ANALYSIS OF SAND GRADATION EFFECTS ON RELATIVE DENSITY

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

Bachelor of Technology
In
Civil Engineering

By

Apurv Kumar Siya

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Under the guidance of

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राष्ट्रीय प्रौद्योगिकी संस्थान, राउरकेला

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

CERTIFICATE

This is to certify that the Project Report entitled “**Analysis of Sand Gradation Effects on Relative Density”** submitted by **Mr. Apurv Kumar Siya (110CE0574)** in partial fulfilment of the requirements for the award of Bachelor Of Technology Degree in **Civil Engineering** at National Institute Of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge the matter embodied in this Project Report has not been submitted to any other University for the award of any Degree or Diploma.

Date:

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ACKNOWLEDGEMENTS

I take the opportunity to express my gratitude and apprehension to all those who encouraged me in completing my project successfully with their guidance and support.

First of all, I avail this occasion to express my heartfelt gratitude to *Prof N.Roy*, HOD, Dept. of Civil Engineering, NIT Rourkela for his valuable guidance, constant encouragement and generous help at various stages during the project work. His dual role, as a guide and HOD has been of immense help towards giving life to this project. An erudite guide, a magnificent person and a strict disciplinarian, I consider myself fortunate to have worked under his supervision.

I also express my sincere gratitude to *Prof R.Jha* and *Prof. (Mrs) Asha Patel*, Project Coordinators, Dept. of Civil Engineering for guiding me in the course of the project and the report preparation. I am also grateful to all the professors of our department who helped me out in finding out the shortcomings in my approach towards the project and gave me their valuable advices to make it an error-free endeavour.

I would fail in my duties if I don't thank the lab assistants of our Geotechnical Lab for their selfless efforts in carrying out the lab experiments without which the project would not have been possible. They have been highly proactive right from procuring the samples and making arrangements for the experiment without which the project would not have come to life.

A truly unbounded word of thanks to my friends for their relentless support and needful advice which is the reason that this attempt of mine has come out successful without any slipups. I am obligated to my family for their affection, constant encouragement and forbearance. Thanks to the Almighty for the blessings bestowed upon in all my endeavours.

Apurv Kumar Siya

CONTENTS

NOMENCLATURE

D_{10}	Effective particle size (Particle size at 30% finer)
D_{30}	Particle size at 30% finer
D_{50}	Mean particle size (Particle size at 50% finer)
D_{60}	Particle size at 60% finer
C_u	Coefficient of Uniformity
C_c	Coefficient of Curvature
G_s	Specific Gravity
ϒw	Unit weight of water
γ	Unit weight of sand
γ_d	Dry unit weight of sand
γ_{dmin}	Dry unit weight at loosest state
γ_{dmax}	Dry unit weight at densest state
e_{max}	Void ratio at loosest state
e_{min}	Void ratio at densest state
e	Void ratio at natural state
D_r	Relative Density
N_c, N_q, N_γ	Bearing capacity factors
ϕ	Angle of internal friction

B	Width of footing
c	Cohesion
q	Surcharge
$\mathbf{q_d}$	Ultimate bearing capacity due to general shear failure

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ABSTRACT

The relative density of a granular cohesionless soil is a better indicator for specifying its level of compaction i.e. coarser soil as compared to relative compaction. It has been also found that sands are a more preferred material for use as filling in foundation/base material because of its affinity to be less affected by pore moisture content as compared to cohesive soils. The reason can be pointed out to their greater void size, which contains more air than water. Practically it is very difficult to obtain homogeneous sands during various cut and fill operations or other purposes of construction. This leads to procuring sand from different sources, which result in heterogeneous properties in the sample used.

From the literature survey carried out, it has been found that there has not been an appropriate effort to establish a relationship between relative density, bearing capacity and gradation of sand, i.e. the different proportions of coarse, medium and fine sand. Hence, an effort is being made to carry out an experimental study regarding the relation between the two and conclude with an empirical relation between the two. Since the mathematical formula relates relative density to the void ratios in the densest, loosest and natural states, vibratory table test have been carried out for the different samples prepared. Erstwhile, sieve analysis and specific gravity test were carried out for the samples from the four sources to find out the natural proportion.

After establishing the empirical relation between relative density and sand gradation, steps have been taken to carry the experiment further and relate the bearing capacity of the sample with the relative density for its easier application in the field. Finding the internal angle of friction from the direct shear test, the bearing capacity has been calculated in accordance with IS 6403:2002. The relation between relative density and internal angle of friction has been found in accordance with the Meyerhof's relation, with an allowable error of ± 5 % from the ideal values.

Keywords: sand; relative density; mixed grading; bearing capacity; compaction; particle size

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION:

Relative Density, defined as the expression used to indicate the relative compactness or looseness of a cohesion less granular soil is one of the concerning properties which decides its usage. The concept of density index (relative density) gives a practically useful measure of compactness of cohesion less soils, suitably known as one of the index properties for sand, etc. The compactive characteristics of cohesion less soils and the related properties of such soils are dependent on factors like grain size distribution and shape of individual particles.

Density index is also affected by these factors and serves as a parameter to correlate properties of soils. Various soil properties like, penetration resistance, compressibility, compaction friction angle, permeability and California bearing ratio are found to have simple relations with density index. Hence, for such purpose it is necessary to find out maximum and minimum density of soil.

1.2 IMPORTANCE OF PRESENT STUDY:

There has been widespread use of sand in fillings for construction of dams, sub foundations, highway embankments, etc. And since it’s difficult to obtain homogeneous sand for the construction purpose, it is important to study how the proportion of different sand grades affects its compaction and its impact on settlement and liquefaction. In this case, the sand can be divided into 3 parts according to IS 1498:2002-*Classification and Identification of Soils for General Engineering Purposes*:

- Coarse : 4.75mm - 2.00mm IS Sieve
- Medium : 2.00mm - 0.425mm IS Sieve
- Fine : 0.425mm - 0.075mm IS Sieve

One of the other major properties is the bearing capacity of soil, which plays a dynamic role in its use in construction avenue. With the non-homogeneity of soil available for the purpose of constructing embankments, foundations, etc., it is also important to study the effects of mixed sand grading on the bearing capacity of the sample and hence establish a relationship between the two which can be beneficial as we can find an optimised method to get the maximum compacted sand sample, thus reducing the need for rigorous compaction methods and machineries.

1.3 OBJECTIVE:

- To study and analyse the effects of sand gradation i.e. different proportions of coarse, medium and fine sand on-
    - relative density
    - bearing capacity

  and also establish an empirical relation between the two.
- To establish an empirical relation between relative density and bearing capacity for ease in field applications.

1.4 OUTLINE OF PRESENT WORK:

This thesis is organised into five chapters. The first chapter is a brief introduction about the project topic and its objectives.

The second chapter is the literature review, which summarises the journals that have been referred to in the making of the project. It also contains the previous work done in this topic, which has helped the project to complete.

The third chapter consists of the methods and experiments that have been taken up during the project viz. sieve analysis, specific gravity, etc.

The fourth chapter contains the results, and graphs relating them regarding all the experiments performed in the project. Also the results are discussed and inferences from them have been noted down.

The fifth chapter has the conclusion inferring from the results that are obtained after performing the experiments.

CHAPTER 2

LITERATURE REVIEW

2.1 PREVIOUS WORK ON THE TOPIC:

Researchers in the past have studied the relationship of relative density and the various factors affecting it. White and Walton (1937) studied on the particle packing and shape. Relative density, maximum and minimum void ratio values of sand were found to be greatly affected by particle shapes, sizes and their way of packing. The practical application of this was also taken up.

Burmister (1948) proposed an analogy about the limit densities of sands. Limit density values of sands should be considered as significant as the properties like the uniformity coefficient, coefficient of curvature, mean particle size, and particle shape, among others, when providing a comprehensive account of sand. Density, or void ratio limits help to describe the material under consideration in a more precise manner and are essential when evaluating the relative density of in-place soils.

Lee et al. (1972) studied the compaction of granular soils. The compaction curves obtained were found to be more dependent on the nature of the material used. Also some discrepancies were found when a large number of curves were considered and the moisture content approached zero, causing the compaction curves to be irregular.

Holubec and D'Appolonia (1973) studied the influence of particle shape on the properties concerning the engineering behaviour of granular cohesion less soils. Experimental data showed that the particle shape has a prominent effect on all the engineering properties. Angularity of the particles causes a proportional increase in the maximum void ratio and decrease in the rigidness of cohesionless soils. The variations due to this can be as large as variations associated with large differences in relative density.

Youd (1973) studied the factors affecting the maximum and minimum densities of sands. It was found that properties like particle size range, shape and changes in the gradation curve affect the density of sand. The void ratios too were found to decrease with increase in uniformity coefficient, which represents the particle size range.

Johnston (1973) presented the experimental studies of maximum and minimum dry densities of cohesion less soils. The results show that one of the significant variables in determining the maximum density of cohesionless soils using the vibratory table method is the amplitude of the vibrating mould.

Masih (2000) proposed a mathematical formula to get the wanted soil density. He used the arithmetical constraints of the grain distribution to correctly guess the maximum dry density of the soil and then applied the fine biasness coefficient to forecast the new density after mixing any random amount of fine particles with the original one. Lab results, on comparision with the results of the prediction were found to be in total agreement, and the margin of error was found to be low.

Further studies by Barton et al. (2001) on the topic of mixed grading effects on the maximum dry density of sands showed an increase in the maximum dry density of the sample with the grading moving more towards the ideal characteristics for dense packing. Also, the experimental values were found to be more than the predicted values for the parent sands.

Cubrinovski and Ishihara (2002) studied the maximum and minimum void ratios features of sands. They examined the effect of presence of fines, grain-size composition and particle shape on the maximum and minimum void ratios and on the difference between the two. They also proposed empirical relations between the void ratios of sand at loosest & densest state and the material properties.

2.2 MOTIVATION BEHIND PRESENT WORK:

It has been found that relative density better indicates the compaction of granular soil, i.e. coarser soil as compared to relative compaction. Also sands are more preferred as a foundation/base material because of its tendency to be less affected by pore water as compared to cohesive soils which can be attributed to its greater void size, which holds more air than water. During cut and fill operations, compaction using sand from different sources may be done, resulting in a mixed sand which will have different compaction characteristics than those of the parent sands. Also it is practically impossible to obtain fines-free sand for construction purpose.

From the number of studies done, there has not been a proper attempt on establishing the relationship between relative density and gradation of sand, i.e. coarse, medium and fine sand. Hence, an attempt through means of experimental study is being made to find a relation among the two, if possible a mathematical one. Also to make the results more practicable in the field, the effect of different proportions of fines present in the sample would also be considered. As the mathematical formula expresses relative density in terms of the void ratios in the natural, loosest and densest soil states, several lab experiments would be performed for determining the different void ratios for different proportions of sand grades. Prior to it, the tests for the grain size analysis to determine the proportion of fines present in the sample and the proportion of different sand grades to be added in the sample would also be taken up.

The effects of relative density on the bearing capacity of the soil has been a topic of research in the past. Many studies have been done establishing relationship between the relative density and SPT value (N), the SPT value and the bearing capacity, etc. So as to eliminate the need of an intermediate SPT value and finding out the bearing capacity from the relative density of soil with the use of some other inputs, many empirical relationships between the two have been proposed using other inputs to find the bearing capacity through the relative density of the sample. The project would thus also focus on analysing the effects of mixed grading on the bearing capacity of the sample and hence make efforts to arrive at an optimum proportion of the coarse, medium and fine sand grades which can help get the maximum relative density for proper sand compaction and hence increase the bearing capacity of the sand to the maximum.

CHAPTER 3

METHODOLOGY

3.1 METHODOLOGY:

The project being an experimental work requires the protocol of collecting samples, analysing them, performing various tests and deriving conclusions from the results. The project can be broken down in the following parts-

- Procurement of Samples-

  Sand samples were procured from the four different sources i.e. the riverbanks of Sankh, Koel and Brahmani at Rourkela. The samples were bought for the construction purposes at the campus site, so they are fit to be used for construction purposes.

- Preliminary Analysis-

  Sieve analysis of the samples collected from different sources was performed for sand gradation. The proportions of coarse, medium and fine sand in the sample was found out, which gave us the idea of the proportions at the riversides. Preliminary tests for finding out primary properties like specific gravity, dry unit weight, etc. were also performed.

- Performing Lab Tests-

  From the procured sand samples, 17 sets were prepared with different proportions to find out the relative density of the sand sample were carried out by the vibratory table test method. Obtaining the maximum and minimum void ratios, the relative densities were found out.

  After relative density, direct shear tests were conducted to find out the angle of internal friction and calculate the bearing capacities for the different samples with the help of IS 6403:2002-*Code of Practice for Determination of Bearing Capacity of Shallow Foundations.*

- Analysis of Results-

The results of various relative densities and bearing capacities for different sand grade proportions obtained were analysed. Empirical relations have also been established between gradation, relative density and bearing capacity.

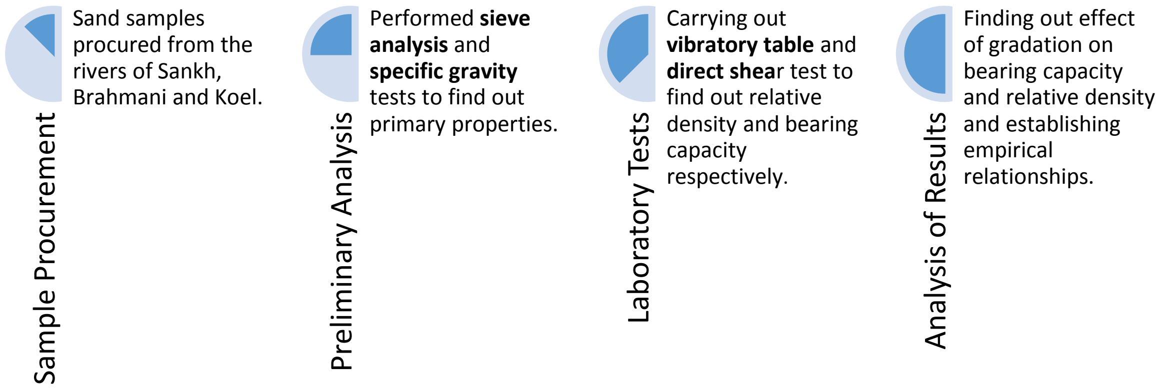

Figure 3.1 – Methods adopted in the project

Sl. No	Experiment Name	Reference
1	Sieve Analysis	IS 2720: Part 4
2	Specific Gravity	IS 2720: Part 3
3	Field Dry Density	IS 2720: Part 28
4	Vibratory Table Test	IS 2720: Part 14
5	Direct Shear Test	IS 2720: Part 13

Table 3.1 – Experiments performed during the project

CHAPTER 4

RESULTS AND DISCUSSION

4.1 SIEVE ANALYSIS:

Sieve Analysis was performed on the samples procured and the following results were obtained. From the plot between percentage finer and particle size, the values of D_{10}, D_{30}, D_{50}, D_{60}, C_u and C_c were determined. D_{10}, D_{30}, D_{50} and D_{60} are found from the gradation curve plotted in the next page. Uniformity and curvature coefficients are calculated as –

$$\mathbf{C_u = D_{60} / D_{10}}$$

$$\mathbf{C_c = (D_{60})^2 / D_{30} \times D_{10}}$$

Table 4.1 – Sieve Analysis data of the samples procured

Sample	**Coarse Sand (%)**	**Medium Sand (%)**	**Fine Sand (%)**	**D10 (mm)**	**D30 (mm)**	**D50 (mm)**	**D60 (mm)**	**Coefficient of Uniformity (Cu)**	**Coefficient of Curvature (Cc)**
1	10	62	28	0.16	0.46	0.77	1	6.25	1.32
2	5	69	26	0.19	0.48	0.8	1.2	6.32	1.01
3	0	88	12	0.13	0.64	0.7	0.8	6.15	3.94
4	14	76	10	0.5	0.8	1.1	1.4	2.8	0.91

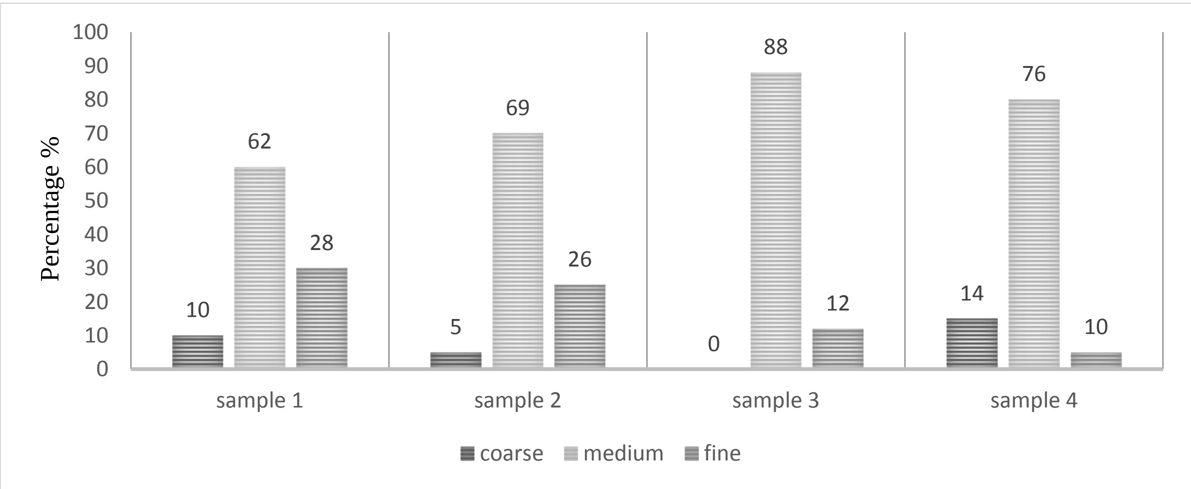

Figure 4.1 – Natural Gradation of the procured samples

For sample 1 & 2, $C_u>6$ and $1<C_c<3$ implying that these are **well-graded** samples and others are not. Therefore, only samples 1 & 2 are taken up for experimentation.

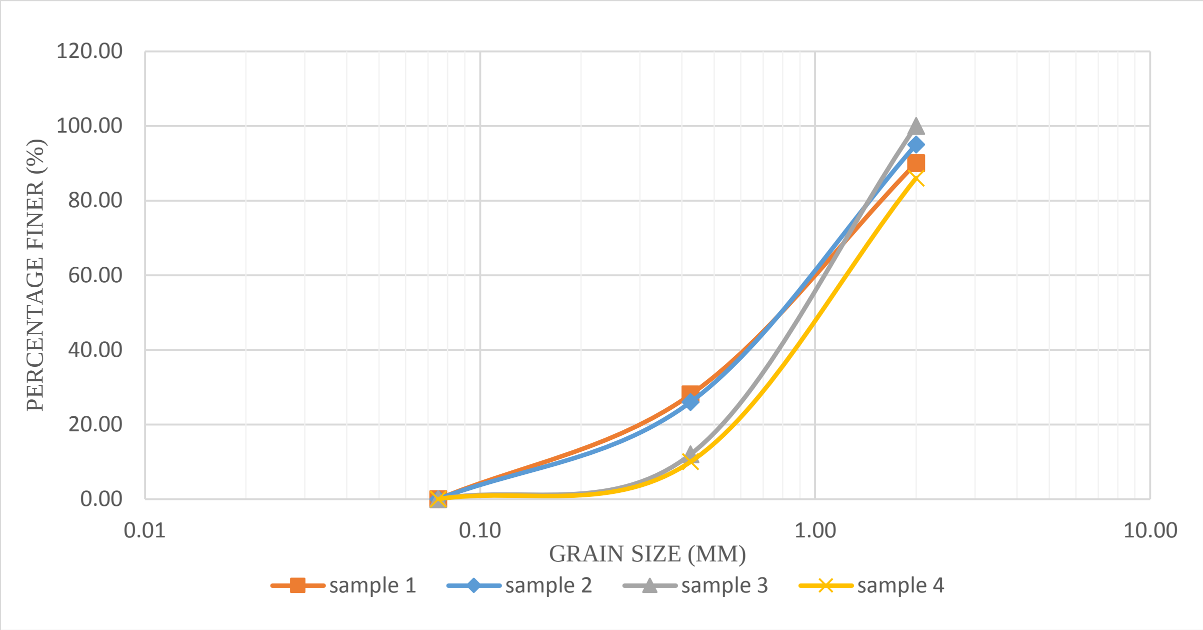

Figure 4.2 - Gradation Curve for the procured samples

The above gradation curve is the plot between percentage finer and grain size. The curve is plotted on a semi-log graph and the size of different percentage finer particles i.e. D_{10}, D_{30}, D_{50}, D_{60} are found out. They are then used in calculating the different coefficients as mentioned earlier.

4.2 Specific Gravity:

Specific Gravity is found out for all the four samples that were procured using the formula-

$$G_s = W_1 / [\ W_1 + (W_2 - W_3)\ ]$$

Table 4.2 - Specific Gravity results for procured samples

SAMPLE	**1**			**2**			**3**			**4**		
	I	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**
Wt. of Pycnometer (gm)	96	100	100	100	100	96	100	100	96	100	96	100
Wt. of Pycnometer + Sand (gm)	146	150	150	150	150	146	150	150	146	150	146	150
Wt. of Dry Sand W_1 (gm)	50	50	50	50	50	50	50	50	50	50	50	50
Wt. of Pycnometer + Water W_2 (gm)	343	351	351	347	351	349	347	349	341	347	344	346
Wt. of Pycnometer + Water + Sand W_3 (gm)	374	382	382	378	382	380	378	380	371	378	375	377
G_s	2.65	2.63	2.66	2.58	2.63	2.60	2.57	2.59	2.54	2.63	2.65	2.66
Average G_s		2.64			2.60			2.57			2.65	

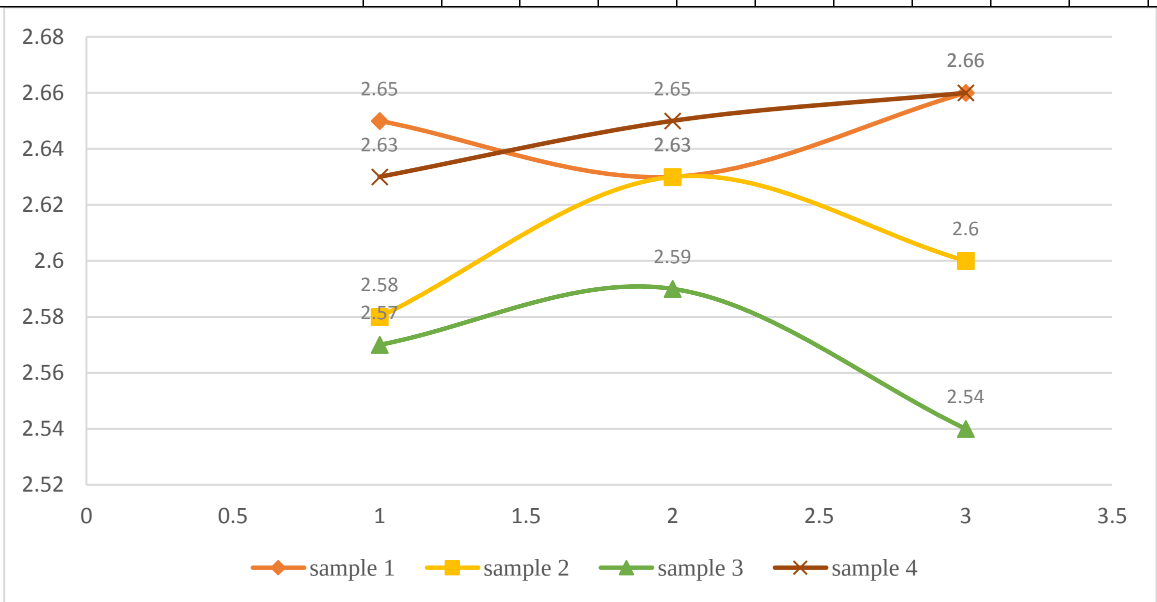

Figure 4.3 – Specific Gravity results for samples procured

4.3 VIBRATION TABLE TEST:

This test gives us the maximum and minimum void ratios which are used to find the relative density for the 17 samples prepared and tested from the procured samples.

Mass of Mould	**(M_1) = 10.631 kg**
Height	**(H) = 17 cm**
Diameter	**(D) = 15 cm**
Area of Cross-section	**(A) = 0.018 m^2**
Volume	**(V) = 0.003 m^3**
Unit Weight of water	**(Υ_w) = 1000 kg/m^3**

The maximum and minimum dry densities and void ratios are calculated as follows-

$$\gamma_{dmin} = \text{Mass of Sand before vibration / Volume of Sand in mould}$$

$$\gamma_{dmax} = \text{Mass of Sand after vibration / Volume of Sand in mould}$$

$$e_{max} = (G_s \times \Upsilon_w / \Upsilon_{dmin}) - 1$$

$$e_{min} = (G_s \times \Upsilon_w / \Upsilon_{dmax}) - 1$$

$$e = (G_s \times \Upsilon_w / \Upsilon_d) - 1$$

$$D_r = (e_{max} - e) / (e_{max} - e_{min})$$

The field density of sand in natural state is found out by sand replacement method by using the formula γ_d **= Mass of Sand / Volume of mould.**

Sample 1

Natural Gradation: Coarse-10% Medium-60% Fine-30%

Table 4.3 – Maximum and Minimum Void Ratios for Sample 1

Sample No	Coarse(%)	Medium(%)	Fine(%)	D_{50}(mm)	γ_{dmin}(g/cc)	γ_{dmax}(g/cc)	Υ_d(g/cc)	e_{max}	e_{min}	e	D_r(%)
1	10	50	40	**0.6**	1.43	1.85	1.63	0.85	0.43	0.53	**76.15**
2	20	50	30	**0.82**	1.50	1.94	1.70	0.76	0.37	0.47	**74.09**
3	30	50	20	**1.12**	1.56	2.01	1.77	0.70	0.32	0.42	**72.71**
4	10	60	30	**0.76**	1.50	1.92	1.69	0.77	0.38	0.48	**74.40**
5	20	60	20	**0.99**	1.54	1.98	1.74	0.73	0.34	0.44	**73.38**
6	30	60	10	**1.34**	1.58	2.05	1.79	0.68	0.29	0.4	**71.40**
7	10	70	20	**0.9**	1.50	1.96	1.72	0.76	0.35	0.46	**73.90**
8	20	70	10	**1.08**	1.54	2.00	1.75	0.72	0.32	0.43	**72.48**

Sample 2

Natural Gradation: Coarse-5% Medium-70% Fine-25%

Table 4.4 – Maximum and Minimum Void Ratios for Sample 2

Sample No	Coarse(%)	Medium(%)	Fine(%)	D_{50}(mm)	$\gamma_{dmin(}$g/cc)	γ_{dmax}(g/cc)	Υ_d(g/cc)	e_{max}	e_{min}	e	D_r(%)
1	5	65	30	**0.72**	1.50	1.90	1.68	0.77	0.39	0.49	**75.13**
2	5	70	25	**0.8**	1.49	1.93	1.69	0.78	0.37	0.48	**74.20**
3	5	75	20	**0.96**	1.51	1.98	1.72	0.75	0.34	0.46	**73.55**
4	10	65	25	**0.82**	1.54	1.92	1.70	0.72	0.38	0.47	**74.98**
5	10	70	20	**0.92**	1.50	1.97	1.72	0.77	0.35	0.46	**73.78**
6	10	75	15	**0.94**	1.49	1.99	1.73	0.78	0.33	0.45	**73.46**
7	15	65	20	**0.92**	1.51	1.96	1.73	0.76	0.34	0.45	**74.78**
8	15	70	15	**1**	1.53	1.99	1.74	0.73	0.33	0.44	**73.62**
9	15	75	10	**1.04**	1.51	2.02	1.75	0.76	0.31	0.43	**73.71**

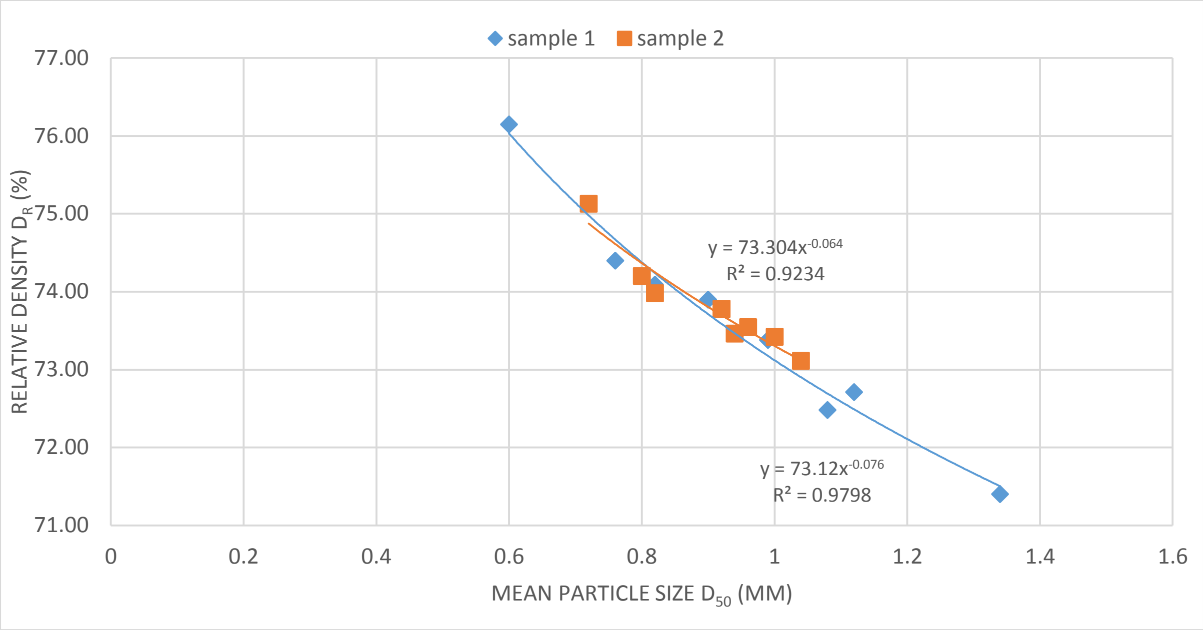

Figure 4.4 – Relative Density vs. Mean Particle Size for the 17 tested samples

The graph above shows the plot between relative density and mean particle size for all the 17 samples prepared by changing the natural gradation. The graph is a decreasing one, showing that the relative density and mean particle size are inversely proportional. Taking the two equations into consideration, an empirical relation can be established between relative density and mean size particle i.e.

$$\mathbf{D_r = 73\ D_{50}^{-0.07}}$$

where D_r is the Relative Density (%) and D50 is the mean particle size (mm).

4.4 DIRECT SHEAR TEST:

Sample 1

Natural Gradation: Coarse-10% Medium-60% Fine-30%

Table 4.5 – Table for ϕ and Bearing capacity of Sample 1

Sample No	Coarse (%)	Medium (%)	Fine (%)	D_{50} (mm)	Normal Stress (kg/cm^2)	Proving Ring Reading (a)	Shear Force = (a)*3.0672N (b)	Shear Stress = (b) / 36 (kg/cm^2)	Angle of Internal Friction (ϕ) (°)	Unit Weight (ϒ) (gm/cc)	Bearing Capacity Factor N_γ	Ultimate Bearing Capacity (kN/m^2)
1.	10	50	40	0.6	4.91	54	165.60	4.60	43.14	1.96	211.37	2071.38
2.	20	50	30	0.82	4.91	50	152.64	4.24	40.86	2.04	137.33	1400.81
3.	30	50	20	1.12	4.91	47	142.92	3.97	38.96	2.12	84.37	894.29
4.	10	60	30	0.76	4.91	52	160.92	4.47	42.31	2.03	184.42	1871.82
5.	20	60	20	0.99	4.91	47	143.28	3.98	39.03	2.09	97.50	1018.90
6.	30	60	10	1.34	4.91	42	129.60	3.60	36.30	2.15	76.26	819.85
7.	10	70	20	0.9	4.91	48	148.32	4.12	40.01	2.06	109.73	1130.27
8.	20	70	10	1.08	4.91	44	133.92	3.72	37.16	2.10	74.55	782.73

Sample 2

Natural Gradation: Coarse-5% Medium-70% Fine-25%

Table 4.6 – Table for ϕ and Bearing capacity of Sample 2

Sample No	Coarse (%)	Medium (%)	Fine (%)	D_{50} (mm)	Normal Stress (kg/cm^2)	Proving Ring Reading (a)	Shear Force = (a)*3.0672N (b)	Shear Stress = (b) / 36 (kg/cm^2)	Angle of Internal Friction (ϕ) (°)	Unit Weight (gm/cc)	Bearing Capacity Factor N_γ	Ultimate Bearing Capacity (kN/m^2)
1.	5	65	30	0.72	4.91	54	166.68	4.63	43.31	2.02	216.89	2190.55
2.	5	70	25	0.8	4.91	47	144.72	4.02	39.34	2.03	101.31	1028.27
3.	5	75	20	0.96	4.91	43	133.20	3.70	37.01	2.06	72.70	748.86
4.	10	65	25	0.82	4.91	53	163.80	4.55	42.86	2.04	202.27	2063.20
5.	10	70	20	0.92	4.91	47	145.44	4.04	39.46	2.06	91.73	944.85
6.	10	75	15	0.94	4.91	45	137.52	3.82	37.92	2.08	71.60	744.64
7.	15	65	20	0.92	4.91	50	154.44	4.29	41.16	2.08	147.08	1529.58
8.	15	70	15	1	4.91	48	147.24	4.09	39.80	2.09	82.65	863.67
9.	15	75	10	1.04	4.91	45	137.88	3.83	37.98	2.10	60.06	630.64

4.5 BEARING CAPACITY:

The formula used to calculate the ultimate bearing capacity is

$$q_d = cN_c + q\,(N_q - 1) + 0.5\,B\,\gamma\,N_\gamma$$

[IS 6403:2002-CODE OF PRACTICE FOR DETERMINATION OF BEARING CAPACITY OF SHALLOW FOUNDATIONS]

Since the sand is cohesionless, no surcharge is used here and we assume the footing to be of unit width, therefore the first two terms are neglected and the working formula becomes

$$q_d = 0.5\,\gamma\,N_\gamma$$

Many factors like the shape of footing, effect of water table, eccentricity of loading, etc. are not considered in the above calculation as this project work did not include any practical testing of bearing capacity for the samples. The same may be carried out in future by performing the plate load test.

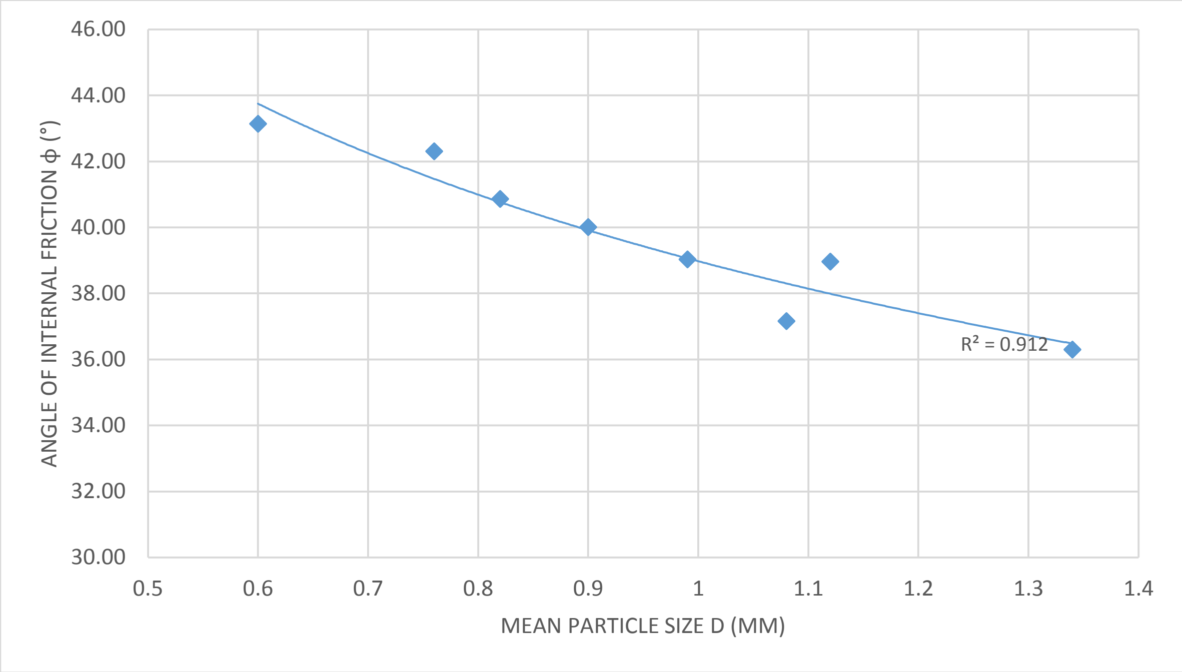

Figure 4.5 - ϕ vs. D for Sample 1

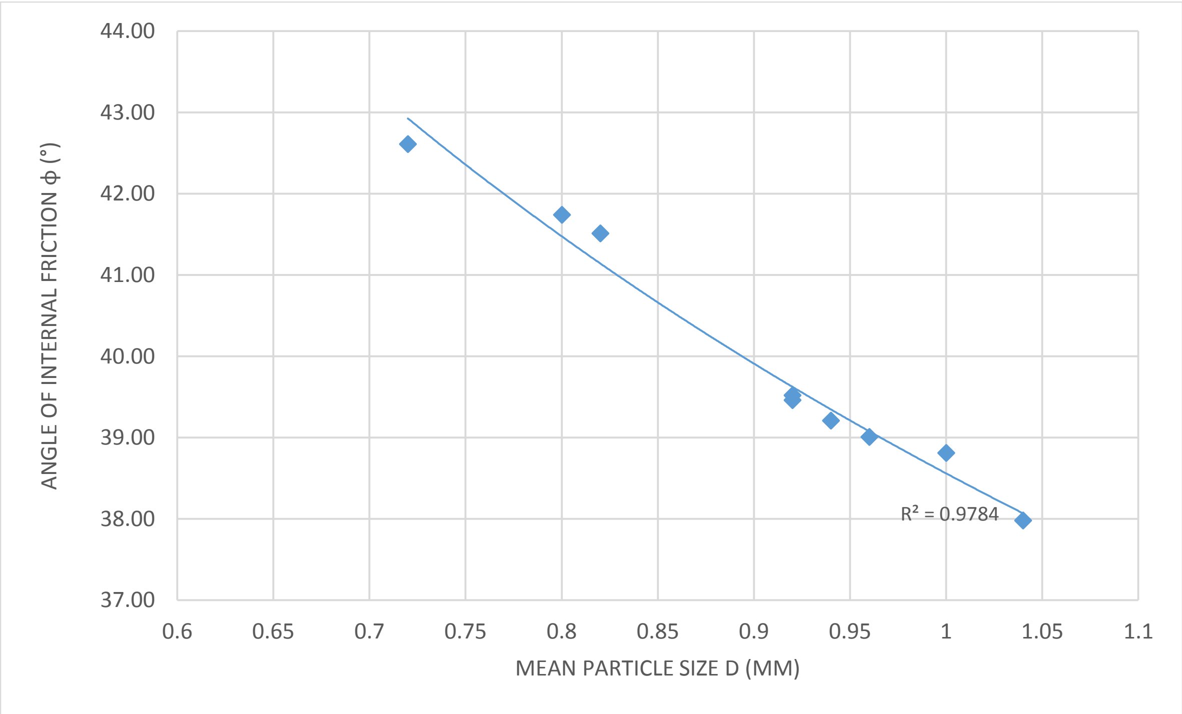

Figure 4.6 - ϕ vs. D for Sample 2

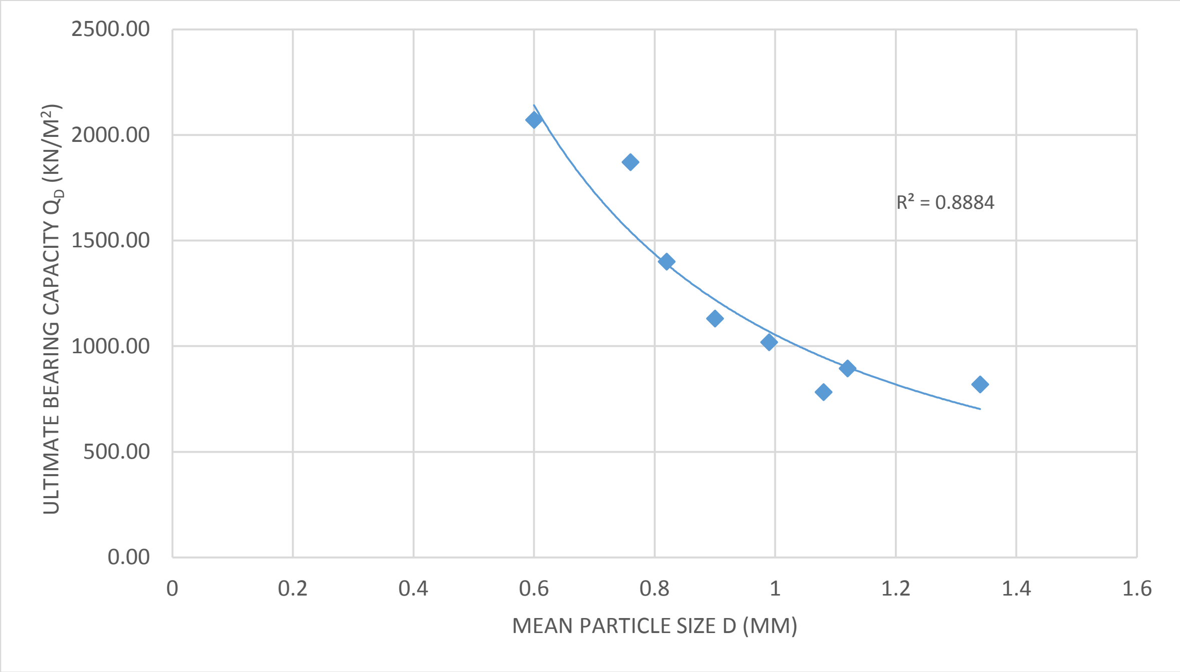

Figure 4.7 - q vs. D for Sample 1

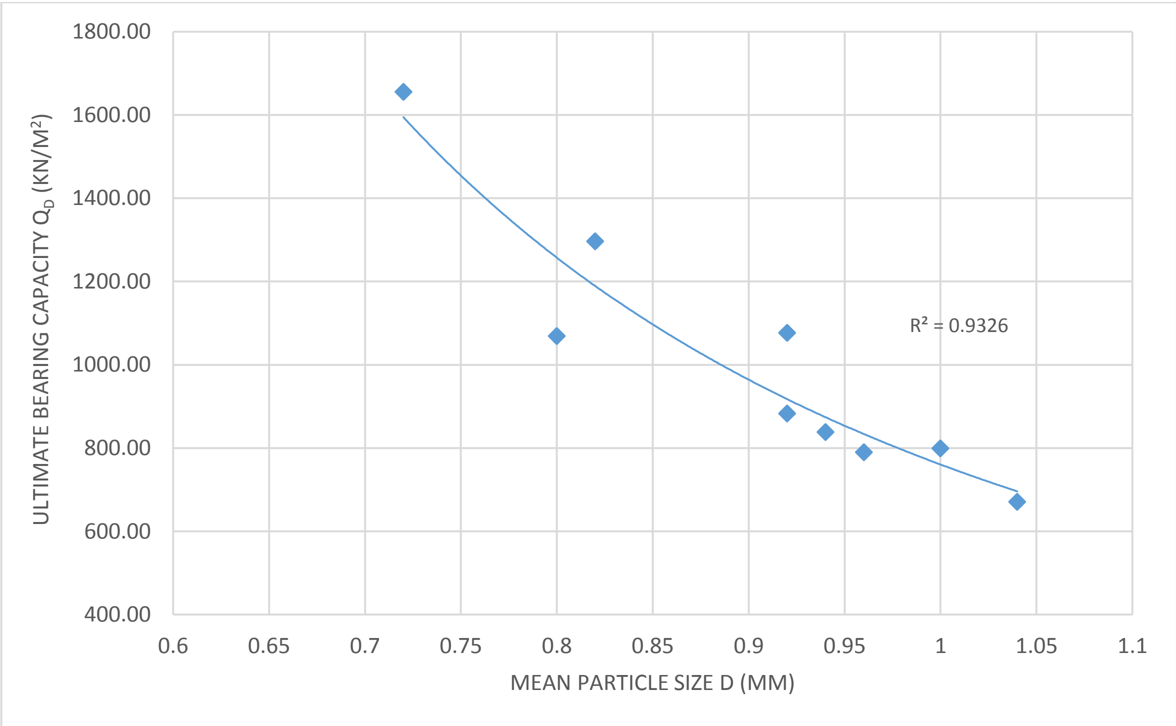

Figure 4.8 – q_d vs. D for Sample 2

4.6 COMPARISION WITH PREVIOUS WORK:

According to *Meyerhof* (1956), the relative density and angle of internal friction can be mathematically related to each other as-

$$\phi=30+0.15\ D_r\ ;\ \text{when silt} < 5\%$$

$$\phi=25+0.15\ D_r\ ;\ \text{when silt} > 5\%$$

The following is the plot between the angle of internal friction and relative density obtained for the samples from the two samples, containing both the experimental plot and the plot representing *Meyerhof's* equation.

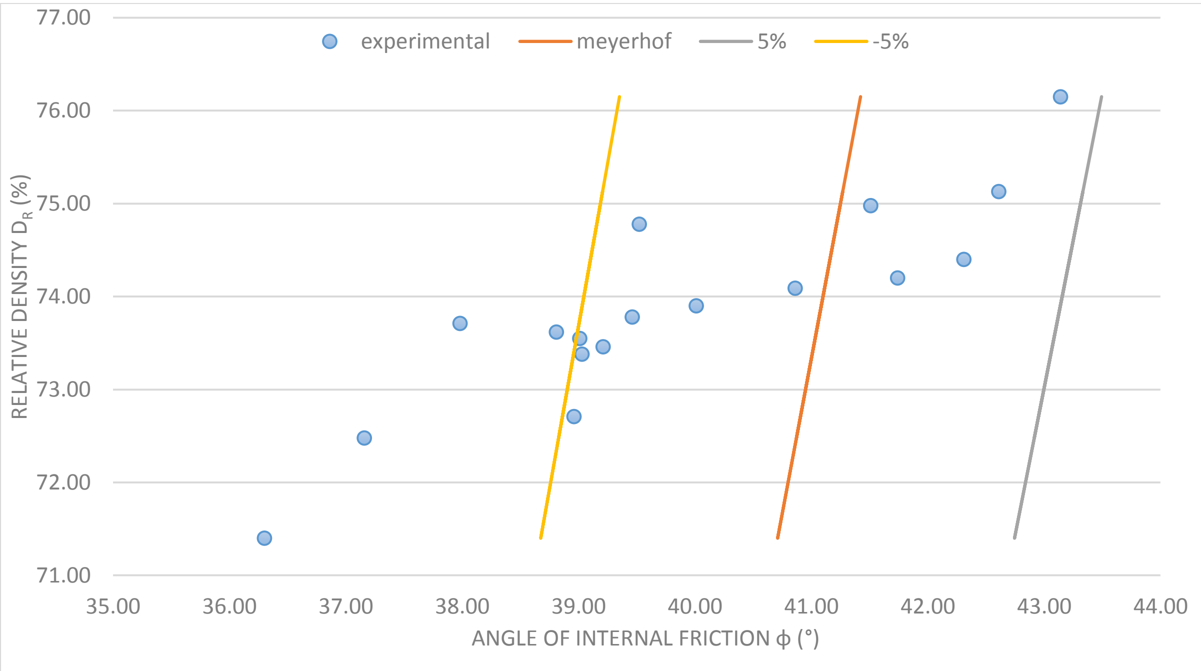

Figure 4.9 – Comparison of experimental data with *Meyerhof* (1956)

The plot above represents the total sets of data taken for the experiment. Out of them, four sets of data are found to lie outside the percentage error line. The rest i.e. 80% of the data points seem to comply with the *Meyerhof*'s equation. The failure for the remaining 20% can be attributed to the fact that those soil proportions taken are not well-graded. Upon the analysis of data obtained from sieve analysis, all the different proportions taken were found to be well graded, except a few which did not tally with *Meyerhof's* equation.

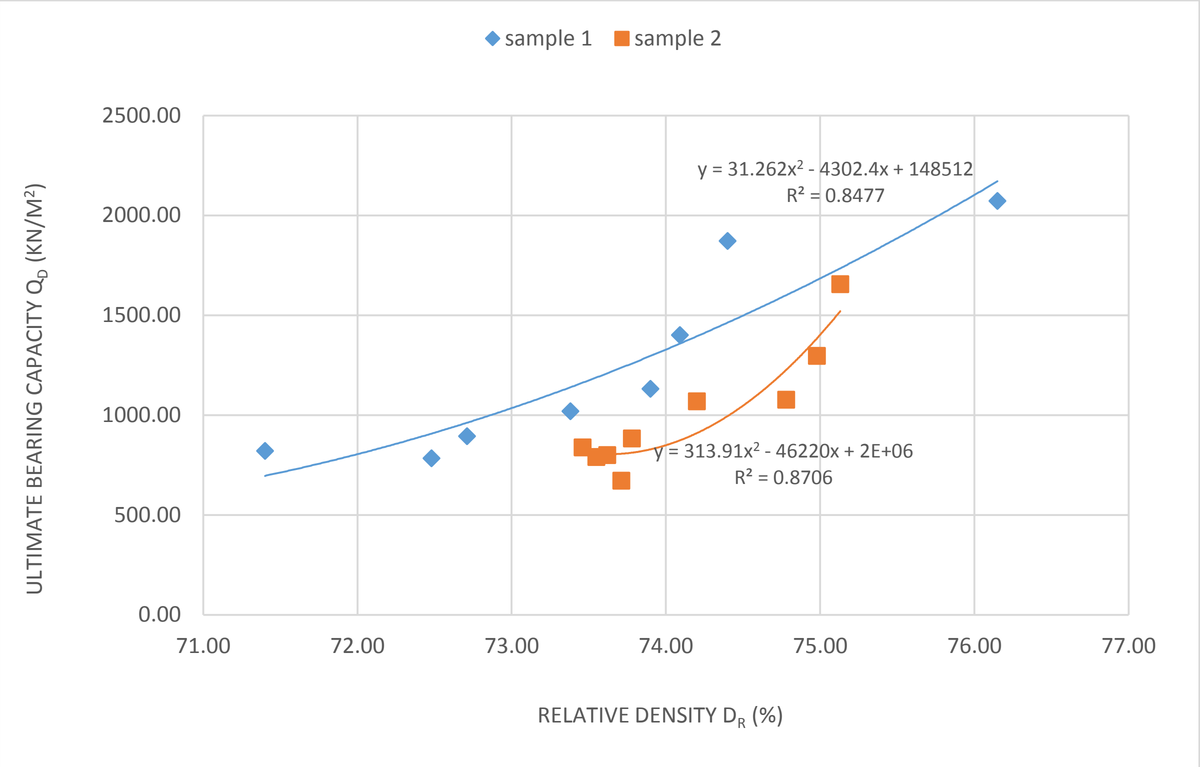

Figure 4.10 – q_d vs. D_r for the 17 samples tested

The above graph shows the plot between ultimate bearing capacity, q_d and relative density, Dr. As can be seen, relative density and ultimate bearing capacity were found to be directly proportional to each other. The plot is an increasing graph but the empirical relations are different for the two samples taken from different sources. The difference can be attributed to the nature of the soil or the stress history of the samples.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION:

On the basis of present experimental study, the following conclusions are drawn-

- Well graded samples i.e. samples with Cu >6 and 1< Cc <3 for sand are found to be denser than the other samples i.e. they have higher relative density of about greater than 70%, which is categorised as 'dense sand' *(McCarthy, 2007).*
- Relative density **(D_r)**, Bearing Capacity **(q_d)** and angle of internal friction **(ϕ)** is found to vary inversely with the mean particle size.
- The relative density and angle of internal friction comply with the empirical relation given by *Meyerhof (1956)*, lying between the range of +/- 5% error.
- The mean particle size is found to be most significant factor in affecting the index property i.e. relative density for cohesion less soils taken. Thus an empirical relation is proposed from the present experimental work as

$$\mathbf{D_r = 73\ D_{50}^{-0.07}}$$

- Relative Density **(D_r)** and Ultimate Bearing Capacity **(q_d)** were found to be directly proportional to each other. The difference in the empirical relations of the two samples can be attributed to the nature of the soil or the stress history of the samples.

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