Load Settlement Behaviour of Circular Plate in Sandy Soil Mixed with Fine Gravels and its Numerical Modelling in Abaqus 6.10

A thesis submitted in the partial fulfilment of the requirements for the award of the degree of

Master of Technology
In
Geotechnical Engineering

By

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(2K15/GTE/13)

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CANDIDATE'S DECLARATION

I do hereby declare that the work presented in this thesis entitled "**Load settlement behaviour of circular plate in sandy soil mixed with fine gravels and its numerical modelling in Abaqus6.10."** in the partial fulfilment of the requirement for the award of the degree "Master of Technology" in Geotechnical Engineering submitted in the Department of Civil Engineering, Delhi technological University, is an authentic record of my own work carried under the supervision of Prof. A.K Sahu. I have not submitted the matter of this thesis for the award of any other degree.

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CERTIFICATE

This is to certify that the thesis entitled "**<u>Load settlement behaviour of circular plate in sandy soil mixed with fine gravels and its numerical modelling in Abaqus6.10 .</u>**" submitted by Priyanka Jain to the Delhi Technological University, Delhi for the award of degree of Master of Technology in Geotechnical Engineering is a bonafide work carried by her under my supervision. The contents of this thesis, in full or part, have not been submitted to any other institute for the award of any degree.

Date :

Signature

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ABSTRACT

This project work evaluates the load settlement response to investigate the influence of density of coarse sand and addition of gravel in sand. For this, modeled plate load test has been conducted on small and large scale setup. In this work to conduct small scale modeled plate load test a mild steel box of 0.4m X 0.7m X 0.5m and plates of 100 mm, 150 mm and 200mm diameter have been used .The influence of density of sand can be investigated by performing plate load test at various densities i.e. 17.8, 19.28, 21.24 and 25 KN/m^3 respectively and effect of fine gravels by adding 8%, 16% and 24% respectively. Large scale model testing has also been conducted on a box of 1.5m X 1.5m X0.8m and plate load test results of large scale and small scale are compared. The experimental results are also compared with numerical simulation done in Abaqus 6.10.

The outcomes of experimental investigation shows that as the soil get densified, the settlement of modeled footing goes on decreasing and the bearing capability of sand can be improved by adding fine gravels. From the outcomes it can also be stated that with increment in plate size the settlement under footing also increases. From the comparison of experimental results with elastic analysis in software it has been found that the settlement at a particular load is more in case of elastic one than that in experimental results that may be the case of elasto- plastic / plastic behavior.

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CONTENTS

List of Abbreviations

Symbol	Title
KN	Kilo Newton
Mm	Millimetre
M	Meters
Kg	Kilogram
Ø	Angle of internal friction
C	Cohesion
C_u	Coefficient of uniformity
C_c	Coefficient of curvature
D_{60}	Diameter corresponding to 60% finer in the particle size distribution
D_{10}	Diameter corresponding to 10% finer in the particle size distribution
D_{30}	Diameter corresponding to 30% finer in the particle size distribution

List of Figures

List of Table

CHAPTER 1

INTRODUCTION

1.1 Introduction

Foundation is the substructure part of any kind of structure which lies below the ground level. Heavy loads of the superstructure are transferred to the foundation first and then foundation distributes it to the underlying soil. So, the foundation should have the ability to withstand the load of building, bridge etc. If the foundation gets settled then the safety of whole structure will be in danger. So, the safety of buildings mostly depends on the strength of foundation and strength of foundation depends on the bearing capacity of soil. So, Soil has a very important role in a structure; load of the whole structure is ultimately supported by soil. Therefore, it is necessary to have the knowledge of the various physical and engineering properties of soil where the structure is going to be constructed. The design of foundation should fulfil three main design criteria, which are strength means the foundation should be strong enough to sustain loads; the total and differential settlements means the settlement of foundation should be in permissible limits recommended by IS codes; and it should also be economical.

To check whether the soil that is present at the construction site is suitable as a bearing material or not, bearing capability of soil is determined. Bearing ability of any soil can be determined by plate load test as stated by IS: 1888-1982.

The fine gravels or pebbles of large mean diameter exist in the soil in the upper area of Himalayan Rivers. The diameter of particles present in the soil decreases as the river courses in the plain region. This occurs due to mechanical enduring of the soil. In the upper reach of the Himalayan river basin, the bearing capacity of the soil may differ due to deviation of particle sizes.

Therefore this present work focuses on to check the influence of presence of fine gravels in sand and density of sand on the load settlement curves of soil, also performed the plate load test in large scale model and also compared the experimental results with numerical simulation.

To evaluate the influence of presence of gravels of 20 mm in sand, the sand was mixed with different proportion of gravels and plate load test was conducted using 100 mm, 150 mm and 200 mm model circular footing.

To evaluate the variation in load settlement characteristics of sand due to change in density of sand, test box was filled in three layers and 50, 100 and 150 number of blows were applied on each layer using rammer of 2.5Kg and then plate load test was conducted using model circular footing.

1.2 Scope of this Project

This project work aims to compute the effect of different parameters on load settlement response of modelled circular shaped footing resting on coarse-sand. The different parameters whose influence was investigated are as follows.

The Scope of this work is-

1. To manufacture the M.S box and M.S plates of specified size as follows. M.S Box is of 40 cmX70cmX50cm and M.S plates are of 100 mm, 150 mm and 200 mm diameter plates.
2. To determine the geotechnical properties of coarse sand like shear parameters, grain size distribution, compaction characteristics etc.
3. To determine the load settlement response of circular plate of different size at different density of soil and interpret the variation in results of plate load test for different density of soil.
4. To examine the load settlement response of each circular plate placed on coarse sand mixed with different percentages of fine gravels (8 %, 16 % and 24%).
5. To repeat the load settlement test for different plate sizes.
6. To perform the tests on large scale model and compare the results with small scale.
7. To perform numerical modelling using Abaqus software.
8. To conclude the results.

1.3 Thesis Overview

The major focus of this thesis is to find the influence of varying size of modelled footing on load-settlement response. And to find the influence of fine gravels and densification on strength of sand.

A brief review of the researches that had already been conducted into the bearing capacity and load settlement characteristics of footings resting on reinforced and unreinforced sand will be presented in Chapter 2.

Chapter 3 provides the background of materials and equipment that were used. The properties of the material and model used will be discussed in this chapter. Methods of the experiments performed will also be discussed in this chapter.

Chapter 4 deliberated about the numerical simulation done in Abaqus software for plate load test under various conditions on coarse sand.

Chapter 5 includes the results obtained from experimental investigation. A wide variety of cases and problems which are separated according to plate size, shape and percentage of fine gravels are examined and results will be deliberated. The outcomes of plate load test for different conditions will be compared in this chapter. Geotechnical properties of sand used are also discussed in this chapter.

The conclusion of this research are presented along with future recommendation is discussed in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

In this chapter recent work done by the different researchers on this issue has been reviewed and presented here. The literature that has surveyed is related to find the effect of reinforcement on the bearing capacity and settlement of soil. Some of the researches are as follows.

- **Consoli et al (2000)-** In this paper they addressed the problem of interpreting the results of loading test in a homogenous soil. They used circular steel plates of 0.30m to 0.60m. They also determine the effects of footing size and shape on the settlement and the bearing capacity of vertically loaded shallow foundations resting on uniform layers of lightly cemented residual soil with basalt. From tests results they conclude that for a homogeneous soil, the effect of size of the loaded area on the measured settlement and bearing capacity was negligible. For the initial stages of loading the circular and the square footings exhibits similar behavior, but for larger strains near the ultimate bearing capacity, small differences were observed.

- **Consoli et al. (2001)** They conducted plate load tests on soil layers compacted with lime and fly ash; in addition to an increase in bearing capacity and reduction in settlement, results were compared with existing theoretical relationships in order to achieve the ultimate bearing capacity of foundations on layered soils, such as Vesic, Meyerhof- Hanna and Thome relationships, and concluded that Vesic and Thome relationships better predicted ultimate bearing capacity of layered systems on a residual soil deposit for $H/D \leq 1$ (H and D stand for stabilized layer thickness and foundation diameter respectively).

- **Alawaji (2001) -** In his study he evaluate the benefits of geo-grid-reinforced sand over collapsible soil to control collapse settlement. He used a circular plate of 100mm diameter and Tensor SS2 geogrids to perform Model Plate load test. The width and depth of the geo-grid were varied to determine their effects on the collapse settlement, deformation modulus and bearing capacity ratios. From the tests results obtained it was found that the efficiency of the sand–geogrid system increased with increasing geo-grid width and decreasing geogrid depth. He also concluded that there is increment in the bearing capacity and decrement in the settlement of sand bed that is over the weak and collapsible soil.

- **Dash et al. (2003)** – In this study they find out the effectiveness of geocell reinforcement placed in the granular fill overlying soft clay beds small-scale model tests in the laboratory. The test beds were subjected to monotonic loading by a rigid circular footing. Footing load, footing settlement and deformations on the fill surface were measured during the tests. They also study the influence of width and height of geocell mattress as well as that of a planar geogrid layer at the base of the geocell mattress on the overall performance of the system has been systematically studied through a series of tests. The test results indicate that with the provision of geocell reinforcement in the overlying sand layer, a substantial performance improvement can be obtained in terms of increase in the load carrying capacity and reduction in surface heaving of the foundation bed. An additional layer of geogrid placed at the base of the geocell mattress further enhances the load carrying capacity and stiffness of the foundation bed. Based on the findings from the present investigation the following conclusions can be made on the behaviour of circular footings resting on geocell reinforced sand beds underlain by soft clay. Provision of geocell reinforcement in the overlying sand layer improves the load carrying capacity and reduces the surface heaving of the foundation bed substantially. The performance improvement increases with increase in the width of the geocell layer up to b=D of 5 beyond which it is negligible. Good improvement in the load carrying capacity of the foundation bed can be obtained even with geocell mattress of width almost equal to the diameter of the footing (b/D=1.2). From the results obtained through limited tests carried out under the present investigation it appears that for same quantity of geogrid material, geocell reinforcement system yields better performance improvement than planar reinforcement system

- **Ming Zhu(2004)** – In their paper "Bearing Capacity of Strip Footings on Two-layer Clay Soil by Finite Element Method"**,** Parametric study was carried out to evaluate the bearing capacity of a strip footing over two-layer clay soil. Finite element solutions for different combinations of layer thickness and soil strength were obtained and presented in both tabular and graphical forms. He considered two layered soil of soft clay and stiff clay. From the test results he found that , At the same strength ratio, the bearing capacity factor decreases as thickness of the top layer increases for a soft-over-strong clay profile, whereas for a strong-over-soft clay profile the bearing capacity factor increase.

- **Kumar A and Walia BS (2005)** – In this paper, they study the behavior of pressure settlement characteristics in shape of rectangular footing on reinforced soil and unreinforced soil. They also study the confining effect of the reinforcement provided in the soil at different layers in the analysis by considering the equivalent stresses generated due to friction at the soil– reinforcement interface. The value of settlement was read directly from pressure–settlement curves for the given pressure intensity. Therefore, the rectangular footing resting on reinforced sand can be proportioned satisfying shear failure and settlement criteria.

- **Trivedi and Sud (2007)-** In this paper, they had performed tests to find out the settlement of footings placed on compacted coal ash. Coal ash that used was the one that formed at ropar thermal power station in India. They performed plate load test on the rigid square plates placed on the ash and compact them at changing amount of compaction. They also vary the percentage of moisture content in coal ash and find settlement characteristics. From the results of test they conclude that the settlement of footing placed on ash is higher for soil compacted on dry side of optimum than on wet side of optimum.

- **Teodoru and Toma (2009)-** They performed plate load test on the soil to study the size effect on settlements and desired values of geotechnical parameters. It is revealed that the subgrade reaction co-efficient is strictly dependent on size of the loaded area and loading magnitude.

- **Dixit M.S and Patil K.A (2009)-** They study the influence of shape, width and depth of footing on load carrying capacity of soil. They also evaluate the effect of water table. They analyzed the results obtained by methods given by Terzaghi and IS code. They observe the variation in bearing capacity obtained from different methods for different shapes. They conclude that the bearing capacity is mainly governed by density of soil, cohesion and angle of internal friction of soil.

- **Arash et al. (2012)-** In this paper they describe experimental work to evaluate the ultimate load, the displacement and the tilt of two types narrowly spaced footings, of square and the circular shapes, on unreinforced and reinforced soil. From the experimental results they conclude that there is a considerable increment in the ultimate bearing ability, whereas the settlement and tilting of the interfering footings at the critical load increased.

- **Moayed, and E. Izadi(2012)**- In their paper "Evaluation on Bearing Capacity of Ring Foundations on two-Layered Soil", they did the numerical simulation for computing the two-layer soil ultimate bearing capacity. The soil was modeled as an elastic-plastic material obeying Mohr-Coulomb yield criterion. Bearing capacity of ring footing was computed using finite element software, ABAQUS. They varied the ratio of internal radius to outer radius of ring footing and observe the effect of it on bearing capacity. From the result of numerical simulation, it was found that the bearing capacity decrease as the ratio of radius increase. Also it was found that as the thickness of underlying soil in this case it is clay layer increases the bearing capacity decreases gradually.

- **Verma et al. (2013)-**They performed load test on plates to observe load settlement features of model footing on layered granular soils. They developed equation for predicting ultimate bearing capacity based on plate load test. From the test results they conclude that the thickness of top layer of fine gravel controls the ultimate bearing capacity of soil.

- **Amr Z. and EL Wakil (2013)** – They find the bearing power of skirted circular footing on sand. They performed various experiments on circular steel footings of different diameters and different skirt lengths. Skirts are used to decrease the displacement and increase the bearing ability of soil system. The effects of skirt and the density of sand on ultimate load attained were investigated. They concluded that the performance of skirted footing depends upon the relative density of sand and on the skirt length to footing diameter ratio. They also found that skirts are more beneficial in case of footings on loose sand than in case of medium and dense sand.

- **Dixit and Patil (2013)-** They have studied the bearing ability and permissible settlement of sand lying below the modeled footing of square shaped. They also notice the effect with variation in size and depth. For this, they used a steel tank of specified size and did model plate load test on square plates. From their test results, they concluded that with increase in size of plate the elastic settlement keeps on increasing.
- **Dixit and Patil** - They have studied the effect of reinforcement on bearing capacity & settlement of sand. They have studied the behavior of reinforced & unreinforced sand and in improving the bearing capacity and settlement resistance under square footing. The parameters that they have selected were depth of the top layer of reinforcement below the footing and D/B ratio of reinforcement.

  It is concluded that as the square plate size increases, ultimate bearing capacity goes on increasing. It is also observed that maximum value of the bearing capacity ratio (BCR) was obtained for D/B ratio in the range of 0.3 to 0.4. The results of the test shows that there is optimum value of D=0.3B for geogrid reinforcement at which the BCR value becomes maximum.

- **Elsamee -** He presented an experimental analysis using plate load test to determine the effect of foundation depth, size as well the shape on modulus of subgrade reaction (ks) of cohesionless soils. He has conducted tests on cohesion less soils with different relative densities under different applied pressures. It was done by using nine rigid plates with different relative densities under different applied pressures.

  He concluded that subgrade reaction ks of cohesionless soil increases with increasing footing depth as well as footing size. Also subgrade reaction of cohesionless soil increases with increasing angle of internal friction. He also found that subgrade reaction of cohesionless soil under rectangular footing is higher than that under square & circular one (at same equivalent area).
- **Mohamed & Vanapalli** - They have determined the bearing capacity of sandy soils using plate load tests, cone penetration tests and standard penetration tests.

- **Sideek & Elsamee** - They have studied the young's modulus Es of sand with or without surcharge by conducting plate load test. They have used two steel rigid plates, one circular plate (dimension 305 mm) & one square plate (size- 305mm x 305mm). They have adopted the British standard method to calculate Es. The settlement that they have measured at different values of stress are at the surface along the center line & edge of the plate.

  They have concluded that modulus of elasticity, Es of sandy soil increases with increasing depth of footing. They have also found that young's modulus of sandy soil using square plate is less than that of circular plate. Also the young's modulus increases significantly with increasing the soil relative density with and without surcharge around the footing.

- **Mosadegh A and Nikraz H (2015)–** They modeled the soil as an elasto-plastic material and calculations were done in the FEM software, Abaqus.

  It was found that bearing capacity obtained by Terzaghi's equation was slightly less than that obtained from FEM analysis

- **Mohite and Admane (2015)-** They performed plate load test on the undisturbed soil sample by placing it on a base plate and applying loading by reaction truss. Their apparatus was similar to California bearing ratio test apparatus. The laboratory plate load test on undisturbed soil samples in the model box was carried out. The value of ultimate bearing capacity of footing that we got from plate load test on undisturbed soil sample is compared with the values that we got from standard plate load test. He concluded that the results of field tests and model test in laboratory were comparable.

- **Keshawarani and Sahu (2015)-** In their work, they have carried out various plate load tests on the sand mixed with coarse aggregates of 20 mm and 10 mm in percentages varying from 5%to 30% by weight of sand . Both the cases with and without aggregate were tested. The executed tests on 100mm, 150mm and 200mm diameters m.s plates. From the results of plate load test they find that displacement at a particular load decreases with the increase in fine gravel percentages and as the plate size increases it also increases.

- **<u>Kiran and Nagraj Bacha (2015)-</u>** In this investigation they study the performance of reinforced sand under square footing and circular footing. They used lateritic soil as layer in sand bed and geo-grid as reinforcement. They performed plate load test for various conditions on model footings of square and circular footings of size 10.5cm and 9.2 cm diameter. They compare the results of bearing capacity of reinforced and unreinforced condition under both footings. They also conclude that reinforced sand have 30% more load carrying capacity than unreinforced sand under square footing and 10% more in circular footing. When compared to the behavior of square and circular footing under reinforced and unreinforced condition the square footing perform well and have high load carrying capacity than circular footing..

- **<u>Sunil and Baral (2015)</u>**- In this study they determine the bearing capability of surface square footing on two layered cohesive soil by Plaxis 2d. This parametric study includes the effect of top layer thickness and strength ratio on bearing capacity of surface square footing. The results were shown in the form of bearing capacity factor, shape factor and efficiency factor. From the results they conclude that for strong clay over weak clay ($c_2/c_1 < 1$), bearing capacity factor (Nc *) keeps on increasing with increase in depth ratio (H_1/b) ratio. Whereas for weak clay over strong clay ($c_2/c_1 > 1$), Nc * decreases with increase in H_1/b ratio till it equals 1 thereafter it remains constant. They also concluded that the shape factor is weakly dependent on thickness ratio (H_1/b) while it showed considerable variation with varying strength ratio (c_2/c_1). Therefore it can be said that the soil properties affects shape factor and its values should not be based on shape of footing only.

- **<u>Ramu, and Satyanarayana (2015)</u>** – In their paper they have conducted field experiments to see the influence of fresh fill on bearing ability of soil. The field study was performed by changing the type, density and thickness of soil used as fill. From their test results they inferred that the ultimate bearing capacity keeps on increasing with the increase in thickness of the fill, the failure envelope is not extended into the fresh fill, may be extended along the interface of the ground and the surface of the fill.

- **<u>Reza Alijani Shirvani (2015) –</u>** In this paper load settlement behavior of footing when stabilized with cement of different dimension on sand was studied. They used rigid square footing. The soil was compacted and filled in layers and stabilized with different percentage of cement by weight of soil. The sample was cured for 28 days and then plate load test was conducted. The experimental results show that the bearing ability of soil increases and displacement of the stabilized soil layers reduces.

- **D. A. M. and Costa (2017) -** They evaluate the effect of size of Footing of shallow foundations in sand. They performed three plate load tests on a sand backfill using plates with diameters of 0.30, 0.5 and 0.80 m. The stress-settlement curves obtained with the tests did not show a clear failure pattern, therefore, a conventional failure criterion was considered to determine the bearing ability. They conclude that for a same applied stress the settlement values increases as the plate dimensions increases, but this increasing is nonlinear. The values of allowable stress obtained by the three-plate method of Housel decreased with the increasing of plate size. The same was observed for Leonards' criterion.

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials and Equipment used – Different material and methods used to fulfil the objective of this research work.

The materials and equipment used are as follows-

- **Coarse Sand -** It is taken from the contractor and passed through 4.75 mm IS sieve. The sand should be free from grass roots and other organic material so it was dried in oven for 24 hours.

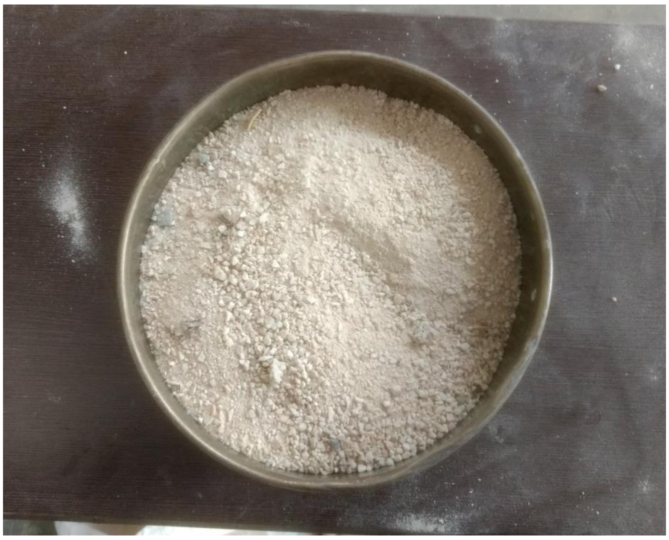


Figure3.1. Coarse sand

- **Fine Gravel-** Gravels of size between 10mm and 20mm is used and the properties of this will also be determined.

Figure3.2. Fine gravel

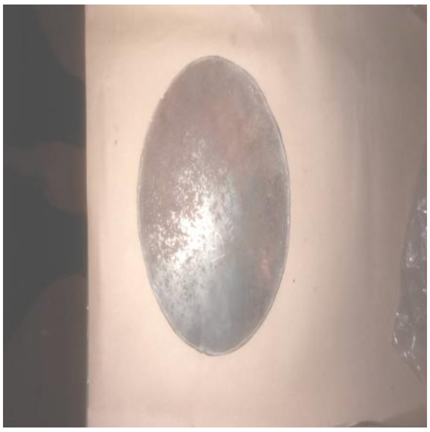
- **M.S Box –** It was manufactured by the steel workshop. The size of box was decided as per the instructions given by IS code and on the basis of the previous researches. As defined by IS: 1888-1982 the width of box should be five times the breadth of test plate such that full failure zone can be developed without intrusion of sides. Keeping the IS code criteria in mind box of size 400x700x500 mm was adopted for circular plate of 100 mm, 150 mm and 200 mm diameter.

Figure3.3 Small scale setup

Figure.3.4. Large scale setup (1.5 m X 1.5 m X 0.8 m).

- **M.S Plate-** Plates of mild steel was manufactured by the steel workshop. The sizes of circular plates were 100 mm, 150 mm and 200 mm diameter of 10 mm thickness.

100 mm



150 mm

200 mm

Figure3.5. Model test footings of mild steel

- **ACTM –** This compression machine has the loading capacity of 5000 KN. The rate of loading can be varied.
- **Dial Gauge-** A dial gauge which can measure settlement of range of 0.01 mm was taken from structure lab to record the displacement of footing.

3.2 Experiments Performed- In this section the procedure adopted to perform various experiments are discussed.

3.2.1. Properties of Coarse Sand

a. **Specific Gravity –** Pycnometer method is generally used for coarse grained soil as: IS- 2720- Part 3- (1985).

   In this oven dried sample was taken and was put in the flask. The weight of flask and soil was weighed as M_2. Then the flask was filled with water up to the top while stirring it. Then mass of flask, soil and water was weighed as M_3. Now the flask was emptied and thoroughly washed and flask was filled with water up to the top. And the weight of flask with water was taken as M_4. Mass of the empty flask was noted as M_1. The results of test will be disused in next chapter.

   Specific Gravity (G) = $(M_2 – M_1) / (M_2 – M_1) – (M_3 – M_4)$.

b. **Particle Size Distribution -** The percentage of different size of particles in Coarse Sand is determined using Sieve Analysis as per IS 2720 part 4. The oven dried soil sample passed through 4.75 mm IS sieve was taken for fine sieve analysis.

   Then sieving of sample was performed by arranging different sizes of sieves in prescribed order and a pan is placed at the bottom and a cover was placed at the top of whole assembly. Then the assembly was placed in sieve shaker and sieving was done for at least 10 minutes. After sieving, the material collected on each sieve was weighed. And Percentage finer was calculated. Then the graph was plotted between Particle Size and %age finer on semi log graph paper. The results of test will be disused in next chapter.

Figure3.6. **Sieve analysis in sieve shaker**

c. **Compaction Characteristics-** Standard proctor test was conducted as stated in IS 2720- part 7(1980). It was conducted to have the knowledge of the optimal water content and maximum dry density of soil i.e. coarse sand. In this test known weight of air dried soil passed through 4.75 mm IS sieve was mixed with known different amount of water and then filled in proctor mould in 3 layers. 25 numbers of blows was applied to each layer with the help of rammer of 2.5 kg dropped from 31cm height. And then compacted soil was weighed. The dry density was calculated by knowing the mass of compacted soil and its water content. Then the graph was plotted in between the dry density and water content.

Dry Density $\gamma_d = \left(\frac{\gamma}{1+w}\right)$

Where γ = Bulk density in KN/m^3.

w = Water content in percentage.

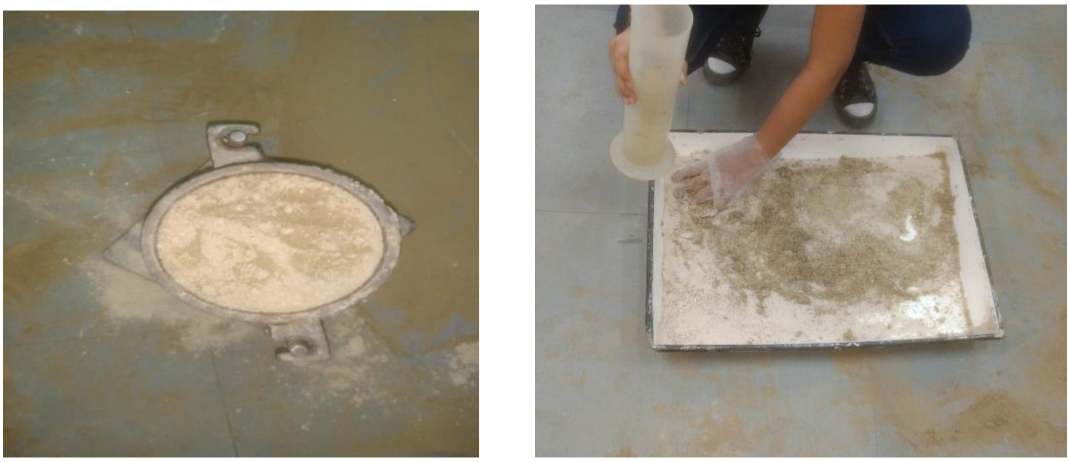


Figure 3.7 Standard proctor test

d. **Direct Shear Test –** Shear parameters of coarse-sand can be found by doing this test. This test contains apparatus as stated in IS: 2720-Part 13. The sample was prepared at optimum moisture content of size 60 mmX60 mmX25 mm. The specimen of the shear box is sheared at rate of 1.25 mm/min under a different value of normal stresses. Then graph between normal stress v/s shear stress has been plotted and values of cohesion and φ were determined**.**

Figure3.8. Shear box and Direct shear apparatus

3.2.2. Properties of Fine Gravel-

a. Specific Gravity - Specific gravity of fine gravel can be related to its strength. It helps in the identification of aggregate.

To perform specific gravity of aggregates, we take washed aggregates of around 2 kg of size greater 10 mm. Then place them in a basket of wire and immersed it in distilled water at room temperature with a cover. The entrapped air is removed by lifting basket over the base of tank and to allow water to drop per second. Take the weight of aggregates in water (W_1). Then the basket and aggregate was removed from the water and to dry for some time. Then remove the aggregates from the basket and empty basket were immersed in water and the weight (W_2) is noted. Then aggregate is dried in in oven at around 100˚C-110˚C for one day. After that it is removed from oven and allowed to cool and note the weight. (W_3).

Apparent Specific Gravity = Weight of fine gravel / Weight of an equal volume of water

$$= (W_3 / \{W_3 - (W_1 - W_2)\})$$

The results of the tests will be discussed in the next chapter.

b. Fineness Modulus- It is used to denote the average diameter of the particles in coarse aggregates by a number. Sieve analysis with the help of the standard sieves has been done to find this. The value of this modulus is more for aggregates of larger size.

To find this, sieving of oven dried sample was performed by arranging different sizes of sieves in prescribed order and a pan is placed at the bottom and a cover was placed at the top of whole assembly. Then the assembly was placed in sieve shaker and sieving was done for at least 10 minutes. After sieving, the material collected on each sieve was weighed. And Then cumulative weight retained is calculated and when it is divided by 100 gives the value of modulus. The results of the tests will be discussed in the next chapter.

3.2.3. Plate Load Test- It is a test generally performed on the field to estimate the ultimate bearing ability of soil and settlement that took place when load is applied. To evaluate the load settlement characteristics of coarse sand under different conditions, model load tests were conducted as per IS 1888:1982. The model load tests consist of bearing plates, test tank, loading arrangement and dial gauge. Details of the equipment used were discussed in the previous section.

Different conditions on which model load test was conducted are as follows.

a. **Effect of density-**

- Placement of sand – To evaluate the effect of density on load settlement curve for different plate the sand is placed in tank in three layers, each layer being given 50 no. of blows for case 1 and 100 no. blows for case 2 and 150 no. of blows for case 3. Each plate of diameter 100 mm, 150 mm and 200 mm was tested at each density of sand achieved due to different number of blows as mentioned in table 1. The density of coarse sand when it was not being densified is 17.8KN/m^3.

Table 1: Density of sand at different number of blows

Case No.	Number of Blows Applied per Layer	Weight of Sand Filled in Box (Kg)	Density of Sand Achieved (Weight of Sand / Vol. of box) (KN/m^3)
1.	50	270	19.28
2.	100	300	21.42
3..	150	350	25.00

Figure3.9. Densification of sand using rammer

- Setting up of setup – After densification of the soil, model footing of circular shape is kept on the topmost of the Sand bed at the centre. Spacer is provided n between the loading unit and the footing. Dial gauge is attached on corner of footing. The whole assembly is shown in figure**.**

Figure3.10. **Setup of dial gauge and plate**

- Test procedure – The load is applied at the rate of 1 KN per sec and settlement for different loads is recorded from the dial gauge. Then to conduct next test on another plate or for different case on same plate, the tank was emptied and then again filled and whole procedure was repeated. The results of each plate load test will be discussed in the upcoming chapters.

Figure3.11. Plate load test in compression testing machine

b. Effect of fine gravel-

- Sample preparation and placement of sample – Plate load test was conducted on sand when mixed with different percentages of fine gravel by weight of sand. For this the sand is thoroughly mixed with 0%, 8%, 16% and 24% of fine gravel. Then the tank is filled with the sample.

Figure3.12. Mixture of sand and fine gravel

- Setting up of equipment- The setup is same as stated in the earlier case of densification. The whole assembly is shown in figure.
- Test procedure – The procedure to apply load and recording of displacement of sand is same as stated in the above case of density. Then to conduct next test on another plate or for different percentage of gravel on same plate, the tank was emptied and then again filled. The results of each plate load test will be discussed in the upcoming chapters.

CHAPTER 4

NUMERICAL SIMULATION

A finite element model of plate and sand has been created by using the finite element software Abaqus. It is software based on finite element modeling that is used for elastic and plastic analysis of different material like sand. Different properties have to put as input in Abaqus for analysis. Different cases were modeled and the influence of density of sand, fine gravel and size of plate on load settlement curves of coarse-sand has been studied. Elastic analysis of modeled plates on coarse sand has been done. This software is used to divide the model in small elements and then to analyze them virtually.

4.1. Properties of Materials Input in Abaqus-

The references for the properties of the soil and the plate, which are used in the numerical problems, are taken from engineersedge.com, geotechdata.info, supercivilcd.com.

Table2: Properties of different materials.

(engineersedge.com, geotechdata.info, supercivilcd.com.**)**

Properties of Material	Coarse Sand	Fine Gravel	Steel Plate
Modulus of Elasticity	20 MPa	50000 MPa	200000 MPa
Poisson's Ratio	0.4	0.5	0.3
Angle of friction	41.2^0	NA	NA
Mass Density	17.80 KN/m^3	26.00 KN/m^3	78.50 KN/m^3

4.2. Finite Element Modelling

In this, an elastic model was adopted for modelling the plate of mild steel and coarse sand of specified size. Load settlement curves are studied for the different cases as stated in the following section.

a. **Effect of density of sand-** A rectangular model of sand with length 400 mm, breadth 700 mm and thickness of 800 mm has created shown in Fig.4.1. The material properties of sand, plate and fine gravel is assigned and the numerical simulation has been conducted for different densities on plates of different diameters with thickness equals to 20 mm. Only density will change as we compact the layer at 50, 100 and

150 no. of blows. Other properties like cohesion, angle of friction remains same for all the cases.

Table 3: Different cases of densification in Abaqus

Case	Density of Coarse Sand
Case1	19.20 KN/m^3
Case2	21.42 KN/m^3
Case 3	25.00 KN/m^3

b. **Effect of fine gravels-** For this, properties of sand when mixed with 8%, 16% and 24% of fine gravels are inserted in Abaqus and numerical simulation has been performed for different plate sizes.

Table 4: Different cases of addition of fine gravels in Abaqus

Cases	Density of Sand	Modulus of Elasticity
Sand +8% fine gravels	19.88 KN/m^3	5236 MPa
Sand +16% fine gravels	20.56 KN/m^3	10432 MPa
Sand +24% fine gravels	21.24 KN/m^3	15628 MPa

4.3. Plate – Soil Interaction- After creating and assembling the two models one of sand and other of plate, contact interaction property has to be created. For that, tangential and normal contact property is provided. Bottom part of the plate is selected as master surface because of its high stiffness and top surface of sand is taken as slave surface, finite sliding is provided between plate and sand. Friction between the plate and soil is defined under penalty section of tangential movement, Friction value that has been provided is 0.25.

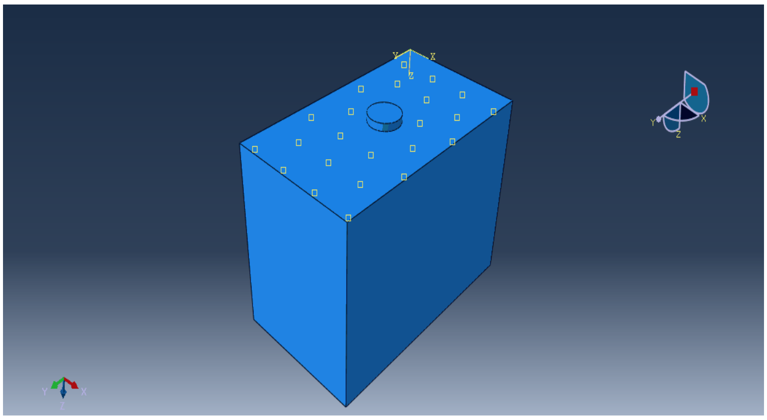


Figure4.1. Showing interaction properties in Abaqus

4.4. Meshing of Model- In this model, the plate and the soil has meshed up means divided into finite elements by using eight-nodded solid continuum elements (C3D8R) to explain the continuum nature of the soil as shown in fig.4.2.

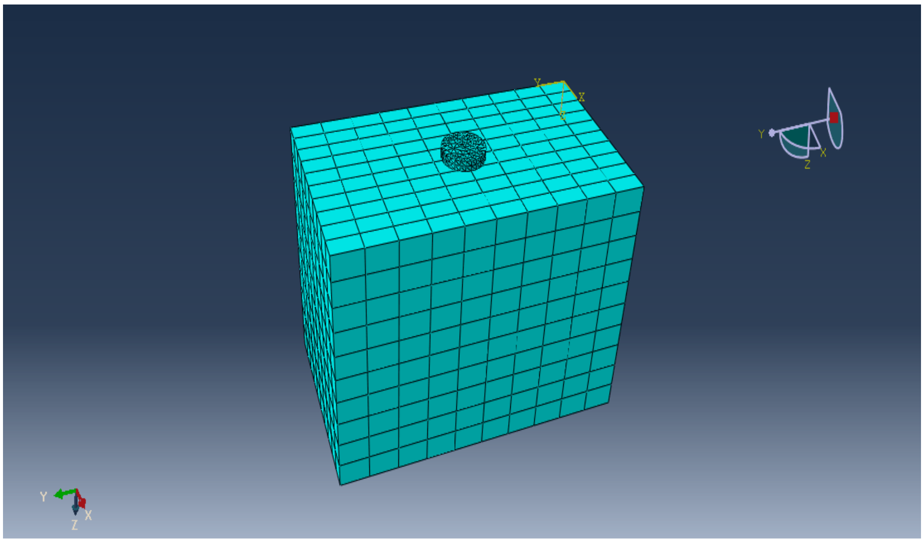


Figure4.2. Meshing of the assembly

4.5. Boundary Conditions and Loading- In the finite element model, the bottom layer of sand is fixed and the sides and the top surface of sand are allowed to displace in vertical Z- direction. Plate is allowed to move in vertical Z-direction. The boundary conditions and the load are step- dependent. The vertical load of 1000 N, 2000 N and up-to 6000 N is applied in (-) Z direction at the selected point that will help to find the settlement of sand due to loads application.

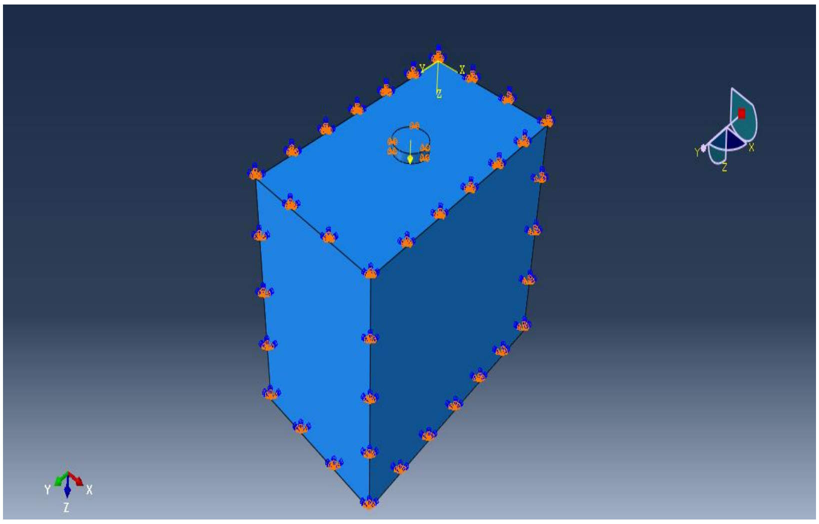


Figure4.3. Boundary condition on assembly

4.6. Settlement of Soil- Due to application of load the soil gets settled and that can be visualised in the software in visualisation module. In job module, job is created for and graphs were made using the plot on x-y section.

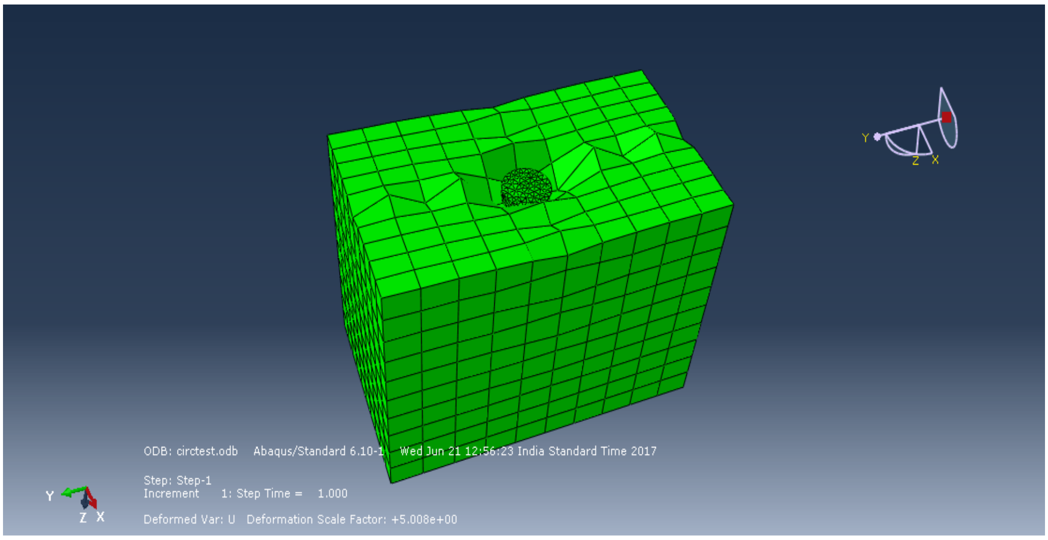


Figure4.4 Settlement of soil in 100 mm plate

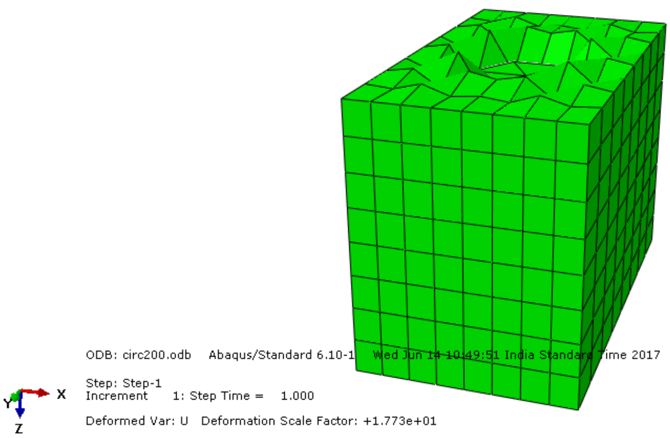


Figure4.5. Settlement of soil in 200 mm plate

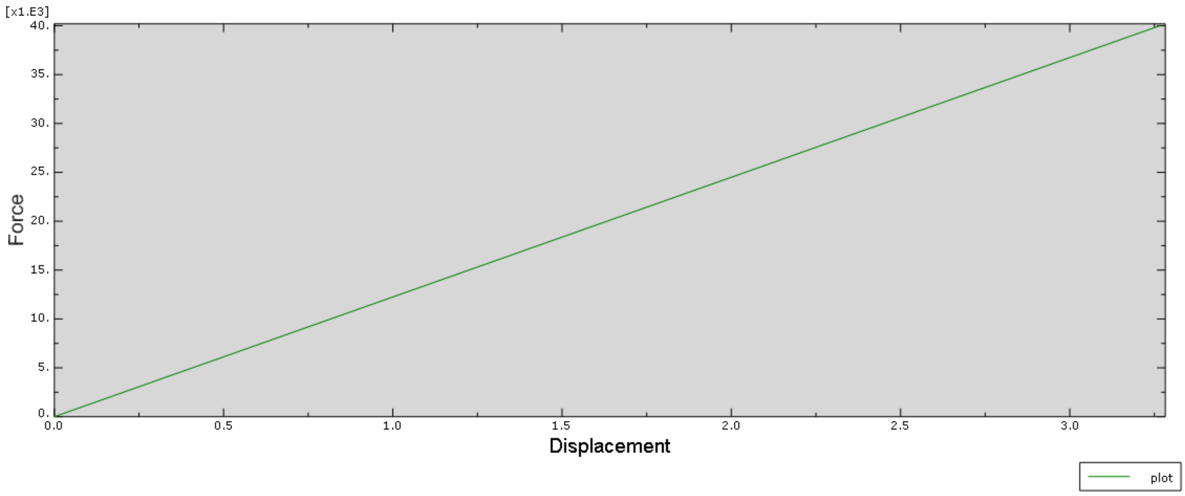


Figure4.6. Load settlement curve in Abaqus on 100 mm

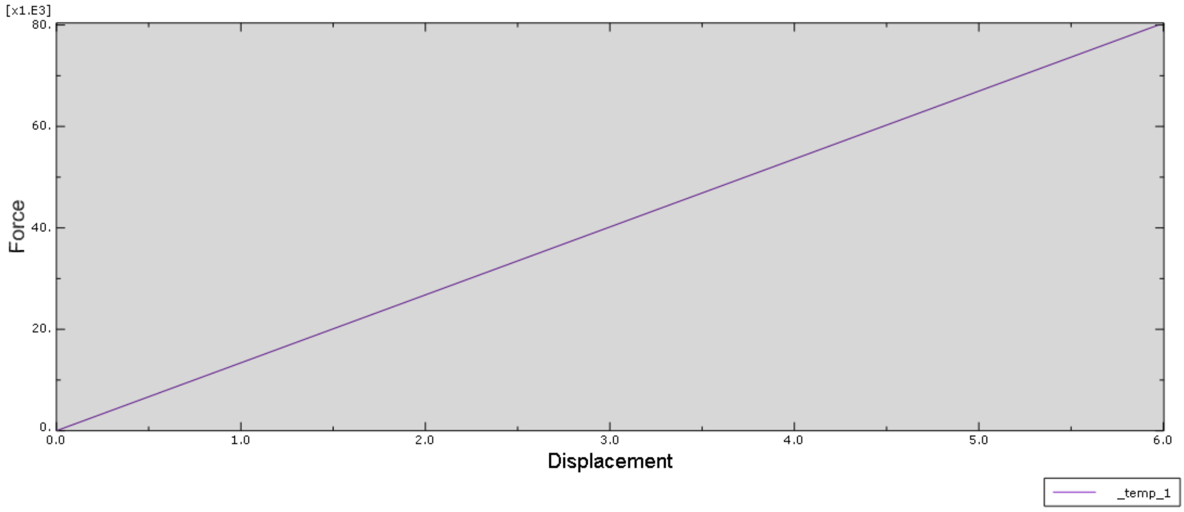


Figure4.7. Load settlement curve in Abaqus on 150 mm

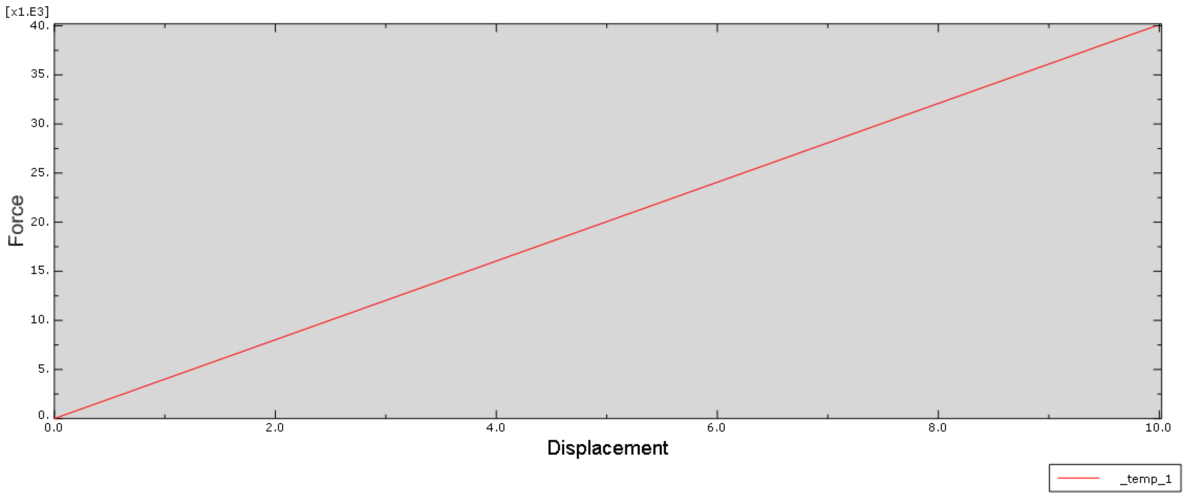


Figure4.8. Load settlement curve in Abaqus on 200 mm

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Properties of Coarse Sand- Different physical and engineering properties of coarse-sand are obtained by conducting different tests. Results of tests will be discussed in this section.

a. **Grain distribution of coarse sand-** Fine sieve analysis results are shown here. Type of soil can be found out using the distribution curve between percentage finer and particle size.

Table 5: Sieve analysis of coarse sand

Sieve Size (mm)	Weight retained (g)	% Weight retained	% Cumulative retained	% Finer
4.75	53	5.3	5.3	94.7
2.36	461	46.1	51.4	48.6
1.18	381	38.1	89.5	10.5
0.60	51	5.1	94.6	5.4
0.30	25	2.5	97.1	2.9
0.15	23	2.3	99.4	0.6
0.075	4.0	0.4	99.8	0.2
Pan	2	0.2	100	0
Sum (Σ)	1000			

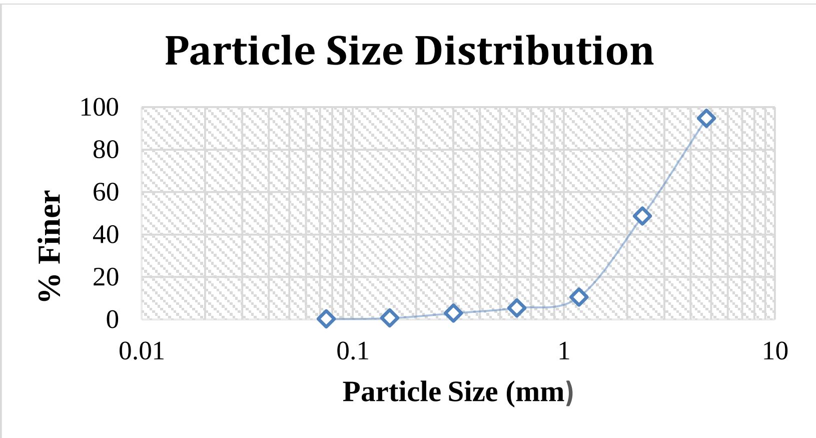


Figure5.1. Gradation curve of coarse sand

Coefficient of uniformity (C_u) = D_{60}/ D_{10} = 3/1.2 = 2.5

Coefficient of curvature (C_c) = D_{30}^2 / D_{60} x D_{10} = 0.9

Classification of soil – SP (Poorly graded sand)

b. Particle size analysis of coarse sand mixed with 8% fine gravels- For this 8% of fine gravels by weight of sand of size between 10 mm and 20 mm is mixed in sand. From the curve C_u and C_c can be estimated.

Table 6: Sieve analysis of coarse sand + 8% fine gravel

Sieve Size (mm)	Weight retained (g)	% Weight retained	% Cumulative retained	% finer
10	30	3	3	97
4.75	70	7	10	90
2.36	380	38	48	52
1.18	250	25	73	27
0.6	180	18	91	9
0.3	50	5	96	4
0.15	40	4	100	0
Sum (Σ)	1000			

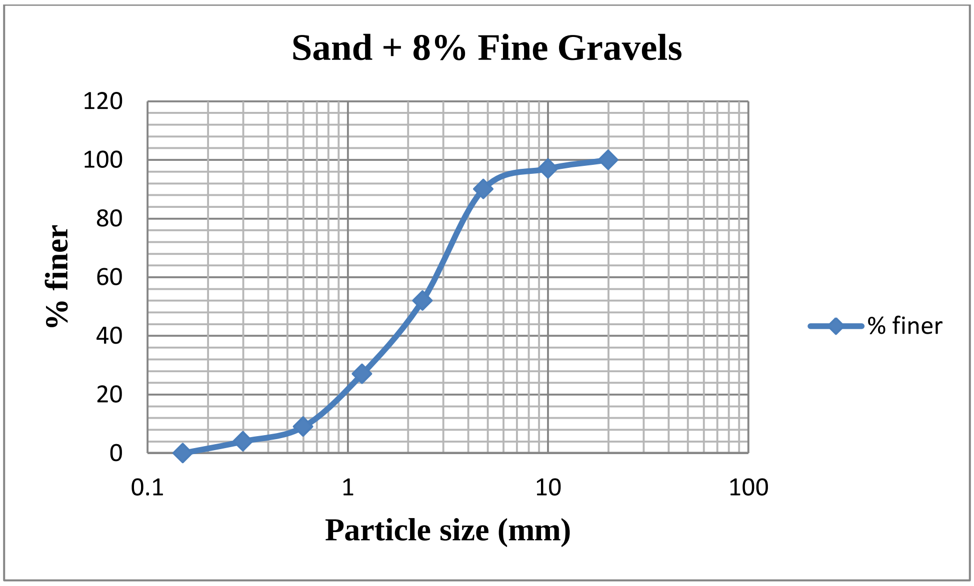


Figure5.2. Gradation curve of coarse sand + 8% fine gravels

Coefficient of uniformity (C_u) = 3.7

Coefficient of Curvature (C_c) = 1.8

Classification – SP (Poorly graded sand)

c. **Particle size analysis of coarse sand mixed with 16% fine gravels-** For this 16% of fine gravels by weight of sand of size between 10 mm and 20 mm is mixed in sand.

Table 7: Sieve analysis of coarse sand + 16% fine gravels

Sieve Size (mm)	Weight retained (g)	% Weight retained	% Cumulative retained	% Finer
10	100	10	10	90
4.75	70	7	17	83
2.36	350	35	52	48
1.18	300	30	82	18
0.6	130	13	95	5
0.3	30	3	98	2
0.15	20	2	100	0
Sum (Σ)	1000			

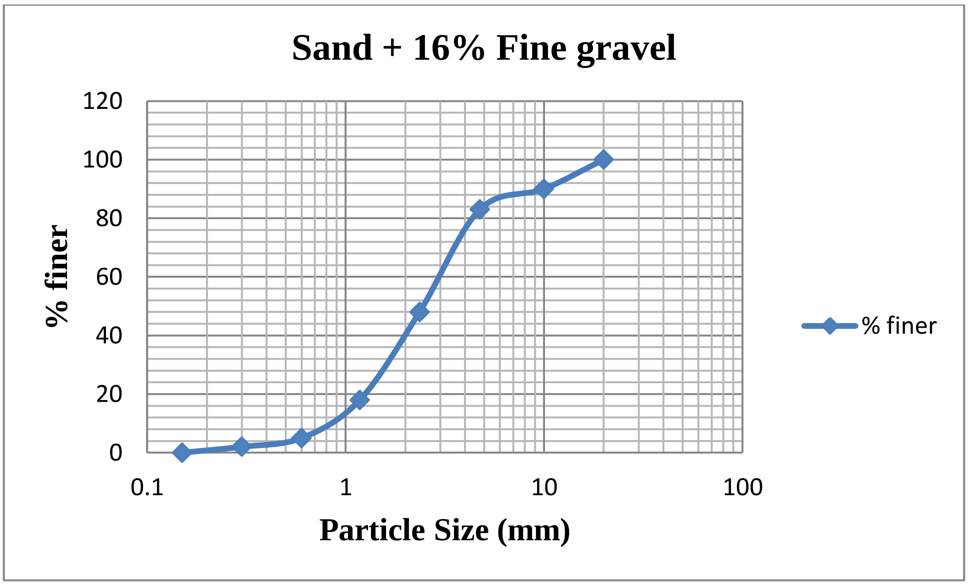


Figure5.3. Gradation curve of coarse sand + 16% fine gravels

Coefficient of uniformity (C_u) = 3

Coefficient of Curvature (C_c) = 1.08

Classification – SP (Poorly graded sand)

d. **Particle size analysis of coarse sand mixed with 24% fine gravels-** For this 24% of fine gravels by weight of sand of size between 10 mm and 20 mm is mixed in sand.

Table 8: Sieve analysis of coarse sand + 24% fine gravels

Sieve Size (mm)	Weight retained (g)	% Weight retained	% Cumulative retained	% Finer
10	140	14	14	86
4.75	120	12	26	74
2.36	320	32	58	42
1.18	290	29	87	13
0.6	90	9	96	4
0.3	25	2.5	98.5	1.5
0.15	15	1.5	100	0
Sum (Σ)	1000			

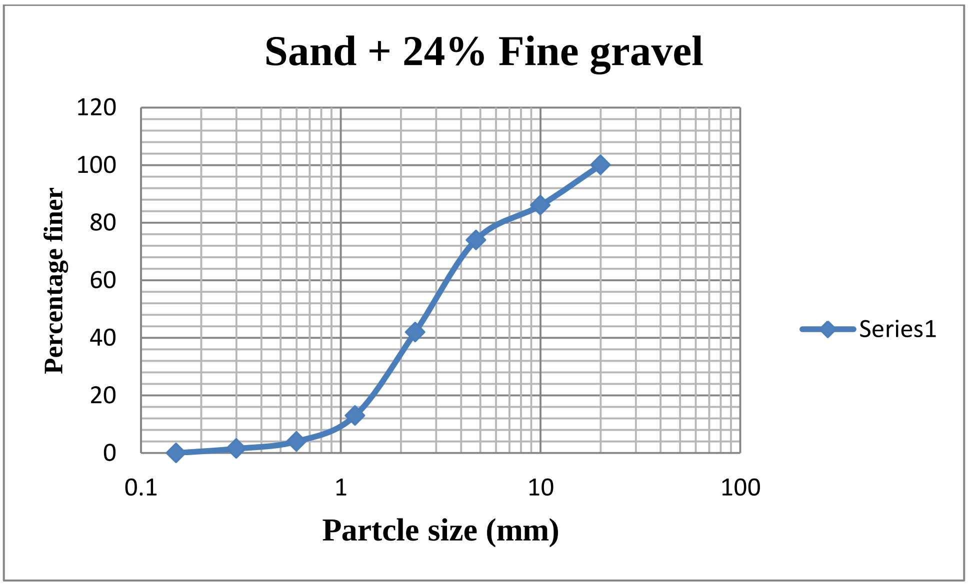


Figure5.4. Gradation curve of coarse sand + 24% fine gravels

Coefficient of uniformity (C_u) = 2.7

Coefficient of Curvature (C_c) = 1.0

Classification – SP (Poorly graded sand)

e. Compaction characteristics – To obtain the optimum water content (%) and maximum dry density (**$\gamma_{d\ max}$**), standard proctor test (S.P.T.) has been conducted. The result of standard proctor test is represented in the graph between water content and dry density.

Table 9: Result of proctor test on coarse sand

Water Content (%)	Dry Density (KN/m^3)
5.8	9.9
7.1	9.3
8.4	11.9
10.1	16.6
11.7	19.9
12.5	18.4
14.4	15.6

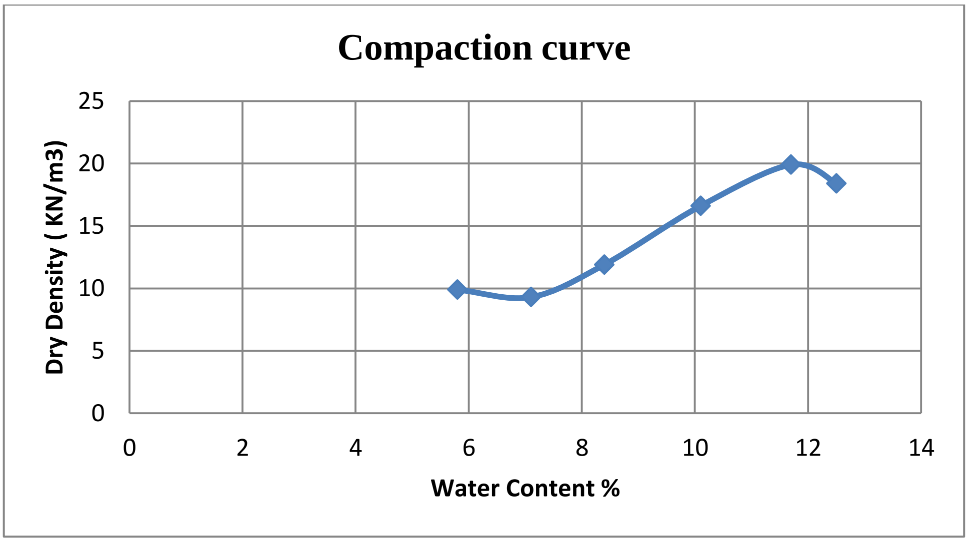


Figure5.5. Compaction curve of coarse sand

f. Direct shear test (D.S.T) –The result of direct shear tests is represented in the graph between normal and shear stress and angle of friction of soil (ø) can be taken from the slope of the curve, whereas the cohesion is represented by Y- intercept.

Table 10: Result of direct shear test on coarse sand

Normal Stress KN/m^2	Shear Stress(KN/m^2)
49.0	40.14
98.1	88.27
147.15	125.91
196.2	171.55
245.25	210.19

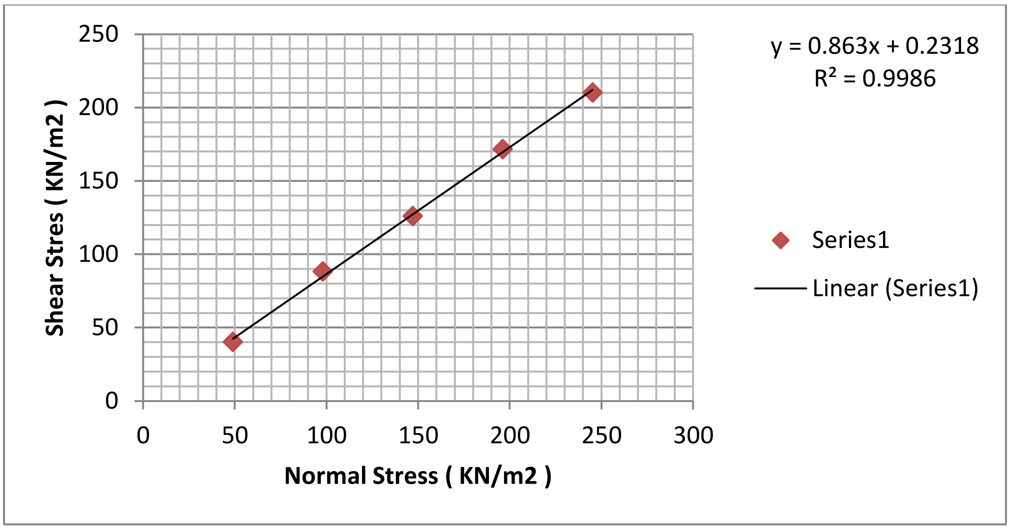


Figure5.6. Failure envelope of coarse sand from direct shear test

Angle of internal friction ø = 41.2 ^{0}

Cohesion = 0 KN/m^2

Table 11: Geotechnical properties of coarse sand

Properties	Values
Coefficient of Uniformity, Cu.	2.5
Coefficient of Curvature, Cc.	0.9
Specific Gravity, G	2.65
Plastic Limit	NP
Optimum water Content, OMC	11.5%
Maximum Dry Density , MDD	19.8 KN/m^3
Angle of internal friction, ø	41.2^0
Cohesion, c	0 KN/m^2
Classification of soil	SP

5.2Properties of Fine Gravels-

a. **Specific gravity-** Specific gravity of fine gravels of size between 10 mm and 20 mm is obtained and results will be discussed. Specific gravity of fine gravels is found to be 2.8.

b. **Fineness modulus**- Fineness modulus is obtained by sieving the fine gravels of size 20 mm and more and calculating the cumulative percentage retained on the sieves.

Table 12: Sieve analysis of fine gravel of 20 mm

Sieve Size (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative % Retained
80mm	0	0	0
20	1850	2100	42
10	1800	3900	78
4.75	1100	5000	100
2.36	0	5000	100
1.18	0	5000	100
0.6	0	5000	100
0.3	0	5000	100

Fineness Modulus = 7.25

Average particle size of fine gravel = 20mm

Table 13: Sieve analysis of fine gravel of 10 mm

Sieve Size (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative % Retained
12.5	0	0	0
10.0	700	700	23.67
6.3	1922	2622	87.43
4.75	265	2887	96.23
2.36	113	3000	100.00
1.18	0	3000	100.00
0.6	0	3000	100.00
Pan	0	3000	100.00

Fineness Modulus = 6.07

Average particle size of fine gravel = 10mm

Sieve analysis of fine gravel of 20mm + 10 mm fine gravel – 50% of 10 mm and 50% of 20 mm fine gravel are mixed and sieve analysis was carried out to find the fineness modulus of fine gravels.

Table 14: Sieve analysis of fine gravel of 20 mm + 10 mm

Sieve Size (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative % Retained
20	0	0	0
12.5	250	250	83.20
10	500	750	16.66
6.3	1672	2422	80.73
4.75	265	2687	89.56
2.36	313	3000	100.00
1.18	0	3000	100.00
0.6	0	3000	100.00

Fineness Modulus = 6.87

Average particle size of fine gravel = 12.5mm

5.3 Plate Load Test- To find the influence of density, addition of fine gravel on the load settlement behaviour of soil total 18 model plate load tests has been conducted on circular plate of 100 mm, 150 mm and 200 mm diameter.

Due to sides and size of the tank, boundary condition may be different from the field conditions which can influence the bearing capacity of soil.

The load settlement curves are plotted from the results obtained from plate load tests for different condition and discussed in this section. From the graphs below, it can be seen that in each case with increment in load application, settlement goes on increasing.

5.3.1 Effect of Densification

Load settlement curves of each circular plate at different density are discussed here. If the results are compared at different densities then it was found that for a particular plate size, the settlement under circular plate keeps on decreasing with the increase in density of sand for a particular load value. Various cases are discussed below.

Case 1: 100 mm circular plate at different densities

Table 15: Load settlement values on 100 mm plate

Load(KN)	Settlement (mm)			
	17.8 KN/m^3	19.28KN/m^3	21.42 KN/m^3	25.0 KN/m^3
0	0.0	0	0	0
5	-1.6	-1.2	-0.5	-0.1
10	-3.2	-2.1	-1.1	-0.4
15	-4.8	-3.6	-2.2	-0.9
20	-6.2	-5.0	-3.7	-1.8
25	-7.6	-6.5	-5.4	-3.1
30	-9.8	-8.6	-7.2	-4.2
35	-12.5	-11.8	-10.4	-6.5
40	-16.2	-16.0	-14.2	-10.4
45	-24.6	-23.4	-21.2	-18.2

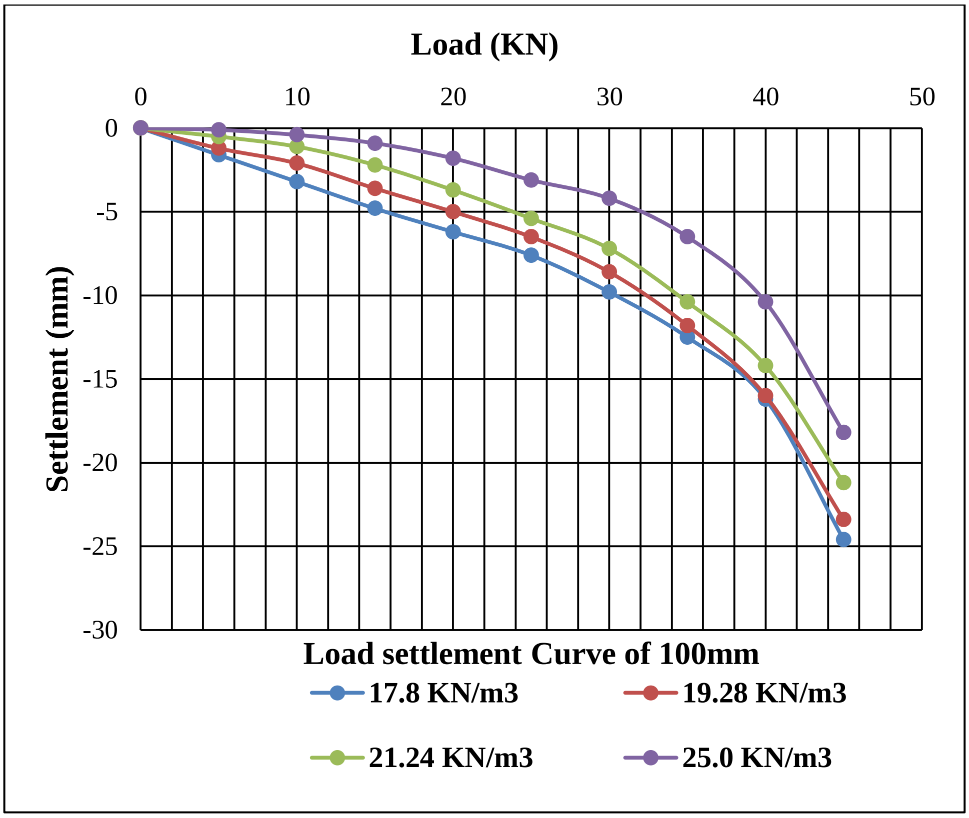


Figure5.7. Comparison curve of 100 mm diameter at various densities

Case 2: 150 mm circular plate at different densities

Table 16: Load settlement values of 150 mm plate

Load(KN)	Settlement (mm)			
	17.8 KN/m^3	19.28KN/m^3	21.42 KN/m^3	25.0 KN/m^3
0	0	0	0	0
5	-2.1	-1.8	-0.7	-0.3
10	-4.1	-2.9	-1.5	-0.6
15	-6.3	-5.1	-3.1	-1.2
20	-9.1	-7.5	-5.6	-2.5
25	-11.5	-9.9	-8.4	-4.8
30	-14.2	-13.1	-12.1	-8.2
35	-17.5	-15.8	-14.8	-12.1
40	-24.3	-23.2	-21.5	-17.4
45	-30.6	-29	-27.2	-23.8

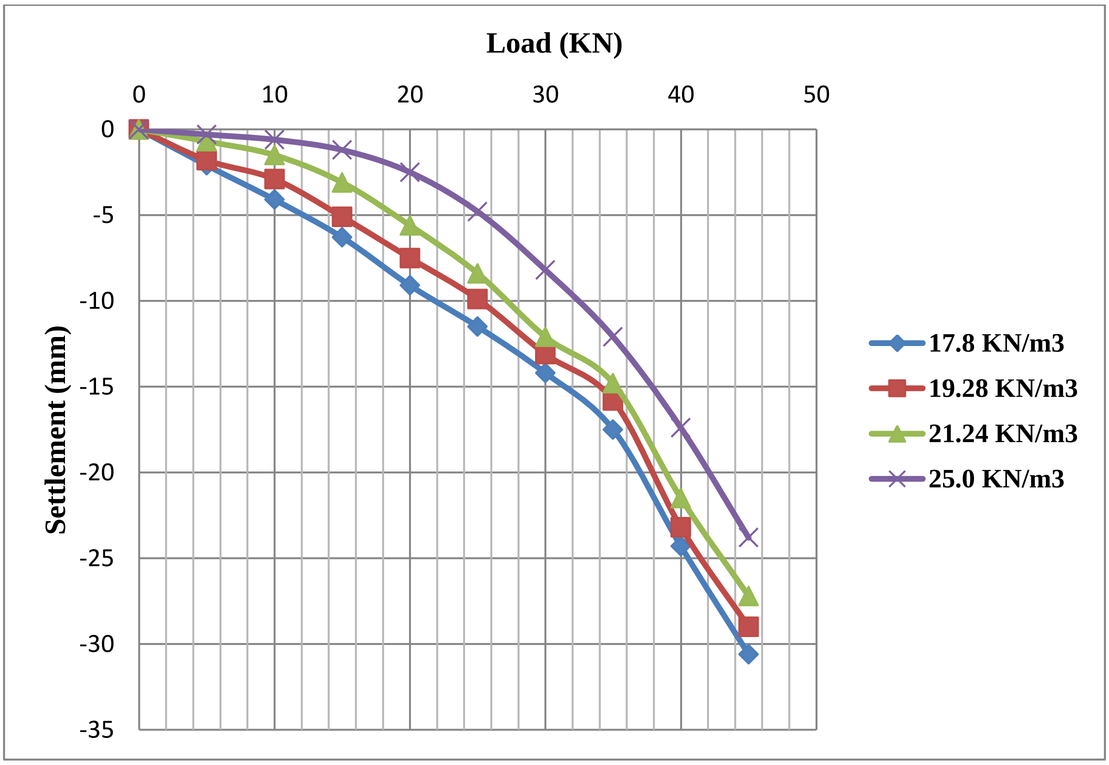


Figure5.8. Comparison curve of 150 mm circular plate at various densities

Case 3: 200 mm circular plate at different densities

Table 17: Load settlement values on 200 mm plate

Load(KN)	Settlement (mm)			
	17.8 KN/m^3	19.28KN/m^3	21.42 KN/m^3	25.0 KN/m^3
0	0	0	0	0
5	-3.0	-2.0	-1.1	-0.5
10	-5.4	-3.8	-2.2	-0.9
15	-7.1	-6.2	-4.2	-1.8
20	-10.2	-8.8	-6.8	-3.4
25	-13.1	-11.2	-9.7	-6.6
30	-17.3	-14.6	-13.5	-10.4
35	-22.2	-19.3	-18.6	-13.9
40	-27.5	-26.2	-24.4	-19.1
45	-34.1	-32.5	-30.6	-25.8

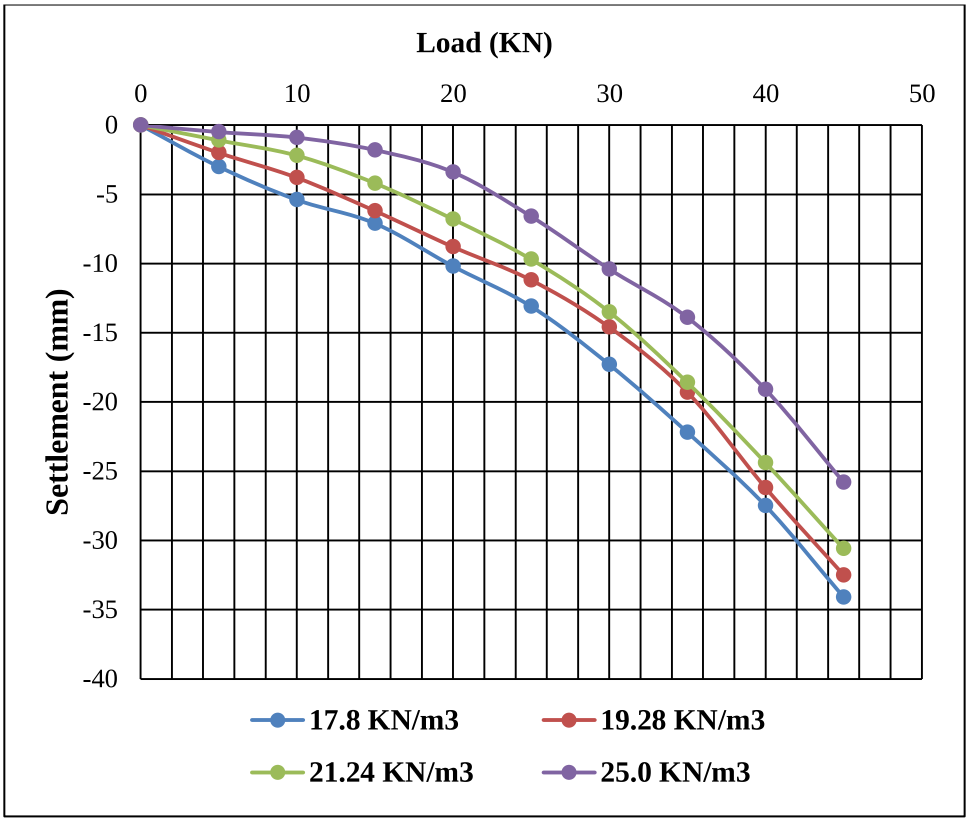


Figure5.9. Comparison curve of 200 mm plate at various densities

- **Effect of variation in size of circular plate at each density-** At a particular density, the variation in load settlement curves are compared with varying diameter of circular plate i.e. 100 mm, 150 mm and 200 mm. Following graphs can be made on the basis of the results obtained above.

  From the comparison graphs it can be seen that for a particular density, the settlement under circular plate keeps on increasing with the increase in diameter of the plate for a particular load value.

a. At Soil Density = 17.8 KN/m^3 –

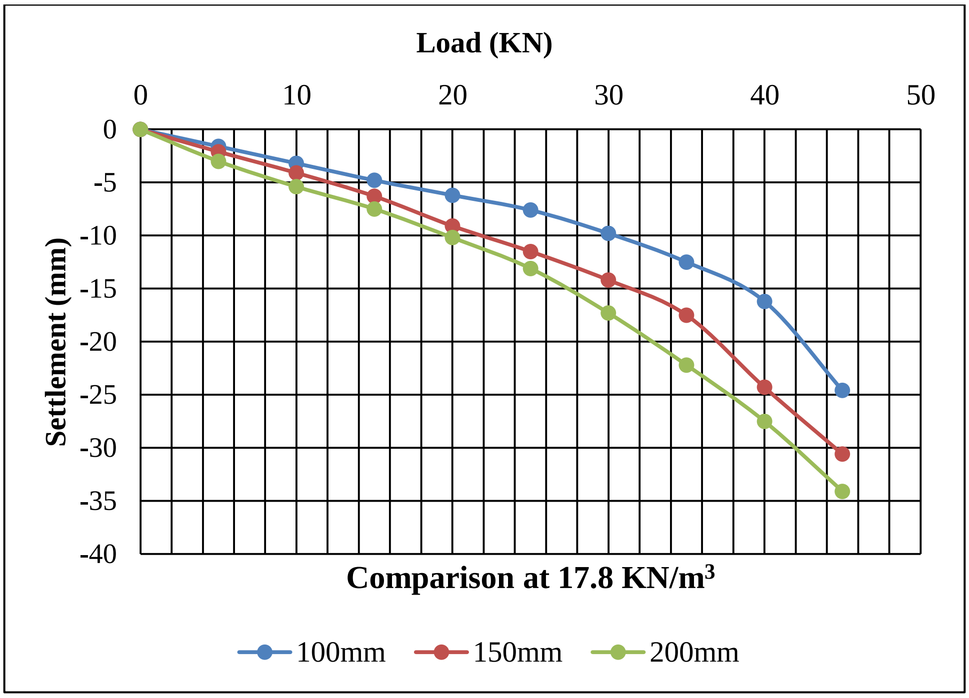


Figure5.10. Comparison of load settlement curve for different plate sizes at 17.8 KN/m^3

b. At Soil Density = 19.28 KN/m^3

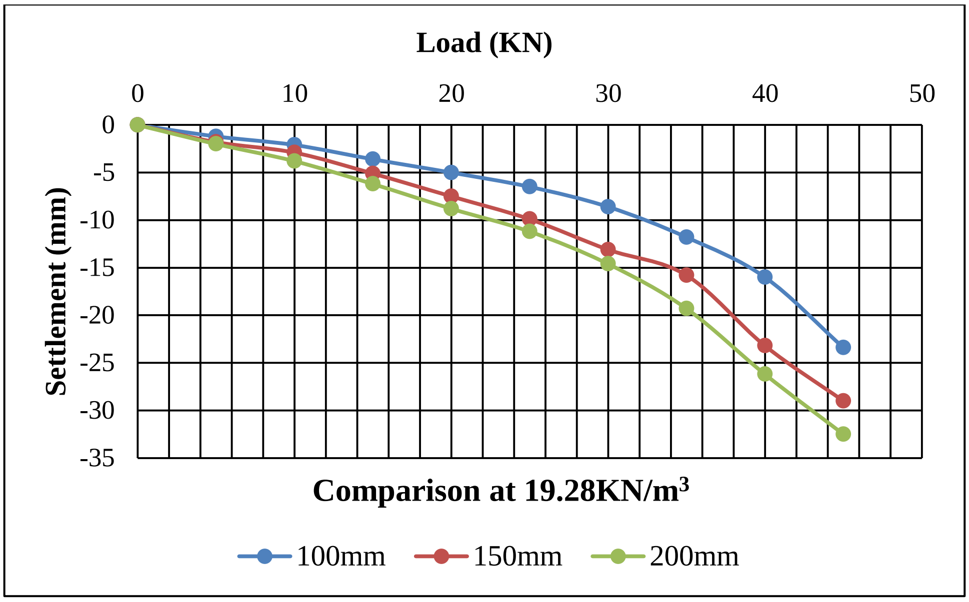


Figure5.11. Comparison of load settlement curve for different plate size at 19.28 KN/m^3

c. At Soil Density = 21.24 KN/m^3

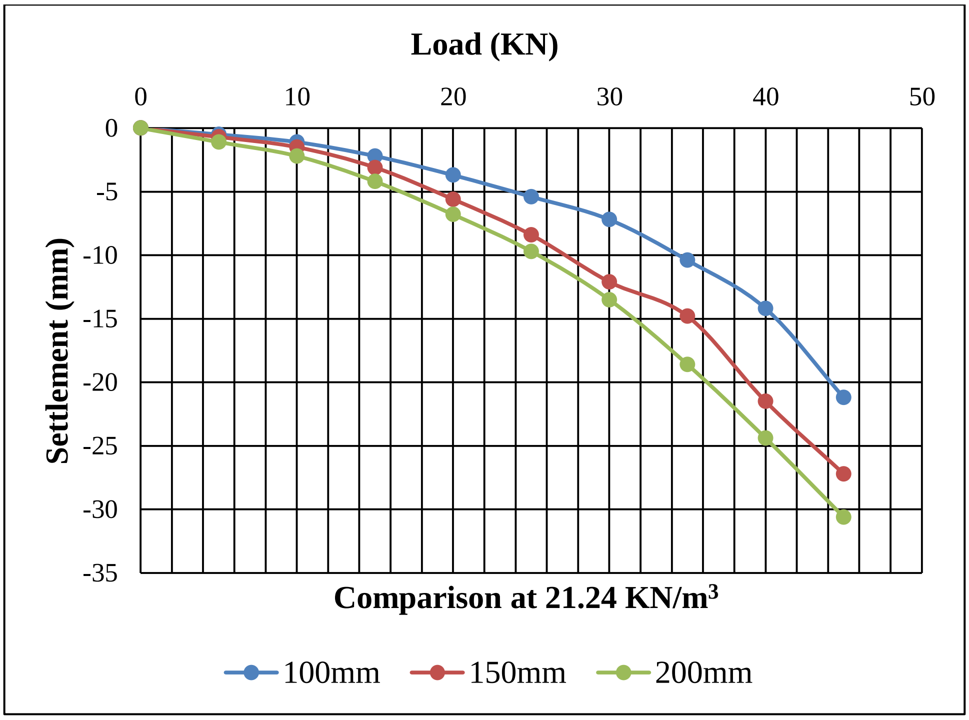


Figure5.12. Comparison curve for different plate size at 21.24 KN/m^3

d. **At Soil Density = 25.0 KN/m^3**

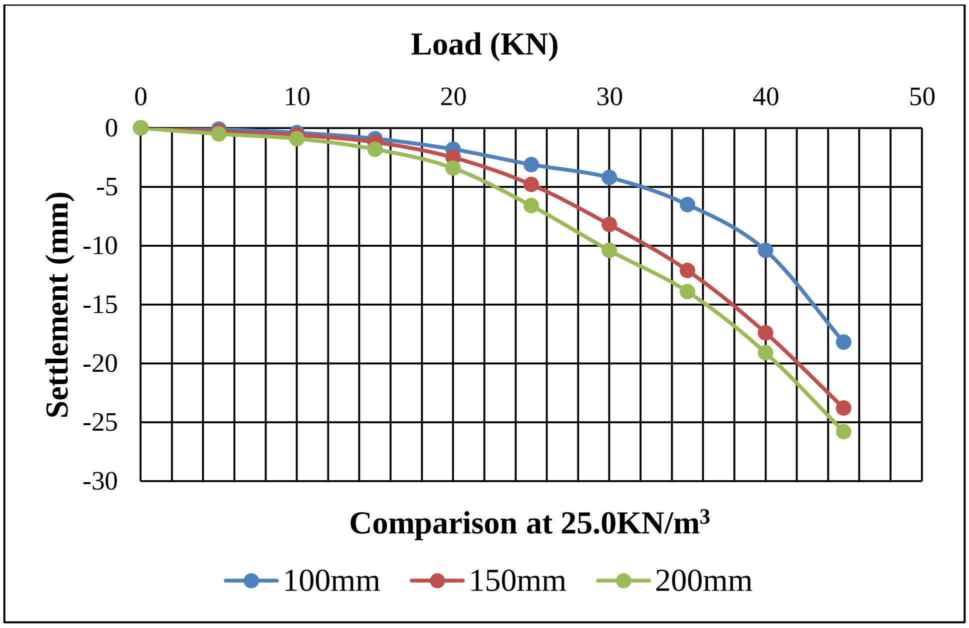


Figure5.13. Comparison curve for different plate size at 25.0 KN/m^3

5.3.2 Effect of Addition of Fine Gravels in Sand

Effect of Addition of Fine Gravels in Sand – Load settlement curves obtained from plate load test conducted on coarse sand with various percentages of fine gravels using different sizes of circular plate is discussed here.

From the load settlement curves below it can be seen that at a particular load the settlement under circular footing goes on decreasing with increase in the percentage of fine gravels in sand.

Case 1: 100 mm circular plate at different percentage of fine gravels

Table 18: Results of 100 mm plate at different percentages of fine gravels

Load (KN)	Settlement(mm)			
	0%	8%	16%	24%
0	0.0	0.0	0.0	0.0
5	-1.6	-0.7	-0.3	0.0
10	-3.2	-1.1	-0.5	0.0
15	-4.8	-1.6	-0.8	-0.1
20	-6.2	-2.2	-1.2	-0.3
25	-7.6	-4.1	-3.6	-0.7
30	-9.8	-6.8	-5.5	-1.4
35	-12.5	-9.1	-6.8	-2.5
40	-16.2	-11.8	-7.9	-3.7
45	-24.6	-14.7	-9.1	-5.4

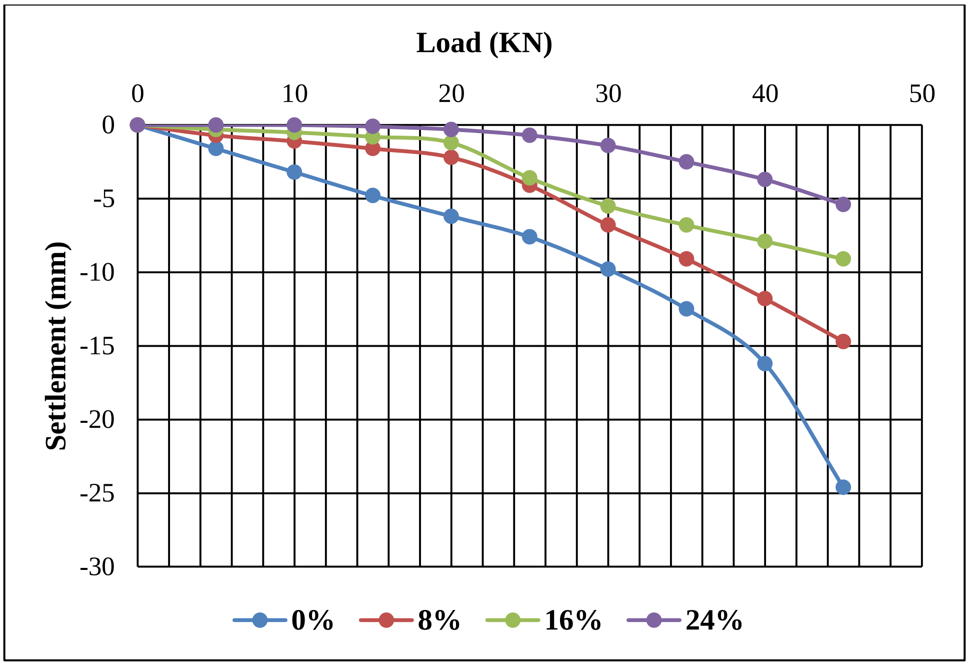


Figure5.14. Comparison curve of 100 mm plate at various percentages of fine gravel

Case 2: 150 mm at various percentages of fine gravels

Table 19: Result of 150 mm plate at various percentages of fine gravel

Load (KN)	**Settlement(mm)**			
	0%	**8%**	**16%**	**24%**
0	0.0	0.0	0.0	0.0
5	-2.1	-1.1	-0.5	0.0
10	-4.1	-1.6	-0.8	0.0
15	-6.3	-2.1	-1.1	-0.3
20	-9.1	-3.2	-2.1	-0.6
25	-11.5	-5.9	-4.8	-1.1
30	-14.2	-8.1	-6.5	-2.9
35	-17.5	-10.9	-7.7	-4.5
40	-24.3	-13.7	-8.9	-6.5
45	-30.6	-17.5	-10.2	-7.8

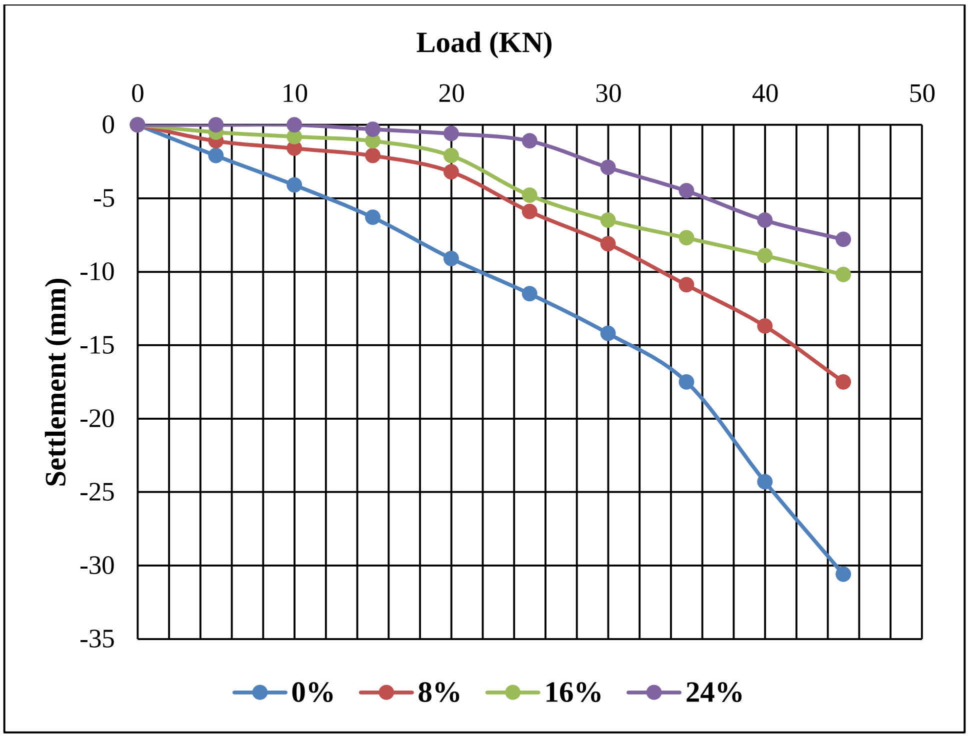


Figure5.15. **Comparison curve of 150 mm plate at various percentages of fine gravels**

Case 3: 200 mm at various % of fine gravels

Table 20: Result of 200 mm plate at various percentages of fine gravel

Load (KN)	**Settlement(mm)**			
	0%	**8%**	**16%**	**24%**
0	0	0	0	0
5	-3	-1.4	-0.8	0
10	-5.4	-1.9	-1.1	-0.1
15	-7.1	-2.8	-1.6	-0.5
20	-10.2	-4.1	-2.9	-0.8
25	-13.1	-7.1	-6.1	-1.5
30	-17.3	-9.4	-7.9	-3.8
35	-22.2	-12.5	-9.8	-5.9
40	-27.5	-16	-11.2	-7.4
45	-34.1	-21.5	-12.8	-9.3

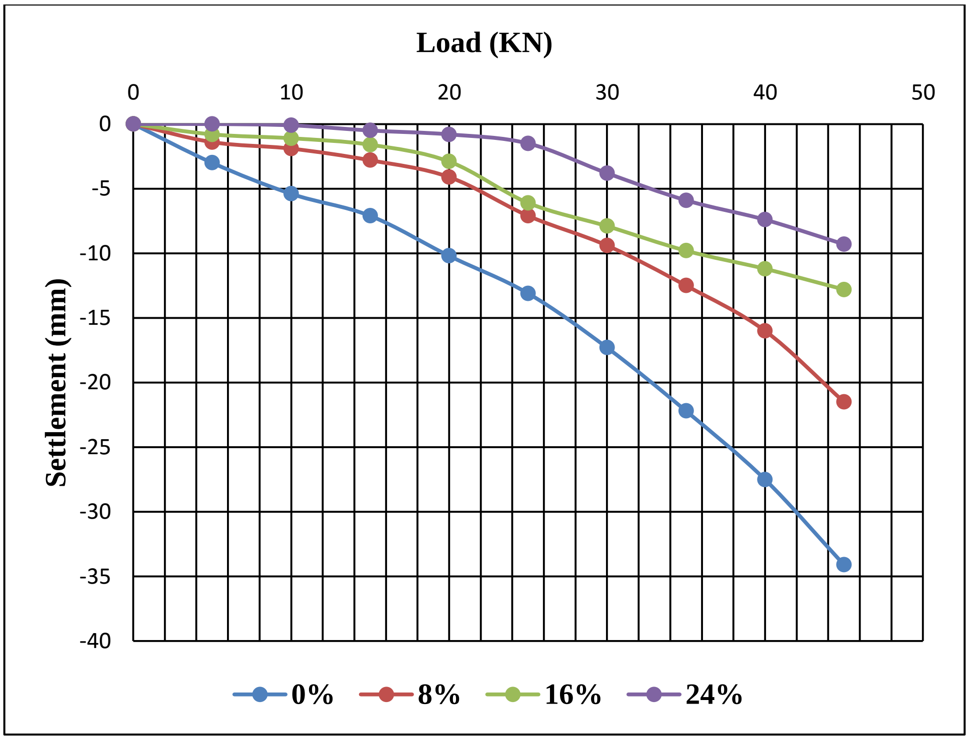


Figure5.16. Comparison curve of 200 mm plate at various percentages of fine gravels

- **Effect of variation in circular plate size at each % of fine gravels-** At a particular percent of fine gravels, load settlement curves are compared for plate of 100 mm, 150 mm and 200 mm diameter. Following graphs can be plotted from the results obtained from plate load test which was discussed in the previous section.

  From the graph it can be seen that for a particular percentage of fine gravels as the plate size increases the settlement at a particular load keeps on increasing. The results of plate load test are discussed here.

a. **At 8% of fine gravels-** In this 8% of fine gravels are added in sand by weight of coarse sand and density of this mix was found to be 19.88KN/m^3. And results are compared for each plate size.

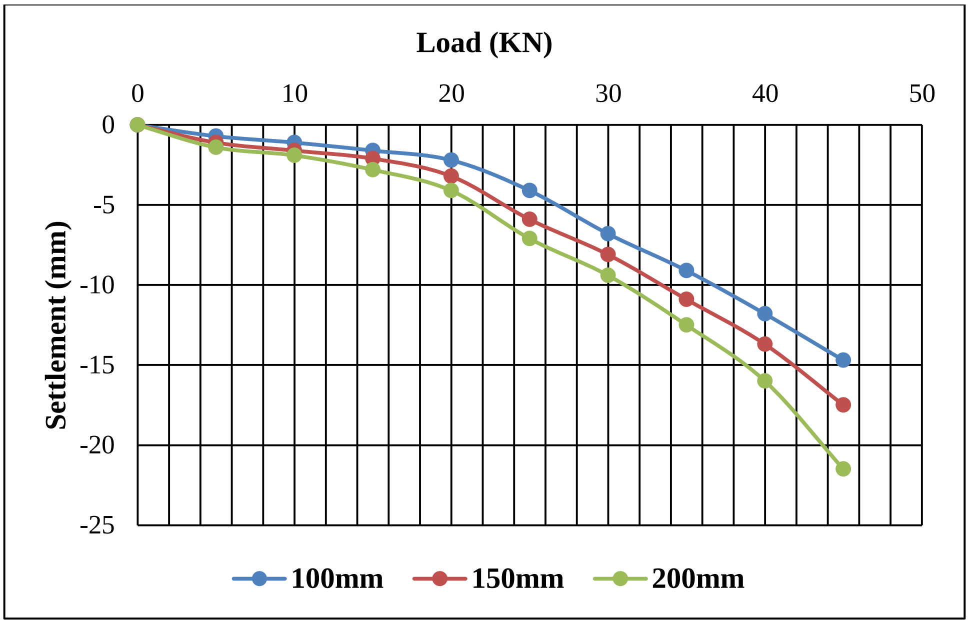


Figure5.17. Load settlement curve for 8% fine gravels for different plate size

b. **At 16% of fine gravels -** In this 16% of fine gravels are added in sand by weight of coarse sand and density of this mix was found to be 20.56 KN/m^3. And results are compared for each plate size.

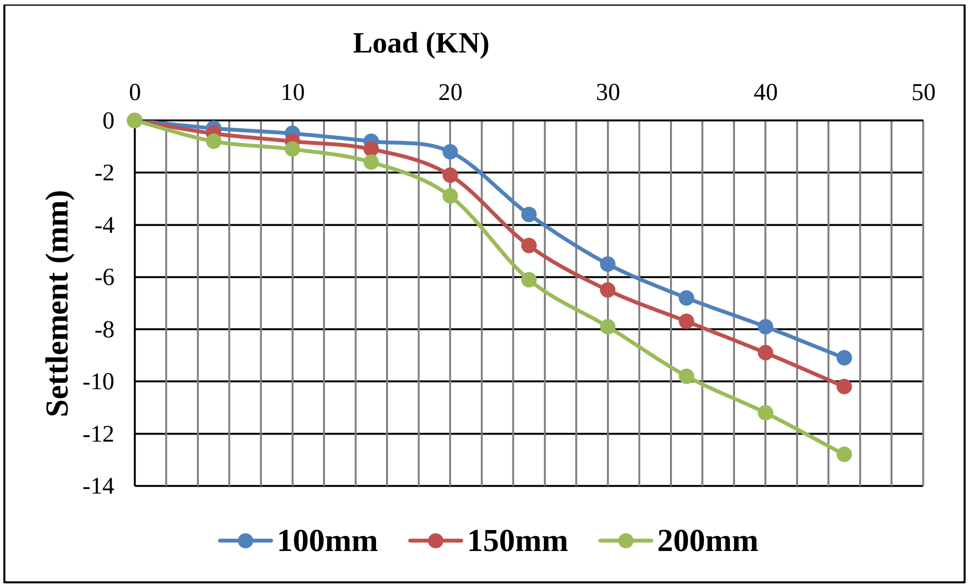


Figure5.18. Load settlement curve for 16% fine gravels for different plate size

c. **At 24% of fine gravels -** In this 24% of fine gravels are added in sand by weight of coarse sand and density of this mix was found to be 21.24 KN/m^3. And results are compared for each plate size.

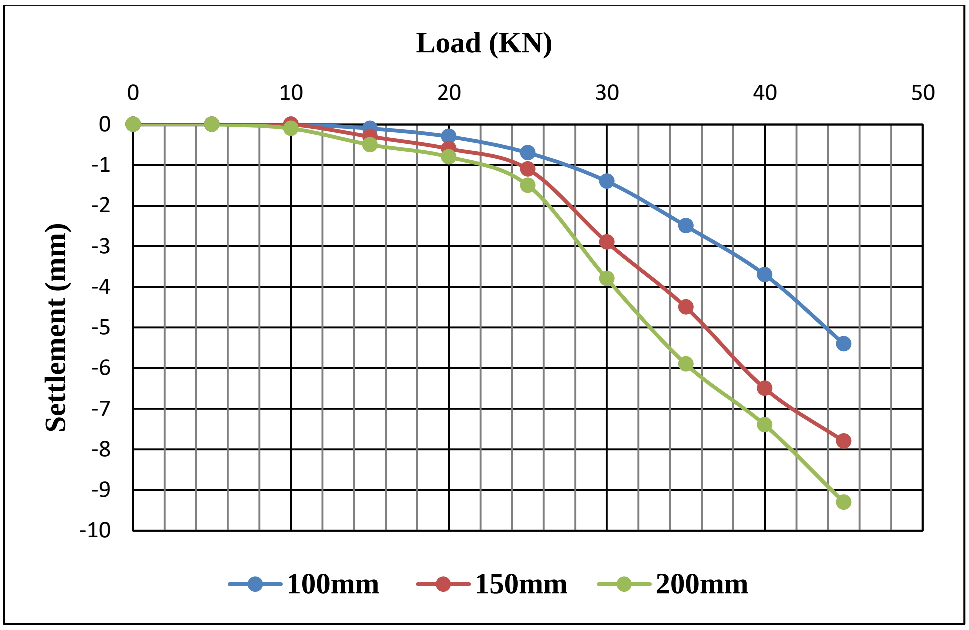


Figure5.19.Load settlement curve for 24% fine gravels for different plate size

5.3.3. Scale Effect of Box on Load Settlement Curves- Modeled plate load test has also been conducted on large scale setup/ tank of 1.5 m x 1.5 m x 0.8 m. Due to the effect of boundary conditions in small tank the results are conservative. Load settlement curves of small scale and large scale tank was compared for 100 mm, 150 mm and 200 mm diameter plates at different percent of fine gravels.

From the result of plate load test it can be observed that at a particular load value the settlement increases for large size box than small size box.

a. **100 mm diameter plate at various % of fine gravels**

Table 21: Comparison of results on small & large scale test on 100 mm plate

Load(KN)	Settlement(mm)							
	0% Small scale	8% Small scale	16% Small scale	24% Small scale	0% Large scale	8% Large scale	16% Large scale	24% Large scale
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	-1.6	-0.7	-0.3	0.0	-5.44	-1.8	-0.9	-0.6
10	-3.2	-1.1	-0.5	0.0	-14.22	-2.0	-1.8	-1.0
15	-4.8	-1.6	-0.8	-0.1	-28.12	-5.9	-4.2	-1.8
20	-6.2	-2.2	-1.2	-0.3	-44.45	-18.2	-13.1	-8.2
25	-7.6	-4.1	-3.6	-0.7	-48.5	-36.8	-30.9	-20.2
30	-9.8	-6.8	-5.5	-1.4				-39.0
35	-12.5	-9.1	-6.8	-2.5				
40	-16.2	-11.8	-7.9	-3.7				
45	-24.6	-14.7	-9.1	-5.4				

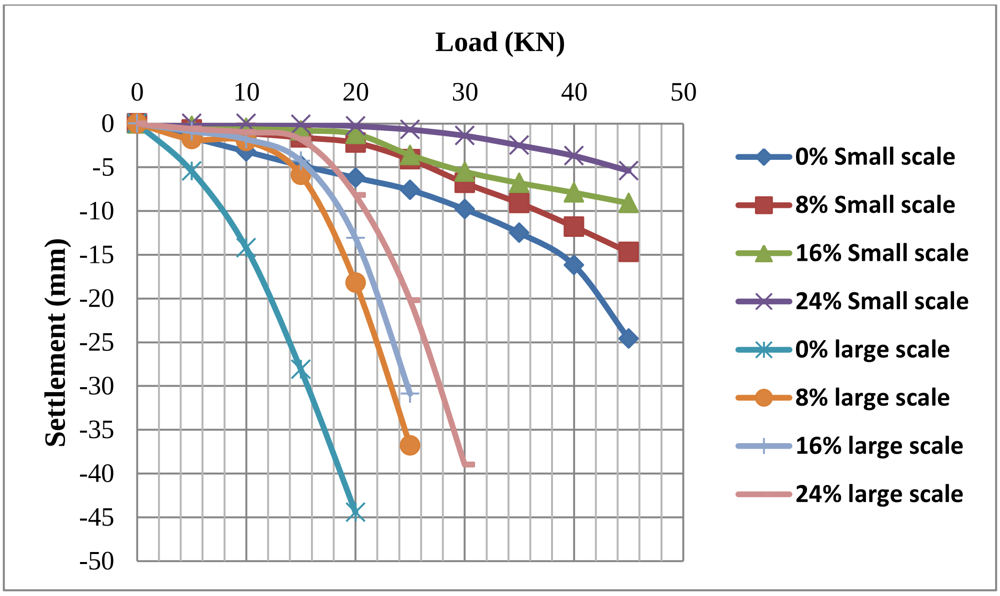


Figure5.20. Comparison of small & large scale test results on 100 mm plate

b. 150 mm diameter circular at various % of fine gravels

Table 22: Comparison of results on small & large scale test on 150 mm plate

Load(KN)	**Settlement(mm)**							
	0% Small scale	8% Small scale	16% Small scale	24% Small scale	0% Large scale	8% Large scale	16% Large scale	24% Large scale
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	-2.1	-1.1	-0.5	0.0	-6.5	-2.9	-1.5	-0.9
10	-4.1	-1.6	-0.8	0.0	-16.5	-10.2	-3.4	-1.6
15	-6.3	-2.1	-1.1	-0.3	-35.2	-18.2	-9.6	-4.5
20	-9.1	-3.2	-2.1	-0.6	-48.5	-39.6	-17.3	-10.3
25	-11.5	-5.9	-4.8	-1.1		-45.6	-31.8	-23.8
30	-14.2	-8.1	-6.5	-2.9				-41.8
35	-17.5	-10.9	-7.7	-4.5				
40	-24.3	-13.7	-8.9	-6.5				
45	-30.6	-17.5	-10.2	-7.8				

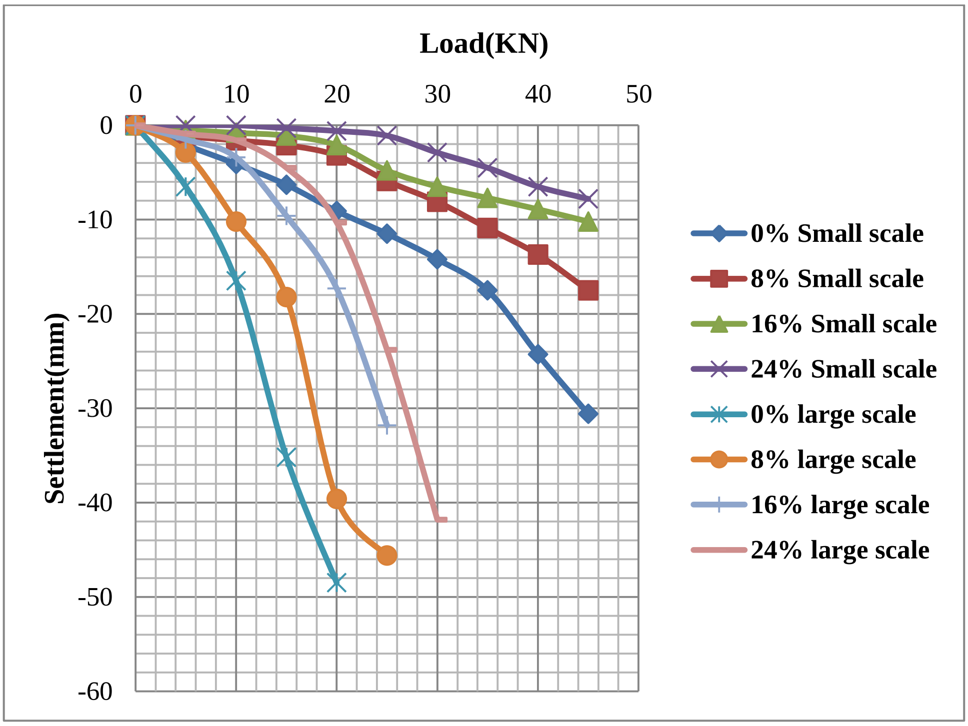


Figure5.21. Comparison of results on small scale & large scale test on 150 mm plate

c. **200 mm diameter circular at various % of fine gravels**

Table 23: Comparison of results on small & large scale test on 200 mm plate

Load(KN)	Settlement(mm)							
	0% Small scale	8% Small scale	16% Small scale	24% Small scale	0% Large scale	8% Large scale	16% Large scale	24% Large scale
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	-3.0	-1.4	-0.8	0.0	-8.2	-4.5	-2.5	-1.2
10	-5.4	-1.9	-1.1	-0.1	-17.5	-12.6	-5.6	-2.9
15	-7.1	-2.8	-1.6	-0.5	-37.6	-28.9	-9.6	-5.8
20	-10.2	-4.1	-2.9	-0.8	-50.2	-43.5	-25.2	-15.6
25	-13.1	-7.1	-6.1	-1.5		-51.4	-40.8	-26.7
30	-17.3	-9.4	-7.9	-3.8				-46.7
35	-22.2	-12.5	-9.8	-5.9				
40	-27.5	-16	-11.2	-7.4				
45	-34.1	-21.5	-12.8	-9.3				

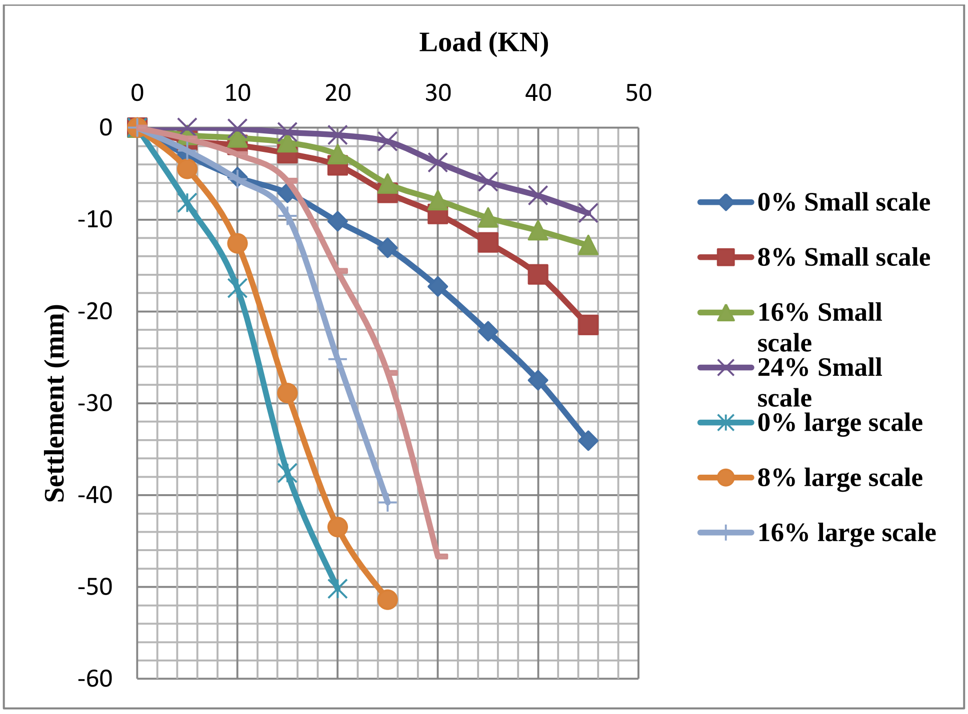


Figure5.22. Comparison of results on small scale & large scale test on 200 mm

5.3.4. Comparison of Numerical Simulation with Experimental Investigations- In this section, elastic results obtained from Abaqus software has compared with the experimental results for each plate size and at different densities.

From the comparison graphs it can be observed that at particular load the settlement is more in case of elastic analysis than in plastic/ elasto- plastic analysis (experimental work).

- **For 100 mm diameter plate-**

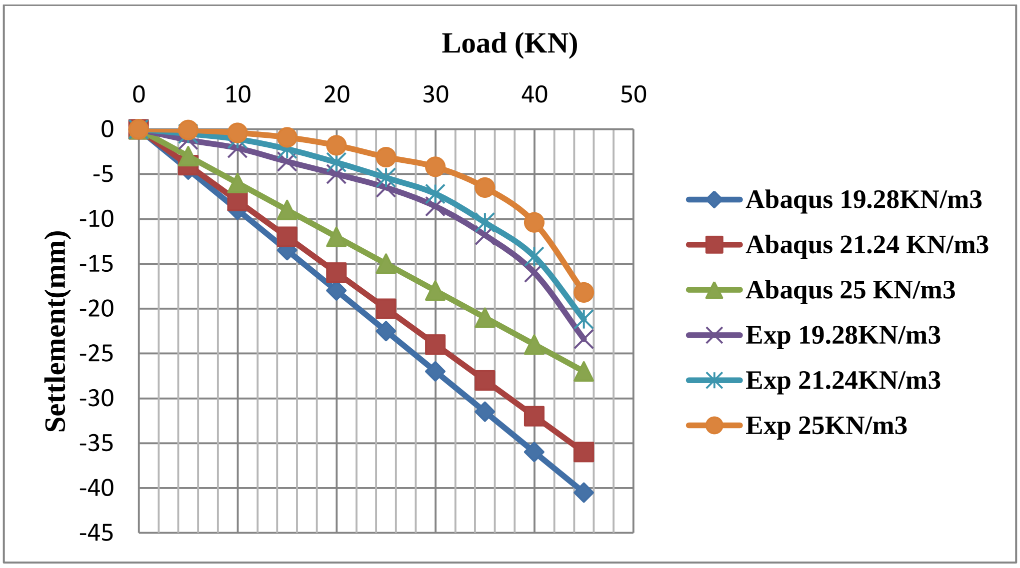


Figure5.23. Comparison of numerical & experimental results on 100 mm

- **For 150 mm circular plate**

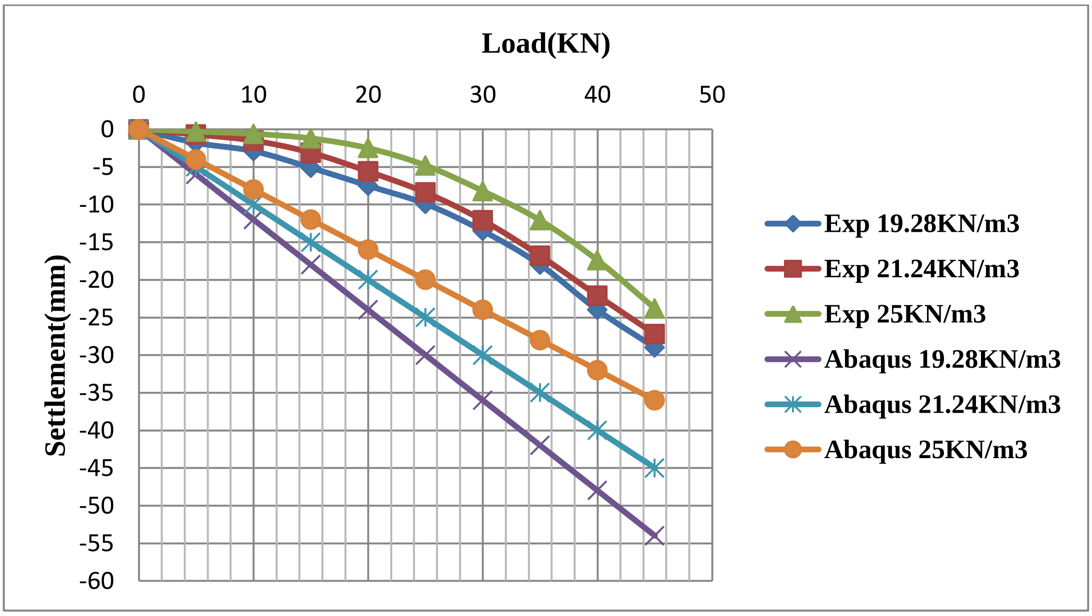


Figure5.24. Comparison of numerical & experimental results on 150 mm

- **For 200 mm circular plate**

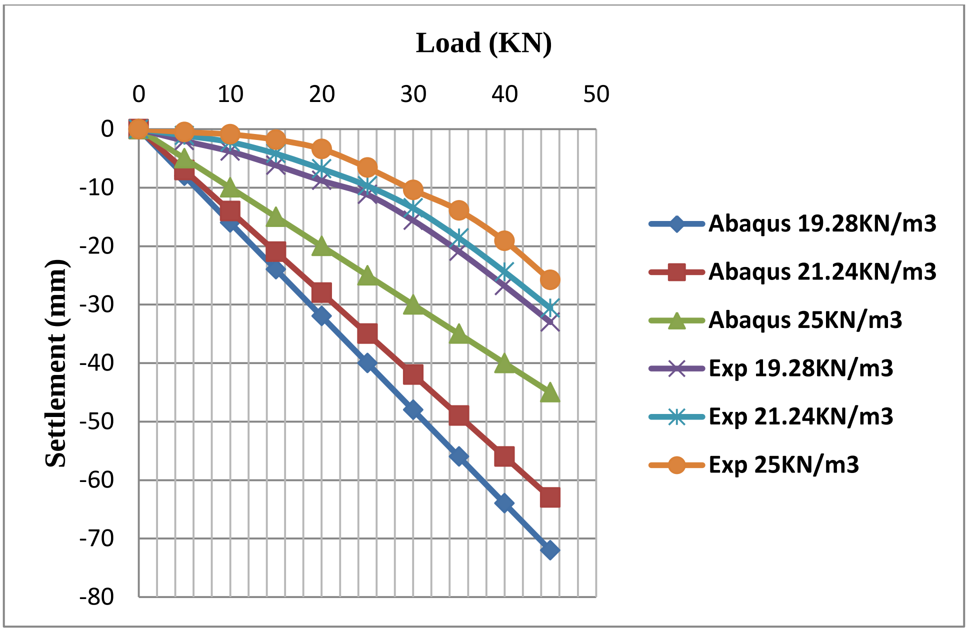


Figure5.25. Comparison of numerical & experimental results on 200 mm

5.4. Discussion of Results- From the above results that we get from plate load test on circular plate under different conditions, following points may be inferred using the curves.

1. In every condition in which plate load test has performed, the settlement of plate increases with application of load increment.
2. It is observed that as the sand gets densified the load at a particular settlement increases which means the load carrying capacity of sand increases. This may be due to the better interlocking within the soil particle which results in more resistivity to load applied. So, to achieve particular settlement more loads are required in comparison to less densified sand.
3. With the increment in the percentage of fine gravels in sand the settlement at particular load goes on decreasing and the load at a constant settlement increases. This improvement may be due to more stiffness of sand mixed with fine gravels than the sand without fine gravels. The stiffness of coarse sand has been increased due to increase in overall density of sand.
4. It can also be inferred that as the plate size varies from 100 mm to 200 mm, the settlement at a particular load increases. As the size of plate increases the size of pressure bulb also increases. The settlement is nothing but the deformation of the soil inside the pressure bulb.

5. The small scale plate load test results are also compared with large scale which shows that the settlement for a particular load the settlement is more in case of large scale modeling. This may be due to the boundary condition effect i.e. confineness in small scale setup.
6. The percentage improvement in bearing capacity due to addition of fine gravel in coarse sand is calculated for large scale plate load test viz. for 100 mm plate size, percentage improvement is 57%, 71% and 93% on mixing of 8%, 16% & 24% fine gravels respectively, for 150 mm plate size, percentage improvement is 42%, 92% and 108% on mixing of 8%, 16% & 24% fine gravels respectively and for 200 mm plate size the percentage improvement is 28%, 82% and 109% on mixing of 8%, 16% & 24% fine gravels respectively.
7. The experimental results are compared with the numerical simulation means elasto-plastic/ plastic analysis is compared with elastic analysis which shows that the settlement in elastic analysis is more than experimental investigations. For a particular load value, the settlement is more is case of elastic analysis as compared to experimental investigations

CHAPTER 6

CONCLUSION

A large number of experiments have been performed to find the geotechnical properties of sand used and mainly plate load test has been performed on the modelled footing under various conditions. The various condition are created by changing the density of sand, by adding the various percentage of fine gravel, by changing the size of modelled footing that is circular plate. So, from all these condition and experiments performed following conclusions can be made-

- With increment in plate size the settlement of model footing also increases for a particular load and the load at a particular settlement decreases.
- With increase in density of sand of sand the settlement for particular load goes on decreasing.
- With increase in percentage of fine gravels the settlement for particular load goes on decreasing.
- The large scale test is less conservative as compared with the small scale test setup.
- It is observed that the settlement under circular plate is more if we have used the large sized steel box in comparison to the small sized box.
- For each plate size, the percentage improvement in bearing capacity of sand maximum when 24% of fine gravels are mixed.
- Elastic settlement as found by numerical simulation is more than plastic settlement occur in experimental plate load test. So, the elastic analysis is less conservative.

6.1. Future Recommendations of this work- After conducting the small scale and large scale plate load test for different condition, this work can be extended in following ways for future study.

1. The similar work can also be done on very large scale modelled plate load test with loading arrangement as reaction truss and the effect of type of loading on load settlement curves can be investigated.
2. Instead of dry soil, wet soil can be used to investigate the effect of moisture on load settlement curves.
3. Particle size present in soil can be correlated with plate sizes used in plate load test.
4. Plaxis software can be used to simulate the similar problem for plastic analysis.

REFERENCES

1. Alawaji, H.A. (2001). "Settlement and bearing capacity of geo-grid reinforced sand over collapsible soil." Journal of Geotextiles and Geo-membranes, Elsevier, Science Direct, vol. 19, pp. 75-88.

2. Amr, Z. EL Wakil.(2013). “Bearing Capacity of Skirt Circular footing on Sand.” Department of structural Engineering, Faculty of Engineering, Alexandria University, Alexandria, Egypt, Alexendra Engineering Journal, Vol. 52, pp. 359-364.

3. Araújo, D. A. M. Costa C. M. L and Costa Y. D. J. (2017). “Dimension Effect on Plate Load Test Results.” Proceedings of the 2nd World Congress on Civil, Structural, and Environmental Engineering (CSEE’17) Barcelona, Spain.

4. Bacha, Nagraj., and Kiran. (2015). “An Experimental Study on Behavior of Bearing Capacity and Settlement of Circular and Square Footing Resting on Reinforced Sand Bed Stratified with Lateritic Soil.” International Journal of Engineering Research & Technology (IJERT), Vol. 4 (6).

5. Consoli, N.C., F. Schnaid, and J. Milititsky. (2000). "Interpretation of plate load test on residual soil site," Journal of Geotechnical and Geo-environmental Engineering, ASCE, vol. 124, pp. 0857-0867.

6. Dash, Sujeet kumar. S, Sireesh. and Sitaram T.G (2003), “Model studies on circular footing supported on geo-cell reinforced sand underlain by soft clay.” Journal of Geotextiles and Geo-membranes, Elsevier, Science Direct, vol. 21, pp. 197-219.

7. Dixit, M.S., K.A. Patil. (2009). “Study of effect of different parameters on bearing capacity of soil” IGC 2009, Guntur, INDIA.

8. Hanna, A.M. (1999). “Bearing capacity of foundations on a weak sand layer overlying a strong deposit.” Canadian Geotechnical J, 19:392–396.

9. Hanna, A.M., Meyerhoff G.G. (1998). “Ultimate bearing capacity of foundations on a three-layer soil with special reference to layered sand.” Can. Geotechnical J. 16:412–414.

10. Hanna, A.M., Meyerhoff G.G.(1997). “Design chart for ultimate bearing capacity of foundations on sand overlying soft clay.” Can. Geotechnical J. 17:300–303.

11. Ismael, Nabil F., (1996) “Loading test on Circular and Ring plates in very dense cemented Sands,” Journal of Geotechnical Engineering , ASCE, vol 122 (4).

12. K. Ramu and G. Ch. Satyanayana. (2015) “Effect of Fresh fill on Bearing Capacity of Footing.” 50th Indian Geotechnical Conference, Pune, Maharashtra, India.

13. Kesharwani, R.S., Sahu A.K., and Khan N.U. (2015) “Load settlement behavior of sandy soil blended with coarse aggregate.” Journal of Asian Scientific Research, ISSN (e): 2223-1331/ISSN (p): 2226-5724.

14. Kumar, A., Walia B.S, and Saran S. (2005). "Pressure settlement characteristics of rectangular footings on reinforced soil." J. Geotechnical Engg., Springer Science and Business Media, Netherlands, 23: 469–481.

15. Lavasan, A.A, and Ghazavi Mahmoud. (2012). "Behaviour of closely spaced square and circular footings on reinforced sand." Civil Engineering Department, K.N. Toosi University of Technology, Tehran, Iran. The Japanese gotechnical society, Soils and Foundations, Vol. 52, pp. 160-167.

16. Lin P.S, Yang, L.W. , Juang C.H.,(1998), " Subgrade Reaction and Load Settlement characteristics of Gravelly Cobble Deposits by Plate Load Tests," Canadian Geotechnical Journal ,Vol. 35 , pp801-810.

17. Moayed, R., Rashidian V., and E. Izadi. (2012). "Evaluation on Bearing Capacity of Ring Foundations on two-Layered Soil", International Journal of civil, environmental, Structural, Construction and Architectural Engineering Vol:6, No:1.

18. Mohite, N.R., and S. Admane. (2015). "Plate load test on undisturbed soil sample," Engineering and Technology Research (IJSETR), vol. 4, pp. 1042-1045.

19. Mosadegh, and Nikraz H. (2015) "Bearing capacity evaluation of footing on a layered-soil using ABAQUS", Department of Civil Engineering, Curtin University, Australia J. Earth Science Climatic Change.

20. Nagraj, T.K.,(1997), " Improvement of the bearing capacity of soil using Geogrid Reinforcement," journal of Indian Geotechnical Conference , Vol.5 (13) , pp 295-299.

21. Pusadkar, S.S., and Baral, M. (2015) "Behavior of square footing resting on two layered clay deposits."50th Indian Geotechnical Conference, December, Pune, Maharashtra, India.

22. Reza, A.S., and· Issa Shooshpasha. (2015). "Experimental Study on Load Settlement Behaviour of Cement Stabilised Footing with Different Dimension on Sandy Soil." Arab J. Science and engineering, vol.40, pp. 397-406, DOI 10.1007.

23. Trivedi, A. and. Sud V. K. (2007). "Settlement of compacted ash fills." J. geotechnical and geo-engineering Springer Science, Business Media B.V, vol. 25, pp. 163-176.

24. Verma, S. K., Jain P. K. and Kumar Rakesh. (2013). "Prediction of Bearing Capacity of Granular Layered Soil by Plate Load Test", International Journal of Advance Engineering Research and Studies, Volume 2, Issue 3, pp. 142-149.

25. Zhu Ming and Michaoski R. L. (2010). "Bearing Capacity of Rectangular Footing on Two layer Clay." American Society of Civil Engineers, pp. 997-1000.

26. IS: 2720 (Part 2)," Determination of water content," 1973.

27. IS: 2720 (Part 13), "Direct Shear Test", 1986.

28. IS: 1498, "Classification and identification of soils for general engineering purposes," 1970.

29. IS: 1888, "Method of load test on soils," 1982.

30. IS: 2720 (Part III/Sec 1) -1980, reaffirmed 2002, "Methods of test for soils: Part-3 , Determination of Specific gravity, Fine grained soils", Bureau of Indian Standards.