An Investigation on Behavior of Centrally Loaded Shallow Foundation on Sand Bed Reinforced with Geogrid

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Abstract-The study pertains to the investigation of the effect of embedment on the load carrying capacity and settlement of strip foundations on sand reinforced with geogrids. Geogrid being an inextensible reinforcing material is widely used all over the world mainly for retaining walls, abutments slope protection and below the foundation in poor soil. Some research works have been done the investigators regarding the optimum placement of geogrids below surface footing however, the work on centrally loaded embedded foundations reinforced with multilayer of geogrids have not been reported in literature. Therefore in this paper attention is being paid to the load carrying capacity and settlement behavior of centrally loaded embedded footing reinforced with multilayer of gerogrids. Load tests have been carried out for this purpose. Strip foundations are considered and loads were being applied through electrically operated hydraulic jack for greater accuracy. Enkogrid @ PRO-40 has been used at the reinforced material and sand as the medium. The studies conducted show

1. In centrally loaded surface footing the load carrying capacity is increased to about 3.55 times by providing geogrid as reinforcement. The load carrying capacity the reinforced soil increases with increase in the depth of embedment while these decrease in settlement because of placement of geogrid.

2. The number of layers of geogrid has significant effect on load carrying capacity and settlement of foundations. Decrease in the layer of geogrid decreases the load carrying capacity and increases the settlement of foundation.

Key words- Geogrid, Reinforcement, Model Footing, Foundation, Embedment, Bearing Capacity, Settlement

I.INTRODUCTION

The reinforced soil is the soil in which the metallic, synthetic or geogrids are provided to improve it's engineering behavior. The technique of ground improvement by providing reinforcement was also in practice in olden days. Babylonians built ziggurats more than three thousand years ago using the principle of soil reinforcement. A part of the Great Wall of China is also an example of reinforced soil construction. Dutch & Romans had used soil reinforcing technique to reinforce willow animal hides & dikes. Basic principles underlying reinforced soil construction was not completely investigated till Henery Vidal of France who demonstrated it's wide application & developed the rational design procedure. A further modified version of soil reinforcement was conceived by Lee who suggested a set of design parameters for soil reinforced structures in 1973.

Rising land costs & decreasing availability of areas for urban infill has established that previously undeveloped areas are now being considered for the sitting of new facilities. However these undeveloped areas often possess weak underlying foundation material a situation that presents interesting design challenges for Geo technical engineers. To avoid the high cost of deep foundation modification of the foundation soil or the addition of a structure fill is essential.

Binquet & Lee (1975) investigated the mechanism of using reinforced earth slab to improve the bearing capacity of granular soils. They tested model strip footings on sand foundations reinforced with wide strips cut from household aluminum foil. An analytical method for estimating the increased bearing capacity based on the tests was also presented Fragaszy & Lawton also used aluminum reinforcing strips & model strip foundations to study the effects of density of sand & length of reinforcing strips on bearing capacity.

In this paper, the results of experimental studies on cohesionless soil reinforced with Geogrids have been presented. Tests have been conducted with the provision of Geogrids in four layers at various spacing & the results have been compared with the results of unreinforced condition.

II-EXPERIMENTAL SET UP AND PROCEDURE

2.1 Sample collection

It has been decided to have a study on the effect of geogrid placed horizontally in the soil on the load carrying capacity and settlement behavior of model strip footing placed on the surface as well as at different embedded depths of cohesion less soil. The sand collected from the river bed was made free from roots, organic matters and etc by washing and cleaning. The above sample was oven dried and properly sieved by passing through 1.18 mm IS sieve and retained on 75 micron IS sieve to get the required grading. Dry sand was used as soil medium for the test as it does not include the effect moisture and hence the apparent cohesion associated with it. Due to limitation of the time and scope of the present investigations it is decided to perform the test using dry sand as medium and hence the complexities developed due to the presence of moisture and cohesion has been avoided. Thus the test has been conducted in a simplified condition.

2.2 Characteristics of sand

Dry sand has been sieved passing through 1.18 mm IS sieve and retained on 75 micron IS sieve. The results of sieve analysis of sand used have been presented in table- 1. The characteristic of sand used are as follows:

(i) Specific gravity = G = 2.64

(ii) Maximum Void ratio = e_{max} = 0.92

(iii) Minimum void ratio = e_{min}= 0.67

(IV) Relative density = I_D = 0.72

(v) Dry density = γ_d= 1.51 gm/cm^3

The angle of internal friction at the adopted bulk density was found to be 41° 12'. The result of direct shear test has been presented in the table-2.

Table-1 Grain size analysis

Sl. No.	Sieve size (mm)	Wt. Of sieves (gm.)	Wt. Of sieve & mass retained	Wt. Of mass retained	% Retained	Cumulative % retained	Cumulative % Finer
1.	1.18	407	0	-	-	-	100%
2.	600mic.	407	514 g.	107 g.	21.4	21.4	78.6
3.	300 mic.	342	602 g.	260 g.	52	73.4	26.6
4.	150 mic.	318	435 g.	117 g.	23.4	96.8	3.2
5.	75 mic.	322	336 g.	14 g.	2.8	99.6	0.4
6.	Container	371	373 g.	2 g.	0.4	100	0.0

Table-2 Direct shear test results

Sample prepared with relative density = 0.72
Bulk unit weight = 1.51 gm/ cc

SL. No.	Normal stress in Kg./cm2	Shear stress in Kg. /cm2
1	0.315	0.275
2	0.630	0.550
3	0.945	0.825

2.3 Test tank

A test tank of size 75 cm X 40.5 cm X 61 cm was made in the laboratory for the purpose. The test tank was made of cast iron 6 mm thick. The side of the box was heavily braced to avoid lateral yielding. The following considerations were taken into account while deciding the dimensions of the tank.

(i) As per provision of IS 1888-1962 the width of the test pit should not be less than 5 times the width of the test plate, so that the failure zones are freely developed without any interference from sides.

(ii) Chumar (1972) in his investigation suggested that incase of cohesionless soil the maximum extension of failure zone was 5 B to the sides and 3 B below the footing.

By adopting the above tank size for the model footing (8 cm X 36 cm), it was ensured that the failure zones are fully and freely developed without any interference due to the presence of sides and bottom of the tank.

2.4 Equipments used

2.4.1 Loading beam with platform

A mild steel channel section of size 152 cm .X20 cm. X 10 cm. was used for this purpose. A mild steel plate welded to a vertical shaft passing through a pipe welded to the channel at it's mid span was used to transfer load to the footing.

2.4.2 Model footing

Model footing used for laboratory tests were made of mild steel plate of sizes 8 cm X 36 cm X 2.5 cm and 10 cm X 40 cm X 2 cm. One footing was meant for centroidal loading while reaming three were meant for eccentrical loading, the eccentricity being 0.05B, 0.1 B, 0.15 B respectively. Circular depressions accommodating steel balls were made on the footings at proper points so that the loading pattern i.e. centroidal and eccentrical can be maintained. The load was transmitted from the loading platform to the footings through the steel balls. Such arrangement permitted rotation of the footing about its longitudinal axis.

2.4.3 Dial gauge

Two dial gauges of following specification were used during the test.
Least count-0.0lmm
Range- 50mm
Dial gauges were kept in position using a magnetic base placed suitably on a rigid support. As the load was applied settlement occurred which was recorded by two dial gauges. The average of the two dial gauge readings was taken as the required settlement in mm.

2.5 Sample preparation

First the internal dimensions of the tank were measured accurately and the different layers for filling the sand were marked with the help of a marking pen. After knowing the volume of the tank weight of sand required to fill the tank was computed step wise Air dried and sieved sand as mentioned earlier was taken .It was found that for a layer of 5 cm the weight of sand required was 23 kg. First the sand was applied in eight equal layers, each layer being 5 cm each. Layer was compacted properly by a tamping rod to achieve the required density of 1.51 gm/cm^3.Then a layer of 5 cm was applied and was compacted to achieve the required density. In each layer the top surface of the sand was made smooth by a straight edge and the horizontality was checked by a sprit level. Care was taken so that the top surface of each layer was just with the mark previously made for that layer. For the test without reinforcement footing was placed on the surface and at different embedment of 0.25B, 0.5B, 0.75B and 1.0B respectively.

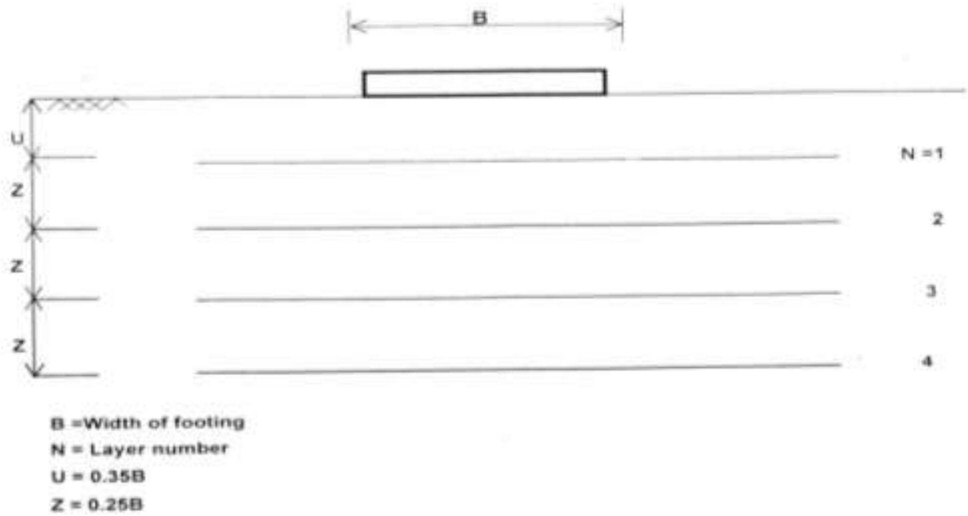

Fig.1 Geometric parameters of Reinforcement

For the test with reinforcement the first geogrid layer was placed at a depth 0.35B from the base of the footing, the other subsequent layer of geogrid being placed at equal spacing of 0.25B as shown in fig.1. After putting the geogrids, small weights were placed on them to keep the geogrids in position and then the required quantity of sand was poured. For each time each layer was compacted properly to achieve the required density. While compacting care was taken not to disturb the geogrid layers. The compaction was done with the help of a tamping rod. Different marks were made at different levels for the compaction of a particular layer. For example for a 5cm layer the mark was made at a height 5cm from bottom. The compaction was done by inserting the rod up to the mark, so that the bottom layers were not disturbed.

2.6 Experimental setup

In some tests after filling the tank with sand and compacting it was transported to the required position with the help of a crane where the load was to be applied. Then the alignment of the tank was fixed by slight longitudinal and lateral movement of the tank to transfer the load centrally. For this purpose the lank was allowed to rest on the rollers. But later on it was realized that in this process the sample might be disturbed and position of the test tank was fixed suitably at the required position so that the load was transmitted centrally.

In case of rigid footing, the footing was fixed in position at the bottom of the vertical shaft by threaded arrangement provided both in the shaft and footing so that the bottom of the shaft and the footing were just in flush with each other. Then the footing with the loading assembly was placed on the top surface of the sand such that the center of the footing was coincided with the center of the tank.

In case of flexible footing circular depression were made both in the footing and vertical shaft. The footing was placed on the top surface of the sand so that its center coincided with the center of the tank. A steel ball was placed on the depression of the footing. Then the loading beam with platform was placed on the top of the tank, so that the vertical shaft rested on the steel ball.

Then two dial gauges were mounted on the loading platform. The dial gauges were so adjusted that the tip of the stem touched the top face of the mild steel plate. As the load was applied and settlement occurred the plate moved downward thus pushing the stem from which settlement was recorded.

Then the load was applied with the help of an electrically operated machine by means of hydraulic jack. The details of the arrangement for load application are shown in fig.2

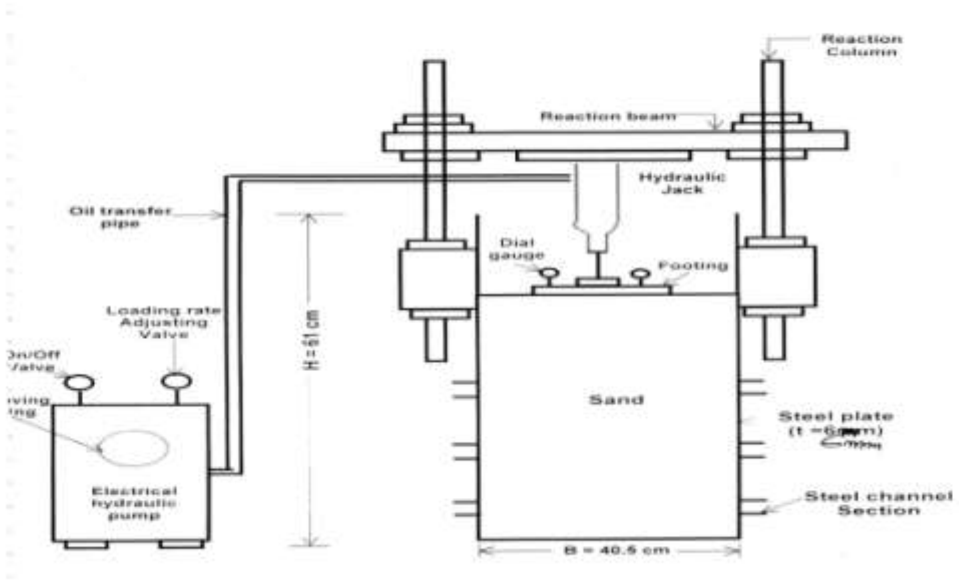

Fig.2 Bearing Capacity test setup

2.7 Experimental procedure

(i) The footing with loading assembly was placed on the top surface of the sand.

(ii) The top of the jack was allowed to move down till it just came in contact with the top of the mild steel plate. Then the weight of the footing with the rod was released by loosening the locking screw which acted as seating load as per IS 1882-1962

(iii) The initial readings of dial gauges were noted.

(iv) The load was then applied and the footing was allowed to settle under the applied load intensity. When the required load intensity was reached settlement observations were taken from the dial gauges.

(v) The next load increment was then applied and the reading of dial gauges were noted

(vi) The process of load application was repeated till the footing failed because of excessive settlement, which was also indicated from proving ring reading.

On completion of the load test, the equipments were removed, the tank was emptied and the tank was again refilled for the next set of load test.

III- RESULT & DISCUSSION

Results obtained from the laboratory test on two types of model footings of size 10cm X 40cm X 2cm and 8cm X 36cm X 2.5cm with sand as medium and two types of geogrid sheet as reinforcement placed horizontally have been presented. The detailed procedure of the load tests conducted on the model footings is highlighted in section 2.7. The load intensity vs. settlement observations have been presented in figures (3 to 25).

3.1 Footing on homogeneous medium

Load test were conducted on surface footing of sizes 10cm X 40cm X 2cm and 8cm X 36cm X 2.5cm with sand as medium without any reinforcement. The peak load at failure has been found from the graphs drawn with load per unit area vs. corresponding settlement of the footings. The peak load at failure of the surface footing as well as embedded footings have been investigated in the both the cases, viz. (a) rotation not permitted (b) rotation permitted.

3.1.1 Rigid footings

It was first decided to conduct the tests throughout the programme without allowing the rotation of the foundation and hence, rigid footing was taken into consideration. Some test have been conducted using rigid footings, but while attempting to do the test on eccentrically loaded foundations, the experimental setup did not allow and experiment was held up. Hence for the rotation of the footing was permitted subsequently for smooth running of the experiment. The load settlement curve for the above case of rigid footing has been shown in fig. (3 to **7)** and the peak load at failure of rigid footing placed on the surface of unreinforced sand bed is found from fig. (3 to 7).

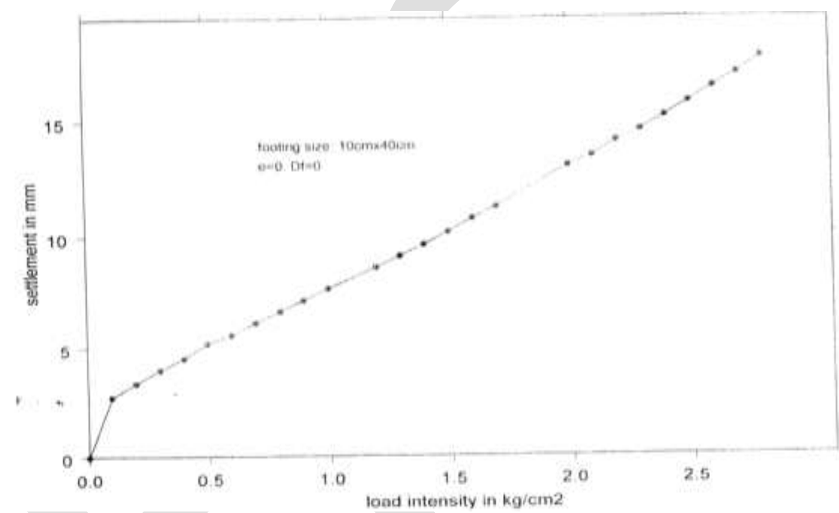

Fig.3 Load settlement curve of (10cm x40cm) strip centrally loaded footing in homogeneous sand bed

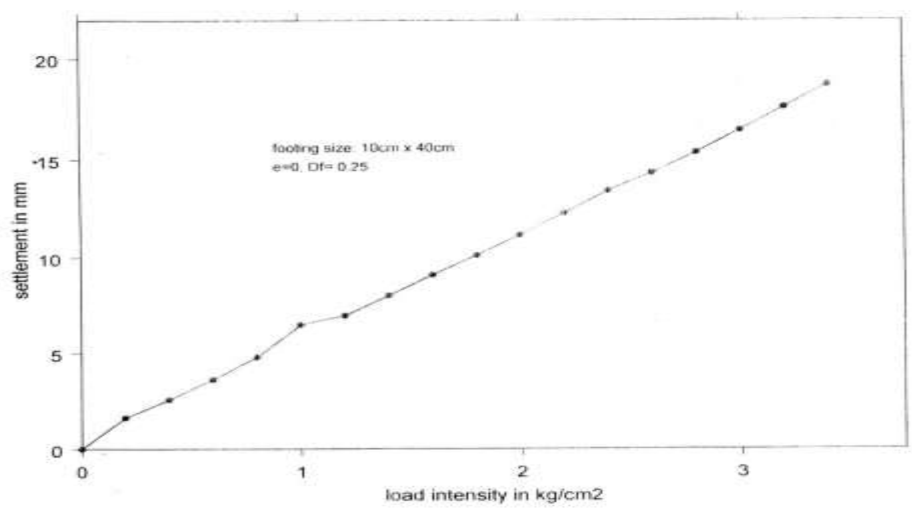

Fig.4 Load settlement curve for centrally loaded foundation (10cm x40cm) with depth of footing at 0.25B from base of footing

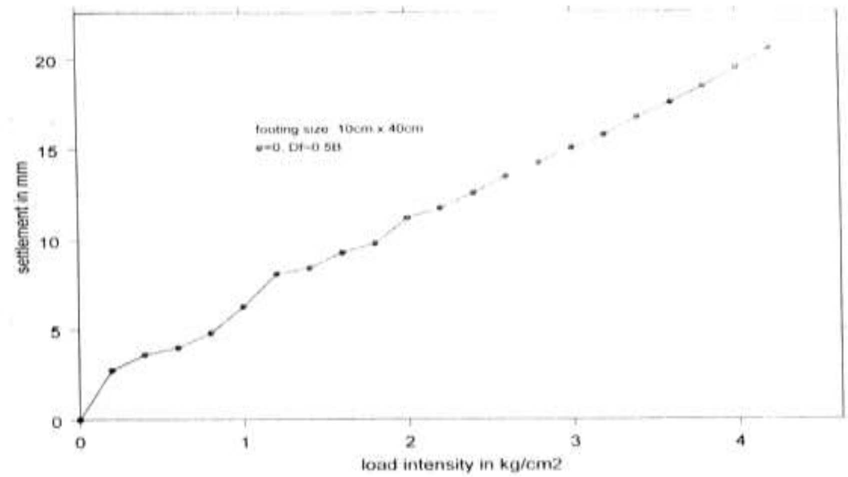

Fig.5 Load settlement curve for (10cm x40cm) centrally loaded footing placed at 0.5B depth

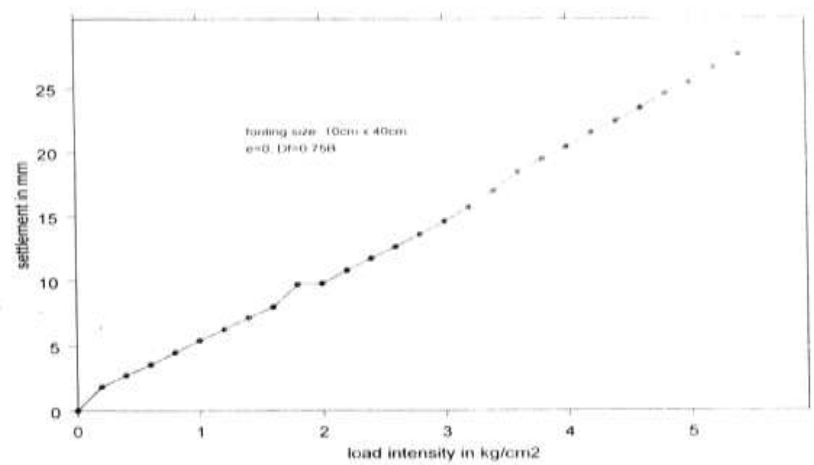

Fig.6 Load settlement curve for centrally loaded foundation (10cm x40cm) placed at 0.75B depth in homogeneous sand bed

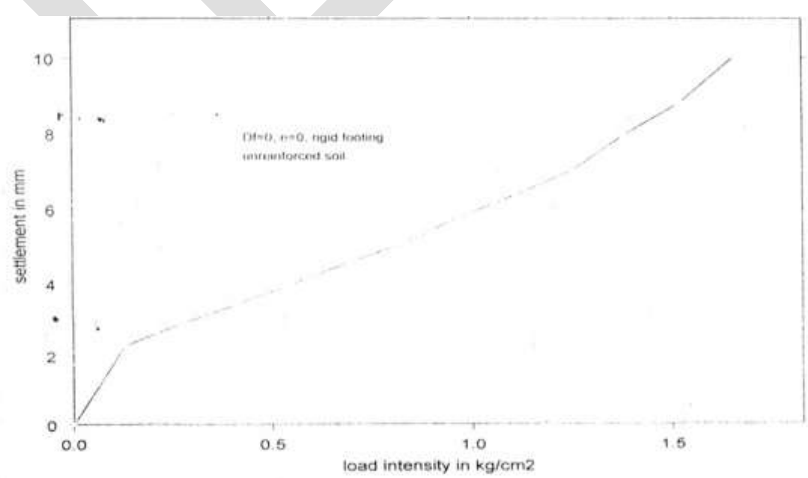

Fig.7 Load settlement curve for centrally loaded rigid surface footing in homogeneous soil

3.1.2 Flexible footings (Rotation permitted)

A number of test have been conducted to study the ultimate bearing capacity and the corresponding settlement of the foundation which are subsequently being used as a reference to analyze in case of reinforced condition. The tests on unreinforced have been conducted for the surface footing as well as for the footings placed at different depths viz. 0.25B, 0.5B, 0.75B, 1.0B. The peak load at failure of the flexible surface footing is found from fig. 8.

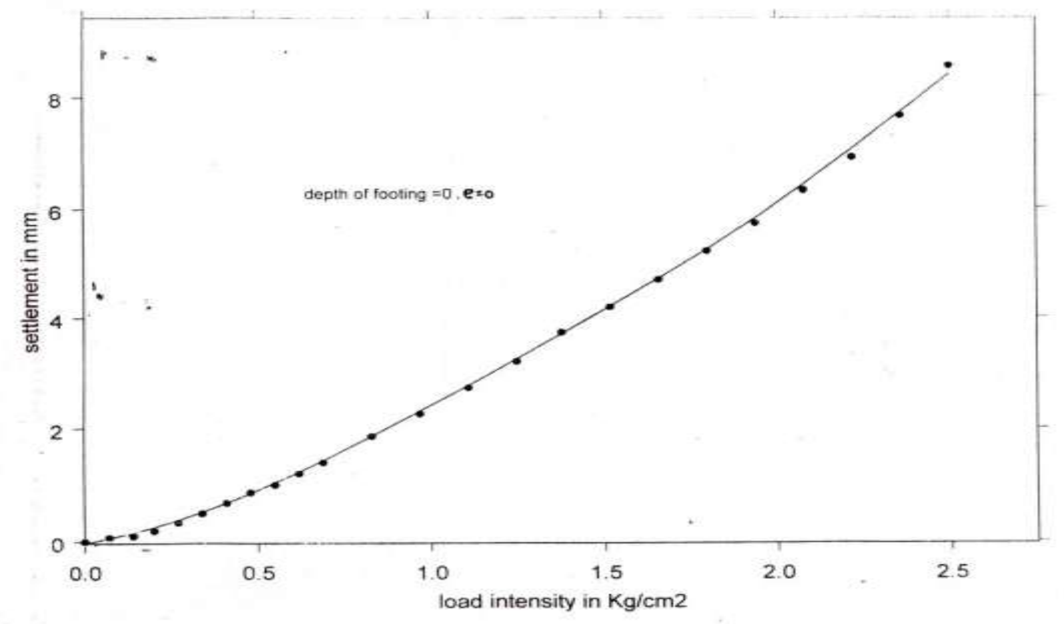

Fig.8 Load settlement curve for (8cm x36cm) strip surface foundations in reinforced soil

The graph showing the plot of load per unit area vs. settlement in all these cases (surface footing as well as embedded footings) has been shown in the fig.9

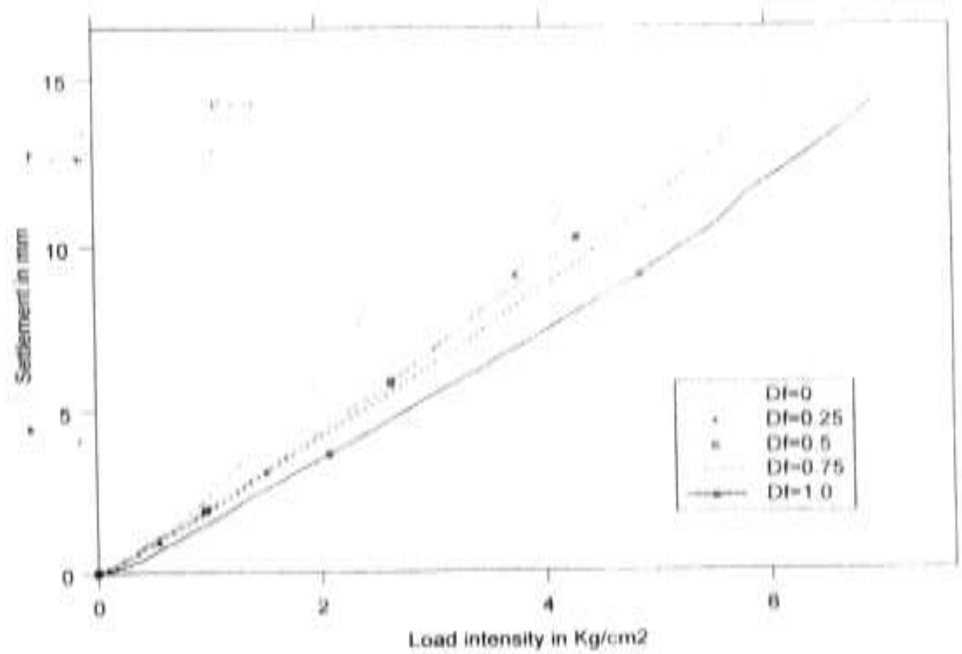

Fig.9 Plot of load per unit area vs. settlement of centrally loaded footing in unreinforced sand showing the effect of depth of embedment

3.2 Effect of embedment on peak load

The peak load at failure of strip footing placed at different depths has been found out from the graph (fig.3 to 7 and fig.10 to 14)

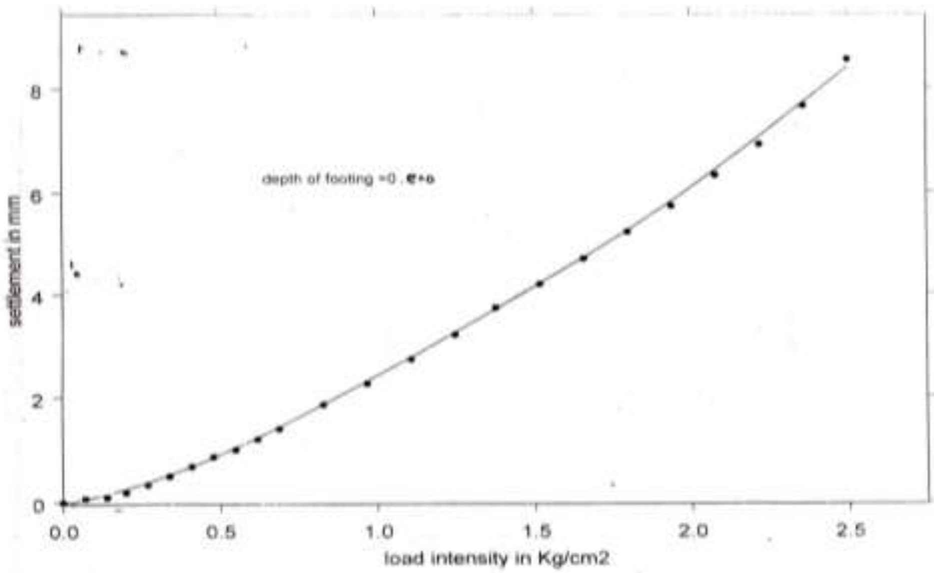

Fig.10 Load settlement curve for (8cm x36cm) strip surface foundations in unreinforced soil

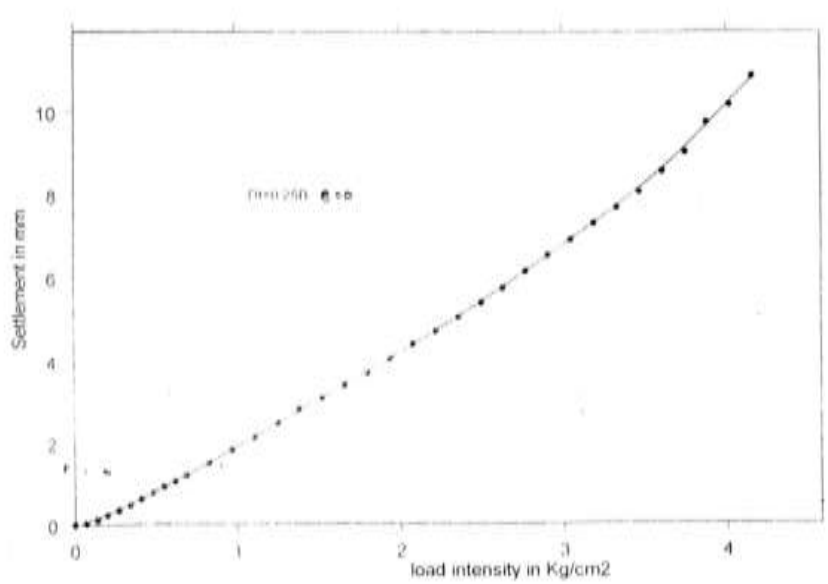

Fig.11 Load settlement curve for (8cm x36cm) strip embedded foundations in unreinforced soil

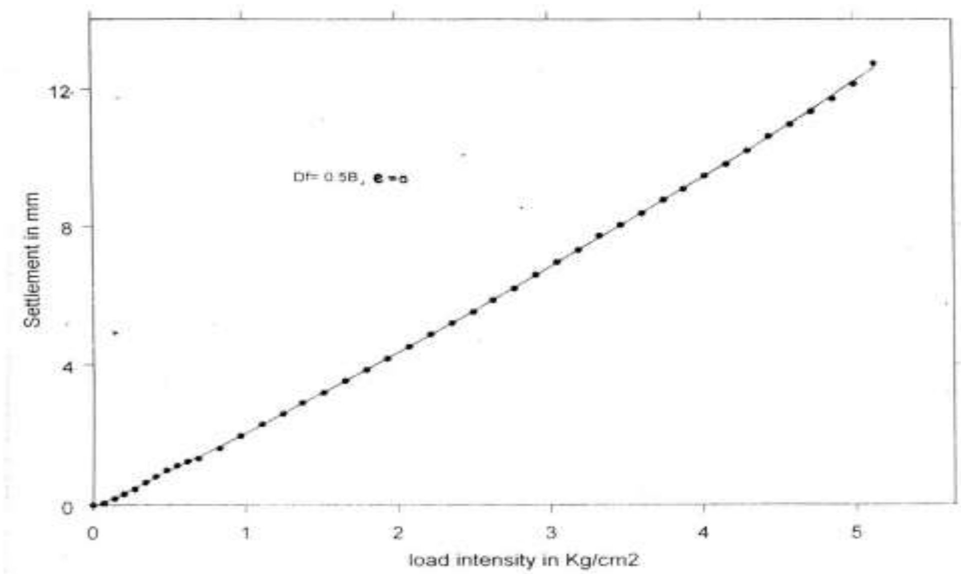

Fig.12 Load settlement curve for (8cm x36cm) strip embedded foundations in unreinforced soil

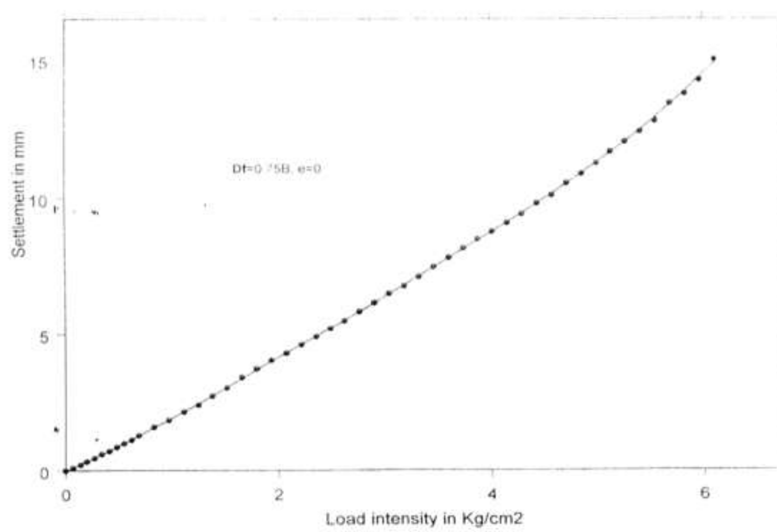

Fig.13 Load settlement curve for (8cm x36cm) strip embedded foundations in unreinforced soil

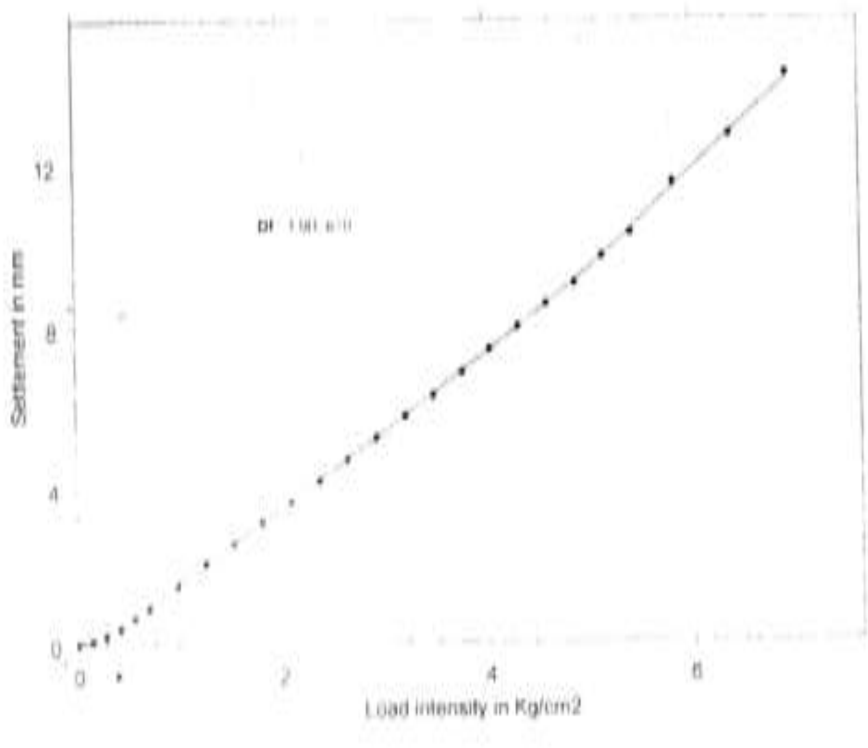

Fig.14 Load settlement curve for (8cm x36cm) strip embedded foundations in unreinforced soil

The ratio of peak load at different embedment to the peak loads at surface footings have been computed and shown in the graph (Fig.9 and Fig.15).

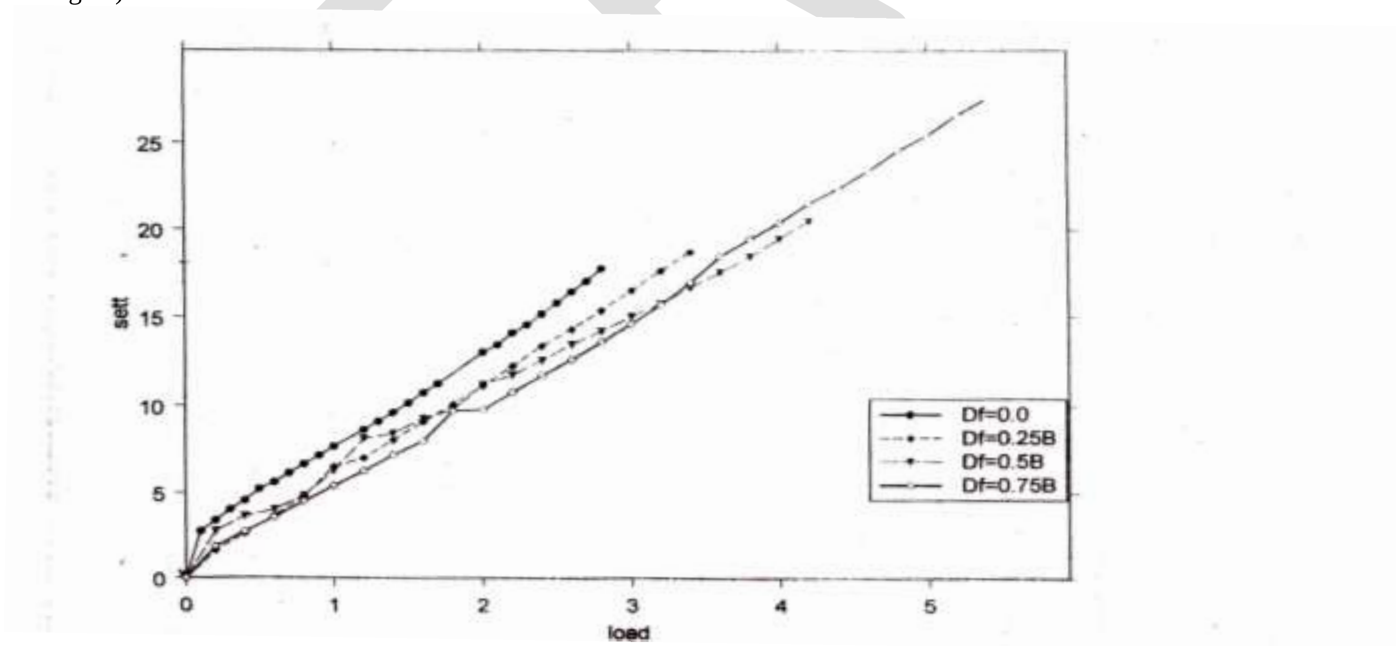

Fig.15Plot of load per unit area vs. Settlement of centrally loaded footing (10cm x40cm)

It is seen the peak load at failure the increases with increase in the depth of embedment, conforming to the reports made by other investigators, in the past.
From the graph it is seen that the peak load at failure of the failure load increase with the depth of embedment.

3.3 Footing on reinforced soil

Load tests have been conducted on the model strip footing of sizes 10cm X 40 cm X 2cm and 8cm X 36cm X 2.5cm with sand as medium and geogrid of the type Enkagrid - @ Pro - 40 and Enkagrid - @ Pro- 80 as reinforcements. Geogrids have been placed in four layers, the top most layers being placed at 0.35B from the base of the footing and other subsequent layers being placed at equal spacing of 0.25B. The load intensity and settlement observation have been presented in fig. (8 to 12) & (16 to 22). To see the effect of providing the geogrids below the foundation for improving the load carrying capacity of soil tests have been conducted on sand reinforced with geogrids. Centrally loaded footings have been considered, placing the footing at different depths (Df = 0, 0.25B, 0.5B, 0.75B, I.0B).

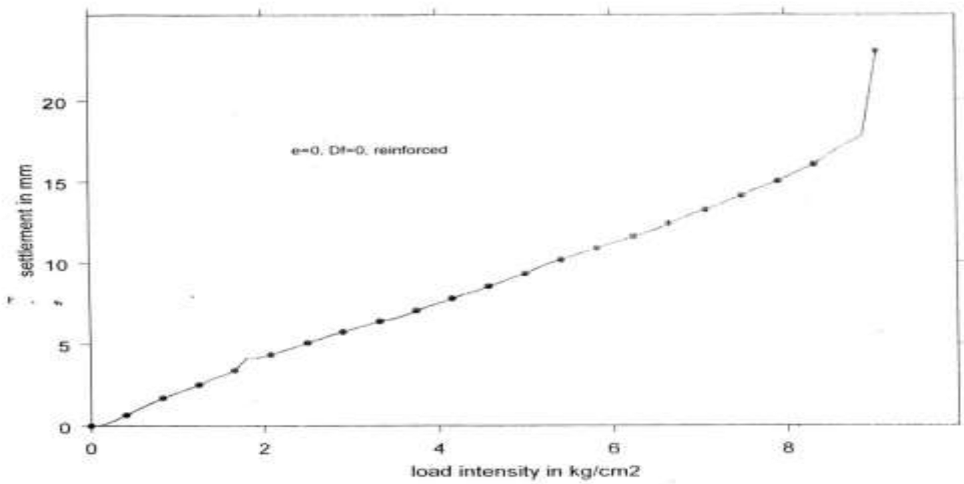

Fig.16 Load settlement curve for (8cm x36cm) centrally loaded surface foundations in reinforced sand

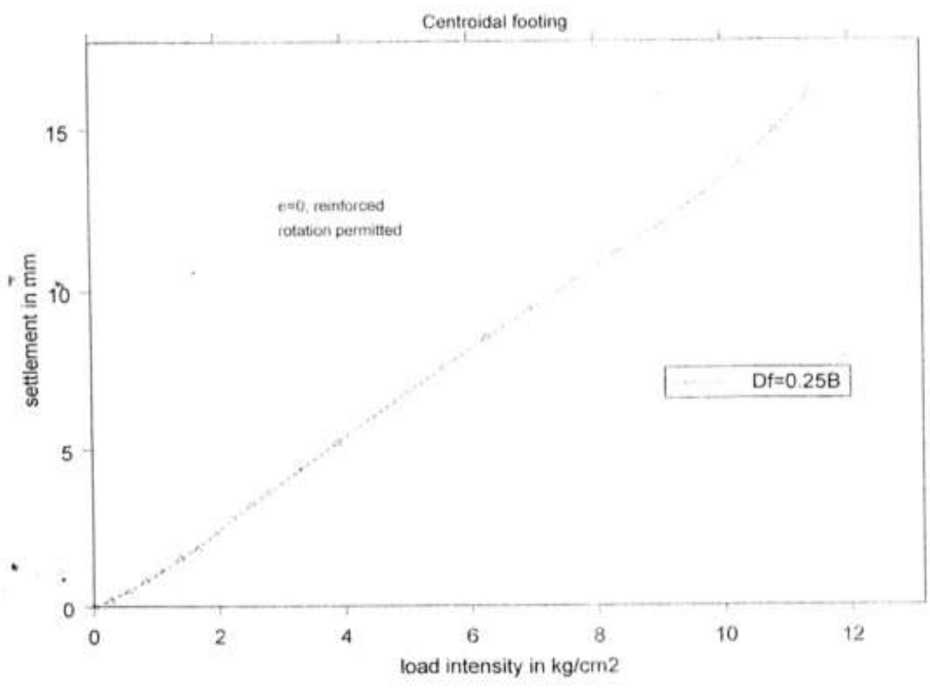

Fig.17 Load settlement curve for centrally loaded footing in reinforced soil placed at 0.25B below base of footing (rotation permitted)

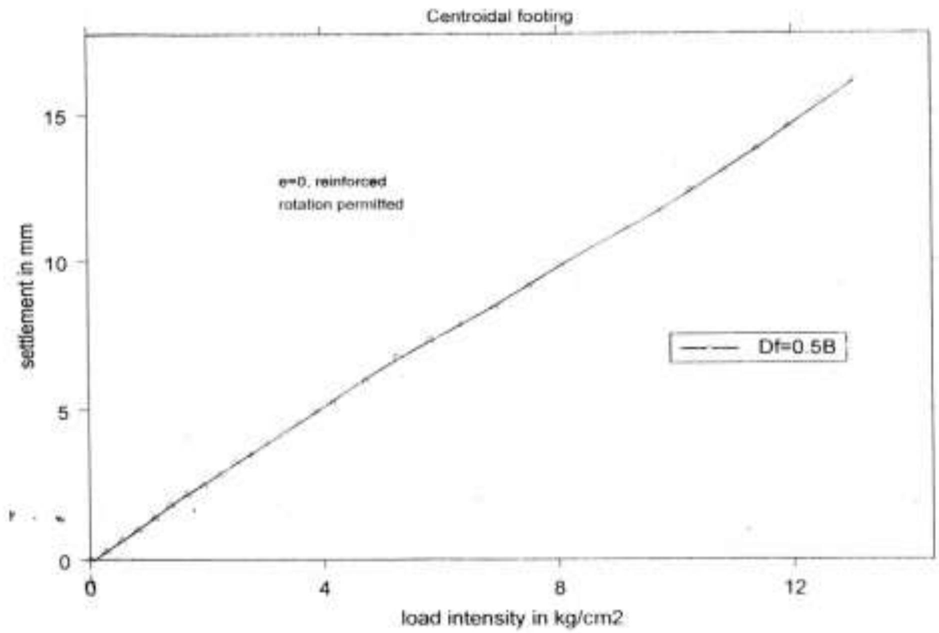

Fig.18 Load settlement curve of centrally loaded footing in reinforced soil placed at 0.5B below base of footing (rotation permitted)

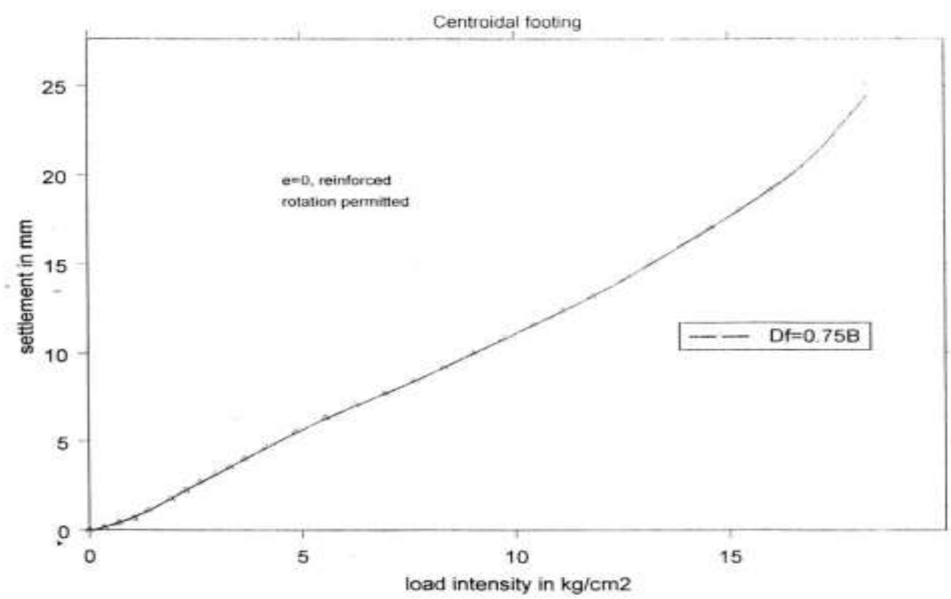

Fig.19 Load settlement curve of centrally loaded footing in reinforced soil placed at 0.75B below base of footing (rotation permitted)

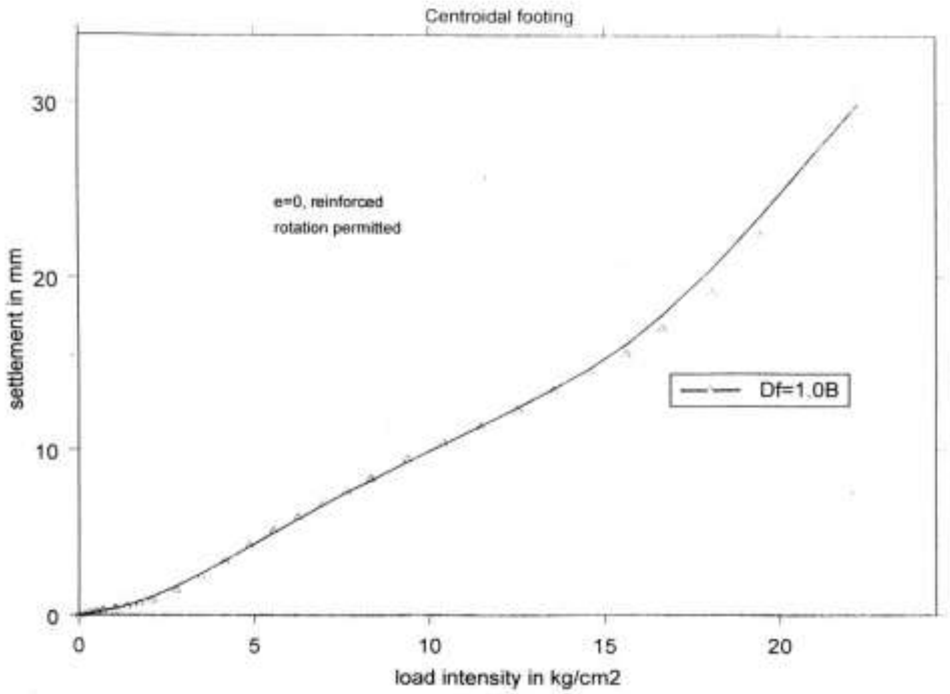

Fig.20 Load settlement curve of centrally loaded footing in reinforced soil placed at 1.0B below base of footing (rotation permitted)

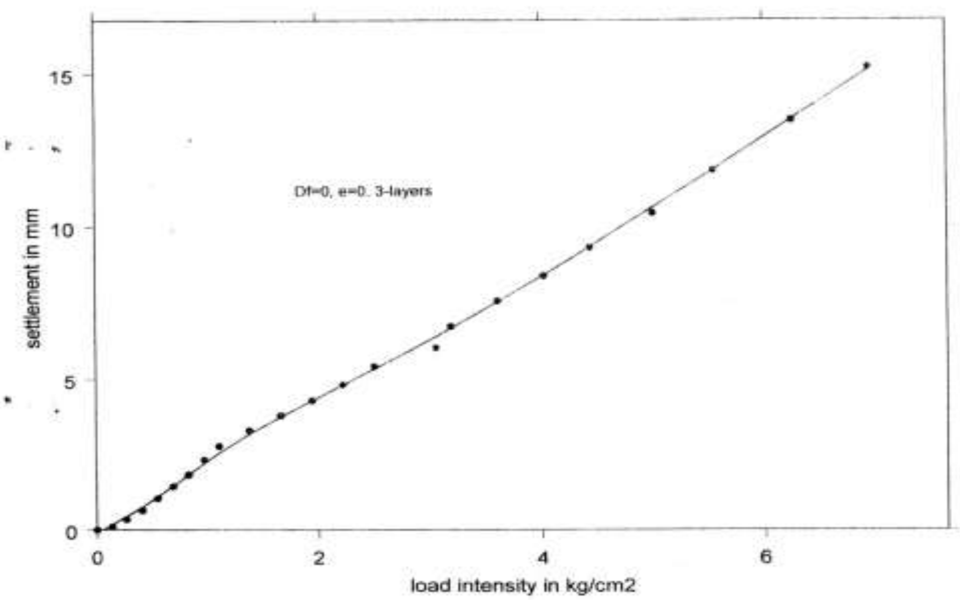

Fig. 21 Load settlement curve of centrally loaded surface footing with three layers of geogrids

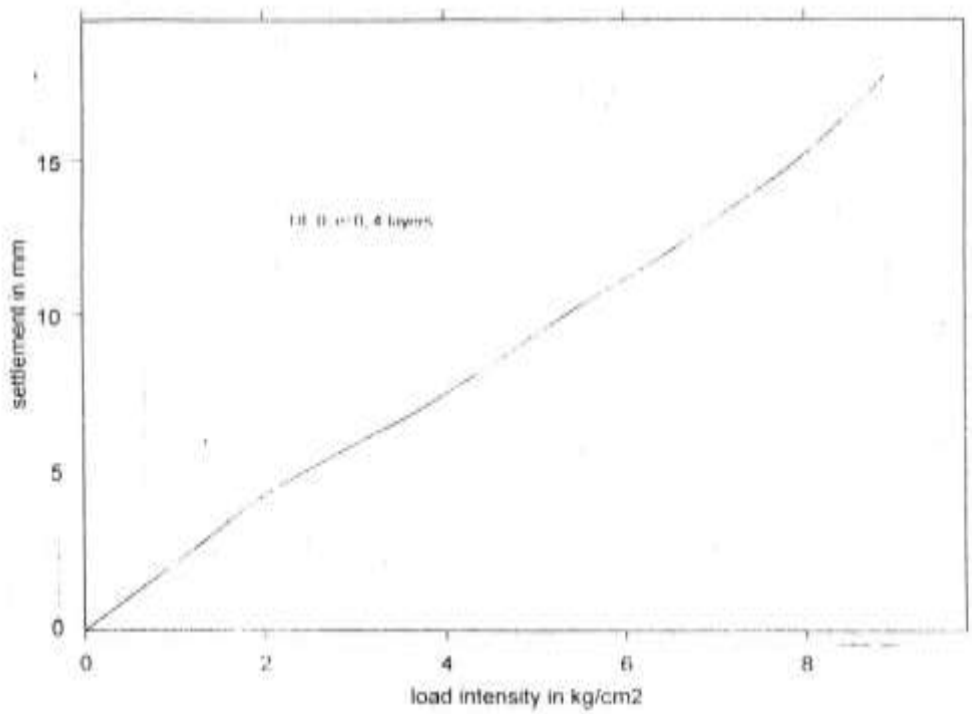

Fig. 22 Load settlement curve of centrally loaded surface footing with four layers of geogrids

Geogrid of variety Enkagrid -@ Pro - 40 and has been used, considering the footing to be rigid while type Enkagrid - fo) Pro – 80 has been used for flexible footing. The purpose was to see the effect of different type of geogrid as well as to test the footings by allowing rotations, such that the flexible footing can be utilized for eccentric load application. Because of the lack of resource of geogrid and time in conducting the tests, limited number of test have been conducted.

3.3.1 Rigid footing (reinforced soil)

Load tests have been carried out on centrally loaded strip footing of size 8cm X 36cm X 2.5cm and with geogrid variety Enkagrid @ Pro-40 to see the effect of embedment on reinforced soil. The load settlement curves have been in shown in fig. (23 to 27)

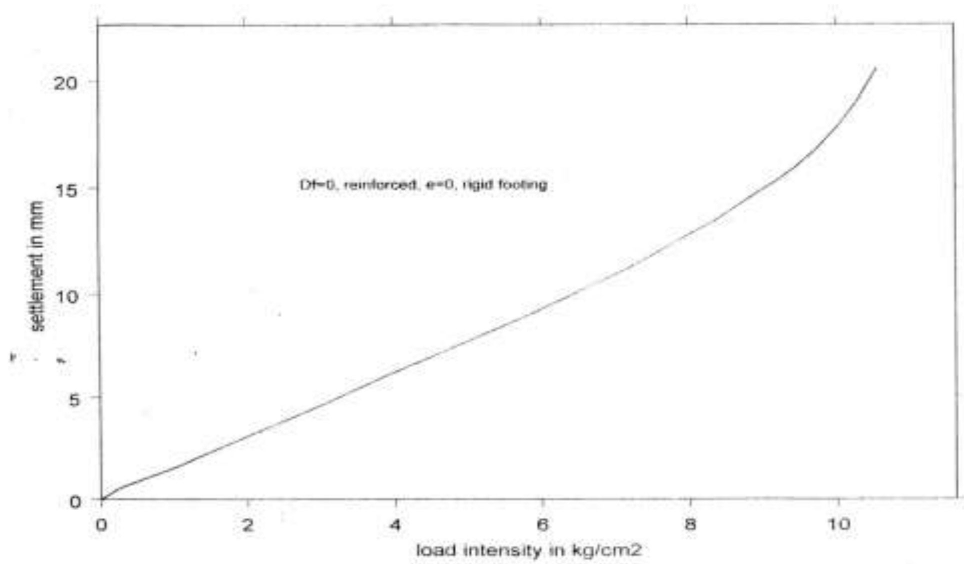

Fig.23 Load settlement curve for centrally loaded rigid surface footing in reinforced soil

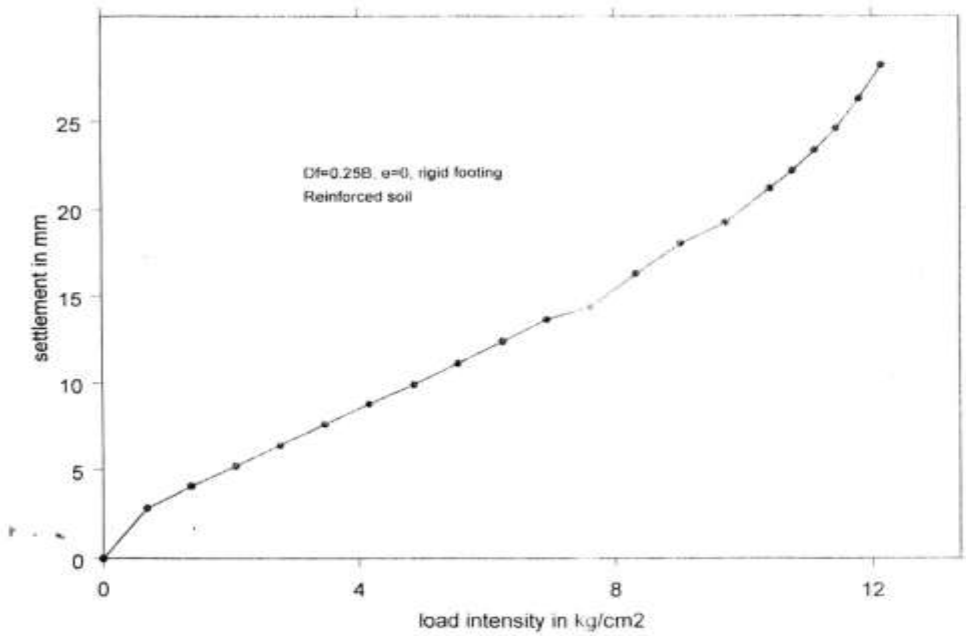

Fig.24 Load settlement curve for concentrally loaded rigid foundation in reinforced sand

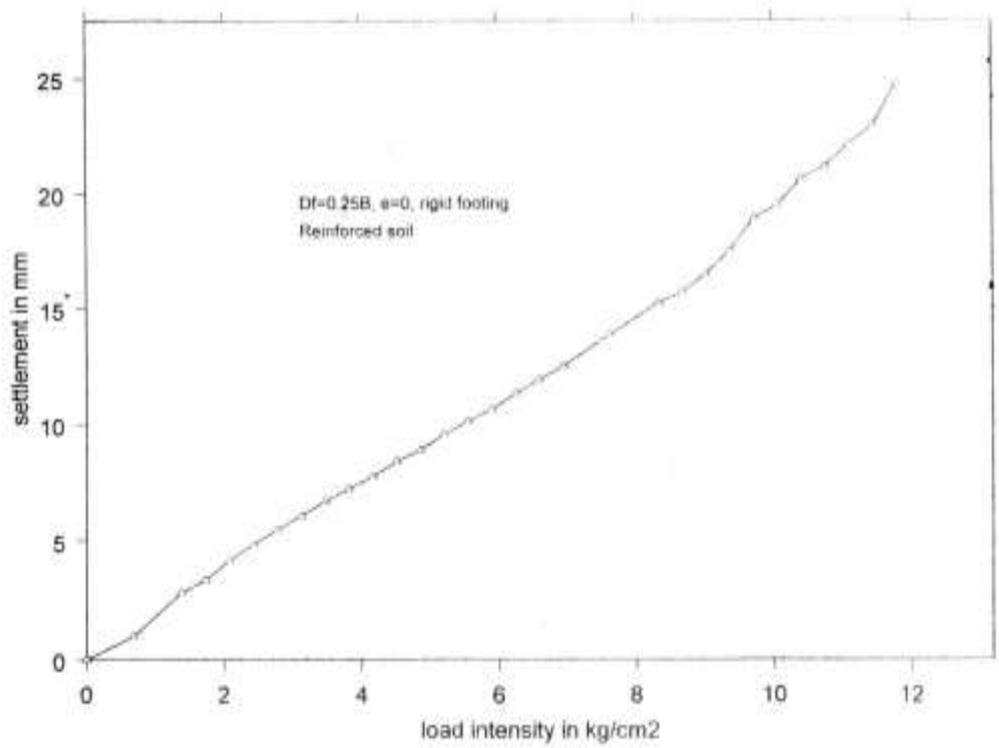

Fig.25 Load settlement curve of concentrated rigid footing in reinforced sand at depth of 0.5B

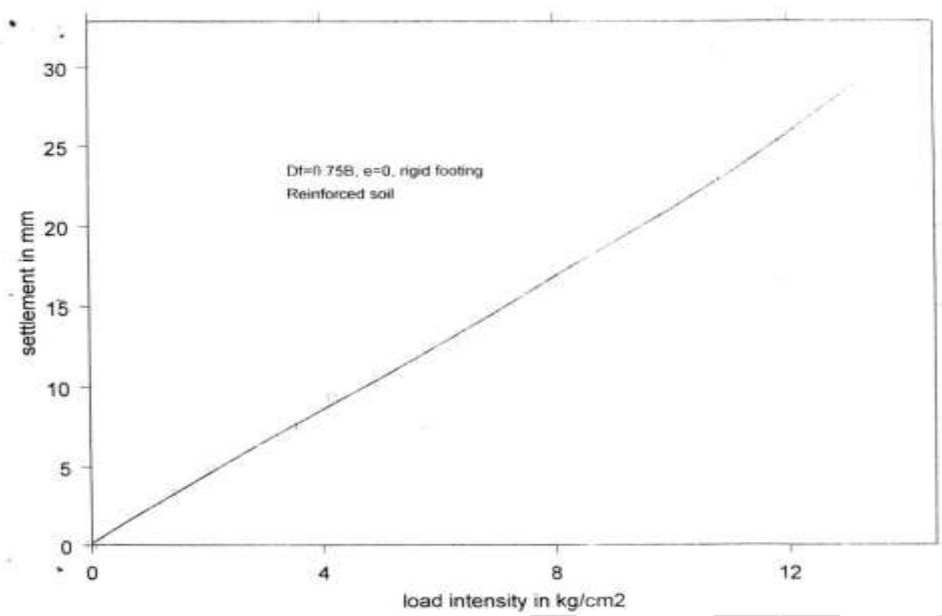

Fig.26 Load settlement curve for centrally loaded rigid footing in reinforced soil at depth of 0.75B

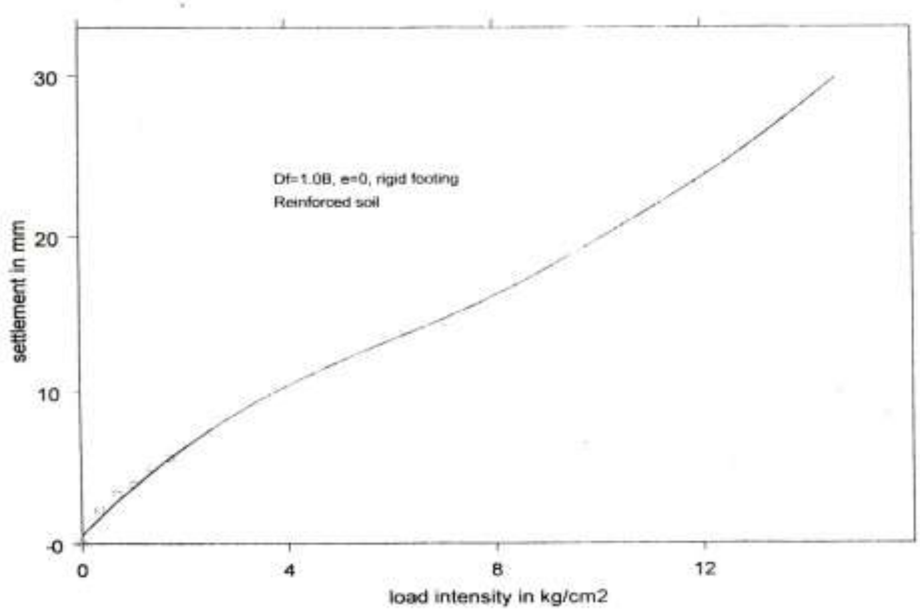

Fig.27 Load settlement curve of concentrated rigid footing on reinforced soil at depth of 1B

The combined load per unit area vs. settlement of the foundation showing the effect of embedment has been shown in fig.28**.**The figure shows that with increase in depth of embedment, the peak load at failure is increased. The effect of providing reinforcement on the centrally loaded surface footing is shown in fig.29 .From the fig. it is seen that by the provision of four layer of geogrid below the model strip footing under consideration increases the peak load by 15% ,18%, 25%, 38% respectively for D_f =0.25B, D_f =0.5B, D_f =0.75B, D_f =1.0B.

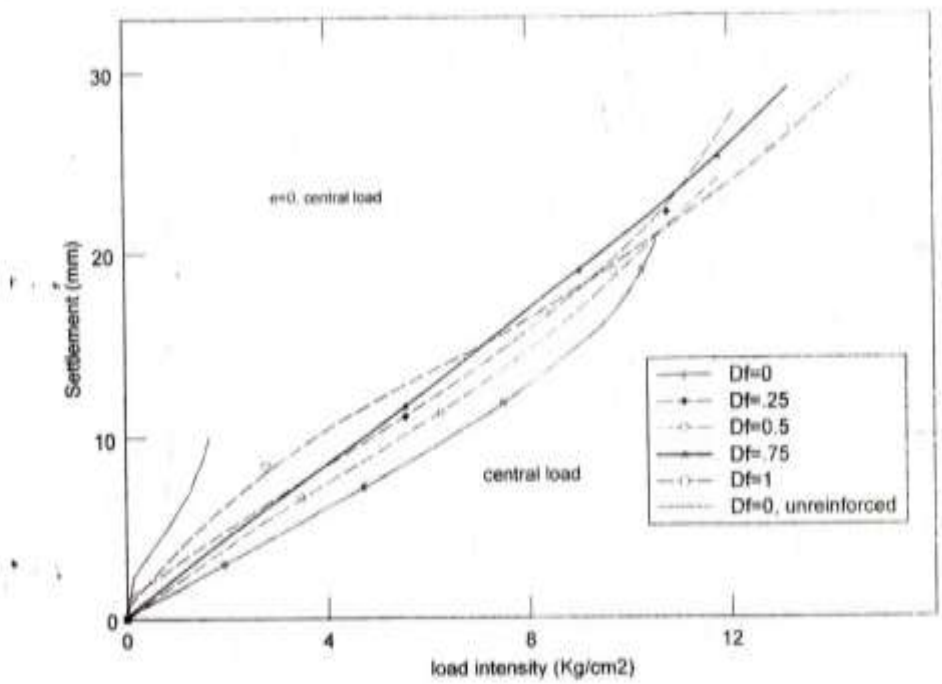

Fig.28 Plot of load per unit area vs. Settlement of centrally loaded foundation showing the effect of depth of foundation in reinforced soil and comparison to unreinforced one

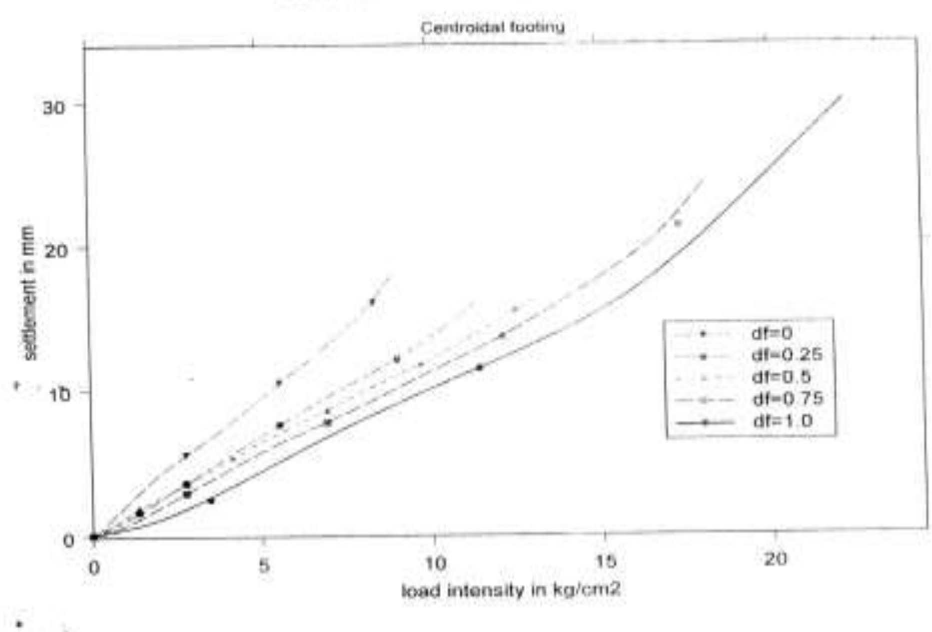

Fig.29 Plot of load per unit area vs. Settlement of centrally loaded strip footing (8cm x36cm) showing the effect of embedment

3.3.2 Flexible footing

Load test have been conducted on centrally loaded strip footing of size 8cm X 36cm X 2.5cm has been considered for the load test using Enkogrid @ PRO- 80 to see the effect of embedment on reinforced soil. The load settlement observation curves have been shown in fig. (16 to 22)

The combined curve of load per unit area vs. settlement of the foundation on the effect of embedment has been shown in fig.29.From the figure it is clear the peak load at failure increases with increase in the depth of embedment. This fig shows the effect of providing reinforcement on the centrally loaded footing. The percentage increase in peak load at different depth of embedment by the provision of four layer of geogrid as seen from the figure are 31%, 46%, 105%, 150% respectably for D_f=0.25 B, D_f=0.5 B, D_f=0.75B, D_f=1.0 B.

The effect of number of geogrid layers on centrally loaded surface footings has also been investigated. The combined graph showing the variation of the load intensity vs. settlement is presented in fig.30 .From the graph it has been observe that with decrease in number of layers, the peak load at failure also decreases. Form the investigations it has been found that the optimum number of layers is four which has been adopted in the present investigation.

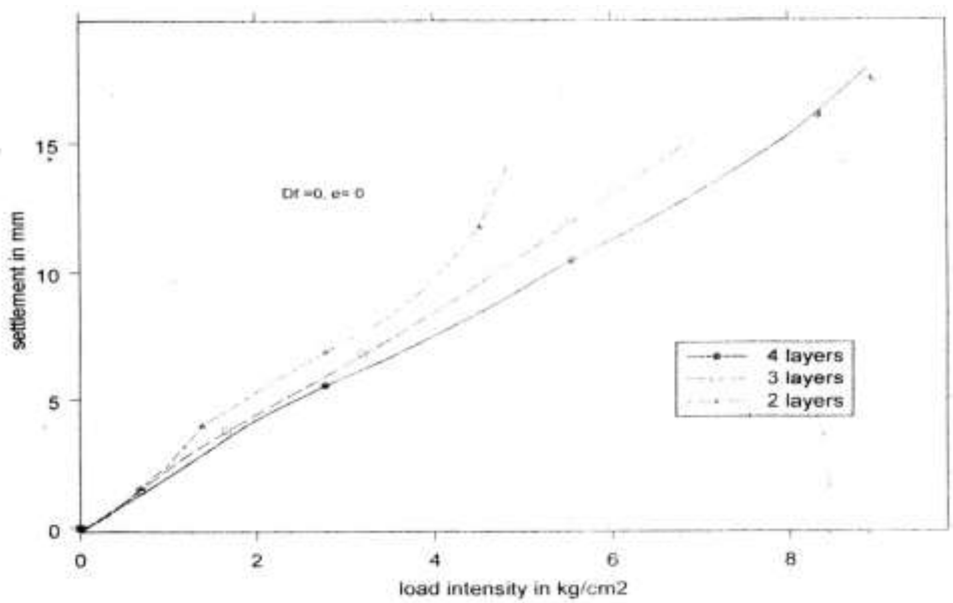

Fig.30 Plot of load per unit area vs. Settlement of centrally loaded surface foundation on reinforced sand bed showing the effect of number of geogrid layers

IV-CONCLUSION

The following conclusion are drawn from the tests conducted in the present study, based on the result and discussions presented in the provision section with regard to embedded foundations on sand reinforced with geogrids and also the effect of numbers of layers of geogrid.

Foundation on homogeneous sand in centrally loaded foundation on homogeneous sand bed, as the depth of the foundation is increased; the peak load at failure is increased.

Foundation on reinforced sand In centrally loaded foundations the load carrying capacity increases with increase in the depth of foundation in surface footing providing geogrids in "four layers increases the load carrying capacity to 3.55 times where as providing there layers of geogrids above value reduces to 2.28 and for two layers the above value reduces to 1.82.The less number of geogrid layers decrease the load carrying capacity.

Provision of geogrid in strip foundations increases the load carrying capacity but decreases the settlement of the foundation.

V-SCOPE FOR FURTHER STUDIES

Keeping in view the limitations of time, available laboratory facilities and its scope of present investigation, only a part of the problem with experimentally investigated. It is necessary to investigate the peak load at failure and the corresponding settlement in cohesive soil with geogrids as reinforcement. The load carrying capacity and the settlement behavior of centroidal footings observed during experiment need theoretical analysis.

Comprehensive investigation, both experimental and theoretical, of the problem with geogrid as reinforcement is desirable.

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