Effect of s/d ratio of Prefabricated Vertical Drains on Consolidation Behavior of Soil.

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in

GEOTECHNICAL ENGINEERING

Under the guidance of

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CERTIFICATE

This is to certify that the project report entitled, "**Effect of s/d ratio of Prefabricated Vertical Drains on Consolidation Behavior of Soil**", is being carried out by **ADITYA SHUKLA, ROLL NO. 2K15/GTE/01** in partial fulfillment for the award of degree of Masters of Technology in Geotechnical Engineering (Department of Civil Engineering, DTU) under my supervision during the session January 1-June 22-2017.

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INTRODUCTION

1.1 General

Soil now a days is generally not safe for supporting modern day infrastructures like highways, residential towers, ports, dams etc. Ongoing infrastructure development in several countries has forced engineers to suggest measure to construct modern and high class infrastructure facilities including highways , residential towers, ports, railways etc over soft marine and alluvial deposits. These soft soils have very low bearing capacity and undergo large detrimental settlements when acted upon by heavy loads. Therefore it is required to improve these soil properties before construction work is started on them in order to avoid damages to life and property.

When load is applied on soft clayey soil, addition of load leads to development of excess pore water pressure in the soil. This excess pore water pressure is initially taken up by water present within the soft layer of soil. This pore pressure developed in soil is equal to externally applied load on the soil. As time passes, water slowly moves out from the voids of soil depending upon the permeability of soil and drainage path in soil, therefore this excess pore water pressure reduces and the pressure gets transferred to soil grains. As more and more time passes, excess pore water pressure keeps on decreasing and the effective stresses in the layer keeps on increasing. After a very long time the excess hydrostatic pore pressure becomes equal to zero and the entire consolidation pressure becomes an effective stress transmitted acting on grains of the soil. Now total externally applied is acting on soil grains therefore soil grains gets consolidated due to this effective stress and settlements continues for longer duration unless remedial measures are taken to help pore water pressure dissipate quickly. Therefore as long as consolidation continues, foundation of the structure will keep on settling. By this time, irreparable damage to structure would have occurred. Due to low permeability and poor drainage properties of soft soil, during construction load will keep on increasing water will keep on draining out until ultimate settlement is reached. Moreover, due to high compressibility of these soils, the consolidation settlements are of a very high magnitude and from structural safety point of view, it is important that major portion of this consolidation settlement takes place before/during construction phase itself. Out of the different methods available for ground improvement, pre-loading is the most successful one. The main disadvantage of this method is that, consolidation still requires longer time as drainage path is still not reduced and also external load required is of higher magnitude. Therefore to increase the speed of drainage before construction pre-loading alone is not always a good solution In these cases, the presence of prefabricated vertical drain with loading greatly reduces the load required and time for It is a well known fact that coefficient of consolidation in the horizontal direction is much higher than that in the vertical direction, installation of vertical drains also shortens the drainage path effectively , therefore the effectiveness of preloading with vertical drains is very high in achieving desired consolidation and that too in reduced time. Therefore, to accelerate the consolidation process, and reduce consolidation time prefabricated vertical drains are installed with preloading.

Prefabricated vertical drains are externally provided drainage paths in soil that can have varied properties depending upon the material used and method of installation. These artificially provided drainage path reduces time required to attain consolidation process period from years to months. Therefore, maximum settlement occurs during construction phase making structure same from damages after construction.

1.2 PREFABRICATED VERTICAL DRAINS

Prefabricated vertical drain(PVD) can be defined as an artificially made product of a central plastic core or sand core having a synthetic filter around it to enhance the drainage properties of soil. This plastic core or sand core provides drainage while the filter around it avoids flow of particles in the core and avoid clogging.

The prefabricated drains can be of two types;
a) Sand wicks
b) Band shaped drains

(a) Sand wicks are made by filling graded sand in perforated pipes of HDPE or other woven permeable fabric, including natural fabric and stitching fabric from sides and the ends. The filter cover around helps in attaining economy in the quantity of graded sand to be used and can be placed causing minimum disturbance in soil. The fabric cover around sand core allows sand drains to be very firm and adjustable, thus enabling them to stretch and compress at different points along their length to accommodate horizontal and vertical deformations. The material to be opted for vertical drains should be well graded coarse to medium sand with permeability in the range of 10^{-3} to 10^{-1} cm/s.

(b)Band shaped drains are generally polypropylene and high-density polyethylene(HDPE) polymers. PVDs consists of a channelized or corrugated core with a geotextile filter around it.

Fig. 1 PVD

Advantage of prefabricated vertical drains is that by providing horizontal and vertical drainage it attains desired degree of consolidation within certain time period . Polymeric prefabricated vertical drains are used for ground improvement applications. These are not economic as well as not good for environment also. Prefabricated vertical drainage has a disadvantage that its efficiency can be higher than what is required at the site. Therefore in such cases, deliberately designed geosynthetic are preferred, whose performance can be predicted with time. Due to economy and environment concerns developing countries are trying to find out more economical and environment friendly solutions to manufacture prefabricated vertical drains .

These prefabricated vertical drains are installed in soil at different spacing and in different pattern like triangular, rectangular or square depending upon the required use. Effectiveness of each pattern is different on consolidation behavior of soil ,therefore in this report we try to study the effectiveness of these pattern with regard to consolidation behavior of soil.

Equivalent diameter of prefabricated vertical drain to be taken:-

$$d = 2(b+t)/\pi$$

where,

d= equivalent diameter

b=width of prefabricated vertical drain

t= thickness of prefabricated vertical drain

Advantages of PVD:-

- Increased rate of consolidation
- Limited disturbance to soil.
- Depth of installation 60m.
- Installation process can be monitored.
- Installation speed as high as 1500 m/hr.
- Spacing as per requirement.
- More efficient than sand drain.

1.3 OBJECTIVE

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

Chapter-2

LITERATURE REVIEW

Dey,A.(2008) studied vertical drains and smear effects. He performed consolidation test and numerical analysis of soft fine grained soils and compared result obtained for triangular and rectangular pattern of prefabricated vertical drains. Equivalent cross sectional area was considered for calculating equivalent diameter of zone of influence around prefabricated vertical drain with grid spacing D

$$D_E \approx 1.13\, D \text{(Square)}$$
$$D_E \approx 1.05 D \text{ (Triangular)}$$

He found out soils where primary consolidation is important and horizontal permeability is more than vertical permeability, prefabricated vertical drains increases rate of consolidation. He also found out that triangular pattern showed higher rate of consolidation and more settlement than rectangular pattern of prefabricated vertical drains.

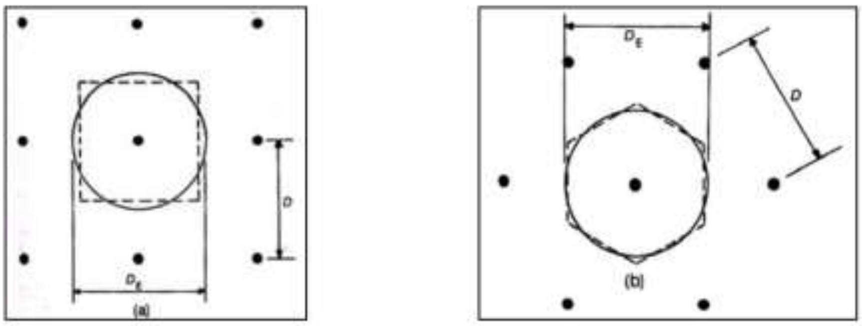

Figure 2 Equivalent diameters of sand drains installed in (a) Square grid (b) Triangular grid pattern

Source- Dey,A., "Vertical drains and smear effects"(2008),Geosymposium

Basu, D. and Prezzi, M.(2007) studied effect of the smear and transition zones around prefabricated vertical drains installed in a triangular and rectangular pattern on the rate of soil consolidation. They studied the effect on consolidation of soil when PVDs are installed in different patterns. They also studied the effect of disturbance on soil due to installation. They found out that the pre-loading with prefabricated vertical drains reduces the drainage path for water therefore accelerating consolidation process. They also found out that triangular pattern performed better than rectangular pattern of prefabricated vertical drains. Increase in percentage was found to be 25-55% when triangular pattern was compared with rectangular pattern after 48 hours.

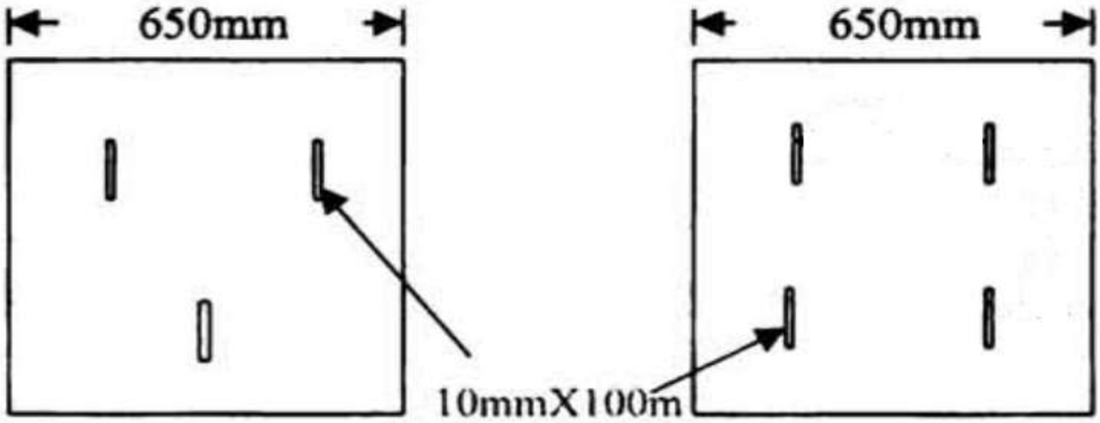

Fig 3 triangular and rectangular pattern of PVDs

Source- Basu, D. and Prezzi, M. “Effect of the smear and transition zones around prefabricated vertical drains installed in a triangular and rectangular pattern on the rate of soil consolidation.” (2007), International Journal of Geomechanics, ASCE

Hansbo, S. (1981) studied consolidation of clay by band shaped prefabricated vertical drains. He studied the effect on consolidation behavior of clays when prefabricated verticals drains are installed in soils. He also studied the effect of different patterns of prefabricated vertical drains on consolidation behavior of soil. He found out that the consolidation time for a square pattern, as opposed to a triangular, results in an increase of consolidation time by about 20%.For equal consolidation times, the calculated number of drains per unit area is the same, whether assumed as placed in a square or a triangular pattern.

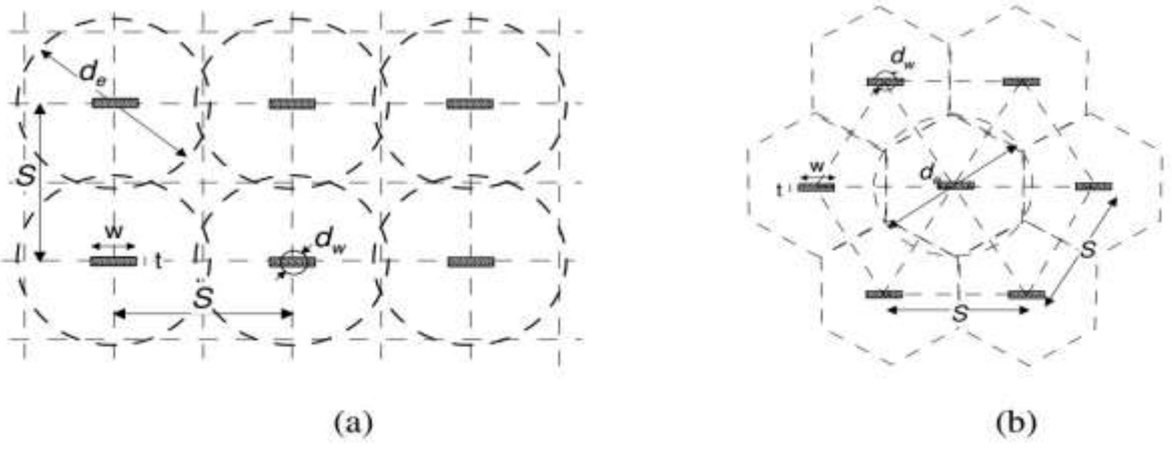

Figure 4 Drain installation pattern (a) square pattern; (b) triangular pattern

Source- Hansbo, S. “Consolidation of clay by band shaped prefabricated vertical drains” (1981),Ground Engineering

From the above study we concluded that installation of prefabricated vertical drains increases rate of consolidation. Pattern of installation and spacing by diameter ratio are also important factors

Chapter-3

METHODOLOGY

3.1 Experimental Setup:-

3.1.1. Model- Wooden box of dimension 0.5mx0.5mx0.5m

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

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

3.1.4. Loading Plate- Mild steel plate to transfer stresses.

3.1.5. Prefabricated Vertical Drains of dimension 30mmx3mm

Fig 5 Experimental Setup

3.2 General Test Procedure:-

3.2.1. Soil is filled in the mould and compacted at saturated moisture content.

3.2.2. Mild steel plate and dial gauges are arranged on top surface.

3.3.3. Load is applied through dead loads on soil and kept constant for 24hrs or till the time their no increase in dial gauge readings for consecutive 2hrs.

3.3 Method of Installation:-

3.3.1. Steel flat of size as close as possible to size of PVD is driven into the soil at the required location upto the required depth.

3.3.2. Flat is removed slowly so that soil does not cave in and PVD is inserted into the soil.

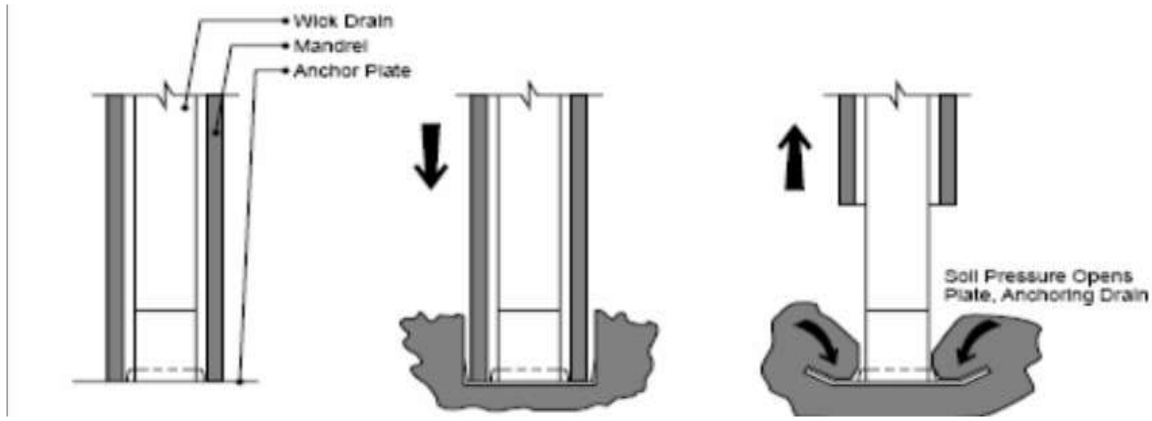

Fig 6 Method of installation of PVD

Source- Preloading and vertical drains, Helsinki University of Technology

3.4 Test Procedure

This test is performed in 4 series which are as follows:-

3.4.1. Series 1-In this consolidation test is performed on plain soil i.e. without having prefabricated vertical drain installed.

Fig 7 Soil inside Mould

3.4.2. Series 2- In this consolidation test was performed on soil having prefabricated vertical drain installed at centre.

Fig 8 PVD installed at centre

3.4.3. Series 3-In this consolidation test is performed on soil having prefabricated vertical drains installed in a triangular pattern.

(a) PVDs installed in triangular pattern with s/d ratio 2.0

Fig 9 PVDs installed in a triangular pattern with s/d=2.0

(b) PVDs installed in triangular pattern with s/d ratio 3.0

Fig 10 PVDs installed in triangular pattern with s/d=3.0

(c) PVD installed in triangular pattern with s/d=4.0

Fig 11 PVDs installed in triangular pattern with s/d=4.0

3.4.4. Series 4- In this consolidation test is performed on soil having prefabricated vertical drains are installed in a rectangular pattern.

(a) PVDs installed in rectangular pattern with s/d=2.0

Fig 12 PVDs installed in a rectangular pattern with s/d=2.0

(b) PVDs installed in rectangular pattern with s/d=3.0

Fig 13 PVDs installed in rectangular pattern with s/d=3.0

(c) PVDs installed in rectangular pattern with s/d=4.0

Fig 14 PVDs installed in rectangular pattern with s/d=4.0

3.5 Loading Stages

15(a)

15(b)

15(c) 15(d)

Fig 15(a)(b)(c)(d) showing different stages of loading

Chapter-4

RESULTS

4.1. Sieve Analysis

Table 1 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	17.73	82.27
3	1.18	205.66	36.18	63.82
4	0.6	142.72	48.98	51.02
5	0.425	178.7	65.01	34.99
6	0.150	291.27	91.14	8.86
7	0.075	98.62	99.98	0.02
8	Pan	2.29	100	-

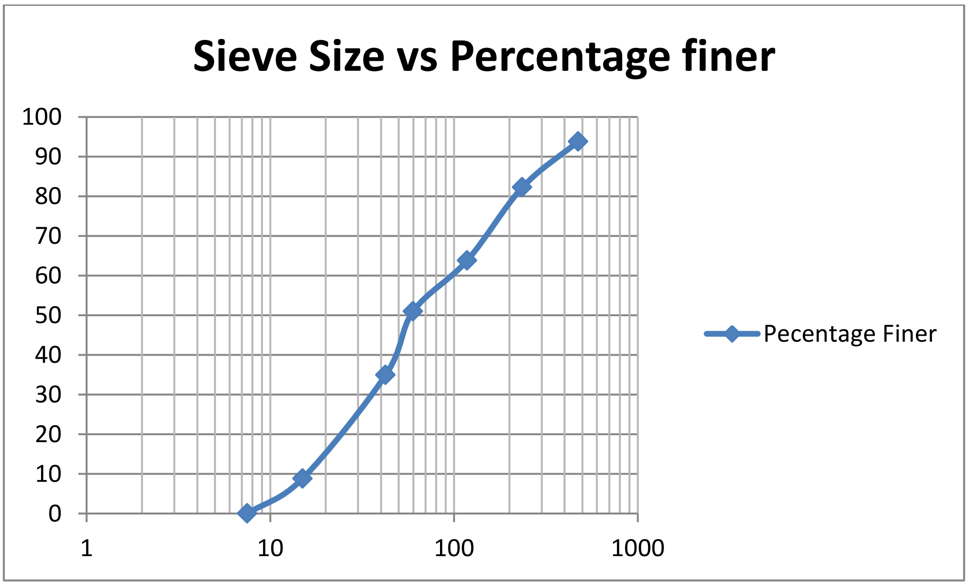

Fig 16 Particle Size Distribution Curve

C_u =5.12 C_c=0.73

Liquid Limit=39% Plastic Limit=19%

Hence the soil is Clayey-Sand

4.2. Maximum Dry Density

Weight of empty mould = 4200g
Maximum Dry Density(Fig. 10)=15.058kN/m^3
Optimum Moisture Content(Fig. 10)=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

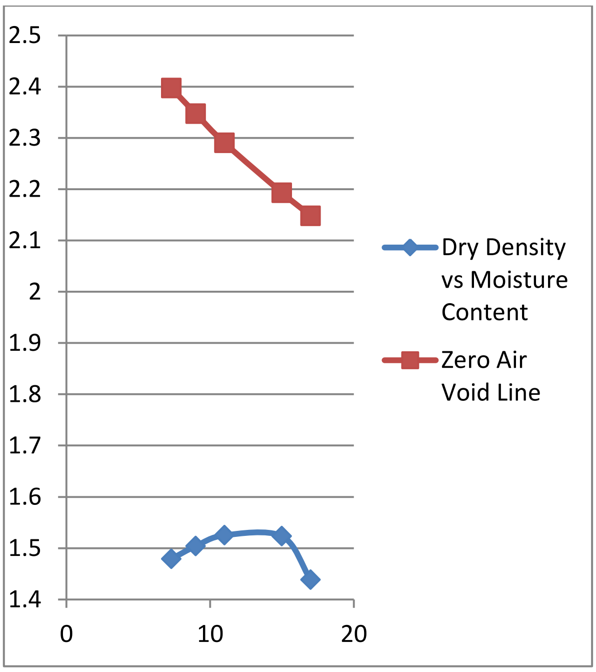

Fig 17 Dry Density vs Moisture Content curve

4.3. Consolidation Tests

(a) Series 1

Table 3 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	4.95
9	300	6.10

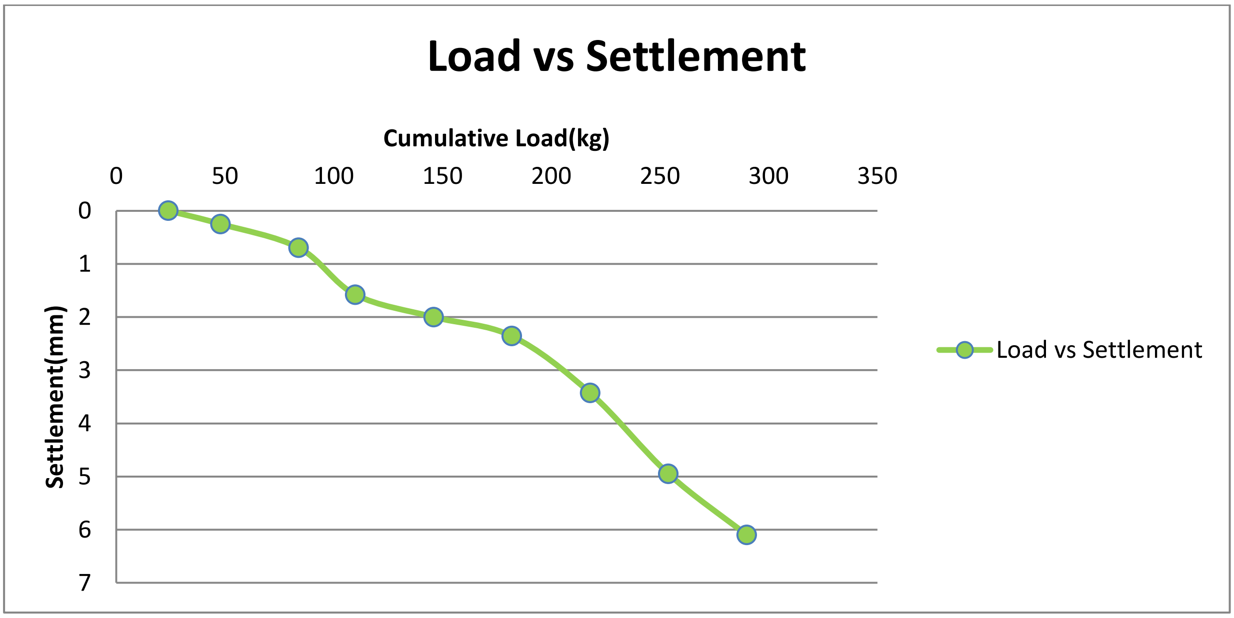

Fig 18 Load vs Settlement curve for soil

(b) Series 2

Table 4 Load vs Settlement for soil having PVD at centre

S.No	Load(kg)	Settlement(mm)
1	24	0.15
2	48	0.29
3	84	0.80
4	120	1.77
5	156	2.44
6	192	3.22
7	228	4.61
8	264	5.87
9	300	6.98

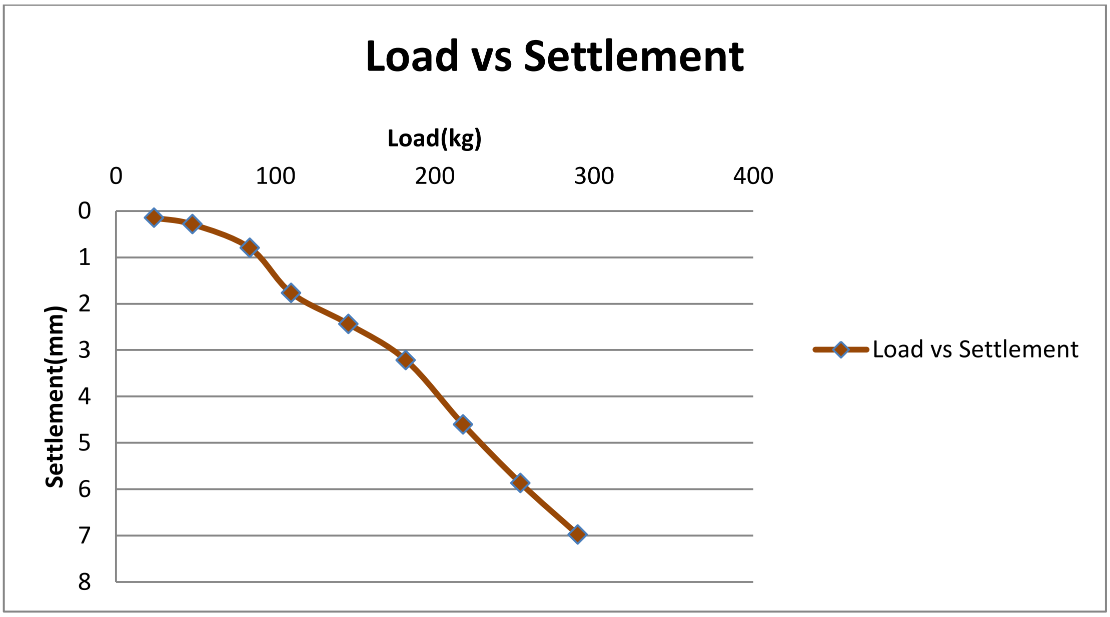

Fig 19 Load vs Settlement for PVD at centre

(c)Series 3(a)

Table 5 Load vs Settlement for soil having triangular pattern PVDs with s/d=2.0

S.No	Load(kg)	Settlement(mm)
1	24	0.50
2	48	1.20
3	84	2.60
4	120	3.89
5	156	4.43
6	192	5.50
7	228	6.87

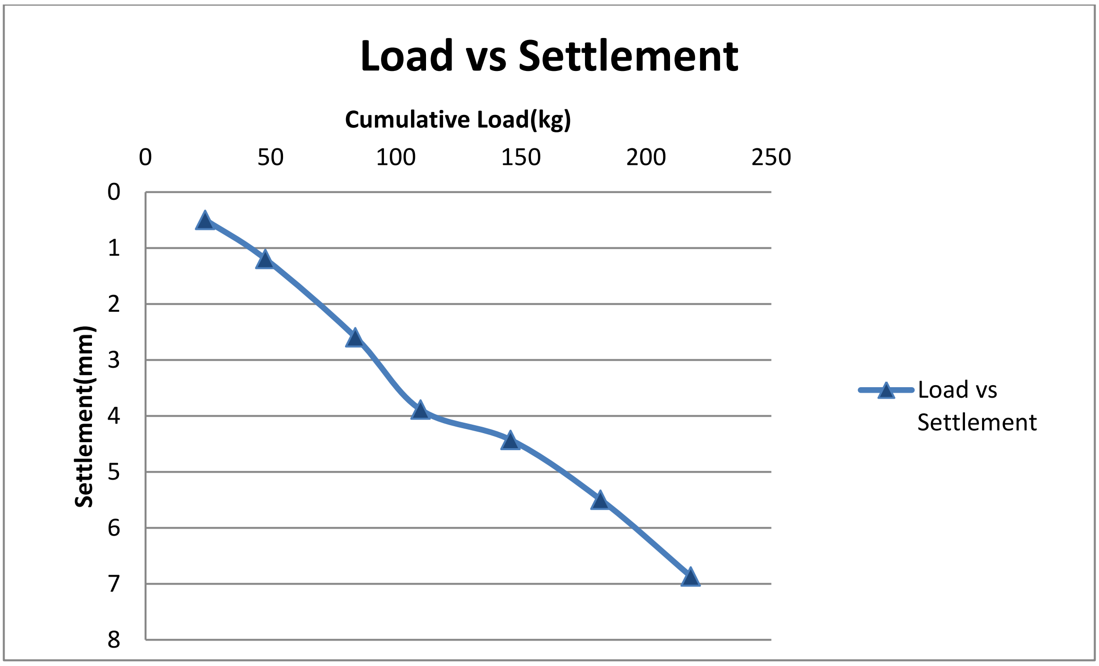

Fig 20 Load vs Settlement curve for soil with triangular pattern PVDs with s/d=2.0

(d) Series 3(b)

Table 6 Load vs Settlement for soil having triangular pattern PVDs with s/d=3.0

S.No	Load(kg)	Settlement(mm)
1	24	0.57
2	48	1.36
3	84	2.97
4	120	4.46
5	156	5.09
6	192	6.20
7	228	7.49

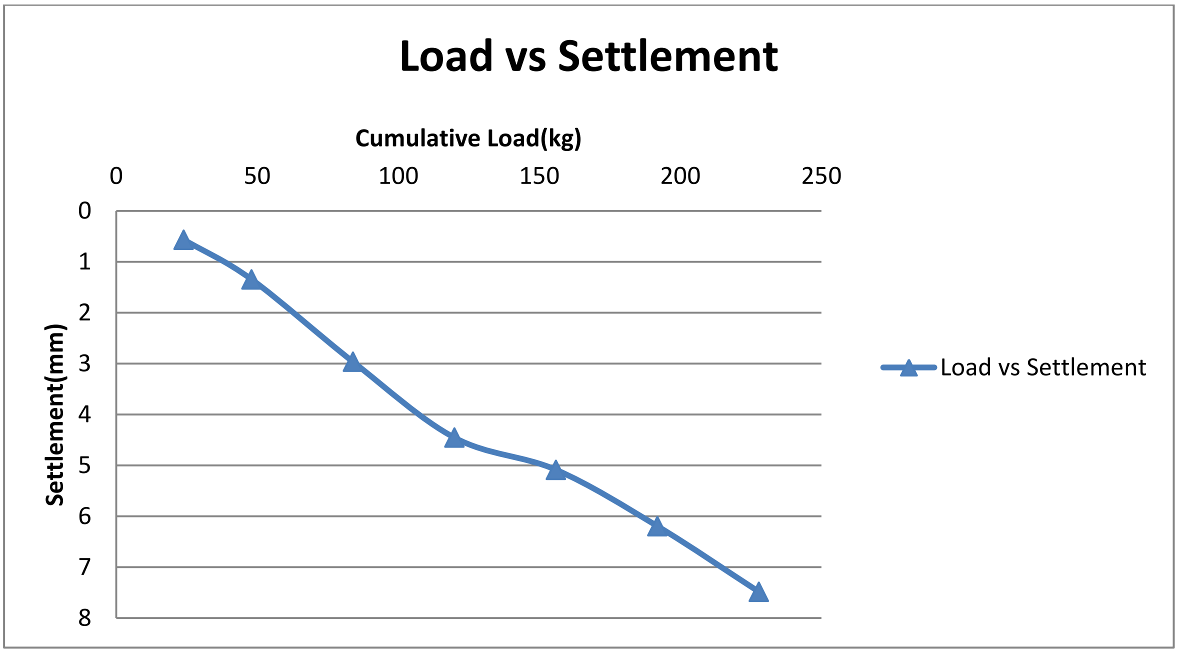

Fig 21 Load vs Settlement curve for triangular pattern of PVDs with s/d=3.0

(e)Series 3(c)

Table 7 Load vs Settlement for soil having triangular pattern PVDs having s/d=4.0

S.No	Load(kg)	Settlement(mm)
1	24	0.55
2	48	1.32
3	84	2.84
4	120	4.34
5	156	4.97
6	192	6.03
7	228	7.19

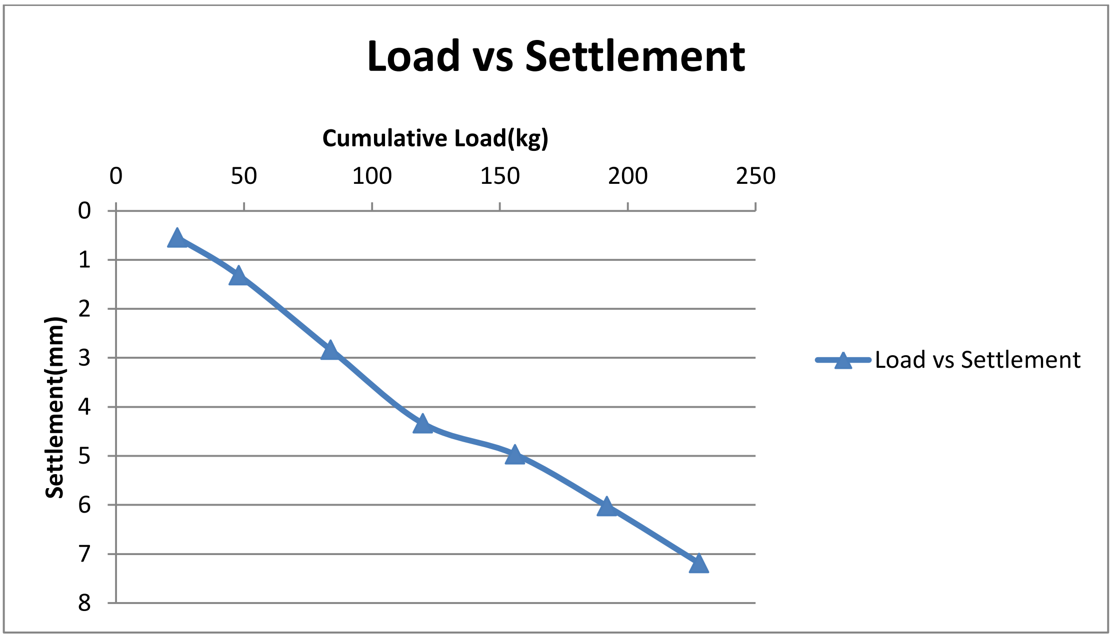

Fig 22 Load vs Settlement curve for triangular pattern of PVD with s/d=4.0

(f) Series 4(a)

Table 8 Load vs Settlement for soil having rectangular pattern PVDs with s/d=2.0

S.No	Load(kg)	Settlement(mm)
1	24	0.34
2	48	0.96
3	84	1.84
4	120	2.96
5	156	3.67
6	192	4.85
7	228	6.2

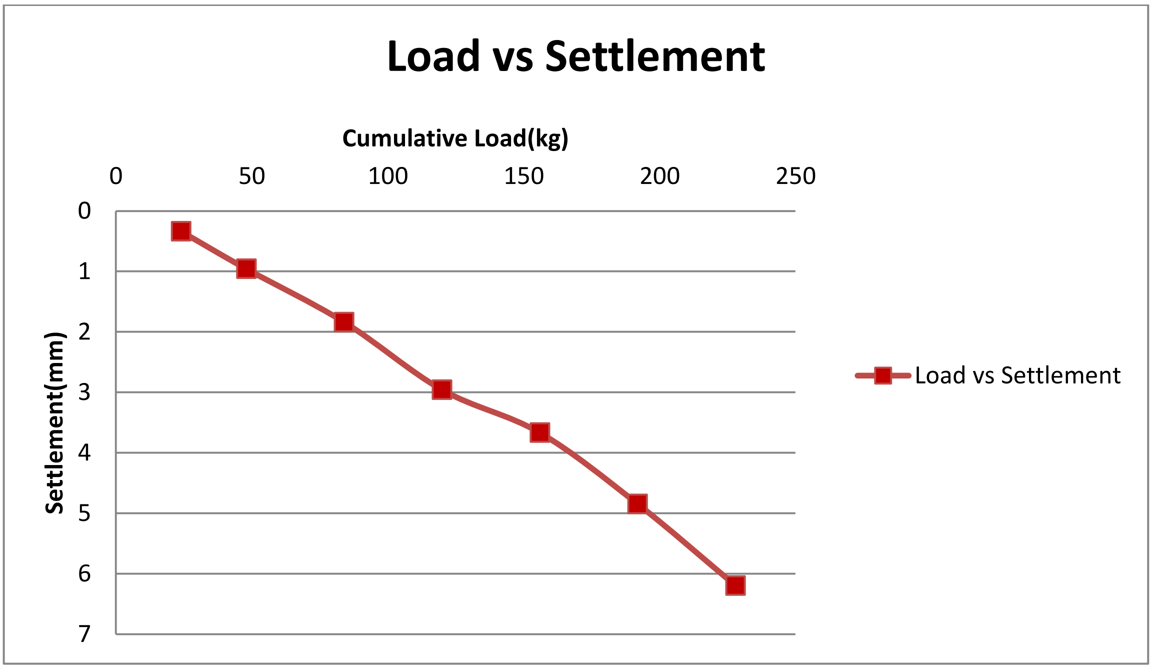

Fig 23 Load vs Settlement curve for rectangular pattern of PVD with s/d=2.0

(g) Series 4(b)

Table 9 Load vs Settlement for soil having rectangular pattern PVDs with s/d=3.0

S.No	Load(kg)	Settlement(mm)
1	24	0.38
2	48	1.07
3	84	2.07
4	120	3.37
5	156	4.14
6	192	5.49
7	228	6.93

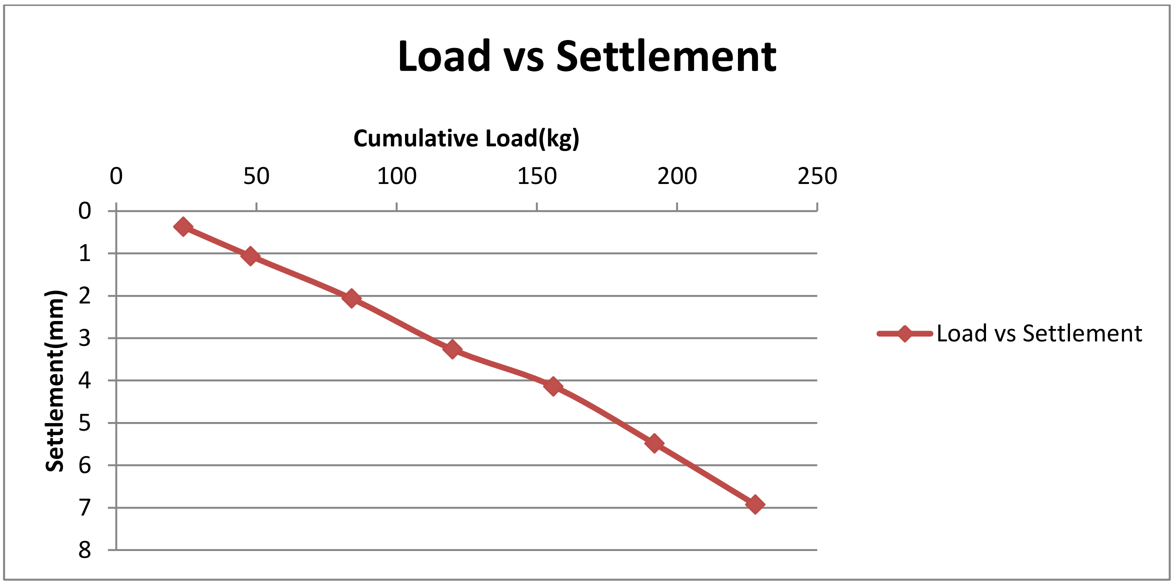

Fig 24 Load vs Settlement curve for rectangular pattern of PVD with s/d=3.0

(h) Series 4(c)

Table 10 Load vs Settlement for soil having rectangular pattern PVDs with s/d=4.0

S.No	Load(kg)	Settlement(mm)
1	24	0.37
2	48	1.05
3	84	2
4	120	3.22
5	156	3.96
6	192	5.30
7	228	6.79

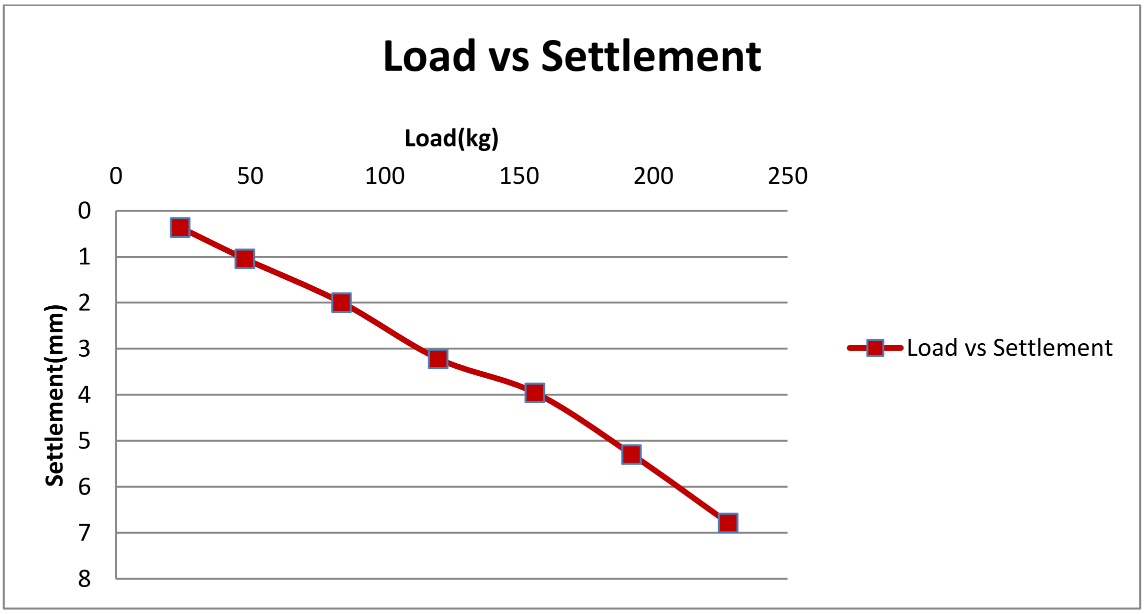

Fig 25 Load vs Settlement curve for rectangular pattern of PVD with s/d=4.0

Chapter-5

CONCLUSION

- From the above results it is clear that Triangular pattern of prefabricated vertical drains performed better than rectangular pattern of prefabricated vertical drains. The average increase in settlement for s/d=2.0 was 27.09%, for s/d=3.0 was 28.12% and for s/d=4.0 was 28.05%. Therefore, average increase in case for triangular pattern as compared to rectangular pattern of prefabricated vertical drains is 27.75% . This occurs because area is effectively covered i.e. drainage path is least in triangular pattern of drainage system that is why more consolidation occurs than rectangular pattern.

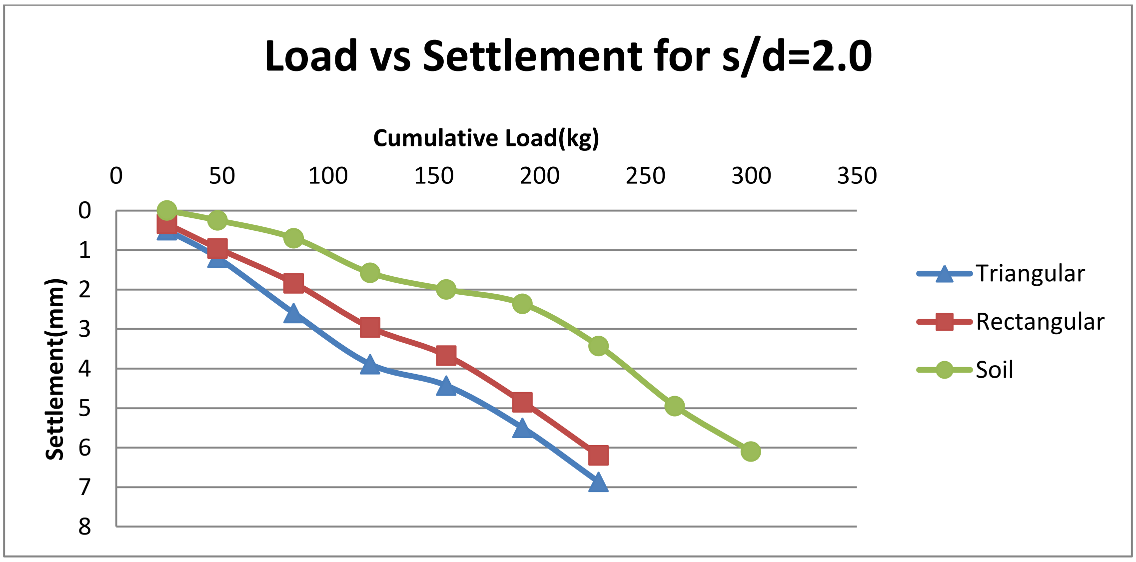

Fig 26 Comparison plot at s/d=2.0

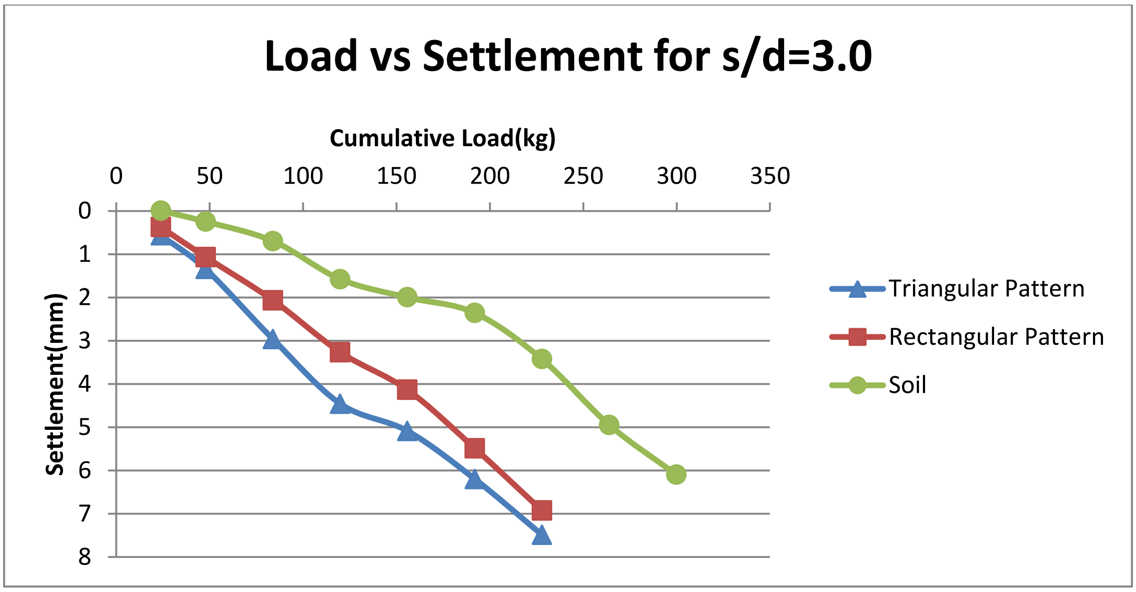

Fig 27 Comparison plot at s/d=3.0

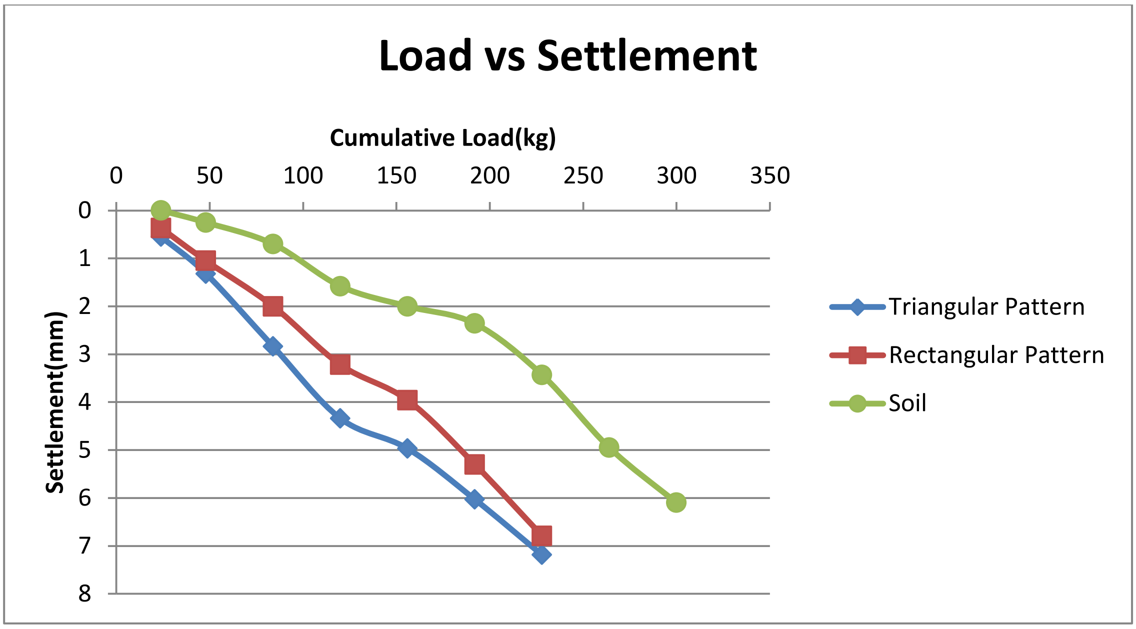

Fig 28 Comparison plot at s/d=4.0

- From the above results we can also conclude that in case of prefabricated vertical drains 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 13.26% and increase in consolidation for s/d=4.0 as compared to s/d=2.0 is 9.61%. This shows that at closer spacing effect of disturbance due to installation of prefabricated vertical drains is dominant which reduces permeability, as spacing is increased this effect reduces. Further increase in spacing results in results in reduction in effective area which a drain can consolidate therefore consolidation decreases.

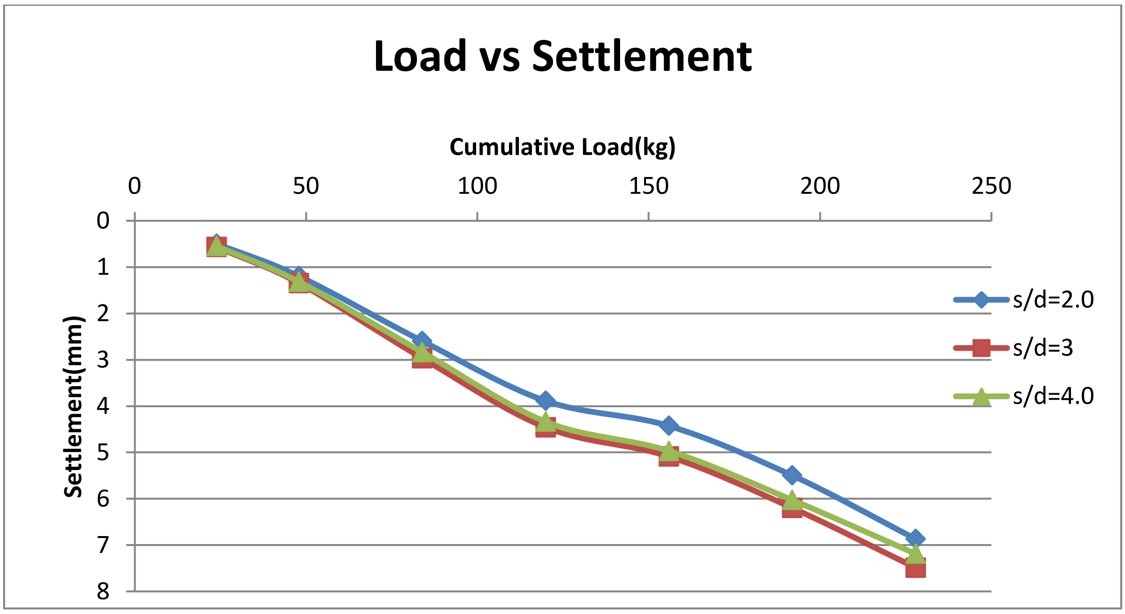

Fig 29 Comparison plot for Triangular Pattern

- From the above result we can also conclude that if prefabricated vertical drains 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 12.48% and increase in consolidation for s/d=4.0 as compared to s/d=2.0 is 8.91%. This shows that at closer spacing effect of disturbance due to installation of prefabricated vertical drains is dominant which reduces permeability, as spacing is increased this effect reduces. Further increase in spacing results in results in reduction in effective area which a drain can consolidate therefore consolidation decreases

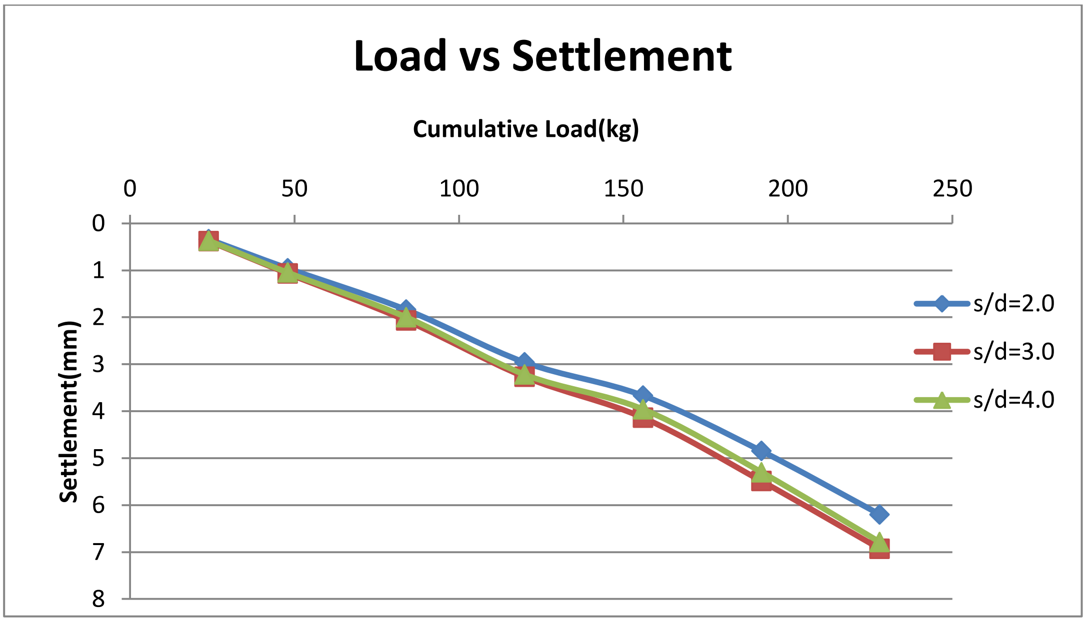

Fig 30 Comparison plot for rectangular pattern

- Installation of Prefabricated vertical drains whether in rectangular or triangular pattern increased the rate of consolidation i.e. same settlement can be reached at a lesser time and less load because a shorter drainage path is now available for water to travel which reduces consolidation time. Average increase was 11.91%.

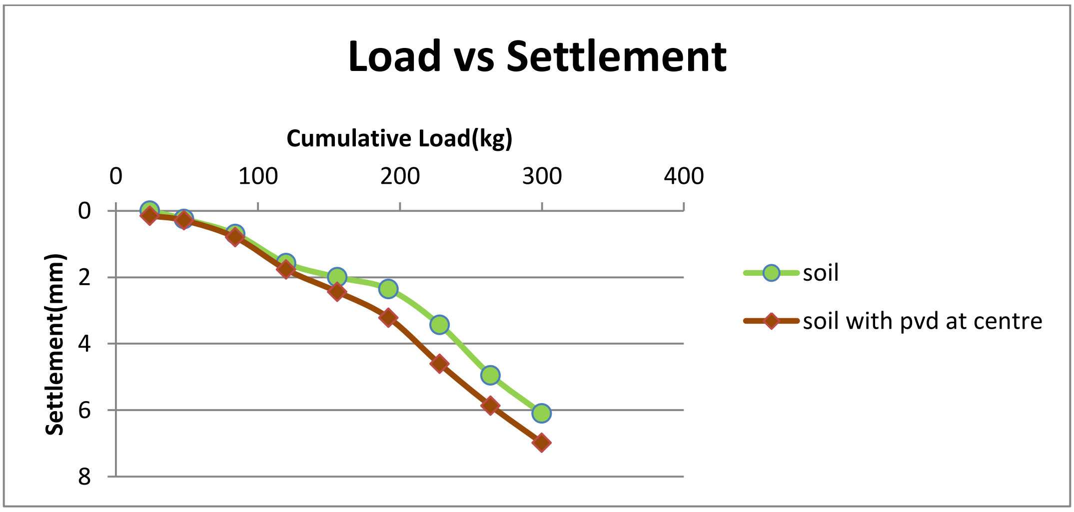

Fig 31 Comparison plot for soil with and without PVD

Chapter-6

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