MAJOR PROJECT

ON

A STUDY OF COLLAPSIBLE BEHAVIOR OF SOIL BLENDED WITH FLY ASH AND KOTA STONE DUST

Submitted in partial fulfillment of requirement for the award of degree of

MASTER OF TECHNOLOGY

IN

GEOTECHNICAL ENGINEERING

Submitted by

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DELHI TECHNOLOGICAL UNIVERSITY

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Department of Civil Engineering

Delhi Technological University, Delhi

CERTIFICATE

This is to certify that the thesis entitled **"A Study of Collapsible Behavior of Soil Blended with Fly Ash and Kota Stone Dust"** submitted by **Farukh Ali** in partial fulfillment of the requirement for the award of the degree of Master of Technology in Geotechnical Engineering to Delhi Technological University, Delhi is an authentic record of student's own work and it was carried out under the guidance and supervision of **Prof. Kongan Aryan** in the academic year 2015-2016.

To the best of my knowledge, the matters enclosed in the thesis have not been submitted to any other university/Institute for the award of any Degree or Diploma.

Date:

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

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ACKNOLEDGEMENT

I would like to express my gratitude to all the people behind the screen who helped me to transform an idea into a real application. I would like to thank my guide **Prof. Kongan Aryan** for his technical guidance, constant encouragement and support in carrying out my thesis work at college. The satisfaction and euphoria that accompany the successful completion of the task would be great but incomplete without the mention of the people who made it possible with their constant guidance and encouragement crowns all the efforts with success. In this context, I would like thank my friends and all the other staff members both teaching and non-teaching who have extended their timely help and eased my task.

Place: DTU Delhi Farukh Ali

Date:

"A Study of Collapsible Behavior of Soil Blended with Fly Ash and Kota Stone Dust"

Abstract

Soil is said to be collapsible in its natural or compacted state if it undergoes abrupt reduction in strength, excessive and sudden settlement upon wetting leading to failure of structure. Before any type of construction, soil should be checked for collapsibility in its natural as well as compacted state because collapsible behavior of soil depends upon various factors such as dry density, water content, applied pressure at wetting and soil type. Collapsibility of soil is measured by determining collapse potential. To determine collapse potential, single oedometer test was performed in laboratory on soil sample. First of all, particle size analysis, consistency limits and compaction test were performed on soil, fly ash and Kota stone dust. Now, compaction test and single oedometer test were performed on soil sample mixed with different proportions (by dry weight of soil) of fly ash and Kota stone dust in order to determine the effect of fly ash and Kota stone dust on compaction behavior and collapsible behavior of soil. Variation of compaction behavior and collapse potential with varying fly ash content was determined at constant content of Kota stone dust mixed. Then, variation of compaction behavior and collapse potential with varying Kota stone dust content was determined at constant fly ash content mixed. Results indicates that mixing fly ash and Kota stone dust to certain content increase maximum dry density of soil and decrease optimum moisture content, collapse potential and settlement of soil. Hence, fly ash and Kota stone dust mixing results in stabilization of soil.

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The Following notations are used in this project:

OMC – Optimum moisture content

MDD – Maximum dry density

CBR – California bearing ratio

C_c – Coefficient of curvature

C_u – Coefficient of uniformity

D_{60} – Particle size corresponding to 60% finer

D_{30} – Particle size corresponding to 30% finer

D_{10} – Particle size corresponding to 10% finer

G_s – Specific gravity

ASTM – American Society for Testing and Materials

FA – Fly ash

KSD – Kota stone dust

SEM – Scanning electron microscope

CHAPTER 1

INTRODUCTION

1.1 General

Collapsible behavior of soil is associated with low initial density, low natural water content, open structure formed by sharp grains, low plasticity and high strength in dry state. If soil is collapsible, it shows large volume change upon wetting with or without extra loading, thus causing structural damage. Various soil types comes under the category of collapsible soil including residual deposits, alluvial deposits, aeolian deposits, colluvial deposits and volcanic tuff. Loess is a type of aeolian deposit, exhibit collapsible behavior, having silt size particles, relatively low density and cohesion but appreciable strength and stiffness in the dry state. Aeolian deposits generally found in arid regions where water table is low.

Collapsible soils have high void ratio, low water content and initial dry density, high stiffness and dry strength, and zero or slight plasticity in their natural state. The soil compacted at dry side of optimum water content, not achieving desired dry density can also show significant collapse upon wetting.

When these soils are subjected to additional water from rainfall, broken water or sewer lines, irrigation, water content increment due to capillarity, ground water table rise etc. loss of shear strength and volume reduction occurs, resulting in collapse of soil. In partially saturated condition these soils have negative pore pressure resulting in higher effective stresses and higher shear strength. Water softening or water soluble cementing agents such as clay minerals and $CaCO_3$ can also help in providing higher shear strength to soil in dry or partially saturated state. Due to wetting, pore pressure become less negative resulting in lower effective stress, so decrease in shear strength occurs. Additionally, introduction of water softens or dissolves the bond between the soil particles resulting in denser state under any type of compressive loading with or without extra load, and this process of collapse is called any of hydrocollapse, hydroconsolidation or hydrocompression.

Collapse of soil can be mitigated by using various methods such as removal of collapsible soil, avoidance of wetting, transfer of load to the stable strata below, injection of chemical stabilizers or grout, prewetting, compaction with rollers or vehicles, vibrocompaction and compaction piles, compaction by heavy tamping, vibroflotation and controlled wetting.

Now a days, to increase the bearing strength and to reduce the collapse of the ground as a foundation material and to reduce the plastic deformation due to presence of fines in the natural soils as fill materials, alternative materials like fly ash, pond ash, crusher dust etc., have been gaining importance. Availability of these wastes in large quantities encourages the geotechnical engineers for their bulk utilization in construction activities in place of natural soils. In this investigation an attempt is made to study the effect fly ash and Kota stone dust as geotechnical material in construction activities. Stone dust has wider applications in the areas of infrastructural facilities as a retaining material without reinforcement, fill material in highway construction, etc.

Fly Ashes are waste product generating from combustion of coal in electricity generating plants. Due to increasing industrialization, fly ashes are being produced at faster rate. Safe disposal and management of fly ashes is the major problem associated with their increasing production. Fly ash possesses pozzolanic property due to siliceous or alumino-siliceous material present in it. Fly ash itself possess little or no cementitious property but, in finely divided form and in presence of moisture it chemically reacts with calcium hydroxide at ordinary temperatures to form cementitious compound.

There are two classes of fly ash are defined in ASTM C 618, one is Class C fly ash, and other is Class F fly ash, based upon chemical composition. Class C category of fly ashes obtained from burning lignite and sub-bituminous type of coal, which contains more than 10% of calcium oxide. Class F category of fly ashes obtained from, burning bituminous and anthracite type of coal, which contains less than 10% of calcium oxide. Class F fly ash has pozzolanic properties. Class C fly ash, in addition to having pozzolanic properties, also has some self-cementing properties, meaning that it has ability to harden and gain strength in the presence of water alone.

The chemical compositions of any fly ashes, which are categorize into class C or class F fly ashes are as follows in Table 1.1

Table 1.1: Chemical requirement of class C and class F fly ashes (ASTM C618-94a)

Component	**Class F**	**Class C**
$SiO_2 + Al_2O_3 + Fe_2O_3$ (% min.)	70	50
SO_3 (% max.)	5	5
Moisture Content (% max.)	3	3
Loss on ignition (% max.)	6	6

Many of fly ashes, in India are basically class F fly ash, since majority of coal are bituminous.

In Kota, Rajasthan, large number of stone crusher units is available, which produces huge quantity of stone dust. Stone dust not only pollutes water, air and land but also their disposal is a great problem. It was found that the stone dust is the material that possess pozolanic as well coarser contents in it while other materials like fly ash possesses only pozzolanic property and no coarser soil particles. Therefore, it was decided to use this material in the present study as stabilizing agent for soil.

1.2 Objectives of study

1. To identify and classify the soil by performing laboratory experiments such as particle size analysis and consistency limit test.
2. To determine the various geotechnical properties of soil such as Specific Gravity, OMC and MDD by performing laboratory experiments.
3. To determine the particle morphology of soil, fly ash and Kota stone dust by scanning electron microscope.
4. To determine the various geotechnical properties of fly ash and Kota stone dust by conducting laboratory experiments such as particle size analysis, consistency limit test, specific gravity test, compaction test etc.
5. To determine the OMC and MDD of soil blended with varying proportions of fly ash and Kota stone dust in order to determine the effect of fly ash and Kota stone dust on OMC and MDD.
6. To determine the collapse potential of soil blended with varying proportions of fly ash and Kota stone dust by performing Single Oedometer Test in order to determine the effect of fly ash and Kota stone dust on collapsible behavior of soil.

CHAPTER 2

LITE RATURE REVIEW

Very little information has been published on the collapsible behavior of soil blended with fly ash and stone dust. However many studies are reported related to use of fly ash and Kota stone dust as construction material which are given below.

Trivedi et al. (2009) conducted several oedometer tests to determine the collapsibility of granular material and found that collapse potential obtained is a dependent parameter of several factors such as grain size characteristics, specific gravity, stress level, testing technique, degree of compaction, moisture content, over consolidation ratio, etc.

Ali (2016) observed that adding fine crushed stone to collapsible soil from 0% to 60% reduces the settlement at same applied pressure and the largest reduction was achieved at the largest percentage of added fine crushed stone (60%). Increasing the percentage of fine crushed stone from 0% to 60% reduces the footing settlement and increase the bearing capacity.

Basma and Tuncer (1992) conducted single oedometer test on eight different soil and found that collapse decrease as the difference between the sand and clay percentage increases and most significant parameter affecting collapse is initial dry unit weight. Collapse was found to be inversely proportional to the initial dry unit weight and increasing the compaction water content of soil decrease the collapse potential. For sandy soil collapse increases with increase in applied pressure prior to wetting.

Baytar (2005) observed the effect of fly ash and desulphogypsum on collapse potential and other properties of collapsible soil and concluded that addition of class C fly ash decreases plasticity index, shrinkage limit and OMC. Up to 15% fly ash added samples, curing decreases collapse potential of stabilized samples. However, samples having more than 15% fly ash, curing has a negative effect on collapse potential. While 28 days curing results are similar to the uncured results, 7 days curing gives worse results for desulphogypsum added samples. Adding fly ash increases the strength of collapsible soil. The addition of 10 % and 15 % fly ash gives the best result among the fly ash added samples. The curing shows a visible increase on the unconfined compressive strengths.

The most effective amount of added desulphogypsum is 15 %. The unconfined compressive strength of the samples decrease after 15% fly ash and desulphogypsum addition, therefore optimum fly ash and desulphogypsum addition appears to be close to 15%.

Ali and Koranne (2011) observed the effect of stone dust and fly ash mixing in different percentages on expansive soil. They observed that at optimum percentages, i.e., 20 to 30% of admixture, the swelling of expansive clay is almost controlled and there is a marked improvement in other properties of the soil as well. Addition of stone dust and fly ash combine at equal proportion to the expansive soil increases the dry density with decrease in the optimum moisture content. It is concluded by them that the combination of equal proportion of stone dust and fly ash is more effective than the addition of stone dust/fly ash alone to the expansive soil in controlling the swelling nature.

Bshara et al. (2014) reported the effect of stone dust on geotechnical properties of poor soil and concluded that the CBR and MDD of poor soils can be improved by mixing stone dust. They also indicated that the liquid limit, plastic limit, plasticity index and optimum moisture content decrease by adding stone dust which in turn increases usefulness of soil as highway sub-grade material.

Satyanarayana et al. (2013) conducted plasticity, compaction and strength tests on gravel soil with various percentage of stone dust and found that by addition of stone dust plasticity characteristics were reduced and CBR of the mixes improved. Addition of 25-35% of stone dust makes the gravel soil meet the specification of morth as sub-base material. They also concluded that crusher dust particles are similar to sand particles and offer more shear strength at wider variation of moisture contents by maintain high dry densities and can with stand high strengths in terms of CBR and angle of shearing resistance which can be used as fill and sub grade material in place of Red soil and sand.

Butt et al. (2015) carried out the detailed investigations on coal ash which shows that fly ash has a good potential for use in geotechnical applications. Its low specific gravity, freely draining nature, ease of compaction, insensitiveness to changes in moisture content, good frictional properties etc. can be gainfully exploited in the construction of embankments, roads, reclamation of low-lying areas, fill behind retaining structures etc.

It can be also used in reinforced concrete construction since the alkaline nature will not corrode steel.

Soosan et al. (2005) reported the effect of addition of query dust on properties of red earth and two different cohesive soils and concluded that compaction characteristics and CBR of soils are improved by addition of quarry dust, thus problem associated with the construction of highways over clayey subgrade can be reduced significantly by mixing quarry dust. Engineering properties of soil, including problematic soils like marine clays, are improved substantially by the addition of quarry dust. Improvement are manifested in the form of reduction of liquid limit, reduction of plasticity, increase in MDD, decrease in OMC, and increase in soaked and unsoaked CBR values.

CHAPTER 3

MATERIALS AND EXPERIMENTAL INVESTIGATIONS

3.1 Materials Used

3.1.1 Soil

Soil for this study was collected from Moradabad District of Uttar Pradesh State, India. This soil was subjected to various laboratory tests to determine particle size distribution, specific gravity, OMC, MDD, consistency limits and collapse potential of soil.

3.1.2 Fly Ash

Fly ash for this study was purchased from NTPC, Badarpur, New Delhi, India. Various laboratory tests were conducted on fly ash such as particle size distribution, consistency limits, specific gravity, compaction, scanning electron microscope etc. Chemical composition of fly ash was provided by staff of NTPC Badarpur is given in following table. Based on its chemical composition fly ash is classified as Class F fly ash.

Table 3.1: Chemical composition of fly ash of present study

S. No.	Chemical constituent	Percentage
1	SiO_2	58.45
2	Al_2O_3	32.38
3	Fe_2O_3	4.71
4	MgO	0.23
5	CaO	0.63
6	K_2O	0.61
7	Na_2O	0.23
8	Loss on ignition	2.71
9	Moisture content	0.05

3.1.3 Kota Stone Dust

For this study, stone dust was purchased from Roop Crushers, Nanta Industrial Area, Kota, Rajasthan, India. This stone dust was subjected to various laboratory test in order to determine the various geotechnical properties of Kota stone dust. A typical chemical composition of Kota stone dust is given in the following table.

Table 3.2: Chemical composition of Kota stone dust (Lakhani et al. 2014)

S. No.	Chemical constituent	Percentage
1	CaO	38-42
2	SiO_2	15-18
3	Al_2O_3 and Fe_2O_3	1.02-1.53
4	K_2O and Na_2O	0.35-0.62
5	MgO	13.74-15.32
8	Loss on ignition	32-34

3.2 Sample Preparation

First of all soil, fly ash (FA) and Kota stone dust samples were oven dried, then samples used in laboratory tests were prepared by mixing Fly ash and Kota stone dust in varying proportion by dry weight of soil. Fly ash mixed with soil is 5%, 10%, 15%, and 20%. Kota stone dust mixed with soil is 10%, 20%, and 30%. Both fly ash and Kota stone dust mixed with soil at same time. Samples were prepared by mixing soil, fly ash, and Kota stone dust according to proportioning of soil, fly ash (FA) and Kota stone dust (KSD) given in the following table.

Table 3.3: Proportioning of soil, fly ash and Kota stone dust for sample preparation

Sample	Soil (%)	Kota stone dust (%)	Fly ash (%)
Sample 1	100	0	0
Sample 2	85	10	5
Sample 3	80	10	10
Sample 4	75	10	15
Sample 5	70	10	20
Sample 6	65	10	25
Sample 7	75	20	5
Sample 8	70	20	10
Sample 9	65	20	15
Sample 10	60	20	20
Sample 11	65	30	5
Sample 12	60	30	10
Sample 13	55	30	15
Sample 14	50	30	20

For each sample, compaction curve is plotted using light compaction method and value of OMC and MDD is determined. To prepare sample for single oedometer test, each sample is compacted using light compaction test at water content corresponding to dry density at degree of compaction=96%. Compaction water content is dry side water content of optimum water content. Then, soil specimen is extruded from proctor mould and fill the consolidometer ring with soil sample keeping cutting edge of ring downward over the soil sample then pushing consolidometer ring slowly by cutting and trimming the excessive soil. The sample obtained in consolidometer ring was cured for 7 days, then single oedometer tests were performed.

3.3 Laboratory Experiments Conducted

3.3.1 Scanning Electron Microscope (SEM) Test

The particle morphology of soil, fly ash and Kota stone dust was analyzed using scanning electron microscope. The particle shape is quantified by analysis of image produced in SEM test. Through SEM we can identify type, shape, and size etc. of particles and structure of soil. SEM test was conducted in Nano Science Laboratory of DTU Delhi.

3.3.2 Particle Size Analysis

The distribution of different particles sizes affects the engineering properties of soil. Particle size analysis provides the grain size distribution, and it is required in classifying the soil. Particle size is one of the suitable criteria of soils for road, airfield, dam and other embankment construction. It is also used to predict soil water improvement, susceptibility to frost action and filter design of dam. The particle size analysis is attempted to determine the relative proportion of the different grain sizes that make up a given soil mass. Before going for hydrometer analysis, samples subjected to wet sieve analysis through 75µ sieve size in case of sample containing silt and clay size particles. Wet Sieve analysis was conducted for coarser particles greater than 75µ and hydrometer analysis was conducted for finer particles less than 75µ as per IS: 2720 (Part IV)-1985. Soil retained on sieve of 75µm in wet sieve analysis was dried and weighed and used for sieve analysis .These dried soils were passed through stack of sieves like 4.75mm, 2.36mm, 1.18mm, 600µm, 300µm, 150µm, 75µm. In hydrometer analysis, About 50 gm of soil was taken and solution of sodium hexameta phosphate was added to it and distilled water was added .Then the soaked soil was transferred to dispersion cup and was stirred for 15 minutes. Then the soil mixture was poured into the standard measuring flask and made total volume of soil suspension exactly by 1000cc. Finally the hydrometer was calibrated and different corrections was made from tables, charts provide to us. Coefficient of uniformity (Cu) and coefficient of curvature (Cc) was also to be found out.

3.3.3 Specific Gravity Determination

Specific gravity is the ratio of the weight in air of a given volume of a material at a standard temperature to the weight in air of an equal volume of distilled water at the same stated temperature. The specific gravity is used to find out the degree of saturation and unit weight of moist soil. Ultimately the unit weight of soil is used to determine pressure, settlement and stability problem. For all normal calculation specific gravity is important tool for geotechnical applications. The specific gravity of soil sample, fly ash and Kota stone dust is determined as per IS: 2720 (Part III/Sec I)-1980. Specific gravity is an important property to study the compaction characteristics and unit weight of materials used.

3.3.4 Liquid Limit and Plastic Limit Determination

The swedish soil scientist Albert Atterberg (1911) originally defined limit of consistency to classify fine-grained soil. This limit is based on water content of soil. If the water content of suspension soil is gradually reduced, the soil water mixture undergoes changes from a liquid state through a plastic state and finally into solid state. Transitions of soil from one state to another state according to increase and decrease in water content are termed as Atterberg Limits. So this test is also called Atterberg limit tests.

The liquid limit is the water content at which soil changes from liquid state to plastic state. At this stage all soil behaves practically like a liquid and possess certain small shear strength. It flow close the groove in just 25 blows in Casagrandes liquid limit device. As it is difficult to get exactly 25 blows in the test 3 to 4 tests are conducted, and the number of blows (N) required in ach test determined. A semi-log plot is drawn between logN and the water content (W). The liquid limit is the water content corresponding to N=25. The plastic limit is the water content at which soil changes from plastic state to semi-solid state. The soil in this stage behaves like plastic. It begins crumble when rolled in to threads 3mm diameter.

The liquid and plastic limit of soils are both dependent on the amount and type of clay in a soil and form the basis for soil classification system for cohesive soil based on the plasticity tests. Besides their use for identification, plasticity tests give information concerning the cohesion properties of soil and amount of capillary water which it can hold. They are also used directly in specifications for controlling soil for use in fill. The liquid limit is sometimes used to estimate settlement in consolidations problems and both limits may be useful in predicting maximum density in compaction studies. The liquid limit and plastic limit were determined as per the procedure lay down in IS: 2720 (Part V)-1985.

3.3.5 Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) Determination using Light Compaction Test

Compaction is the process of densification of soil by reducing air voids suing mechanical methods. The degree of compaction of a given soil is measured in terms of its dry density. The dry density is maximum at the optimum moisture content. A curve is drawn between the water content and dry density to obtain the maximum dry density and optimum water content. Compaction method cannot remove all the air voids and therefore, the soil never becomes fully saturated. Thus the theoretical maximum dry density is only hypothetical. The line indicating theoretical maximum dry density can be plotted along with the compaction curve. MDD and OMC of soil sample, fly ash and Kota stone dust is determined as per IS: 2720 (Part VII)-1980.

3.3.6 Collapse Potential Determination by Single Oedometer Test

In this study single oedometer test is used according to the "ASTM D 5333 – 92 Standard Test Method for Measurement of Collapse Potential of Soils". In the standard, prepared sample is consolidated with the load increments on every hour until reaching 200 kPa. The soil is inundated at 200 kPa, and the strain is observed for 24 hours. After 24 hours, the consolidation is continued. The details of the test are given in the following paragraphs. The prepared sample was placed in the oedometer after placing dry filter papers on top and bottom of it. In placing the consolidation ring into the oedometer, air-dry porous stones were also placed on top and bottom of the sample. Then, the oedometer was mounted and the dial gauge was adjusted to zero reading. The sample was protected from the dry air by using a wet towel. The sample was loaded up to 5 kPa for 5 minutes, after that the load increments per hour were as 12.5, 25, 50, 100, 200 kPa. After reaching and loading 200 kPa for an hour, the sample was inundated by providing water through stand pipes and by pouring water directly from the top of the oedometer. Collapse of the sample started right after the inundation of water. As collapse continued deflections of the dial gauge was recorded. After waiting for 24 hours, consolidation was continued with loads of 400, 800, 1600 kPa. Then collapse potential was calculated from the following expression:

Collapse potential (%) = $\frac{\Delta H}{H} \times 100$

Where, ΔH = change in height of sample upon inundation, H = initial height of sample

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Scanning Electron Microscope (SEM) Test

4.1.1 SEM Test on soil (sample 1)

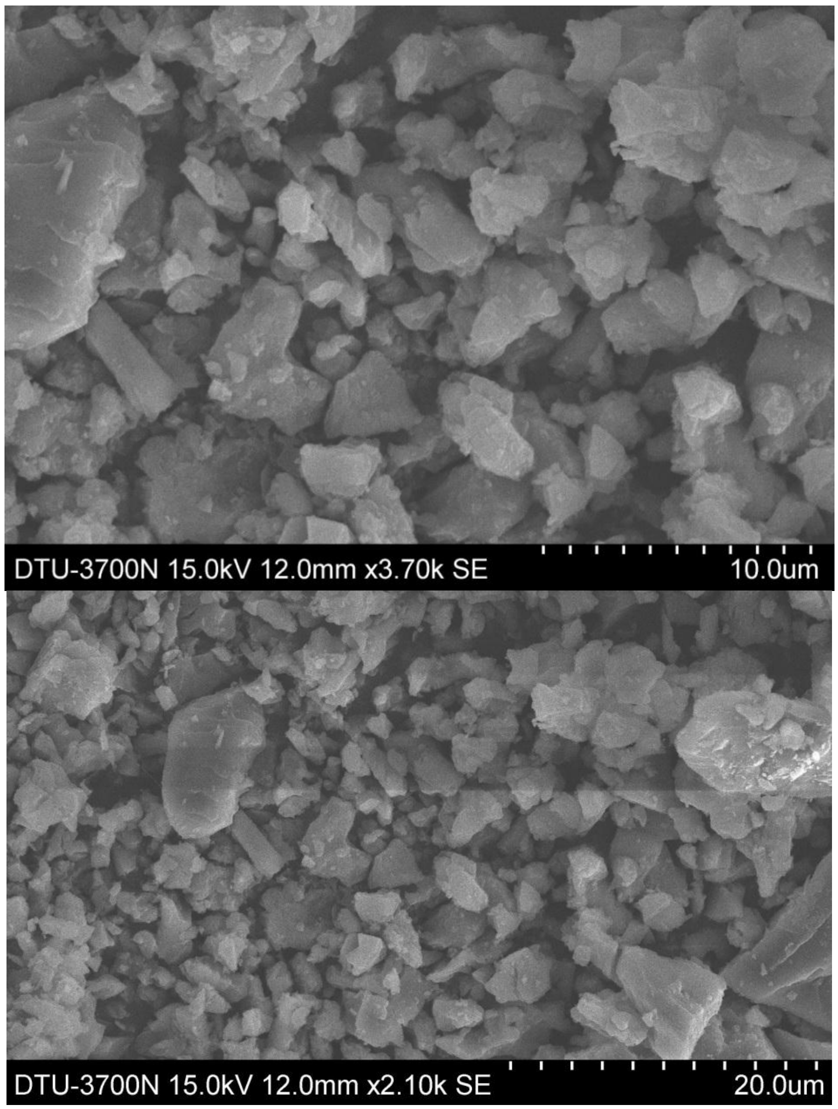

Figure 4.1: Particle morphology of soil (sample 1)

It is clear from SEM image (Figure 4.1) that soil contains mostly fine sand particles with fewer mediums to coarse sand particles as it is also observed in particle size analysis. Particles are sub-angular in shape.

4.1.2 SEM Test on Fly ash

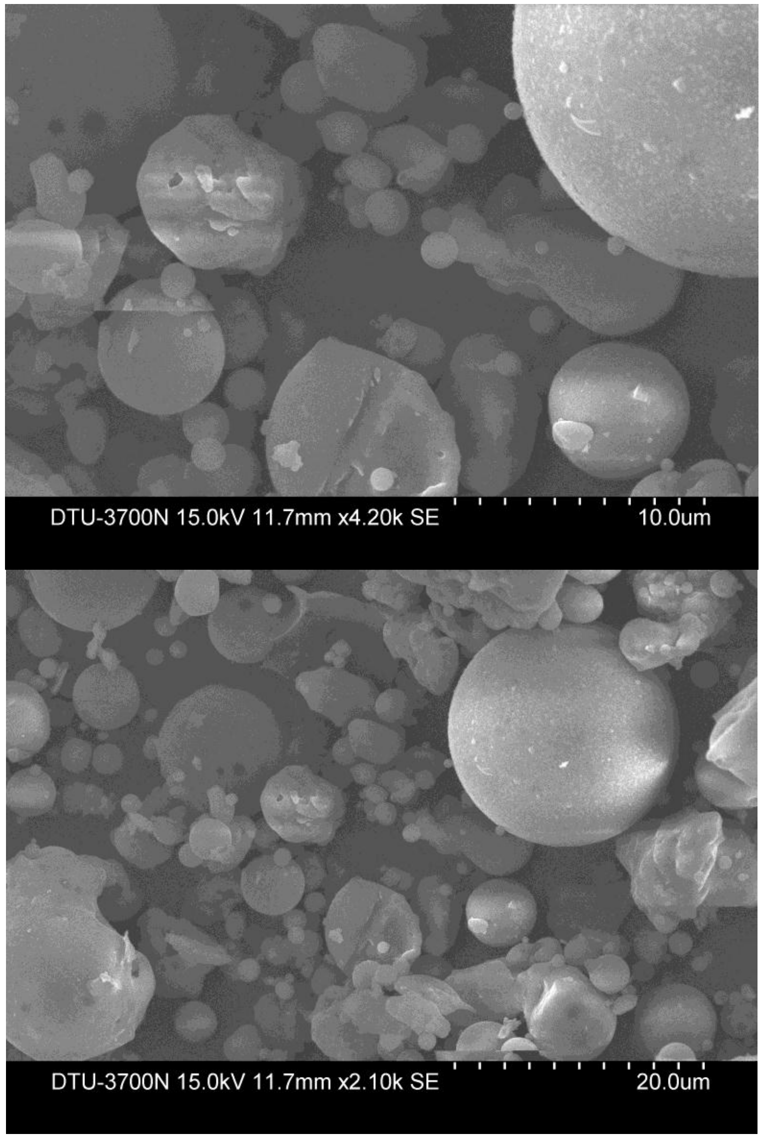

Figure 4.2: Particle morphology of fly ash

It has been observed from SEM image (Figure 4.2) of fly ash that particles are glassy, smooth and spherical in shape with maximum of single grained cells. Fly ash contains both cenospheres and plerospheres and there is no coating over the surface of particles which indicates low calcium and iron content in fly ash as it is clear from chemical composition that fly ash contains low calcium oxide and iron oxide.

4.1.3 SEM Test on Kota Stone Dust

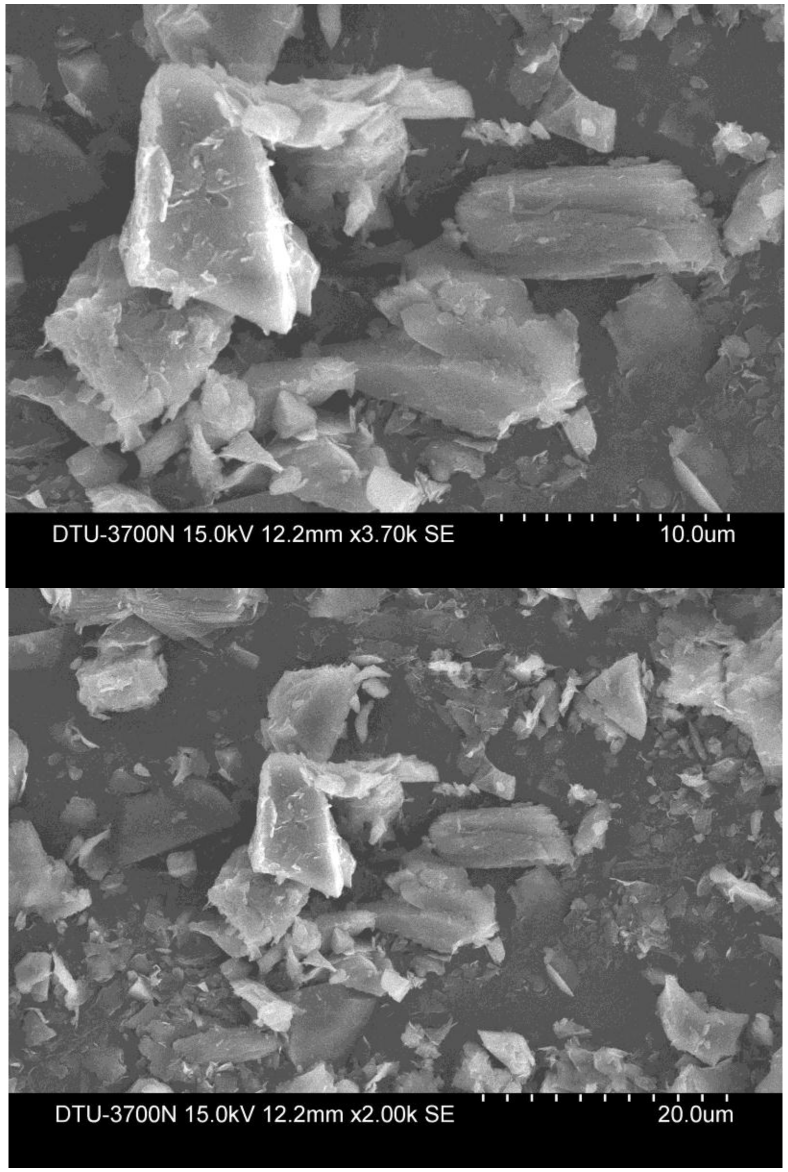

Figure 4.3: Particle morphology of Kota stone dust

It has been observed from SEM image (Figure 4.3) of Kota stone dust that particles are angular in shape and coarser than soil particles as it has been observed that Kota stone dust is well graded sand. As particles of Kota stone dust are angular and surface is more rough which lead to higher shear strength as compared to soil.

4.2 Particle Size Analysis

4.2.1 Particle Size Analysis of Soil Sample (Sample 1)

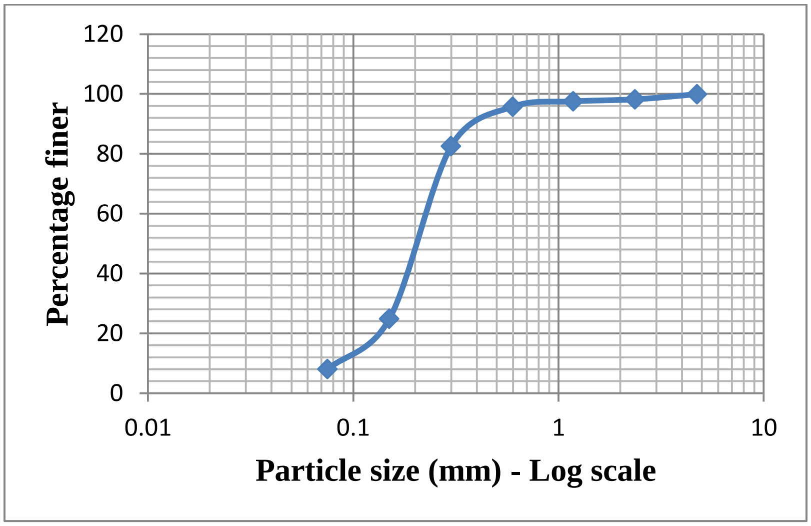

Figure 4.4: Particle size distribution curve for soil sample (Sample 1)

$D_{60} = 0.2414$ mm, $D_{30} = 0.1634$ mm, $D_{10} = 0.0838$ mm,

$C_c = 1.95 > 1$, and $C_u = 2.88$, Sand content = 91.97 %, Silt content = 8.03 %.

Hence, Soil is classified as poorly graded sand with silty fines (SP-SM).

4.2.2 Particle Size Analysis of Fly ash

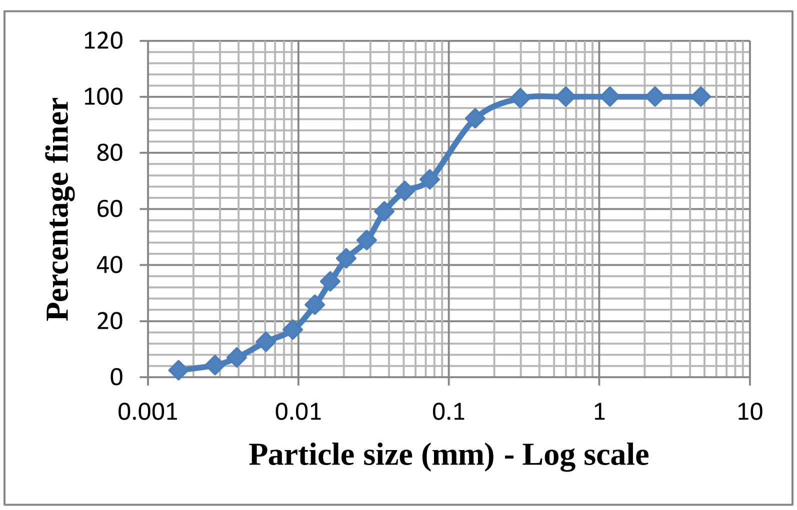

Figure 4.5: Particle size distribution curve for fly ash

$D_{60} = 0.0389$ mm, $D_{30} = 0.0146$ mm, $D_{10} = 0.0051$ mm,

$C_c = 1.07 > 1$, and $C_u = 7.63$,

Sand content = 29.5 %, Silt content = 67.46 %, and Clay content = 3.04 %.

Hence, Fly ash classified as clay with low to medium compressibility (CL-CI).

4.2.3 Particle Size Analysis of Kota stone dust

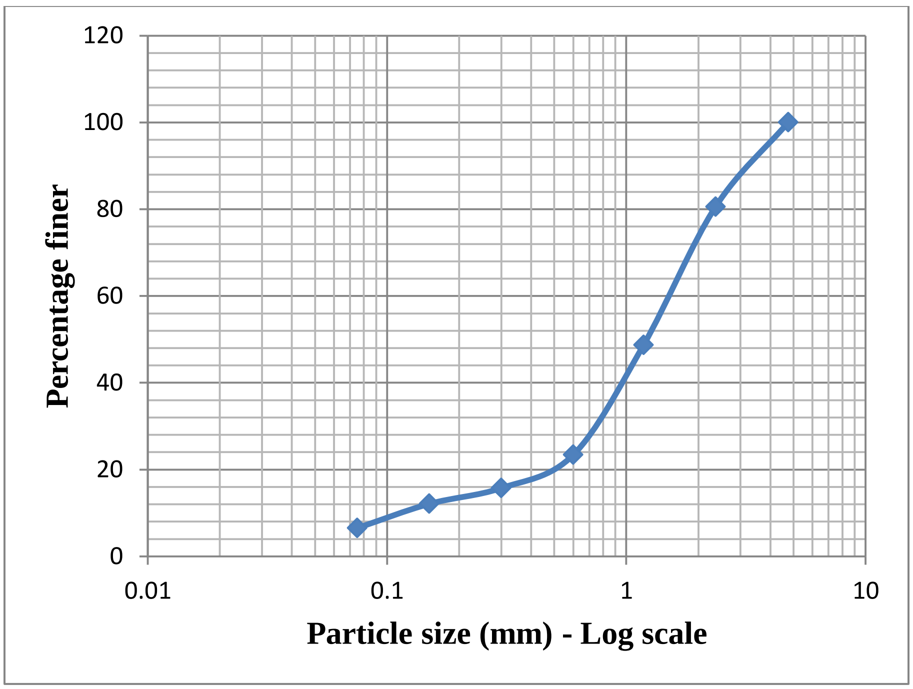

Figure 4.6: Particle size distribution curve for Kota stone dust

$D_{60} = 1.599$ mm, $D_{30} = 0.7514$ mm, $D_{10} = 0.1217$ mm,

$C_c = 2.9 > 1$, and $C_u = 13.14$,

Sand content = 93.47 %, Silt content = 6.53 %.

Hence, Kota stone dust classified as well graded sand with silty fines (SW-SM).

4.3 Specific Gravity Determination

Table 4.1: Specific gravity of soil, fly ash and Kota stone dust

Sample Type	Specific Gravity, G_s
Soil	2.64
Fly ash	2.08
Kota stone dust	2.67

4.4 Liquid Limit and Plastic Limit Determination

Liquid limit and Plastic limit determination is not possible for soil and Kota stone dust as they are classified as coarse grained soil and liquid limit and plastic limit are associated with fine grained soil specially clayey soil.

4.4.1 Liquid Limit and Plastic Limit Test on Fly ash

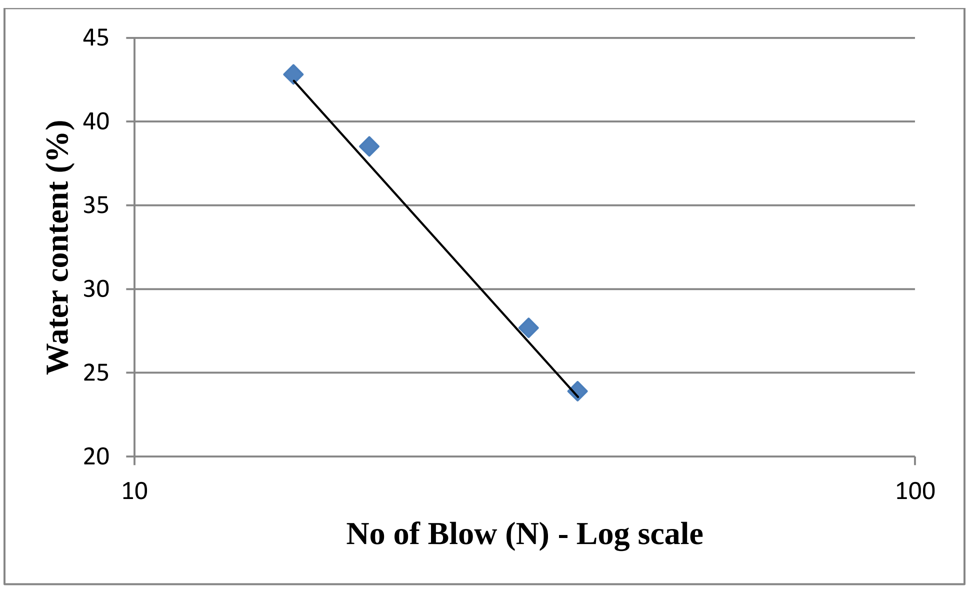

Figure 4.7: Liquid limit curve for fly ash

Liquid Limit of fly ash is 34.3 %.

Plastic limit of fly ash is 23.8 %.

4.5 Compaction Test

4.5.1 Compaction Test on Sample 1 (100% Soil)

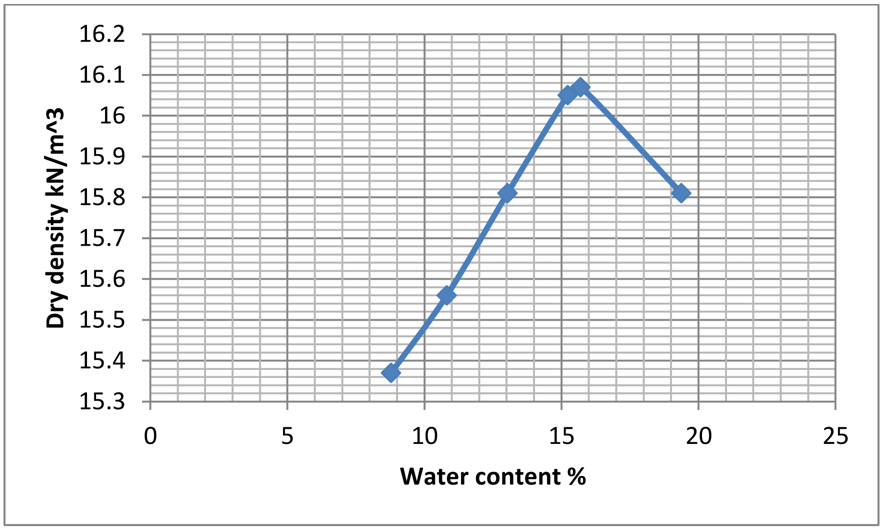

Figure 4.8: Compaction curve for sample 1

MDD = 16.07 kN/m^3 and OMC = 15.7 %.

4.5.2 Compaction Test on Fly ash

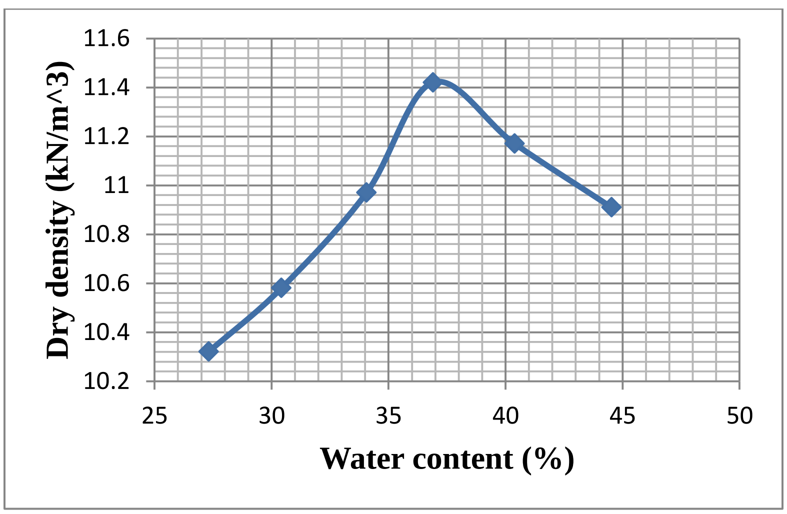

Figure 4.9: Compaction curve for fly ash

OMC = 36.9% and MDD = 11.42 kN/m^3.

4.5.3 Compaction Test on Kota Stone Dust

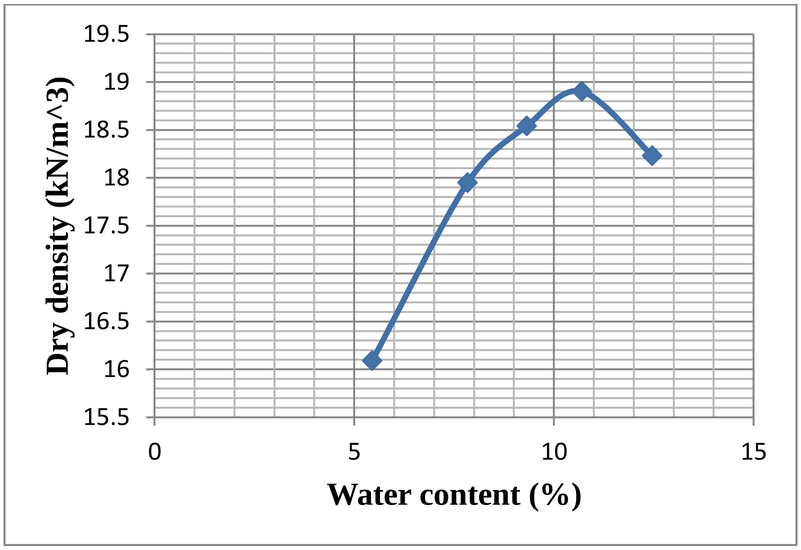

Figure 4.10: Compaction curve for Kota stone dust

OMC = 10.7 % and MDD = 18.9 kN/m^3.

4.5.4 Compaction Test on Sample 2 (85 % soil, 5 % FA & 10 % KSD)

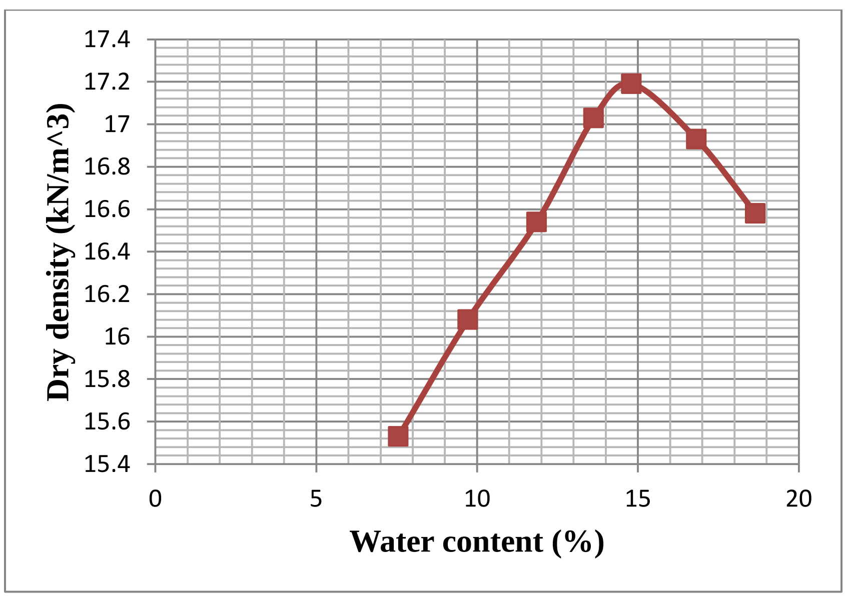

Figure 4.11: Compaction curve for sample 2

OMC = 14.8 % and MDD = 17.19 kN/m^3

4.5.5 Compaction Test on Sample 3 (80% Soil, 10% FA & 10% KSD)

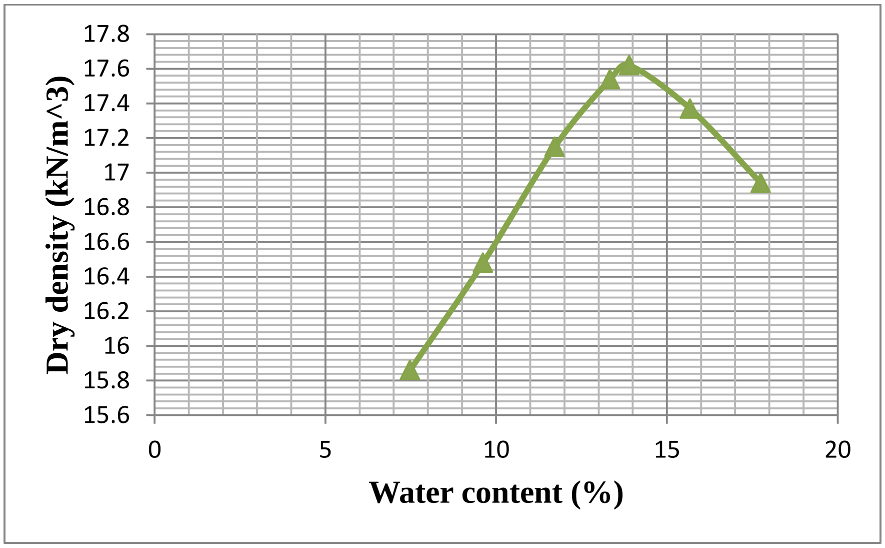

Figure 4.12: Compaction curve for sample 3

OMC = 13.9 % and MDD = 17.62 kN/m^3.

4.5.6 Compaction Test on Sample 4 (75% Soil, 15% FA & 10% KSD)

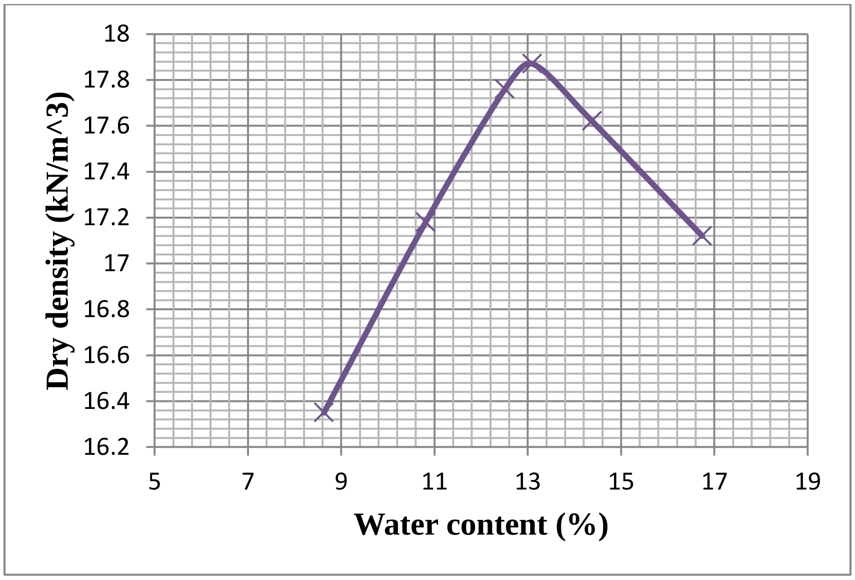

Figure 4.13: Compaction curve for sample 4

OMC = 13.1 % and MDD = 17.87 kN/m^3.

4.5.7 Compaction Test on Sample 5 (70% Soil, 20% FA & 10% KSD)

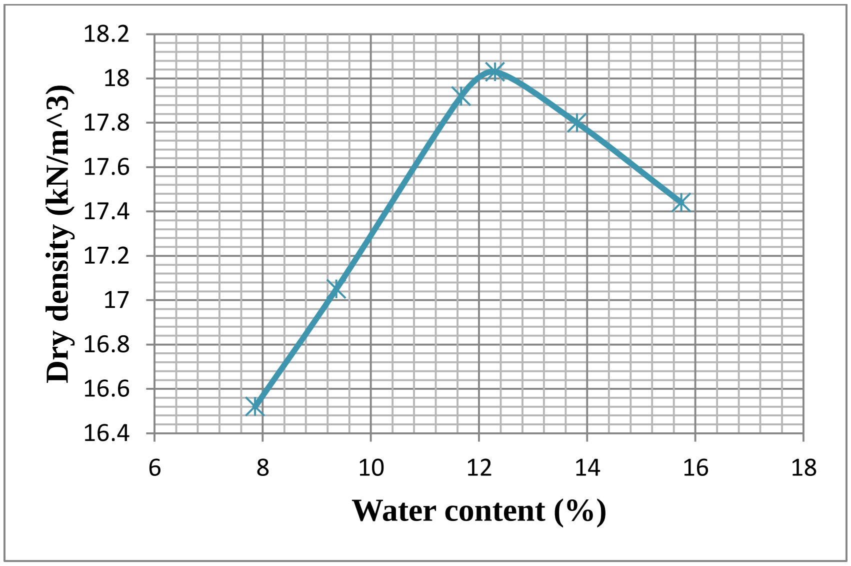

Figure 4.14: Compaction curve for sample 5

OMC = 12.3 % and MDD = 18.03 kN/m^3.

4.5.8 Compaction Test on Sample 6 (65% Soil, 25% FA & 10% KSD)

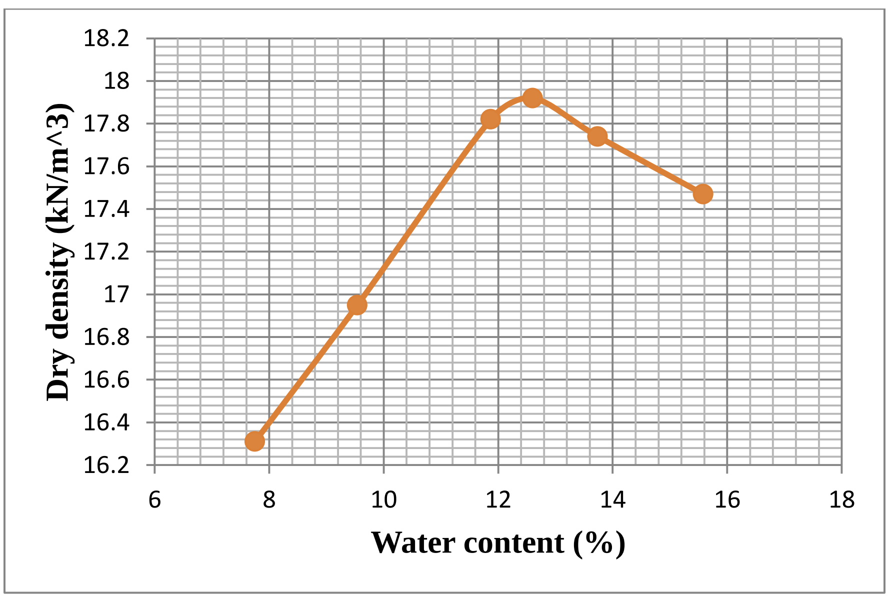

Figure 4.15: Compaction curve for sample 6

OMC = 12.6 % and MDD = 17.92 kN/m^3.

4.5.9 Compaction Test on Sample 7 (75% Soil, 5% FA & 20% KSD)

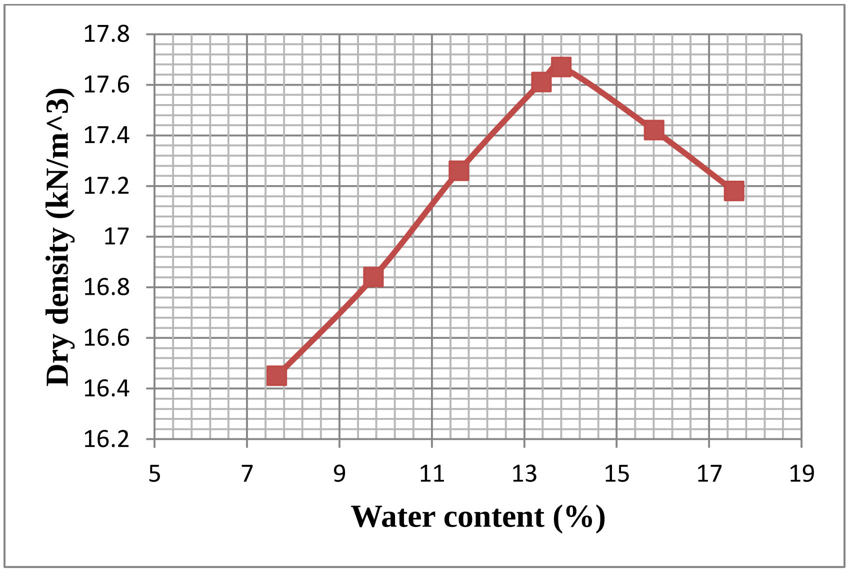

Figure 4.16: Compaction curve for sample 7

OMC = 13.8 % and MDD = 17.67 kN/m^3.

4.5.10 Compaction Test on Sample 8 (70% Soil, 10% FA & 20% KSD)

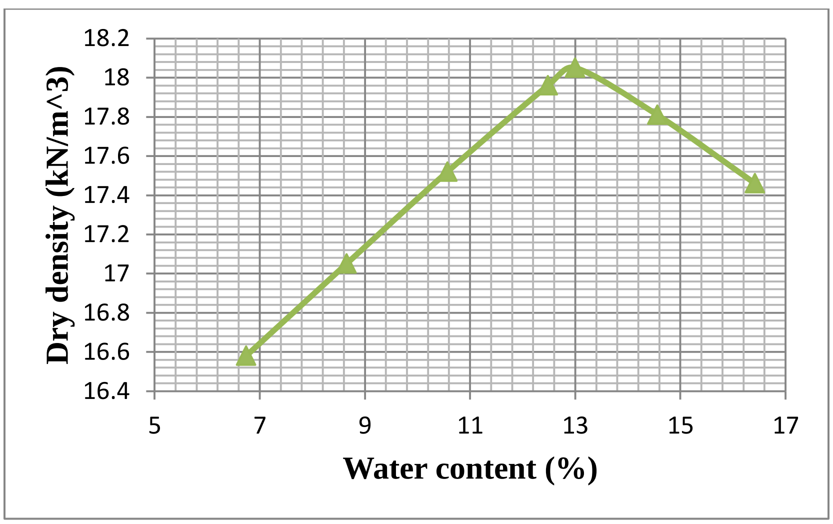

Figure 4.17: Compaction curve for sample 8

OMC = 13 % and MDD = 18.05 kN/m^3.

4.5.11 Compaction Test on Sample 9 (65% Soil, 15% FA & 20% KSD)

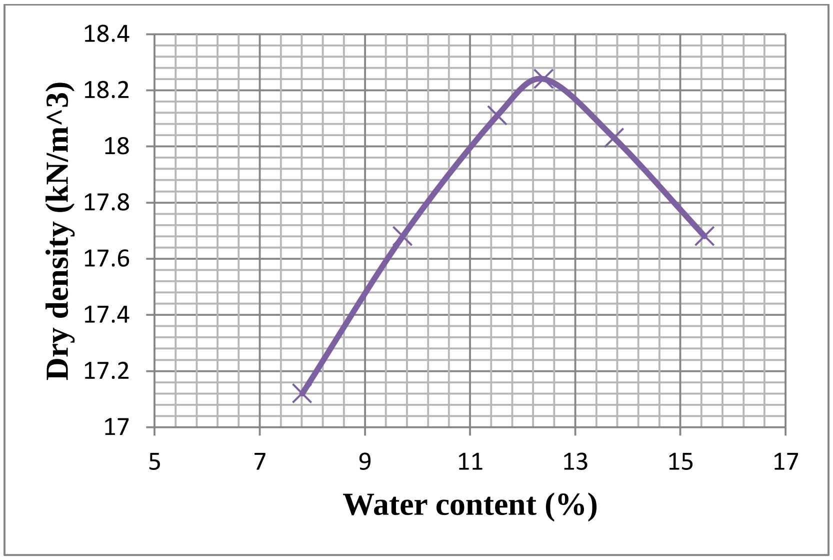

Figure 4.18: Compaction curve for sample 9

OMC = 12.4 % and MDD = 18.24 kN/m^3.

4.5.12 Compaction Test on Sample 10 (60% Soil, 20% FA & 20% KSD)

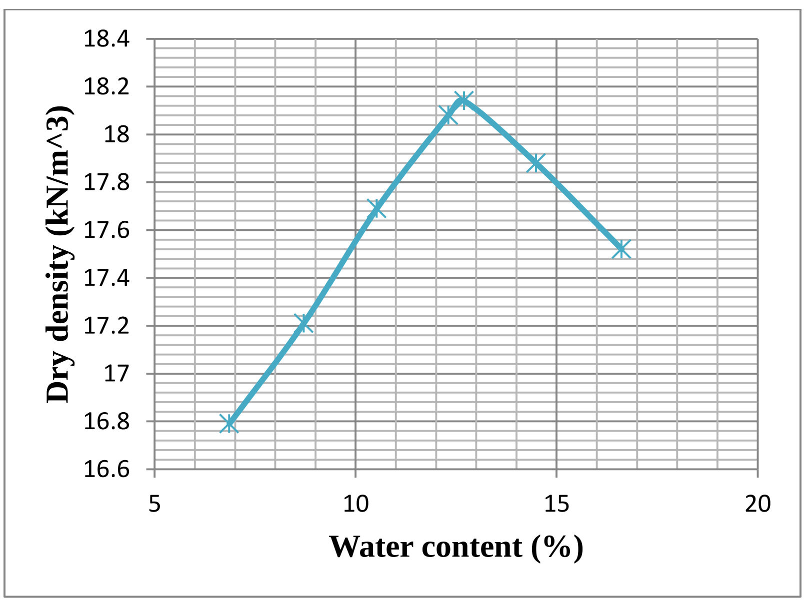

Figure 4.19: Compaction curve for sample 10

OMC = 12.4 % and MDD = 18.14 kN/m^3.

4.5.13 Compaction Test on Sample 11 (65% Soil, 5% FA & 30% KSD)

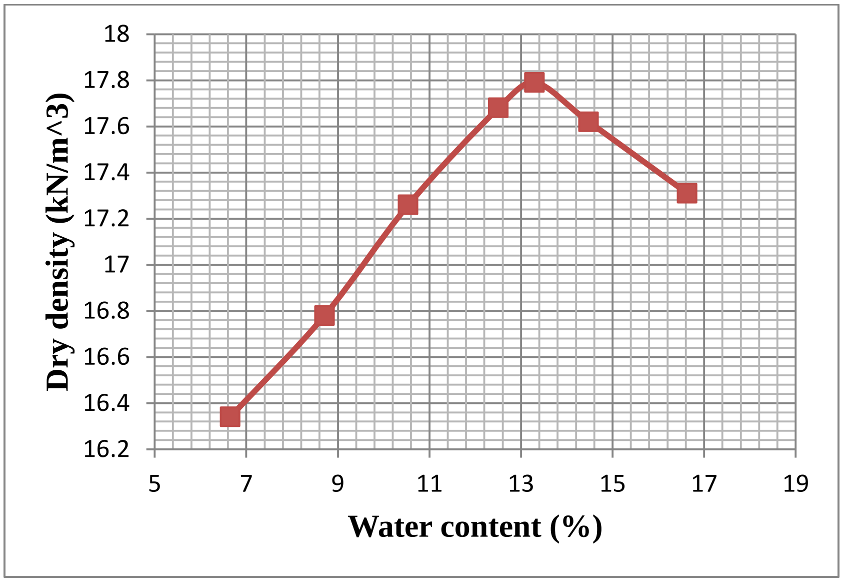

Figure 4.20: Compaction curve for sample 11

OMC = 13.3 % and MDD = 17.79 kN/m^3.

4.5.14 Compaction Test on Sample 12 (60% Soil, 10% FA & 30% KSD)

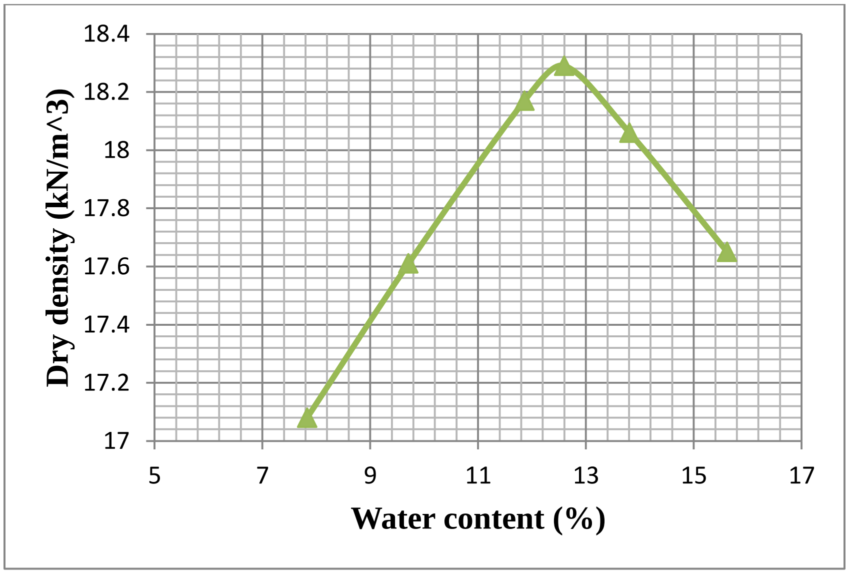

Figure 4.21: Compaction curve for sample 12

OMC = 12.6 % and MDD = 18.29 kN/m^3.

4.5.15 Compaction Test on Sample 13 (55% Soil, 15% FA & 30% KSD)

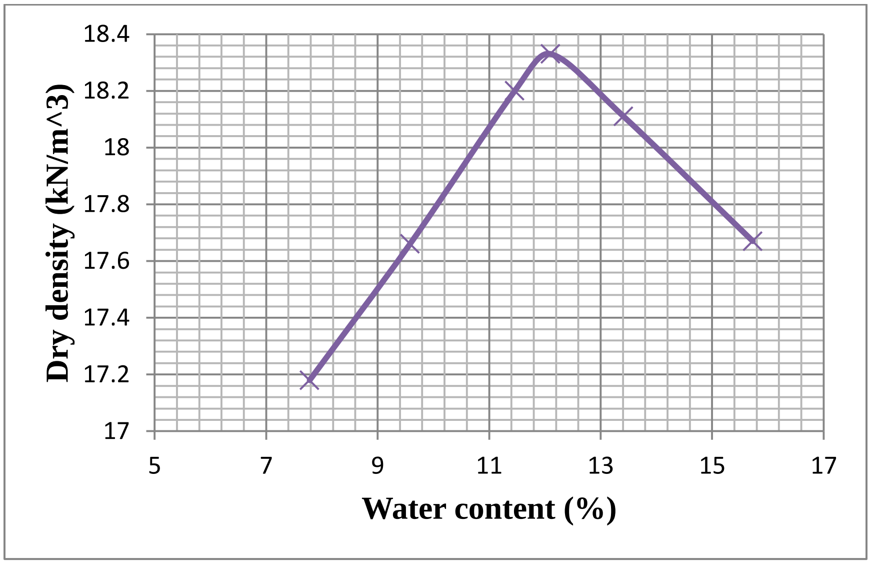

Figure 4.22: Compaction curve for sample 13

OMC = 12.1 % and MDD = 18.33 kN/m^3.

4.5.16 Compaction Test on Sample 14 (50% Soil, 20% FA & 30% KSD)

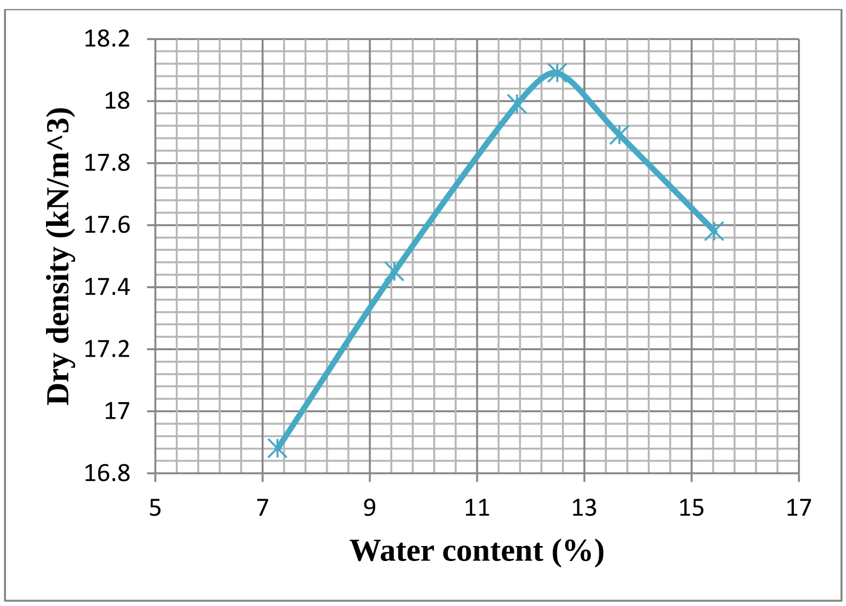

Figure 4.23: Compaction curve for sample 14

OMC = 12.5 % and MDD = 18.09 kN/m^3.

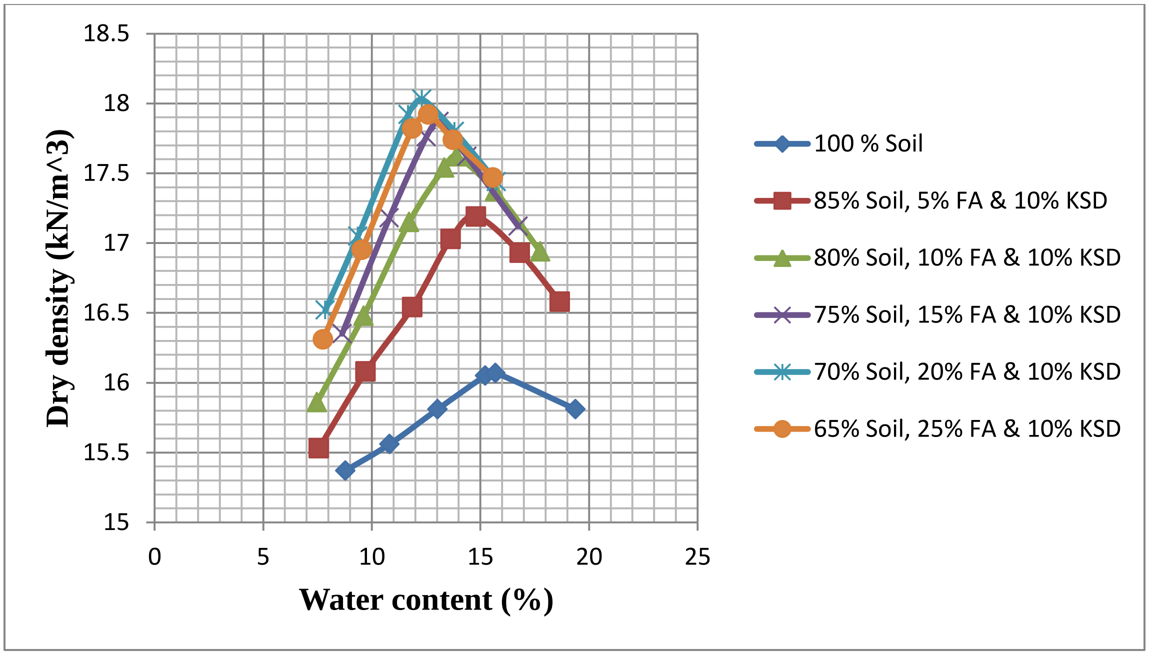

Figure 4.24: Compaction behavior of soil mixed with varying proportion of fly ash and 10% Kota stone dust

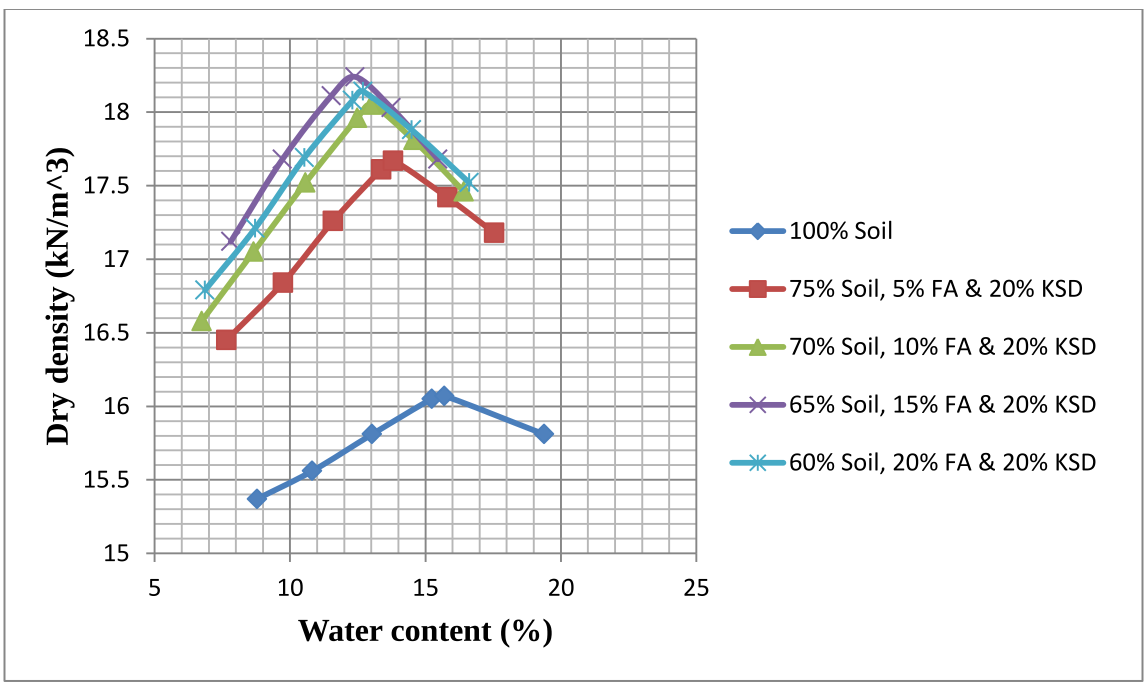

Figure 4.25: Compaction behavior of soil mixed with varying proportion of fly ash and 20% Kota stone dust

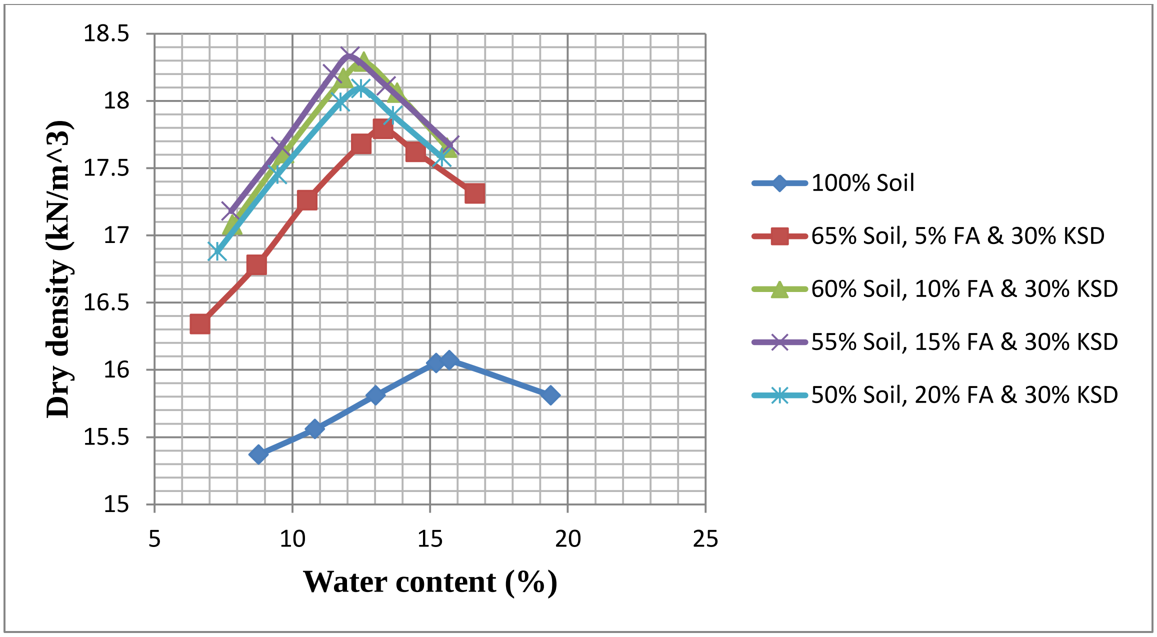

Figure 4.26: Compaction behavior of soil mixed with varying proportion of fly ash and 30% Kota stone dust

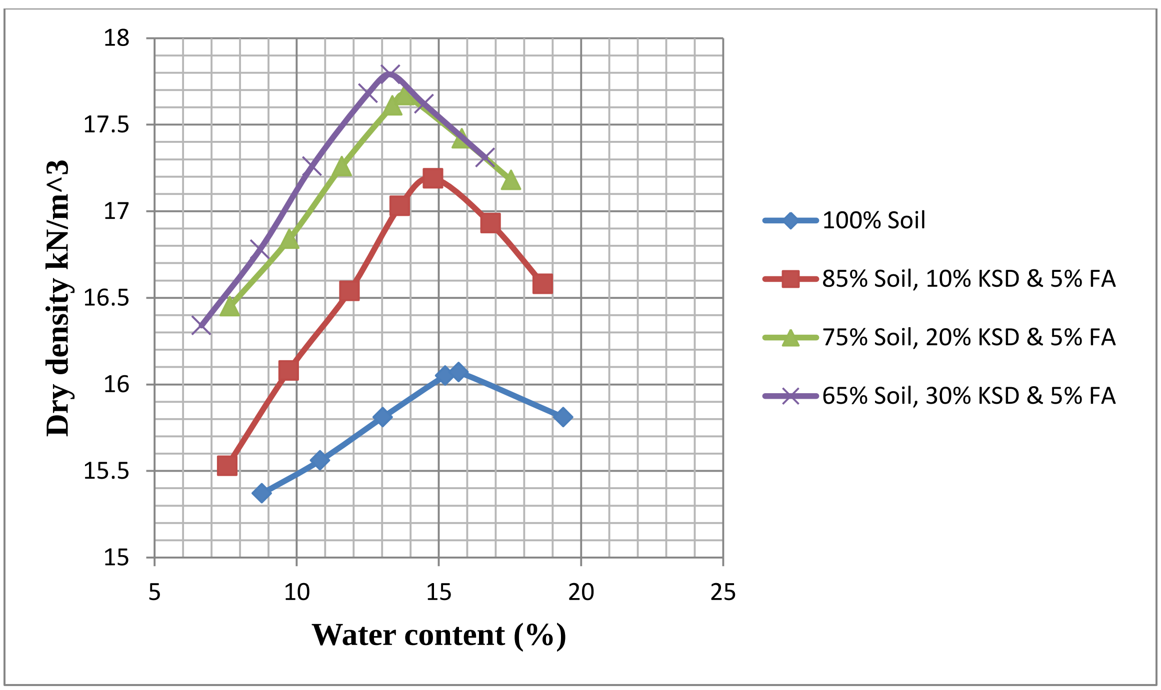

Figure 4.27: Compaction behavior of soil mixed with varying proportion of Kota stone dust and 5% fly ash

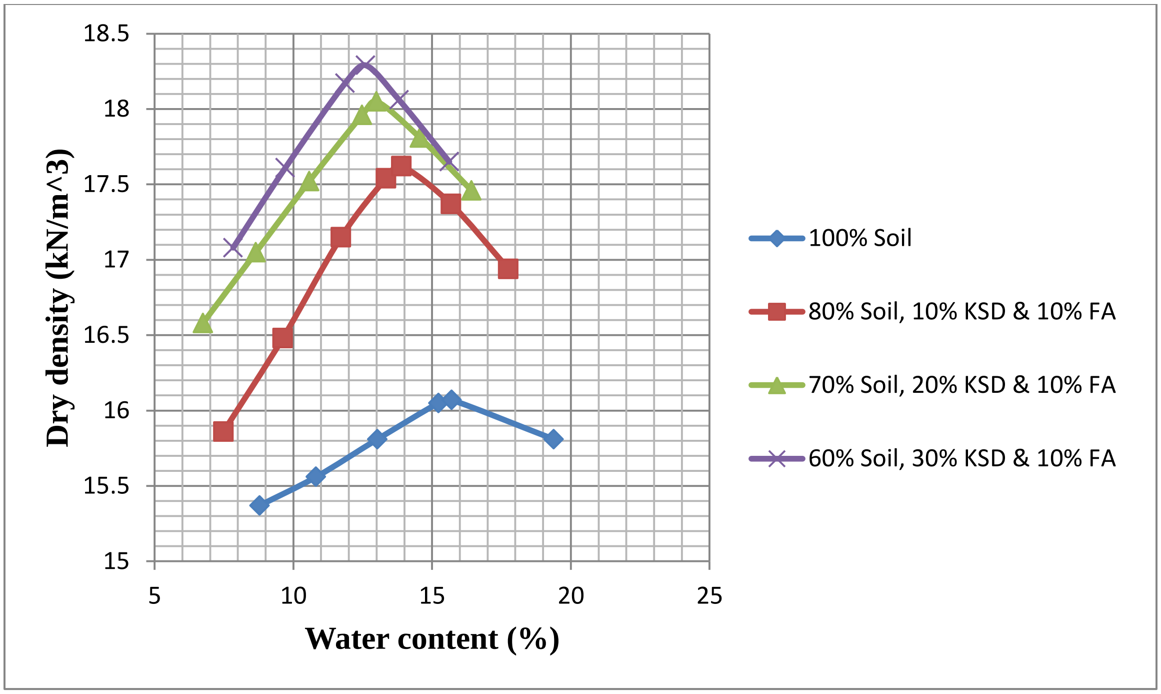

Figure 4.28: Compaction behavior of soil mixed with varying proportion of Kota stone dust and 10% fly ash

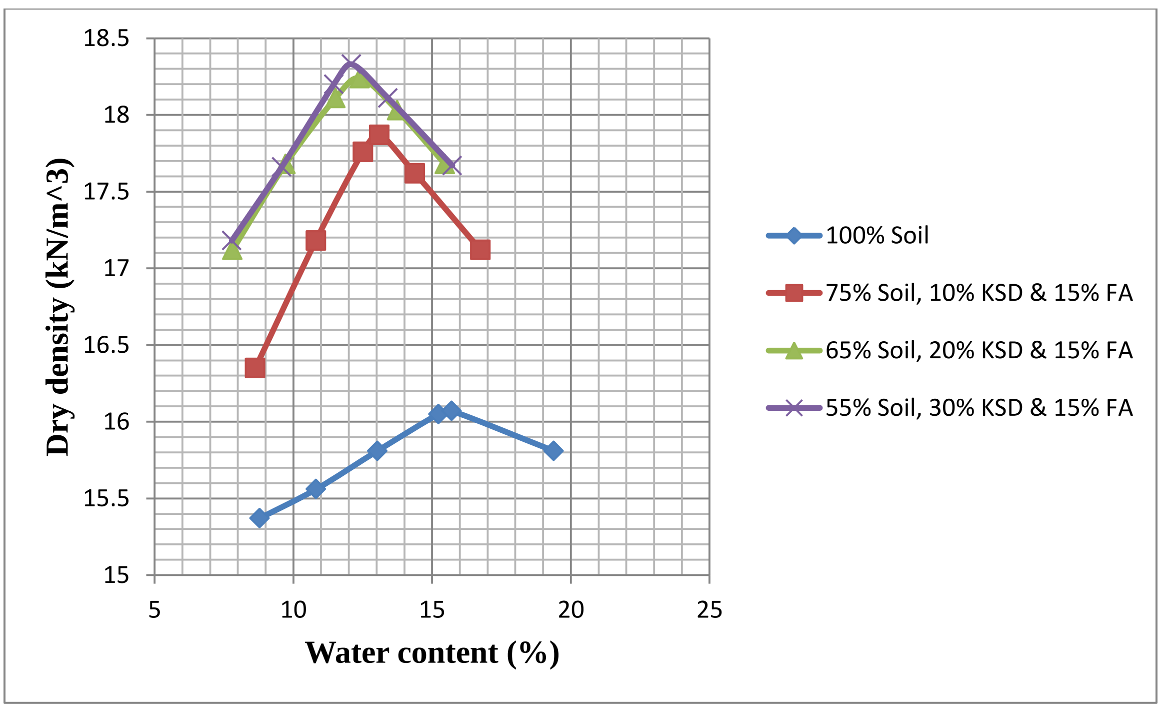

Figure 4.29: Compaction behavior of soil mixed with varying proportion of Kota stone dust and 15% fly ash

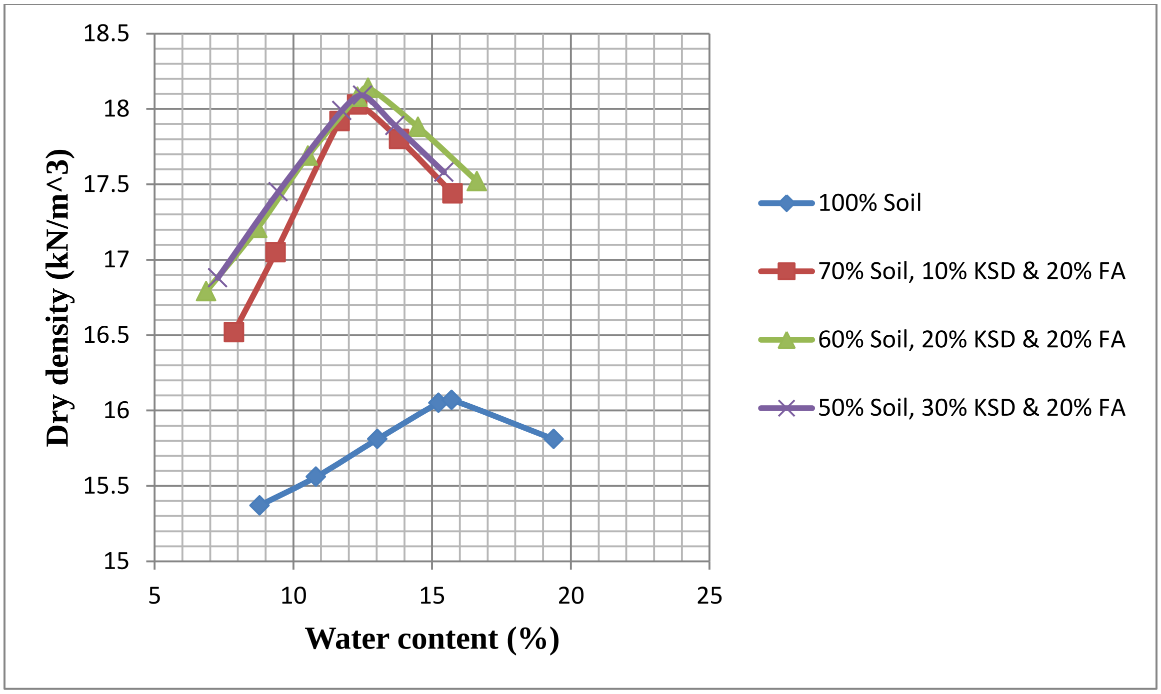

Figure 4.30: Compaction behavior of soil mixed with varying proportion of Kota stone dust and 20% fly ash

Table 4.2: Maximum dry density of soil mixed with varying proportion of fly ash and Kota stone dust

Fly Ash (%)	Maximum Dry Density (kN/m^3)		
	10% KSD	**20% KSD**	**30% KSD**
5	17.19	17.67	17.79
10	17.62	18.05	18.29
15	17.87	18.24	18.33
20	18.03	18.14	18.09
25	17.92		

Adding fly ash and Kota stone dust in soil increases maximum dry density of soil. Maximum value of maximum dry density is obtained at 15% fly ash and 30% Kota stone dust mixing (Table 4.2, Figure 4.31, and Figure 4.32). However, further increasing fly ash and Kota stone dust content decreases maximum dry density of soil.

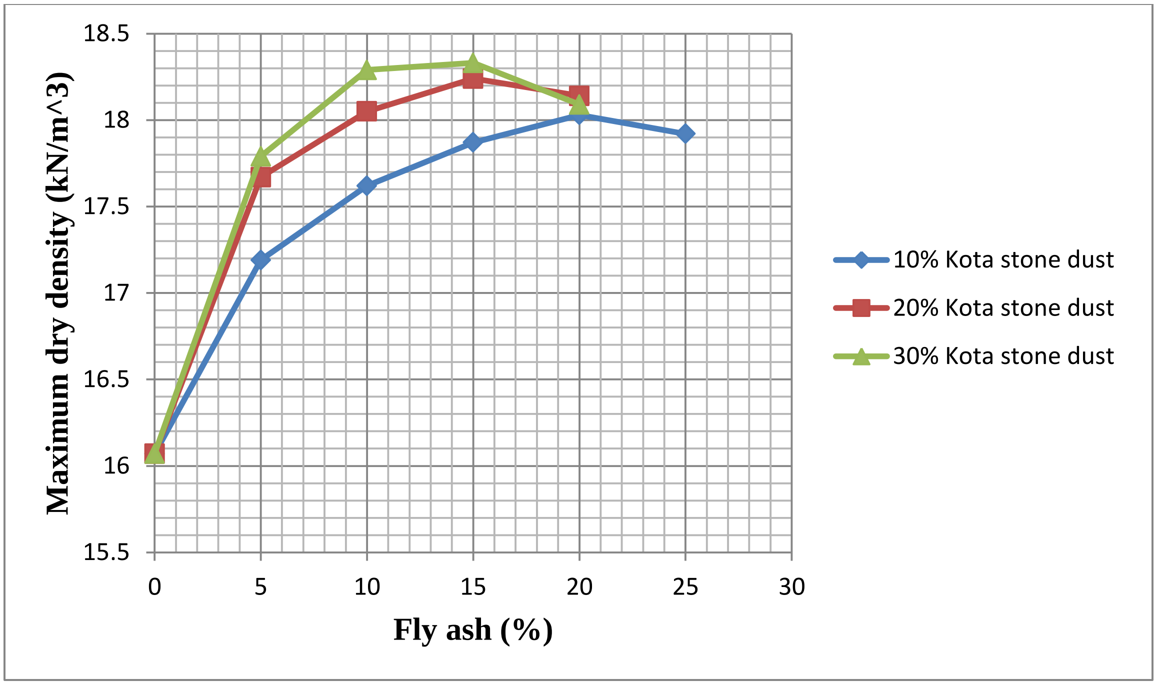

Figure 4.31: Variation of MDD of soil with fly ash mixed at constant proportion of Kota stone dust

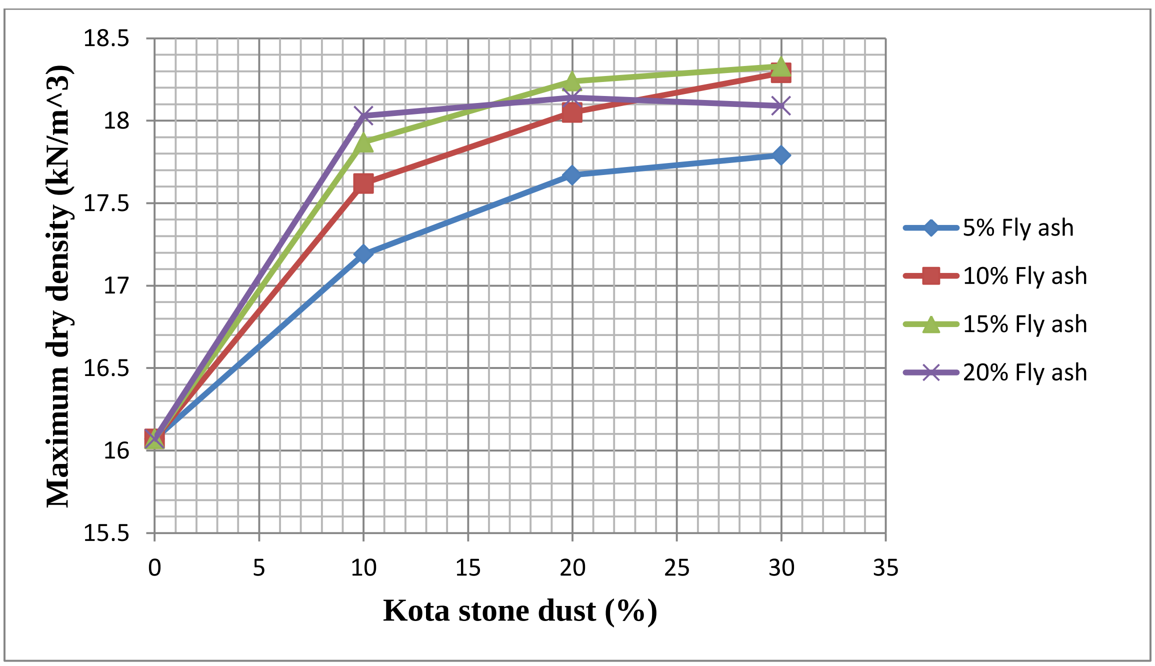

Figure 4.32: Variation of MDD of soil with Kota stone dust mixed at constant proportion of fly ash mixed

Table 4.3: Optimum moisture content of soil mixed with varying proportion of fly ash and Kota stone dust

Fly Ash (%)	Optimum Moisture Content (%)		
	10% KSD	20% KSD	30% KSD
5	14.8	13.8	13.3
10	13.9	13	12.6
15	13.1	12.4	12.1
20	12.3	12.7	12.5
25	12.6		

Adding fly ash and Kota stone dust in soil decreases optimum moisture content of soil. Minimum value of optimum moisture content is obtained at 15% fly ash and 30% Kota stone dust mixing (Table 4.3, Figure 4.33, and Figure 4.34). However, further increasing fly ash and Kota stone dust content increases optimum moisture content of soil.

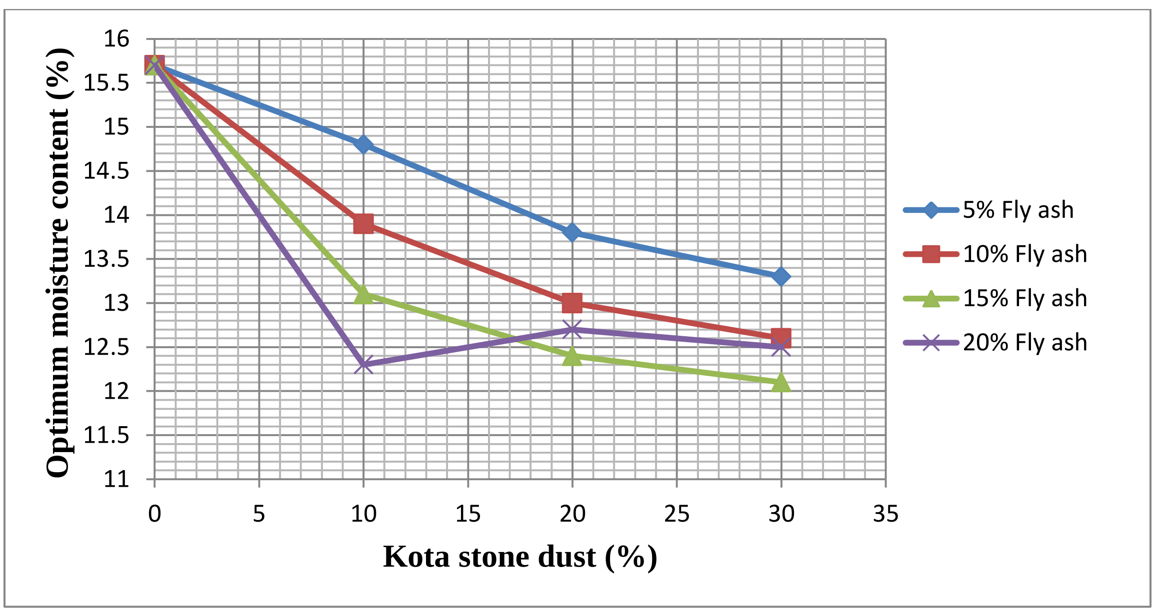

Figure 4.33: Variation of OMC of soil with Kota stone dust mixed at constant proportion of fly ash mixed

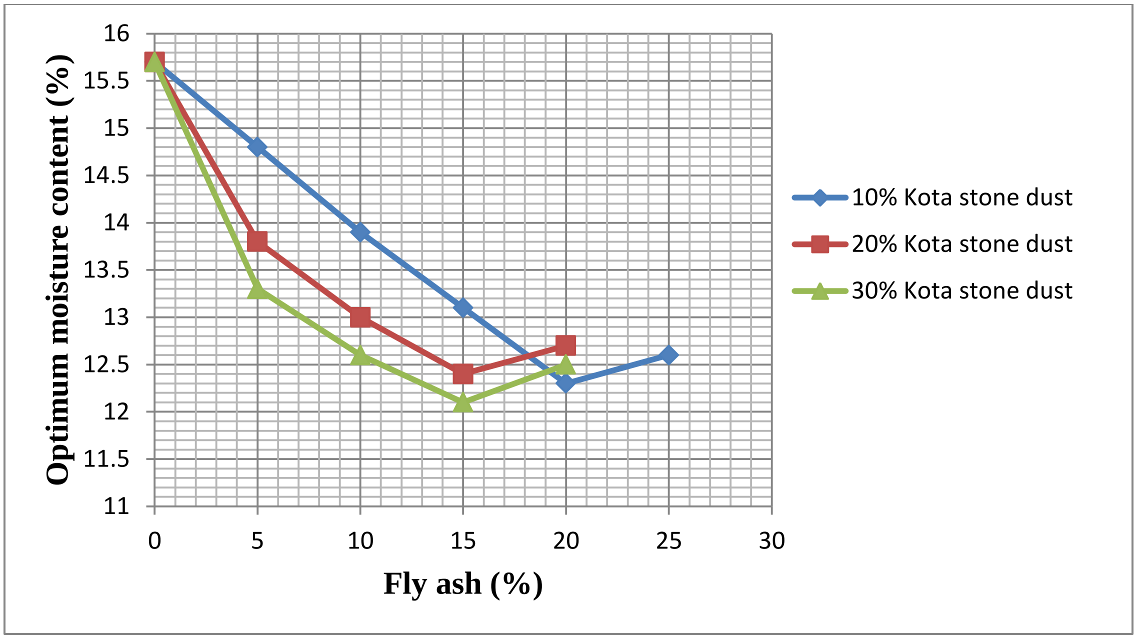

Figure 4.34: Variation of OMC of soil with fly ash mixed at constant proportion of Kota stone dust

4.6 Collapse Potential Determination by Single Oedometer Test

4.6.1 Sample 1 (100% Soil)

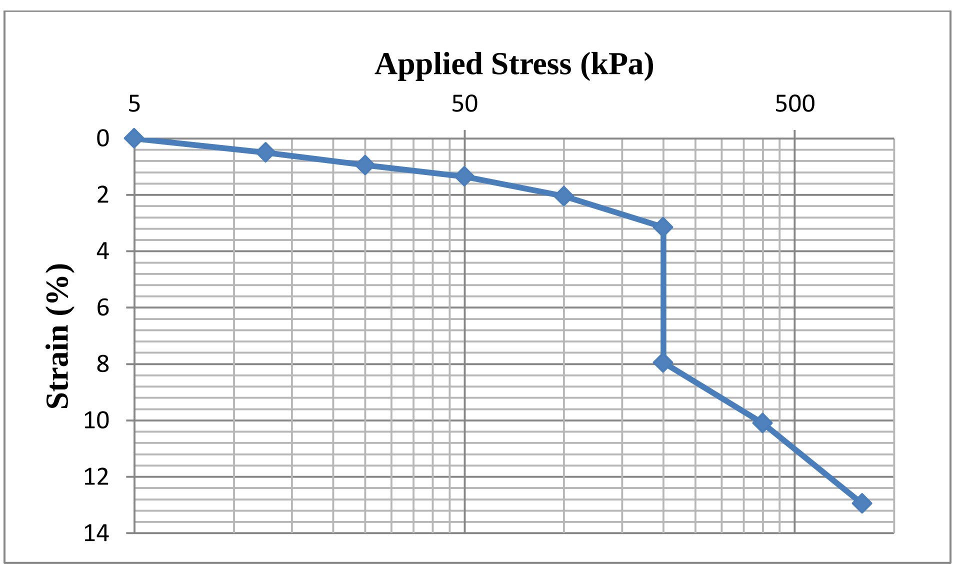

Figure 4.35: Compression curve of collapse potential test for sample 1

Collapse potential = 4.8 %.

4.6.2 Sample 2 (85% Soil, 5% FA & 10% KSD)

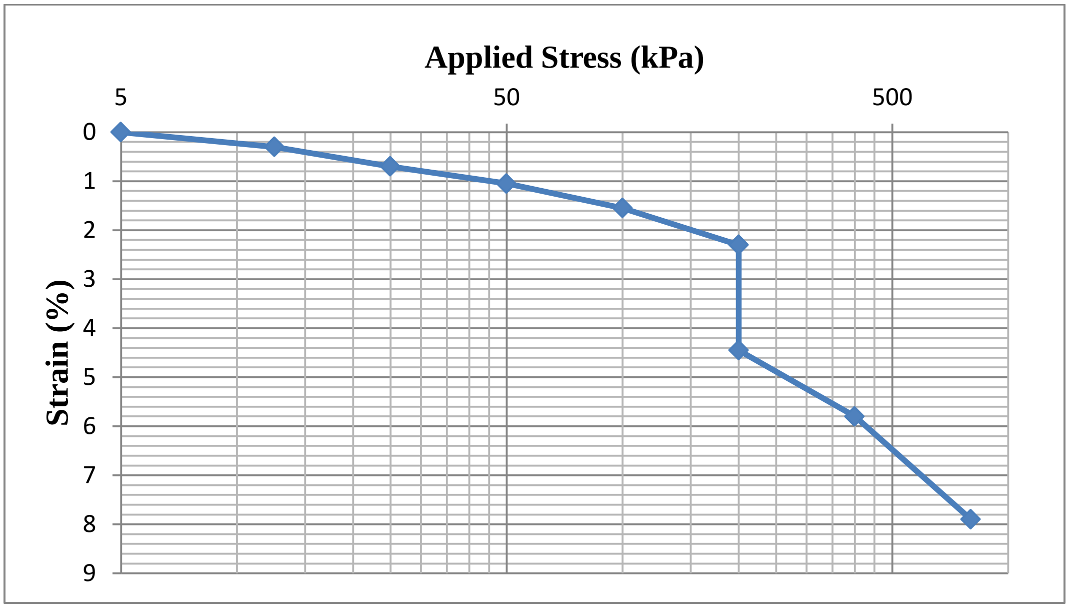

Figure 4.36: Compression curve of collapse potential test for sample 2

Collapse potential = 2.15 %.

4.6.3 Sample 3 (80% Soil, 10% FA & 10% KSD)

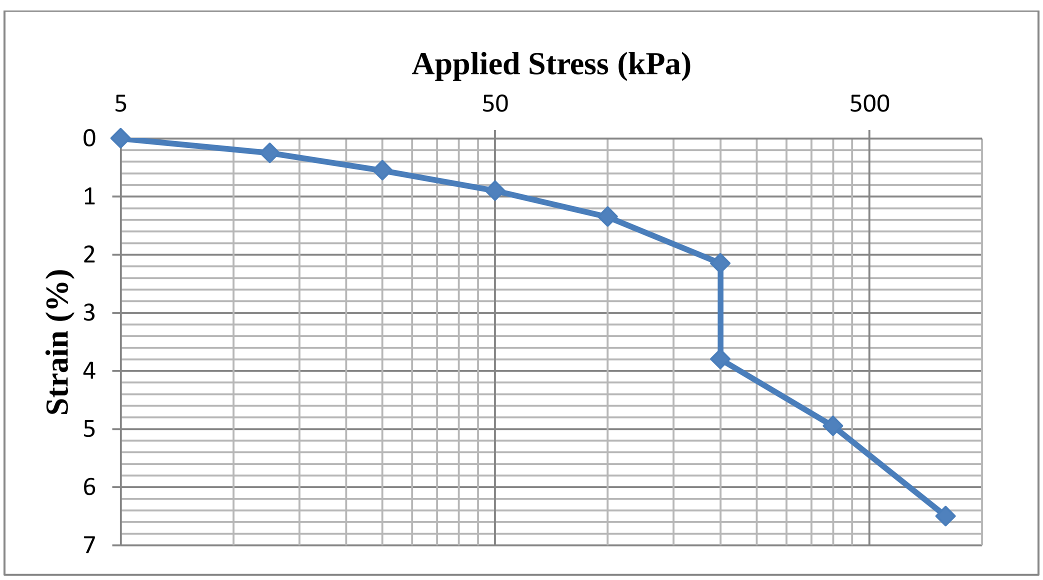

Figure 4.37: Compression curve of collapse potential test for sample 3

Collapse potential = 1.65 %.

4.6.4 Sample 4 (75% Soil, 15% FA & 10% KSD)

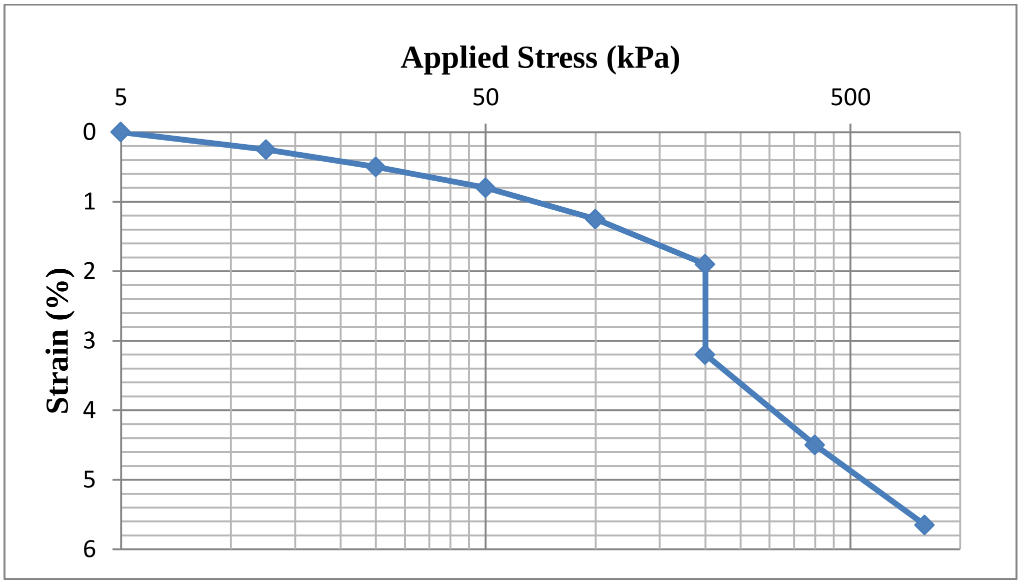

Figure 4.38: Compression curve of collapse potential test for sample 4

Collapse potential = 1.3 %.

4.6.5 Sample 5 (70% Soil, 20% FA & 10% KSD)

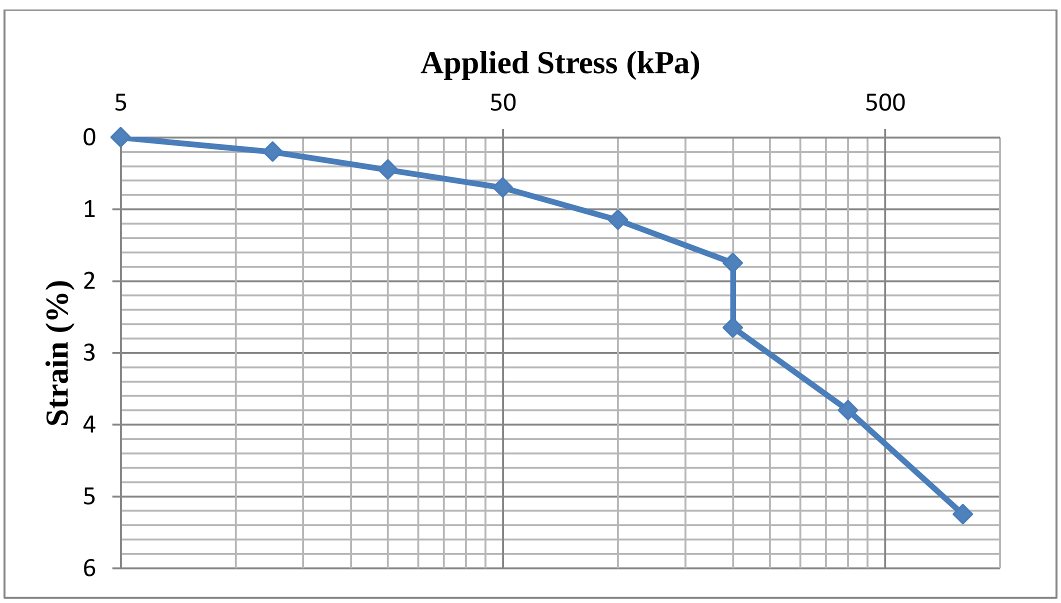

Figure 4.39: Compression curve of collapse potential test for sample 5

Collapse potential = 0.9 %.

4.6.6 Sample 6 (65% Soil, 25% FA & 10% KSD)

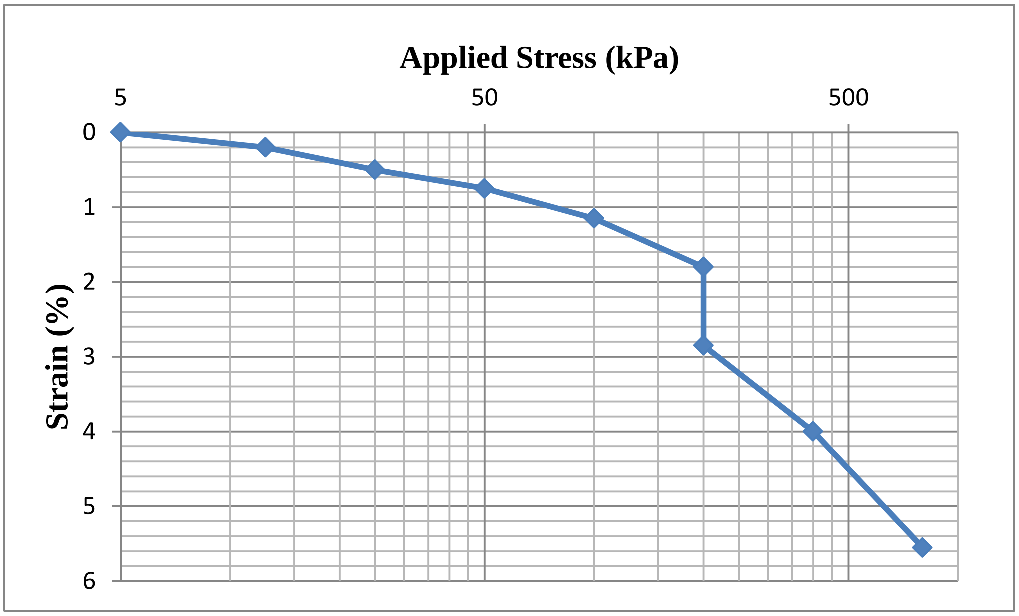

Figure 4.40: Compression curve of collapse potential test for sample 6

Collapse potential = 1.15 %.

4.6.7 Sample 7 (75% Soil, 5% FA & 20% KSD)

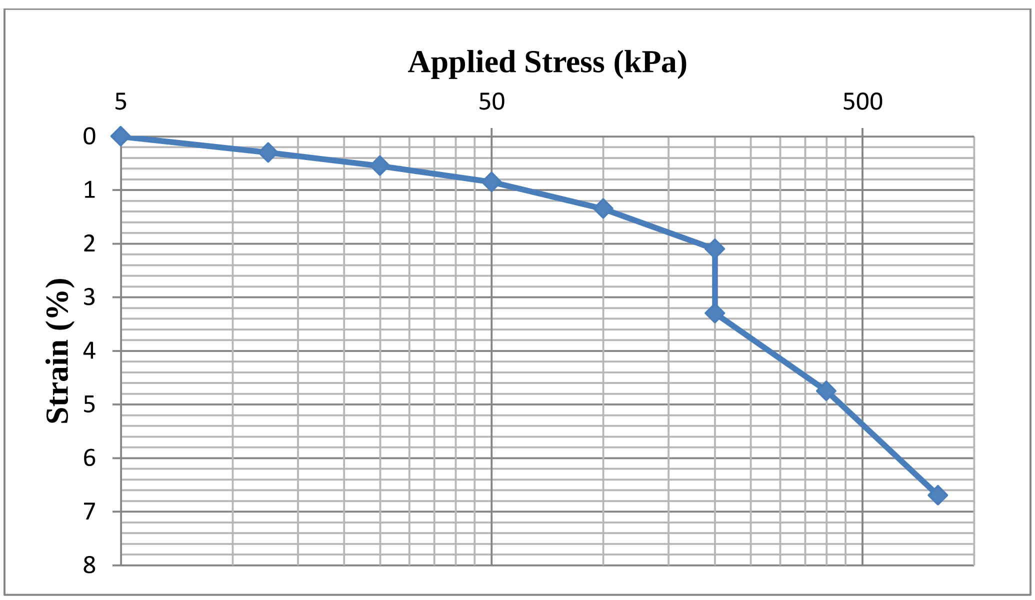

Figure 4.41: Compression curve of collapse potential test for sample 7

Collapse potential = 1.2 %.

4.6.8 Sample 8 (70% Soil, 10% FA & 20% KSD)

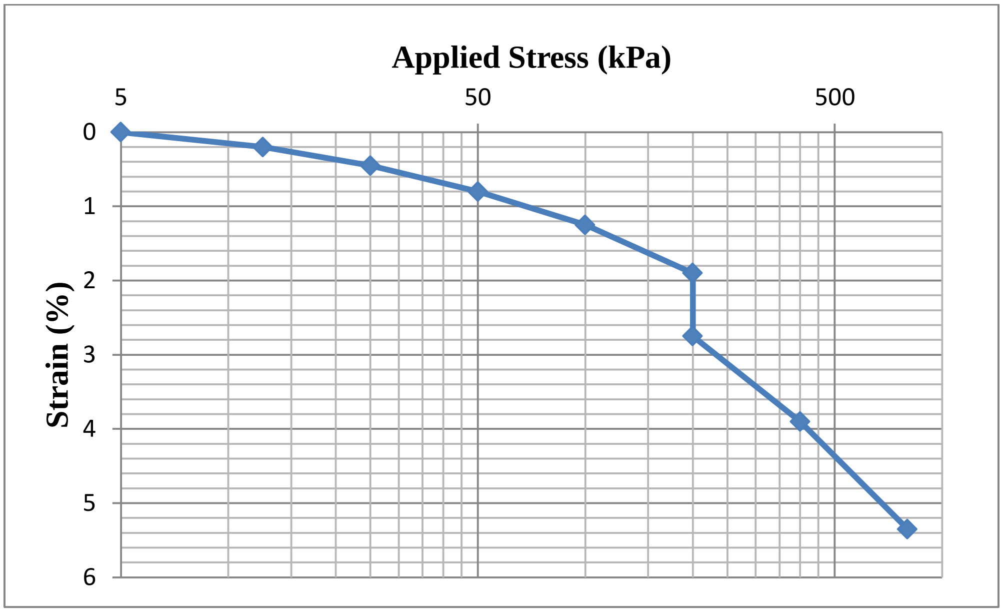

Figure 4.42: Compression curve of collapse potential test for sample 8

Collapse potential = 0.85 %.

4.6.9 Sample 9 (65% Soil, 15% FA & 20% KSD)

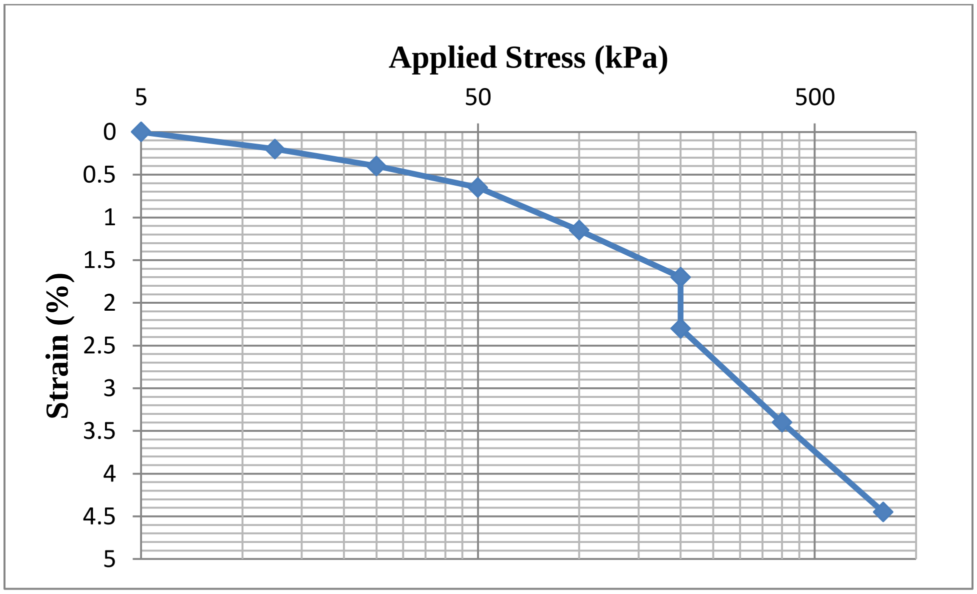

Figure 4.43: Compression curve of collapse potential test for sample 9

Collapse potential = 0.6 %.

4.6.10 Sample 10 (60% Soil, 20% FA & 20% KSD)

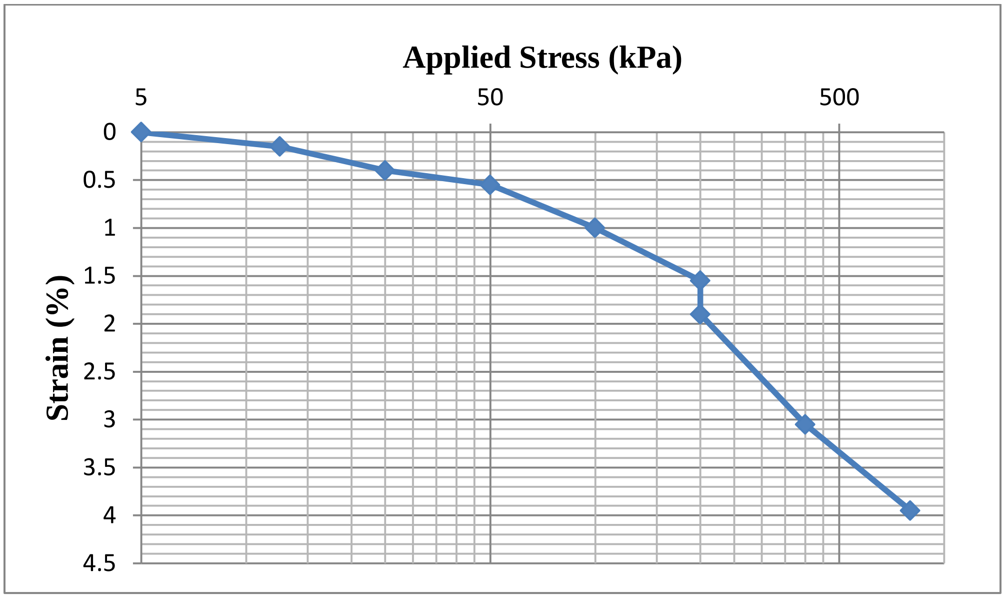

Figure 4.44: Compression curve of collapse potential test for sample 10

Collapse potential = 0.35 %.

4.6.11 Sample 11 (65% Soil, 5% FA & 30% KSD)

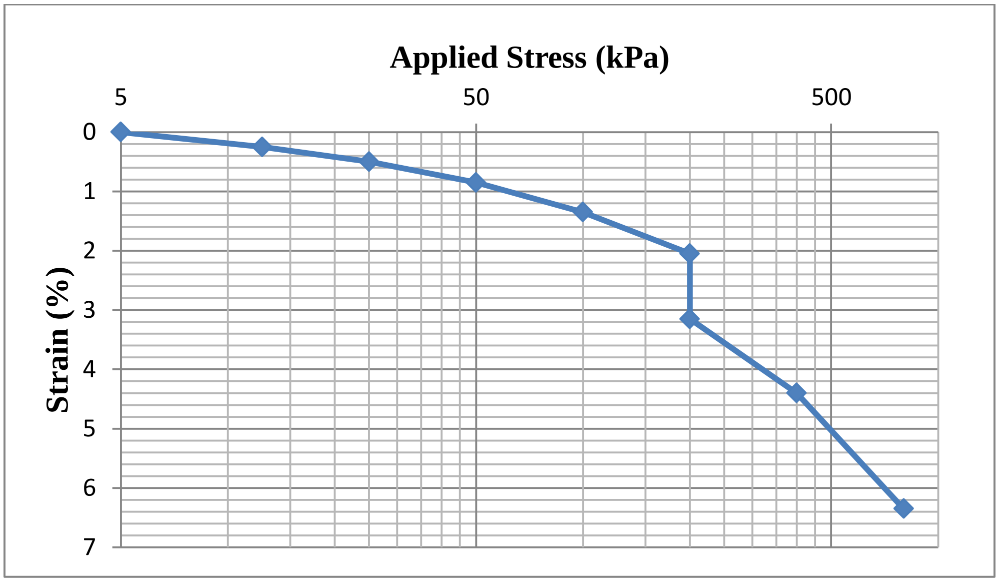

Figure 4.45: Compression curve of collapse potential test for sample 11

Collapse potential = 1.1 %.

4.6.12 Sample 12 (60% Soil, 10% FA & 30% KSD)

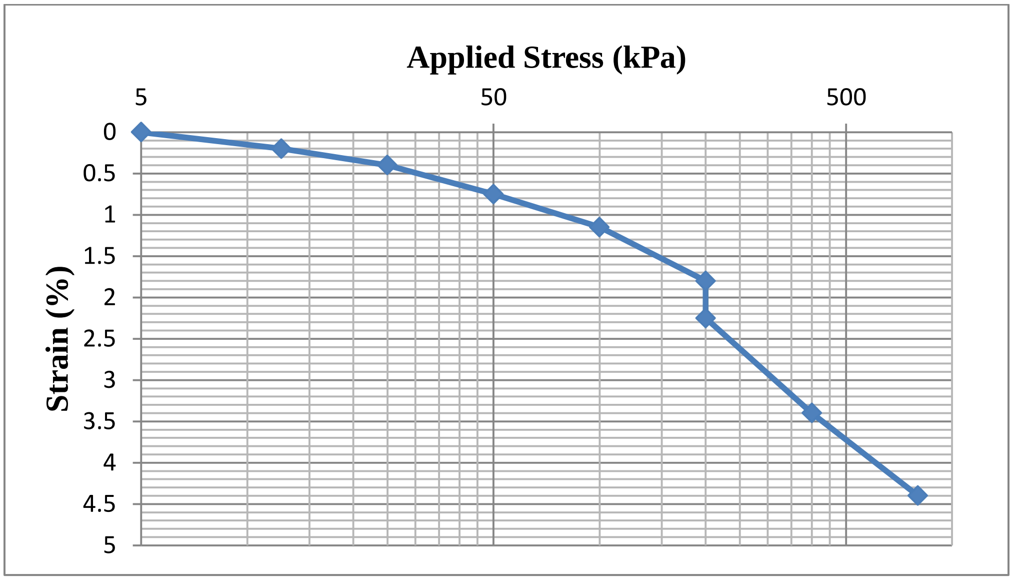

Figure 4.46: Compression curve of collapse potential test for sample 12

Collapse potential = 0.45 %.

4.6.13 Sample 13 (55% Soil, 15% FA & 30% KSD)

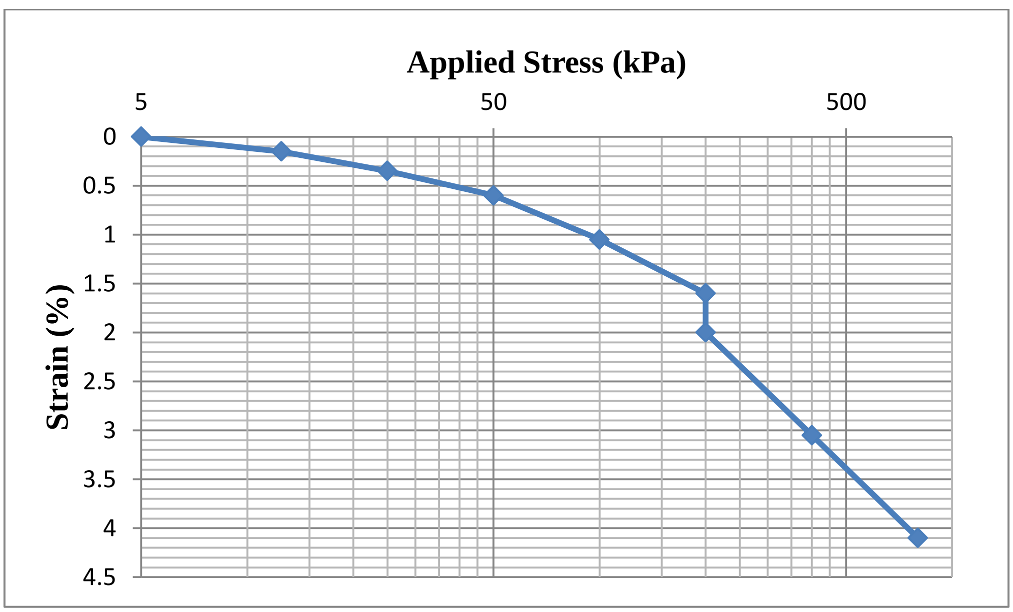

Figure 4.47: Compression curve of collapse potential test for sample 13

Collapse potential = 0.4 %.

4.6.14 Sample 14 (50% Soil, 20% FA & 30% KSD)

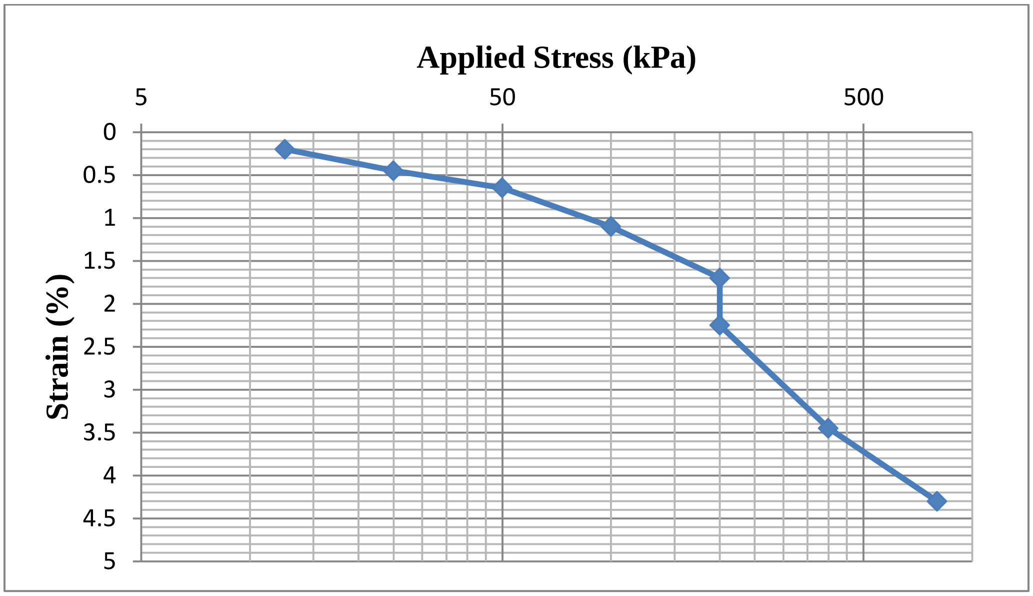

Figure 4.48: Compression curve of collapse potential test for sample 14

Collapse potential = 0.55 %.

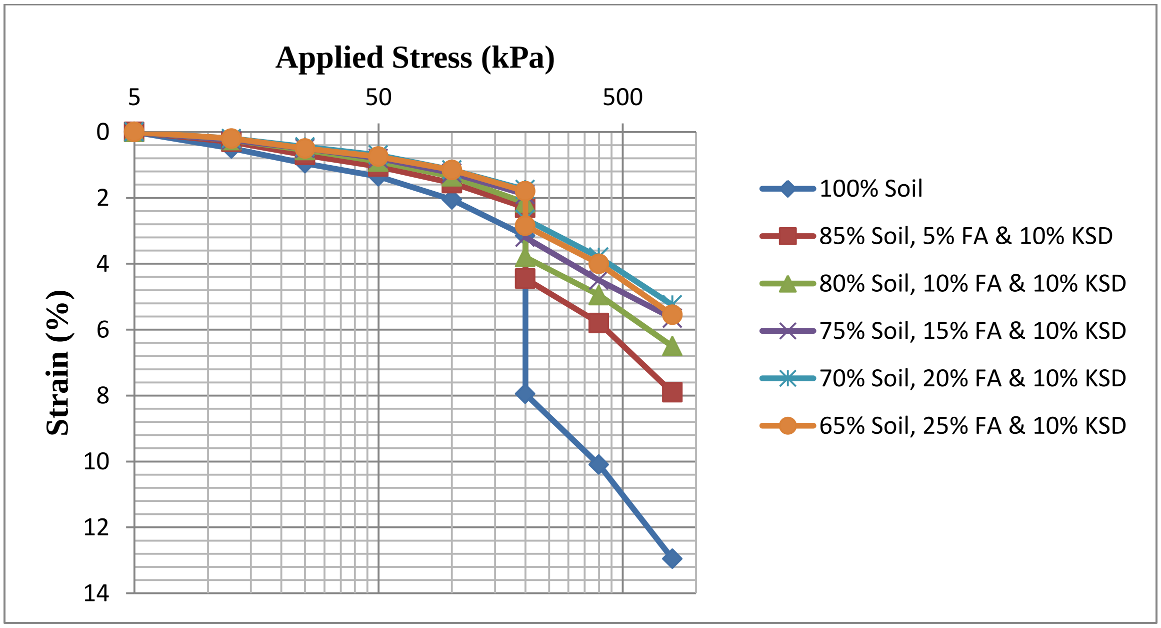

Figure 4.49: Collapsible behavior of soil mixed with varying proportion of fly ash and 10% Kota stone dust

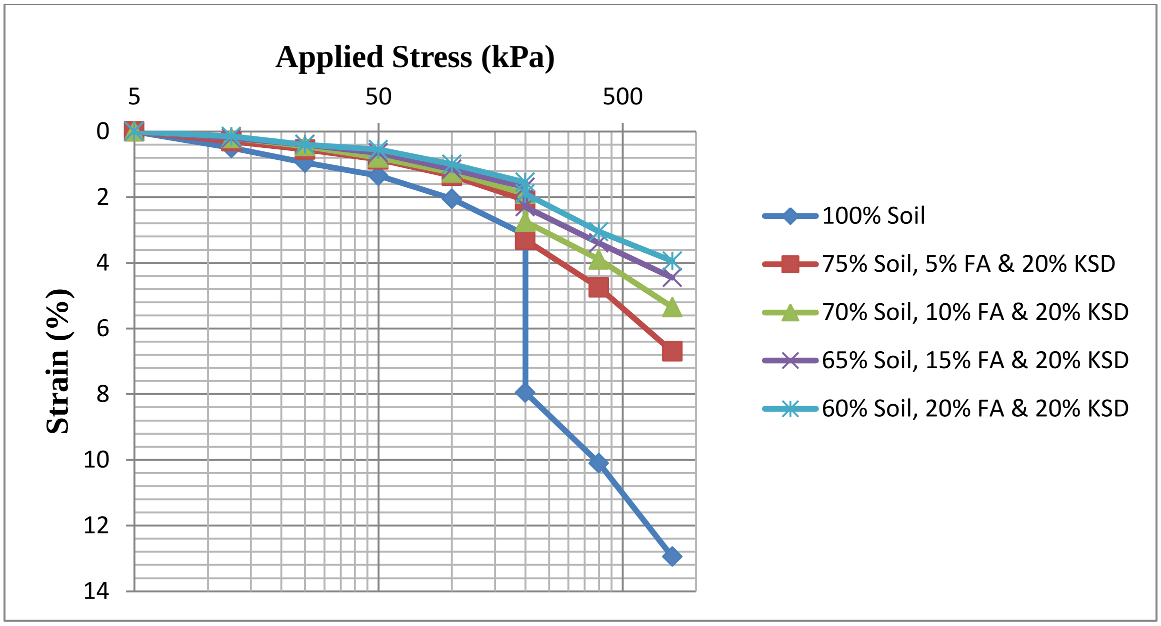

Figure 4.50: Collapsible behavior of soil mixed with varying proportion of fly ash and 20% Kota stone dust

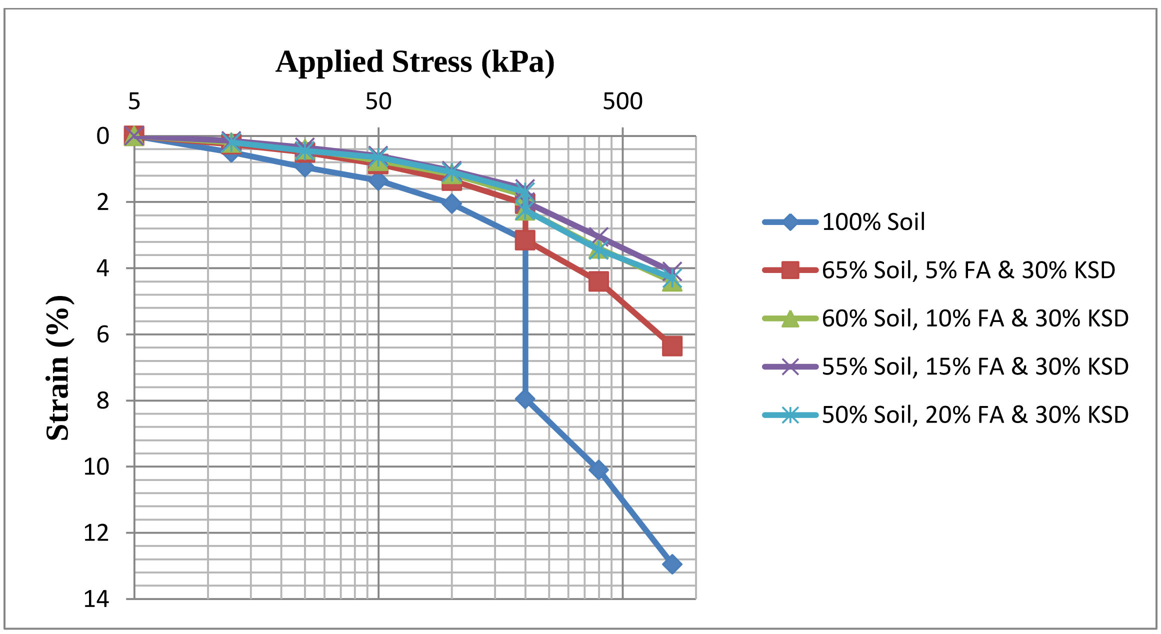

Figure 4.51: Collapsible behavior of soil mixed with varying proportion of fly ash and 30% Kota stone dust

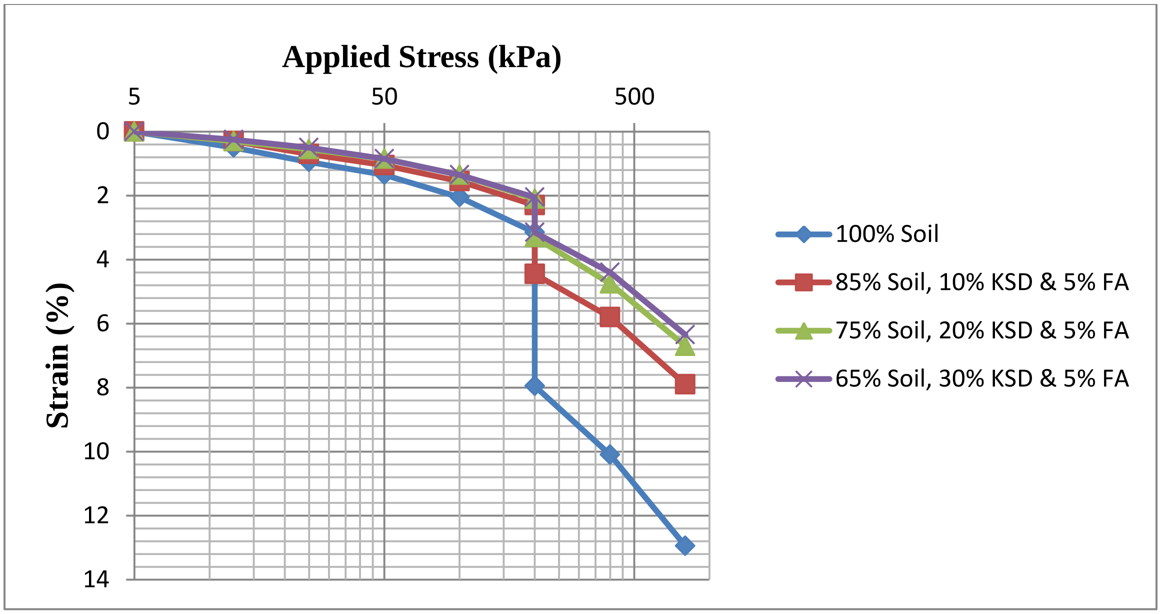

Figure 4.52: Collapsible behavior of soil mixed with varying proportion of Kota stone dust and 5% fly ash

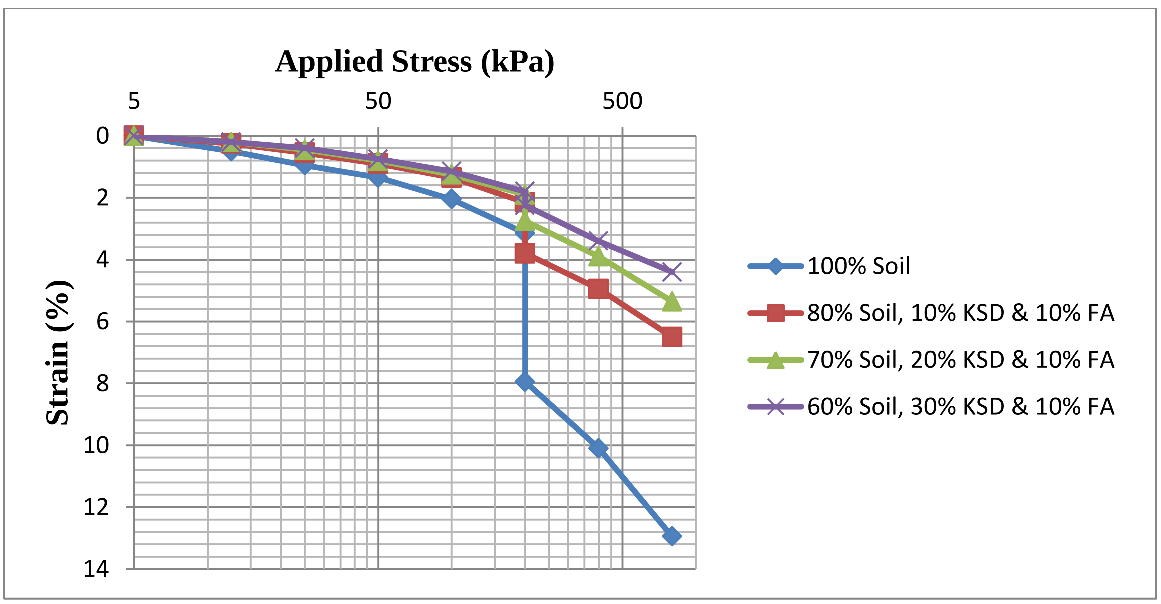

Figure 4.53: Collapsible behavior of soil mixed with varying proportion of Kota stone dust and 10% fly ash

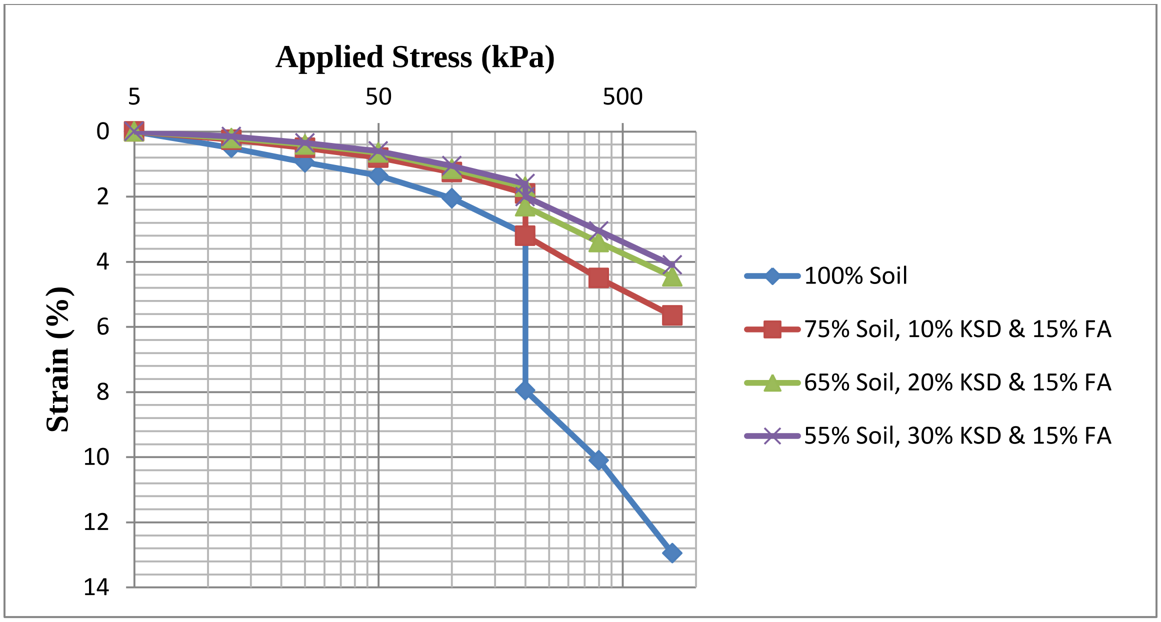

Figure 4.54: Collapsible behavior of soil mixed with varying proportion of Kota stone dust and 15% fly ash

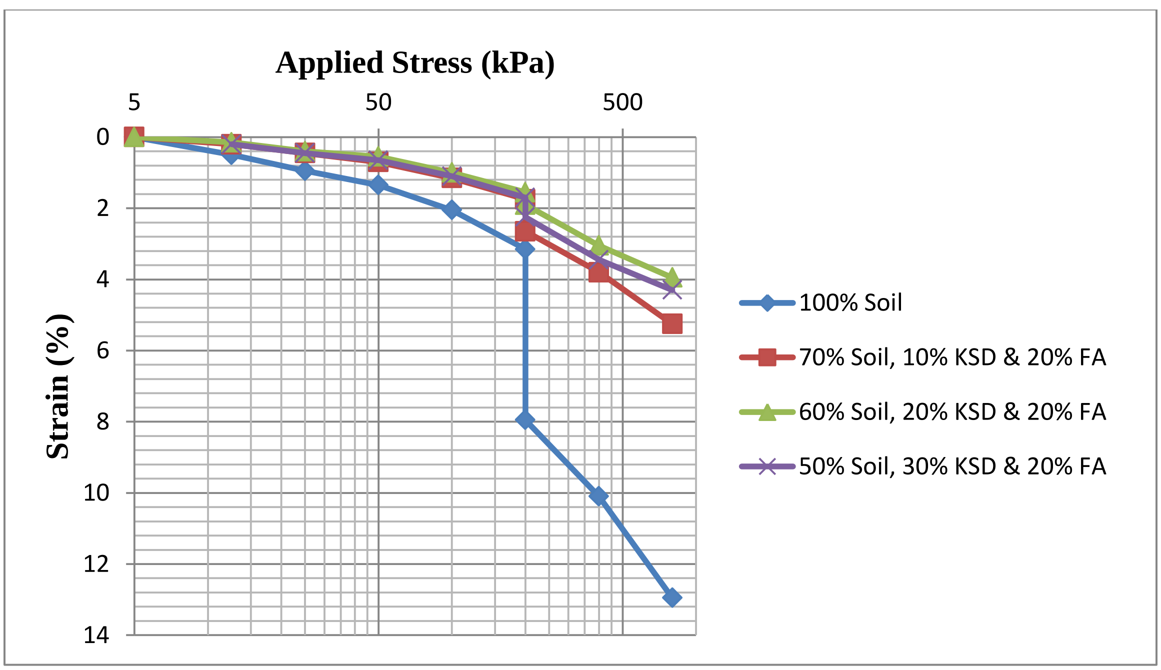

Figure 4.55: Collapsible behavior of soil mixed with varying proportion of Kota stone dust and 20% fly ash

Table 4.4: Collapse potential of soil mixed with varying proportion of fly ash and Kota stone dust

Fly Ash (%)	Collapse Potential (%)		
	10% KSD	20% KSD	30% KSD
5	2.15	1.2	1.1
10	1.65	0.85	0.45
15	1.3	0.6	0.4
20	0.9	0.35	0.55
25	1.15		

Adding fly ash and Kota stone dust decreases collapse potential of soil. Maximum reduction is obtained at 20% fly ash and 20-30% Kota stone dust mixing (Table 4.4, Figure 4.56, and Figure 4.57). However, further increasing fly ash and Kota stone dust content increases collapse potential of soil.

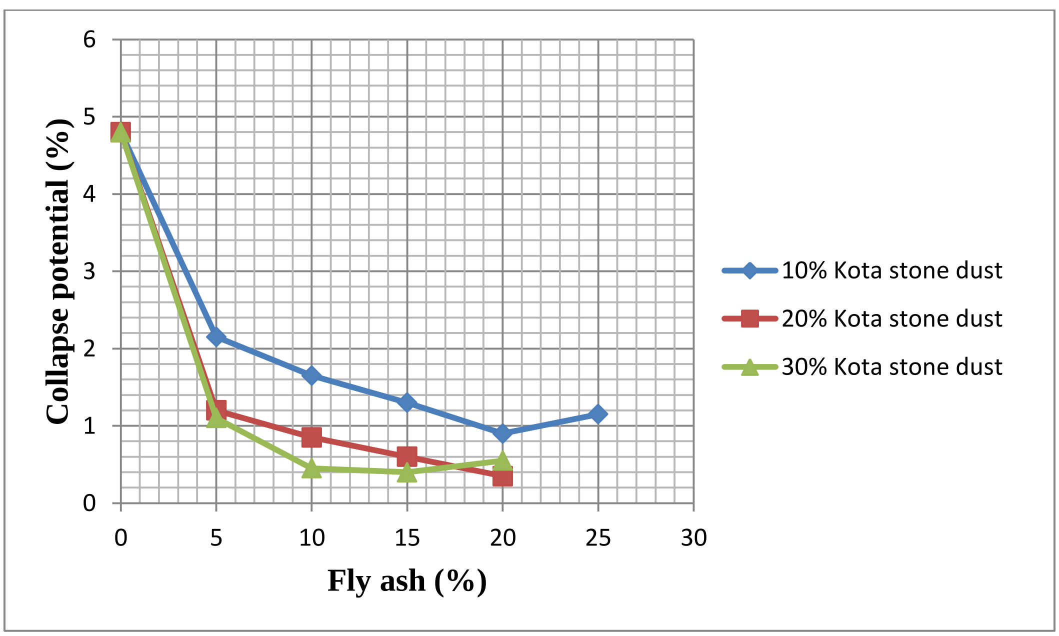

Figure 4.56: Variation of collapse potential of soil with fly ash mixed at constant proportion of Kota stone dust

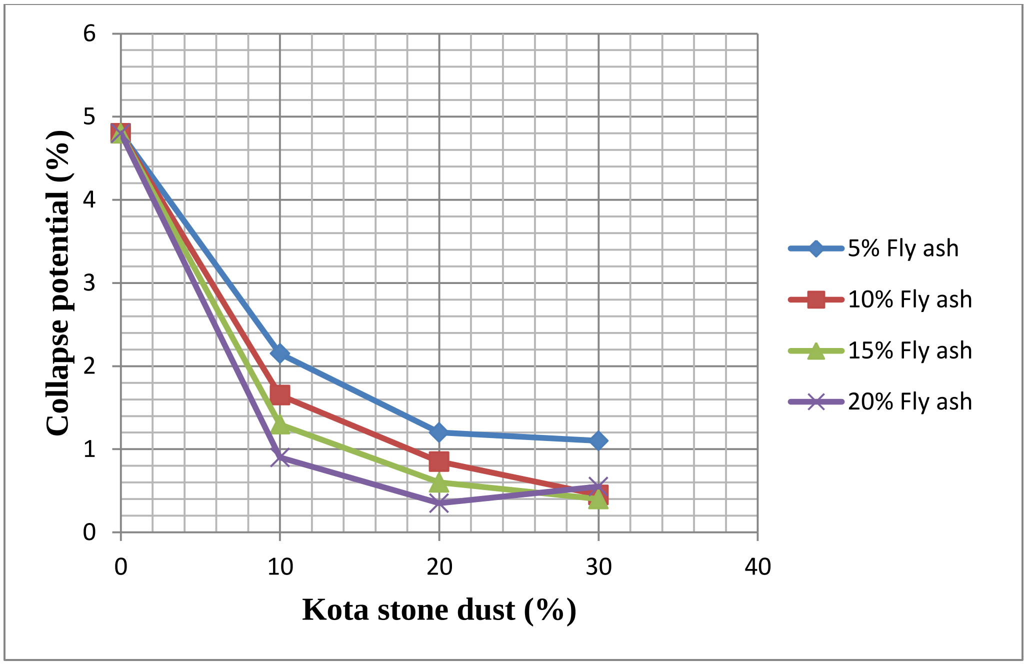

Figure 4.57: Variation of collapse potential of soil with Kota stone dust mixed at constant proportion of fly ash mixed

CONCLUSIONS

After performing various experiments on soil, fly ash, Kota stone dust and soil mixed with varying proportion of fly ash and Kota stone dust, it has been observed that fly ash and Kota stone dust is improving the soil. Based upon results of present study various conclusions are summarized as:

1. Kota stone dust contains higher fraction of coarse and medium sand particle than soil and Kota stone dust is well graded sand with silty fines, whereas soil is poorly graded sand with silty fines and fly ash is classified as clay with low to medium compressibility and fly ash is Class F having 0.63% calcium oxide content.
2. Soil particles are sub-angular in shape, whereas Kota stone dust particles are angular in shape leading to higher shear strength as compared to soil. Surface of Kota stone dust particle is more rough than soil particles leading to higher friction between particles. Fly ash contains glassy, smooth and spherical particles.
3. Optimum water content decrease with increasing fly ash and Kota stone dust content and maximum decrement is obtained at 15% fly ash and 30% Kota stone dust mixing, further increasing fly ash and Kota stone dust content results in increasing optimum moisture content.
4. Maximum dry density increase with increasing fly ash and Kota stone dust content and maximum increment is obtained at 15% fly ash and 30% Kota stone dust mixing. However, further increasing fly ash and Kota stone dust content mixed in soil results in decrement of maximum dry density.
5. Collapse potential of soil decrease with increasing fly ash and Kota stone dust content and maximum decrement occurs at 20% fly ash and 20-30% Kota stone dust mixing, beyond that content fly ash and Kota stone dust mixing results in increment of collapse potential. Along with collapse potential, settlement of soil is also decreasing with increasing fly ash and Kota stone dust content.
6. Fly ash and Kota stone dust stocks pose a serious problem in terms of both land use and potential environmental pollution. The utilization of these industrial by-products for the stabilization of soils may be regarded as economically and environmentally beneficial.

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