EFFECTIVENESS OF TRIANGULAR AND RECTANGULAR PATTERN OF STONE COLUMN WITH VARYING S/D RATIO ON CONSOLIDATION BEHAVIOUR OF SOIL

A Major Project dissertation submitted

In partial fulfillment of the requirement for the degree of

Master of Technology

In

Geotechnical Engineering

Submitted by

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CERTIFICATE

This is to certify that the project report entitled, "**Effectiveness of triangular and rectangular pattern of stone column with varying s/d ratio on consolidation behavior of soil**", is being carried out by **SRIJAN (2K15/GTE/16)** in partial fulfillment for the award of degree of Masters of Technology in Geotechnical Engineering (Department of Civil Engineering), Delhi technological University under my supervision.

Under the guidance of

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ACKNOWLEDGEMENT

I take this opportunity to express my profound gratitude and deep regards to Dr. A K GUPTA (Professor, Civil Engineering Department, DTU) for his exemplary guidance, monitoring and constant encouragement throughout the course of this project work. The blessing, help and guidance given by him from time to time shall carry me a long way in life on which I am going to embark.

I would also like to thank Dr. NIRENDRA DEV (Head of Department, Civil Engineering Department, DTU) for extending his support and guidance.

Professors and faculties of the Department of Civil Engineering, DTU, have always extended their full co-operation and help. They have been kind enough to give their opinion on the project matter; I am deeply obliged to them. They have been a source of encouragement and have continuously been supporting me with their knowledge base, during the study. Several of well-wishers extended their help to me directly or indirectly and we are grateful to all of them without whom it would have been impossible for me to carryon my work.

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ABSTRACT

Fast urbanization and development of infrastructure, in the present days, has brought about drastically expanded interest for arrive space. This has constrained the building industry to enhance the delicate soil grounds which generally are unsatisfactory for development exercises. Among the different ground change methods utilized, stone columns and geosynthetic support are likely the most prevalent ones. This is basically because of their simple construction procedure and general economy that discovers support with the engineers. This paper introduces a test settlement investigation of delicate soil establishments reinforced by stone sections. A progression of tests must be done to develop an understanding of the performance change of soft soil beds utilizing stone section. Tests were carried out first for the simple soil and then with the triangular and rectangular pattern of stone column installed in it. The above procedure is followed for a different s/d ratio. A correlation will be appeared to separate the settlement obtained from the triangular and rectangular pattern of stone column along with the differences for the varying s/d ratio. Using the solutions obtained, graphs and charts were prepared and the important behavior of soil consolidation is discussed and presented. Finally it has to be found out which geometrical pattern between triangular and rectangular stone column is more effective at which s/d spacing.

CHAPTER-1

INTRODUCTION

1.1 GENERAL

Because of the quick industrialization and big scale building development, there will be absence of valuable land. By and large, the development is done just on typical valuable land. Generally the useless places such as city strong waste dumping areas, locales comprises of marine muds, compressible soft soils recovered terrains and so forth are currently worthy of establishments. Development on these kinds of areas is a test therefore ground improvement methods are favored because of many considerations. This has been continually challenging work to give protected and sound establishments to structure with heavy loads and permissible low settlements. Normal practice is for enhancing the limit of the ground by various means, e.g., pre-compression, woven fiber reinforcement, vibration, dynamic compaction, compaction grouting, blast, and so on. Presently, stone columns (granular piles) have been effectively used in order to enhance the properties and various other parameters of the delicate earth because of its adequacy, effectiveness and simplicity of establishment and installation.

1.2 STONE COLUMN

Stone column comprises of granular substance properly compacted in a long cylindrical hole. The main focus of putting a stone column is to substitute a part of the soft soil with harder granular substance such that it is able to sustain the weight of given structure. They can be more economical if gravel, sand and crushed granules are available in plenty in and around. A large portion of the load is transferred to the column because of larger stiffness of the stone column as related to that of surround soil. Therefore the entire soil beneath the foundation, provide as a reinforced soil with more load carrying capacity than the original soil. The confinement provided by the nearby soil provides its load carrying capacity.

1.2.1 Advantages of stone column

Mostly these are used to:

- Increase the bearing capacity of relatively soft ground in order to be utilized as the foundation of the structure.

- Improve settlements and stiffness.
- Strengthen shearing capacity of soil along with drainage conditions.
- Lower down the settlement of structure.
- Lower down the liquefaction chances of soft clay ground.

1.2.2 Methodology of construction of Stone Column

The utilization of stone sections or granular columns as a ground change method is by and large done in clayey or silty-clayey soils. It is that the granular material or crushed stone is filled in boreholes and compacted appropriately, the subsequent structure is called stone column. Stone section reinforcement can be done by utilizing either replacement or displacement strategies. So, stone columns can be made by the following two methods.

1) Ramming method
2) Vibro-replacement method
   a) Wet top feed method
   b) Dry bottom feed method

1) Ramming Method

Datye and Nagaraju (1985) proposed this method of installation of stone column. According to this method, granular material is filled in a pre-bored hole and a heavyweight rammer is used to compact over the borehole. Bailer with casing to full length is used to make the bore hole. The stability of borehole is maintained by casing. The stone column is used as an important part to function for the drainage and therefore it is advised that bentonite mixture is not used for maintaining the stability of the hole. This methods significance is gaining the advancement in India. An essential sized case hole is bored with the help of flap valve bailer with required size of casing tube. Soon after driving the casing tube to desired depth, the bored hole is poured with granular material. Heavyweight rammer is used to compact the casing tube and granular fill. To have ceaseless stone segment, filling the granular substance, withdrawing of tube and slamming of fill ought to be so skillful. Compaction was done by a heavyweight rammer normally of 1.5 to 2.0 tonnes also falling from a height of 1.0 – 2.0m.

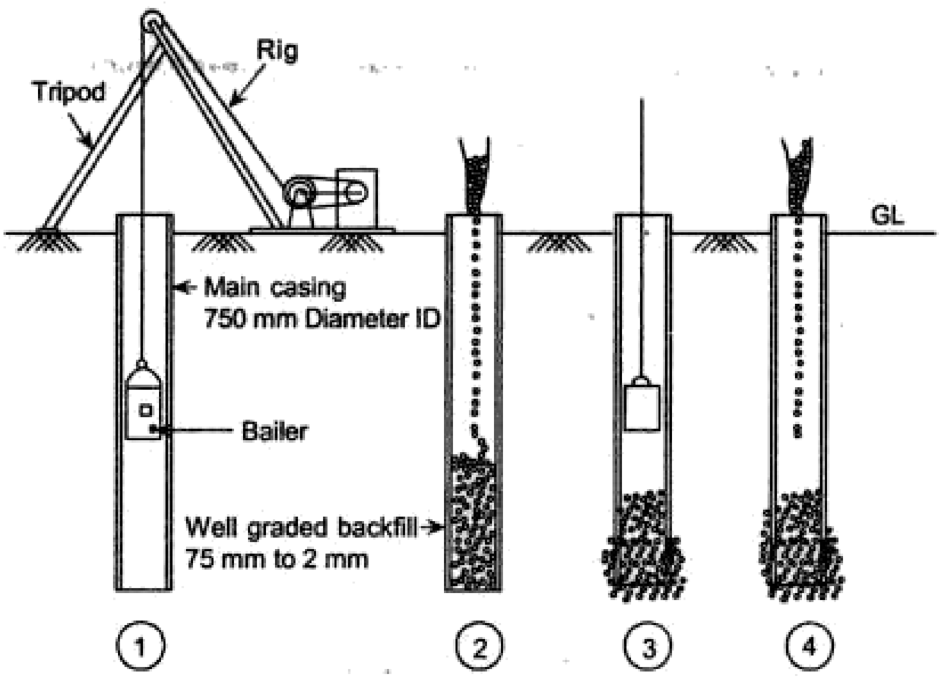


Fig. 1.1 Installation of stone column by ramming method (Datye and Nagaraju 1975)

2) Vibro-replacement method

According to this method, vibrofloat is used to construct the stone columns. With the help of water jet along with vibrator vibrofloat goes into the ground because of its self-weight. Generally a vibrator is around 3.0 to 5.0 m long along a mass of 2.0-8.0 tonnes. Wet top feed method or the dry bottom feed method are the two procedures of vibro replacement methods.

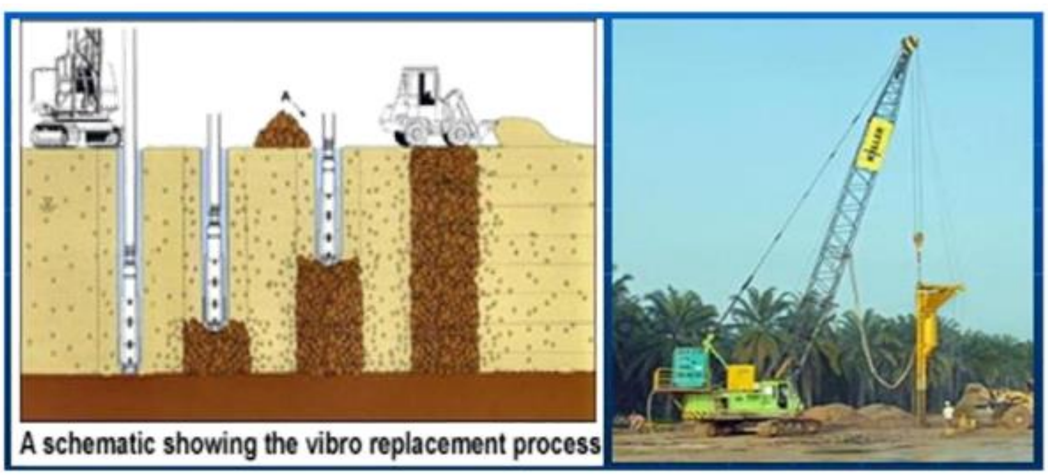


Fig. 1.2 Vibro-replacement method

a) **Wet top feed method**

In this method of installation, the lower water stream is left opened which brings about a saturated soil mass prepared to infiltration and compacted by the vibrator. Then the column is created by adding the stone chips which may be crushed chips or recycled concrete on the ground surface near the vibrator.

Fig. 1.3 Wet top feed method

b) **Dry bottom feed method**

This method is almost similar to that of wet top feed method with an exception that of water jet not being used and given stone chips are supplied through vibrator along with a pipe added to the given vibrator. The pre boring of thick strata near the area of segment might be needed for the vibrator to infiltrate the desired designing depth. Amid the procedure of withdrawal of the vibrator, the vibration is persistently kept up to guarantee vital compaction required for the granular substance.

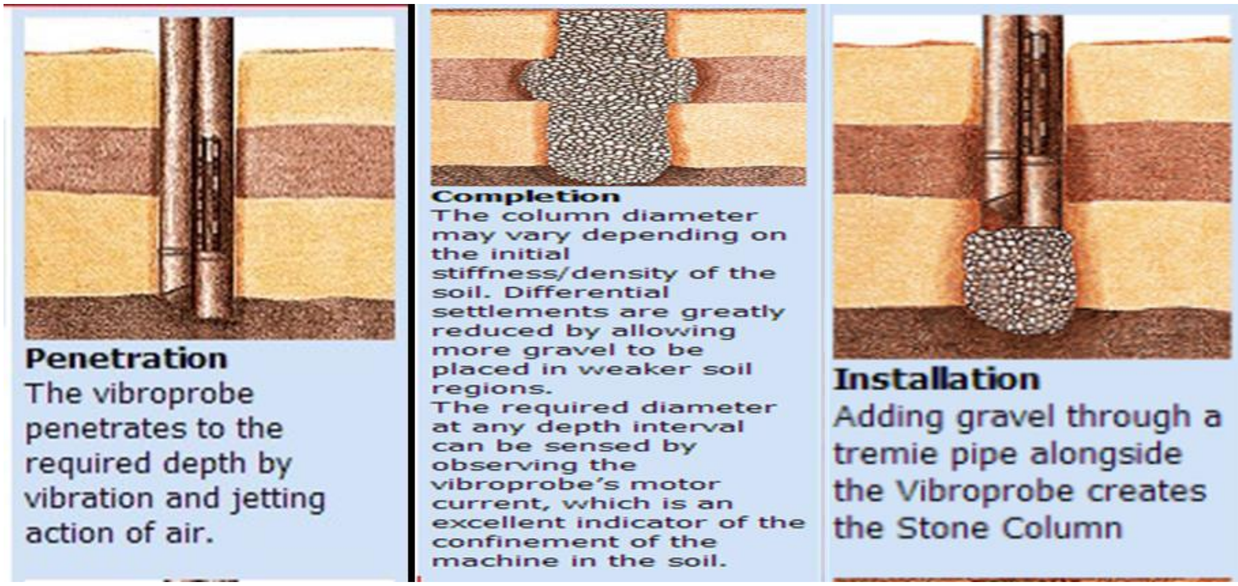


Fig 1.4 Dry bottom feed method

1.2.3 Failure Mechanism of Stone Column

The different modes of failure of stone sections are:

- Bulging Failure
- Punching Failure
- General Shear Failure

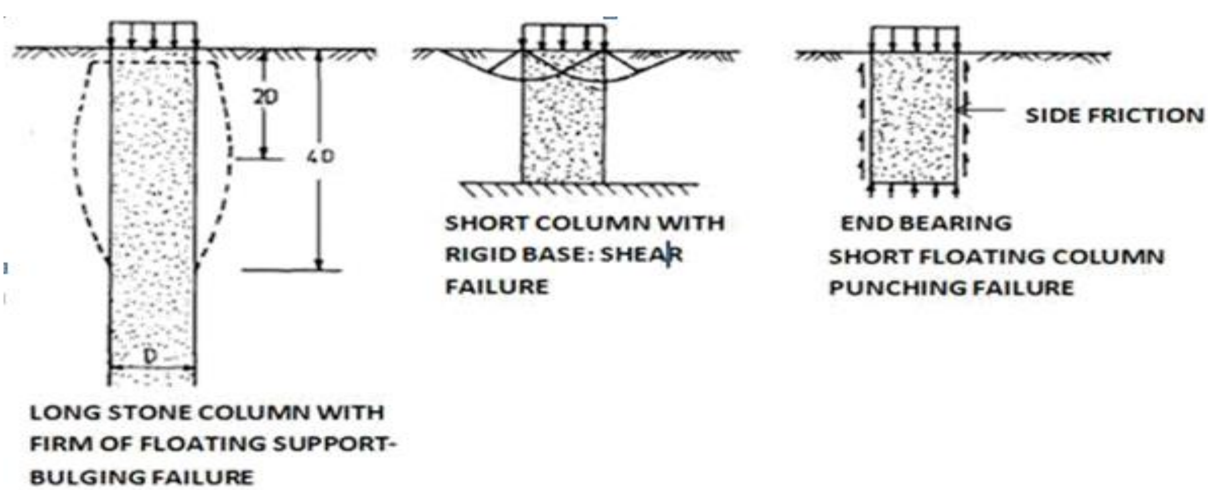


Fig. 1.5 Mechanism of failure of stone column in homogenous soft layer

(IS 15284.1.2003)

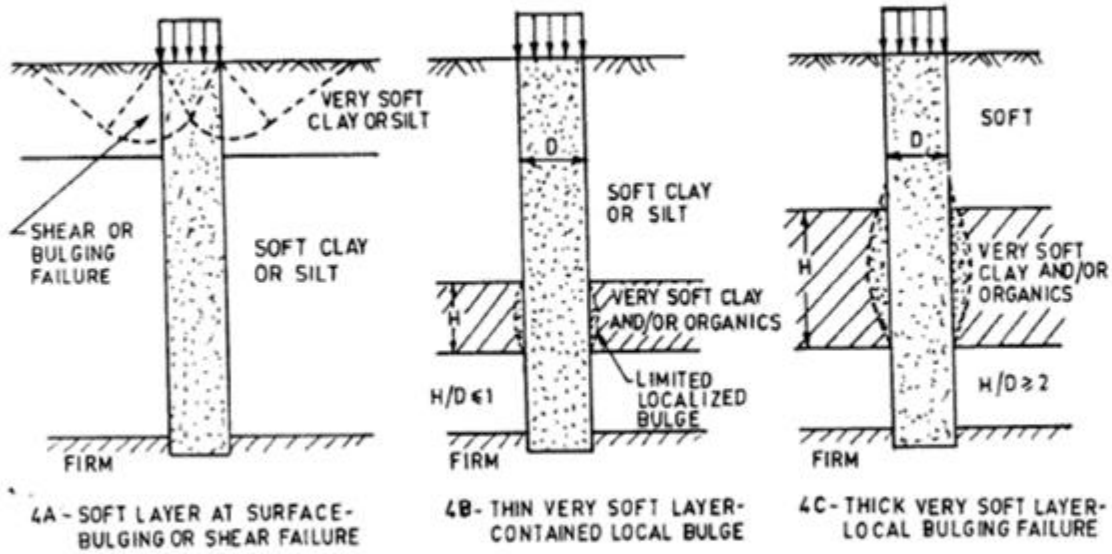


Fig. 1.6 Mechanism of failure of stone column in non-homogenous soft layer

(IS 15284.1.2003)

1.3 OBJECTIVE

- To study the consolidation behaviour of soil when stone columns are installed in triangular and rectangular pattern in soft soils.
- To study the effect of spacing on consolidation behaviour of soil when stone columns are installed in triangular and rectangular pattern in soil.
- To compare the effectiveness of triangular and rectangular pattern of stone columns at different spacing and find which one performs better.
- To find out the most efficient spacing of stone column when installed in triangular and rectangular pattern for consolidation of soil.

CHAPTER 2

LITERATURE REVIEW

Mitchell and Huber(1985) used vibro-replacement method for constructing compacted gravel stone columns for increasing the load carrying capacity of compressible fine grained soils was used in Santa Barbara, Calif, to support a new 11,000,000 gal/day (42,000,000 L/day) wastewater treatment plant. Over 6,500 stone columns were installed. All stone columns extended completely through the soft estuarine deposits and penetrated a minimum of 1 ft (0.3 m) into the underlying older marine deposits. The lengths of the stone columns varied from 30-49 ft (9-15 m). The diameters of stone columns exposed for load testing or inspection following construction varied from 32-48 in. (0.81-1.22 m) or both, with an average of 42 in. (0.07 m).
Settlements calculated by the finite element method for the stone column foundation were approximately 30% of the settlements calculated for the same loading on an unimproved site.

Ambily and Gandhi (2007) performed an experimental study on behavior of single stone column and group of seven stone columns by varying the parameters like spacing between the stone columns, shearing strength of soft soil and loading condition. Finite Element Analysis (PLAXIS-2D) is also analysed using 15-noded triangular elements and obtained results are compared with the experimental results.

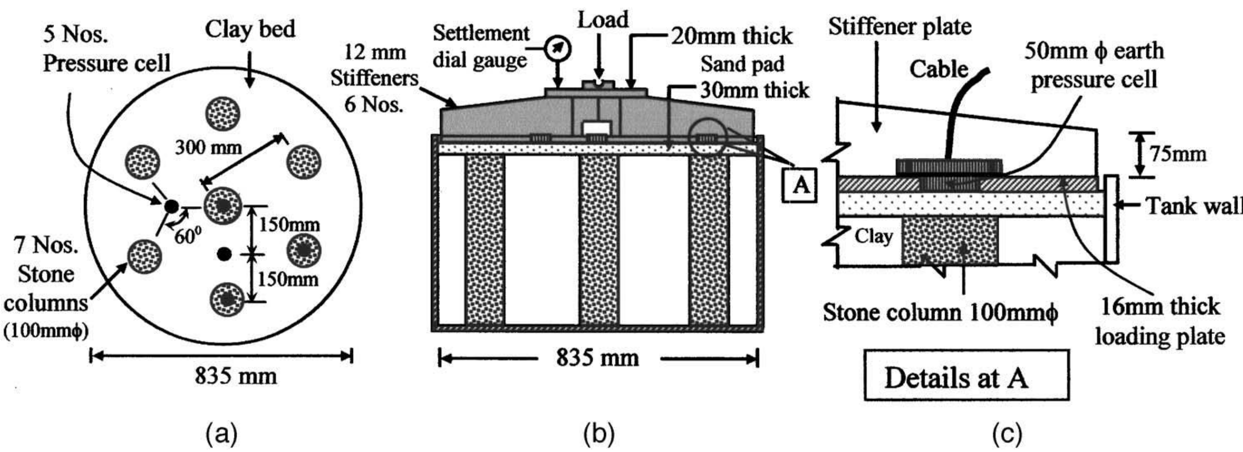


Fig 2.1 Group test arrangement: a) plan view; b) section of test tank; and c) details of pressure cell

Murugesan and Rajagopal (2010) did the experimental tests on the qualitative and quantitative improvement of load carrying capacity of an encased stone column. Load tests are done on both single and group of stone columns both without encasement and with encasement. And it was found that ultimate load carrying capacity of stone columns increases with encasement. The increment in load carrying capacity depends on the modulus of encased material and the diameter of the stone columns

Guocai Wang (2009) developed a closed-form analytical solution of consolidation of soft clay foundations reinforced by stone columns under various forms of time-dependent loading while considering smear and well resistance under time-dependent loading. The differential equations of the foundations reinforced by stone columns are obtained including smear and well resistance under arbitrary applied loadings.

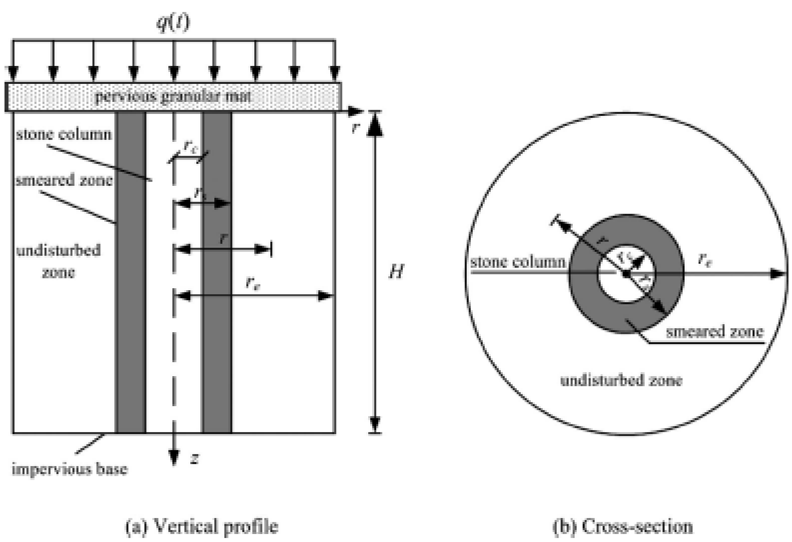


Fig 2.2 Schematic cell representing typical stone column-reinforced foundation

Zhang; Zhao; Shi and Zhao (2013) produced an axial compression in a stone column under vertical loads on its top, and radial expansion against the surrounding soil near the top portion of the column was accompanied. They discussed the influences of stress concentration ratio, internal friction angle and cohesion of the surrounding soil, and the elastic modulus of the column on the deformations of the stone column.

CONCLUSION: The above papers suggest that the use of stone column helps in improving the strength of the soft clay bed by faster settlement at early stage and also by providing the required compaction. The papers used the various parameters like spacing of stone column, shearing strength of soft soil and loading condition to study their effect on the strength of the stone column. The influences of stress concentration ratio, internal friction angle and cohesion of the surrounding soil, and the elastic modulus of the column on the deformations of the stone column were discussed.

CHAPTER 3
METHODOLOGY

3.1 Experimental Setup:-

1) Model- Wooden box of dimension 0.5mx0.5mx0.5m

2) Dial Gauge- To measure settlement (least count 0.01mm)

3) Loading Equipment- Concrete cubes and beams able to provide sufficient load to consolidation of the soil.

4) Loading Plate- Mild steel plate to transfer stresses.

5) Stone column of diameter 35mm

Fig 3.1 Model test set up

3.2 General Test Procedure

- Soil is filled in the mould and compacted at saturated moisture content.
- Mild steel plate and dial gauges are arranged on top surface.
- Load is applied through dead loads on soil and kept constant for 24hrs or till the time there no increase in dial gauge readings for consecutive 2hrs.

3.3 Test procedure

Tests are performed in 4 steps:-

STEP 1: In this consolidation test is performed on plain soil i.e. without having stone column installed.

Fig 3.2 Mould with virgin soil

STEP 2: In this consolidation test was performed on soil with stone column being installed at the centre of the mould.

Fig 3.3 Mould with stone column at the centre

STEP 3: In this consolidation test is performed on soil having prefabricated vertical drains installed in a triangular pattern.

a) With s/d =2

Fig 3.4 Triangular pattern of stone column with s/d = 2

b) With s/d=3

Fig 3.5 Triangular pattern of stone column with s/d=3

c) With s/d=4

Fig 3.6 Triangular pattern of stone column with s/d=4

STEP 4: In this consolidation test is performed on soil having stone columns installed in a rectangular pattern.

a) With s/d=2

Fig 3.7 Rectangular pattern of stone column witn s/d=2

b) With s/d=3

Fig 3.8 Rectangular pattern of stone column witn s/d=3

c) With s/d=4

Fig 3.9 Rectangular pattern of stone column witn s/d=4

3.4 Loading stages

Fig 3.10 Stages of loading

CHAPTER 4
RESULTS

4.1 PROPERTIES OF THE CLAY BED AND STONE

The different test has been performed on fine soil and stone to get its classification and basic properties.

1) **SOIL**(20% bentonite powder mixed with normal DTU soil)

Liquid Limit = 39%
Plastic Limit = 19%
Plasticity Index = 20%
Maximum Dry Density = 15.45 kN/m^3
Optimum Moisture Content = 16.25%

SIEVE ANALYSIS OF CLAY SOIL

C_u= 5.29 C_C=0.80(from Fig. 4.1)

Hence the soil used is clayey sand.

TABLE1. SIEVE ANALYSIS

S.NO.	SIEVE SIZE(mm)	WEIGHT RETAINED(g)	% RETAINED	% FINER
1	4.75	68.84	6.17	93.83
2	2.36	128.81	11.56	82.27
3	1.18	205.66	18.45	63.82
4	0.600	142.72	12.80	51.02
5	.425	178.7	16.03	34.99
6	.150	291.27	26.13	8.86
7	.075	98.62	8.84	0.02
8	PAN	2	-	-

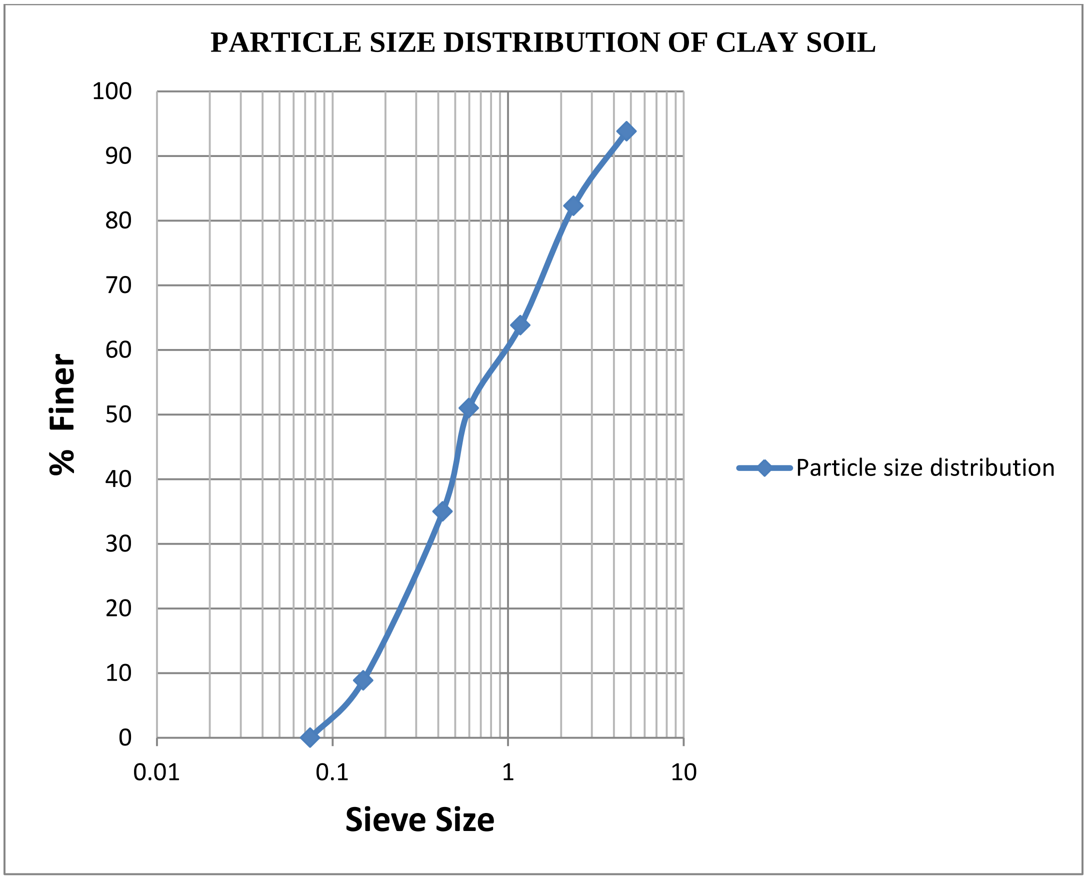


Fig 4.1 Particle size distribution of soil

MAXIMUM DRY DENSITY

Weight of empty mould = 4200g

Maximum Dry Density(Fig. 4.2)=15.058kN/m^3

Optimum Moisture Content(Fig. 4.2)=13.5%

Vol. of standard proctor mould =945cc

Density at fully saturated=19.199kN/m^3

Saturation moisture content=27.5%

TABLE 2: DRY DENSITY

S.No	Mass of Soil+ Mould(g)	Mass of Soil(g)	Bulk Density (g/cc)	Water content(%)	Dry Density(g/cc)
1	5700	1500	1.587	7.3	1.479
2	5750	1550	1.640	9	1.504
3	5800	1600	1.693	11	1.525
4	5855	1655	1.751	15	1.523
5	5790	1590	1.682	17	1.438

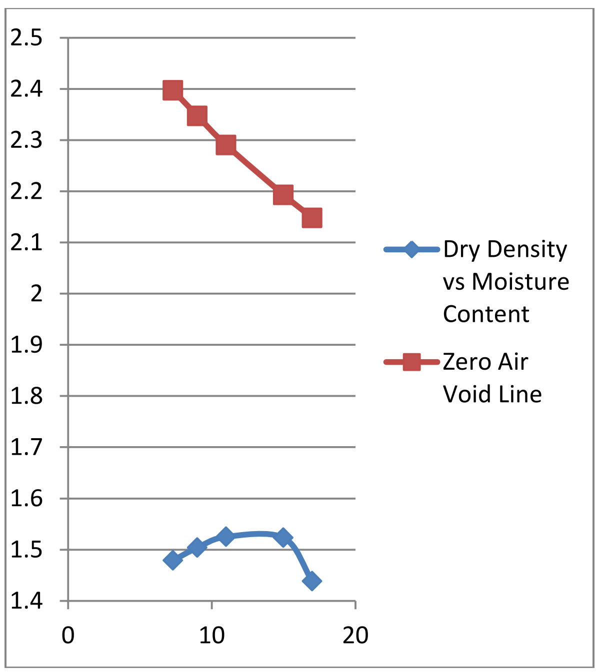


Fig 4.2 Dry Density vs Moisture Content curve

2) STONE

Size = 2-10mm
Specific Gravity = 2.63
C_u = 1.78
C_c = 0.69
Poorly Graded Gravel (GP)

TABLE 3: SIEVE ANALYSIS OF STONE CHIPS

SIEVE SIZE(mm)	WEIGHT RETAINED	% WEIGHT RETAINED	CUMULATIVE % WEIGHT RETAINED	% FINER
15	107.23	2.81	2.81	97.19
13.2	77.35	2.02	4.83	95.17
12.5	28.68	0.75	5.58	94.42
11.2	85.11	2.23	7.81	92.19
10	593.50	15.57	23.38	76.62
6.3	1652.4	43.35	66.73	33.27
4.75	951.01	24.95	91.68	8.32
Pan	316.05	8.29	100	-

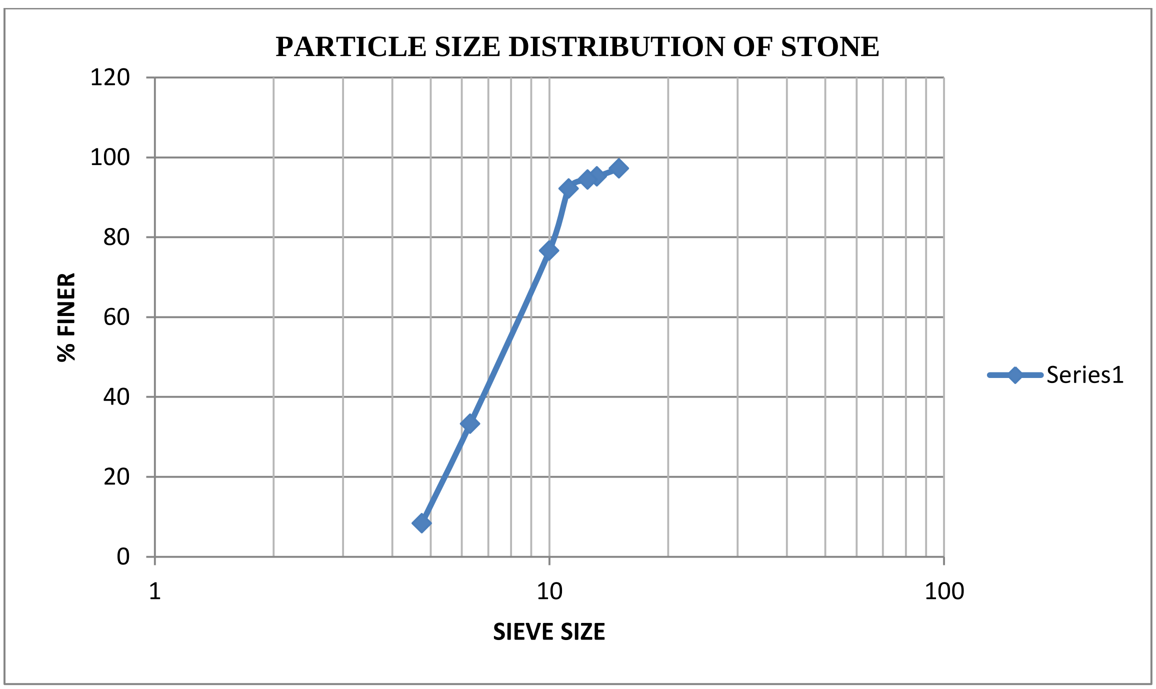


Fig 4.3 Particle size distribution of stone chips

4.2 CONSOLIDATION TESTS

4.2.1 FOR VIRGIN SOIL

TABLE 4: LOAD VS SETTLEMENT FOR SOIL

S.No	Load(kg)	Settlement(mm)
1	24	0
2	48	0.25
3	84	0.7
4	120	1.58
5	156	2.00
6	192	2.36
7	228	3.43
8	264	4.45
9	300	5.90

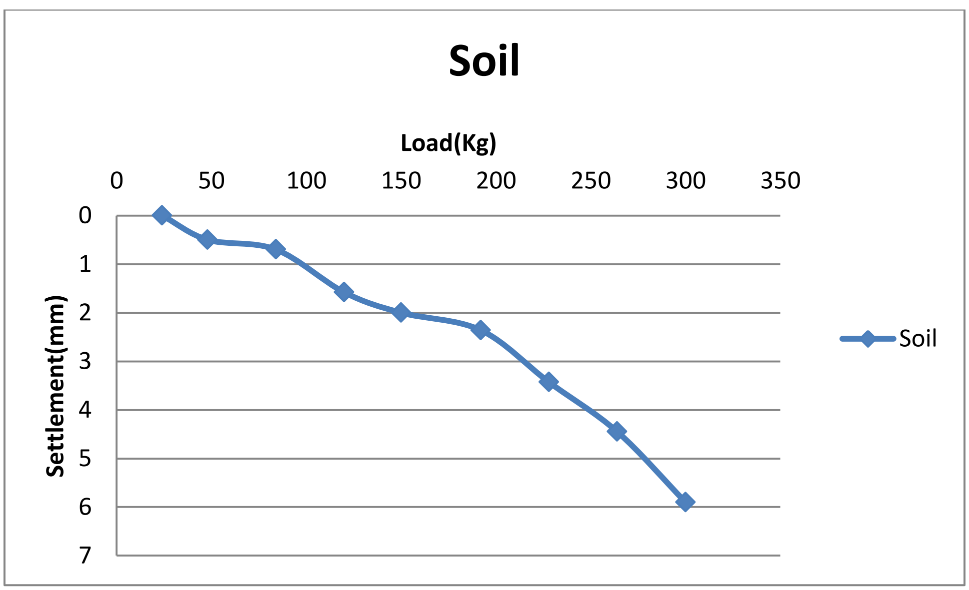


Fig 4.4 Load vs Settlement curve for soil

4.2.2 STONE COLUMN AT CENTRE

TABLE 5: Load vs settlement with stone column at centre

S.NO	Load(kg)	Settlement(mm)
1	24	0
2	48	0.30
3	84	0.84
4	110	1.67
5	146	2.32
6	182	2.42
7	218	3.65
8	254	5.44
9	290	6.60

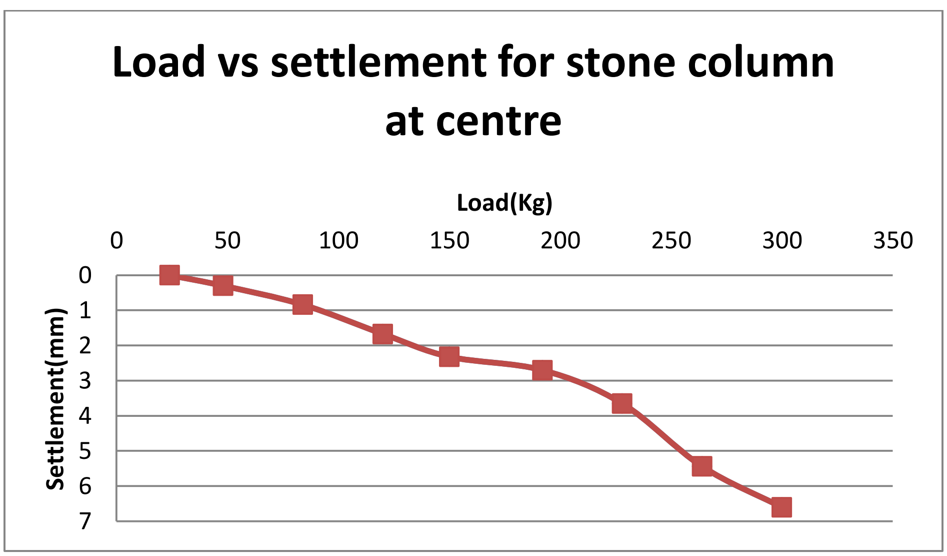


Fig 4.5 Load vs settlement for stone column at centre

4.2.3 TRIANGULAR PATTERN OF STONE COLUMN

a) With s/d =2

TABLE 6: Load vs settlement for triangular pattern with s/d=2

S.NO	Load(kg)	Settlement(mm)
1	24	0.30
2	48	0.42
3	84	0.98
4	110	1.90
5	146	2.46
6	182	2.94
7	218	4.20
8	254	6.10
9	290	7.00

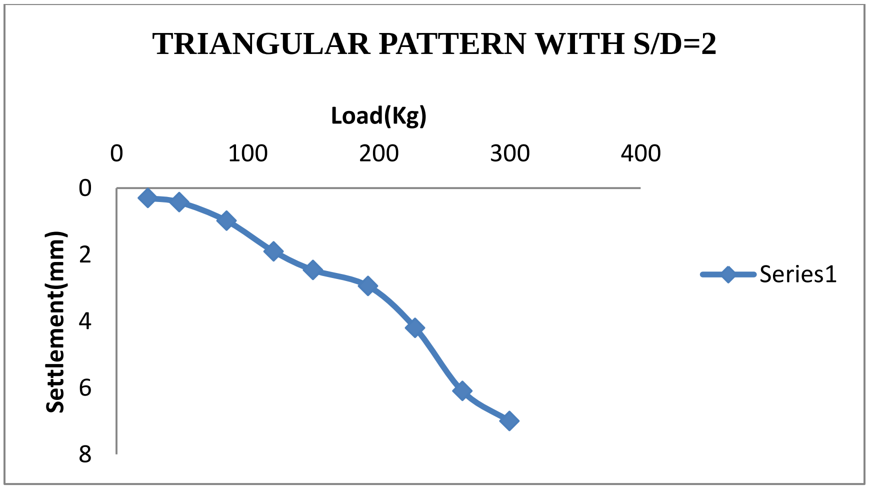


Fig 4.6 Load vs settlement for triangular pattern with s/d=-2

b) With s/d=3

TABLE 7: Load vs settlement for triangular pattern with s/d=3

S.NO	Load(kg)	Settlement(mm)
1	24	0.35
2	48	0.45
3	84	1.02
4	110	2.10
5	146	2.80
6	182	3.24
7	218	4.60
8	254	6.20
9	290	7.30

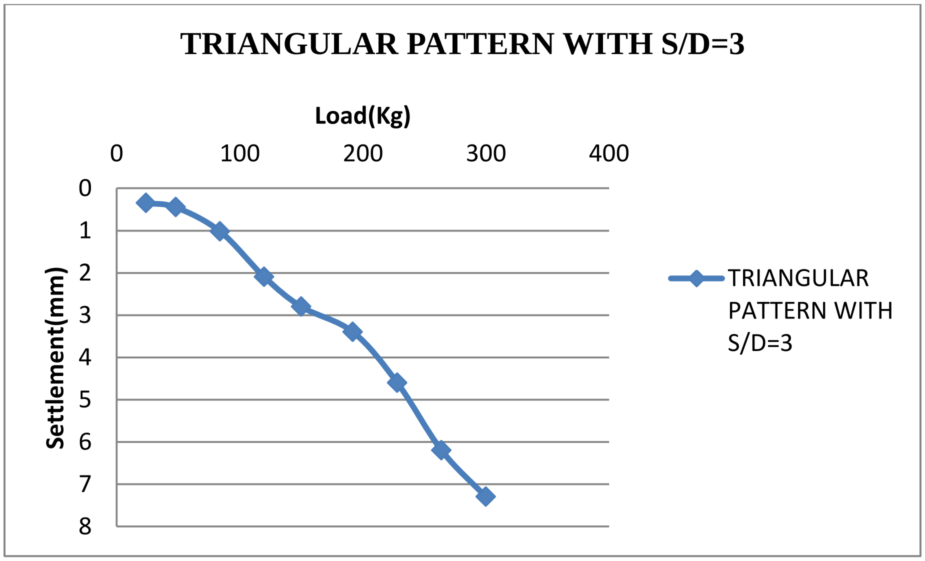


Fig 4.7 Load vs settlement for triangular pattern with s/d=3

c) With s/d=4

TABLE 8: Load vs settlement for triangular pattern with s/d=4

S.NO	Load(kg)	Settlement(mm)
1	24	0.30
2	48	0.46
3	84	1.02
4	110	1.98
5	146	2.70
6	182	3.25
7	218	4.30
8	254	6.14
9	290	7.10

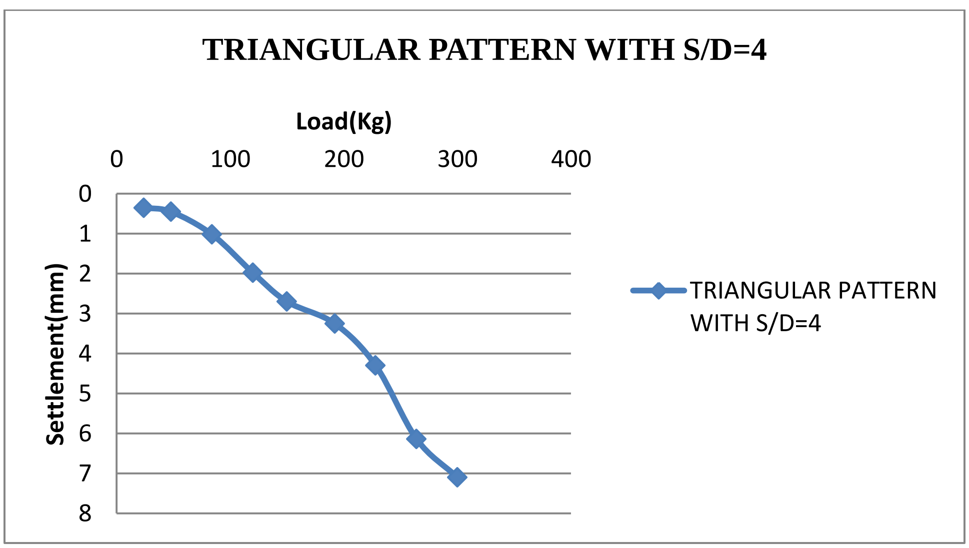


Fig 4.8 Load vs settlement for triangular pattern with s/d=4

4.2.4 RECTANGULAR PATTERN OF STONE COLUMN

a) With s/d=2

TABLE 9: Load vs settlement for rectangular pattern with s/d=2

S.NO	Load(kg)	Settlement(mm)
1	24	0.25
2	48	0.36
3	84	0.80
4	110	1.15
5	146	2.21
6	182	2.62
7	218	3.14
8	254	5.42
9	290	6.30

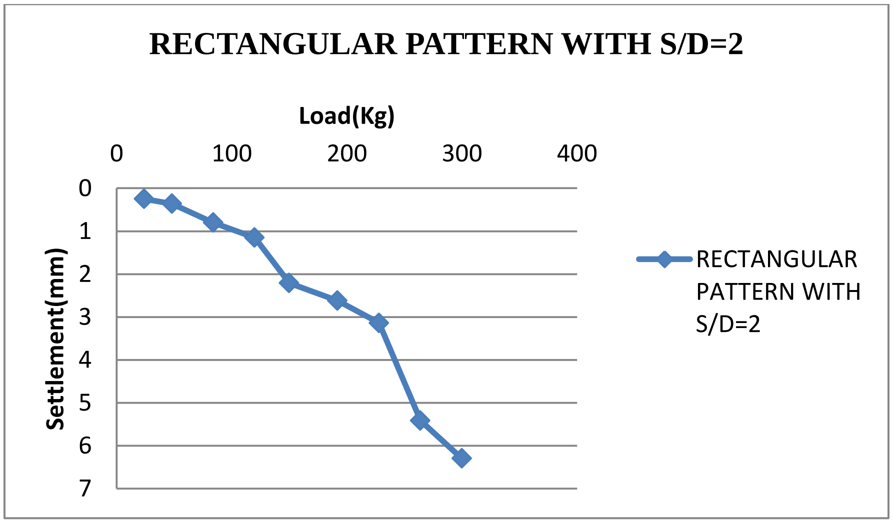


Fig 4.9 Load vs settlement for rectangular pattern with s/d=2

b) s/d=3

TABLE 10: Load vs settlement for rectangular pattern with s/d=3

S.NO	Load(kg)	Settlement(mm)
1	24	0.25
2	48	0.35
3	84	0.90
4	110	1.40
5	146	2.42
6	182	2.80
7	218	3.40
8	254	5.84
9	290	6.92

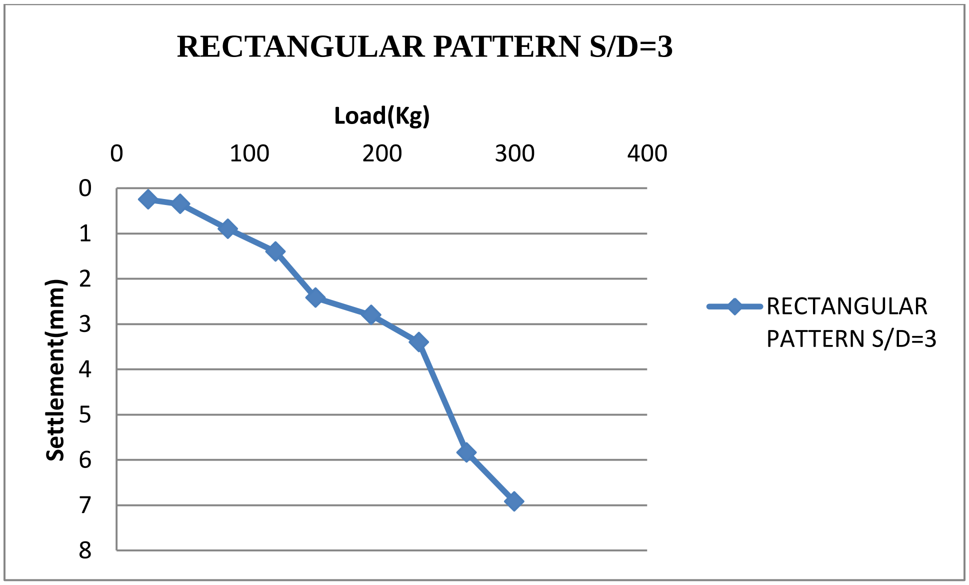


Fig 4.10 Load vs settlement for rectangular pattern with s/d=3

c) s/d=4

TABLE 11: Load vs settlement for rectangular pattern with s/d=4

S.NO	Load(kg)	Settlement(mm)
1	24	0.25
2	48	0.35
3	84	0.85
4	110	1.30
5	146	2.35
6	182	2.70
7	218	3.3
8	254	5.5
9	290	6.5

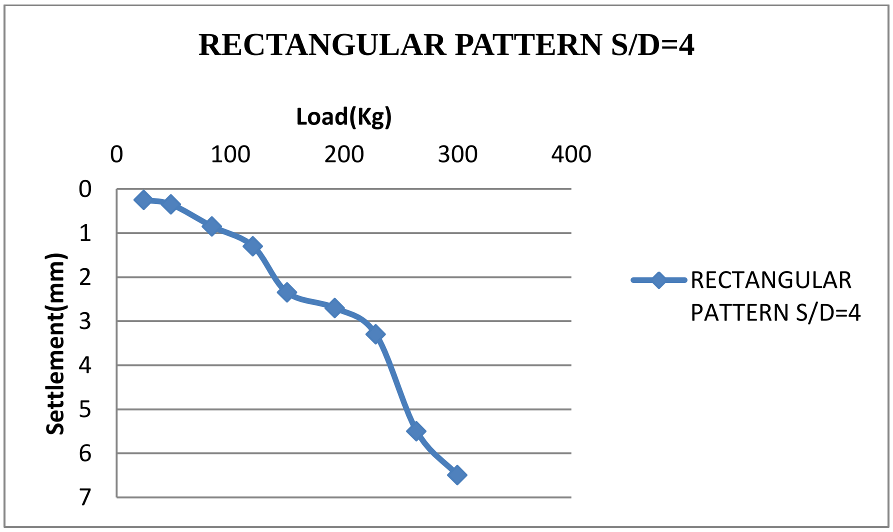
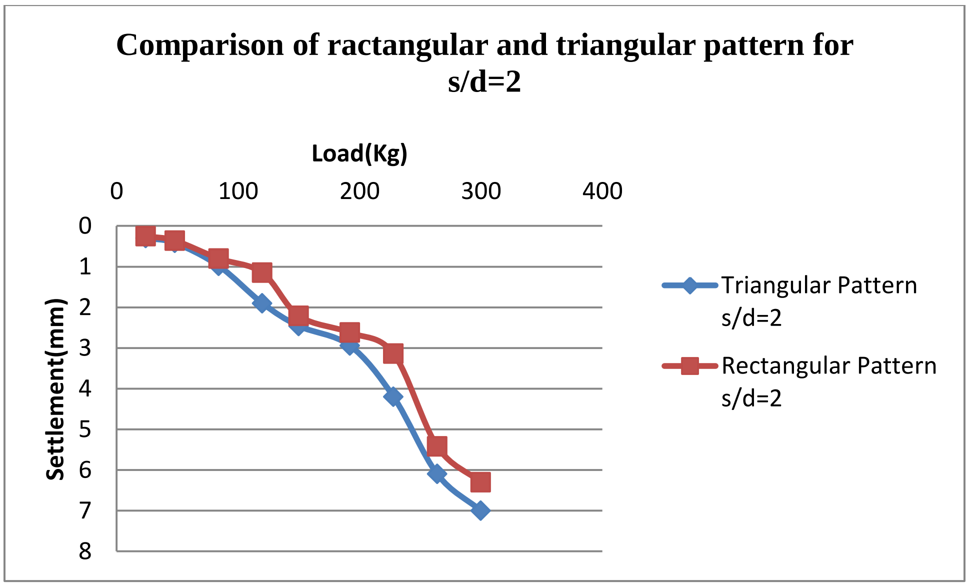
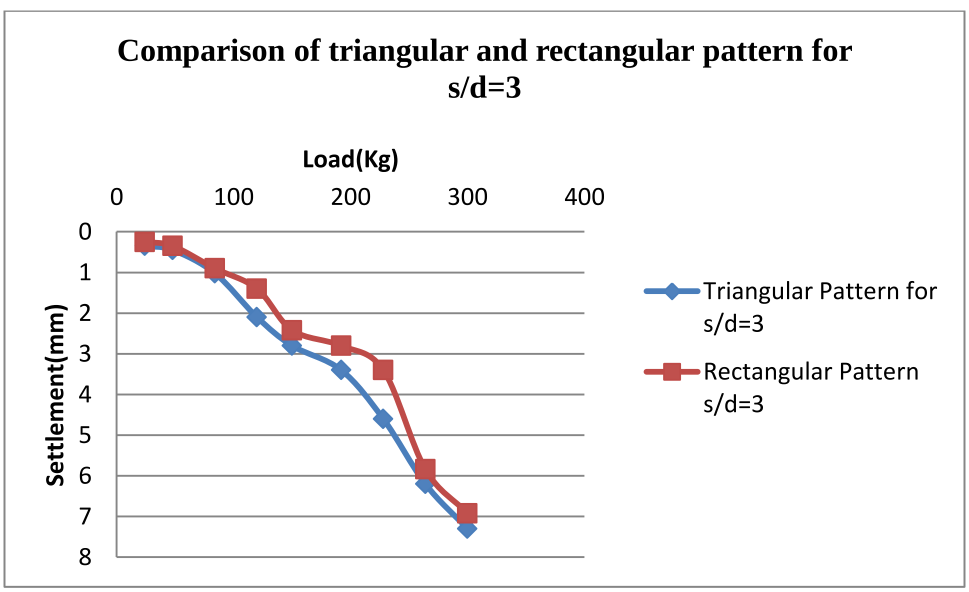


Fig 4.11 Load vs settlement for rectangular pattern with s/d=4

CHAPTER 5
CONCLUSION

- From the above results it is clear that Triangular pattern of stone column performed better than rectangular pattern of prefabricated vertical drains. The average increase in settlement for s/d=2.0 was 22.79%, for s/d=3.0 was 24.12% and for s/d=4.0 was 23.34%. Therefore, average increase in case for triangular pattern as compared to rectangular pattern of prefabricated vertical drains is 23.42%.





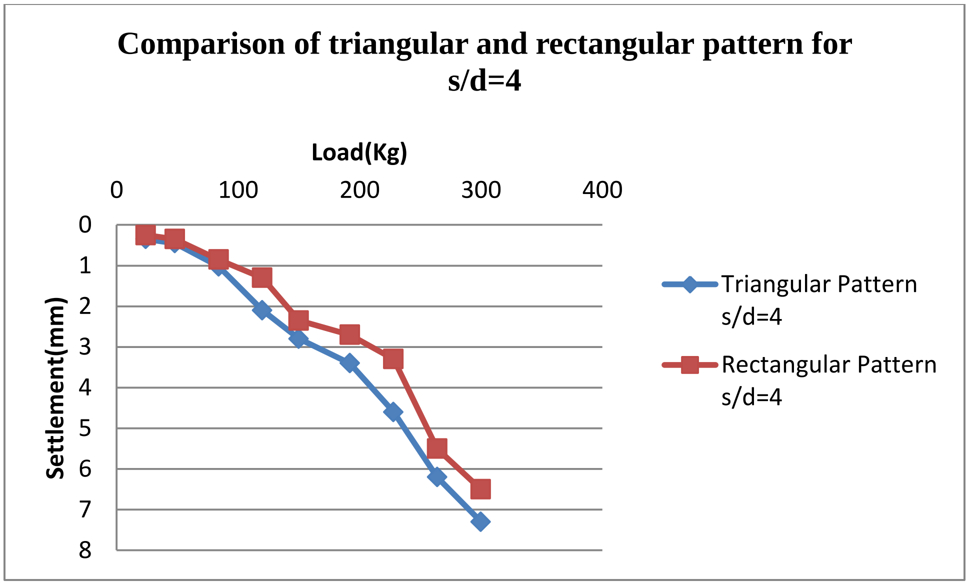


Fig 5.1 Comparison of triangular and rectangular pattern fors/d=2; s/d=3and s/d=4

- From the above results we can also conclude that in case of stone column installed in triangular pattern maximum consolidation occurs when s/d=3.0. Average increase in consolidation for s/d=3.0 as compared to s/d=2.0 is 8.09% and increase in consolidation for s/d=3.0 as compared to s/d=4.0 is 4.4%.

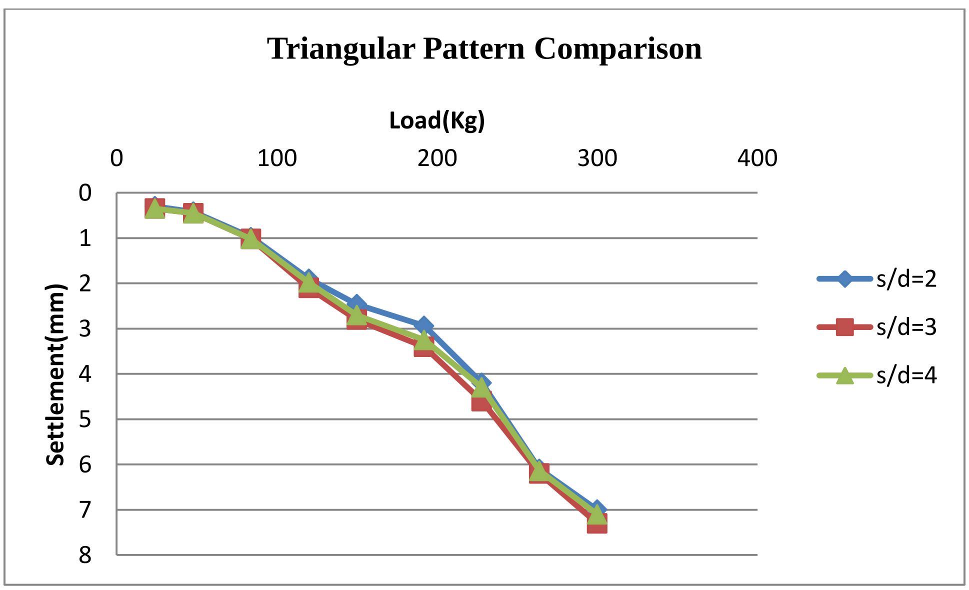


Fig 5.2 Comparison for varying s/d ratio in triangular pattern

- From the above result we can also conclude that if stone column are arranged in rectangular pattern maximum consolidation occurs when s/d=3.0. Average increase in consolidation for s/d=3.0 as compared to s/d=2.0 is 8.33% and increase in consolidation for s/d=3.0 as compared to s/d=4.0 is 4.01%.

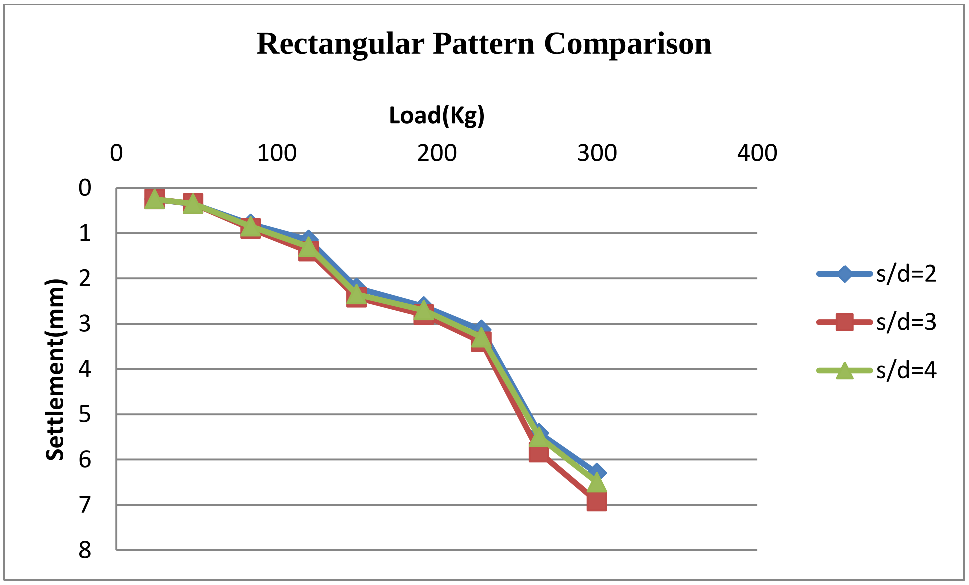


Fig 5.3 Comparison for varying s/d ratio in rectangular pattern

- Comparison of virgin soil with stone column at centre

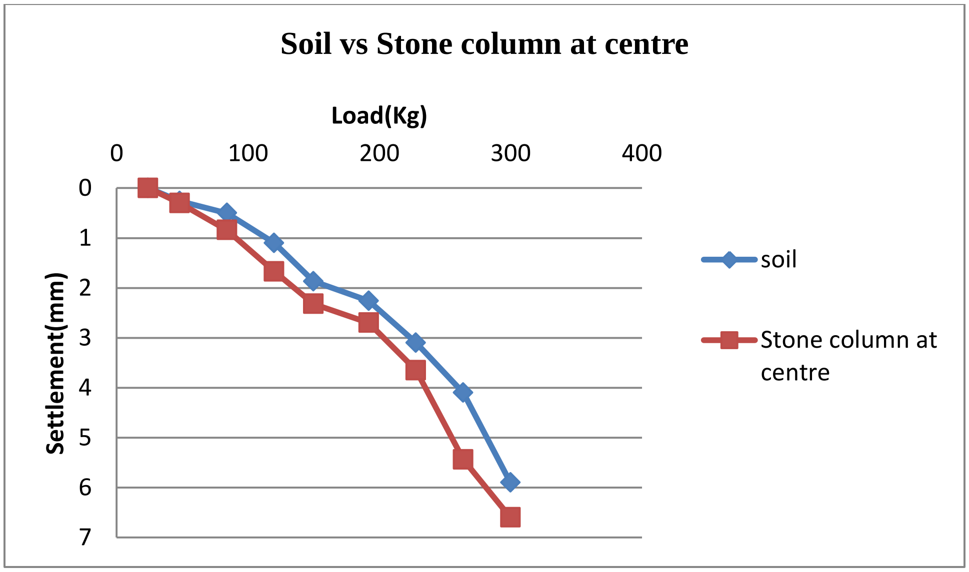


Fig 5.4 Settlement of soil vs stone column at centre

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