The Major Project- II

On

A Study on stability of stone column in silty sand

Submitted In Partial Fulfillment for the Award of the Degree of

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IN

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With Specialization In

GEOTECHNICAL ENGINEERING

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2015

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CERTIFICATE

This is to certify that major project-II entitled **"A STUDY ON STABILITY OF STONE COLUMN IN SILTY SAND"** is bona fide record of work carried out by Rajkumar Singhal (Roll No. 2K13/GTE/14) under the guidance and supervision, during session 2015 in partial fulfillment of the degree of Master of Technology (Geotechnical Engineering) from Delhi Technological University, New Delhi.

The work in this major project- II has not submitted for the award of any other degree to the best of my knowledge.

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As I write this acknowledgement, I clarify that this is note of thanks and regard from my side. I am very thankful toward my project guide **Dr. A. K. GUPTA**, Professor, Civil Engineering Department, Delhi Technological University New Delhi for giving me an opportunity to work under his guidance. I am also thankful to **Dr. Nirendra Dev,** HOD of Civil Engineering Department, Delhi Technological University New Delhi for supporting me during the project.

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DECLARATION

I hereby declare that the work in this Project Report entitled **"A STUDY ON STABILITY OF STONE COLUMN IN SILTY SAND"** is bona fide record of work carried out by me as a part of major project-II in partial fulfillment for the Master of Technology in Geotechnical Engineering.

I have not submitted the matter presented in this report for the award of any other degree.

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Abstract

Heavy structures such as high rise buildings, Dams, oil storage tanks etc demand soil of good bearing capacity for their foundation. Due to lack of availability of good soil, there is a need of improve the soil for a good foundation. Several techniques are available for stabilizing or improving the soil. In recent years it has been proved that installation of stone column is acceptable method to improve the soil. Installation of stone column in soil is cost effective, feasible and environmentally friendly technique.

Stone aggregates and Waste materials like crushed concrete can also be used for formation of stone column. Stone columns are also provided with encasing of geosynthesis for increasing the load carrying capacity of stone column. Generally stone columns are provided in group. These are installed in weak soil to enhance the shear resistance of soil and bearing capacity and acts as reinforcement to weak soil. Stone columns also reduce the liquefaction potential of soil and decrease the compressibility of fine grained and loose soils.

The main aim of this project is to study the effect of the various parameters such as diameter of stone column, length of stone column, number of stone columns, spacing of stone column and encasement of stone column with geotextile on load bearing capacity of stone column. Load test was carried out to study the effects of above parameters.
Increase in diameter of stone column leads to enhance load carrying capacity of stone column. If length of floating column is increased then there is an increase in load carrying capacity of stone column. Encasement of stone column also improves load carrying capacity.

Keywords**:** soil, stone aggregates, geosynthetic

CONTENTS

LIST OF SYMBOLS

Sc …..Stone column

Nc……………………………………………………….............Number of stone columns

l/d……………………………………………….......Length to diameter ratio of column

Dc……………………………………………….................diameter of Stone column

% ………………………………………………………................................. Percentage

Fig...…………………………………………………...Figure

dia. ……………………………………………………......................................diameter

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CHAPTER - 1

INTRODUCTION

1.1 GENERAL

Large area covered with soft clay or very thick layers of deposits is not preferred for construction of a foundation. But with the time, due to increase in population, industrial needs, urban areas and human needs, there should be realizing of foundations on such areas. So there is a need to improve such soil strata. In present several techniques are available for Guidelines are not well defined for design of stone column. For experimental study, stiffness and deformation behavior of Weak soil and improved ground are studied. Some parameters like column spacing, length of column, no. of columns are varied in experiment work and observe the improvement of ground. This is done in a cylindrical tank having stone column and surrounding soil. The effective lateral confining stress which is provided by surrounding soil governs the strength and stiffness of a stone column. There is a problem in very soft soil with low undrained shear strength because this soil may not achieve the full lateral confining stress. To overcome this, stone columns with high strength geosynthetic reinforcement encasing are provided. An increase in the rate of consolidation and acceleration in settlement is caused by short drainage pathway which is provided by stone columns. However, when stone columns are used in sensitive clays, these have certain limitations. There is increase in the settlement because of no presence of the lateral restraint. The clay particles are clogged around the stone column so reducing radial drainage. To overcome these difficulties, and to enhance the efficiency of the stone columns on the bases of strength and the compressibility, these are encased (reinforced) using geocomposite/geogrid. Deshpande & Vyas (1996) gave conceptual performance of stone columns surrounded by geosynthetic material. Katti et al (1993) gave a theory for improvement of soft soil using stone columns encased in geosynthetic based on particulate concept. In 1995 pribe introduced the general shear failure pattern for the group of stone columns. He gave an analytical method to predict the group capacity by considering the equivalent width of foundation. He also considered the angle of shear resistance of unreinforced or weak ground and a cohesion value for the same equivalent foundation width. Driven stone columns are now a day's used to strengthen the weak soil. After a so much use of stone columns in construction developments, there is only empirical design methods are available and limited information is available in codes.

Stone columns are always used in group. So centre to centre spacing of columns is considered a variable parameter, depending on load carrying capacity of stone column and deformation characteristics. Centre to centre spacing of stone columns depends on influence area of each stone column. Influence area of a stone column is the area which can be treated by that individual stone column. This influence is determined by unit cell concept. This influence area also depends on failure nature of stone column. Generally bulging failure is considered for stone column. Centre to centre spacing is also effected by pattern like triangular, square, hexagonal etc. in which these are installed. According to centre to centre spacing or influence area, number of stone columns which is required for complete area is determined.

The soil improvement by reinforcing the soil is best method for soft clay or cohesive soil. This can be done by both in horizontal and vertical directions. Stone columns enhance the bearing capacity of soil and reduce the settlement. Loose deposits can be improved by using dense columns made of gravels. These columns are called stone columns. Gravels may be natural aggregate, concrete debris etc. installation of stone column can be done in both coarse grained and fine grained soil. Shear strength of soil below structures is increased by accelerating the consolidation in fine grained soil by installation of stone column. The lateral confinement which is applied by surrounding soil on stone column governs the load carrying capacity of stone column. In soft soil, this lateral confinement may not be developed so in case of soft soil, stone columns with geosynthetic encasing are used. This also improves the performance of stone column.

1.2 APPLICATION OF STONE COLUMNS

- Roadways and railways embankments
- Sewage treatment plants
- Commercial buildings and Industrial warehouses
- Apartment buildings, high rise buildings, town houses, shopping malls
- Retaining walls
- Buildings in seismic areas

Table 1.1 Suitability or effectiveness of Stone column in different types of Soil

Ground type	Densification	Reinforcement
Sand	Excellent	Very good
Silty sand	Very good	Very good
Non plastic silt	Good	Excellent
Clay	Marginal	Excellent
Mine spoils	Depending upon gradation	Good
Dumped fill	Good	Good
Garbage	Not applicable	Not applicable

1.3 DESIGN CONCEPT

The parameters which are considered to determine the capacity of stone column

- diameter of the stone column
- lateral resistance of surrounding soil
- deformation characteristics of soil
- angle of internal friction of stone column material
- undrained shear strength of surrounding soil
- length of stone column

The angle of internal friction depends on the material type, its shape, gradation, effectiveness of compaction. Normally angle of internal friction is varying from 38 to 55 degree.

1.4 FAILURE CRITERIA OF STONE COLUMN

There are three possible failure mechanisms of stone column

- bulging failure
- punching failure
- general shear failure

1.5 DEFORMATION ANALYSIS

Generally Stone columns are provided in a regular grid. In analysis, a stone column with surrounding soil is considered to be an equivalent cylindrical unit cell. The radius of influence of this unit cell is generally 0.525S, 0.565S, 0.645S where S is centre to centre distance between two stone columns in triangular, square and in hexagonal patterns.

Some other assumptions for geotextile encased stone columns are also assumed for analytic solution.

- Geotextile is assumed as an elastic material of constant stiffness modulus.
- Tension developed in geotextile due to column installation is supposed to be uniform along the length of column.
- Shear stresses between soil and geotextile and between geotextile and column in circumferential direction are assumed to be zero.
- The stone column is supposed to be on a hard strata and settlement is ignored.
- Lateral confinement by soil is due lateral earth pressure of soil.

1.6 INSTALLATION OF STONE COLUMN

When stone columns are installed below ground surface then soil surrounding the column is disturbed and results in smear effect. Soil is divided in three zones.

1) Penetration zone in which granular particles are inserted in clay.

2) Smear zone up to which soil is reoriented and can be densified.

3) Densification zone in which soil structure is unchanged but soil can be compacted.

1.7 ROLE OF GEOSYNTHICS IN STONE COLUMN

Geosynthetic include geotextile, geogrid, geomembranes, geocomposite, geonet and other such types of materials. These are used to modify or improve the properties of soil. Geosynthetic have been used in recent time to improve the soil in construction projects. Civil engineers are frequently using geosynthetic as a solution for weak soil. Geosynthetic are also cost effective solution where other techniques for improving the soil are not economically fit.

TYPES OF GEOSYNTHETIC

- Geotextile
- Geomembranes
- Geogrid
- Geonet
- Geocomposite
- Steel reinforcement

On the bases of results obtained from study, it can be observed that the performance of a stone column is improved significantly by the application of encasement of geotextile to provide an additional lateral confinement. Some conclusions can also be given:

1. As compared to non encased stone columns, columns with geotextile encasement have a reduction effect on settlement of the stone columns, and this reduction effect is more effective for encasements of higher stiffness values as compare to encasements with lower stiffness values.

2. due to additional lateral confinement provided by the geotextile encasement of the stone column, Column bulging is decreased significantly which implies that encased stone columns with geotextile are better supported laterally than ordinary stone columns and therefore they can provide bearing capacity of higher values.

3. Geotextile encased stone columns have undergone higher lateral expansions at greater depths as compare to non encased stone columns. Encased stone columns observe greater lateral bulging near the top surfaces and gradually decrease with depth up to depth equal to about three times of the column diameter below the surface.

4. Centre to centre Column spacing and column diameter have a effect on settlement reduction. Increasing column diameter and decreasing the spacing of columns, and so increasing the area replacement ratio, give a significant reduction in settlement. Hence the selection of encasement stiffness for the encased stone column should be based on column diameter and centre to centre column spacing.

1.8 STONE COLUMN FOR GROUND IMPROVEMENT

Stone columns improve the deformation and strength properties of soil by providing the primary functions of reinforcement and drainage. Improvement of soil by stone columns includes three factors. First is inclusion of stone column material in soil like gravels, crushed stones etc. which is so stiffer. Second factor is that surrounding soil is densified by the installation of stone columns. Last factor is that stone column acts as a vertical drain. So it can be said that installation of stone column is not only the replacement of soil but also it can alter state of stresses and the material properties in the improved soil mass. Stone columns are used in a variety of soils, from loose sand to soft soils. Stone columns are used to increase the bearing capacity, to improve slope stability of embankments, to reduce the differential and total settlements and also to increase rate of consolidation. Stone columns are most effective in clayey and silty soil.

Vibro replacement technique is a ground improvement technique which constructs stone columns with the help of a crane suspended down vibrator to densified granular soils and reinforces all soils. By Vibro replacement technique, stone columns are constructed in two ways. First is the wet top feed process and other is dry bottom feed process. In wet top feed process, the vibrator is penetrated to the desire depth using the vibrator's weight and its vibrations. The water jets are located in that vibrator's tip. The stone aggregates or crushed stones are now introduced at ground surface to the space which is created by the jetting water around the vibrator. The stone aggregates then fall through that annular space to the vibrator's tip and fill the voids which is created by the means of vibrator is lifted up several feet. Now the vibrator is gradually lowered for displacing and densifying the underlying stone aggregates. This Vibro replacement process is continued until a stone column is constructed up to the ground surface.

The dry bottom feed process is similar to wet feed process but there is a difference that in later process, water jets are not used and the stone aggregates are introduced to the vibrator's tip through a feed pipe which is attached to the vibrator. For the vibrator to penetrate to the desire depth Pre drilling of strata at the stone column location may be require.

Both techniques of construction create a dense stone column that reinforces the weak zone and densified the surrounding soils. stone columns constructed by Vibro replacement technique have been used to decrease settlement and increase bearing capacity, reduce liquefaction potential for all types of structures including buildings, dams, embankments, towers and tanks.

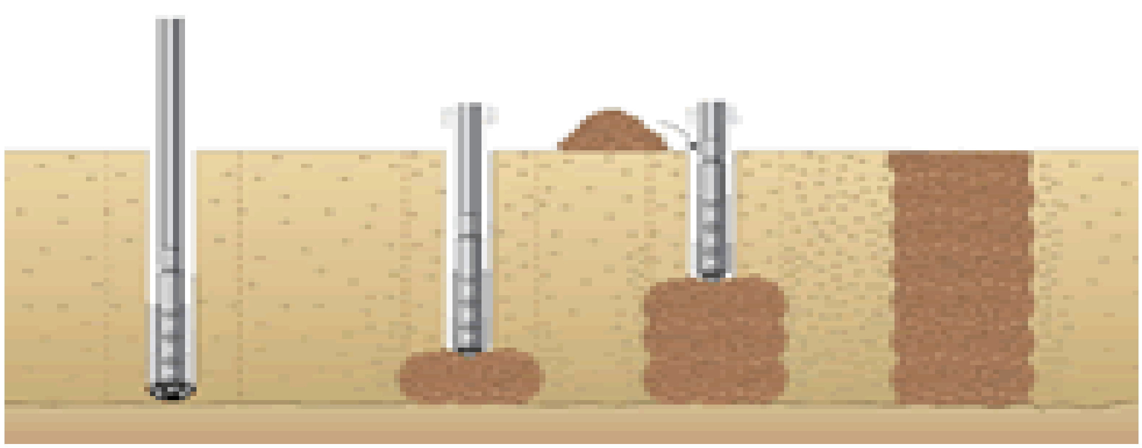

Fig. 1.1 Insertion of Stone column in ground

Vibro displacement is also an installation technique to compact stone columns in cohesive soils using vibratory probes. In this technique, to advance the probe hydraulically, special rigs are used for displacing the soil without removing. Stone aggregate columns can be constructed with or without pre-drilling but depending on the type of soil which is to be improved and the availability of equipments. Vibro displacement process is the cost effective since if it is possible.

Spacing of stone columns and pattern of stone columns like triangular, square etc. also effect the strength characteristics. Radius of influence of each stone column also depends on spacing of stone columns. Radius of influence is equal to CS where C is a constant and its value is 0.525 and 0.564 for triangular and square pattern respectively. Equivalent circular effective area for each stone column is two times of diameter of column.

1.9 OBJECTIVE OF THE STUDY

To study the effect of installation of stone columns on bearing capacity of soil by changing various parameters of stone column like diameter, length, number of stone columns etc.

CHAPTER - 2

LITERATURE REVIEW

2.1 INTRODUCTION

In the recent past years, for improving the properties of soil, several studies have been made using stone columns. Several studies were also carried out to enhance the performance of stone columns. So some literatures related to numerical and experimental studies on stone column are reviewed below.

2.2 REVIEWS OF LITERARTURE

Vesic (1972), Hughes and withers (1974) [6] proposed the theory of load transfer, determination of ultimate bearing capacity and ideas about settlement.

Later this was modified by Priebe (1976), Aboshi et al. (1979), Datye and Nagaraju (1981), De Beer (1983) Madhav et al. (1994).

Bergado et al. (1990) did field study and found that by installation of stone columns, bearing capacity is increased nearly four times and also increase in factor of safety of slopes nearly 25%.

Mitchell (1985) [10] told that stone columns also reduce the settlement. It was also observed that stone columns are better than prefabricated vertical drains. **Katti et al. (1993)** gave a theory that stone columns with geosynthesis improve the soft soil strata. **Deshpande and Vyas (1996) [8]** proved the performance of stone column if used with encasing in geosynthetic material.

Shankar and Shroff (1997) [15] did experimental studies and observed the effect of pattern of stone columns in which they are installed. He found that triangular pattern of stone columns is more optimum and rational.

Mitra and Chatopadhyay (1999) [11] studied the factors which influence the capacity of stone column. He found that in case of failing of column by bulging, critical length of column is approximately three to five times the diameter of stone column. Effect of ratio of length to diameter on floating and end bearing stone columns was also stuied.

Malarvizhi and Lamparuthi (2008) [9] told about the effect of stiffness of encased material on the load carrying capacity of stone column through studies.

Ambily and Gandhi (2007) [1] conducted the experimental study to see the behavior of individual column and group of columns with variation in parameters like shear strength of soft clay, spacing between columns, different loadings.

Malarvizhi (2004), Gneil and Bouazza found that stone column's load carrying capacity depends on the lateral confining thrust which is provided by the surrounding soil. In case of installation of stone columns in soft clay, load carrying capacity of stone column is reduced due to less lateral confinement.

Black et al. (2007) [2] did research on performance of stone columns in a weak soil deposit and evaluated the effects of stone columns surrounded with a wire mesh. After formation of soil bed, stone columns are inserted using aggregates. Load deformation characteristics were observed by applying load in plate load test. Tests were conducted on untreated soil, treated soil with stone column and also soil treated with reinforced stone column. Reinforcing of stone column was done by various methods like by wire mesh, metal bridging rod, concrete plug etc. metal bridging rod method was found well in terms of both initial stiffness on the bases of modulus of sub base reaction and load carrying capacity

Murugesan and Rajagopal (2007) [12] found from his laboratory testing that stiffness of encasement material enhance the strength of stone column. It was also observed that increase in diameter of stone column results in decease in effect of encasing of stone column. So improvement in strength of stone column depends on both diameter of stone column and modulus of encased material.

It was found from test results that strength of stone column depends on maximum radial reaction of the surrounding soil against the bulging of column and also a limitation of vertical movement in stone column nearly four times of diameter of stone column.

According to **Lee et al. (2007), Khabbazian et al. (2009) [7] and Rajgopal (2010),** due to a vertical load on the top of a stone column, axial deformation is generated and this is due to lateral expansion near the top of the column. So volume of column will change and under vertical load stone column will be subjected to different lateral deformations.

Shubber et al. (2009) [17] determined the possibility of using of large base stone columns to enhance the performance of stone columns, mainly increase load carrying capacity of stone columns. Experiments were carried out on 400 mm depth of saturated bed of soft clay. Undrained shear strength of clay was 7.5 Kpa. Circular footings of diameter 60, 70, 80, 100 mm were loaded gradually up to failure. Due to enlarged based stone column there was an increase in load carrying capacity of stone column about 3.5 times in comparison to ordinary stone column when area replacement ratio is 0.72.

Shiva Shankar et al. (2010) [16] proposed another method to improve the performance of stone columns by inserting small diameter steel bars along the circumference vertically of stone column. Unit cell concept was used in this study to design the apparatus which are required to assess the behavior of an individual column in a group of stone columns.

Behavior of stone column was studied by Beena and Shukoor (2012) studied in which a part of the broken stone is replaced by some other locally available material like rice husk. Stone column accommodate a drainage path to the water which is confined in clay and rise husk results in degradation of consolidation of clay.

Tests were performed by **Sharma et al. (2012)** on stone columns by placing the horizontal strips of geosynthetic at different locations over the column length and also encasing the column over full length as reinforcement. It is seen that placement of geosynthetic at half diameter spacing over column length is best configuration. Encasement over full length of column subjected to greater failure stress in comparison to encasement on top half column length.

Poorooshasb and Mayerhof (1907) studied about efficiency of end bearing stone column and changes in the settlement of a foundation. Various factors like properties of granular material used for formation of stone column, weak soil properties, column spacing, depth of bed rock relative to the tip of the stone columns and load which is supported by raft foundation.

Tandel et al. (2012) found that the encased stone column of small diameter is better than the stone column of large diameter of same encasement.

Castro and Segesta (2011) [3] formulated an analytical method in which soft soil is assumed as an elastic material from the Mohr coulomb yield pattern and a fixed dilatancy angle. For encasement, elastic plastic behavior is considered.

Stone columns are formed and installed to decrease the settlement of loose soil or compressible soil layers so it would be easy to construct structures with shallow foundation on soft soil. Stone column results in increase in time rate of consolidation settlement due to draining characteristics. These are made of compacted granular soil so installation of stone column can be done in a easy manner below the shallow footing. Shear strength and stiffness of soil is improved by stone columns.

Generally stone columns are used in group in field. Since column to soil, stiffness ratio is high so there is more stress transfer from soil to column. After applying the load, column under goes undrained elastic settlement but after that it results in primary consolidation. Stone column creates drained condition in soil below ground so consolidation rate is increased. Due to this, problem of settlement after building construction is reduced. Stone column increases the load carrying capacity of soil by reinforcing it. In case of very soft soil, stone column is not adequate for developing the load carrying capacity. So geosynthetic is used for encasing the stone column.

CHAPTER - 3

MATERIALS USED

3.1 INTRODUCTION

Materials used in this project are soil, stone aggregates, geosynthetic. Soil was taken from power house in DTU campus. Soil was removed up to 200 mm depth below ground surface. Beyond this depth, soil was taken out for testing in plate load test. Soil properties were investigated by laboratory testing. Tests like specific gravity, standard proctor test, liquid limit, sieve analysis etc are conducted to classify the soil and to evaluate the soil properties.

Stone aggregates were used to fill the stone columns. Aggregates of varying size were used. Aggregates were taken from concrete laboratory of DTU. Aggregates of size 10 to 20mm were used. Size was fixed by sieve analysis.

3.2 TESTING OF SOIL

3.2.1 SIEVE ANALYSIS

Table 3.1 Particle size distribution by sieve analysis

S. No.	Sieve size (mm)	Mass of soil retained (gm.)	Percentage on each sieve Retained Mass of soil/Wt. *100	Cumulative % retained	% finer = 100 - % cum. Retained
1	4.75	34.30	3.43	3.43	96.57
2	2.36	84.01	8.401	11.831	88.169
3	1.18	137.0	13.70	25.531	74.469
4	0.600	115.2	11.52	37.051	62.948
5	0.300	127.60	12.76	49.811	50.189
6	0.150	221.4	22.14	71.951	28.049
7	0.075	155.39	15.539	87.490	12.505
	pan	125.05	12.505		

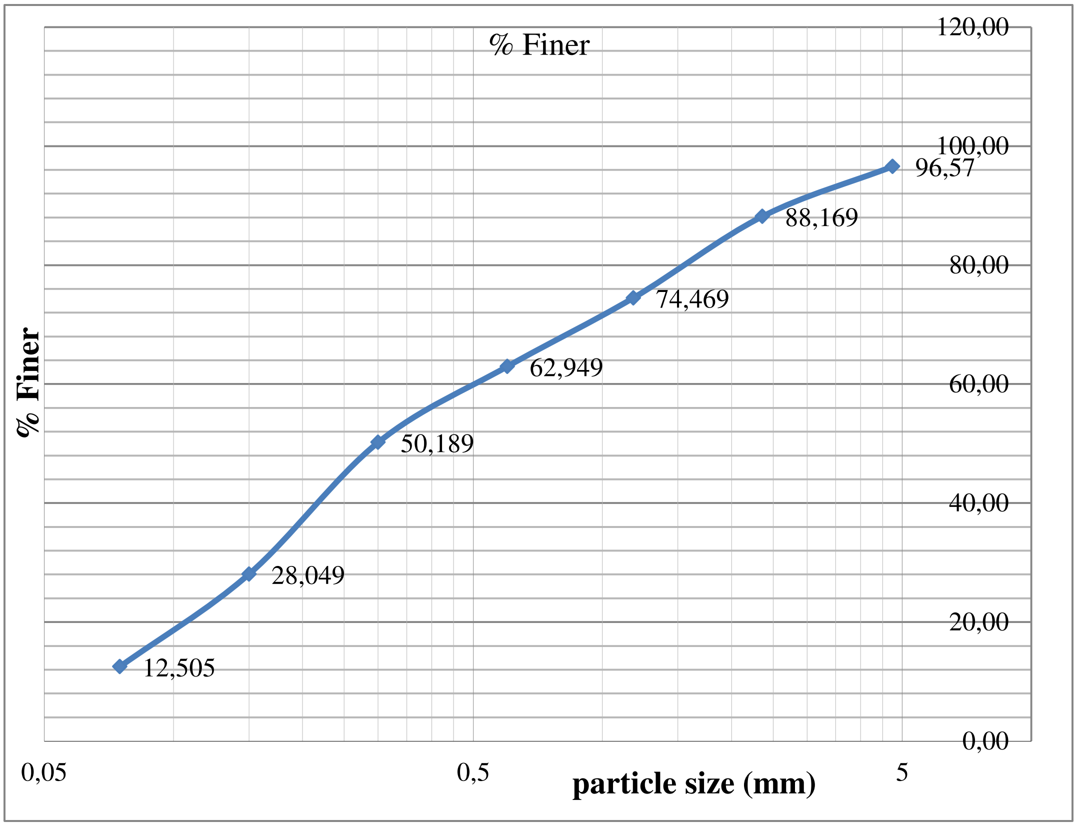

Fig. 3.1 grain size distribution curve

By particle size distribution curve soil is classified as silty sand.

3.2.2 SPECIFIC GRAVITY

Specific gravity was determined by pycnometer test.

Table 3.2 Observation table of pycnometer test

Empty wt.	W_1 (gm)	698.07	698.07	698.07
Empty wt. + dry soil	W_2 (gm)	897.80	945.42	996.56
Empty wt. + dry soil + water	W_3 (gm)	1670.26	1700.5	1733.3
Empty wt. + water	W_4 (gm)	1547.4	1547.4	1547.4
Specific gravity	G	2.598	2.608	2.631

Specific gravity $G = (W_2 - W_1) / ((W_2 - W_1) - (W_3 - W_4))$

Average specific gravity = 2.61

3.2.3 LIQUID LIMIT

Liquid limit was determined by cassagrande's liquid limit method.

Table 3.3 Observation table of liquid limit test by cassagrande's apparatus

Water content (%)	No. of blows
15	63
18	51
22	37
26	29
30	20

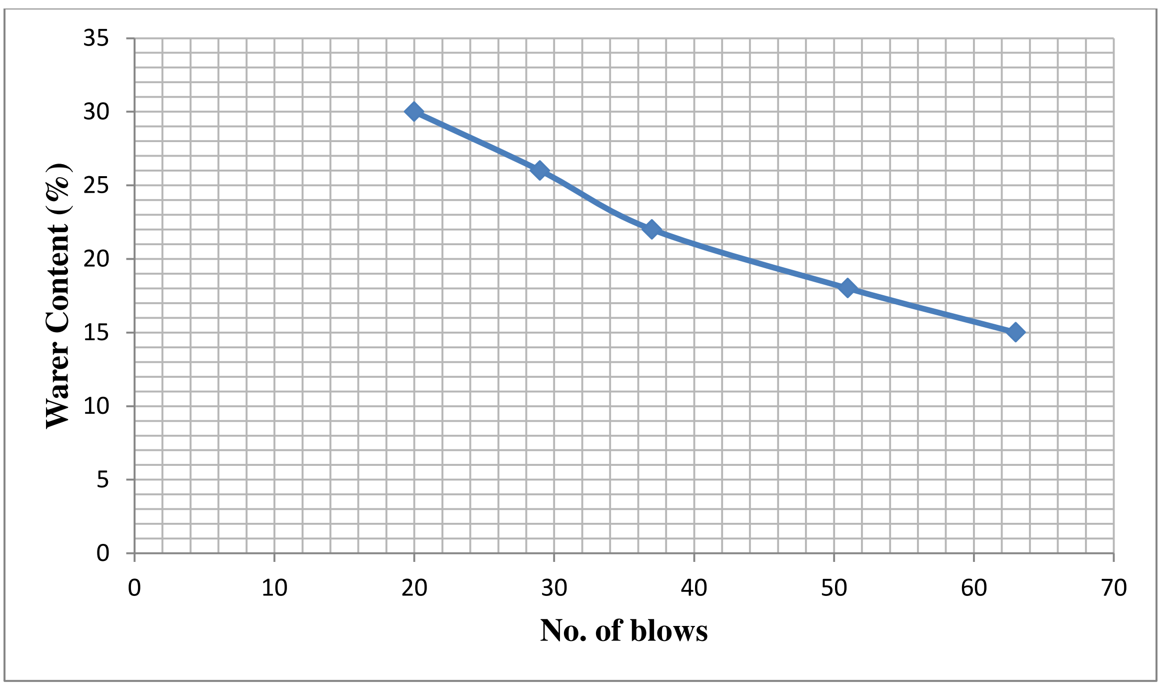

Fig 3.2 water content (%) v/s no. of blows in cassagrande apparatus

Liquid limit of soil is 28%.

3.2.4 STANDARD PROCTOR TEST

To determine the maximum dry density and optimum moisture content of soil, standard proctor test was conducted in laboratory.

Table 3.4 Calculation of dry density at varying moisture content of soil

Weight of empty mouldw_1,kg	4.02	4.02	4.02	4.02	4.02	4.02
Weight of empty mould +compacted soil w_2,(kg)	5.52	5.66	5.85	5.93	5.87	5.82
Bulk unit weight of compacted soilγ (gm./cc)	1.50	1.64	1.83	1.91	1.85	1.80
Water content w (%)	6.60	8.75	10.64	12.86	15.73	17.69
Dry unit weight $\gamma_d=\gamma/(1+w)$ (gm./cc)	1.407	1.508	1.639	1.68	1.60	1.53

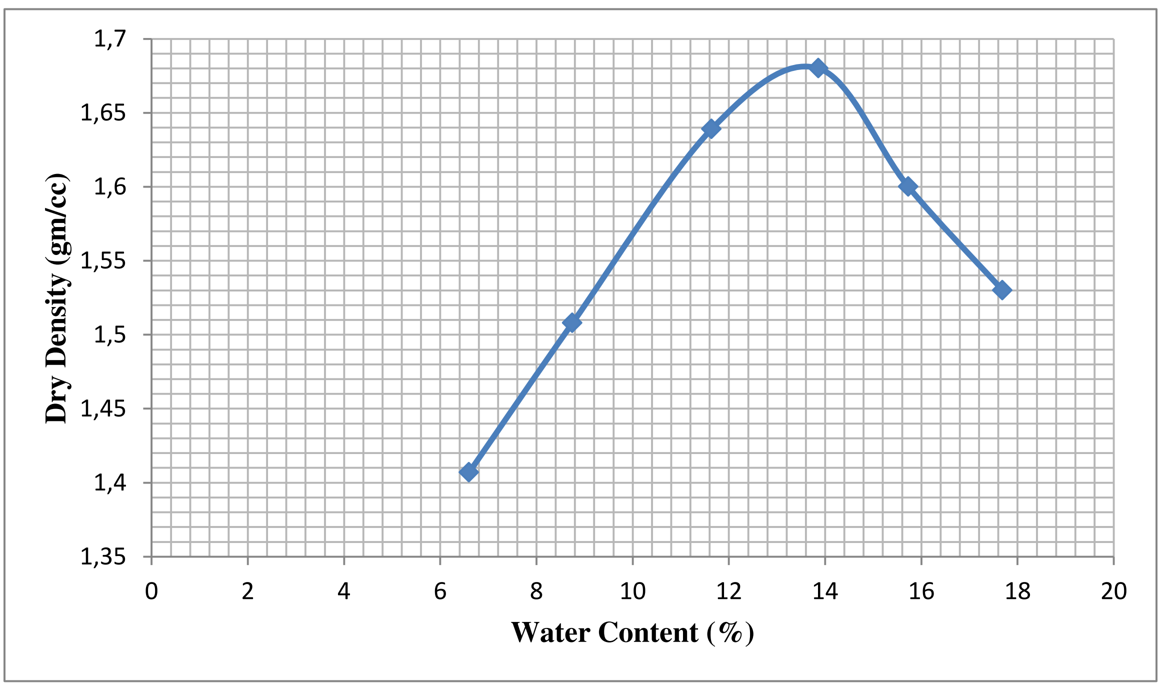

Fig 3.3 water content (%) v/s dry density (gm/cc)

Maximum dry density = 1.68 gm/cc

Optimum moisture content = 13.86 %

3.2.5 DIRECT SHEAR TEST

This test was conducted to determine the shear strength parameters of soil.

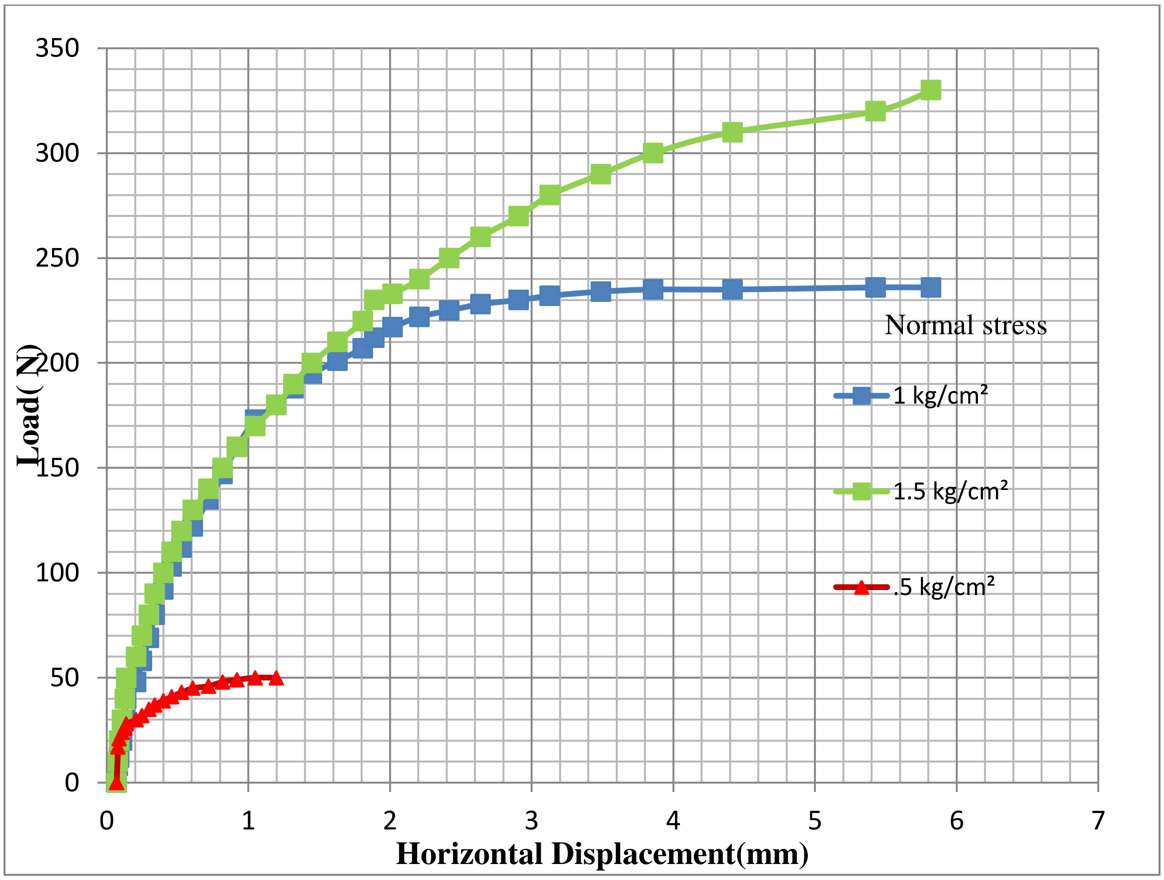

Fig. 3.4 load v/s displacement curve for varying normal stress

Value of cohesion = 9.83 kN/m^2

Angle of internal friction = 25.4°

Table 3.5 Properties of soil

S. No.	Property	Value
1	Specific gravity	2.61
2	Liquid limit	28%
3	Maximum dry density	1.68gm/cc
4	Optimum moisture content	13.86%
5	Cohesion value	9.83 kN/m^2
6	Angle of internal friction	25.4°

3.3 TESTING OF AGGREGATE

3.3.1 SPECIFIC GRAVITY TEST

Specific gravity of stone aggregates was determined by pycnometer.

Table 3.6 Observation table of pycnometer test for aggregates

S.N.	Particulars	Weight (gm)		
1	Wt. of Pycnometer (W_1)	681.8	681.8	681.8
2	Wt. of Pycnometer + material W_2	1207	1281.8	1316.6
3	Wt. of Pycnometer + material + distilled water W_3	1907.27	1946.49	1980.67
4	Wt. of Pycnometer + distilled water W_4	1573.4	1573.4	1573.4
5	Specific gravity	2.745	2.72	2.79

Specific gravity of aggregates $G = (W_2 - W_1) / ((W_2 - W_1) - (W_3 - W_4))$

$= 2.752$

3.3.2 IMPACT TEST

Stone aggregates were passed from 12.5 mm IS Sieve and also retained on 10 mm IS Sieve. For standard test, stone aggregate should be in dry condition. A stone aggregate, retained on 10 mm IS Sieve was filled in cylinder in three layers of equal depth. Each layer was temped 25 times by temping rod. Then crushing aggregates were sieved on 2.36 mm sieve. Crushed aggregated passed through 2.36mm sieve is weighted and named as W_2.

Total wt of dry sample = W_1 = 800gm

Wt. of aggregates passing through 2.36 mm sieve = W_2 = 145gm

Aggregate crushing value = $W_2 / W_1 * 100$ = 18 %

so it can be said that aggregates are of good quality.

Fig. 3.5 Impact test for crushing value of stone aggregate

3.4 GEOTEXTILE

Fig. 3.6 weaving geotextile

Geotextile are generally made from one of synthetic polymers like polyethylene, polyamide, polyester and polypropylene, natural materials. These are formed from natural or synthetic fibers by weaving techniques. By this weaving technique, geotextile are made in which two sets of threads interlaced in right angles. Warp runs in the direction of the loom and weft is at right angle to the warp.

CHAPTER - 4

EXPERIMENTAL PROGRAM

4.1 INTRODUCTION

This chapter deals with the methodology and description of the experiment. Plate load test was conducted on soil with stone column. Test was conducted in different conditions by varying parameters like length of column, diameter of column, number of columns, effect of geosynthesis encasement etc. a hydraulic pump and jack was used for applying pressure on stone column. Pressure is applied by hydraulic jack using oil pressure of pump. Circular plates are used for transferring the load from jack to stone column. Dial gauges are also used to measure settlement.

4.2 EXPERIMENTAL SET UP FOR LOAD TEST

A rectangular tank of length 1.5m, width 0.9m, depth 0.6m was used for testing. All tank dimensions are inner dimensions. PVC pipes of different diameters were used for casting of stone columns.

The PVC pipe was placed at the desired location of stone column. Oil was painted on pipe's outer surface so that it can be easily taken outside after stone column casting. Soil was filled in tank except PVC pipe. Soil was filled in layers and each layer was compacted by a wooden hammer. After filling the tank by soil, stone column was filled by stone aggregates through its opening. Aggregates were introduced in stone column in layers and tempered each layer by a temping rod. Pipe was also withdrawn together with inserting of aggregates in PVC pipe. PVC pipe was withdrawn in such a way that a minimum depth of pipe was filed with stone aggregates. After constructing up to desired height of stone column, PVC pipe was completely withdrawn outside. Then this stone column was tested.

4.3 TEST CARRIED OUT FOR INVESTIGATION

- On untreated soil bed
- Stone column (sc) of diameter 50mm at centre of soil bed or rectangular tank
- Stone column of diameter 100mm at centre of soil bed
- Stone column of diameter 200mm at centre of soil bed
- Stone column of diameter 50mm at centre and length to diameter ratio is 5
- Stone column of diameter 50mm at centre and length to diameter ratio is 7
- Stone column of diameter 50mm at centre and length to diameter ratio is 9
- Stone column of diameter 50mm at centre and encased with geosynthesis
- Stone column of diameter 100mm at centre and encased with geosynthesis
- A stone column of 50mm diameter at centre and three stone columns of 50mm diameter in triangular pattern at a radial spacing of 2 times of diameter of column from centre column.
- A stone column of 50mm diameter at centre and six stone columns of 50mm diameter at an angle of 60^{o} and at a radial spacing of 2 times of diameter of column from centre column.

These tests were carried out to see the effect of change in

- Diameter of stone column
- Length of stone column
- Number of stone columns
- Encasing with geosynthesis

Fig. 4.1 Placing of PVC pipe at the location of stone column

Fig. 4.2 Soil filling up to design level in tank

Fig. 4.3 Stone column after complete withdrawn of PVC pipe

Fig. 4.4 Load applying by Hydraulic jack on stone column

Fig. 4.5 Use of geotextile for encasement of stone column

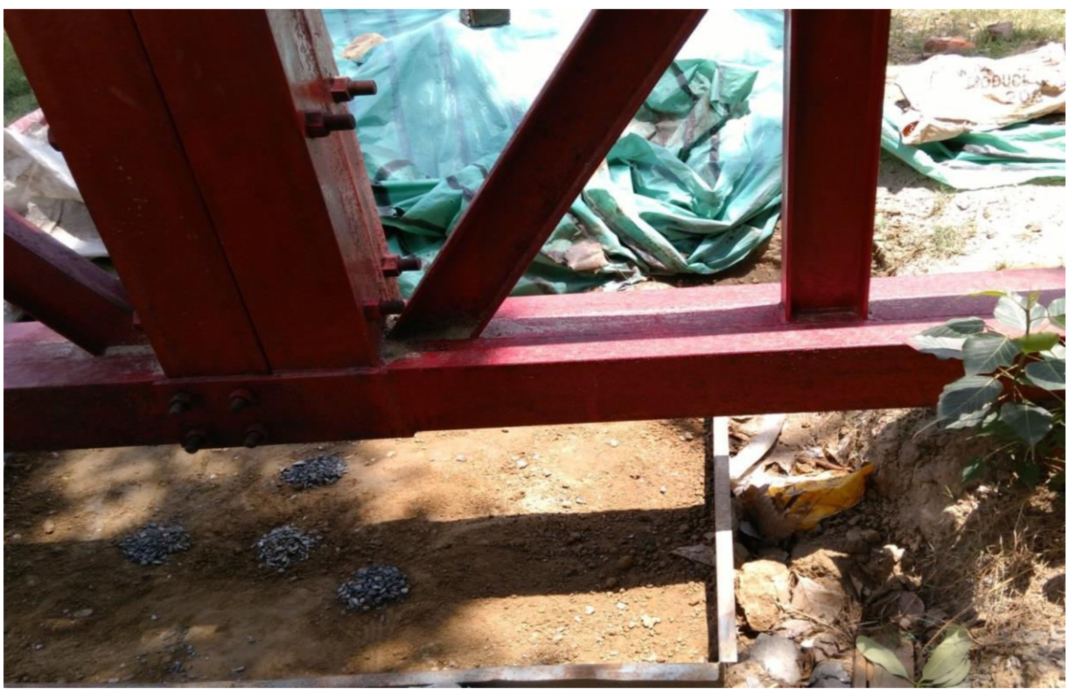

Fig. 4.6 Four stone columns in triangular pattern

CHAPTER - 5
RESULTS AND ANALYSIS

Table 5.1 Observation table of load test for stone column of diameter 50mm, 100mm and 200mm

Load (N)	Diameter of sc = 50mm	Diameter of sc = 100mm	Diameter of sc = 200mm
0	0	0	0
100	0.3	0.3	0.2
200	0.6	0.6	0.3
300	1.1	0.9	0.5
400	1.9	1.1	0.7
500	3.3	1.5	0.8
600	5	1.9	0.9
700	7.3	2.5	1.1
800	10.4	3.3	1.2
900	14.8	4.9	1.4
1000	20.7	7.2	1.7
1100	26.1	10.3	1.9
1200	39.6	13.8	2.4
1300		16.7	2.8
1400		20.1	3.2
1500		23.1	3.7
1600		25.9	4.4
1700		29.3	5.5
1800		32.9	7.2
1900		39.8	8.4
2000			9.9
2100			11.2
2200			12.5
2300			14.1
2400			15.8
2500			17.5
2600			19.1
2700			20.6
2800			21.9
2900			23.2
3000			24.7
3100			25.9
3200			27.3
3300			29.7
3400			32.4
3500			35.8
3600			39.4

Table 5.2 Observation table of load test for stone column of l/d = 5, 7 and 9

Load (N)	l/d of sc = 5	l/d of sc = 7	l/d of sc = 9
0	0	0	0
100	0.3	0.3	0.1
200	0.7	0.6	0.3
300	1.3	1.1	0.7
400	3.5	1.9	1.4
500	6.2	3.3	1.8
600	12.7	5	2.9
700	19.3	7.3	3.9
800	27.1	10.4	5.2
900	38.9	14.8	7.9
1000		20.7	10.4
1100		26.1	13.8
1200		39.6	17.1
1300			20.3
1400			24.6
1500			28.1
1600			38.4

Table 5.3 Observation table of load test for stone column with encasing of geotextile on 50mm, 100mm diameter stone column

Load (N)	Sc of 50mm with geotextile encasing	Sc of 100mm with geotextile encasing
0	0	0
100	0.1	0
200	0.2	0.1
300	0.4	0.2
400	0.5	0.3
500	0.8	0.5
600	1.2	0.7
700	1.7	0.9
800	2.2	1.2
900	2.9	1.6
1000	3.9	2
1100	5.1	2.6
1200	6.4	3.1
1300	7.9	3.6
1400	10.2	4.2
1500	12.7	5.1
1600	15.2	5.8
1700	17.8	6.6
1800	20.6	7.5
1900	23.5	8.6
2000	26.5	9.8
2100	29.8	11.2
2200	32.8	13.6
2300	38.9	15.2
2400		16.9
2500		18.8
2600		20.7
2700		22.9
2800		24.8
2900		27.1
3000		29.1
3100		31.2
3200		33.5
3300		35.7
3400		42.3

Table 5.4 Observation table of load test for different number of columns

Load (N)	Nc = 1	Nc = 4	Nc = 7
0	0	0	0
100	0.3	0	0
200	0.6	0.1	0.1
300	1.1	0.2	0.1
400	1.9	0.3	0.2
500	3.3	0.5	0.3
600	5	0.8	0.4
700	7.3	1.1	0.6
800	10.4	1.5	0.9
900	14.8	2.3	1.2
1000	20.7	3.2	1.6
1100	26.1	4.7	2.1
1200	39.6	6.4	2.6
1300		8.8	3.3
1400		11.6	3.9
1500		14.8	4.8
1600		18.3	6.1
1700		22.1	7.5
1800		25.9	9.2
1900		28.6	11.1
2000		31.9	12.7
2100		37.5	14.9
2200			17.2
2300			19.5
2400			22.1
2500			24.9
2600			27.3
2700			30.1
2800			33.4
2900			40.2

Comparison of Load carrying capacity of untreated soil bed and treated soil bed with a stone column of diameter 100mm

Plate load Test was conducted on untreated soil bed (no stone column) and treated soil using one stone column of diameter 100mm at centre. From noted readings of load and settlement, load settlement curve was plotted for both cases. An increase in load carrying capacity is observed in treated soil bed in comparison to untreated soil bed.

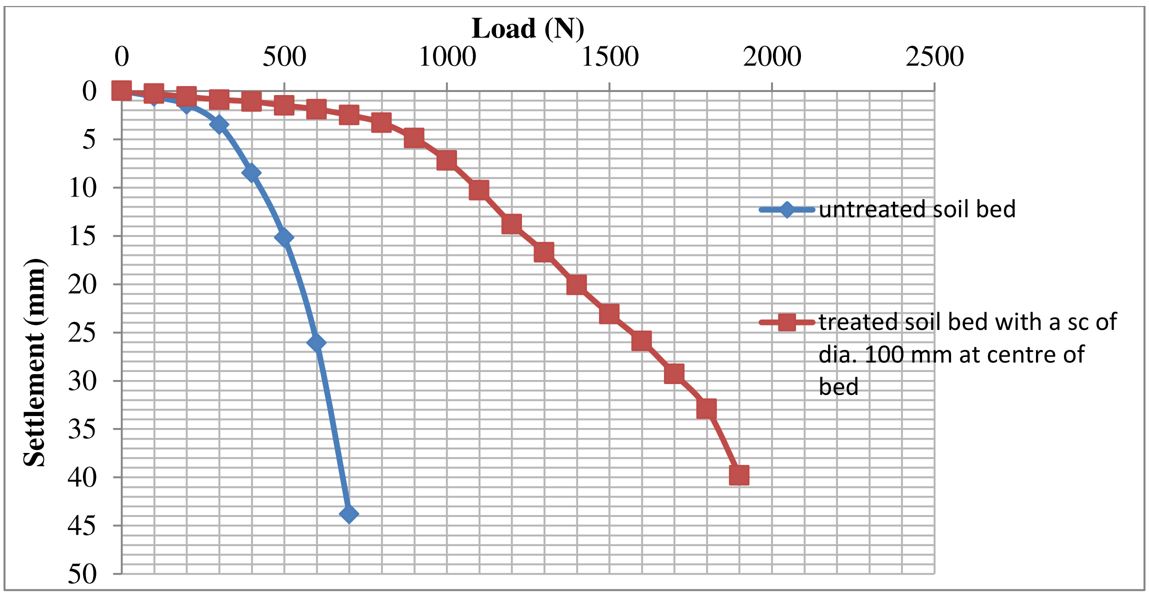

Fig. 5.1 Load v/s Settlement curve for untreated and treated soil with sc of 100mm dia.

Table 5.5 Bearing capacity of untreated and treated soil with sc of 100mm diameter

S. No.	test name	load carrying capacity (N)	Bearing capacity (kN/m^2)
1.	Untreated soil bed	600	53.08
2.	Treated soil with a sc of 100mm diameter at centre	1800	159.31

Change in load carrying capacity of stone column with change in diameter of stone column

Plate load test was conducted on stone column of different diameter like 50mm, 100mm, 200mm. All stone columns were placed at centre individually to see the change in load carrying capacity of stone column with increase in diameter.

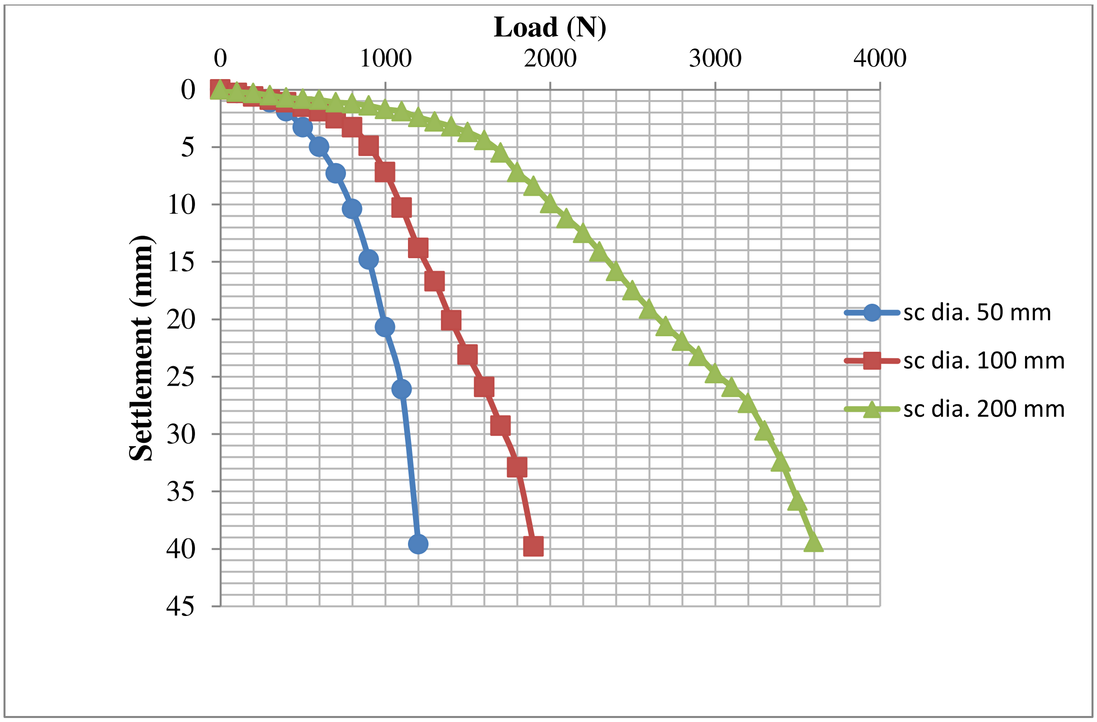

Fig. 5.2 Load v/s settlement curve for varying diameter of stone column

Table 5.6 Bearing capacity for varying diameter of stone column

S. No.	Test name	Load carrying capacity (N)	Bearing capacity (kN/m^2)
1.	Sc of diameter 50mm at centre	1100	97.31
2.	Sc of diameter 100mm at centre	1800	159.235
3.	Sc of diameter 200mm at centre	3500	226.12

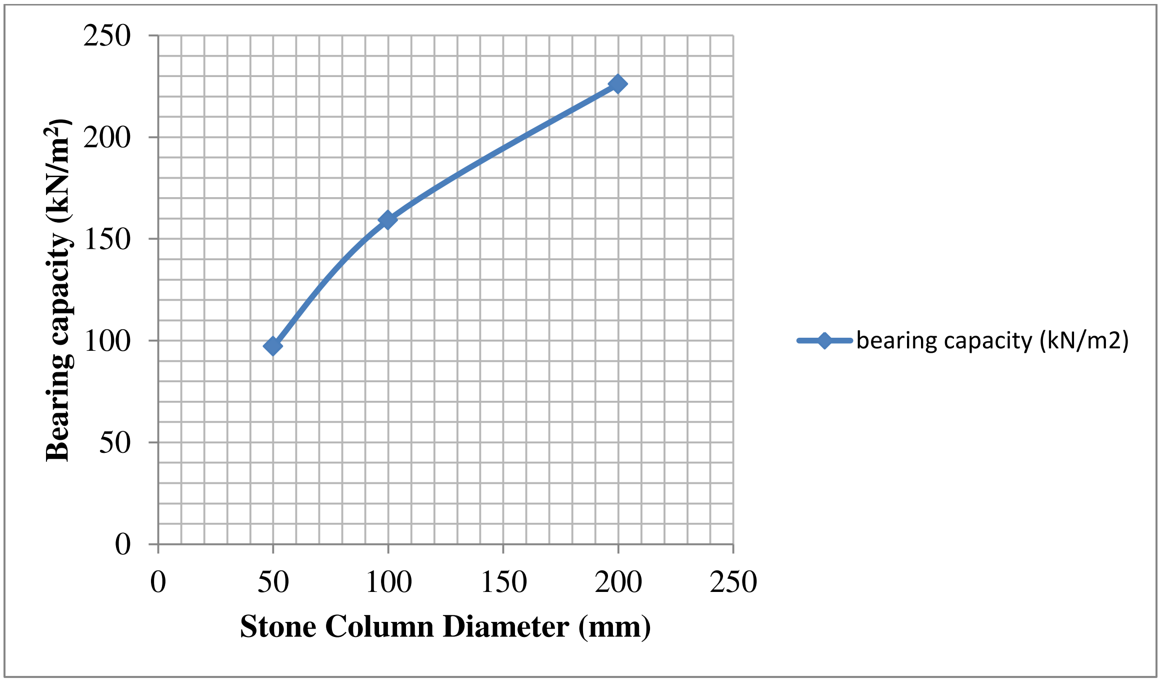

Fig. 5.3 behavior of bearing capacity with increase in diameter of sc

Change in load carrying capacity of stone column with change in length of stone column at constant diameter 50mm

Plate load test was carried out by changing the length of stone column for a fix diameter 50mm. three tests were done for 250mm, 350mm, 450mm lengths of stone column or length to diameter ratio is 5, 7 and 9 respectively.

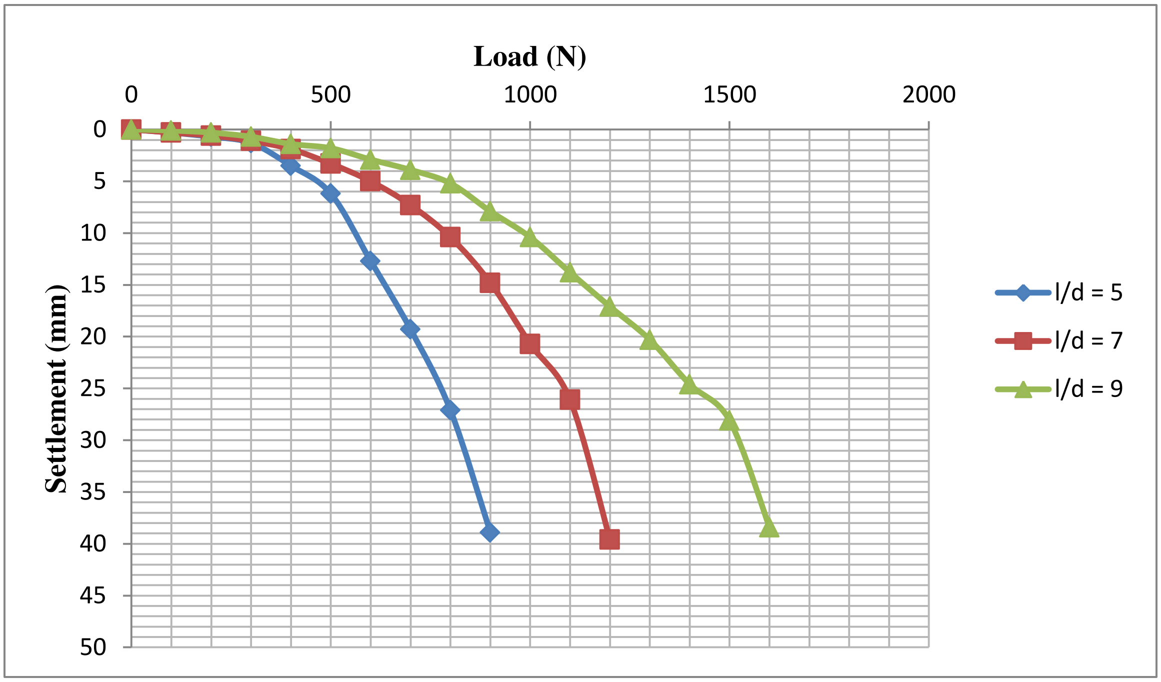

Fig. 5.4 Load v/s settlement curve of sc of diameter 50mm for different lengths of column

Table 5.7 Bearing capacity for sc of diameter 50mm for different lengths of column

S. No.	Test name	Load carrying capacity (N)	Bearing capacity (kN/m^2)
1	Length/depth = 5	800	70.77
2	Length/depth = 7	1100	97.31
3	Length/depth = 9	1500	132.696

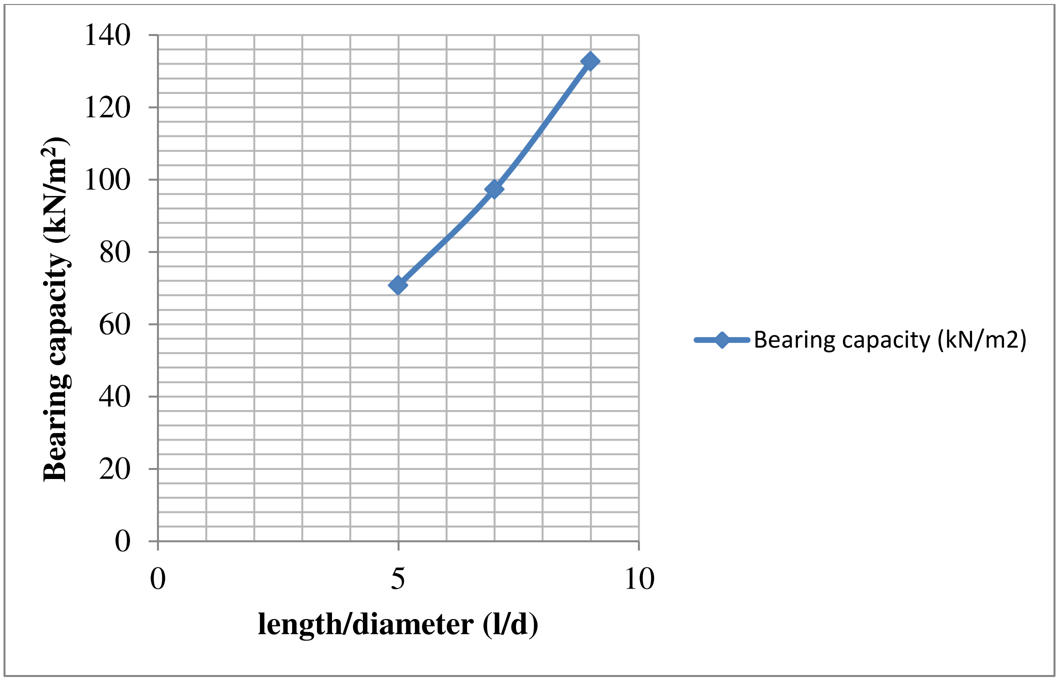

Fig. 5.5 behavior of bearing capacity with change in l/d

Change in load carrying capacity of stone after encasing with geosynthetic for sc of 50mm diameter

Geosynthetic is provided to improve the soil. Stone column was provided with geosynthetic to improve the lateral resistance or it can be said that stiffness of stone column is increased by encasing it with geosynthetic. Geosynthetic was attached to the surface of PVC pipe and then pipe was placed in soil bed. With the filling of stone column, only PVC pipe was withdrawn and geosynthetic was remained in soil.

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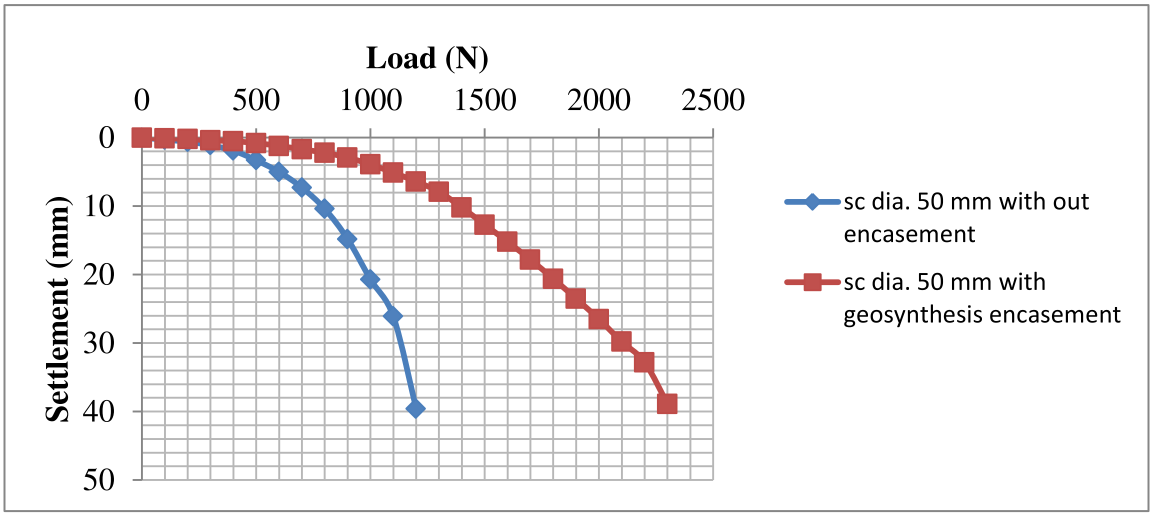

Fig. 5.6 Load v/s settlement curve for sc of 50mm diameter, with and without encasing

Table 5.8 Bearing capacity for stone column of 50mm diameter, with and without encasing

S. No.	Test name	Load carrying capacity (N)	Bearing capacity (kN/m^2)
1	Sc of dia. 50mm without encasing	1100	70.77
2	Sc of dia. 50mm with encasing	2200	141.54

Change in load carrying capacity of stone column of diameter 100mm after encasing with geosynthetic

Stone column was encased with geosynthetic as in case of 50mm diameter stone column and test was conducted.

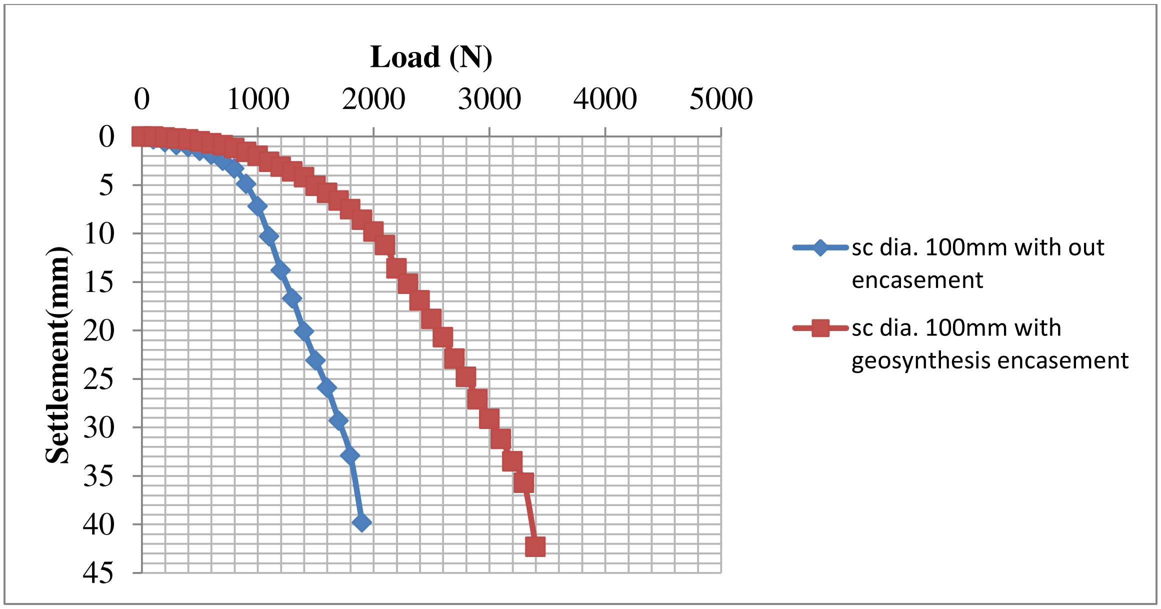

Fig. 5.7 Load v/s settlement curve for sc of 100mm diameter, with and without encasing

Table 5.9 Bearing capacity for sc of 100mm diameter, with and without encasing

S. No.	Test name	Load carrying capacity (N)	Bearing capacity (kN/m^2)
1	Sc of dia.100mm without encasing	1800	159.235
2	Sc of dia.100mm with encasing	3300	291.93

Change in load carrying capacity of stone column by increasing number of columns

An area of particular radius is influenced by a stone column or soil can be improved or densified up to a zone beyond which there is negligible effect of stone column. For increasing the load carrying capacity of stone column, number of stone columns was increased. Four columns are introduced at a time. One column was at centre and three columns were placed at a radial distance of 2d where d is diameter of stone column. Each radial stone column was 120^o from other stone columns. Radial stone columns are in triangular pattern. In triangular pattern radius of influence of each stone column is 0.645s where s is spacing between columns. Then centre column was checked for load carrying capacity.

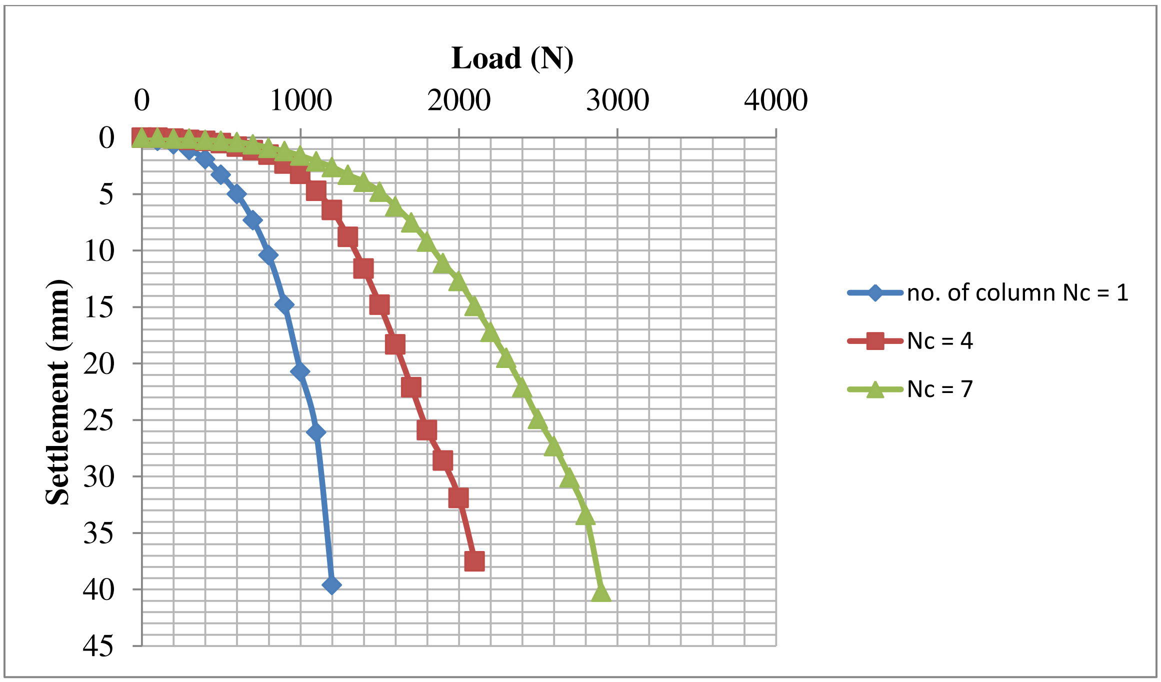

Fig. 5.8 Load v/s settlement curve for different number of columns

Table 5.10 Bearing capacity for varying the number of stone columns

S. No.	Test name	Load carrying capacity (N)	Bearing capacity (kN/m^2)
1	Nc = 1	1100	97.21
2	Nc = 4	2000	176.928
3	Nc = 7	2800	247.44

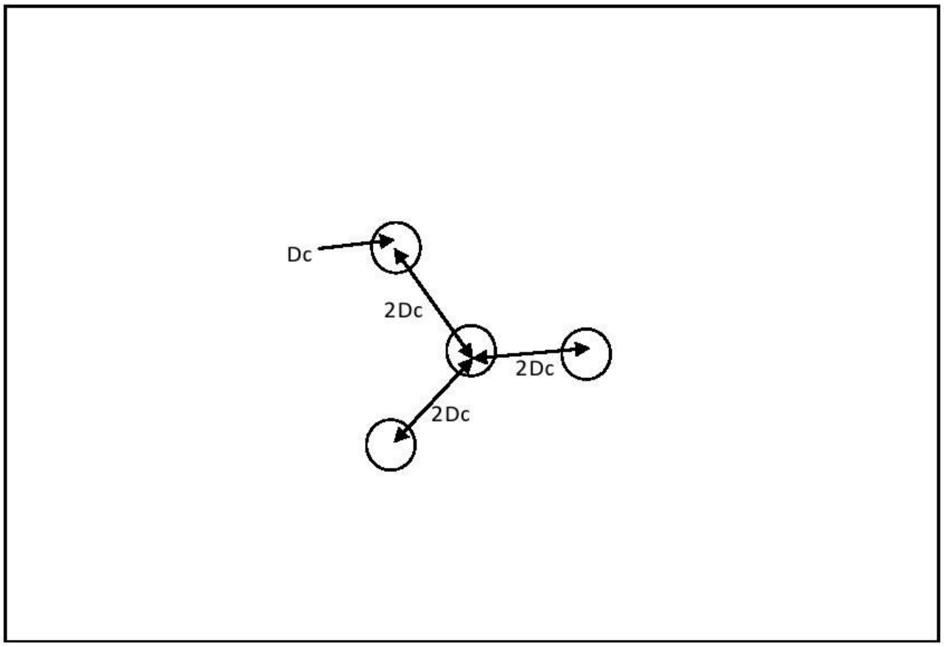

Fig. 5.9 Three columns are at a radial distance 2Dc from central column where Dc is diameter of stone column is 50mm

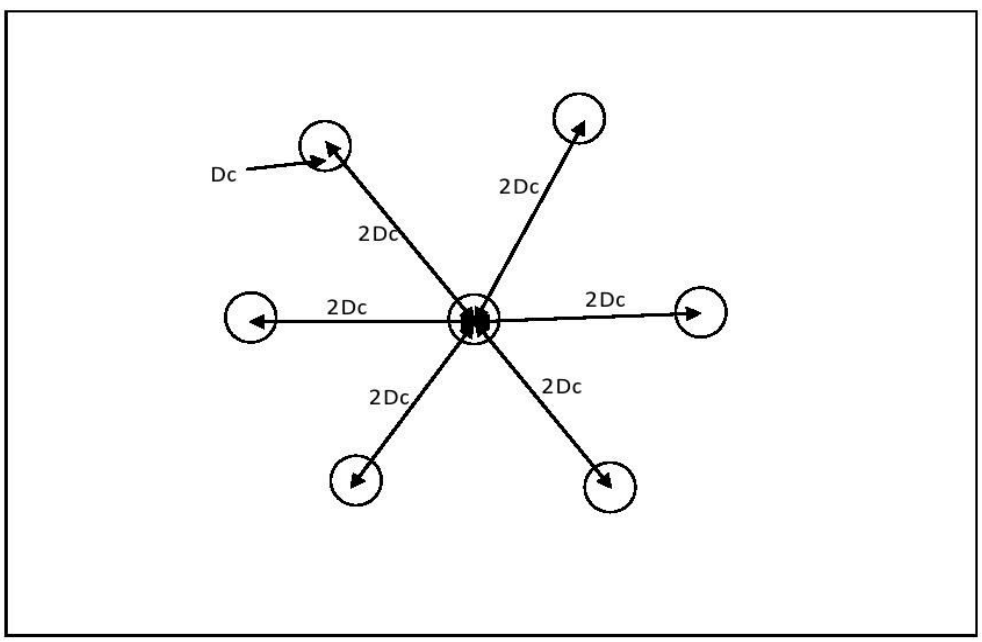

Fig. 5.10 Six columns are at a radial distance 2Dc from central column

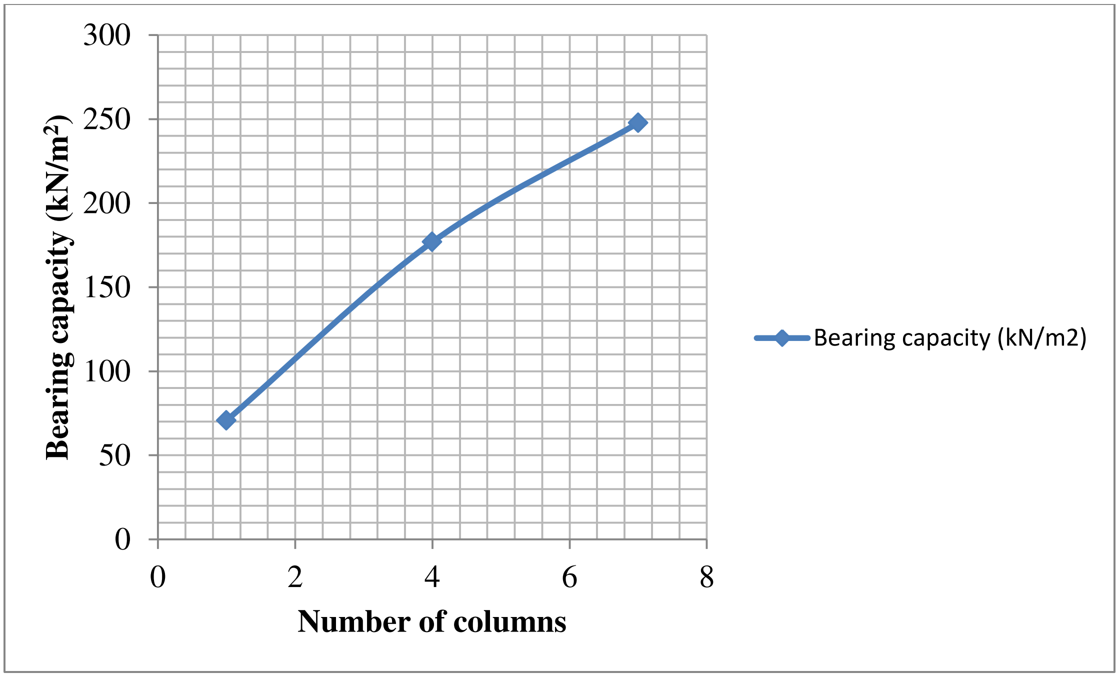

Fig. 5.11 Behavior of bearing capacity with change in number of stone columns

CHAPTER - 6

CONCLUSIONS AND DISCUSSION

In this project, plate load test was carried out in different conditions on silty sand. These conditions were created by varying the parameters like diameter of stone column; length to diameter ratio of stone column, number of stone columns etc. from results of plate load tests following conclusions can be made.

When a stone column of diameter of 100mm is used at centre of soil bed it gives more bearing capacity in comparison to untreated soil bed. Bearing capacity in case of treated soil is 159.23kN/ m^2 which is equal to three times bearing capacity of untreated soil.

When the diameter of stone column is increased then there is an increase in bearing capacity. When diameter of sc is increased from 50 to 100mm then bearing capacity is increased up to 1.64 times of 50mm diameter sc. Similarly when diameter is increased from 100mm to 200mm then bearing capacity is increased up to 1.95 times of bearing capacity of 100mm diameter sc.

When length of stone column is increased then there is also an increase in bearing capacity. When length/diameter is increased from 5 to 7 then bearing capacity is increased by 37.5% of sc of l/d = 5. When l/d is increased from 7 to 9 then this gain is 36.4%.

When number of stone columns is increased then increase in bearing capacity occurs. When stone columns are increase from 1 to 4 then bearing capacity is increased by 81.1%. This number is increased from 1 to 7 then this gain is 145%.

Encasing of geosynthetic also increases the bearing capacity. Encasing on 50mm diameter sc increases the bearing capacity by 109%. Encasing on 100mm diameter sc increases the bearing capacity by 73.6%. So it can be said that with increase in diameter of sc, effect of encasing reduces.

By analyzing results, it can be said that problem of low bearing capacity can be solved by installing the stone columns. We can reach up to design bearing capacity for foundation by stone columns.

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