	1006.13	-12.24
11	1006.13	-15.95

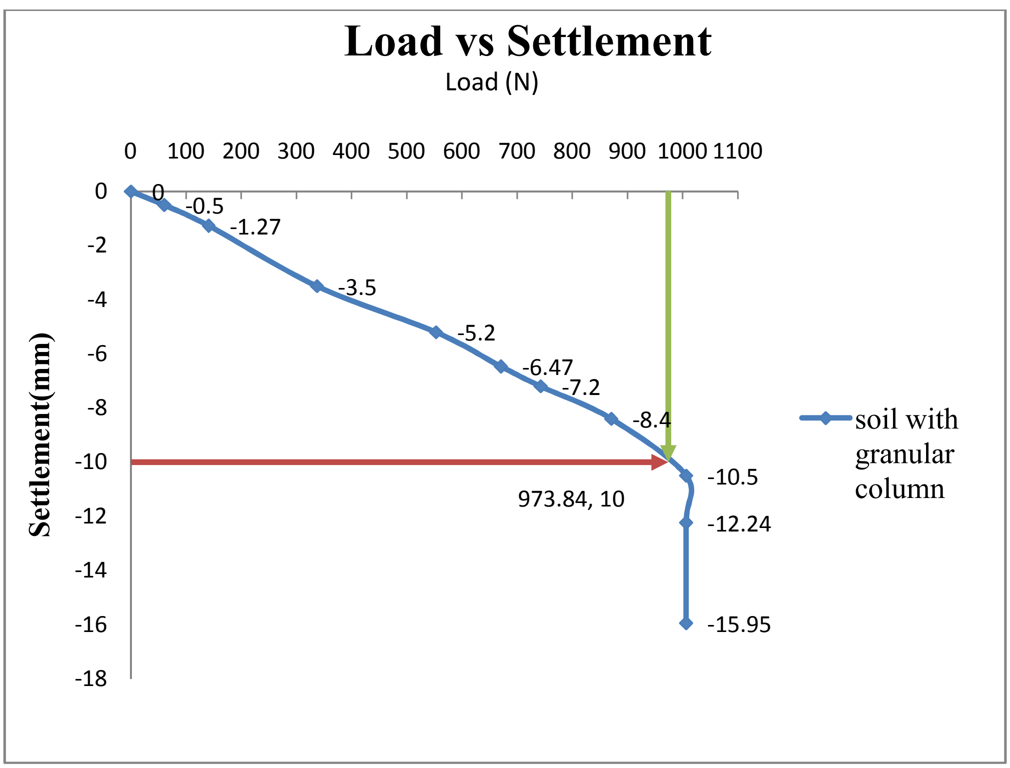

Fig.4.6.Load Settlement Curve of soil with granular column

Table 4.14 Load Settlement Calculation of soil with geo textile

S.N.	Load(N)	Settlement(mm)
1	0	0
2	60.23	-0.45
3	150.86	-1
4	403.87	-2.5
5	542.85	-3.25
6	670.79	-4.47
7	865.45	-7.23
8	980.52	-8.49
9	1286.13	-9.55
10	1398.35	-10.24
11	1575.28	-12.95
12	1575.28	-13.85
13	1575.28	-15.28

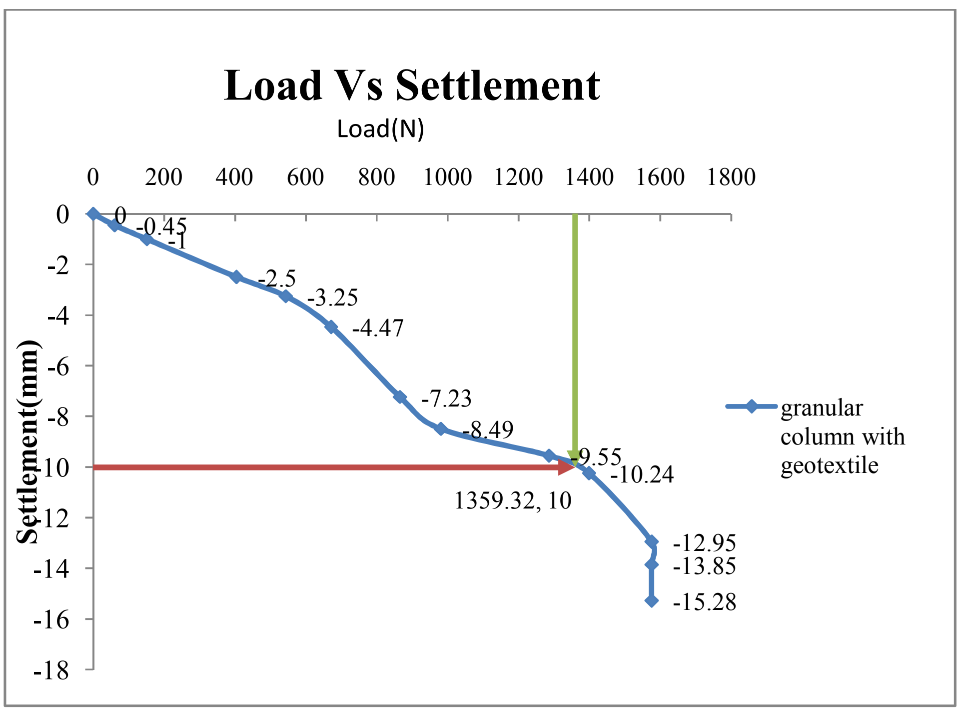

Fig.4.7. Load settlement curve of soil column encased with geo textile

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

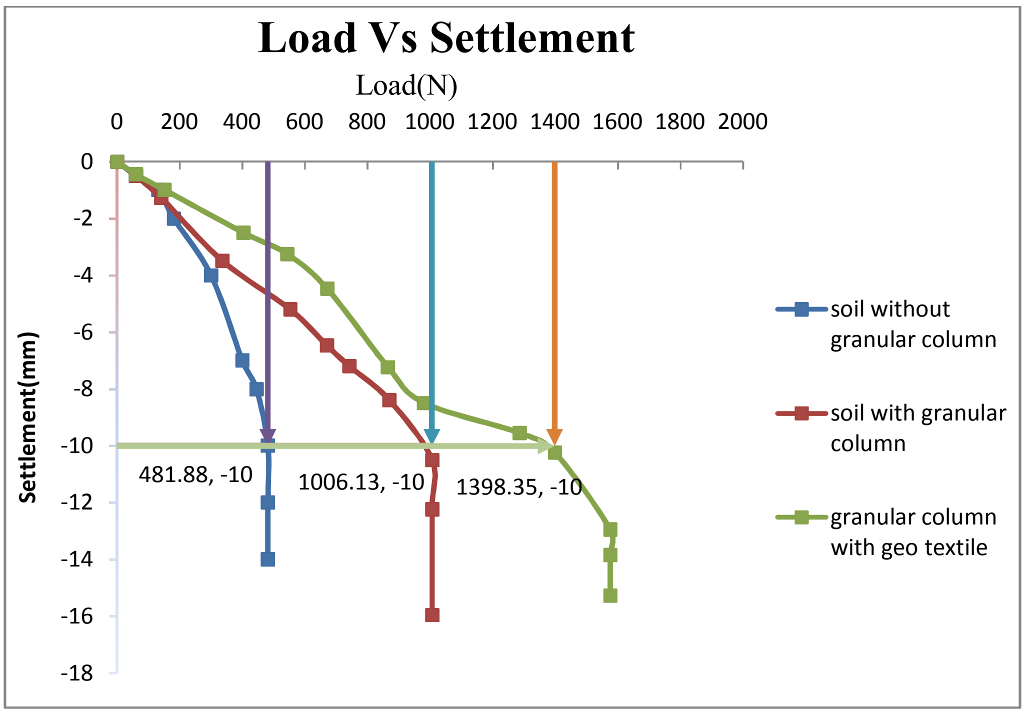

Fig.4.8 Comparison curve of load vs settlement of soil under different fill conditions

Variation in settlement and load carrying capacity of granular column with the different fill conditions of the column in soil is shown below in tabular form. As per IS 15289 part 1, load carrying capacity of granular 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 soil without stone column ,soil with granular column, soil with geo textile wrapped granular column, load experienced by granular column at 10 mm settlement is given below. It can be seen from the table that load carrying capacity of soil increases if granular column is provided with encasement in expansive soil.These results shows that geotextile encasement have increases the load carrying capacity of soil and reduces the settlement.The load carrying capacity of all the three specimens along with their improvement percentage have been tabulated below:

Table .4.15 Load carrying capacity of granular column

Types of Granular column	Load carrying capacity at 10 mm settlement(KN/mm^2)	Improvement (%)
Soil without granular column	42.190	-
Soil with granular column	86.150	104.19
Soil with granular column encased with geotextile	120.25	185.02

From the above results it can be said that settlement of the footing occurs due to the settlement of circular plate, which may be due to destruction of soil generated under the pressure bulb beneath the plate. The load carrying capacity of the expansive soil reinforced with granular column is higher as compare to that of the compacted expansive soil alone. This is due to the inclusion of high density grouted granular mix. As a result there is a reduction in the settlement of granular column as compare to that compacted expansive soil alone at any level of simultaneously increasing load.

Effect due to encased granular column was also observed that is the load carrying capacity of encased column is more as compare to the granular column alone, this is due to the fact that as bulging starts in the column all the tensile stresses was being carried by the geotextile encasing which reduces the failure in soil at early age .

CHAPTER 5
CONCLUSION

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

1. There is a increase in the load carrying capacity of expansive soil and decrease in the settlement of soil with the intrusion of grouted granular column.
2. A mixed failure condition is observed due to the bulging and heaving of surrounding soil during the failure of encased column.
3. In this study, use of fly ash in granular column is useful in both ground improvement and also environment related problems will be derived as fly ash is a waste generated from electric power plant, produced in large amount which is approximately 7000 tons per day and its disposal is very difficult.
4. From this experiment it can be derived as addition of materials in appropriate ratio of fly ash and cement (fly ash more than 40%) result as a strong mixture for granular column, strength of column also depends on the types, amount and proportion in which the materials are being used. However a positive behaviour was showed by the cement when added in higher amount.

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