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

A Dissertation submitted in partial fulfilment of the requirement for the award of degree of

Master of Technology
In
Geotechnical Engineering

By

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CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report entitled "**Load Settlement Behaviour of Square plate in Sandy Soil Mixed with Fine Gravels and its Numerical Modelling in Abaqus 6.10**" in the partial fulfilment of the requirement for the award of the degree of "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 out under the supervision of Prof. A.K Sahu, Department of Civil Engineering.

I have not submitted the matter embodied in the report for the award of any other degree or diploma to any other institution.

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CERTIFICATE

This is to certify that above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

This project work evaluates the benefits of plate load test in investigating the effect of density of coarse sand and fine gravels mixed it with the shape and size of the plates on the bearing ability of soil. The plates used in this test is square shaped with dimension 100mm, 150mm & 200mm. For conducting the tests, a steel box of size 40cm x 70cm x 50 cm has been modelled. The effect of density can be studied by conducting tests at various densities i.e. 19.28 KN/m^3, 21.42 KN/m^3 and 25 KN/m^3 by giving 50, 100 & 150 number of blows respectively. The effect of fine gravels can be studied by mixing different percentages of fine gravels i.e. 8% , 16 % and 24% by weight in the coarse sand. The same model has been modelled in the finite element software Abaqus 6.10 with the elastic analysis to compare its result with the experimental analysis. The scale effect of the box has also been studied in this project. For this purpose, the plate load tests were performed on the large sized box of size 1.5 m x 1.5 m x 0.8 m. This has been done to nullify the boundary effects of the small sized box.

The experimental result indicates that with increase in the density of sand, the footing settlement keeps on decreasing. Also the bearing capacity can be improved by adding fine gravels. It has been found that with increase in the size of square plate , the settlement of footing keeps on increasing. It is also observed that at any level of pressure , the settlement was found to be less in case of square plate as compared to that of circular plate. This observation is valid for any mix i.e. soil blended with different percentages of aggregates. This is also true for any plate size. It has also found out that the theoretical modelling results are less conservative than the experimental results.

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List of Abbreviations

Symbol	Title
KN	Kilo Newton
mm	Millimeter
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 gradation analysis
D_{10}	Diameter corresponding to 10% finer in the gradation analysis
D_{30}	Diameter corresponding to 30% finer in the gradation analysis
OMC	Optimum Moisture Content
MDD	Maximum Dry Density
G	Specific gravity

Chapter 1

Introduction

These days soil plays a very important role in civil engineering. Soil engineering is practically the base for the civil engineering. All our structures sustained on soil itself.

The load on the building is sustained by various beams, beams transfers the load to columns, columns to foundations and ultimately foundation transfers it to soil. Yet it is the soil that is going to sustain the load of the structure. Because of this reason it is very essential to know & analyze various properties of fine aggregates where the structure has to be constructed. A little displacement of soil below the structure can destroy it. That's why it is beneficial to know the properties like strength, bearing ability of soil, permeability of soil etc. before building of any structure.

In the region of Himalayan rivers, the large sized rocks are present in the soil. As the river of Himalayan regions moves in downward stream, the particle size of the soil will keeps on decreasing. It happens because of mechanical segregation i.e. weathering of the gravels. Anyhow, in the higher regions of Himalayas, the bearing capacity of the soil fluctuates because of variety of molecule sizes. That's why in this research plate load tests were done on the coarse sand mixed with fine gravels of sizes greater than 20 mm in different percentages. Bearing limit is a parameter, which can be analysed by performing the plate load tests for deciding the reasonableness of soil for sustaining the load of the superstructure. The bearing ability of the soil is the main parameter which has to be decided for the selection of type of footing as per the load of the structure. The soil ought to have a maximum limit of settlement so as the soil do not fail in shear or in collapse settlement. Its settlement must remain in the permissible limits. Expansive soil will have very low bearing capacity, hence they have to be reinforced by any method just to increase its bearing capacity. To upgrade the quality of establishment soil, a few strategies like compaction, electrical/warm adjustment, expansion of geo-material, geo-manufactured, fly fiery debris or haphazardly dispersed discrete strands are utilized.

To change the properties of the fine aggregates in the upper part of Himalayan regions, the sand is being mixed with the fine gravels of different sizes and in various percentages is readied. The fine gravels are defined as the stone pieces which are being limited to rounded or sub rounded adjusted particles

The fundamental point of this research is to upgrade the quality/bearing limit of the soil whereupon diverse sorts of structures rests.

Bearing capacity is a parameter which is being analysed by various tests. One of the test is plate load test. Bearing ability of the soil is a beneficial parameter to decide the type of the footing which has to be adopted for the construction to bear the load of the super structures. The size of the footing is also dependent on the bearing capacity of soil of that region. For the soil with low bearing ability values, the size of the footing should be taken more. However, the size of the footing will gets reduced if bearing capacity value of soil is high.

Ultimate bearing ability problem may be resolved with the use of numerical simulation or experiments. Numerical Simulation can be analyzed by using theories or finite element method like Abaqus software etc, whereas the second one is done by experimentation.

This study focuses on the first of the design criteria that is the ultimate bearing ability of shallow foundations and, in particular, foundations on cohesion-less soil. This research particularly found the effect of presence of coarse aggregate in sand and effect of density of sand on the bearing ability of soil.

To evaluate the consequence of presence of coarse aggregate of 20 mm in sand, the sand was mixed with different proportion of coarse aggregate and plate load test was conducted using 100 mm, 150mm and 200 mm model square footing

To evaluate the influence of density of sand on bearing ability, test box was filled in three layers and 50, 100 and 150 number of blows were applied on each layer using rammer of 2.5 kg and then plate load test was conducted using model square footing. Hence, the extensive literature explaining both theoretical and experimental studies associated with this issue has been done.

1.1 Scope of this Project:

This project work aims to examine the influence of different variables on the pressure settlement response of square footing placed on coarse sand. The different parameters whose effect was investigated are as follows.

The Scope of this research is-

- To manufacture the M.S box and M.S plates of specified size as follows:
  M.S Box is of 40 x 70 x 50 cm and M.S square plates are of 10, 15 and 20 cm plates.
- To determine the geotechnical properties of coarse sand like shear parameters, grain size distribution, compaction characteristics etc.
- To investigate the load settlement response of square plate of different size i.e. 100 mm, 150 mm and 200 mm at different densities of coarse sand. Density of soil was varied by applying different number of blows i.e. 50, 100 and 150 using rammer of 2.5 Kg..
- To study the influence of shape on the settlement by comparing the load settlement response of sand with square and circular plates at different densities.
- To examine the load settlement response of each square plate placed on coarse sand bed blended with different percentages of fine gravel. The different percentages of fine gravel that are blended with sand are 8%, 16% and 24% by weight.
- To perform the plate load tests on the large sized box of size 1.5 m x 1.5m x 0.8m using square plates of size 100mm, 150mm & 200mm. This test is being done to examine the influence of boundary conditions on the small sized box.
- To perform the numerical modelling of the above model using Abaqus Software by elastic analysis.
- To compare the results of numerical simulation with the experimental results.
- To conclude the results.

1.2 Thesis Outline

The basic focus of this thesis is to find the effect of size of modelled footing on Pressure settlement response and on bearing ability of soil..

Chapter 2 includes an extensive literature review of research on the estimation of bearing ability and load settlement response of footings resting on reinforced and unreinforced soil.

Chapter 3 provides the background of material that were used. The properties of the material and model used will be discussed in this chapter. Different type of experiments performed will be discussed in this chapter.

Chapter 4 includes detailed discussion on the plate load test performed in the laboratory on modelled footing and its results. The plate load test results for different conditions will be compared in this chapter.

Chapter 5 includes the results obtained from experimental investigation. Various cases and problems according to plate size, shape and percentage of reinforcement are examined and results will be discussed in this chapter.

Chapter 6 includes the summary and conclusion of this research presented along with future recommendation.

Chapter 2

Literature Review

In this chapter recent work done by the different researchers on this issue is review and presented. Foundation designs must be adequate to both the strength and serviceability criteria. The soil below the foundations must have appropriate bearing capacity value so as to carry the load of the super structure without having considerable settlements or gets failed in shear. The cracks are made in the soil mass upon reaching a particular stress condition.

Alawaji (2001): In his study he evaluate the benefits of geo-grid-reinforced sand over collapsible soil to constrain settlement. He used a circular plate of 100mm and Tensor SS2 geogrids to perform Model Plate load test. The width by depth ratio of the geo-grid were changed to find their cosequences on the settlement, young's modulus and bearing capability ratios. From his tests results obtained it was observed that the performance of the sand–geogrid system increased with increasing geo-grid width and reducing geogrid depth. He also observed that by this method the bearing ability of sand over collapsible soil can be increased and the settlement can be reduced.

Trivedi and Sud (2003): In this paper, they had performed to find out the settlement of footings placed on compacted coal ash. Coal ash used was that manufactured 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 various degree 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 on dry side of optimum is more than that on wet side of optimum.

Dixit M.S and Patil K.A (2007): They study the cosequence of shape, width and depth of footing on soil's bearing capacity. 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 ability obtained from different methods for different shapes. They observed that the bearing ability of strip footing was least as compared with square, circular and rectangular shaped footings by local shear failure or terzaghi's method. And in IS code method, the ultimate bearing capacity was observed to be found for circular footing and minimum for strip footing. In general shear failure case by Terzaghi's method, bearing capacity was maximum for strip and minimum for circular. And in case of IS code method max for square and min for circular. They concluded that the important parameters which effect the bearing ability of soil are, breadth of the foundation, unit weight, cohesion and depth of the foundation, and friction angle.

Arash Alimardani Lavasann and Mahmoud Ghazavi (2012) In this paper they describe an experimental investigation conducted to investigate the ultimate bearing ability, the settlement and the two types of closely spaced footings, one having square shapes and the other having circular shapes, on reinforced and without reinforced soil. They performed total number of 20 large-scale model tests on sets of closely spaced circular and square footings placed on unreinforced and reinforced sand with more than one layers of geo-grid. From the experimental results they conclude that there is a huge enhancement in the ultimate bearing capability, whereas the settlement and tilting of the interfering footings at the ultimate load increased.

Verma *et al.* (2013): They performed plate load test to observe load settlement behaviour 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 as we increase the height of top layer of fine gravel will reduce the settlement and the ultimate bearing ability is dependent on the thickness of top layer.

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

Amr Z. and Wakil (2013): They calculated the bearing ability 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 of the footing and increases its bearing capacity of soil system. The effects of skirted length and the relative density of sand on the 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 fine aggregates than in case of medium and dense fine aggregates.

Mosadegh A and Nikraz H (2015): They modeled the soil as an elasto-plastic material and all the analysis we done using FEM software, ABAQUS.
Sand's bearing capacity values were found through ABAQUS and then they are compared with those which are being predicted by Terzaghi's equation. It was found that bearing capacity obtained by Terzaghi's equation was slightly less than that obtained from FEM analysis.

D. A. M. Araújo and C. M. L. Costa (2015): 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, conventional failure criteria were used to find the bearing capacity. 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.

Kiran and Nagraj Bacha (2015)- In this investigation they studied the conduct of sand which is being reinforced for improving the bearing ability and reducing the settlement when square footing and circular footing are used. 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. From the test results they observed that by providing a perfect set up of the reinforcing geo-grid, the bearing capacity of sand can be improved as compared to the unreinforced sand & settlement can be reduced. 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 performs good and have high load carrying capacity than circular footing.

Sunil and M. Baral (2015): In this study they determine the bearing ability of surface footing of square shaped which rests on two layered cohesive soil system by using 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 *) enhances 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.

Reza Alijani Shirvani (2015): In this paper the load settlement behavior of cement stabilized footing with various dimension on soil 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 reveals the increase in the bearing ability and reduction of settlement of the system.

Mohamed and Vanapalli (2016): They have determined the bearing capacity of sandy soils using plate load tests , cone penetration tests and standard penetration tests.

Samny, Sideek and Elsamee (2016): 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 young's modulus, Es of sand 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.

Chapter 3

Materials & Methods

3.1 Material and Equipment used

Different material and methods used to fulfil the objective of this research work.

The material and equipment used are as follows.

3.1.1 Coarse Sand

The Coarse sand is taken from the contractor which 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.

Fig.3.1: Coarse sand

3.1.2 Fine Gravels

Fine gravel is defined as an aggregate most of which is retained on 4.75mm IS sieve. The broken stone is generally used as a coarse aggregate. The fine gravels size ranging from 10mm & 20 mm are used for enhancing the bearing ability of the coarse sand.

Fig. 3.2 : Fine gravel

3.1.3 **M.S Steel Box**

It was manufactured by the steel workshop. The size of Box was modelled on the basis of IS code and on the basis of the previous researches. As per IS 1888:1982 the width of box should be five times the breadth of test plate such that complete failure zone can be formed without any interference of sides of the box. Keeping the IS code criteria in mind Box of size 400x700x500 mm was adopted for square plate of 100, 150 and 200mm size. The tests were performed in the college laboratories.

To examine the scale influence of the box, the large sized box of dimension 1.5m x 1.5m x 0.8m is used for carrying out the plate load tests on the square sized plates of dimension 100mm, 150mm and 200mm. The tests has been carried out at the consultancy in Pitampura, Delhi (near college).

Fig.3.3. (a) M.S steel box of size 40mm x 70mm x 50mm

Fig. 3.3 (b) Large sized rectangular steel box

3.1.4 **M.S Steel Plate**

Plates of mild steel were manufactured by the steel workshop. The size of square plates used are 100 mm, 150 mm and 200 mm of 10mm thickness.

Fig. 3.4: M.S square steel plates of size 100mm & 150mm respectively

Fig.3.5: M.S square steel plate of size 200mm

3.1.5 ACTM

This compression machine has the loading capacity of 5000KN. The rate of loading can be varied by changing the load rate of the machine.

Fig.3.6: Placed MS steel box in ACTM machine

3.1.6 Dial Gauge

A dial gauge which can measure settlement of range of 0.001mm was used to record the settlement of footing. The dial gauge was placed over the footings.

3.2 Experiments Performed

3.2.1. Properties of Coarse Sand

The various properties of coarse sand which are being analysed are as follows:

3.2.1.1 Specific Gravity

It can be determined by using pycnometer method as per IS 2720 part 3.

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) = $M_2 – M_1 / (M_2 – M_1) – (M_3 – M_4)$

Fig. 3.7: Pycnometer used for the determination of specific gravity

3.2.1.2 Particle Size Distribution

The gradation analysis in the 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 10minutes. After sieving has been done, the material retained 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.

Fig. 3.9: Sieve shaking of coarse sand

3.2.1.3 Compaction Characteristics

Standard proctor test was conducted as per **IS 2720- part 7- 1980.** It was conducted to find out the OMC and MDD 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 number of blows was applied to each layer with the help of rammer of 2.6kg 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. From the graph, OMC and MDD can be obtained.

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

Where γ = Bulk density in KN/m^3.

w = Water content in percentage.

 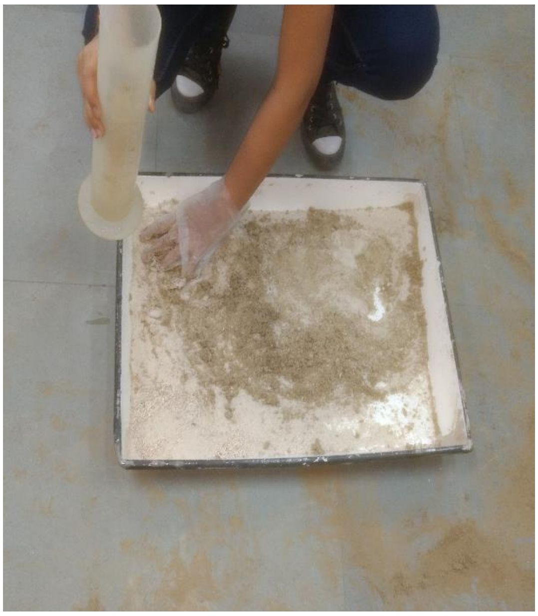

Fig. 3.10 (a) Mould filled with the coarse sand

(b) Mixing of coarse sand with water to carry out the standard proctor test

3.2.1.6 Direct Shear Test

This test was performed to find the shear parameters of sand using direct shear apparatus as per **IS 2720: Part 13**. The sample was prepared at optimum moisture content of size 60 x 60 x 25mm. The specimen of the shear box is sheared at rate of 1.25mm/min under a normal stresses of 50,100 and 150 KPa. The shear strength parameters of various compacted specimens were determined from shear stress versus normal stress plots**.**

 

Fig.3.11: Direct Shear apparatus

3.2.2. Properties of Fine Gravel

The various properties of coarse sand which are being analysed are as follows:

3.2.2.1 Specific Gravity

It is supposed to be a measure of strength of material. It helps in the identification of the aggregate.

To perform specific gravity of aggregates, we need a weigh balance of more than 3 kg capacity, of such a type and shape so as to allow the basket containing the sample which is suspended from the beam and then weighed in water.

Take 2.5 kg of coarse aggregate of size greater than 10mm. Wash them thoroughly. Then place them in a basket and submerged it in water at a temp. between 22˚C and 32˚C with a cover. Remove the air which is being entrapped by lifting the basket which contains the sample 25 mm. Take the weight of aggregates in water (W_1). Remove the basket and aggregates from water and allow to drain for some minutes. Empty the aggregates from the basket. Put the empty basket in water and note the weight (W_2). Keep the aggregates in oven at a temp. of 100˚C to 110˚C for 24 hours. Take it out from the oven and cool it down and note the weight. (W_3).

Specific Gravity = Weight of the material / 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.

3.2.2.2 Fineness Modulus

It can be defined by a number which shows the average size of the particles in fine gravels. The results of the tests will be discussed in the next chapter.

3.2.3. Plate Load Test

It is a field test used to estimate the ultimate bearing ability of soil and settlement under given loading. 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 consists of bearing plates, test tank, loading arrangement and dial gauge. Details of the equipment used was discussed in the previous section.

The load was applied at loading rate of 1KN/sec. using ACTM and the settlement of modelled footing was recorded using dial gauge. Different conditions on which model load test was conducted are as follows.

3.2.3.1 Effect of density-

The plate load test was conducted at different density for that the coarse sand was packed in tank in three equal layers, each layer being given 0 number of blows of rammer 2.6 kg for case 1, 50 no. of blows for Case 2 and 100 no. blows for Case 3 and 150 no. of blows for Case 4. Each square plate of size 100mm, 150mm and 200mm was tested at each density of sand achieved due to different no. of blows as mentioned in table 1.After conducting each test on plate the box was then emptied and again filled for the next test. The results of each plate load test are discussed in the upcoming chapters.

Table 3.1: Various cases done for examining the effect of density of sand

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.	0	250	17.8
2.	50	270	19.28
3.	100	300	21.24
4.	150	350	25.2

Fig.3.12: (a) Providing number of blows to sand for increasing its density
(b) Placement of square plate over the top of soil

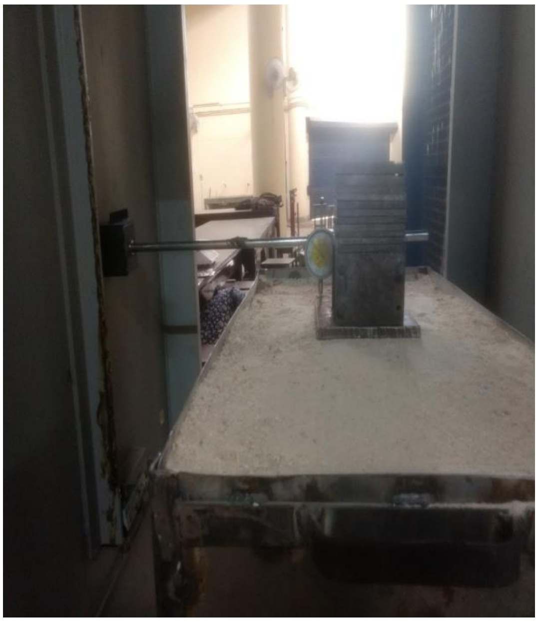


Fig. 3.13 (a) Arrangement of setup for performing plate load test

(b) Plate load test in compression testing machine

3.2.3.2 Effect of fine gravel

The Plate load tests was done on sand when blended with different percentage of fine gravels by weight of sand. The percentages at which each plate was tested are 0%, 8%, 16% and 24% of fine gravel. For this, the Sand and fine gravel is thoroughly mixed and filled in the tank. Then 100mm plate was positioned over the top of filled sand at its center and settlement was recorded at different loads. The box was then emptied and then again filled for another condition. This procedure has been continued to perform plate load tests for all cases. The results of each test will be discussed in the chapter later on.

Fig.3.14: Mixture of sand and fine gravel

Chapter 4

Numerical Simulation

4.1 Introduction of Abaqus software

The software that we have used for the numerical simulation in this research is Abaqus 6.10. It is a finite element model of the plate and soil interaction which was developed by using the Abaqus. Different cases of various densities and the sand blended with various sizes of gravel were modeled and their effect on its settlement and the influence of size of plate has on bearing capacity has been studied.

4.2 Properties of the materials assigned in Abaqus software:-

The various properties that are assigned in the input parameters of the software are being tabulated as below.

Table -4.1 Basic parameters assigned in the abaqus software

(source- engineersedge.com, geotechdata.info)

Properties	Coarse Sand	Fine Gravel	Steel plate
Elastic Modulus (MPa)	20	50000	200000
Poisson's ratio	0.4	0.5	0.3
Mass Density (Kg/m^3)	1780	2600	7850
Angle of friction	41.2^o	NA	NA

4.2 Finite Element Modelling

In this research, an elastic modelling was done for modelling the plate on the coarse sand to study the influence of effect of density & sand blended with fine gravels on its settlement.

4.2.1 Effect of Density

The effect of density on the coarse sand was studied by modelling the model with the coarse sand bed. On the top of the bed, a square shaped plate is being placed at the centre. For checking the effect of density, the input parameter of density has been changed for various cases. These various cases are being tabulated in the following table. Each square plate of size 100mm, 150mm and 200mm was modeled at each density of sand achieved due to different no. of blows as mentioned in the table.

Table 4. 2: Various cases done for investigating the effect of density

Case	**No. of blows**	**Density given in Abaqus**
Case1	0	17.48 KN/m^3
Case2	50	19.28 KN/m^3
Case 3	100	21.42 KN/m^3
Case 4	150	25.00 KN/m^3

4.2.2 Effect of Fine gravels

The effect of fine gravels on the coarse sand was studied by modelling the model with the coarse sand bed. On the top of the bed , a square shaped plate is being placed at its centre. For checking the influence of fine gravels, the input parameter of density & young's modulus has been changed for various cases. These various cases are being tabulated in the following table. Each square plate of size 100mm, 150mm and 200mm was modeled for each case.

Table 4.3 : Various cases done for investigating the effect of fine gravels

Case	**Percentage of fine gravels**	**Density given in Abaqus (kg/m^3)**	**Young's modulus given in Abaqus (MPa)**
Case1	8%	1988	5236
Case2	16%	2056	10432
Case 3	24%	2124	15628

4.3 Meshing of Model

The basic concept in the finite element method involves further division of given structure into smaller elements for analysis called finite elements and these elements are interconnected at a discrete number of joints/nodes. In this research, we have modelled the plate and the soil by using eight-nodded solid continuum elements (C3D8R) to explain the continuum nature of the soil. The meshing of the soil and plate model is shown in the following figure.

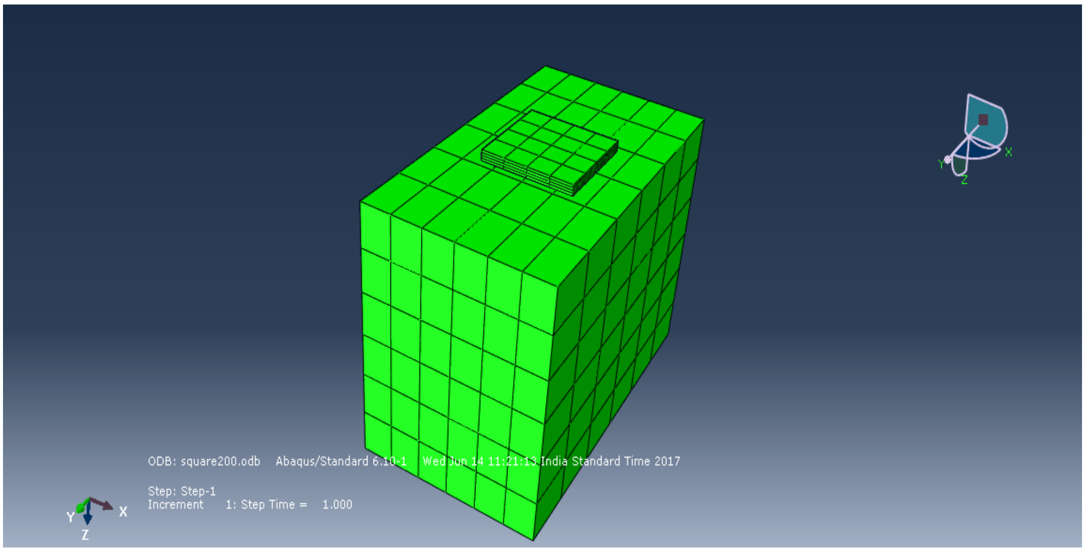

Fig.-4.1: Meshing of the model of soil and 200mm sized square plate

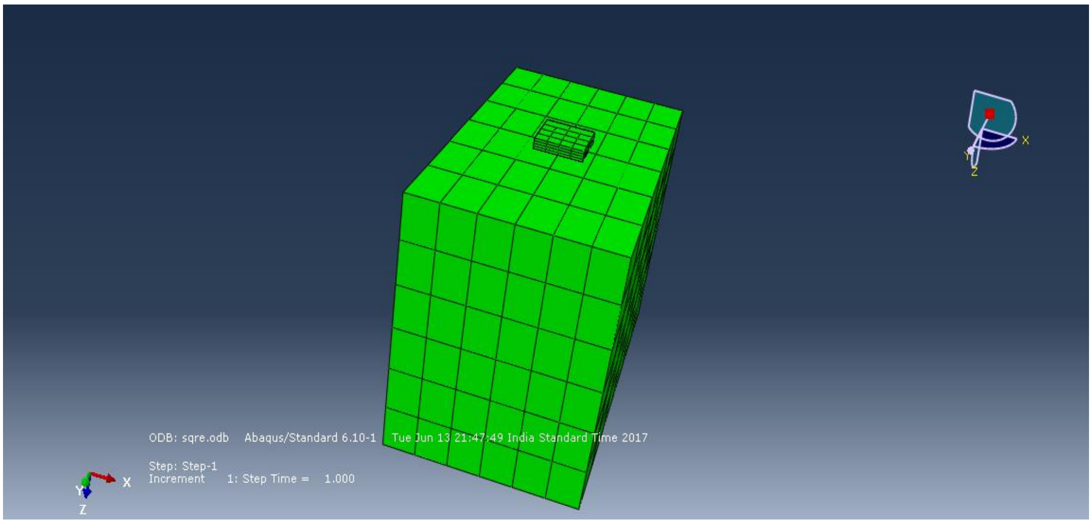

Fig.-4.2: Meshing of the model of soil and 100mm sized square plate

4.4 Boundary Conditions and Loading

In this model, the bottom of the sand layer is fixed and the outer surfaces of the soil medium are fixed to simulate the confinement of the soil. Plate is allowed to move in vertical (-negative z) direction and top surface of soil is also allowed to displace in vertical Z-direction. The boundary conditions and the load are step dependent. The vertical pressure of 10000N, 15000N and upto 35000N is applied in negative z direction at the cited point that defines the rigid body motion at the top of the plate to examine the settlement of plate due to the application of load. The conditions applied and the load applied are shown in the following figures.

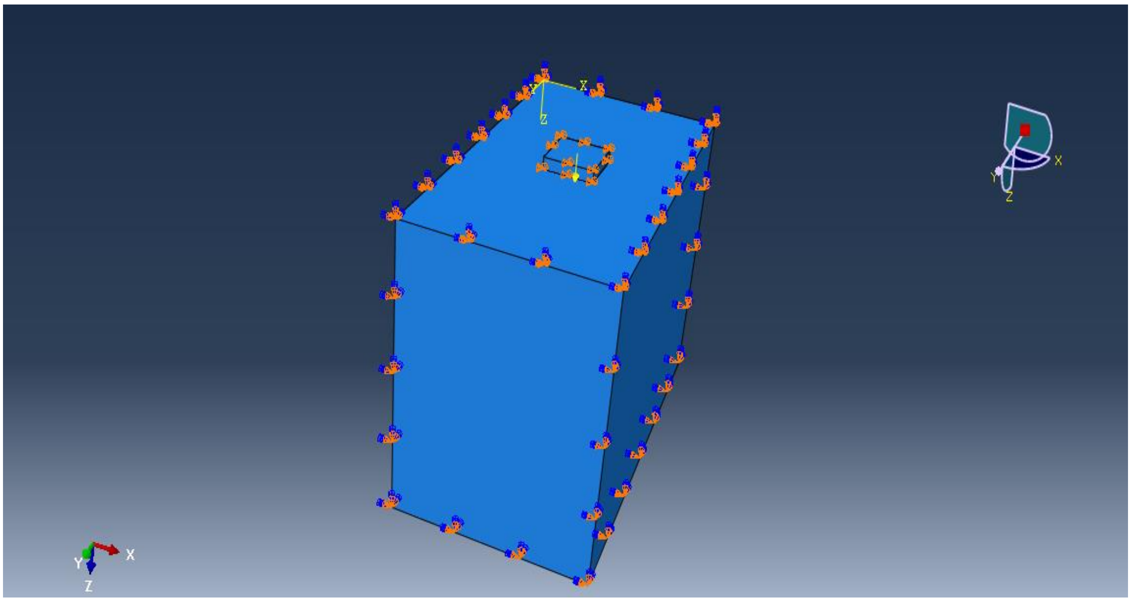

Fig. 4.3 : Boundary conditions & loading applied to the model with 100 mm square sized plates

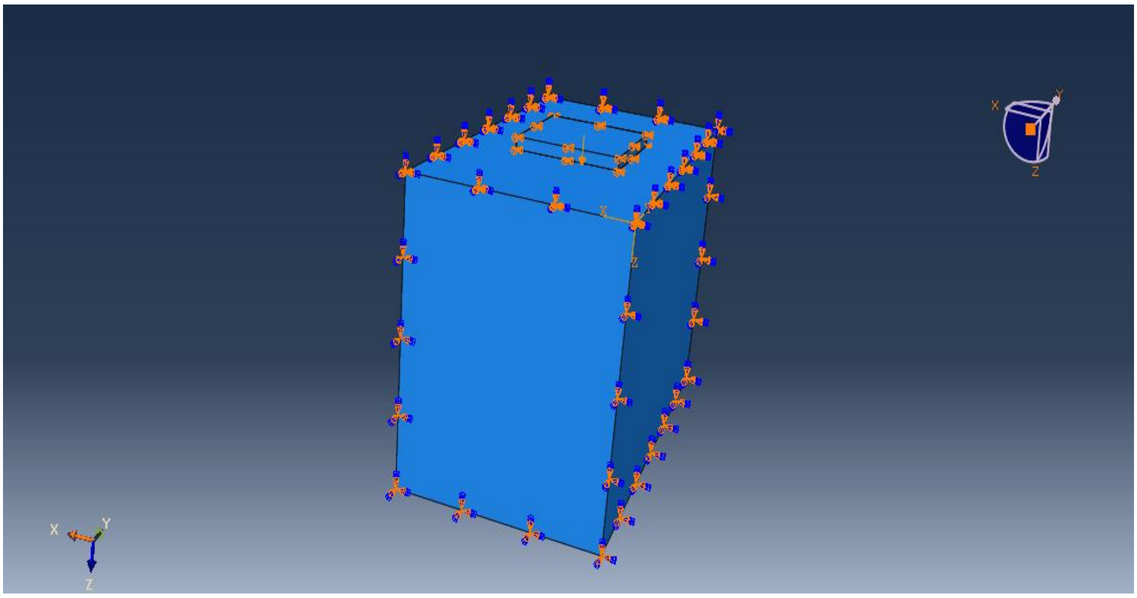

Fig. 4.4 : Boundary conditions & loading applied to the model with 200 mm square sized plates

4.5 Settlement of the Plate

The settlement of the square plate is clearly visible in the model that has been made. The settlement of the square plate is keep on increasing as we increase the size of the plate. Since the analysis that has been done in this research is elastic in nature, hence the load settlement curves that has been obtained are linear in nature. From the graphs of abaqus , the load settlement curves are being drawn in Microsoft excel sheet and then its results are being compared with the results of experimental analysis.

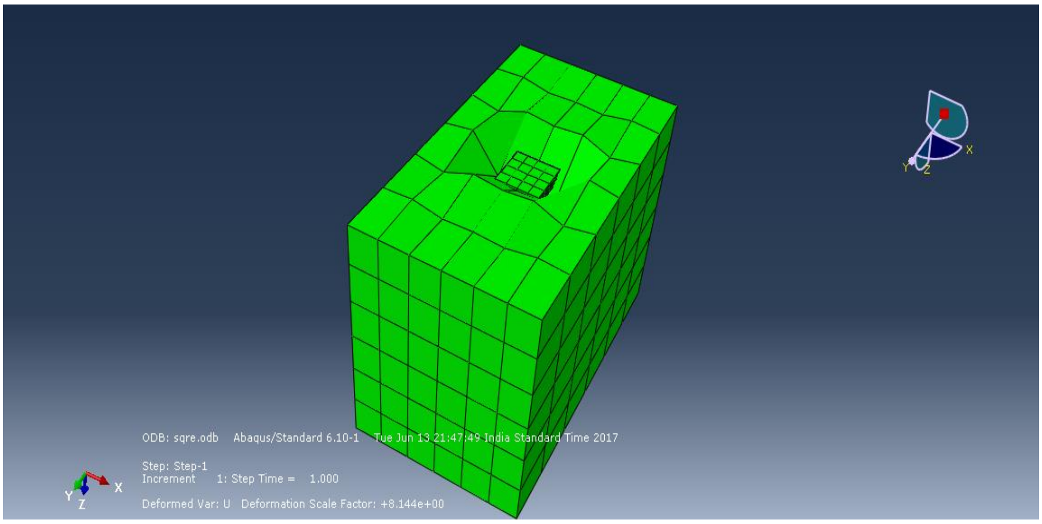

Fig. 4.5: Settled plate of size 100mm

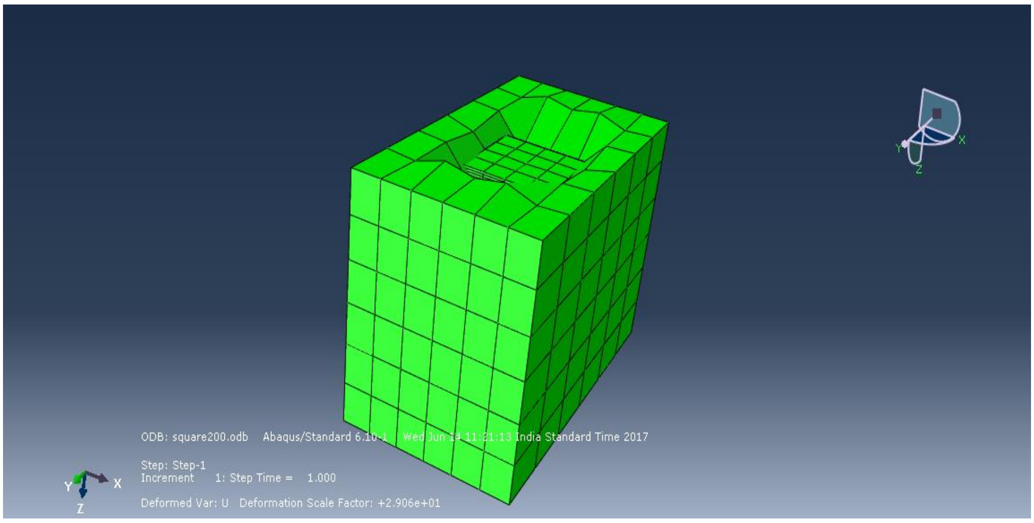

Fig. 4.6: Settled plate of size 200mm

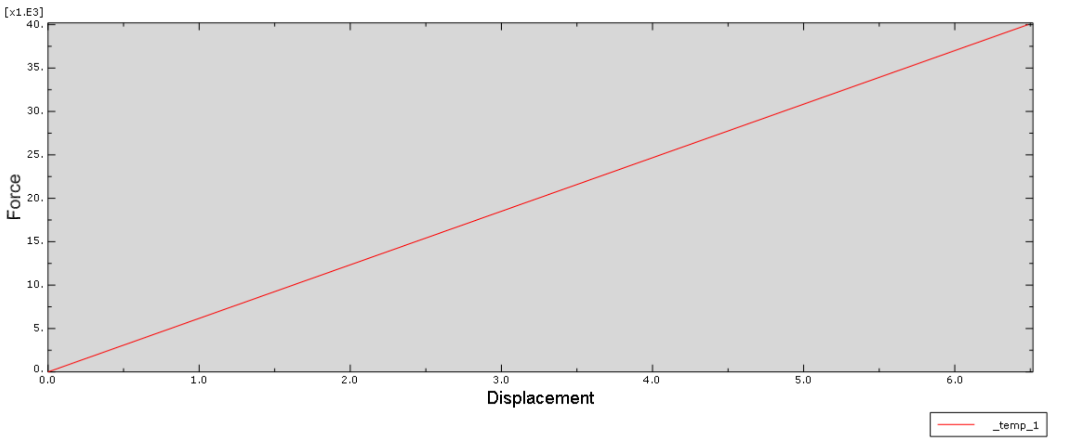

Fig. 4.7 : Load Settlement curve of 100 mm square size plate obtained in Abaqus

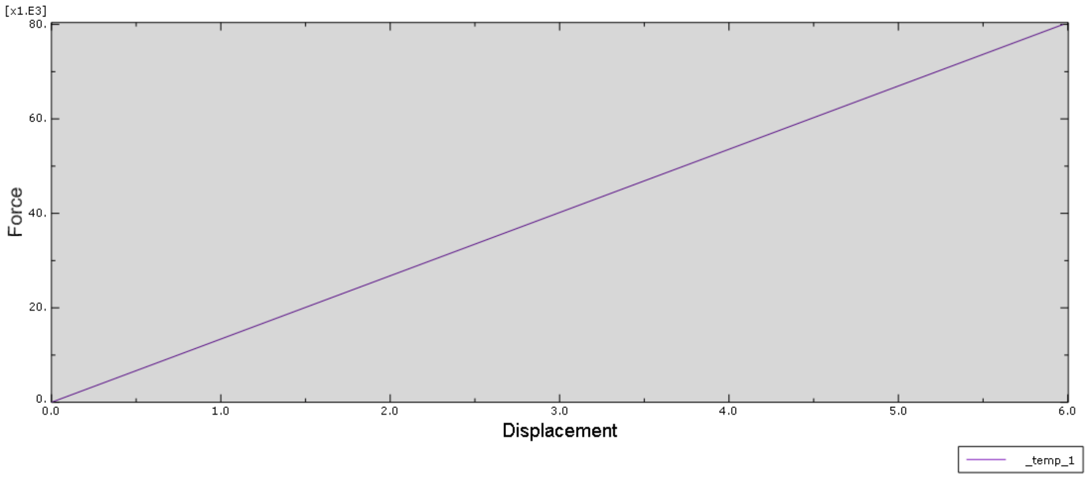

Fig. 4.7 : Load Settlement curve of 150 mm square size plate obtained in Abaqus

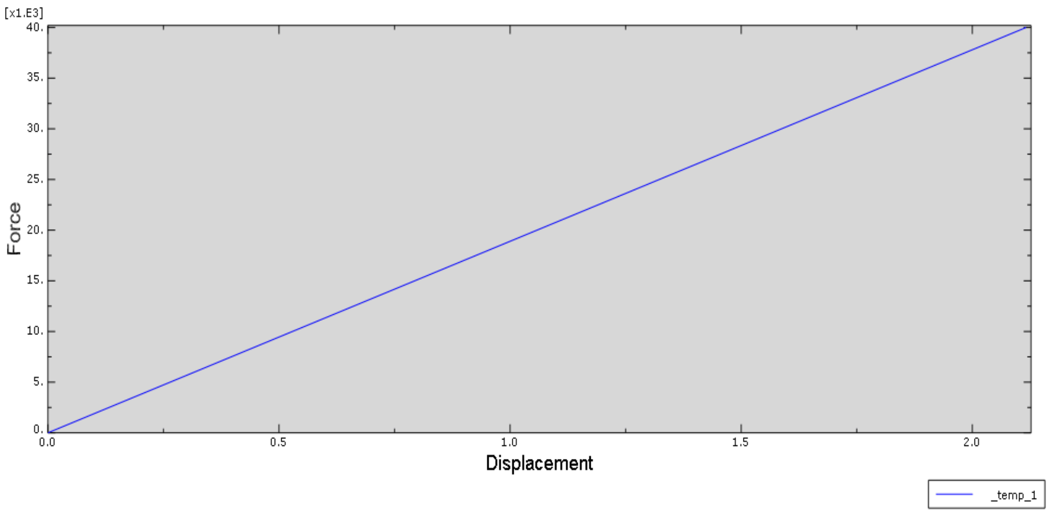

Fig. 4.8 : Load Settlement curve of 200 mm square size plate obtained in Abaqus

Chapter 5

Results And Discussion

5.1 Properties of Coarse Sand and Sand blended with fine gravels

Different physical and engineering properties of the coarse sand is obtained by conducting different tests on different plate sizes. Results of the tests will be discussed in this section.

5.1.1 Particle Size Distribution of coarse sand

Fine Sieve analysis of the coarse sand has been performed and its results are shown here. It has been done by sieve analysis of various sizes of the sieves.

Type of soil can be found out using the distribution curve between percentage finer and particle size.

Table- 5.1: Gradation 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
0.6	51	5.1	94.6	5.4
0.3	25	2.5	97.1	2.9
0.15	23	2.3	99.4	0.6
0.075	4	0.4	99.8	0.2
Pan	2	0.2	100	0
Sum (Σ)	1000			

From the gradation curve , C_u & C_c can be found out.

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

Thus, it can be said that the soil is poorly graded.

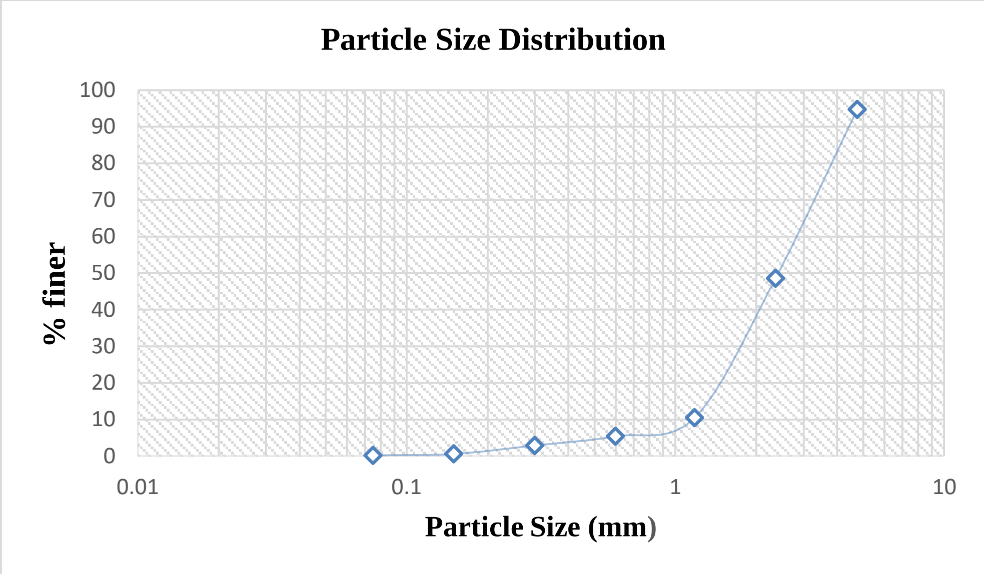

Fig. 5.1: Gradation Curve of Coarse Sand

5.1.2 Particle Size Distribution of coarse sand blended with 8 % fine gravel

Fine Sieve analysis of the mix is shown here. C_u and C_c can be found out using the distribution curve between percentage finer and particle size.

Table 5.2: Gradation of coarse sand blended with 8 % fine gravel

Sieve Size (mm)	Weight retained (g)	% Weight retained	% Cumulative retained	% finer
20	0	0	0	100
10	30	30	3	97
4.75	70	100	10	90
2.36	380	480	48	52
1.18	250	730	73	27
0.6	180	910	91	9
0.3	50	960	96	4
0.15	36	996	99.6	0.4
Pan	4	1000	100	0
Sum (Σ)	1000			

From the gradation curve , the C_u & C_c can be found out.

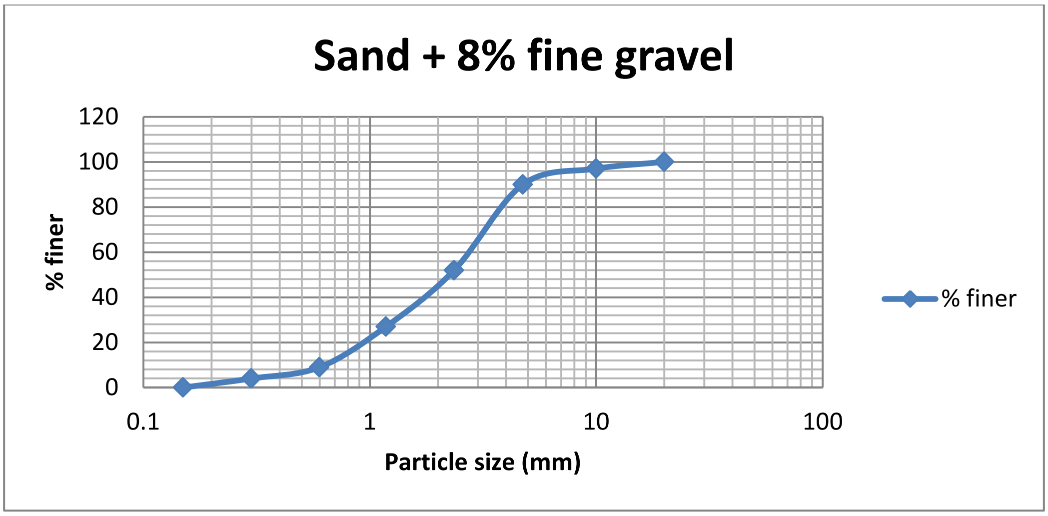

Fig. 5.2 : Gradation curve of coarse sand blended with 8% fine gravels

Coefficient of uniformity (C_u) = D_{60}/ D_{10} = 3/1.2 = 5

Coefficient of Curvature (C_c) = D_{30}^2 / (D_{60} x D_{10})= 1.8

From the values of C_u & Cc , it can be stated that this mix is poorly graded.

5.1.3 Particle Size Distribution of coarse sand blended with 16 % fine gravel

Fine Sieve analysis of the mix is shown here. Type of soil can be find out using the distribution curve between percentage finer and particle size.

Table 5.3: Gradation of coarse sand blended with 16 % fine gravel

Sieve Size (mm)	Weight retained (g)	% Weight retained	% Cumulative retained	% finer
20	0	0	0	100
10	100	100	10	90
4.75	70	170	17	83
2.36	350	520	52	48
1.18	300	820	82	18
0.6	130	950	95	5
0.3	30	980	98	2
0.15	18	998	99.8	0.2
Pan	2	1000	100	0
Sum (Σ)	1000			

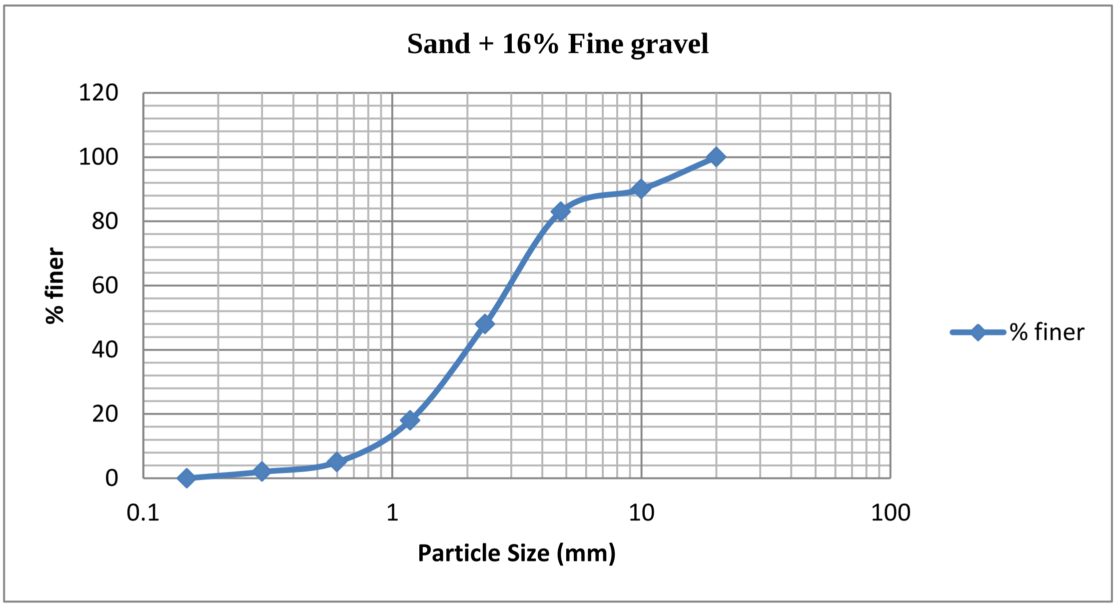

Fig. 5.3 : Gradation curve of coarse sand blended with 16% fine gravels

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

Coefficient of Curvature (C_c) = D_{30}^2 / (D_{60} x D_{10}) = 1.08

From the values of C_u & Cc , it can be stated that this mix is poorly graded.

5.1.4 Particle Size Distribution of coarse sand blended with 24 % fine gravel

Fine Sieve analysis of the mix is shown here. Type of soil can be find out using the distribution curve between percentage finer and particle size.

Table 5.4: Gradation of coarse sand blended with 24 % fine gravel

Sieve Size (mm)	Weight retained (g)	% Weight retained	% Cumulative retained	% finer
20	0	0	0	100
10	140	140	14	86
4.75	120	260	26	74
2.36	320	580	58	42
1.18	290	870	87	13
0.6	90	960	96	4
0.3	25	985	98.5	1.5
0.15	10	995	99.5	0.5
Pan	5	1000	100	0

Sum (Σ)	1000			

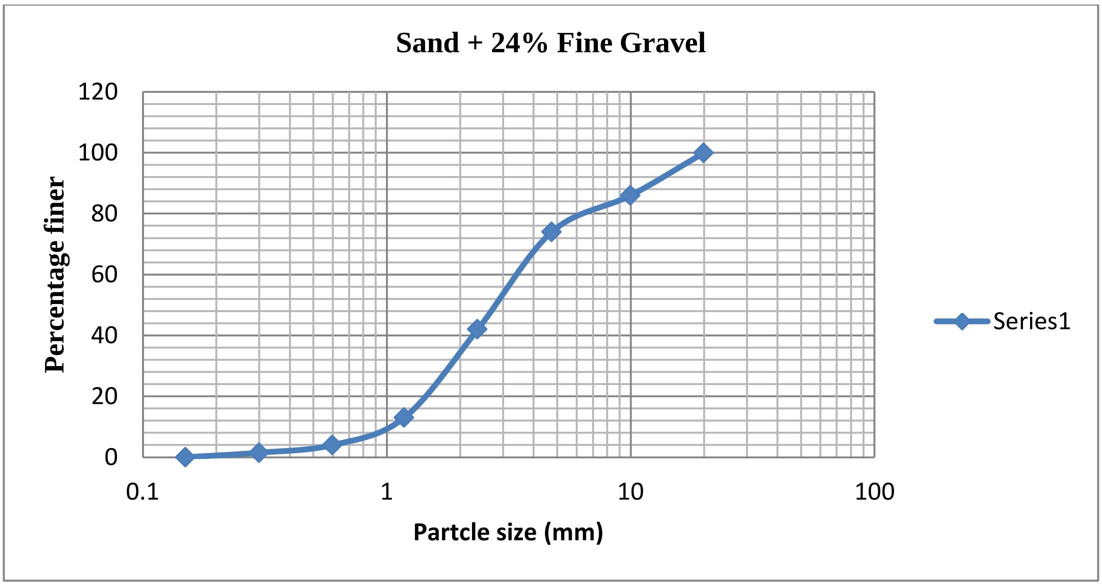

Fig. 5.4 : Gradation curve of coarse sand blended with 24% fine gravels

Coefficient of uniformity (C_u) = D_{60}/ D_{10} = 3/1.2 = 2.7

Coefficient of Curvature (C_c) = D_{30}^2 / (D_{60} x D_{10}) = 1

From the values of C_u & Cc , it can be stated that this mix is poorly graded.

5.1.5 Compaction Characteristics of Coarse Sand

To obtain the Optimum moisture content and maximum dry density standard proctor test was conducted. The results of standard proctor test is represented in the graph between Water content and dry density.

Table 5.5: Compaction characteristics of 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

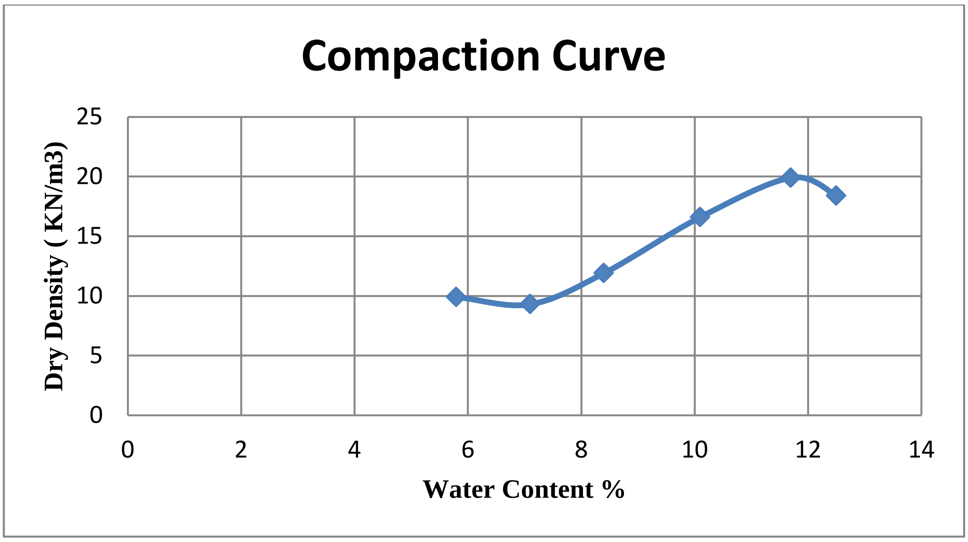

Fig. 5.5: Compaction Curve of coarse sand

5.1.6 Shear characteristics of Coarse Sand

This test is used to determine the shear strength parameters of sand. The result of direct shear tests is represented in the graph between normal stress and shear stress and the slope of the curve represent the angle of friction (ø) and Y- intercept represent the cohesion.

Table 5.6: Shear Characteristics of coarse sand

Normal Stress KN/m^2	Shear Stress(KN/m^2)
49	40.14
98.1	88.27
147.15	125.91
196.2	171.55
245.25	210.19

From the graph of normal stress vs shear stress, the angle of internal friction & cohesion are found out as follows:

Angle of Internal friction ø = 41.2^0

Cohesion = 0 KN/m^2

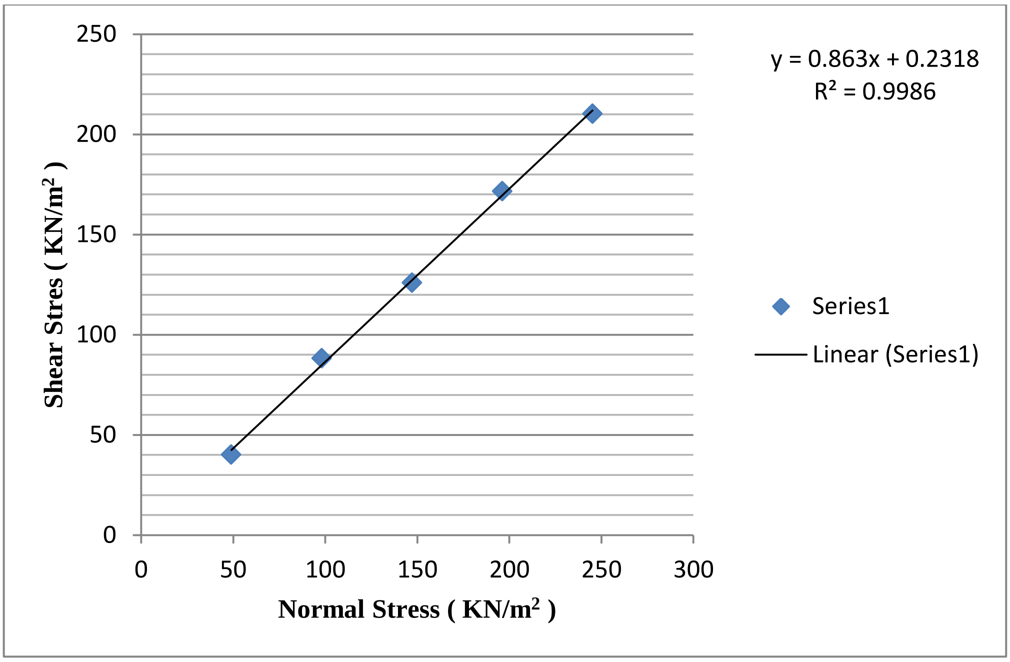

Fig. 5.6 Shear Stress vs Normal Stress curve

All the physical and engineering properties of coarse sand are tabulated as below:

Table 5.7: Physical & Engineering 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 Moisture 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

5.2 Properties of Fine Gravel

5.2.1 Specific Gravity

Specific gravity of fine gravel of size 10mm and 20mm mix is obtained and result is discussed.

Specific Gravity of coarse aggregates is found to be 2.8

5.2.2 Fineness Modulus

Fineness Modulus is obtained by sieving the fine gravels of size 10mm and 20mm mix and calculating the cumulative percentage retained on the sieves.

Table 5.8: Gradation Analysis of fine gravel of size 20mm

Sieve Size (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative % Retained
80mm	0	0	0
40mm	245	245	4.5
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
0.15	0	5000	100

Sum of Cumulative % retained = 725

Fineness Modulus = **7.25**

Table 5.9: Gradation Analysis of fine gravel of size 10mm

Sieve Size (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative % retained
20	100	100	3.33
10	700	800	26.67
6.3	1720	2520	84
4.75	250	2770	92.33
2.36	230	3000	100
1.18	0	3000	100
0.6	0	3000	100
0.3	0	3000	100

Sum of Cumulative % retained = 656

Fineness Modulus = **6.56**

Table 5.10: Gradation Analysis of fine gravel of 10mm and 20mm size mix

Sieve Size (mm)	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative % retained
20	0	0	0
10	500	500	16.66
6.3	1922	2422	80.73
4.75	265	2687	89.56
2.36	313	3000	100
1.18	0	3000	100
0.6	0	3000	100
0.3	0	3000	100

Sum of Cumulative % retained = 687

Fineness Modulus = **6.87**

5.3 Plate Load Test

5.3.1 Effect of density with the size of plate

As the plate load test was conducted at different density of the sand, their results can be inferred from the load settlement curves. The tests were conducted on square plates of sizes 100mm, 150mm & 200mm.Various cases of tests are discussed below:

5.3.1.1 Case 1 : Coarse sand with 0 Number of Blows

For 0 number of blows , the density of coarse sand is found to be 17.8 KN/m^3. The load settlement values of this case is being tabulated as below.

Table 5.11: Load Settlement values of Coarse sand for density 17.8 KN/m^3

	Settlement (mm)		
Load (KN)	**100mm**	**150mm**	**200mm**
0	0	0	0
5	-0.8	-1.2	-2.5
10	-1.7	-3.1	-4.1
15	-2.8	-4.8	-5.9
20	-4.9	-6.9	-7.8
25	-6.8	-9.2	-10.5
30	-9.1	-11.5	-13.1
35	-11.5	-14.4	-16.8
40	-14.6	-17.8	-22.5
45	-18.5	-22.6	-28.9

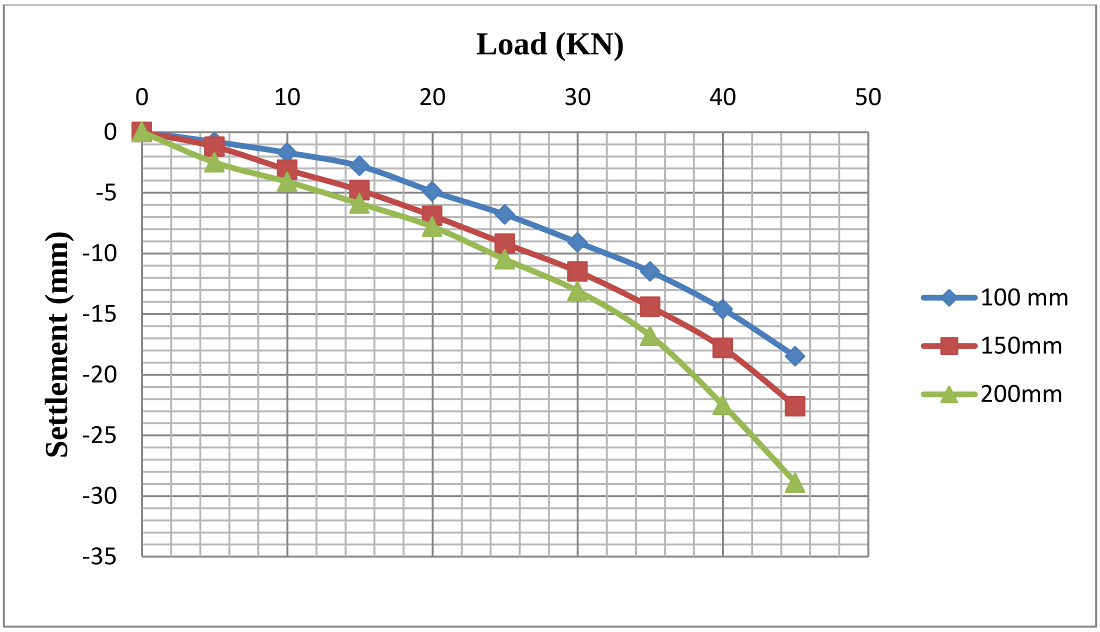

Fig 5.7: Load Settlement Curve for Coarse Sand for 17.8 KN/m^3 density

5.3.1.2 Case 2 : Coarse Sand with 50 Number of blows

For 50 number of blows, the density of sand is found to be 19.28 KN/m^3.

Table 5.12: Load Settlement Values for Coarse Sand with density 19.28 KN/m^3

	Settlement (mm)		
Load (KN)	**100mm**	**150mm**	**200mm**
0	0	0	0
5	-0.5	-1.1	-1.6
10	-0.9	-2.1	-3.2
15	-1.7	-3.5	-4.8
20	-2.5	-4.8	-6.2
25	-3.8	-6.4	-7.7
30	-5.6	-8.9	-10.1
35	-7.9	-12.9	-14.2
40	-11.2	-16.8	-18.9
45	-16.8	-21.5	-26.8

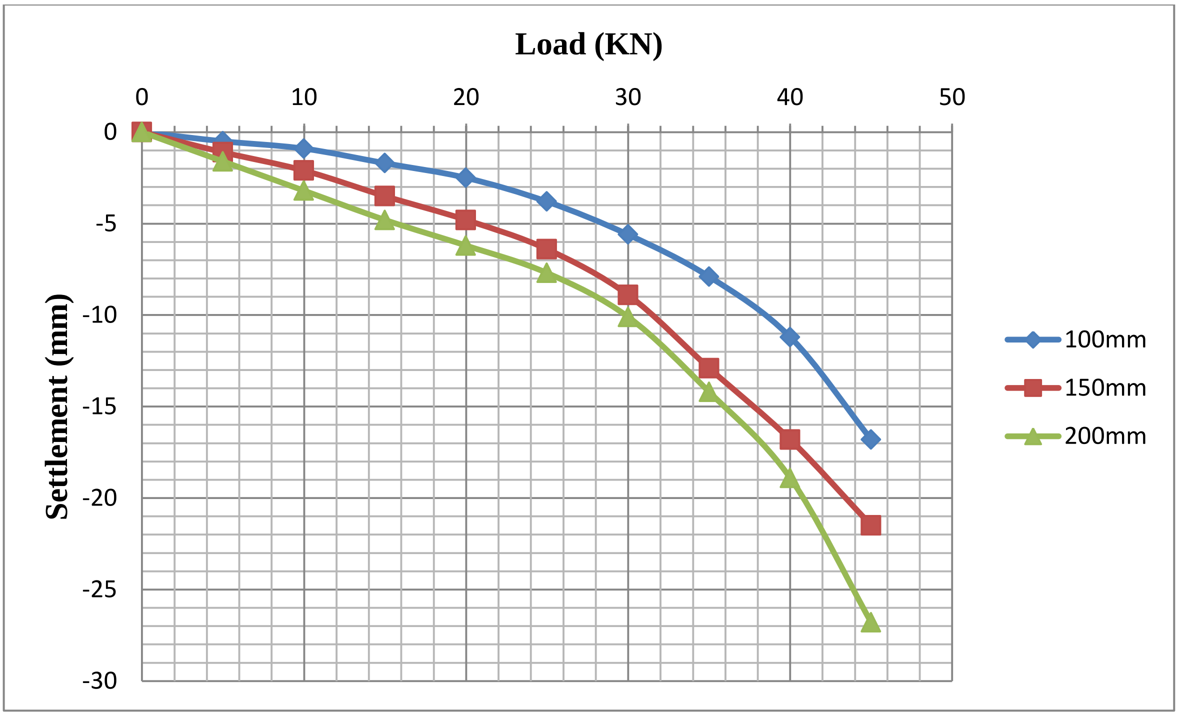

Fig. 5.8: Load Settlement Curve for Coarse Sand with density 19.28 KN/m^3

5.3.1.3 Case 3: Coarse Sand with 100 Number of Blows

For 100 number of blows, the density of sand is found to be 21.42 KN/m^3.

Table 5.12 Load Settlement Values for Coarse Sand with density 21.42 KN/m^3

	Settlement (mm)		
Load (KN)	**100mm**	**150mm**	**200mm**
0	0	0	0
5	-0.2	-0.4	-0.9
10	-0.6	-0.9	-1.6
15	-1.1	-1.9	-2.8
20	-1.9	-3.2	-4.2
25	-2.8	-4.6	-6.5
30	-4.5	-7.1	-8.6
35	-6.6	-10.2	-12.3
40	-9.8	-13.4	-16.4
45	-14.6	-18.9	-23.6

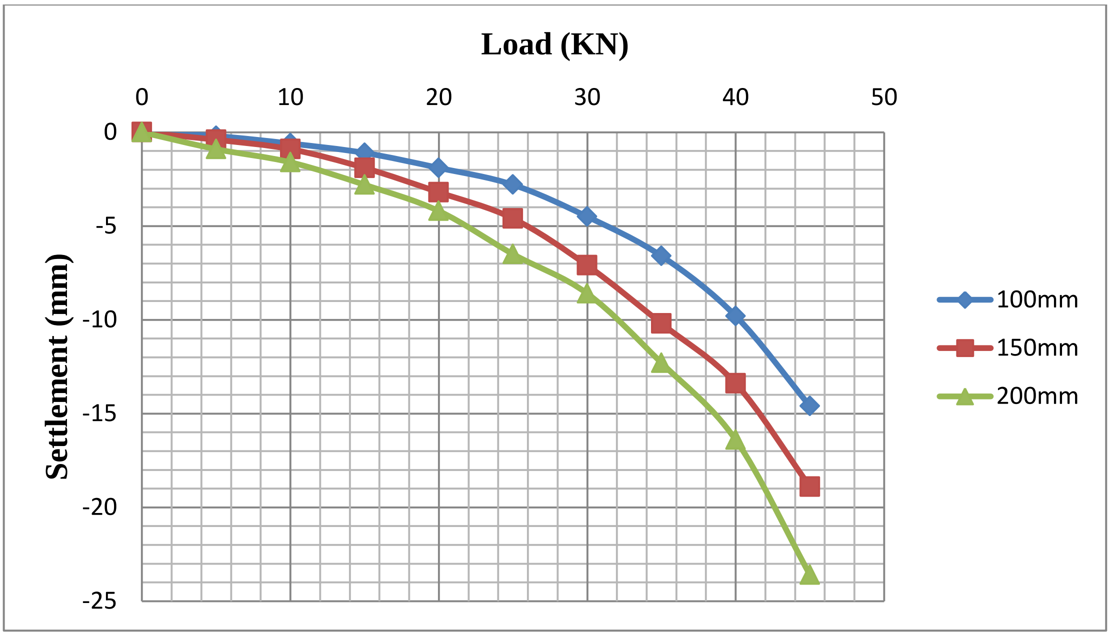

Fig. 5.9: Load Settlement Values for Coarse Sand with density 21.42 KN/m^3

5.3.1.4 Case 4 : Coarse Sand with 150 number of blows

For 150 number of blows, the density of sand is found to be 25 KN/m^3.

Table 5.14:.Load Settlement Values for Coarse Sand with 25 KN/m^3

	Settlement (mm)		
Load (KN)	**100mm**	**150mm**	**200mm**
0	0	0	0
5	0	-0.1	-0.3
10	-0.1	-0.3	-0.6
15	-0.5	-0.9	-1.1
20	-0.9	-2	-2.4
25	-1.8	-3.4	-4.2
30	-2.7	-5.2	-6.5
35	-4.8	-7.8	-8.6
40	-7.3	-11.4	-12.8
45	-11.5	-16.6	-19.5

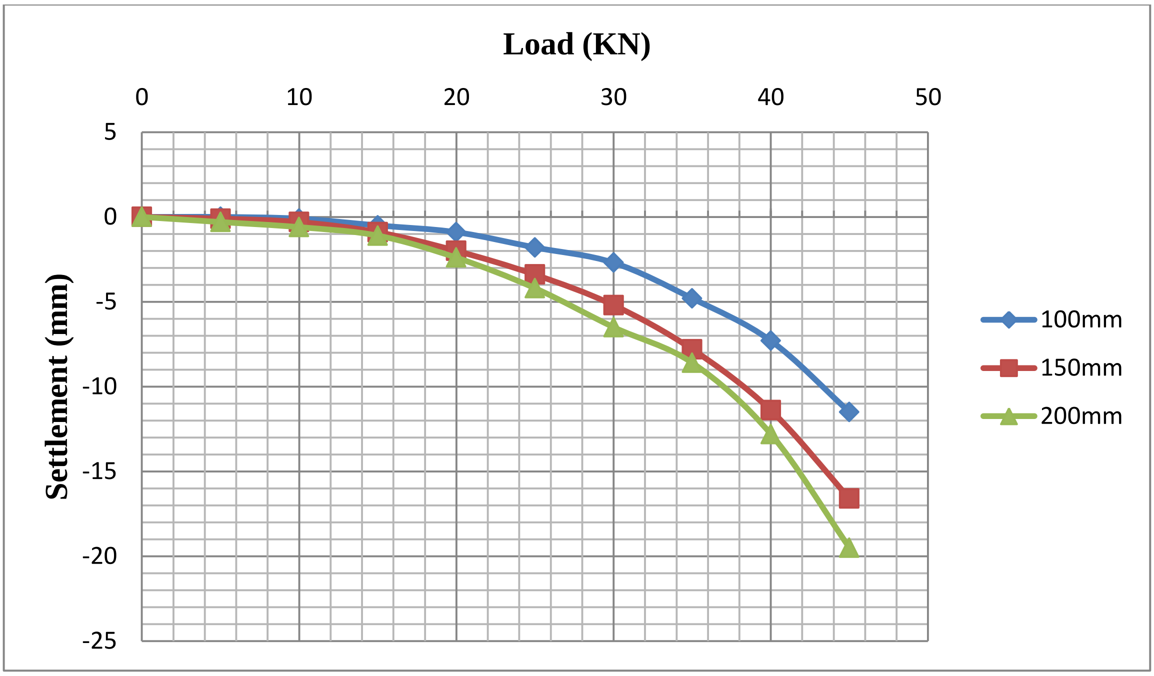

Fig. 5.10: Load Settlement Curve for Coarse Sand with 25 KN/m^3

It can be observed from the above graphs that for a particular density, the settlement under the square plate will keep on increasing with the increase in plate size.

5.3.2 Effect of Density on settlement for a particular plate size

It can be seen from the graphs below that for a particular plate size, the settlement keeps on decreasing with the increase in density i.e. with increasing number of blows.

5.3.2.1 Case 1: For 100mm size square plate

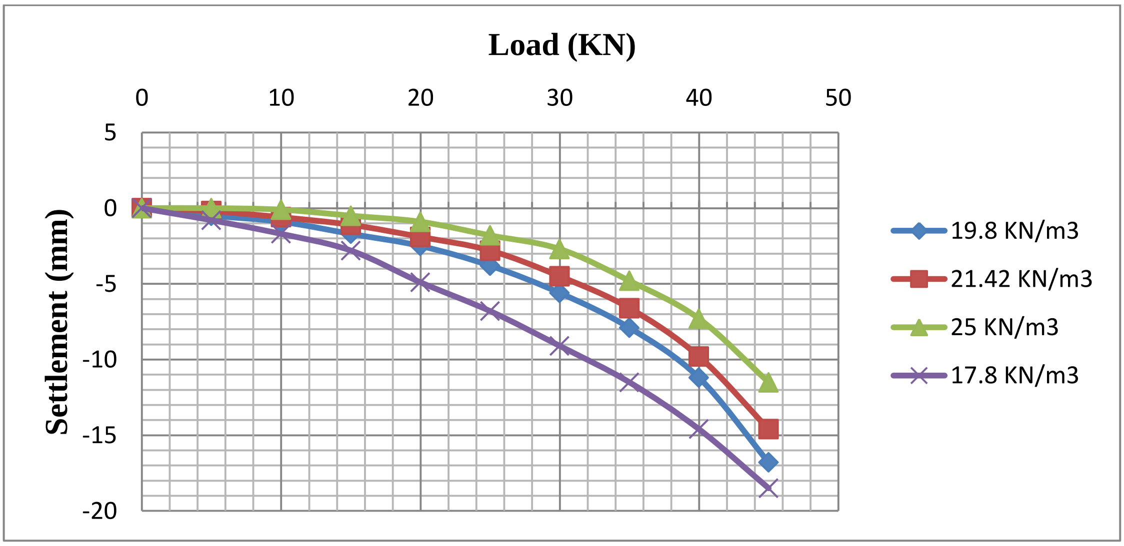

Fig. 5.11 Load settlement curve for 100mm square plate at different densities

5.3.2.2 Case 2: For 150mm size square plate

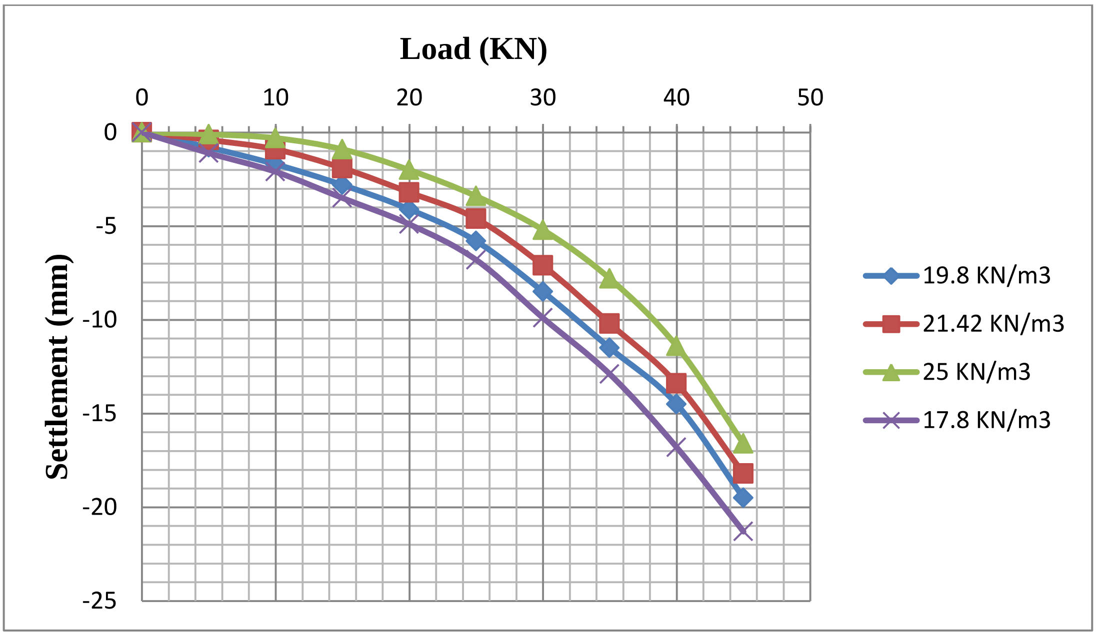

Fig.12 : Load settlement curve for 150mm square plate at different densities

5.3.2.3 Case 3: For 200mm size square plate

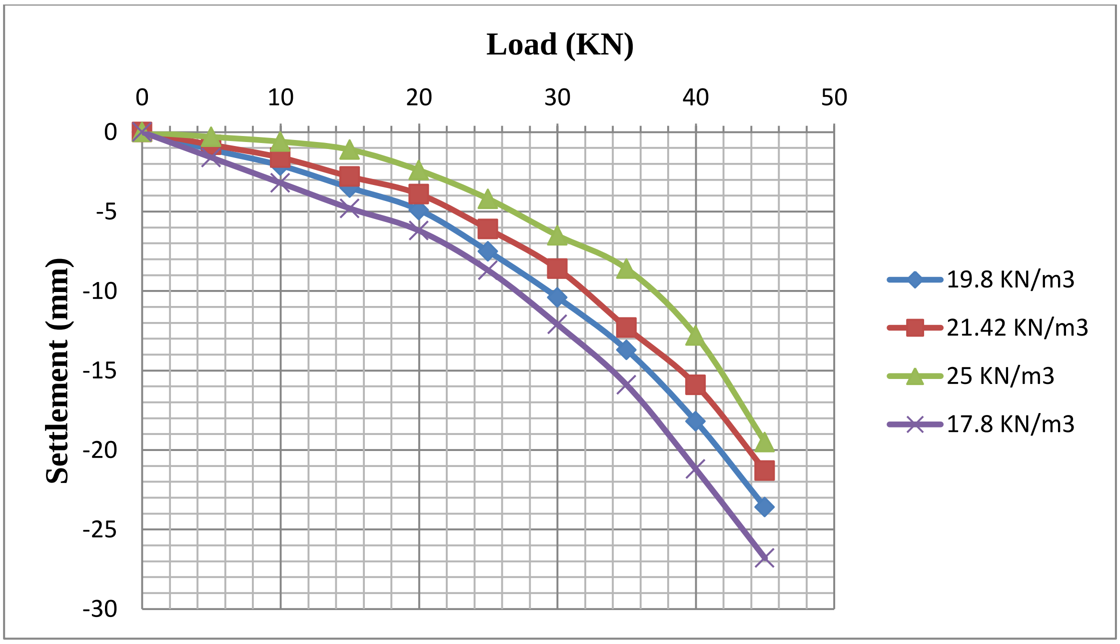

Fig.13 : Load settlement curve for 200mm square plate at different densities

5.3.3 Effect of Fine Gravel

The Plate load tests were conducted on fine aggregates when mixed with different percentages of fine gravels by weight. The percentages at which each plate was tested are 0%, 8%, 16% and 24% of fine gravels. The results of these cases are discussed below:

5.3.3.1 Case 1: Sand mixed with 8% fine gravels

Table 5.15: Load-Settlement values of coarse sand mixed with 8% fine gravels

	Settlement (mm)		
Load (KN)	**100mm**	**150mm**	**200mm**
0	0	0	0
5	-0.3	-0.6	-0.8
10	-0.6	-0.9	-1.4
15	-0.9	-1.4	-2.1
20	-1.5	-2.1	-3.2
25	-3.2	-4.6	-5.9
30	-5.9	-7	-8.1
35	-7.8	-9.3	-10.5
40	-9.7	-12.2	-13.8
45	-12.5	-15.1	-18.1

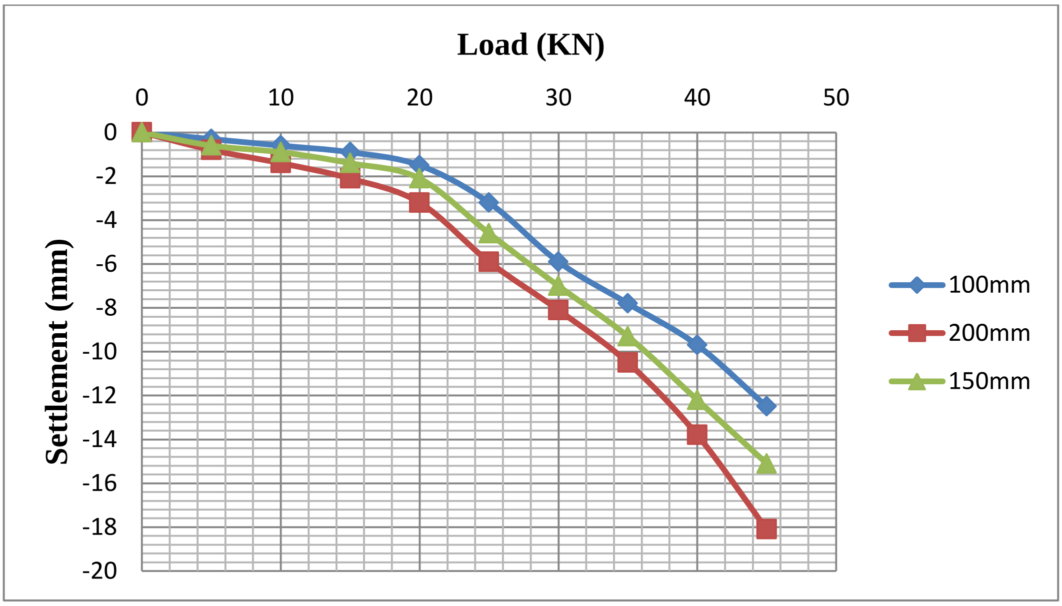

Fig.5.14: Load Settlement Curve for sand mixed with 8% fine gravels

5.3.3.2 Case 2 : Coarse sand mixed with 16% fine gravels

Table 5.16. Load-Settlement values of coarse sand mixed with 16% coarse aggregate

	Settlement (mm)		
Load (KN)	**100mm**	**150mm**	**200mm**
0	0	0	0
5	-0.1	-0.4	-0.6
10	-0.3	-0.6	-0.85
15	-0.55	-0.75	-1.1
20	-0.85	-1.6	-2.2
25	-3.2	-4.1	-5.2
30	-4.9	-6	-6.7
35	-5.8	-7.2	-8.3
40	-7	-8.1	-9.4
45	-8.2	-9.1	-10.5

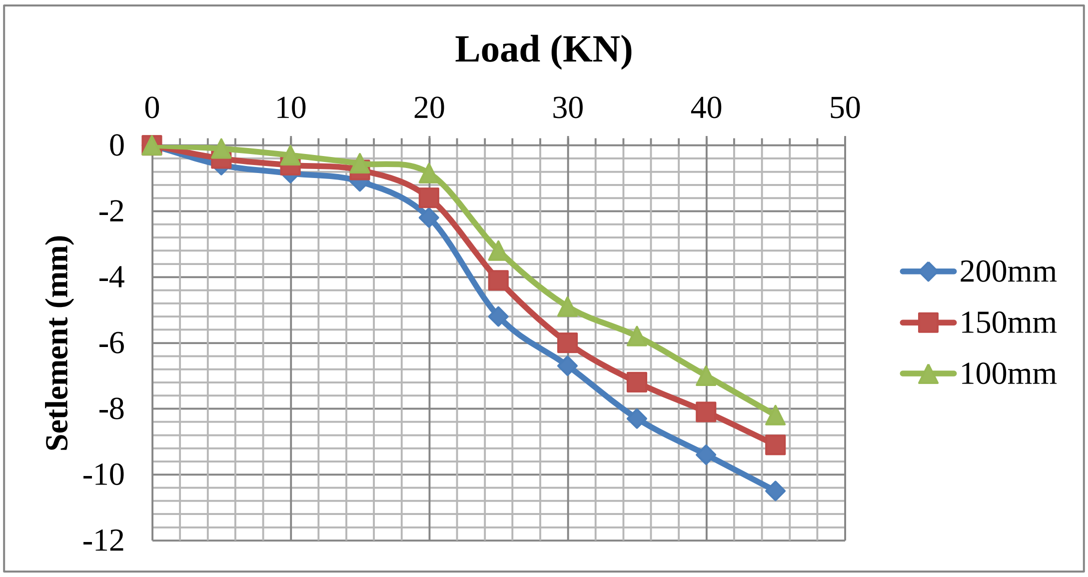

Fig. 5.15: Load Settlement Curve for sand mixed with 16% fine gravels

5.3.3.3 Case 3 : Sand mixed with 24% coarse aggregates

Table 5.17: Load-Settlement values of coarse sand mixed with 24% coarse aggregate

	Settlement (mm)		
Load (KN)	**100mm**	**150mm**	**200mm**
0	0	0	0
5	0	0	0
10	0	0	0
15	0	0	0
20	0	0	-0.2
25	-0.1	-0.5	-0.8
30	-0.6	-1.1	-1.7
35	-1.6	-2.9	-3.7
40	-2.8	-4.5	-5.4
45	-4.5	-6.3	-7.6

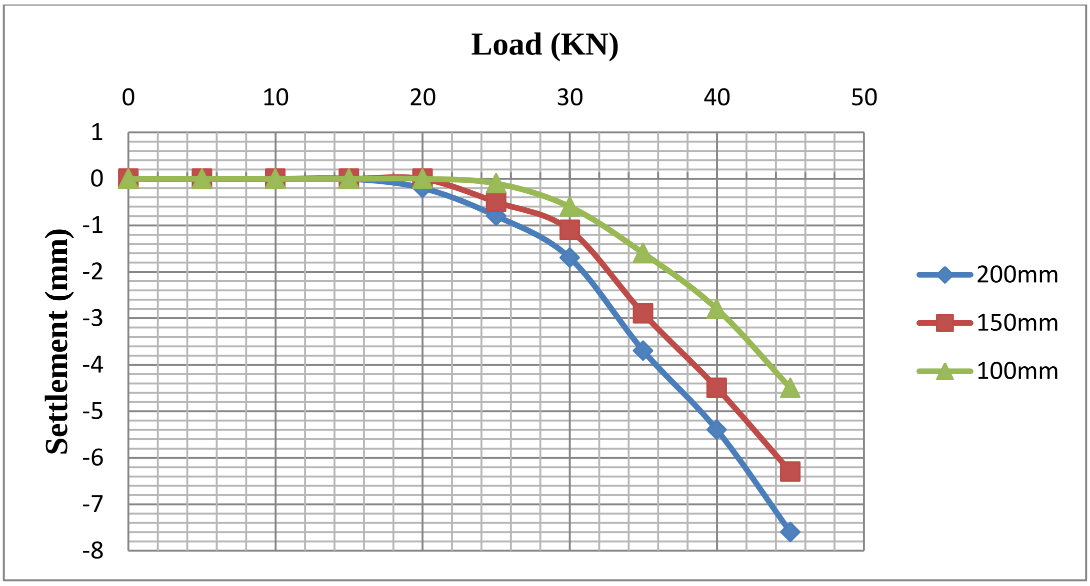

Fig 5.16: Load Settlement curve for sand blended with 24% aggregates

It can be observed from the above graphs that settlement of square plate will keep on increasing with the increase in plate size.

5.3.4 Comparison of Load Settlement Results by Numerical Simulation & Experimental set up:

The results obtained from the numerical simulation (i.e. Abaqus software) are found to be more conservative as compared to the experimental analysis. As the analysis that has been done in the software is elastic in nature , so its comparison with the experimental results is not that reliable. The plastic analysis in the Abaqus software could not carried out because of lack of time.

5.3.4.1 Case 1: For 100mm square plate size

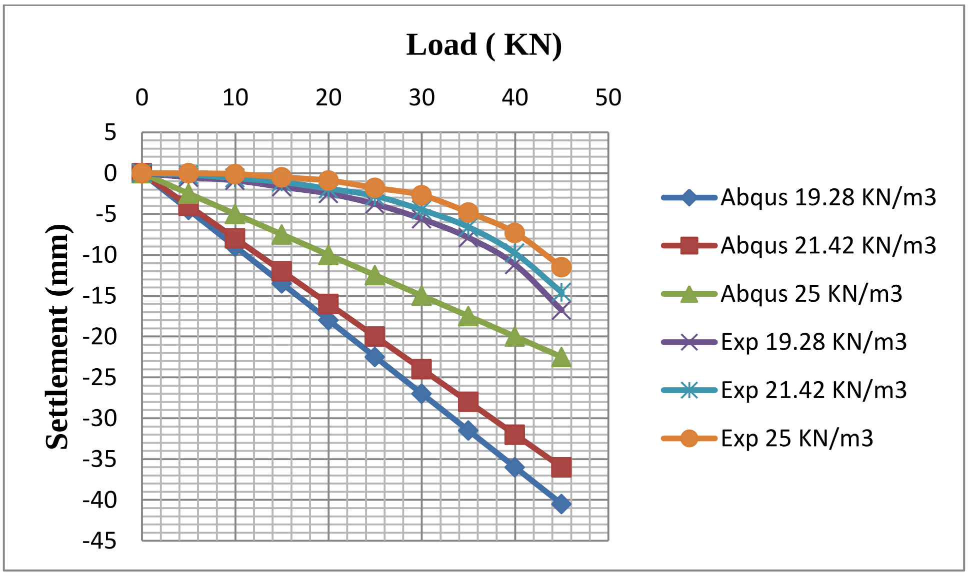

Fig. 5.17 : Comparison of numerical simulation and experimental set up results under square plate at various densities for 100mm plate size.

5.3.4.2 Case 2: For 150mm square plate size

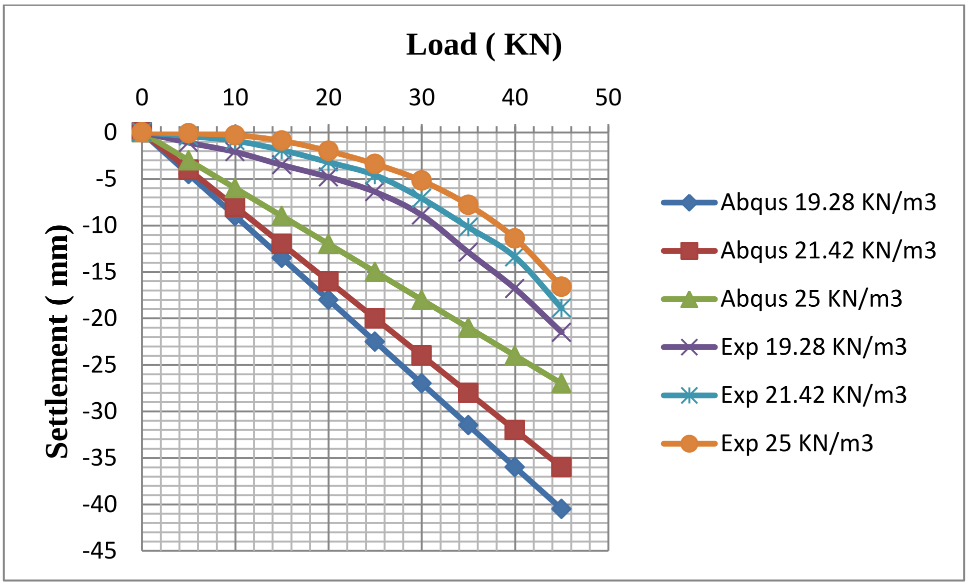

Fig. 5.18 : Comparison of numerical simulation and experimental set up results under square plate at various densities for 150mm plate size.

5.3.4.2 Case 2: For 200mm square plate size

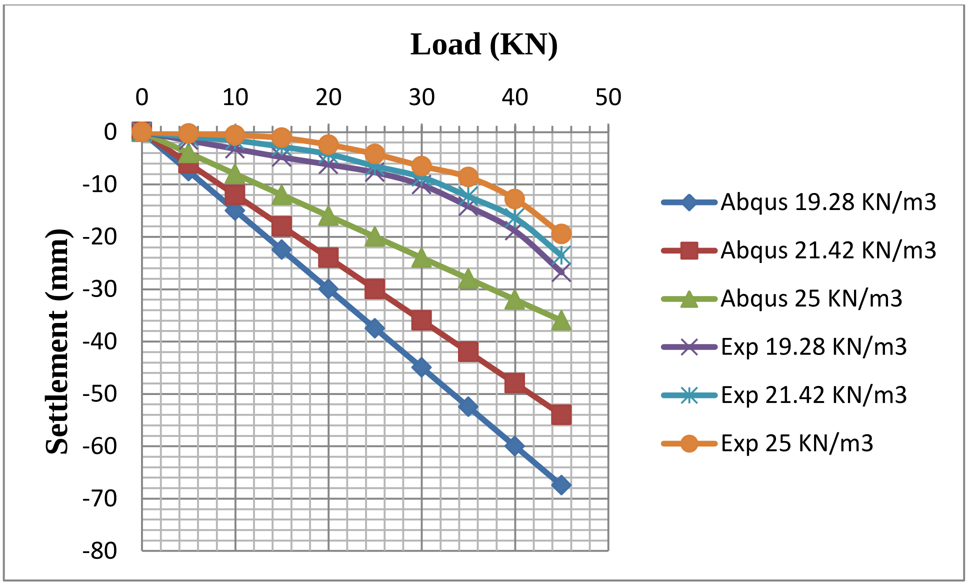

Fig. 5.19 : Comparison of numerical simulation and experimental set up results under square plate at various densities for 200mm plate size.

5.3.5 Comparison of load settlement results due to scale effect

To nullify the effect of boundary conditions of the small sized box on the settlement, we have performed the plate load test on the large sized box of size 1.5m x 1.5m x 0.8m. The tests which were performed on the large sized box were done to interpret the influence of fine gravels on the coarse sand. Various cases of the tests which were performed on the square size plates are the cases when the coarse sand is blended with 8%, 16% and 24 % of coarse gravels .

The load settlement values for different cases performed are being tabulated below. The settlement found in large sized box is normally higher than the settlement found in small sized box.

5.3.5.1 Case 1: Tests performed on 100mm square sized plate

The tests were performed on the 100 mm square size plate in the large sized box for various percentages of fine gravels

Table 5.18: Load Settlement Values for 100 mm square size plate in large sized box

	Settlement (mm)			
Load (KN)	**0% fine gravels**	**8% fine gravels**	**16% fine gravels**	**24% fine gravels**
0	0	0	0	0
5	-4.5	-1.5	-0.8	-0.5
10	-12.5	-3.2	-1.5	-1.2
15	-25.8	-6.2	-4.1	-3.2
20	-38.8	-20.1	-15.2	-10.8
25		-32.8	-26.6	-18.4

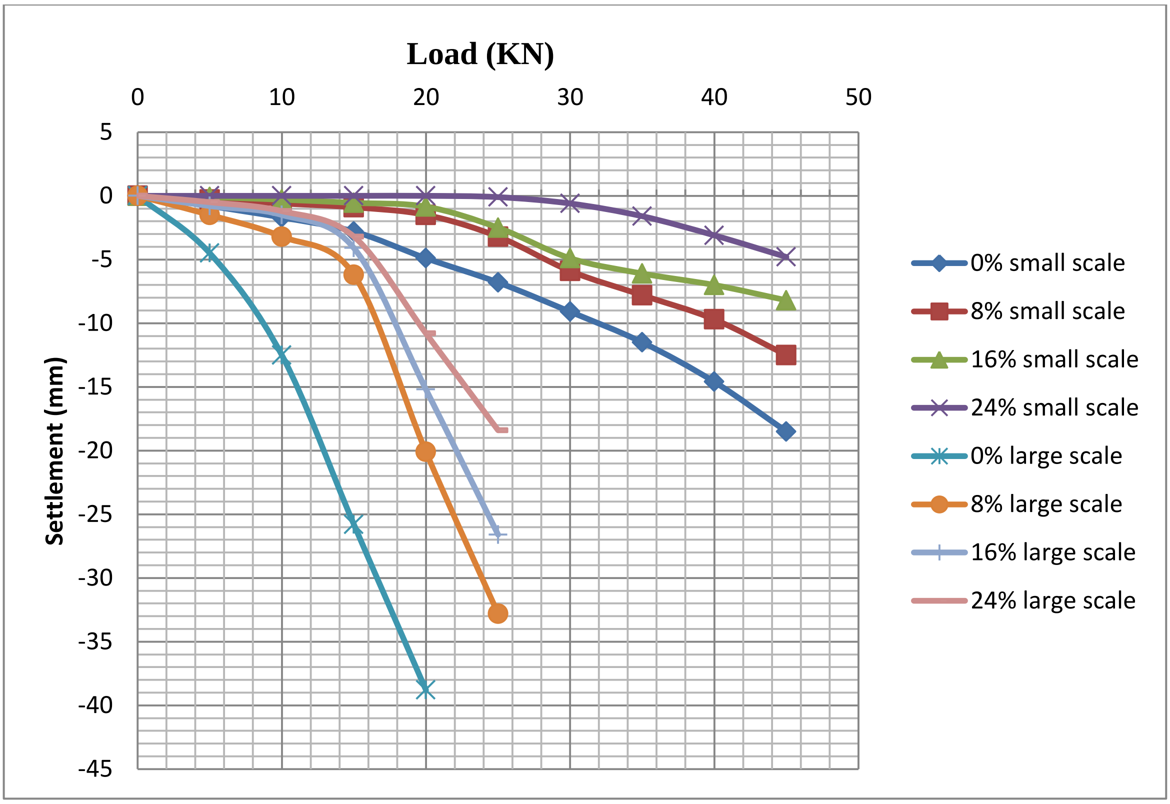

Fig. 5.20 - Load Settlement Curve for 100 mm square size plate in large sized box

5.3.5.2 Case 2 : Tests performed on 150mm square sized plate

The tests were performed on the 150 mm square size plate in the large sized box for various percentages of fine gravels.

Table 5.19: Load Settlement Values for 150 mm square size plate in large sized box

	Settlement (mm)			
Load (KN)	**0% fine gravels**	**8% fine gravels**	**16% fine gravels**	**24% fine gravels**
0	0	0	0	0
5	-4.5	-2.4	-1.6	-0.9
10	-12.5	-4.2	-2.9	-1.9
15	-25.8	-9.2	-5.8	-3.7
20	-38.8	-24.2	-18.1	-14.1
25		-36.8	-30.2	-24.2

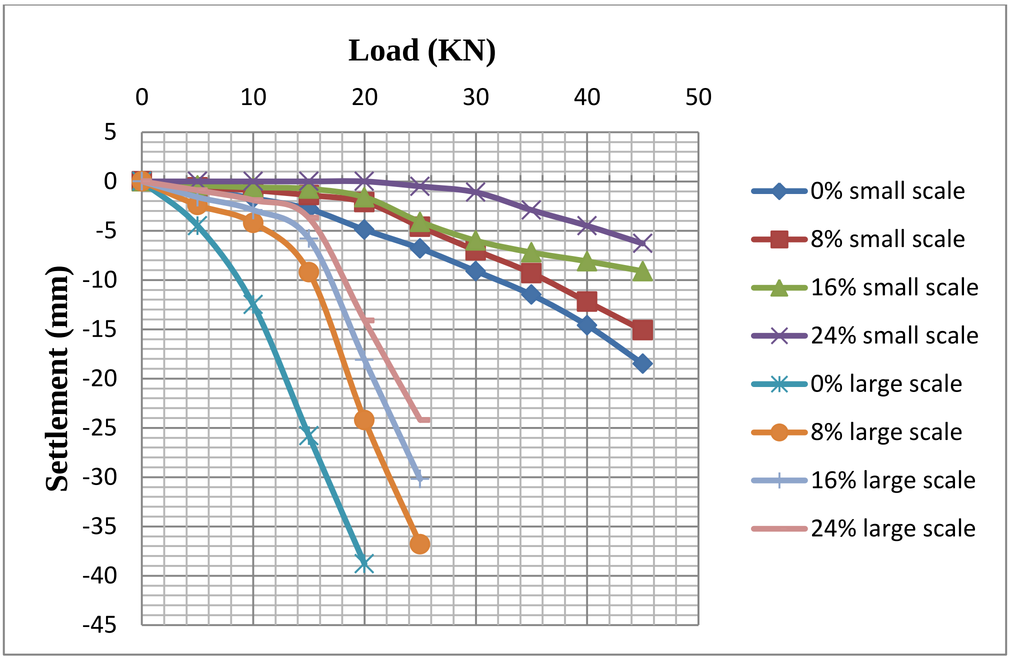

Fig.5.21: Load Settlement Curve for 150 mm square size plate in large sized box

5.3.5.3 Case 3: Tests performed on 200mm square sized plate

The tests were performed on the 200 mm square size plate in the large sized box for various percentages of fine gravels

Table 5.20: Load Settlement Values for 200 mm square size plate in large sized box

	Settlement (mm)			
Load (KN)	**0% fine gravels**	**8% fine gravels**	**16% fine gravels**	**24% fine gravels**
0	0	0	0	0
5	-4.5	-3.1	-2.2	-1.6
10	-12.5	-5.2	-4.1	-2.8
15	-25.8	-10.2	-8.2	-4.8
20	-38.8	-28.9	-20.8	-16.2
25		-39.8	-34.5	-27.8

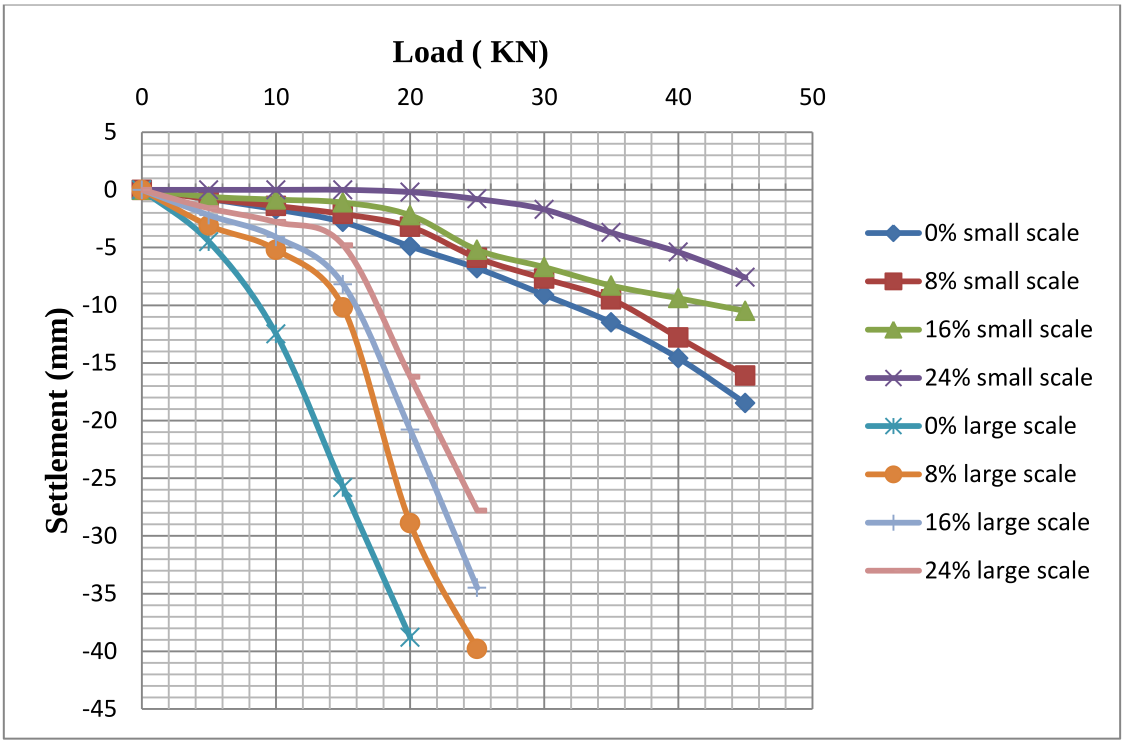

Fig. 5.22: Load Settlement Curve for 200 mm square size plate in large sized box

5.3.6 Discussion of Results

From the above results and graphs that we obtained from the plate load test on square plate for various different cases , following points may be inferred:

1. It is observed that in every condition in which plate load test has been performed, the settlement increases with application of load increment.
2. It is observed that as the density of the sand increses, the load at a particular settlement increases which means the load carrying capacity of sand increases.It may happens because of the better interlocking within the soil particle which results in more resistivity to load applied. So, to achieve particular settlement more loads is required in comparison to non-densified sand.
3. It has been found that with the increment in the percentage of fine gravel in coarse sand the settlement at particular load goes on decreasing and the load at a constant settlement increases. This improvement happens because of more stiffness of Sand with fine gravels than the sand without aggregates.
4. From the above results it can also be inferred that as the plate size varies from 100mm to 200mm, the settlement at a particular load increases. Because with the increase in the plate size, the size of pressure bulb also increases.

5. The variation in results of Plate load test has been observed for square shaped and circular shaped modeled footing and it was found that the settlement at a constant load is more for circular footing than square footing. The reason for this behavior is the peripheral area. Since the peripheral area of the square footing is more than the peripheral area of the circular footing, thus the settlement is lesser in case of square footing.
6. It is observed that numerical simulation results are less conservative than experimental results. Since the analysis done on the software is elastic in nature, so its results are not that reliable.
7. It is observed that the settlement under square plate will increase if we have used the large sized steel box in comparison to the small sized box. It may happen because of the more boundary effect in the small sized steel box.
8. It has been observed that the percentage improvement in the bearing ability of the sand blended with fine gravels is more in case of 100 mm size than in the case of 200 mm square size plate.
9. The increase in the percentage bearing ability for 200 mm size plate is found to be 20%, 43.33% and 60% when the sand is blended with 8%, 16% and 24 % fine gravels respectively. Thus, the percentage of bearing ability of the soil keeps on increasing as we increase the percentage of fine gravel.
10. The increase in the percentage bearing ability for 150 mm size plate is found to be 33.33%, 53.33% and 73.33% when the sand is blended with 8%, 16% and 24 % fine gravels respectively. Thus, the percentage of bearing ability of the soil keeps on increasing as we increase the percentage of fine gravel.
11. The increase in the percentage bearing ability for 100 mm size plate is found to be 46.67%, 66.67% and 100% when the sand is blended with 8%, 16% and 24 % fine gravels respectively. Thus, the percentage of bearing ability of the soil keeps on increasing as we increase the percentage of fine gravel.

Chapter 6

Conclusion

The following conclusions can be made in this research work:

1. It is observed that with increase in density of coarse sad the settlement under square plate keeps on increasing.
2. It is observed that at particular density of coarse sand, the settlement under square plate keeps on increasing as we increase the size of the square plate.
3. It has been found that settlement under square plate keeps on increasing if we increase the plate size when the coarse sand is blended with fine gravel at different percentages of 8%, 16% and 24% by weight.
4. It has been found that at any level of pressure, the settlement was found to be less in case of square plate as compared to that of circular plate. It is valid for any mix i.e. soil blended with different percentages of aggregates. It is also true for any plate size.
5. It is observed that the settlement under square plate will increase if we have used the large sized steel box in comparison to the small sized box.
6. It is observed that the results obtained in large scale plate load tests are less conservative than the results obtained in small scale tests.
7. It is observed that numerical simulation results are less conservative than experimental results.
8. The increase in the percentage bearing ability for 200 mm size plate is found to be 20%, 43.33% and 60% when the sand is blended with 8%, 16% and 24 % fine gravels respectively.
9. The increase in the percentage bearing ability for 150 mm size plate is found to be 33.33%, 53.33% and 73.33% when the sand is blended with 8%, 16% and 24 % fine gravels respectively.
10. The increase in the percentage bearing ability for 100 mm size plate is found to be 46.67%, 66.67% and 100% when the sand is blended with 8%, 16% and 24 % fine gravels respectively.

6.1 Future recommendation of this project

This study can be extended with the following objectives:

1. The plastic analysis can be done in the Abaqus software and the results obtained from them can be compared with the experimental results as they are more reliable. The Plaxis software can also be used for the plastic analysis of this model.
2. To nullify the boundary conditions, very large sized box and large sized square plates can be used to perform the plate load tests.
3. In this study , the tests which are performed are done on the dry coarse sand. But the moisture effect of coarse sand can also be studied.
4. The effect of depth of plate on the bearing ability of sand can also be studied. It will influence the bearing ability because of the overburden pressure.
5. The influence of coarse gravels on the bearing ability of the sand can also be studied.
6. The relation of particle size with the plate size has not been developed in this study. It can be done in the future.
7. The effect of shape of the particles on the bearing capacity can also be studied.

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