A Major Project Report on

STUDY OF SHEAR BEHAVIOUR OF YAMUNA SAND BLENDED WITH SOFT SOIL

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DELHI TECHNOLOGICAL UNIVERSITY

CERTIFICATE

This is to certify that project report entitled "STUDY OF SHEAR BEHAVIOUR OF YAMUNA SAND BLENDED WITH SOFT SOIL" is a bonafide record of work carried out by Deepak Rana (2k14/GTE/08) under my guidance and supervision, during the session 2016 in partial fulfilment of the requirement of degree of Master of Technology (Geotechnical Engineering) from Delhi Technological University, Delhi.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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ABSTRACT

The structure resulting from compacting the soil at different water contents and energy levels can have a substantial effect on its shear strength. While the shear strength can be estimated based on the saturated shear strength parameters and the unsaturated angle of shearing resistance, limited studies have explored the variation of shear strength properties with different compaction states. In the present study, shear behaviour of virgin Yamuna sand and Yamuna sand blended with two clays of different mineralogy i.e. bentonite and kaolinite was investigated by Direct Shear test and Unconsolidated Undrained Triaxial test. Index properties and compaction characteristics of soil is also studied in this project. It was aimed to observe the shear behaviour of sand-bentonite and sand-kaolinite mixtures.

Various tests conducted on virgin soil were performed for the determination of following parameters: field moisture content, Atterberg Limits, Grain Size Analysis, Standard Proctor Compaction test, Direct Shear and Triaxial Unconsolidated Undrained test. Compaction tests were conducted on mixtures of 5%,10%,15%,20% by weight bentonite and kaolinite. Direct Shear test and UU Triaxial tests were performed on mixes with 5%,10%,15%,20% by weight of bentonite and kaolinite.

It was found that there is increase in MDD and OMC of the soil mixes for both kaolinite and bentonite. Maximum MDD was achieved with kaolinite clay and maximum OMC with bentonite clay. Direct shear test resulted in the increase in cohesion and decrease in friction angle for both bentonite and kaolinite. Similar results are obtained in UU Triaxial tests. However, shear parameters obtained in Direct Shear test is slightly more than obtained in Triaxial tests.

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LIST OF NOTATIONS

The Following notations are used in this project:

OMC – Optimum moisture content

MDD – Maximum dry density

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

UU – Unconsolidated undrained

SEM – Scanning electron microscope

XRD– X-ray diffraction

LL– Liquid limit

PL– Plastic limit

c – Cohesion

µm– Micrometer

ϕ – Angle of internal friction

CHAPTER-1

INTRODUCTION

1.1 GENERAL

Yamuna sand is chiefly found alongside the river Yamuna in Delhi .It has low load carrying capacity and also get eroded easily. Delhi lies in the seismic zone 4 which is high damage risk or seismic active zone. Moreover, Yamuna sand in Delhi as well as NCR region contains remarkable quantity of silt and thus it is in peril to liquefaction during earth tremor below ground water table. At several places ground water is at shallow depth and structures built over sand under such conditions are not safe. Therefore, understanding the shear behaviour of Yamuna sand and its improvement in shear strength is necessary. One of the best method to improve the strength of sand is to blend it with soft soil. Soft soil is mainly a clay that is expansive in nature, highly compressible, low permeability, have high specific surface and large water holding capacity as well as cohesion when come in contact with water. There are two type of clays used in the present study namely: 1) bentonite clay and 2) kaolinite clay.

Bentonite clay : It is essentially absorbent aluminium phyllosilicate clay that contains primarily of montmorillonite mineral.It is highly plastic clay formed by the weathering of volcanic ash generally in presence of water. There are three types of bentonite based on the dominant element present in them:

1. Sodium bentonite
2. Potassium bentonite
3. Calcium bentonite

Sodium bentonite has property to enlarge several times of its dry mass in presence of water. It is used in several geotechnical explorations such as drilling mud for gas and oil wells,in boreholes ,as a low permeability liner in various landfills etc.

Potassium bentonite has potassium as its main element. It is formed from the alteration of volcanic ash and contains illite clay mineral.

Calcium bentonite is fundamentally used as adsorbent in ionic solution and also in oils. It is important element in the fuller's earth which is used as an rinsing agent. Calcium bentonite can be converted into sodium bentonite by ion exchange process.

It is also used in several geotechnical works such as drilling mud, as a binder, purification, ground water barrier and also bentonite slurry walls used in modern construction. Sand-bentonite mixtures have been used as a liner in the landfills due to its low permeability. In the present study Yamuna sand has been mixed with varying proportions of bentonite and its effect on shear behaviour is studied. Bentonite used in the project was procured from a dealer in delhi.

Kaolinite clay: kaolinite is a clay mineral that has low swelling and shrinkage property. It also exhibits low cation exchange capacity.It has generally white color ,soft and earthlike.It occurs in large quantity in soils that are formed by the chemical weathering of rocks in warm climates such as tropical rainforest. Rocks having kaolinite as main clay mineral are called as kaolin or china clay. In the present study an attempt has been made to study shear behaviour of sand mixed with varying proportions of kaolinite clay. Kaolinite powder used in the present study was obtained from a dealer in Delhi.

1.2 OBJECTIVE OF PRESENT STUDY

- To determine the basic properties of Yamuna sand.
- To study the effect of different proportions of bentonite and kaolinite on the compaction characteristics of Yamuna sand.
- To study the effect of varying proportions of bentonite and kaolinite on shear strength parameters of Yamuna sand by direct shear test.
- To study the effect of different proportions of bentonite and kaolinite on shear strength parameters of Yamuna sand by UU triaxial test.
- To compare the results obtained on mixing bentonite in varying proportions in Yamuna sand with results obtained on mixing kaolinite in different proportions in Yamuna sand.

CHAPTER-2

LIRERATURE REVIEW

Georgiannou V.N. (1988) carried out an investigation on the behaviour of clayey sands under monotonic and cyclic loading. He stated that stress strain response of soil is greatly affected by the quantity of fines present in it. When the percentage of finer fraction increases, the dilatant behaviour of the soil mass got reduced. Thus, the response of the soil get controlled gradually by the fine matrix at about 40%.

Georgiannou, Burland & Hight (1990) performed an investigational study about stress-strain behaviour of anisotropically consolidated clayey sands encorporating computer monitored triaxial cells. The specimens were made by sedimenting Ham River sand into a kaolin suspension. They witnessed the effects of differences in clay content and initial granular void ratio. They determined that this process makes a material which is noticeably less stable, which has a higher granular void ratio and shows a higher undrained brittleness behaviour, which is the engineering characteristic like ductile behaviour and it is stated by stress history, rate of shearing and fabric of clays, if matched with the same sand that is sedimented through clean water.

Kenney et al. (1992) carried out standard compaction tests on 4%, 8%, 12% 16%, and 22% bentonite–sand mixtures. His study considered utilization of freshwater, so all the compaction tests were performed with fresh water. Maximum dry density values were examined to be in the range of 1.70-1.85 Mg/m 3 corresponding to 12%-15% optimum moisture content values for various sand-bentonite mixes. He noticed that increase of bentonite content resulted in increased values of maximum dry density and beyond an optimum sand-bentonite ratio, which in this case equal to 20%, maximum dry density decreased. He stated the reason for this might be that as the bentonite is added, sand particles are increasingly supported by bentonite. When the sand-bentonite ratio is small, the sand is the main load-bearing component of the mixture. The structural component role of sand is shared with bentonite as the ratio of bentonite is increased in the mix.

Bayoğlu and Esra (1995), carried out an experimental investigaion. In this study, effects of the fines (diameter < 0.074 mm.) on the shear strength behaviour and compressibility characteristics of the soil mixtures were examined. Soil mixtures having wide range of particle size from sand to silt-clay mixtures were examined. Drained shear box and triaxial tests(consolidated- undrained) were executed on normally consolidated clay-sand blends to attain strength and compressibility parameters. As per the results obtained from drained direct shear tests on mixtures containing 5 %, 15 %, 35 %, 50 %, 75 %, and 100 % fines, the internal friction angles changed between 30-38 degrees until 50 % fines and a little decrement occurred in the friction angle with increasing percentage of fines . At fine particle content higher than 50%, the reduction in the friction angle was noteworthy and decreased to about 10 degrees.

Saurav De and Prabir Kumar Basudhar (2008) investigated steady state behaviour of Yamuna sand by conducting consolidated drained triaxial test and also observed volume changes in the soil. It was determined that undrained response rises after the formation of quasi steady state. The results obtained by an effective stress approach containing conventional consolidated drained triaxial tests with volume change measurements on rebounded samples are in fair agreement with that found by strain-controlled consolidated undrained test with pore pressure measurements.

Ch. Hanumantha Rao and G.V. Ramana (2010) performed undrained triaxial tests on Yamuna sand procured from Delhi. They determined resistance to liquefaction is up to 15% silt content and thereafter there is decrease in resistance. They observed that liquefaction resistance increases upto 15% silt content and thereafter liquefaction resistance decreased with the further increase in silt content at particular relative density.Cyclic resistance increased as the density of the soil increased.

Purvana YM, Nikraj H and Jitsangiam P(2012) carried out suction monitored CBR tests on sand-kaolin clay mixtures at varying proportions (5%,10% and20%) of kaolin clay content. They stated that increase in moisture content lead to increase in metric suction which in turn increases the CBR value of the mix. There was tremendous increase in CBR value for the mix at 10% kaolin content when the specimen was dried up. They also developed relationship between CBR and water content and also or CBR and metric suction.

Mohammad S. Pakbaz and Ali Siadati Moqaddam(2012) carried out consolidated drained triaxial tests on mixture of sand clay at different gradation and fine content. They found that the shear strength behaviour of mix was significantly affected by the fine content at about 30%. The angle of internal friction decreases with the increase in fine content and so the drained shear strength. The value of m got decreased for the increase in fine content and it increased with increase in sand fraction. For all mixes the increase in normal stress lead to increase in shear strength and decrease in over consolidation ratio. This may be attributed to the increase in surface contact area of the soil particle due to increase in effective normal stress. Moreover, the minimum void ratio first decreased with increase in fine content and after that it increased.

Sadanand Ojha and Asutosh Trivedi (2013) studied shear strength parameters for Yamuna sand using relative compaction. They carried out a series of tri-axial tests to establish a relation between shear strength of sand with increasing proportions of silt. They also investigated effect of fine particles on the angle of internal friction, void ratio, coefficient of uniformity, effective particle size, mean particle size and UCS sands with silt. They stated that there is decrease in minimum and maximum void ratios with the increase in silt content. Also, with the increase in silt content there is increase in critical angle of internal friction.

Md. Abdullah Asad, shantanu Kar and Mohammad Ahmeduzzaman(2013) studied various samples of bentonite clay collected from India ,China and Pakistan for their suitability. They performed specific gravity and liquid limit tests on these samples. They found china sample to have maximum specific gravity which is attributed to the presence of high clay content in it. In case of activity china and Pakistan sample have high activity with China sample to be most active. China sample had high liquid as well as plastic limit and it is also cheapest of them all. So, China clay is most suitable among them all.

Pratibha Panwar and Ameta N.K. (2013) studied the behaviour of dune sand mixed with bentonite and lime. They performed proctor test and unconfined compression tests on dune sands mixed with varying proportions of bentonite and lime. They found that there is increase in unconfined compression strength with the increase of bentonite content upto 15% and lime content upto 3%. Further increase in bentonite content made the mix sticky and thus compaction difficulties. They also said that the strength is directly proportional to the rate of strain i.e.strength increases with the increase of rate of strain. They also studied the effect of curing period and environment and found that strength increases with the increase in curing period.

Muawia A. Dafalla(2013) performed direct shear test on sand mixed with bentonite clay found that there is increase in shear strength of the mix at all normal stresses upto 15%.Beyond that there will be decrease in shear strength of mix. He also reported drop in cohesion with increase in moisture content. Similarly angle of internal friction decreased with increase in moisture content. Also angle of internal friction showed minimum value at10% bentonite clay content for non-moist mixes.

D.C. Simpson and T.M. Evans(2015) studied behavioural threshold for the mixtures of sand and kaolinite clay. Sand used for investigation was Ottawa sand and pure kaolinite clay was used in the mix. Consistency tests, undrained shear strength test by triaxial testing machine, compressibility test using oedometer , thermal conductivity test by thermal needle probe were conducted on the binary mixtures of sand-kaolinite clay mixtures ranging from 0-100% fine content. They found that behavioural threshold exists at a critical fine content where a minimum void ratio occurs and continuous force chains were present at percolation threshold. Behaviour of the sand was greatly affected by the presence of fines and there was abrupt change in the nature of soil at a particular percentage of fines. The reason for this was that the fine particles started displacing the coarser particles in a unit volume. Observed behavioural threshold was summarised in the following table.

Table 2.1: Observed behavorial thresholds

Threshold	**Approximate fine content**	**Applicable behaviour**
t_1	0.2	Consistency, compressibility
t_2	0.4-0.6	Critical state strength, conductivity
t_3	0.9	Compressibility

Anup Tiwari, Sanjeev Suman and Subir Sharma(2016) conducted series of specific gravity test, compaction test, direct shear test and permeability test on various sand-bentonite mixes. They found that maximum dry density increased and optimum moisture content decreased with the growing amounts of bentonite. Maximum value of MDD was examined at 24% bentonite mix. They stated that angle of internal friction decreased with the increasing percentage of bentonite in the mix, minimum value at 24%. Cohesion increased with the increasing value of bentonite and attained a maximum value of 0.31 kg/cm2.

CHAPTER-3

MATERIALS USED

AND

METHODOLOGY

3.1 AIM OF THE PRESENT STUDY

The present investigation aims to study the "Study of Shear Behaviour of Sand blended with soft soil".

3.2 MATERIALS USED IN THE PRESENT STUDY

SAND: It is a naturally occurring material composed of finely divided rock and mineral particles. It is defined by size i.e. soil which passes through 4.75 mm sieve and retained on 75 micron sieve is called sand.

In this project Yamuna sand is taken from the alongside of river Yamuna. It is firstly washed and the wetted soil is passed through 4.75 mm sieve and retained on 75 micron sieve, then soil is oven dried, is taken.

BENTONITE CLAY: It is basically bentonite powder collected from a dealer in Delhi.

KAOLINITE CLAY: It is gathered in powdery form from a dealer in Delhi.

3.3 MIXES USED IN THE STUDY

Yamuna sand was mixed with the bentonite and kaolinite separately in different proportions and their effect on the index properties and shear behaviour of the Yamuna sand was investigated.

SM0: Virgin Yamuna sand

SMB5: Yamuna sand mixed with 5% bentonite

SMB10: Yamuna sand mixed with 10% bentonite

SMB15: Yamuna sand mixed with 15% bentonite

SMB20: Yamuna sand mixed with 20% bentonite

SMK5: Yamuna sand mixed with 5% kaolinite

SMK10: Yamuna sand mixed with 10% kaolinite

SMK15: Yamuna sand mixed with 15% kaolinite

SMK20: Yamuna sand mixed with 20% kaolinite

3.4 METHODOLOGY FOR THE INVESTIGATION

In the current investigation following tests have been performed on the soil:

- SEM Test
- XRD Test
- Sieve Analysis
- Hydrometer Analysis
- Specific Gravity Test
- Liquid Limit Test
- Plastic Limit Test
- Standard Proctor Test
- Direct Shear Test
- Unconsolidated Undrained Triaxial Test

3.5 TESTING PROGRAM

3.5.1 SEM TEST:

A scanning electron microscope is basically a kind of electron microscope that creates images of a sample by scanning it with a focused electron beams. The electrons interrelate with atoms in the sample, constructing various signals that comprise data about the sample's surface topography and composition. A` raster scan pattern scans the electron beam and the position of beam is pooled with the perceived signal to yield an image. SEM can attain resolution better than 1 nanometer. Specimens can be witnessed in high vacuum, in low vacuum, in moist situations (in environmental SEM), and at a wide variety of cryogenic or raised temperatures.

The most common SEM mode is recognition of secondary electrons released by atoms motivated by the electron beam. The amount of secondary electrons that can be sensed depends, among other things, on the angle at which beam encounters surface of specimen i.e. on specimen topography. By scanning the sample and assembling the secondary electrons that are emanated by means of a special detector, an image exhibiting the topography of the surface is produced. . A wide variety of enlargements can be done, from nearly 10 times (about equivalent to that of a powerful hand-lens) to more than 500,000 times, about 250 times the magnification limit of the finest light microscope. Back-scattered electrons (BSE) are beam of electrons that are replicated from the sample by elastic scattering.

Figure 3.1 : Scanning Electron Microscope at DTU

3.5.2 XRD TEST

An electron in an alternating electromagnetic field will oscillate with the similar frequency as the field. The electrons nearby the atom start to oscillate with the same frequency as the incoming beam, when an X-ray beam hits an atom. In practically all directions we will have destructive interference, that is, the combining waves are out of phase and there is no resultant energy leaving the solid sample. Nevertheless the atoms in a crystal are organized in a unvarying pattern, and in a very little directions we will have constructive interference.

The waves will be in phase and there will be well demarcated X-ray beams leaving the sample at various directions. Therefore, a diffracted beam may be termed as a beam made of a large amount of scattered rays conjointly reinforcing one another. Mathematically, this model is complex to handle and in daily work we talk about X-ray reflections from a series of parallel planes inside the crystal. The three integers h, k, l called indices define the orientation and inter planar spacing of these planes .

3.5.3 SIEVE ANALYSIS

Grain size analysis is basically a method of separation of soils into various fractions based on the grain size. It is also called as particle size analysis or mechanical analysis.it is generally carried out for coarse grained soils. This test was carried out on Yamuna sand as per **IS 2720 (Part 4):1985.**

3.5.4 HYDROMETER ANALYSIS

Hydrometer analysis on bentonite and kaolinite was carried out as per **IS 2720(Part 4) 1980.** In hydrometer analysis the weight of solids present at any time is calculated indirectly by reading the density of soil specimen. Here in present study 50 g of the soil sample was mixed with 8 g sodium hexametaphosphate and 2 g sodium carbonate(dispersive agents) in 250 ml distilled water then the distilled water is poured in evaporating dish containing the soil sample. The mixture in the dish was allowed to stand for about 1 hr. Then, the sample was passed through 75 µ sieve using wash bottle. Soil retains on the sieve was then placed in oven. The solution passing through the 75µ sieve was poured in the measuring cylinder. More water was added to make it 1000ml. The mixture was stirred thoroughly and then hydrometer was inserted in the solution. Readings were taken at regular intervals 15 sec, 30 sec,1 min, 2 min, 4 min, 8 min,16 min, 32 min,64 min, 128 min, 256 min ,512 min and 24 hr.

(a)

(b)

Figure 3.2 (a) hydrometer analysis of bentonite, (b) hydrometer analysis of kaolinite

3.5.5 SPECIFIC GRAVITY TEST

Specific gravity of soil solids is the ratio of weight, in air of a given volume of dry soil solids to the weight of equal volume of water at 4ºC defined as per **IS 2720 (Part 3):1980**. Specific gravity of soil grains is used in the calculation of void ratio, porosity and degree of saturation, by knowing the moisture content and density. Its value helps in identifying and classifying the soil type. In the present study specific gravity of Yamuna sand, bentonite and kaolinite has been evaluated.

3.5.6 LIQUID LIMIT

The liquid limit was determined with the help of standard liquid limit apparatus defined as per **IS 2720(Part 5):1985**. About 120g of the soil passes through 425µ sieve was taken and groove was made by groove tool which is designates by. The brass cup was elevated and allowed to fall on the rubber base and then water content correspond to 25 blows was taken as the liquid limit. In the current study liquid limit test was carried out on bentonite and kaolinite as per above mentioned code provisions.

3.5.7 PLASTIC LIMIT

This test is performed to determine the plastic limit of soil defined as per **IS: 2720(Part 5):1985**. The plastic limit of fine-grained soil is the water content below which soil ceases to be plastic. Its crumble when rolled into the threads of 3mm dia. Here, plastic limit of bentonite and kaolinite has been evaluated.

3.5.8 STANDARD PROCTOR TEST

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil at a specified compactive effort defined as per **IS 2720 (Part 7):1980**. In the present study Standard Proctor test was carried out on Yamuna sand and sand mixed with varying proportions of bentonite and kaolinite(5%,10%,15%,20%) separately.

3.5.9 DIRECT SHEAR TEST

This test was carried out on soil to determine the shear parameters of soil. A standard size (60mm*60mm) Direct Shear box was used for the investigation. The tests were conducted on three different normal stress i.e. 50, 100 & 150 kPa and the angle of internal friction & cohesion values were obtained by plotting a straight line through the plot of shear stress versus the normal stress. Direct Shear tests were performed strictly according to **IS 2720(Part 13):1986** on Yamuna sand and Yamuna sand mixed with different proportions of bentonite and kaolinite. All the tests were performed at mdd and omc of the soil sample.

`

(a)

(b)

Figure 3.3(a) Direct Shear test machine , (b) soil sample in sampler

3.5.10 TRIAXIAL TEST(UU)

A series of unconsolidated and undrained triaxial compression tests was performed on virgin Yamuna sand and Yamuna sand blended with varying proportions of bentonite and kaolinite separately(10%, 15 %and 20%). Tests were performed as per **IS 2720(Part 11):1993**. All test specimens were 38 mm in diameter and 76 mm high. All tests were performed at mdd and omc. The soil sample and amount of water is weighed and then mixed in the evaporating dish with the help of spatula. The mix is then poured in mould. The soil is compacted with a small tamper into three layers in a mould. After each compaction soil surface is scratched and next layer is filled and compacted. Sample was extracted from mould with the help of sample extractor machine. Sample was then placed in triaxial cell having porous stone with filter paper at bottom and glass stopper at top. Rubber membrane is then placed on the sample with the help of sampler. The cell in then filled with water and then required cell pressure is applied. Displacement is set to zero. Tests were performed at 1,2,3 kg/cm2. Displacement(in mm)and load(kg) readings were taken at regular intervals at 0.25mm,0.50mm,0.75,1.0mm,1.25mm and so on upto failure or 15.2 mm whichever is earlier. Then cell pressure was released and water from triaxial cell was drained. The sample was taken out carefully to observe the failure. In the present study 38 tests were performed of which 27 were successful. All the tests were performed at HEICO Engineering Services Pvt.

Ltd. ,A13, Phase-2, Naraina Industrial Area, New Delhi.

(a)

(b)

(c)

(d)

Figure 3.4(a) sample extractor,(b) Triaxial machine,(c) failure of sample,(d) failed samples

CHAPTER-4

RESULTS

AND

ANALYSIS

4.1 SEM TEST

4.1.1 Yamuna sand

The test was performed at three scales 5µm and 20 µm respectively. From the figure below it can be witnessed that sand particles are angular, experienced non uniform weathering and have larger silica dissolution.

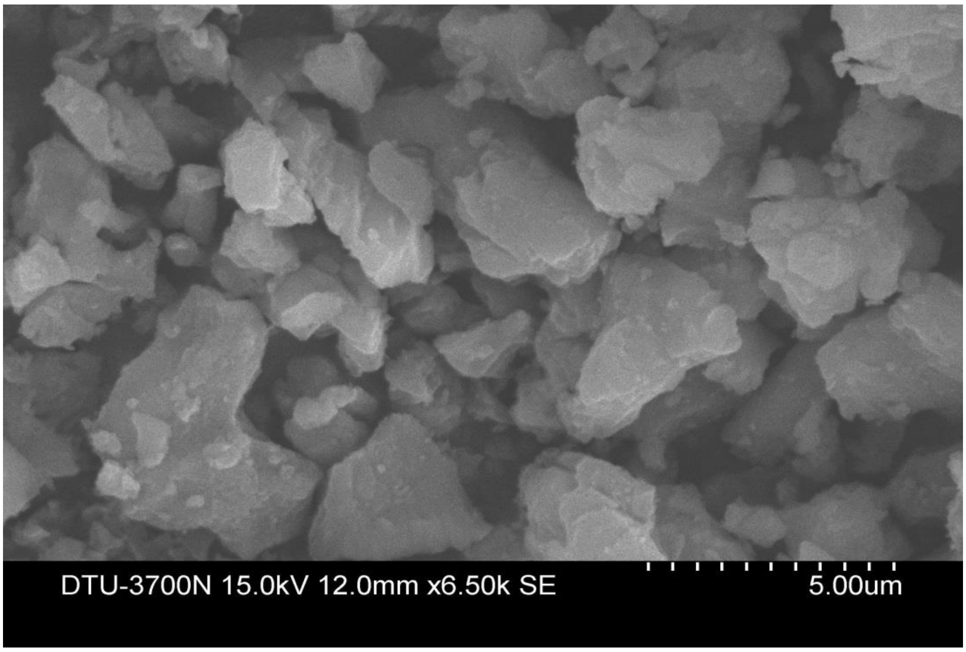


Figure 4.1 : SEM test on Yamuna sand at 5µm

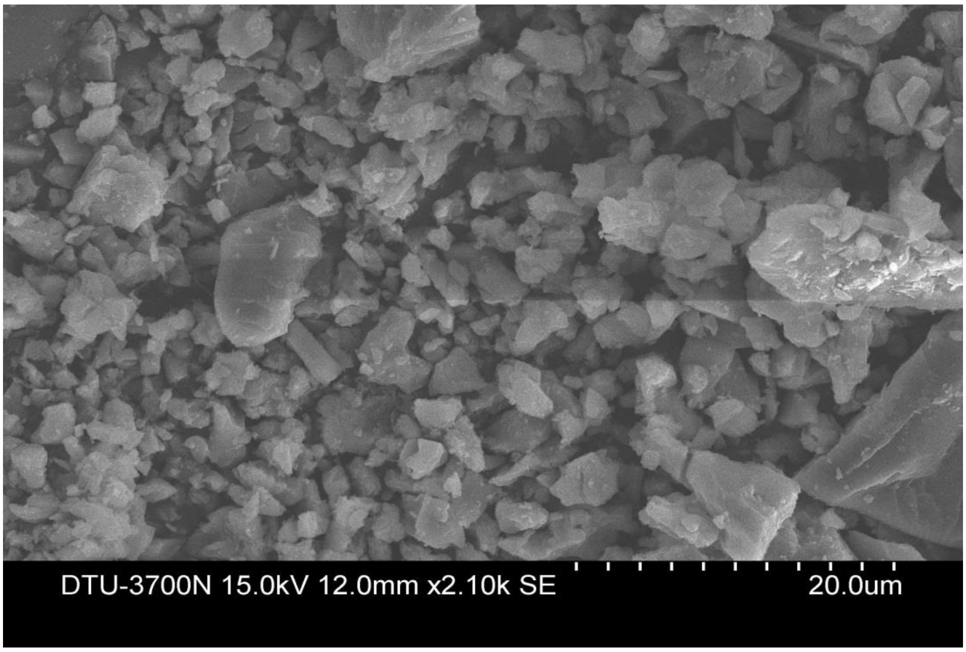


Figure 4.2 : SEM test on Yamuna sand at 30µm

4.1.2 Bentonite clay

SEM test was conducted on bentonite at 5 µm and 30µm. It can be seen that particles present in bentonite sample are of irregular size and shape and having large voids. Moreover, it has agglomerated due to the presence of water in the atmospheric condition. This establishes the hygroscopic nature of bentonite.

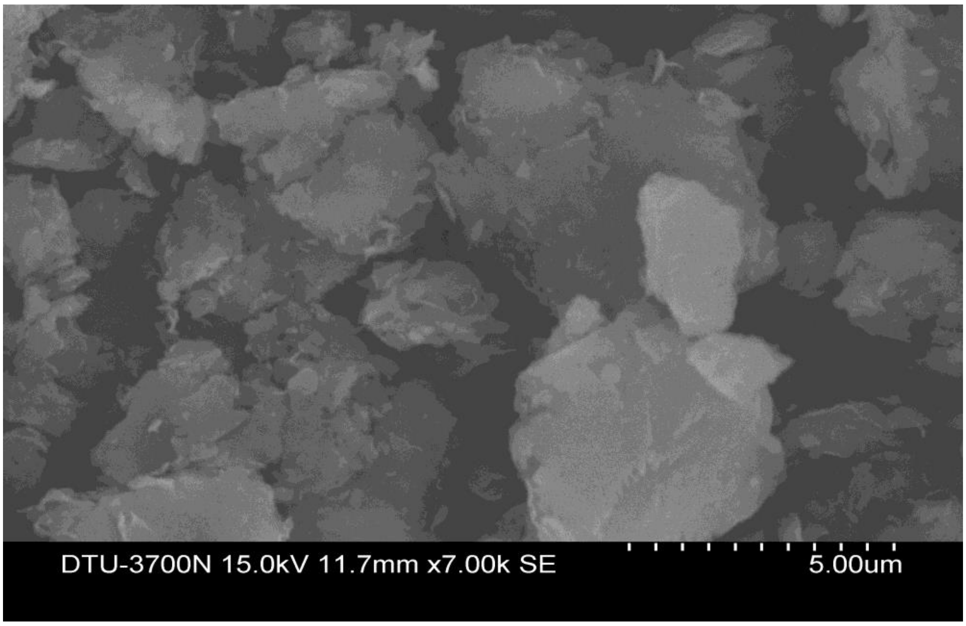


Figure 4.3 : SEM test on bentonite clay at 5µm

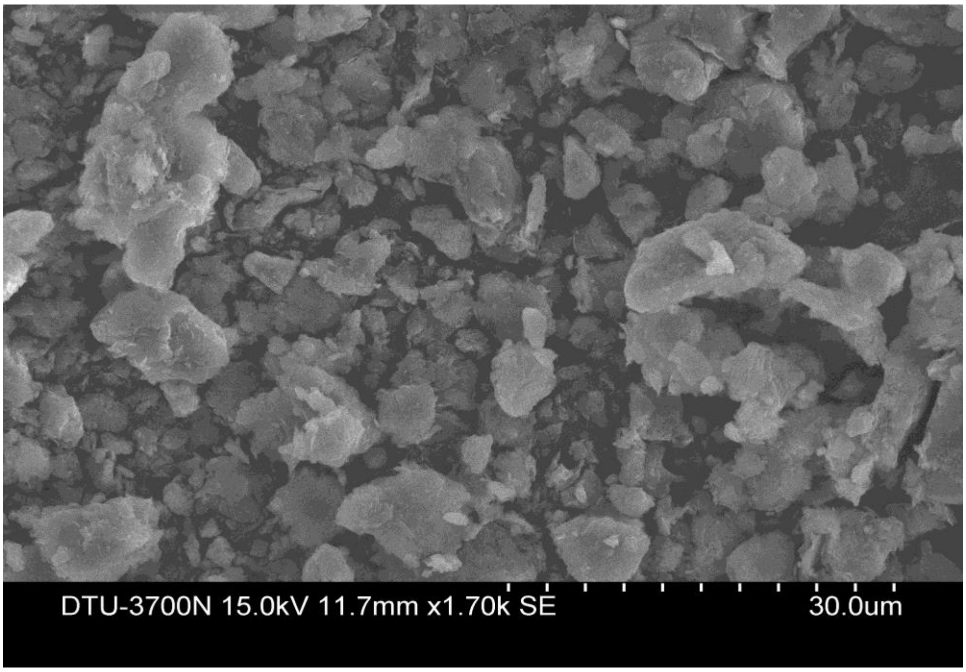


Figure 4.4 : SEM test on bentonite clay at 30µm

4.1.3 Kaolinite clay

SEM test on kaolinite clay was carried out at 5µm and 20µm. It can be observed that particles present in bentonite sample are of irregular size and shape and having large voids.

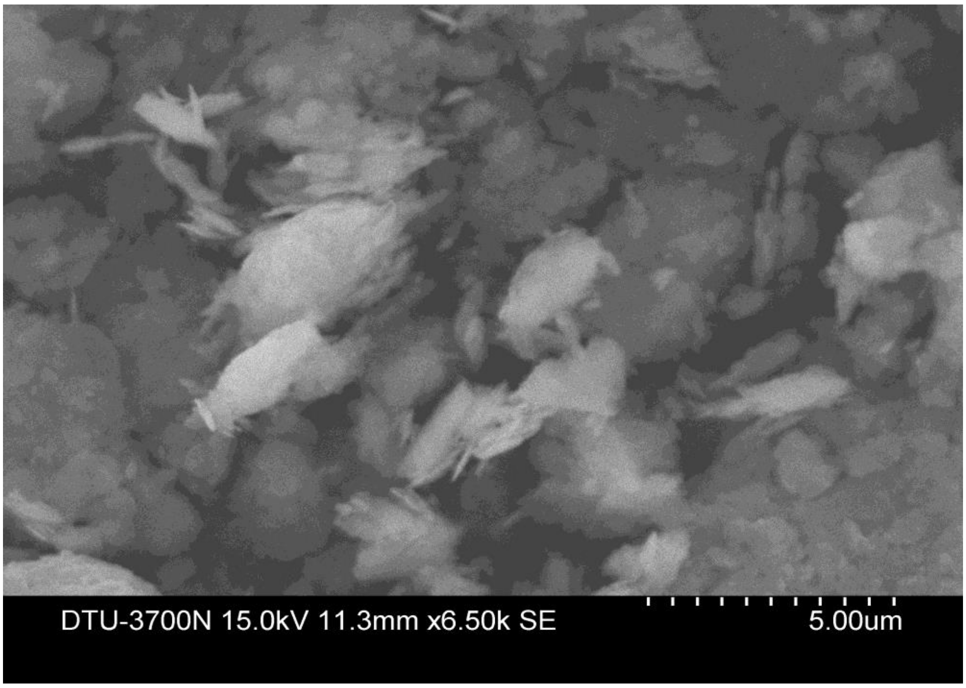


Figure 4.5 : SEM test on kaolinite clay at 5µm

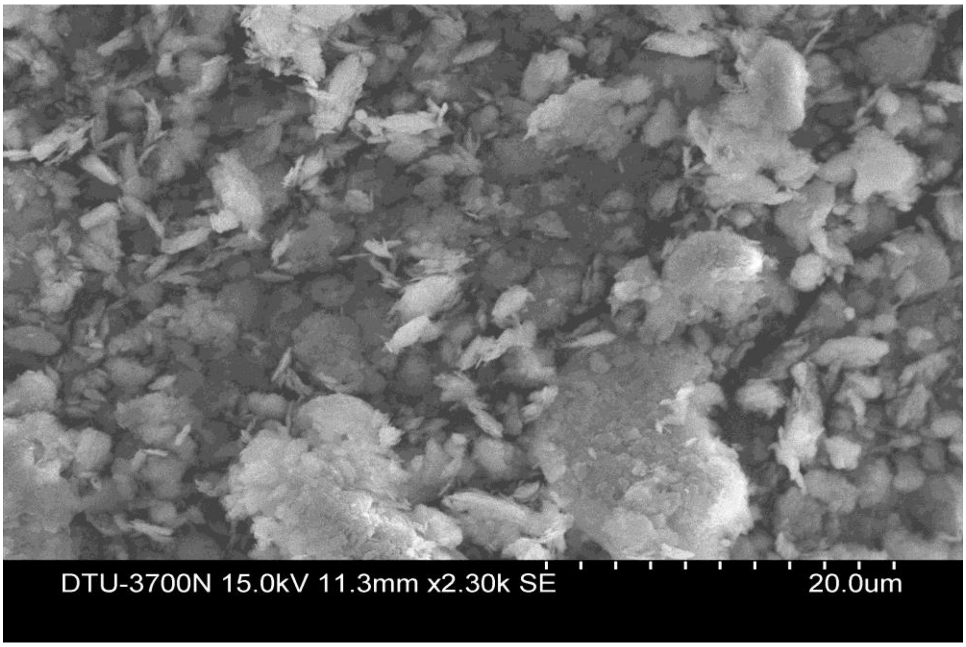


Figure 4.6: SEM test on kaolinite clay at 20µm

4.2 XRD TEST

4.2.1 XRD test on Yamuna sand

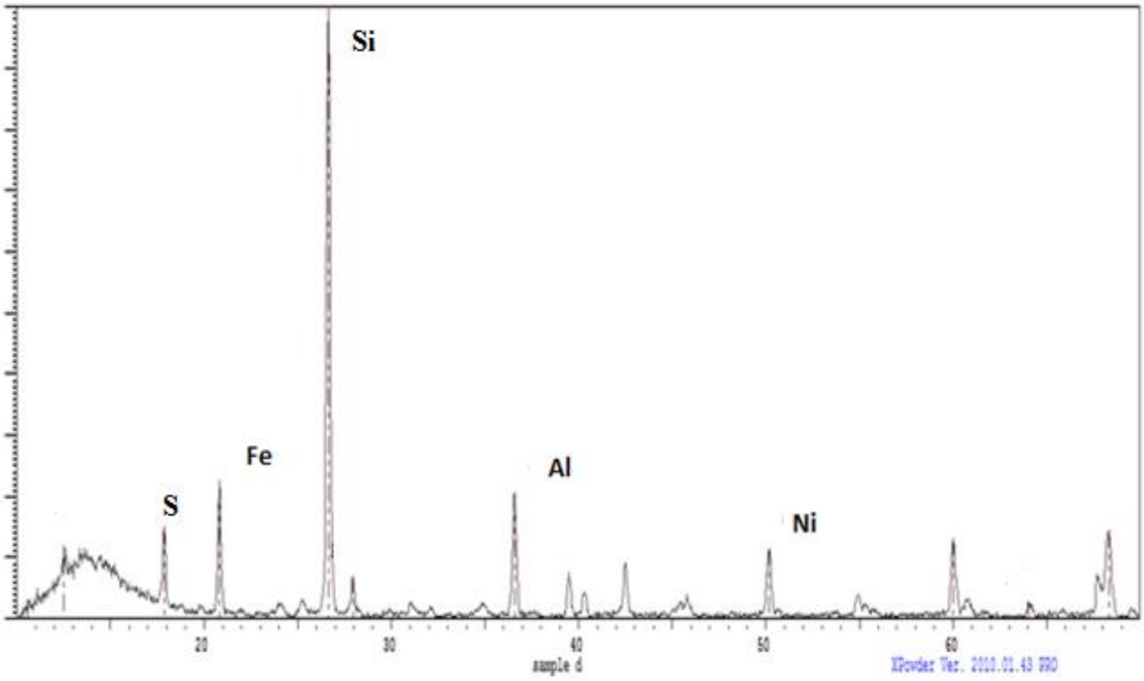


Figure 4.7: XRD of Yamuna sand

From the XRD the grain size are determined by the formula:

$$t = \frac{0.9\lambda}{\beta\cos\theta}$$

where t is grain size,

λ = wavelength at which XRD is conducted is equal to 1.540A°.

β = full width at middle height i.e. 0.02cm

θ= incident angle =13.324

putting the values we get the size of particles of Yamuna sand to be 70µm

Chemical Composition :

1. Sulphur
2. Nickel

3. Quartzite
4. Aluminium
5. Silicon

4.2.2 EDX of Bentonite clay

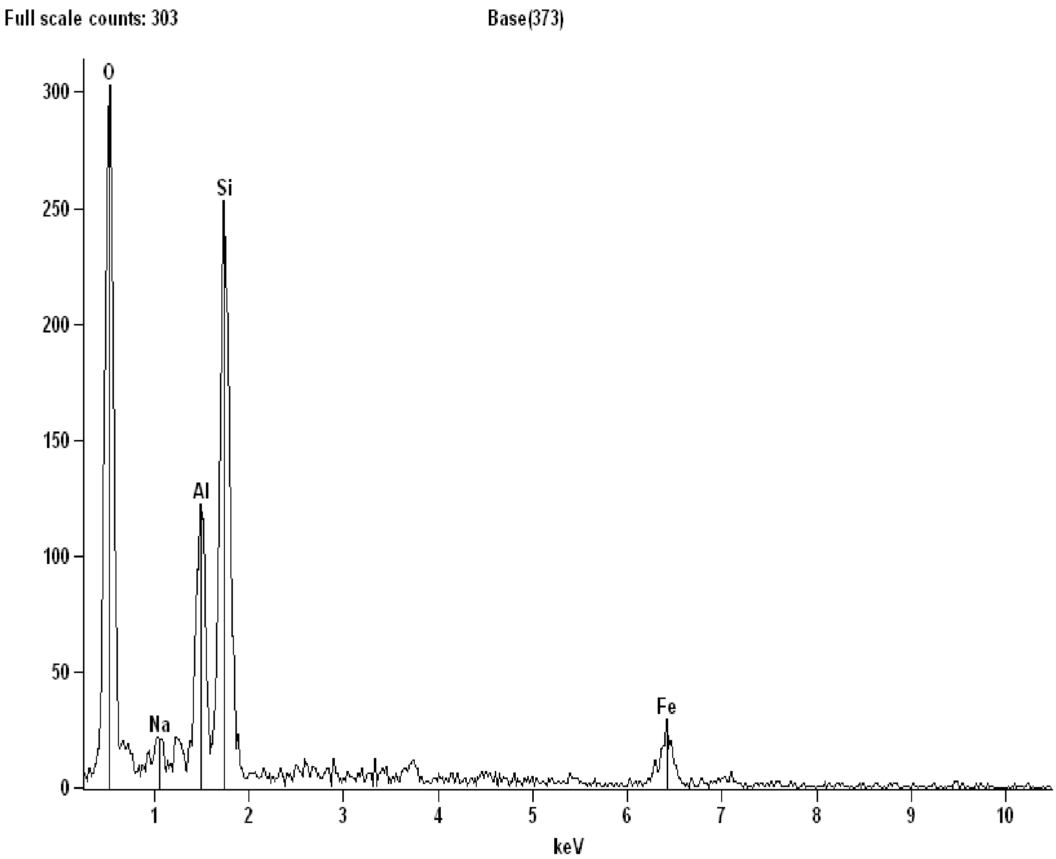


Figure 4.8 : EDX spectrum of bentonite clay

It can be observed that chemical composition of bentonite clay is

1. Sodium
2. Aluminium
3. Iron
4. Oxygen
5. Silicon

The spectrum achieved from the XRD shows that there are traces of sodium ions in bentonite samples which goes to show that the bentonite used in work is a type of sodium bentonite.

4.2.3 EDX of Kaolinite clay

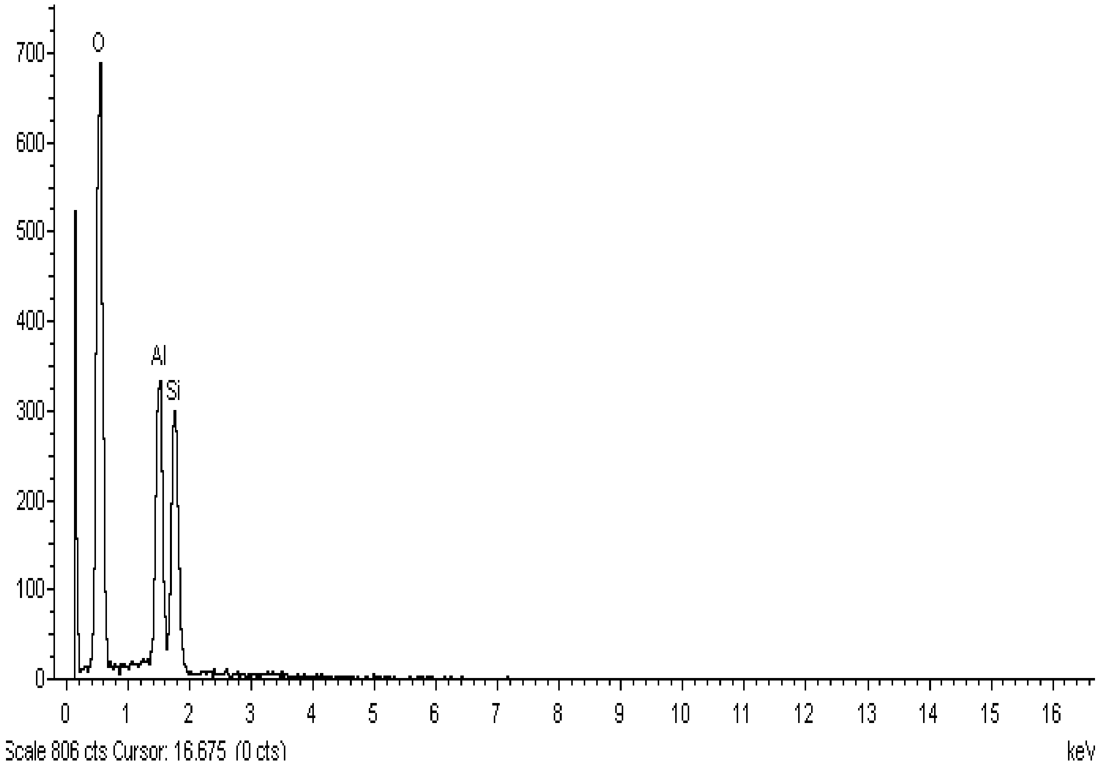


Figure 4.9 : EDX spectrum of kaolinite clay

It can be observed that chemical composition of kaolinite clay is

1. Oxygen
2. Calcium
3. Aluminium
4. Iron
5. Silicon

4.3 SIEVE ANALYSIS

Table 2: Grain size analysis of virgin sand

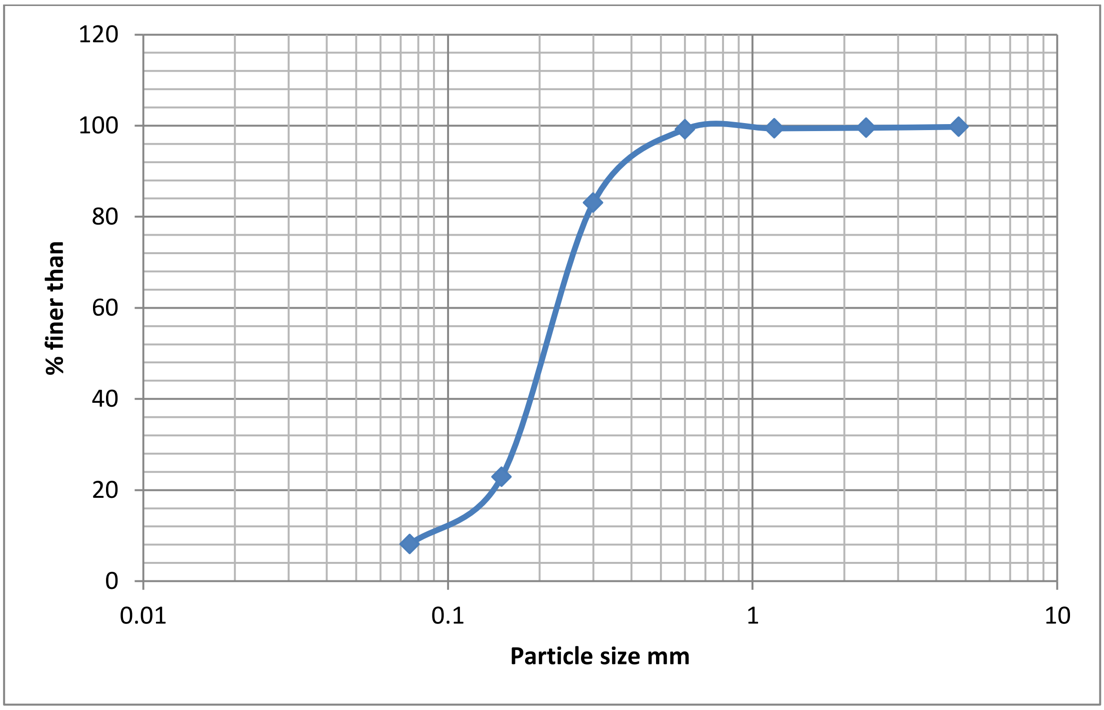


Figure 4.10 : Particle size distribution curve of Yamuna sand

Table 4.1: Analysis of particle size distribution curve

S No.	**PROPERTIES**	**VALUE**
1	D_{10}	0.0845
2	D_{30}	0.1677
3	D_{50}	0.2425
4	Coefficient of uniformity	01.37
5	Coefficient of curvature	02.87
6	Fine soil fraction(<75µ)	07.6%
7	Soil classification(USCS)	SP-SM

Hence soil is classified by USCS as poorly graded sand with silt as fines.

4.4 HYDROMETER ANALYSIS

4.2.1 Bentonite clay

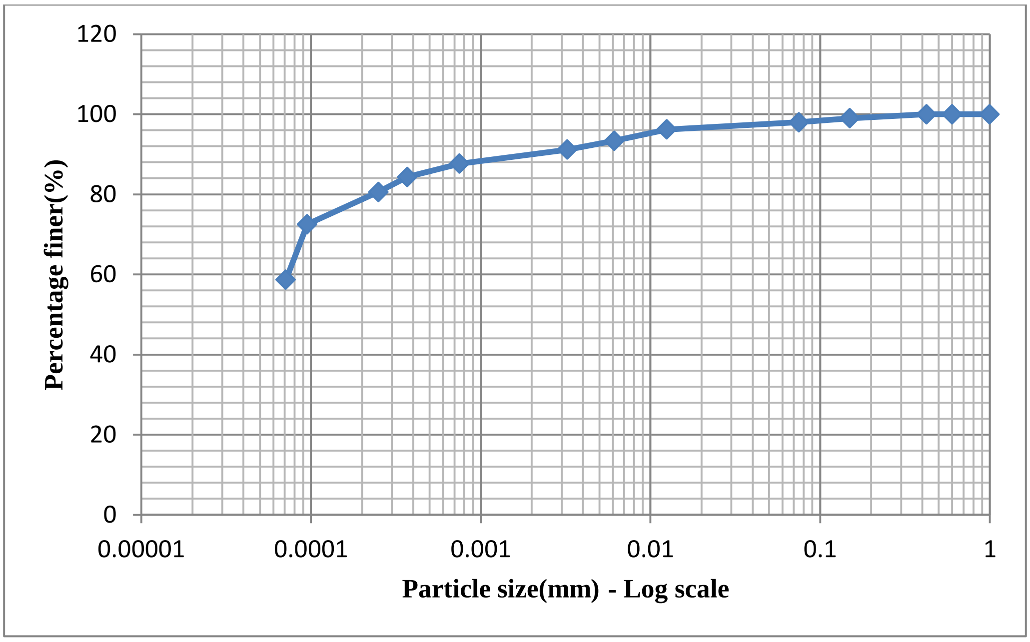


Figure 4.11 : Particle size distribution curve for bentonite clay

4.2.2 Kaolinite clay

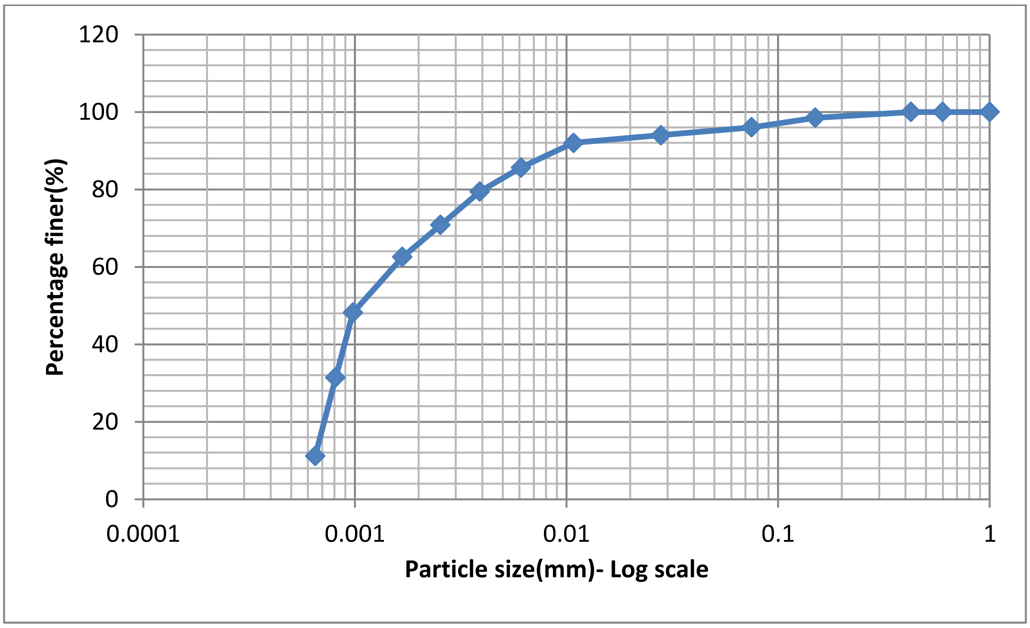


Figure 4.12 : Particle size distribution curve for kaolinite clay

4.5 SPECIFIC GRAVITY, LIQUID LIMIT AND PLASTIC LIMIT

Table 4.2: LL, PL and specific gravity value table

	Specific gravity	**Liquid limit(%)**	**Plastic limit(%)**
Yamuna sand	2.65	NP	NP
Bentonite clay	2.20	550	87.46
Kaolinite clay	2.62	71.60	41.67

4.6 COMPACTION CHARACTERISTICS

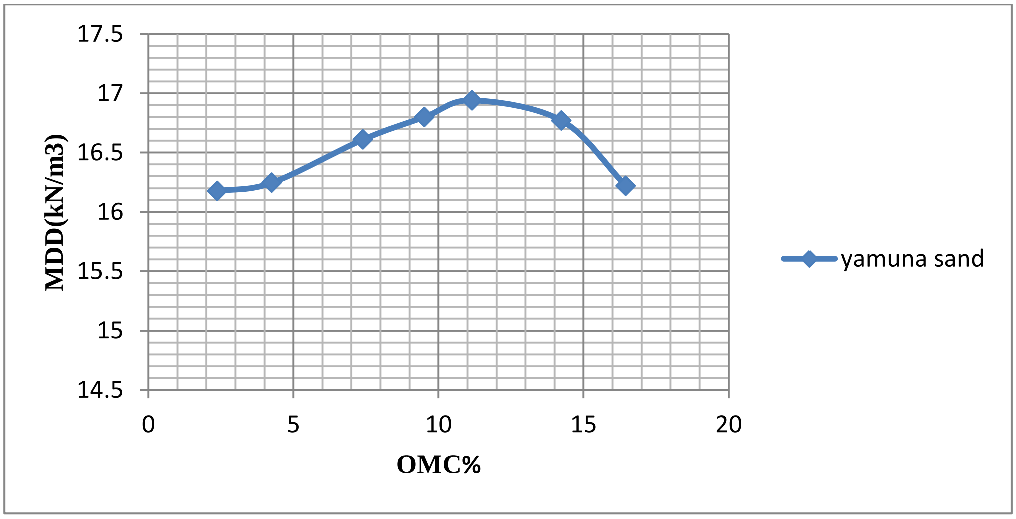


Figure 4.13: Compaction curve for virgin Yamuna sand

OMC = 11.2%, MDD = 16.94 kN/m3

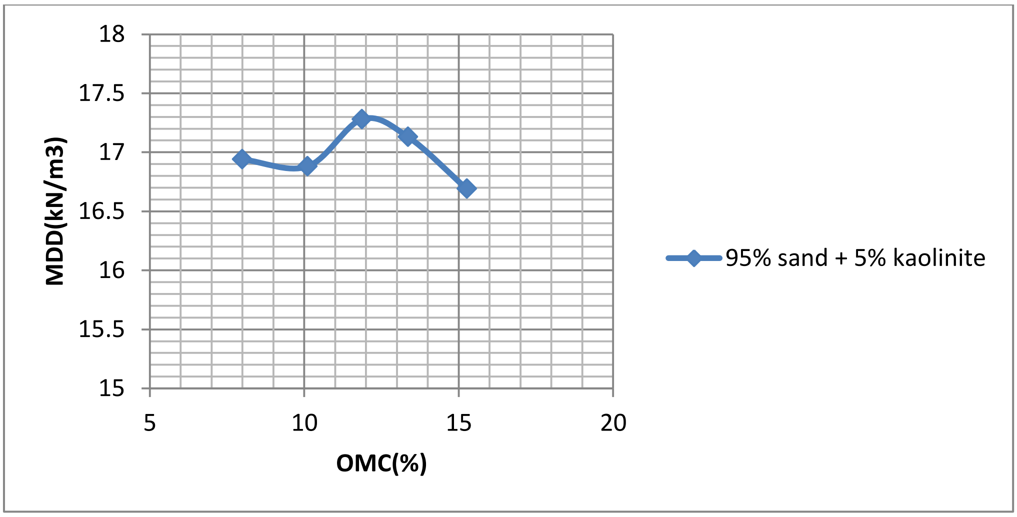


Figure 4.14: Compaction curve SMK5

OMC = 11.87%, MDD = 17.28 kN/m3

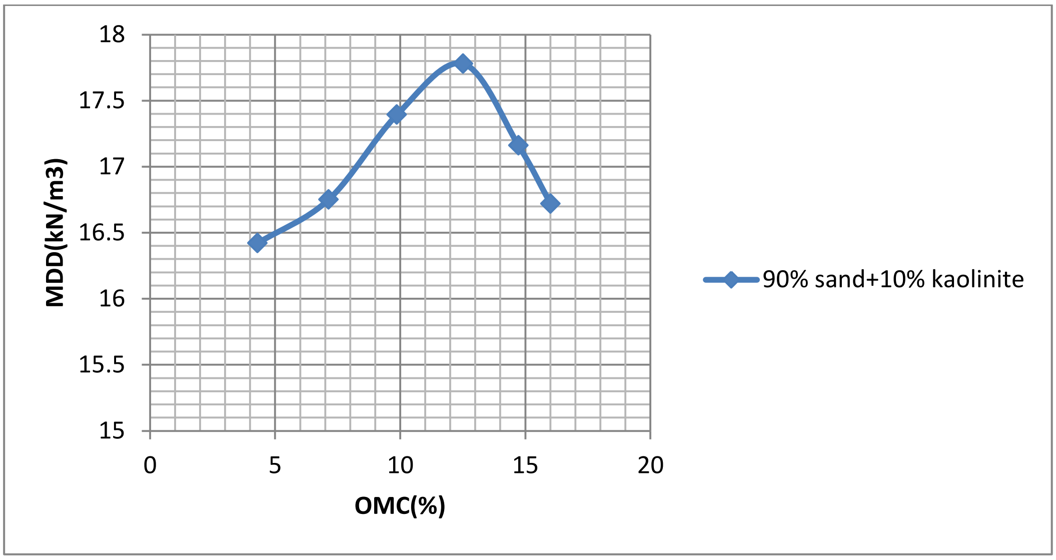


Figure 4.15: Compaction curve for SMK10

OMC = 12.51%, MDD = 17.78kN/m3

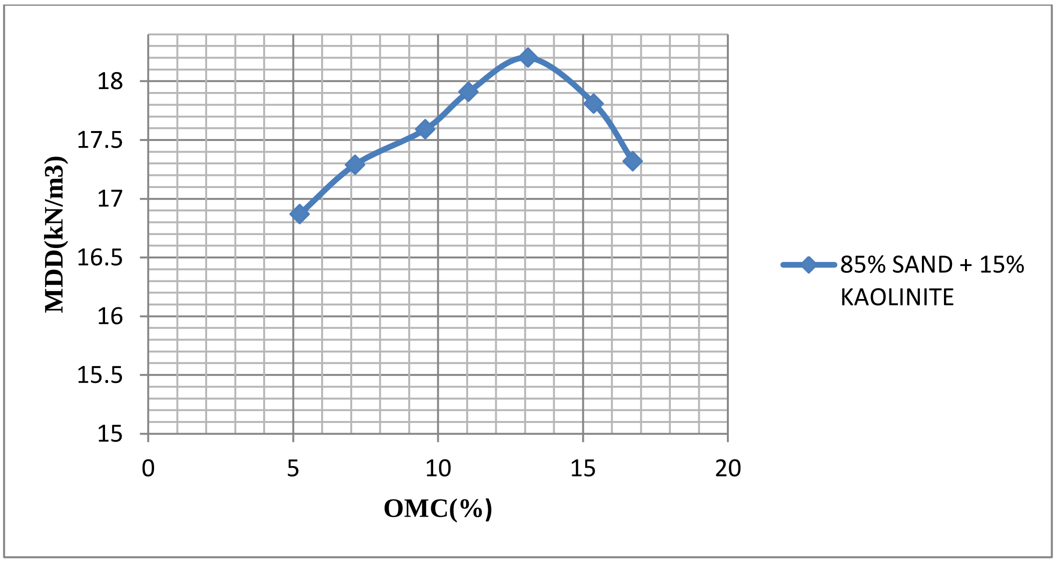


Figure 4.16 : Compaction curve for SMK15

OMC = 13.11%, MDD = 18.20 kN/m3

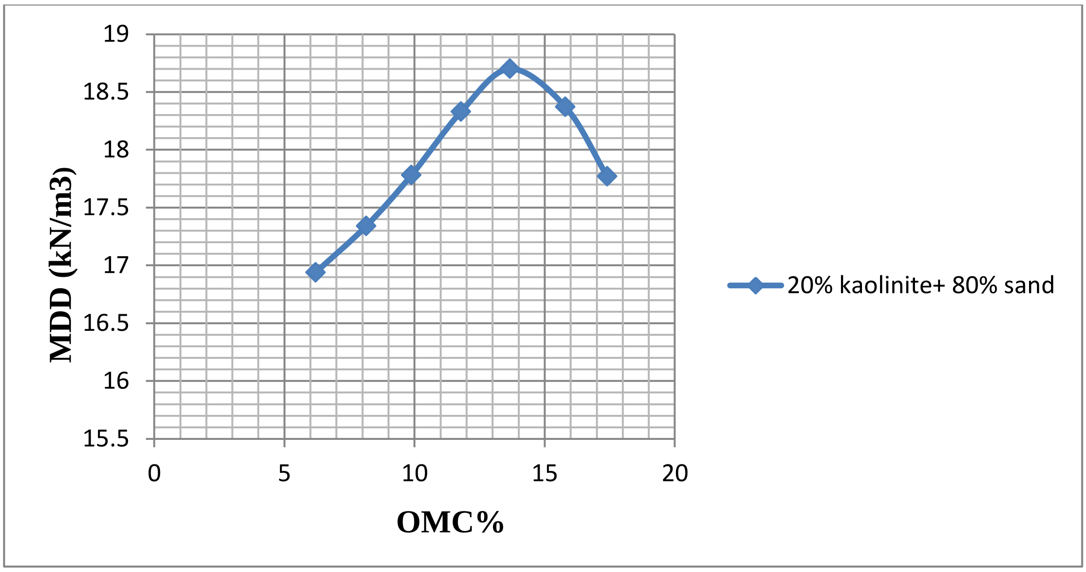


Figure 4.17 : Compaction curve for SMK20

OMC = 13.67%, MDD = 18.70 kN/m3

Table 4.3: OMC and MDD variation for various sand-kaolinite mixes

	OMC(%)	MDD(kN/m3)
Yamuna sand	11.20	16.94
SMK5	11.87	17.28
SMK10	12.51	17.78
SMK15	13.11	18.20
SMK20	13.67	18.70

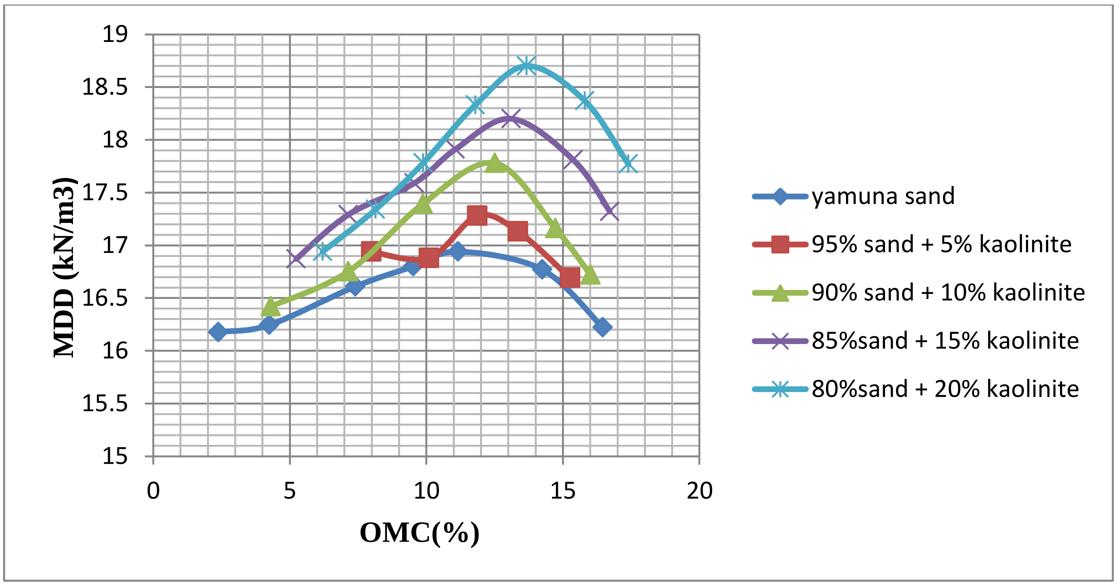


Figure 4.18: Variation of MDD and OMC for varying sand-kaolinite mixes

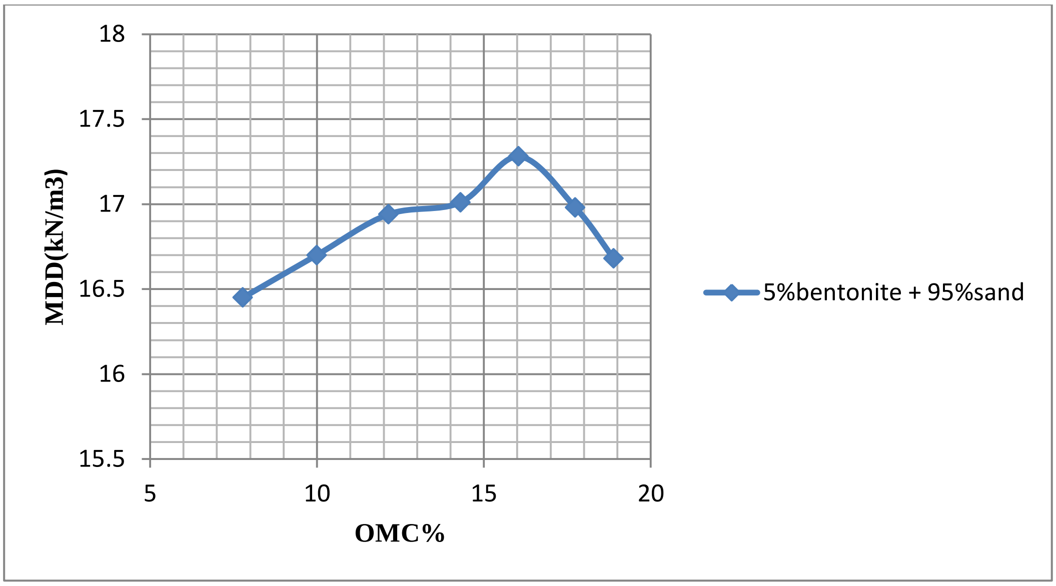


Figure 4.19 : Compaction curve for SMB5

OMC=16.04%, MDD=17.28kN/m3

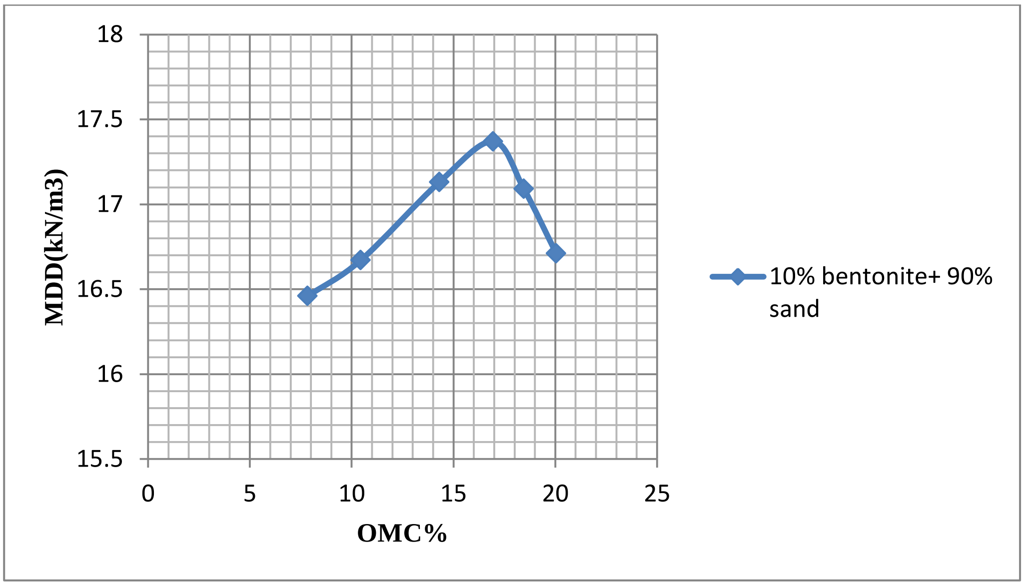


Figure 4.20 : Compaction curve for SMB10

OMC=16.95, MDD=17.37 kN/m3

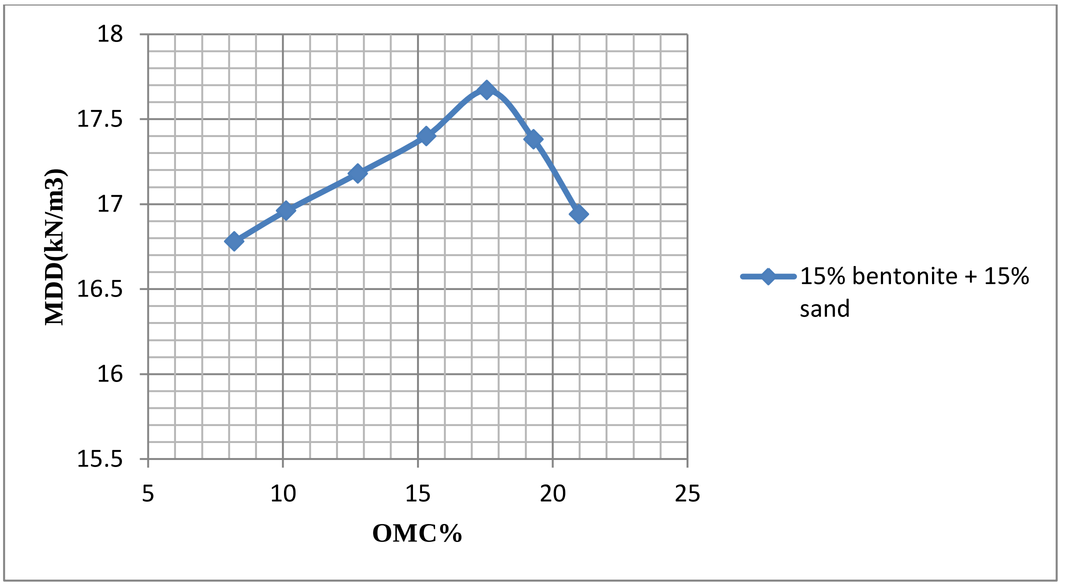


Figure 4.21: Compaction curve for SMB15

OMC=17.56%, MDD=17.66kN/m3

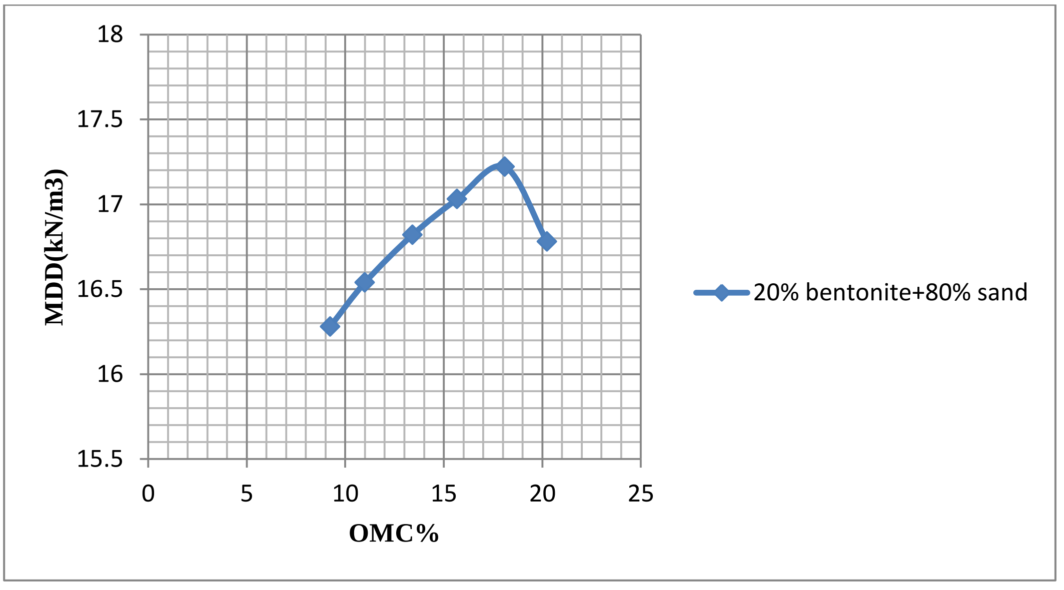


Figure 4.22 : Compaction curve for SMB20

OMC=18.10%, MDD=17.22kN/m3

Table 4.4: OMC and MDD variation for various sand-bentonite mixes

	OMC(%)	MDD(kN/m3)
Yamuna sand	11.20	16.94
SMB5	16.05	17.24
SMB10	16.95	17.38
SMB15	17.56	17.67
SMB20	18.10	17.22

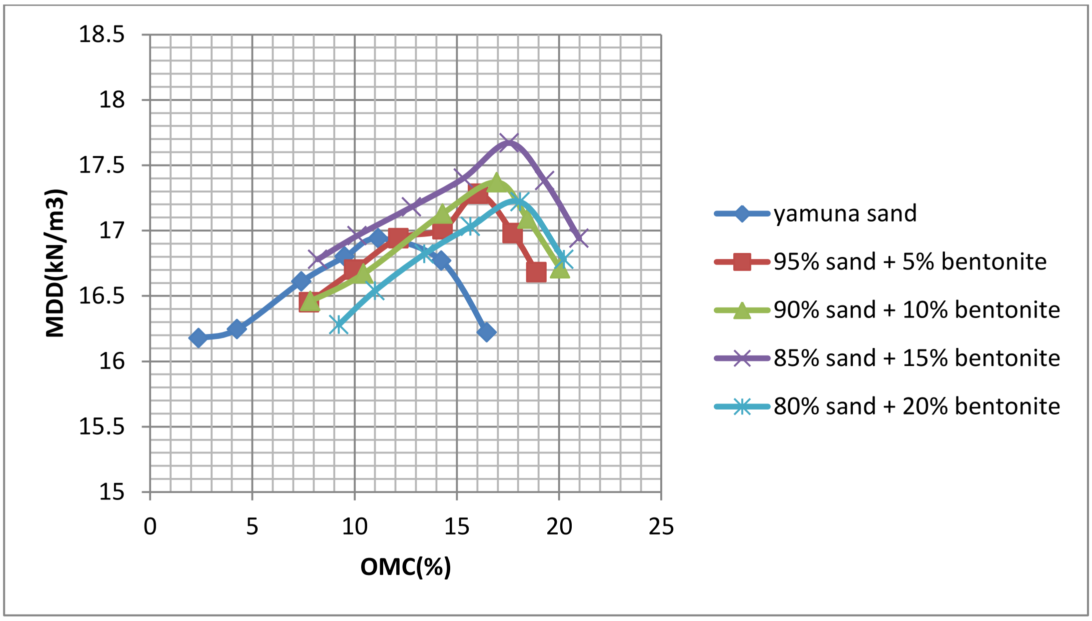


Figure 4.23 : Compaction curve for various sand-bentonite mixes

4.7 DIRECT SHEAR TEST

Direct Shear Test on Yamuna sand

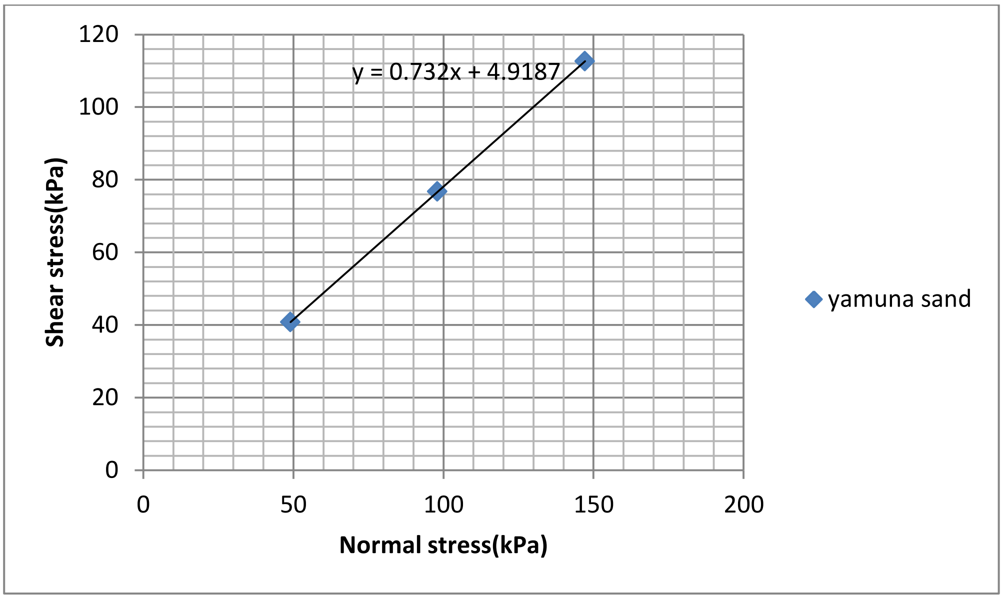


Figure 4.24 : Normal stress vs shear stress of virgin Yamuna sand

c= 4.91, ϕ=36.3 degrees

Direct shear test on sand-bentonite mixes

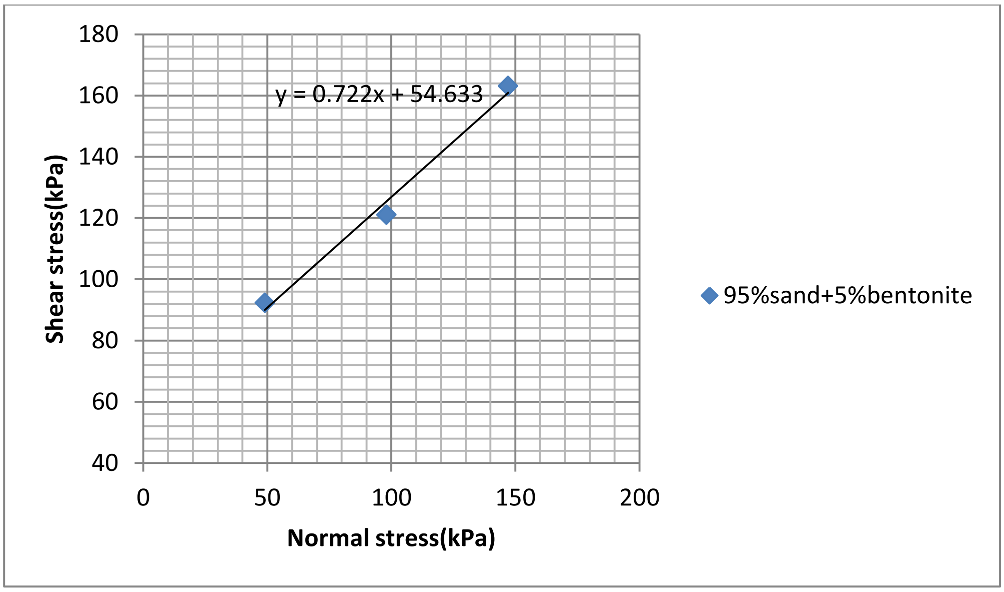


Figure 4.25 : Normal stress vs shear stress of SMB5

c= 54.63kPa, ϕ=35.62 degrees

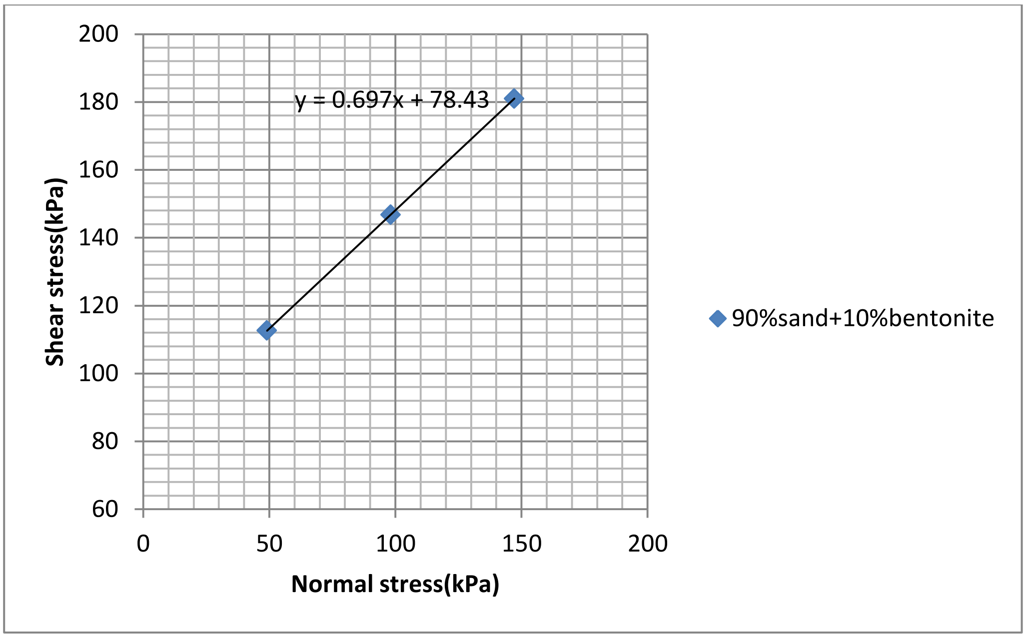


Figure 4.26 : Normal stress vs Shear stress for SMB10

c=78.43kPa, ϕ=34.91 degrees

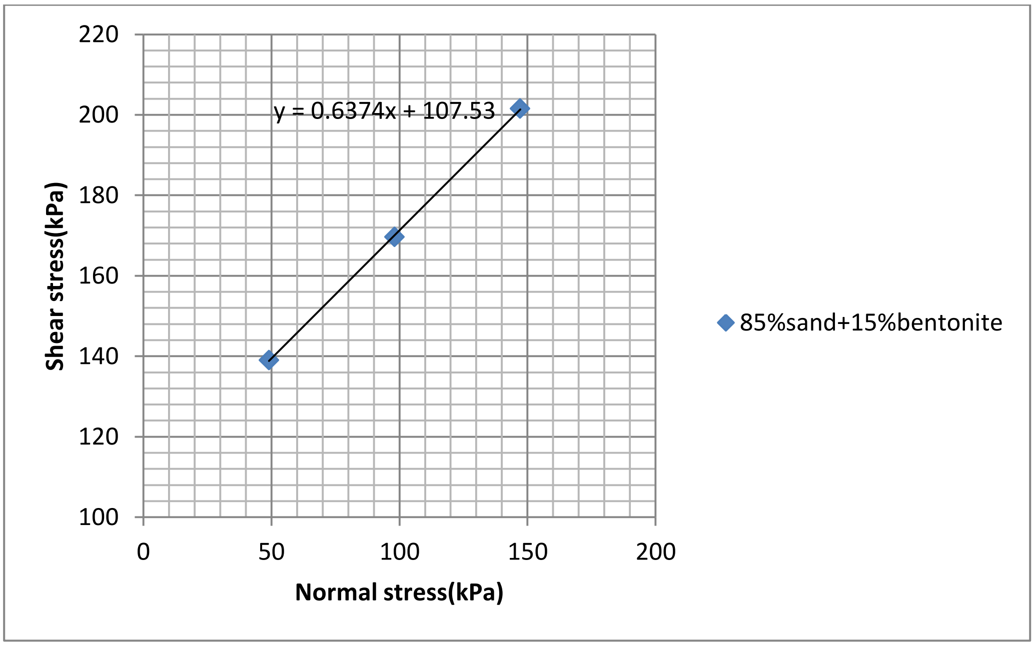


Figure 4.27 : Normal stress vs shear stress of SMB15

c=107.53kPa, ϕ=32.49 degrees

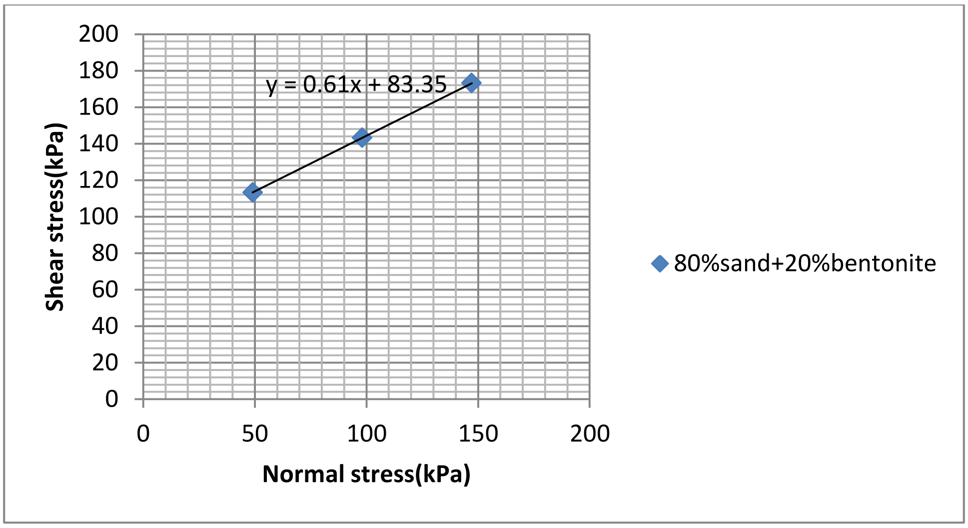


Figure 4.28 : Normal stress vs shear stress of SMB20

c=83.35, ϕ=31.38 degrees

Table 4.5: c-ϕ variation for sand-bentonite mixes

	Cohesion(kPa)	ϕ(degrees)
Virgin Yamuna sand	4.91	36.31
SMB5	54.63	35.62
SMB10	78.43	34.91
SMB15	107.53	32.49
SMB20	83.35	31.38

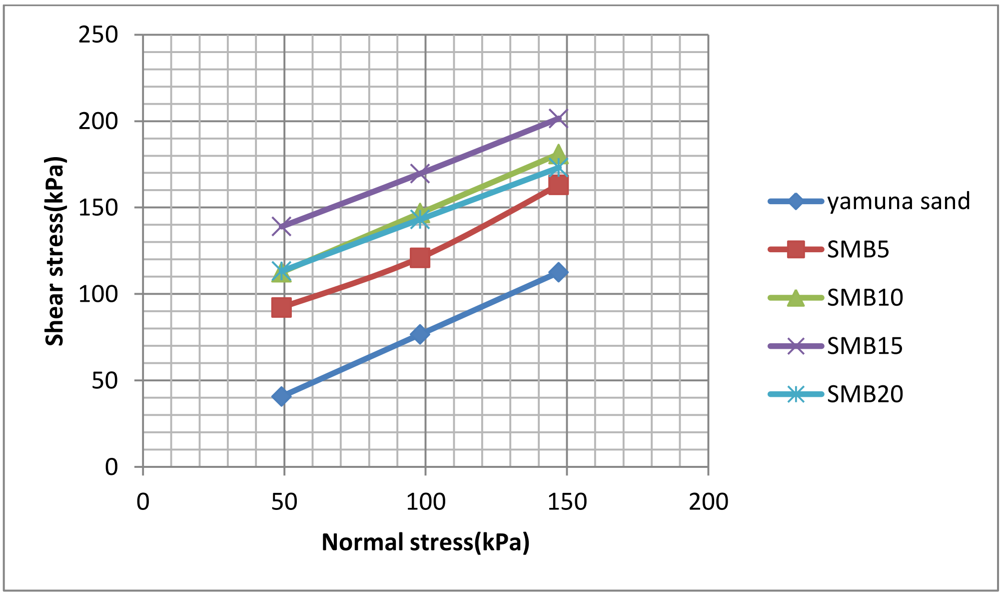


Figure 4.29 : Normal stress vs shear stress variation of sand-bentonite mixes

Direct Shear Test on sand-kaolinite mixes

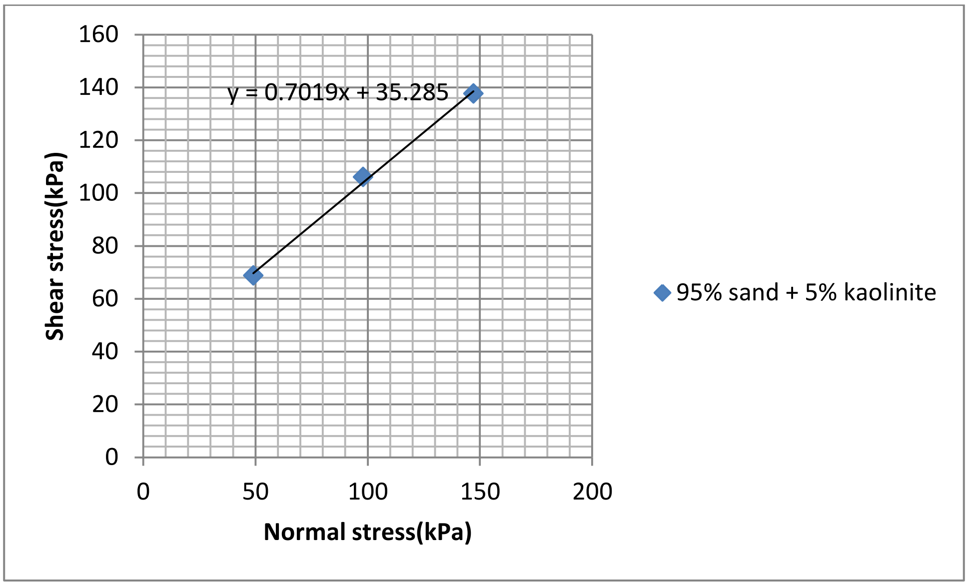


Figure 4.30 : Normal stress vs shear stress of SMK5

c=35.28kPa, ϕ=35.06 degrees

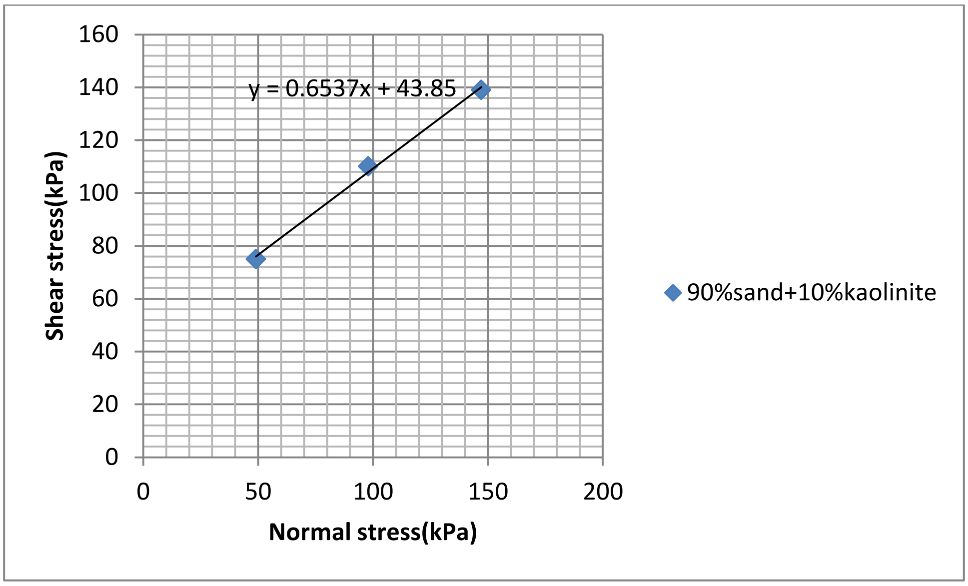


Figure 4.31 : Normal stress vs shear stress of SMK10

c=43.85kPa, ϕ=33.17 degrees

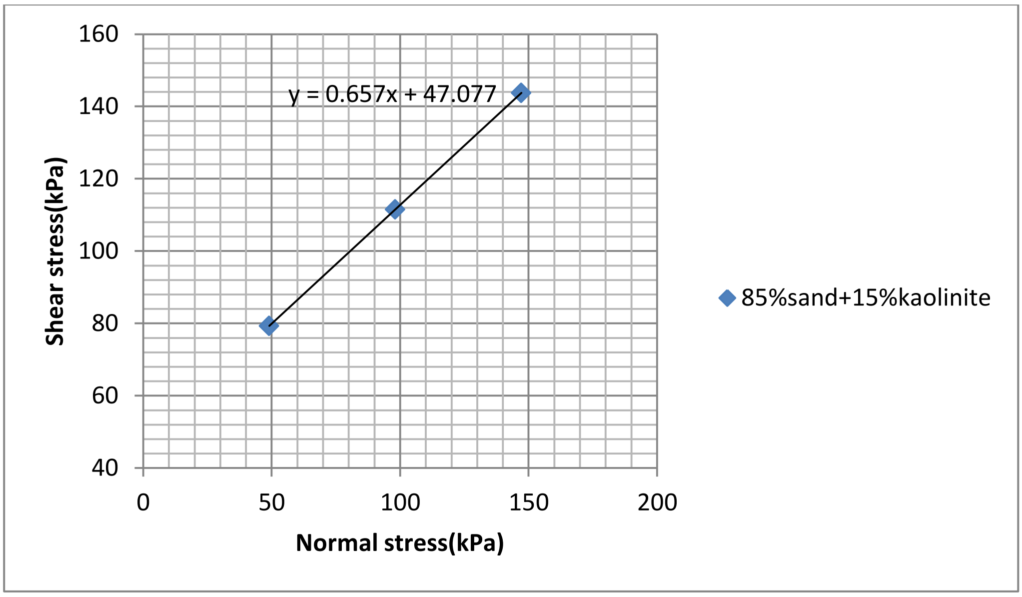


Figure 4.32 : Normal vs shear stress of SMK15

c=47.07, ϕ=32.90 degrees

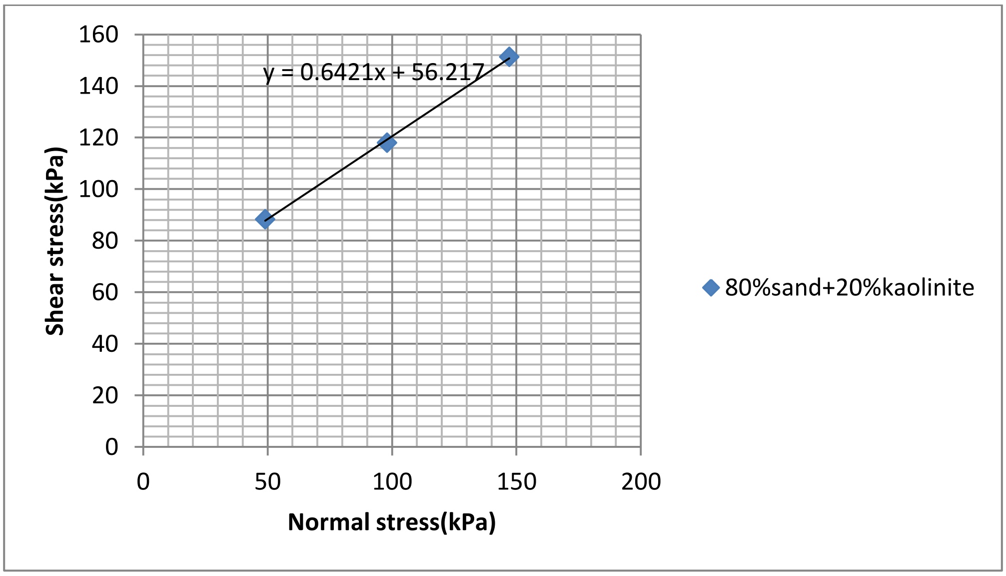


Figure 4.33: Normal vs shear stress of SMK20

c=56.22, ϕ=32.62 degrees

Table 4.6 : c-ϕ variation for various sand-kaolinite mixes

	Cohesion(kPa)	ϕ(degrees)
Virgin Yamuna sand	4.91	36.31
SMK5	35.28	35.06
SMK10	43.85	34.17
SMK15	47.07	32.91
SMK20	56.22	32.62

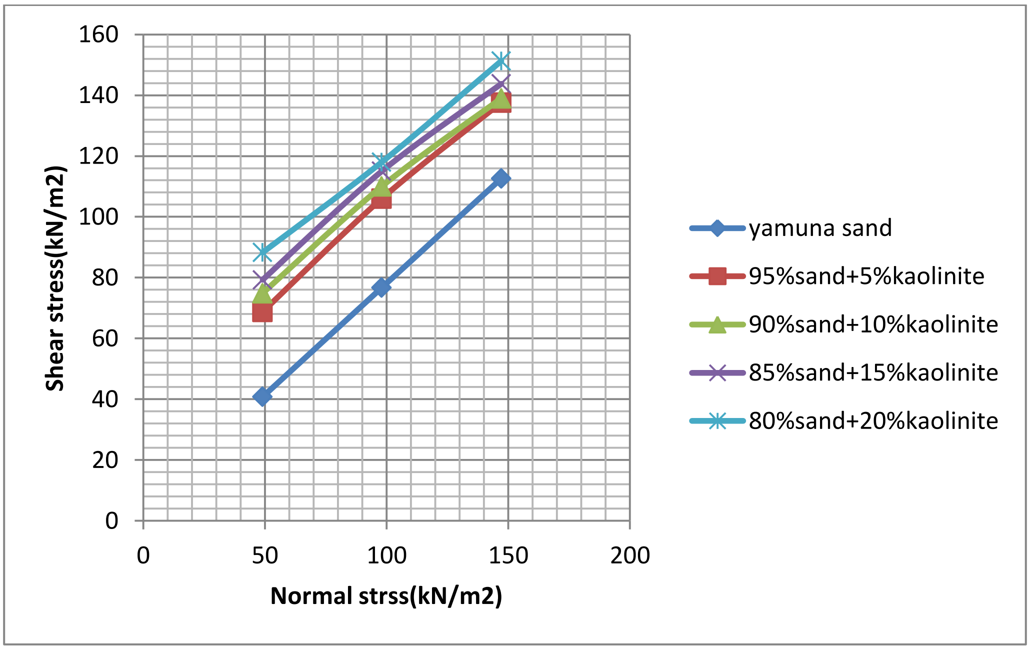


Figure 4.34 : Normal stress vs shear stress variation for various sand-kaolinite mixes

4.8 UNCONSOLIDATED UNDRAINED TRIAXIAL TEST

<u>Triaxial test on Yamuna sand</u>

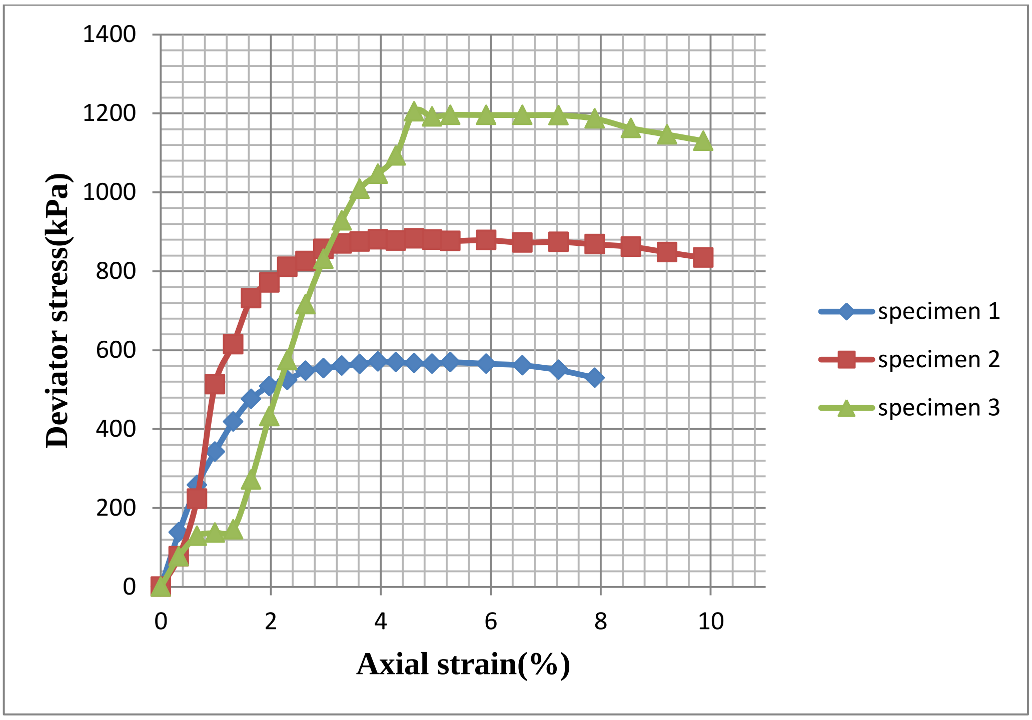
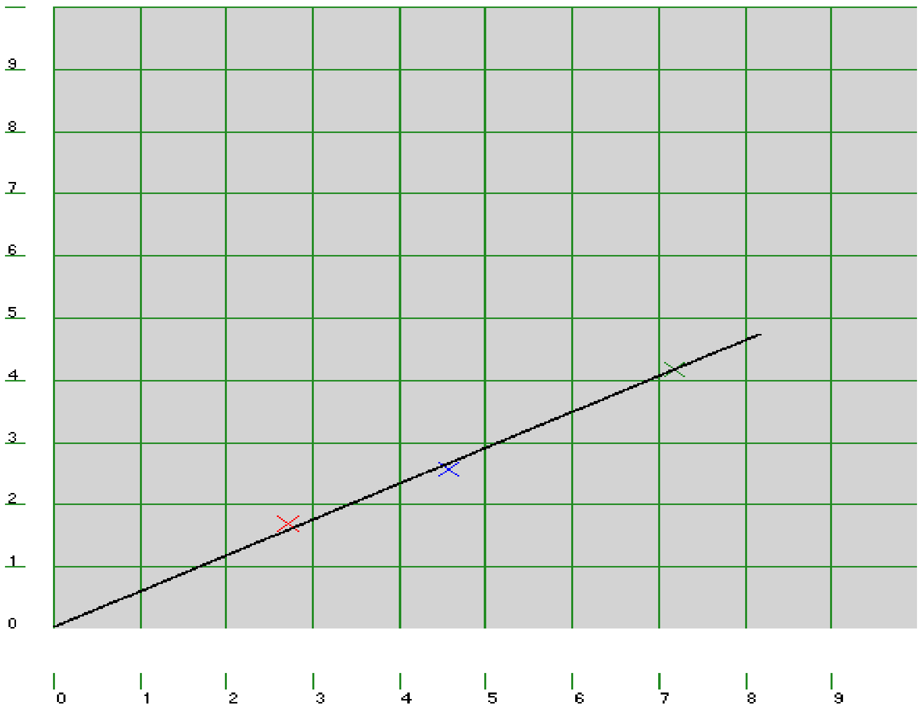


Figure 4.35: Deviatric Stress vs Axial Strain curve for Yamuna sand



Mean stress vs Shear stress [a=0.04kg/sq.cm ,alpha=30.0deg]
Figure 4.36 : p-q plot for Yamuna sand

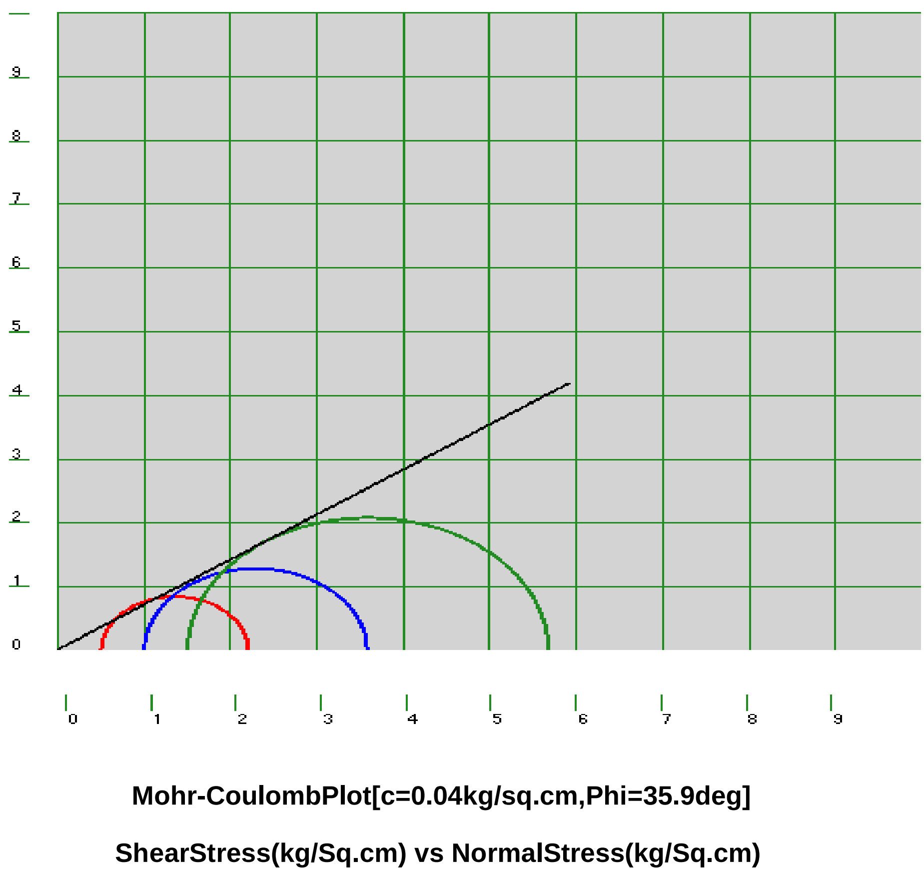


Figure 4.37 : Mohr coulomb plot for Yamuna sand

Triaxial test on sand-bentonite mixes

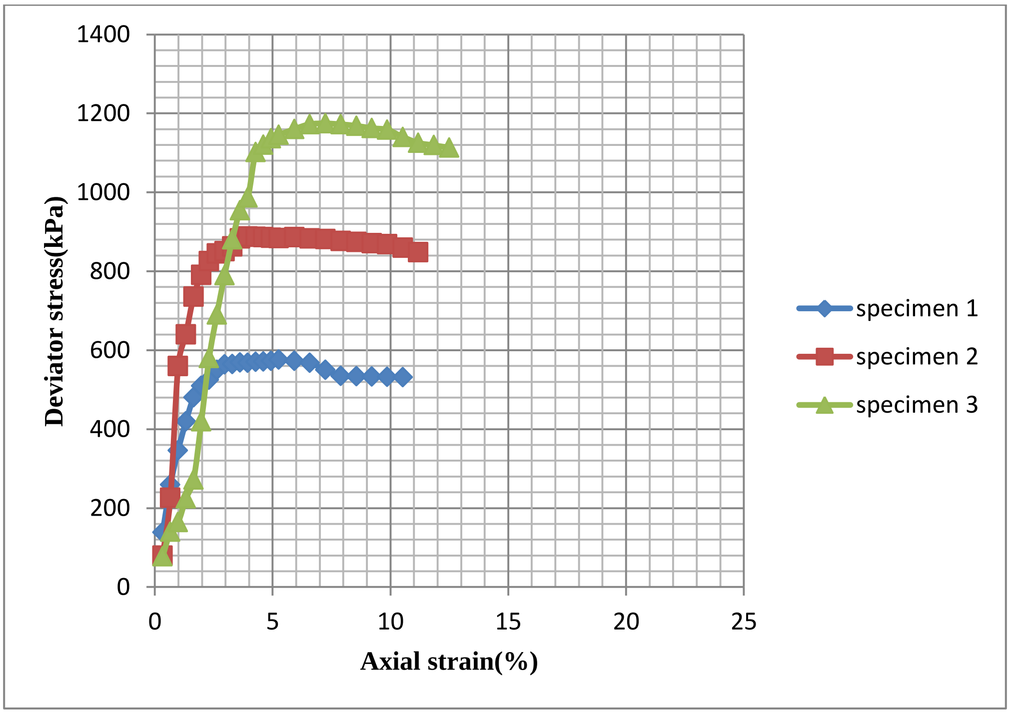


Figure 4.38: Deviatric Stress vs Axial Strain curve for SMB5

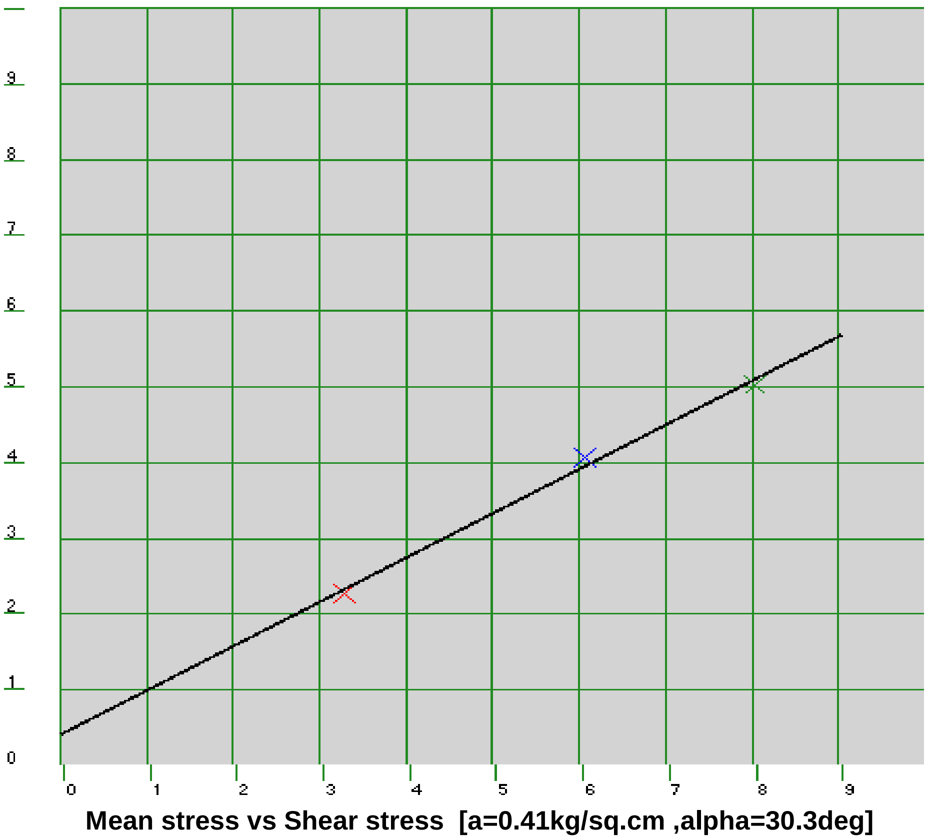


Figure 4.39 : p-q plot for SMB5

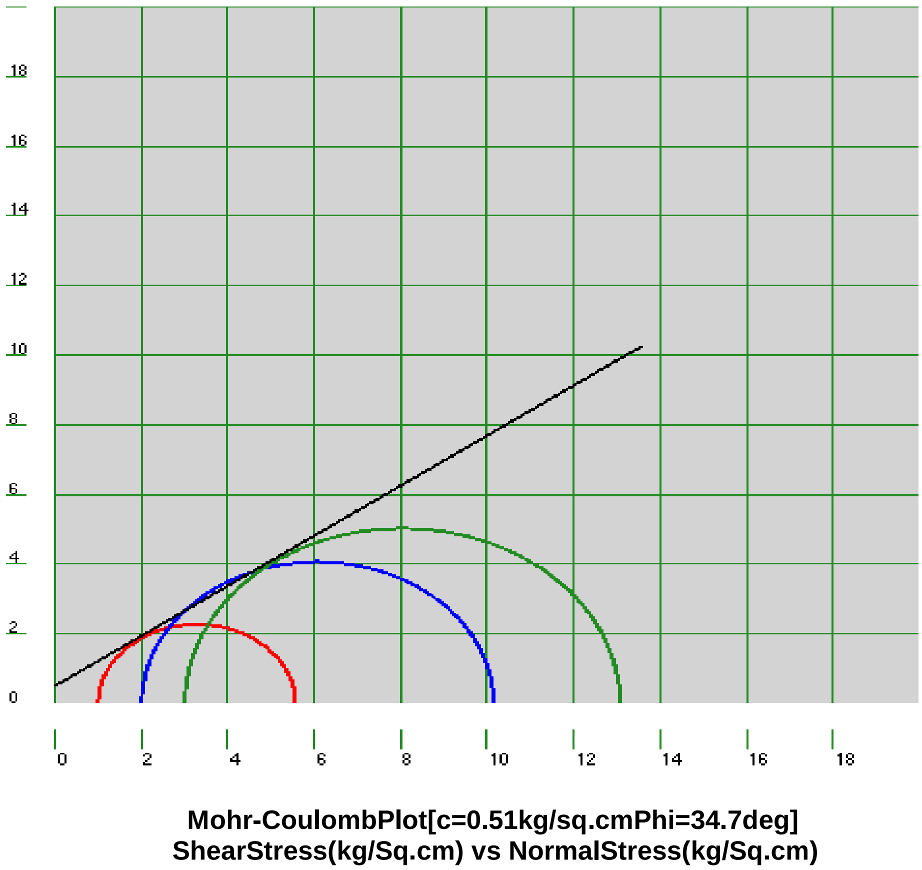


Figure 4.40: Mohr Coulomb plot for SMB5

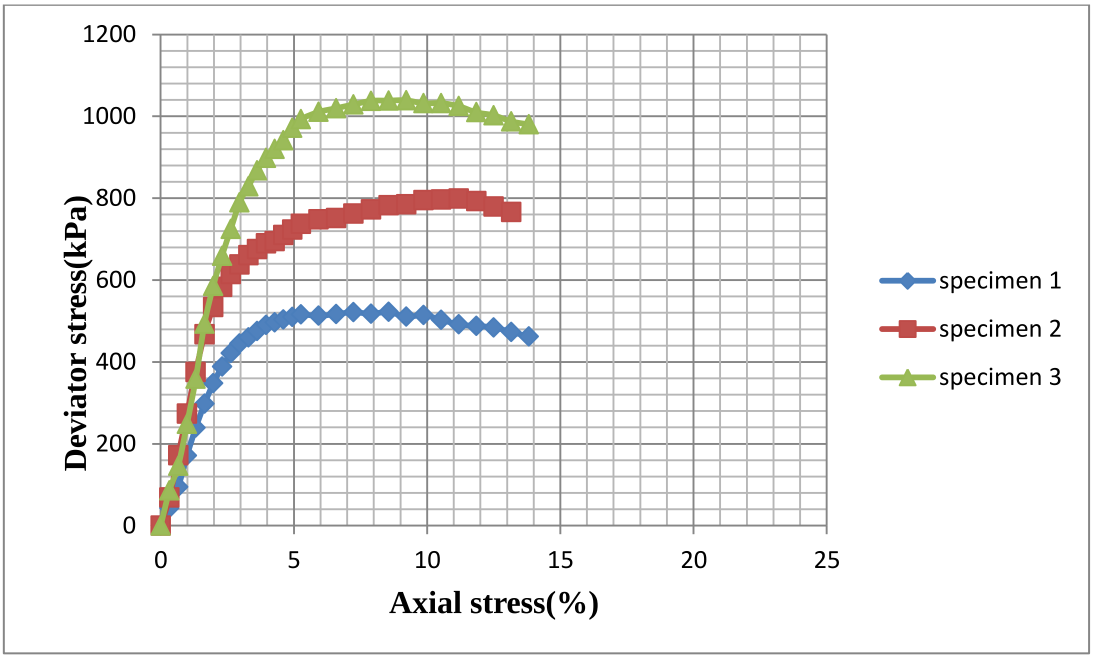


Figure 4.41 : Deviator stress vs Axial strain curve for SMB10

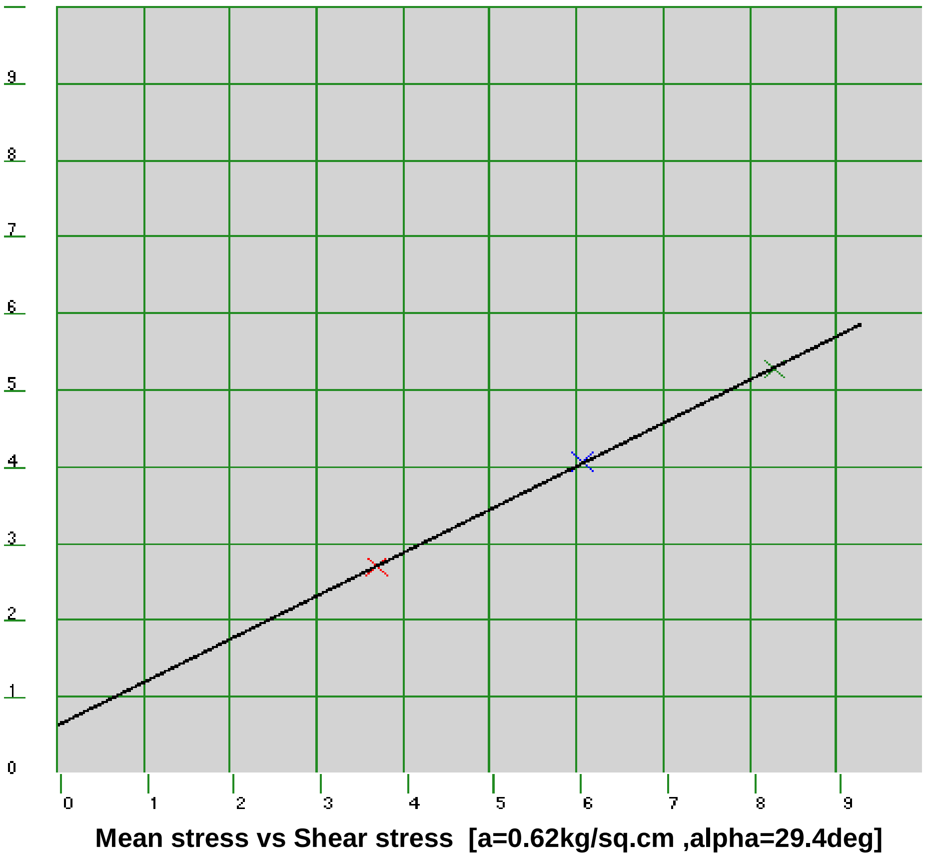
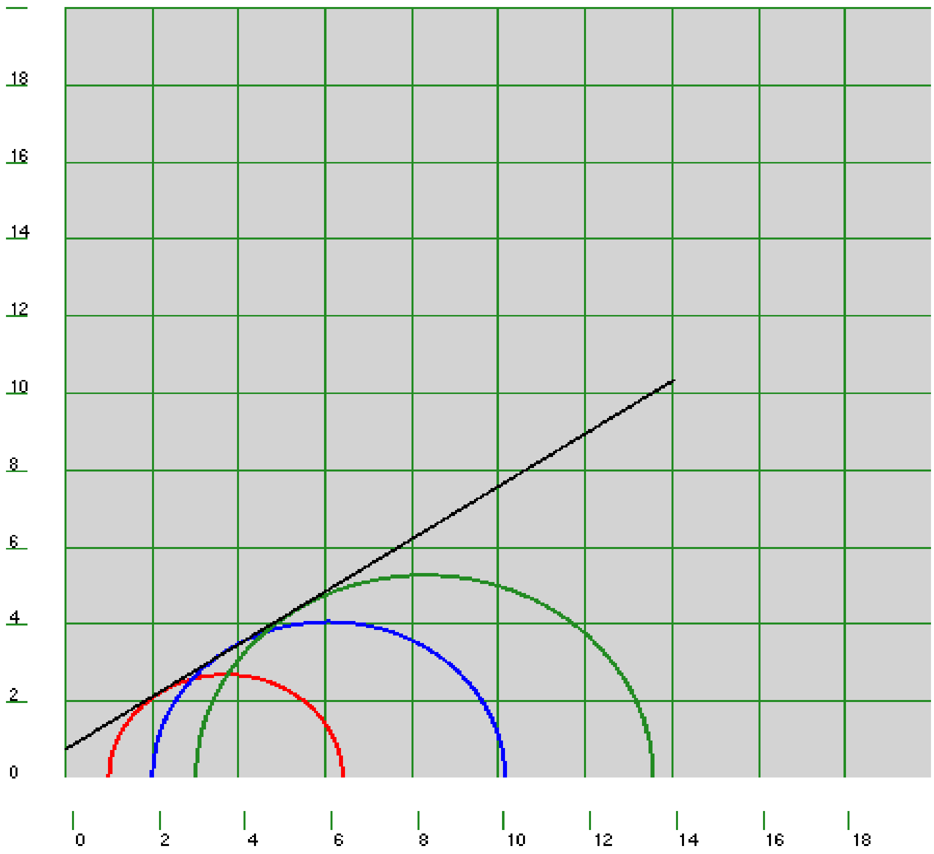


Figure 4.42 : p-q plot for SMB10



Mohr-Coulomb Plot [c=0.76kg/sq.cm Phi=34.1deg]
ShearStress(kg/Sq.cm) vs NormalStress(kg/Sq.cm)

Figure 4.43 : Mohr-Coulumb plot for SMB10

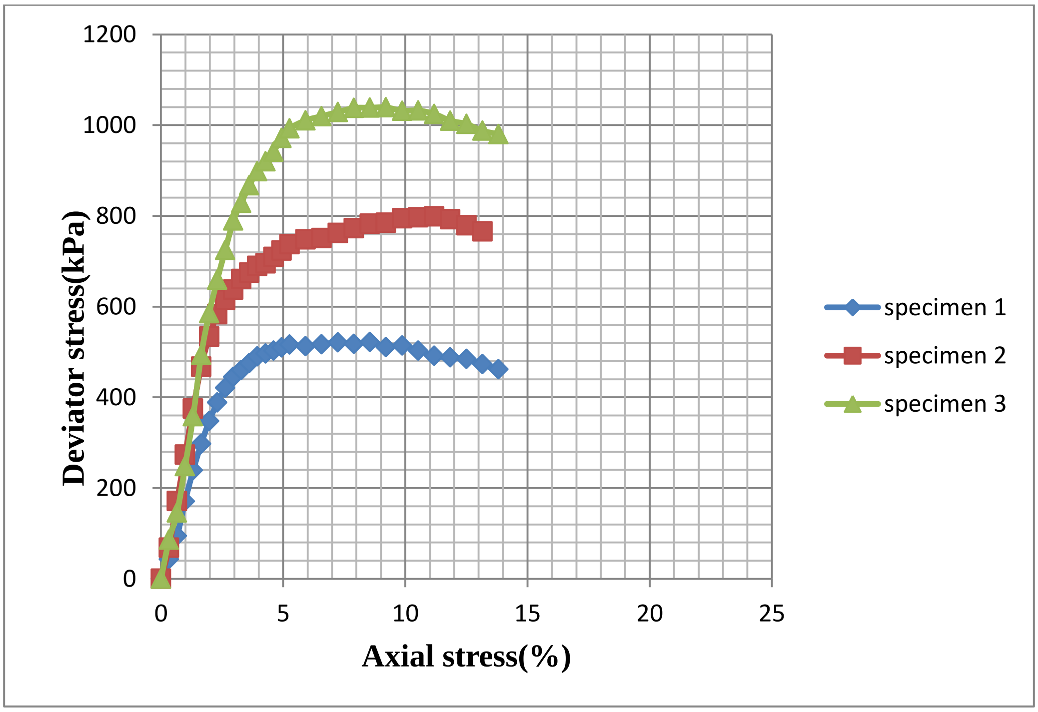
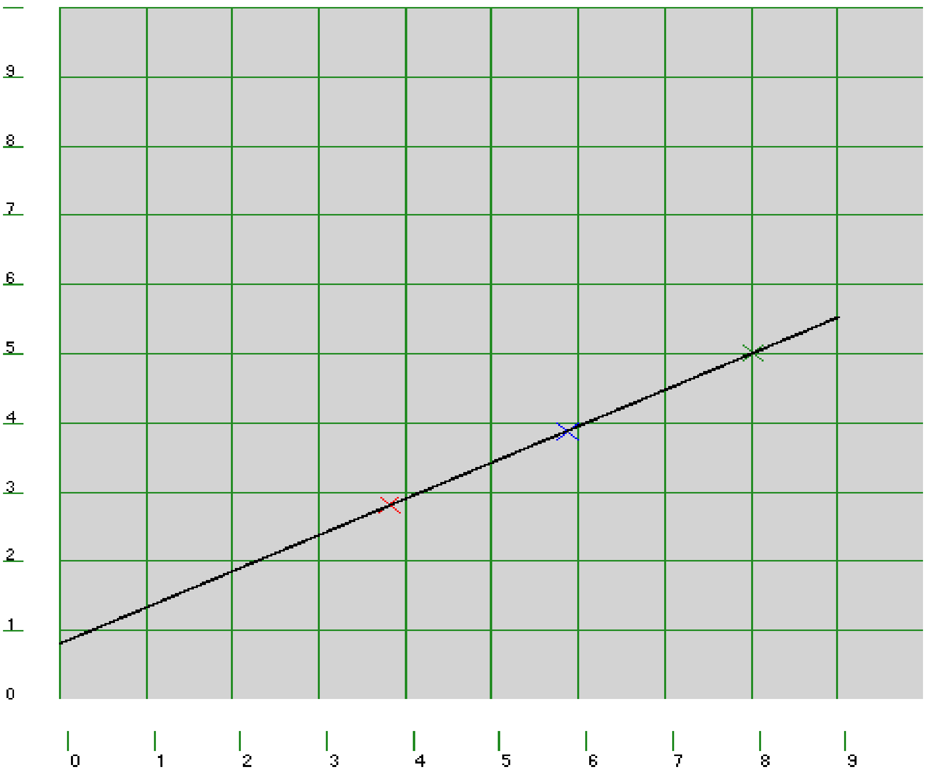
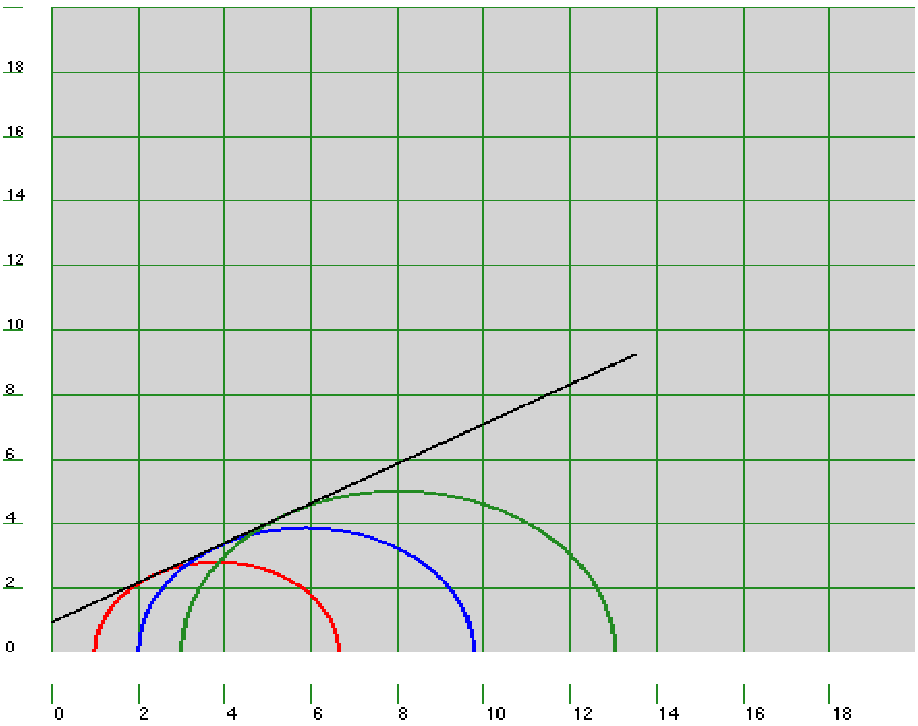


Figure 4.44 : Deviatric stress vs Axial strain curve



Mean stress vs Shear stress [a=0.81kg/sq.cm ,alpha=27.6deg]

Figure 4.45: p-q plot for SMB15



Mohr-CoulombPlot,[c=0.95kg/sq.cm,Phi=31.6deg]
ShearStress(kg/Sq.cm) vs NormalStress(kg/Sq.cm)

Figure 4.46 : Mohr- Coulumb plot for SMB15

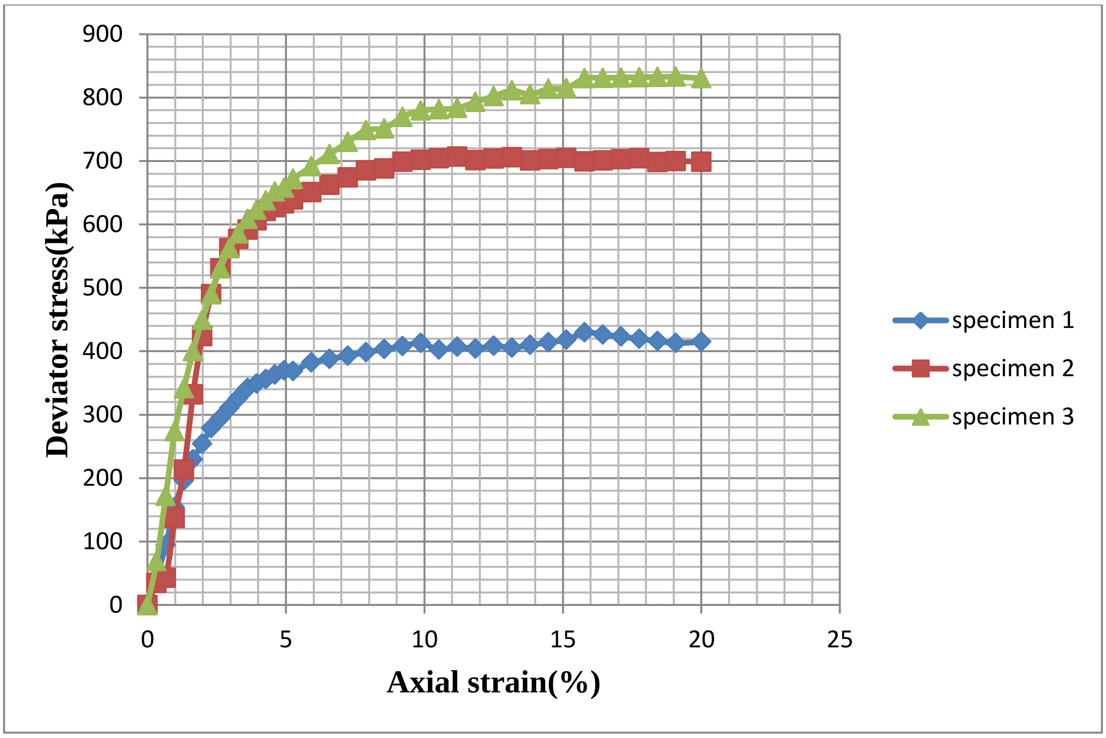
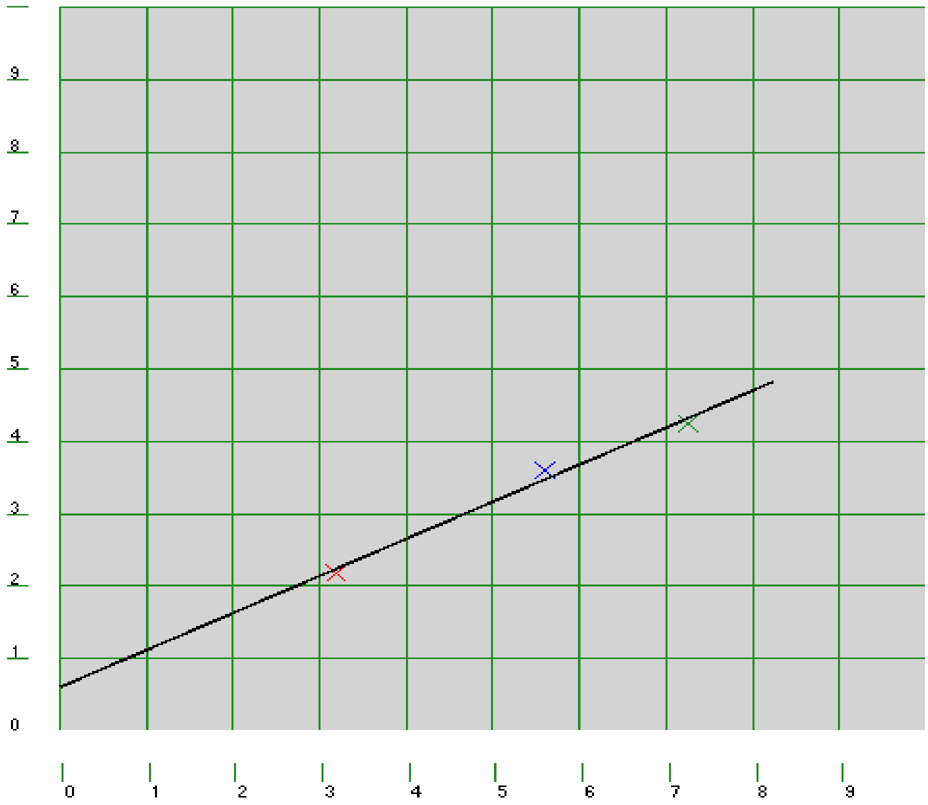


Figure 4.47 : Deviator stress vs Axial strain curve for SMB20



Mean stress vs Shear stress [a=0.61kg/sq.cm ,alpha=27.1deg]

Figure 4.48 : p-q plot for SMB20

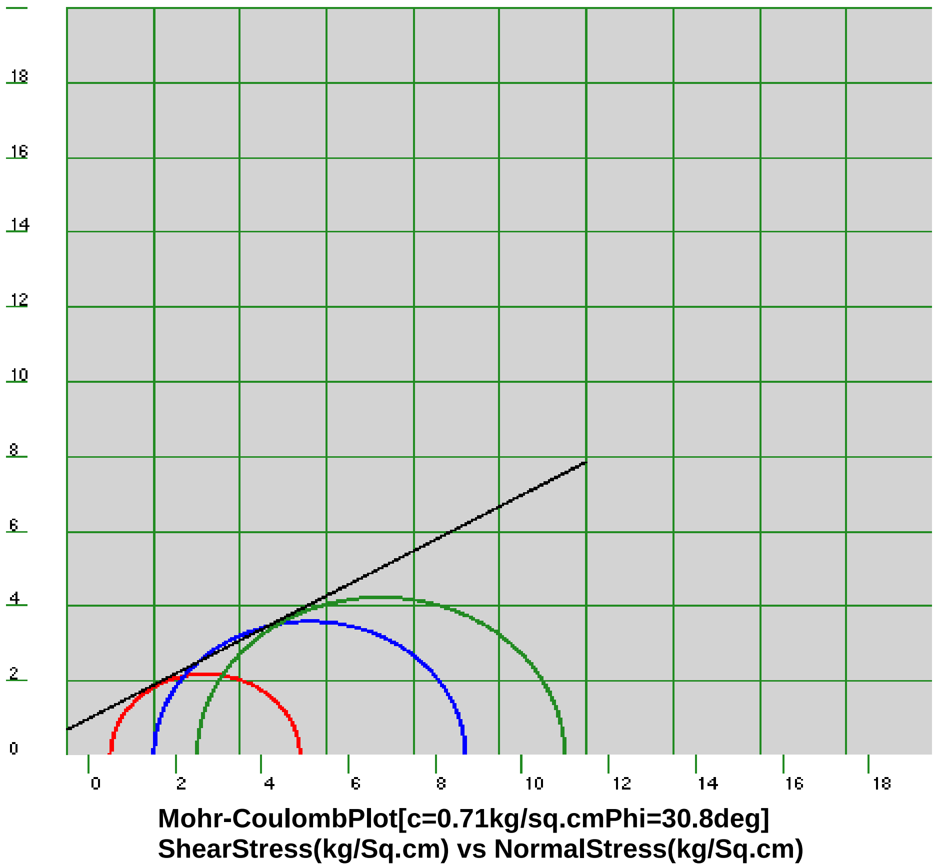


Figure 4.49: Mohr-Coulumb Plot for SMB20

Table 4.7 : Variation of C-ϕ values for various sand-bentonite mixes

	Cohesion(kPa)	ϕ(degrees)
Virgin Yamuna sand	3.92	35.90
SMB5	50.01	34.70
SMB10	74.53	34.10
SMB15	93.15	31.60
SMB20	69.62	30.80

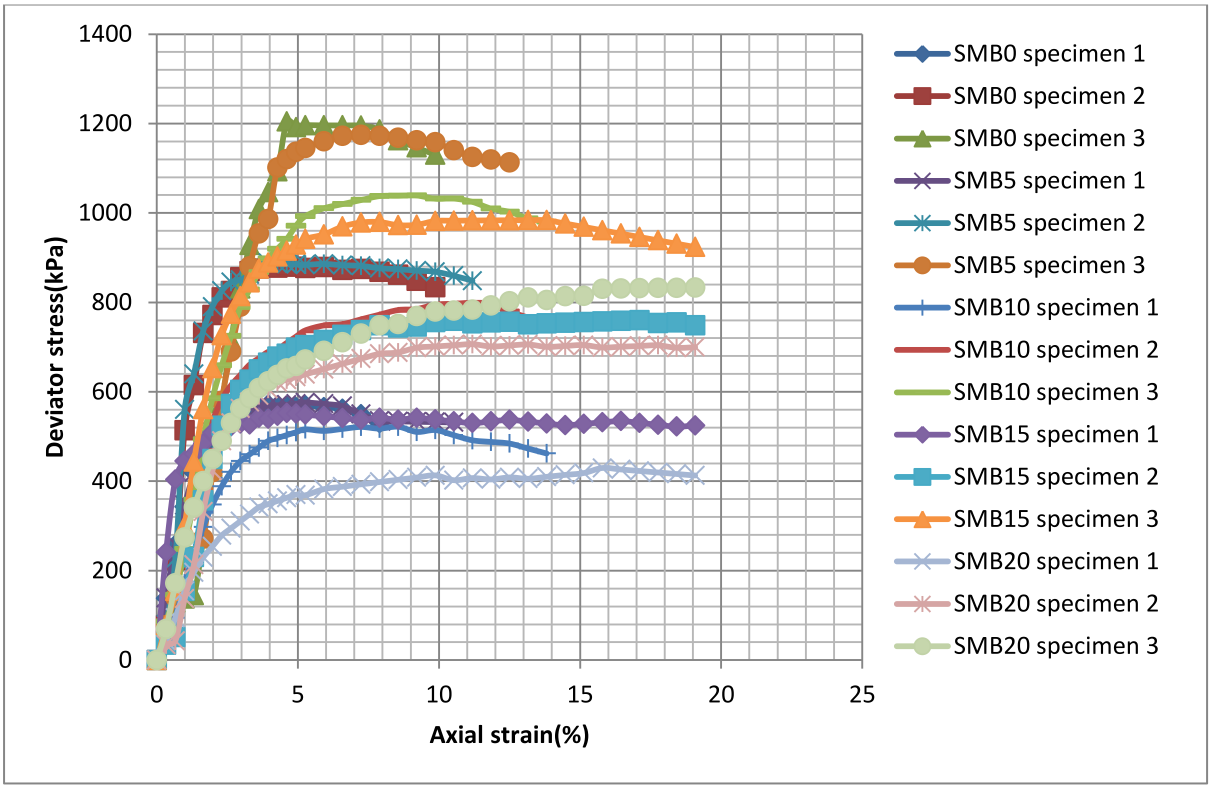


Figure 4.50 : Deviator stress vs Axial strain curve variation for various sand-bentonite mixes

<u>Triaxial test on sand-kaolinite mixes</u>

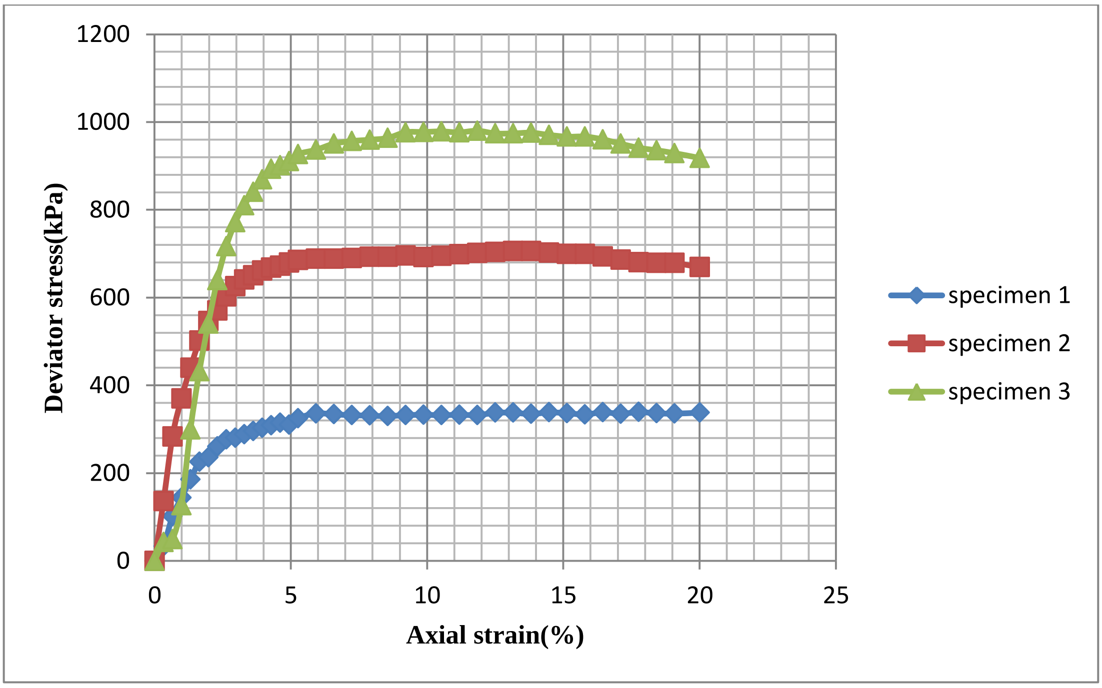


Figure 4.51: Deviatric stress vs Axial strain curve for SMK5

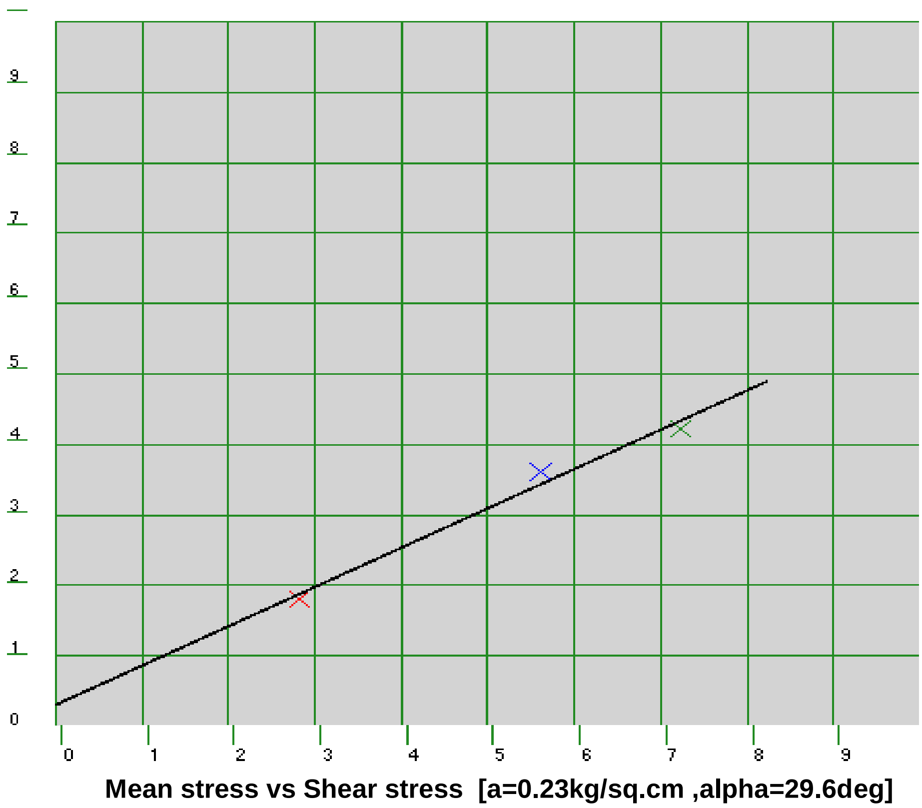


Figure 4.52 : p-q plot for SMK5

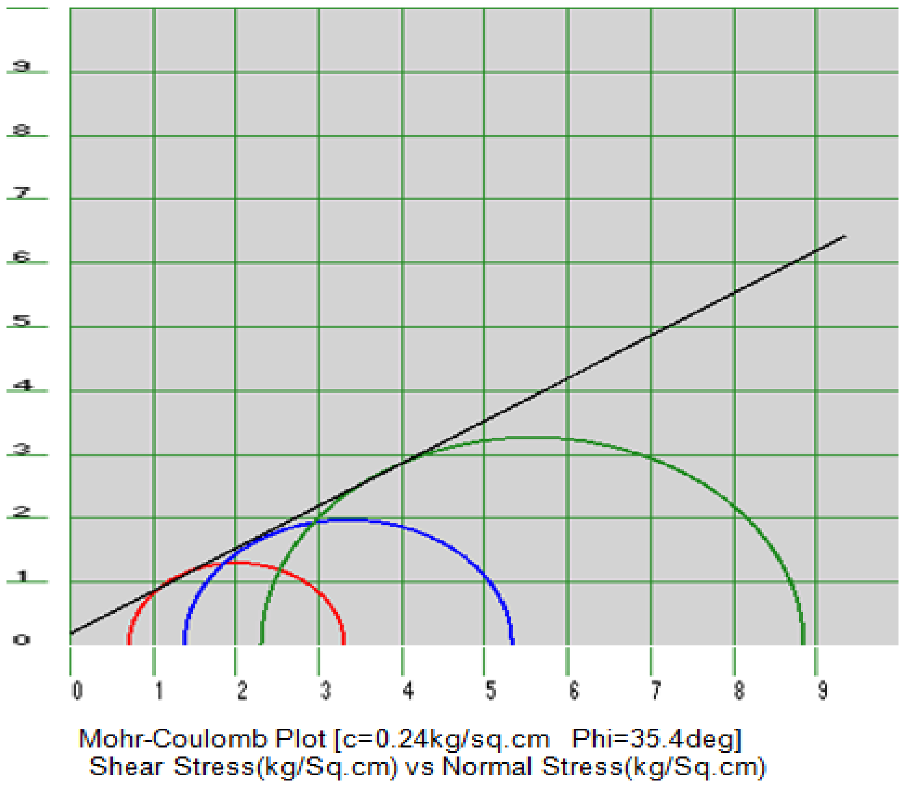


Figure 4.53 : Mohr-Coulumb Plot for SMK5

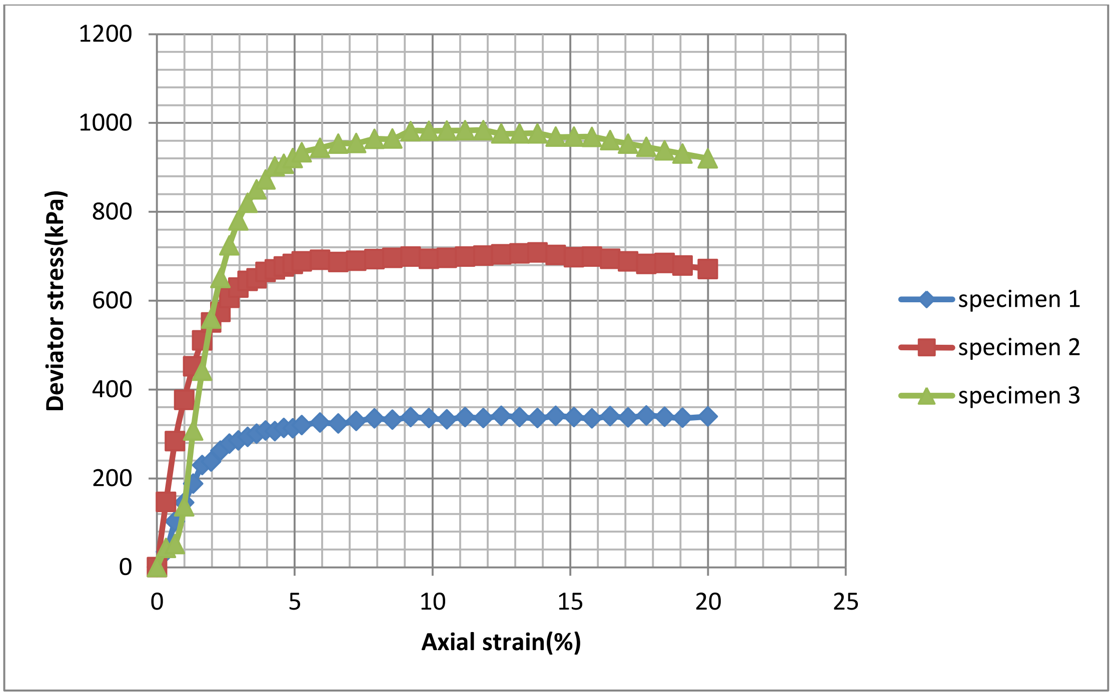


Figure 4.54: Deviatric stress vs Axial strain curve

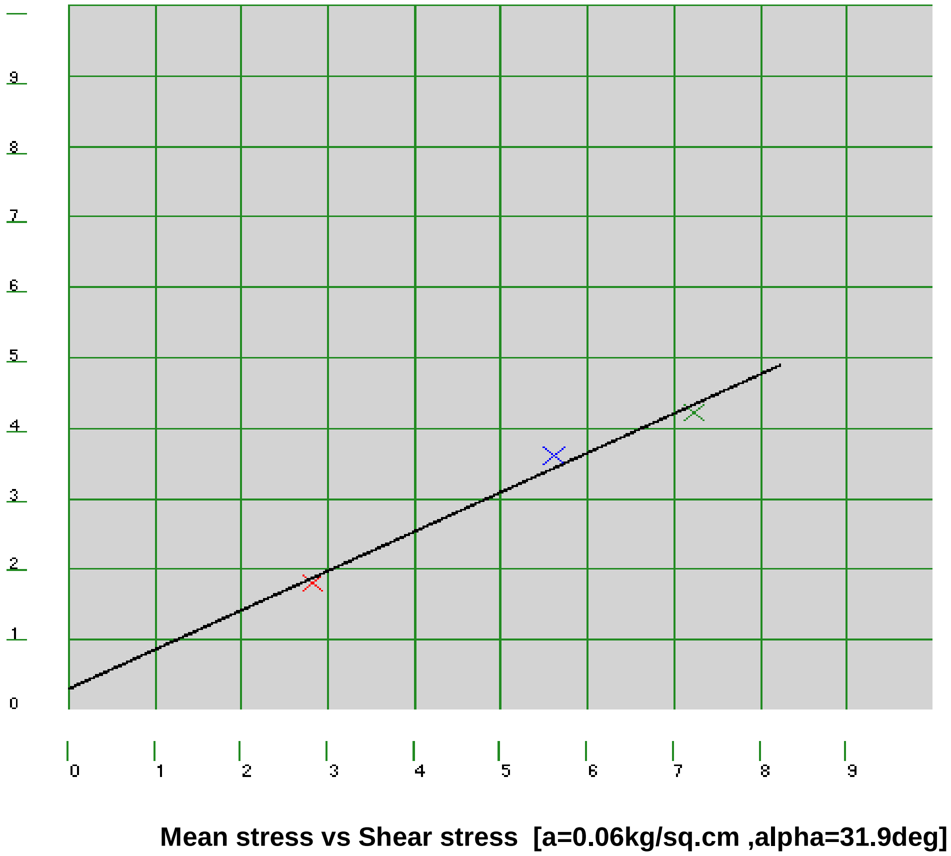


Figure 4.55 : p-q plot for SMK10

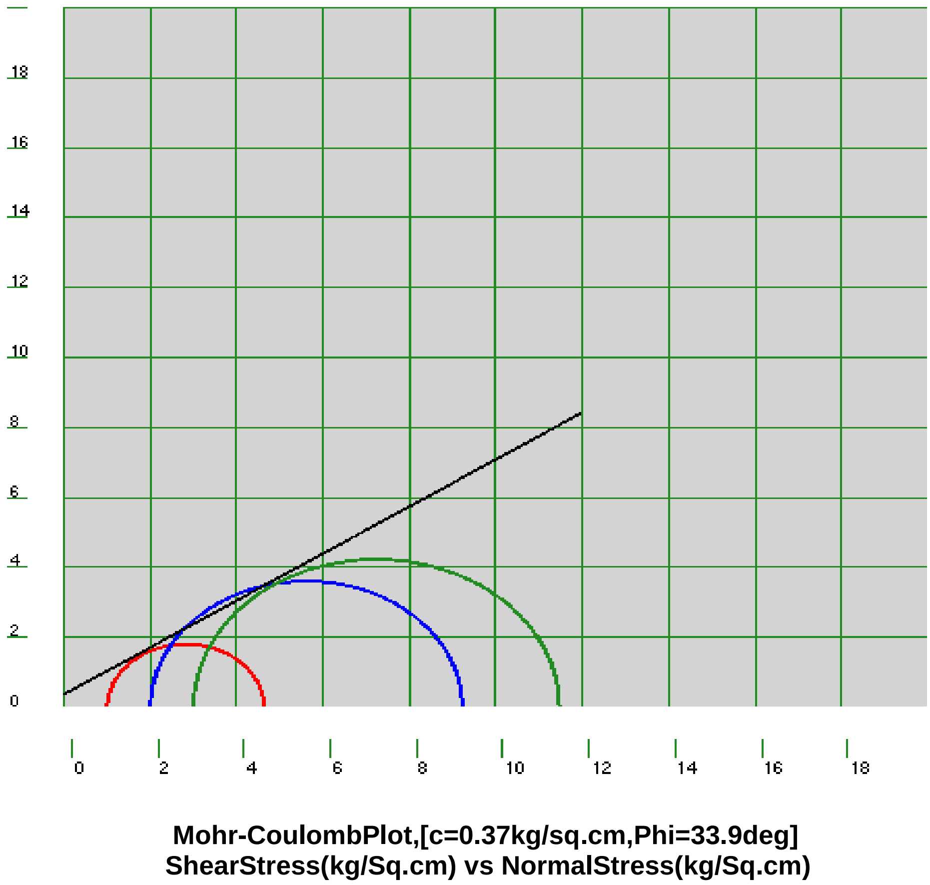


Figure 4.56 : Mohr-Coulumb Plot for SMK5

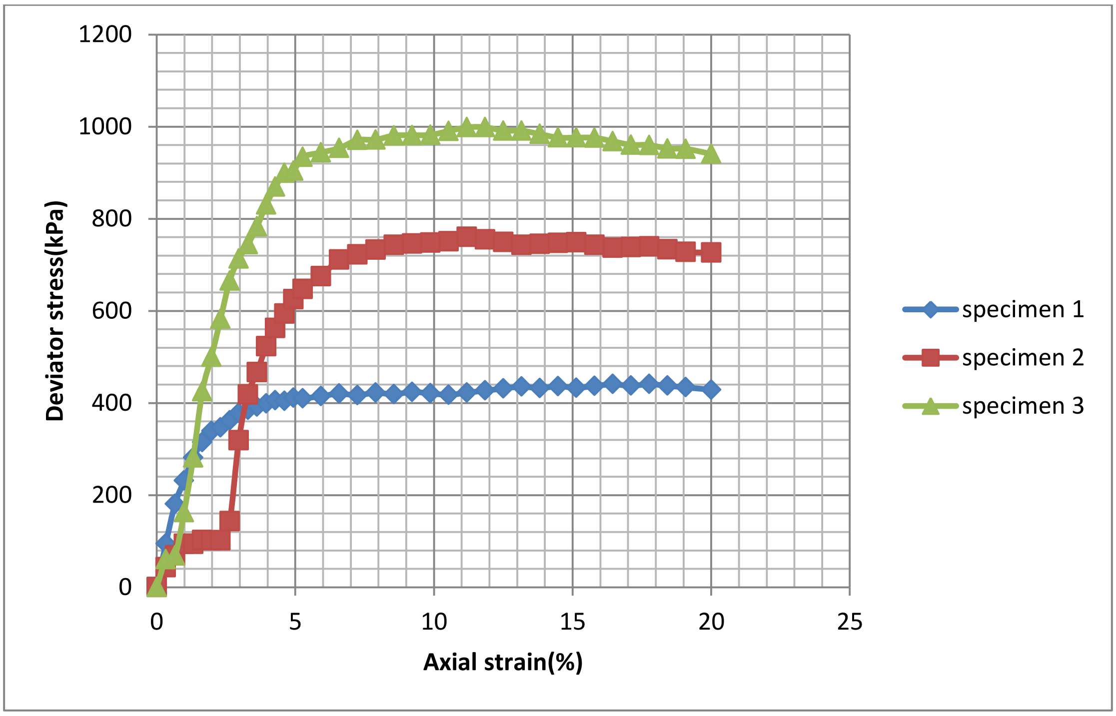
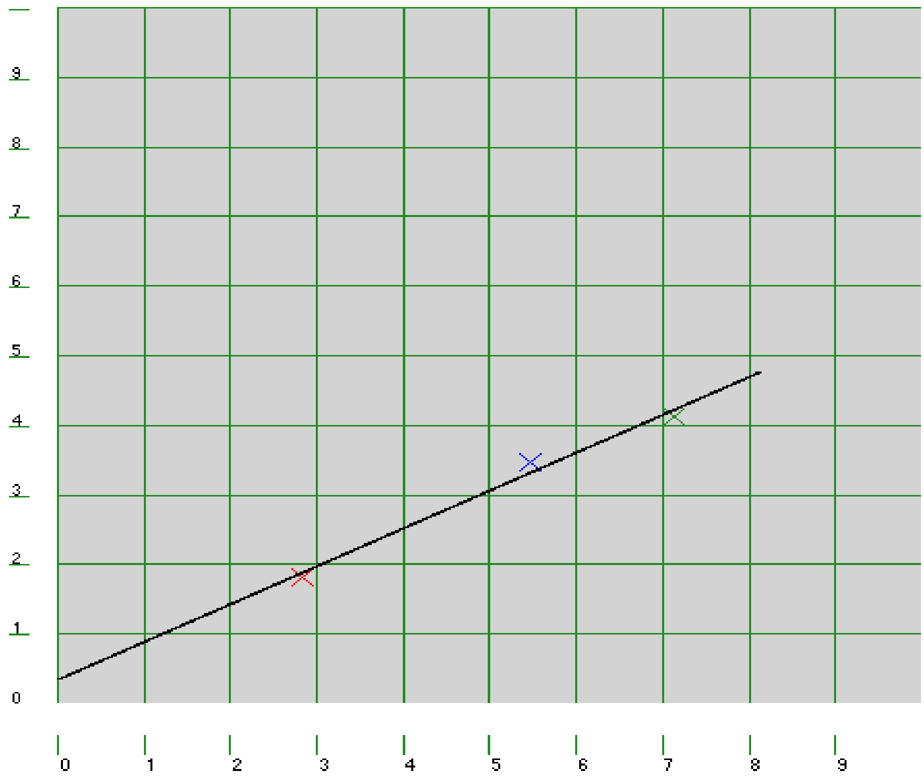
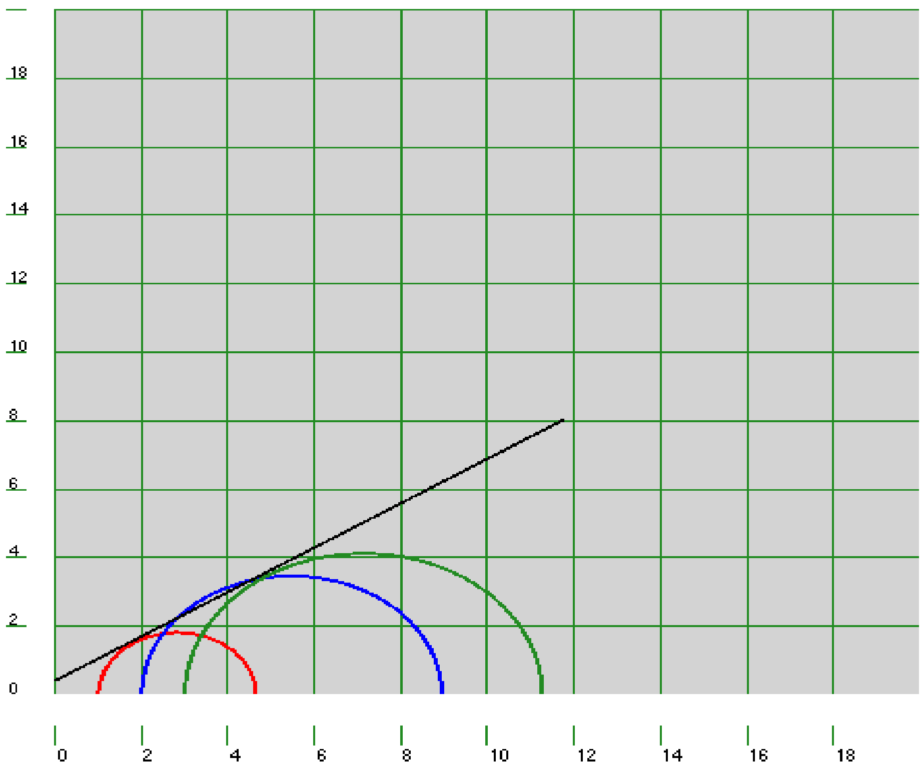


Figure 4.57: Deviatric stress vs Axial strain curve for SMK15



Mean stress vs Shear stress [a=0.35kg/sq.cm ,alpha=28.5deg]

Figure 4.58 : p-q plot for SMK15



Mohr-CoulombPlot,[c=0.41kg/sq.cm,Phi=32.9deg]
ShearStress(kg/Sq.cm) vs NormalStress(kg/Sq.cm)

Figure 4.59 : Mohr-Coulumb Plot for SMK15

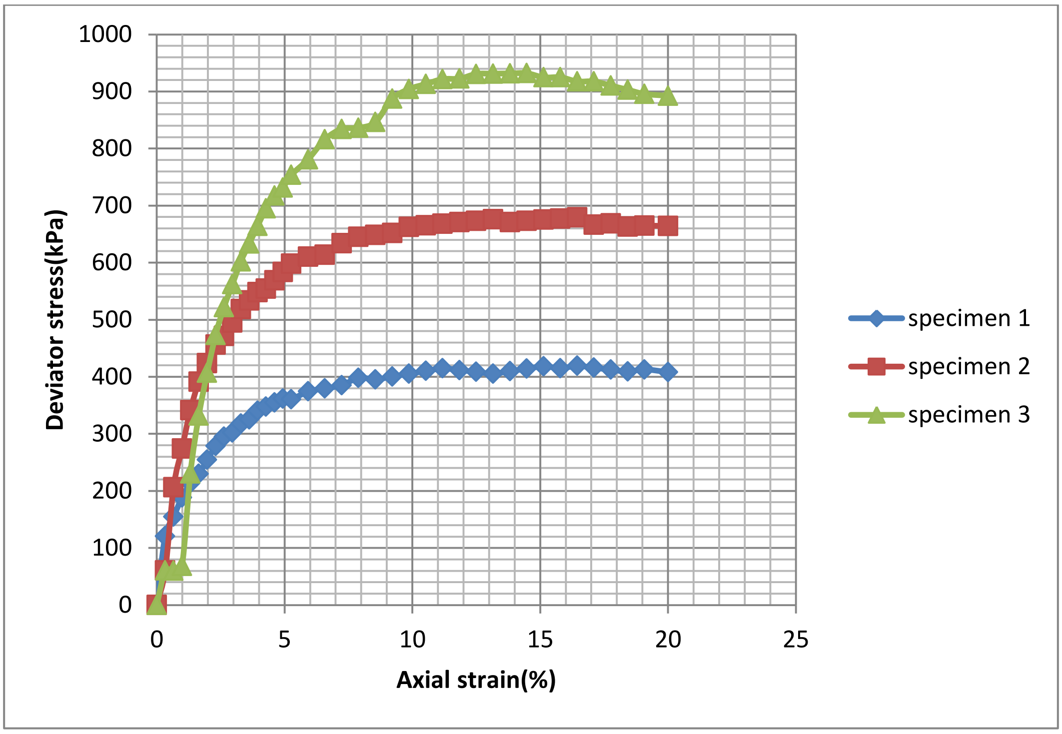
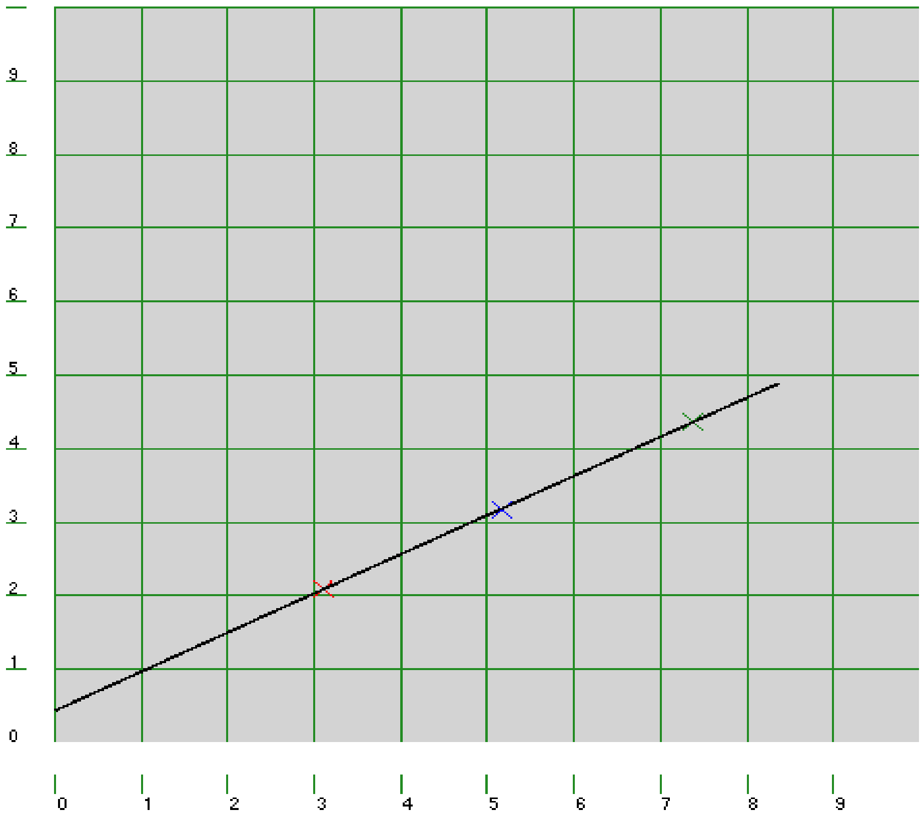


Figure 4.60 : Deviatric stress vs Axial strain curve for SMK20



Mean stress vs Shear stress [a=0.44kg/sq.cm ,alpha=28.0deg]

Figure 4.61 : p-q plot for SMK20

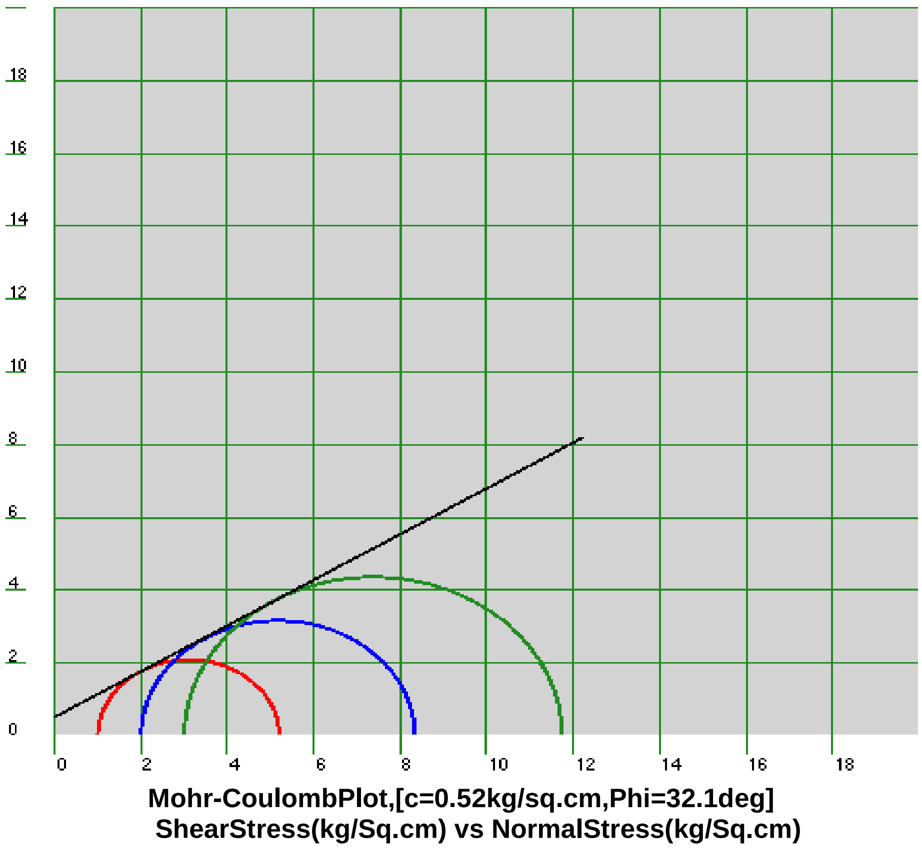


Figure 4.62 : Mohr-Coulumb Plot for SMK20

Table 4.8 : Variation of C-ϕ values for various sand-kaolinite mixes

	Cohesion(kPa)	**ϕ(degrees)**
Virgin Yamuna sand	3.92	35.90
SMK5	23.53	35.40
SMK10	36.28	33.90
SMK15	40.20	32.90
SMK20	50.99	32.10

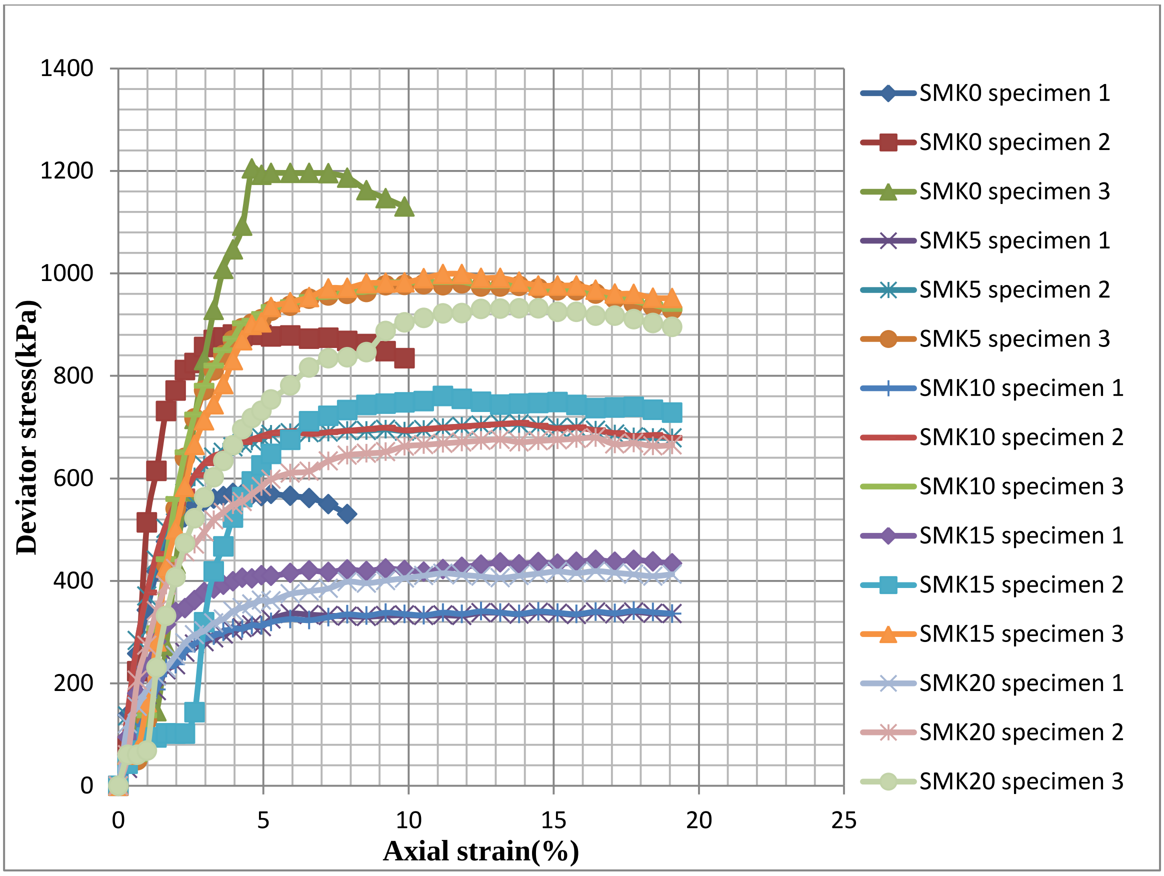


Figure 4.63 : Deviatric stress vs Axial strain curve for various sand-kaolinite mixes

CHAPTER 5

CONCLUSIONS

6.1 GENERAL

The present thesis carried out to study the effect bentonite and kaolinite on the shear behaviour of soft soil yielded following conclusions.

Compaction Characteristics

1. With the increase in bentonite content there is increase in OMC of the soil mix having maximum value at 20%. This may be attributed to the high specific surface and large water holding capacity of bentonite.
2. As the bentonite content increases there is increase in MDD upto 15% and then MDD decreases at 20%. The reason for this might be that bentonite particles fill the voids of the sand thereby increasing maximum dry density upto 15% and afterwards decrease in MDD is due to the fact that clay particles start taking up the space which would have been taken by the sand.
3. With the increase in kaolinite content there is increase in OMC of the soil mix which is due to the high specific surface of kaolinite.
4. As the kaolinite content increases there is increase in MDD of the soil mix. The maximum value of mdd is at 20% mix. This due to the fact that kaolinite particles fill the voids of the sand thereby increasing MDD.

Direct Shear Test

Direct shear tests were conducted at 50, 100, 150 kPa normal stress resulted following:

1. There is increase in cohesion with the increase in bentonite and kaolinite content.
2. Angle of internal friction decreases as the bentonite and kaolinite content increased with max decrement at 20% for both type of clays.
3. Increase in cohesion is more pronounced in case of bentonite as compared to kaolinite.
4. Angle of internal friction decreased more in case of bentonite as compared to kaolinite.

Unconsolidated Undrained Triaxial Test

UU Triaxial tests performed on various samples at 100, 200, 300 kPa resulted following:

1. There is increase in cohesion for both bentonite and kaolinite content increment.

2. Angle of internal friction decreased as the bentonite and kaolinite content increased.
3. For bentonite maximum value of cohesion is 93.15 kPa whereas in case of kaolinite it is 50.99 kPa.

Moreover, it has been observed that C-ϕ values obtained from direct shear test are slightly more than the values observed from UU triaxial test.

6.2 FUTURE SCOPE OF WORK

Many researches have been done to study the shear behaviour of sands blended with clays.The results obtained in the present thesis may further add to the knowledge of behaviour of sands mixed with various clays.

1. Based on results of these laboratory tests further tests should also be conducted in the field to correlate the values obtaine from laboratory to that of field.
2. Strength and durability tests are required to be examined for 28 days & 56 days of curing to identify the geotechnical properties.
3. Durability on the sand-bentonite and sand-kaolinite on the basis of freezing and thawing should be investigated.

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