B. TECH. PROJECT REPORT

On

Experimental Investigation on the Engineering Characteristics of Reconstituted Black cotton Soil blended with Fly Ash

BY

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DISCIPLINE OF CIVIL ENGINEERING

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Experimental Investigation on the Engineering Characteristics of Reconstituted Black cotton Soil blended with Fly Ash

A PROJECT REPORT

Submitted in partial fulfillment of the
Requirements for the award of the degrees

of
BACHELOR OF TECHNOLOGY
in
CIVIL ENGINEERING

Submitted by:
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Saurabh Jaiswal

Guided by:
Dr. Lalit Borana
(Assistant Professor, IIT Indore)

INDIAN INSTITUTE OF TECHNOLOGY INDORE
December 2019

CANDIDATE'S DECLARATION

We hereby declare that the project entitled **"Experimental Investigation on the Engineering Characteristics of Reconstituted Black cotton Soil blended with Fly Ash"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'Civil Engineering' completed under the supervision of **Dr. Lalit Borana, Assistant Professor, Department of Civil Engineering,** IIT Indore is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

Ashok Kumar Yadav **Saurabh Jaiswal**

Signature and name of the students with date

CERTIFICATE by BTP Guide

It is certified that the above statement made by the students is correct to the best of my knowledge.

Signature of BTP Guide with date and his designation

Preface

This report on **"Experimental Investigation on the Engineering Characteristics of Reconstituted Black cotton Soil blended with Fly Ash"** is prepared under the guidance of **Dr. Lalit Borana**.

In this report, we have tried to utilize the waste material "fly ash" for improving properties of black cotton soil for economic and sustainable construction.

All the basic engineering properties of black cotton soil and black cotton soil blended with fly ash are studied. Consolidation, creep and swelling behaviour is investigated using the multi-staged oedometer test and the same are compared for the black cotton soil and by adding fly ash to the soil. Shear behaviour of fly ash blended with black cotton is studied for different strain rates under single and multi-staged process.

We have tried to the best of our abilities and knowledge to explain the content in a lucid manner. We have also added illustrated graphs and flow charts to explain the results and conclusions in a comprehensive manner.

Ashok Kumar Yadav, Saurabh Jaiswal
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It is their help and support, due to which we became able to complete the experiments and analysis of results for this report. Without their support, this report would not have been possible.

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Abstract

Sustainable development is more preferred in the modern era. Sustainable infrastructure is a part of sustainable development. Sustainable infrastructure goals to upgrade infrastructure with greater adoption of clean environmental and economic sound technologies. Black cotton soil is found mostly in the central part of India and covers 20% area of the total area of India. It has low shear strength, high swelling and shrinkage and compressibility characteristics and due to these properties it possesses problem for construction of structures. Fly ash is waste material of coal fibered electric and steam generating plant. Further fly ash as a waste material causing huge environmental problems and health hazards on direct exposure and its disposal is a great concern for the clean environment. In this report, utilization of fly ash blended with black cotton soil as a construction fill material is explored which leads to sustainable infrastructure. Large scale land reclamation projects require the prediction of long term creep and swelling behaviour of soil. In this regards, the long-term consolidation and creep behaviour of different proportions of fly ash mixed with black cotton soil is investigated using multi-staged oedometer tests and analysed using EVPS model. Utilization of fly ash with black cotton soil enhance swelling and compressibility properties of black cotton soil. Fly ash also has high shear resistance hence it had been used with clay soils to construct embankments, dams, and retaining walls. Shear behaviour of disturbed black cotton soil mixed with different proportion of fly ash is investigated using direct shear test for different strain rates under single and multi-staged process.

Keyword: Black cotton soil, clay soil, fly ash, creep, swelling, consolidation, Elastic-Visco-plastic model (EVPS), shear.

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1. Introduction

Black cotton soil is a highly clayey soil which is found mostly across Gujarat, Maharashtra, Karnataka and Madhya Pradesh in India which is a part of Deccan lava plateau and Malwa plateau. Black cotton soil is suitable for growing cotton and it is generally black or dark in colour due to its richness of organic matter in it (Ramachandran et al. 1959). The most important feature of black cotton soil is its expansive property or swelling behaviour that it possesses on absorbing moisture attributed to the presence of mineral montmorillonite and few in illite. The highly expansive property of the soil possesses a problem from the construction point of view. Construction of structures on black cotton soil is challengeable because black cotton soil have high compressibility and low shearing strength, swelling and shrinkage properties which leads to crack and differential settlement in foundation. The developed cities are getting overcrowded hence there is a need to develop strategies regarding the re-use of land and considering this, various land reclamation projects came into effect of which Rotterdam port (Netherlands), Changi Airport (Singapore), Yas Island, Al Reem Island, and Al Lulu Island (Abu Dhabi, UAE) are popular examples. Land reclamation is a process by which new land is created from ocean, river-bed and lake-bed or improving the status of disturbed land or landfill. Reclamation projects require ground improvement techniques and prediction of long-term settlement. Fly ash is a by-product of burning pulverized coal and it is a pozzolanic material which consists of siliceous and aluminous material that shows cementitious property when mixed with water. It is a waste product which is in abundance and its disposal causes various environmental hazards including contamination of surface and groundwater ultimately disturbing ecological and environmental balance. Fly ash is utilizing in concrete, agriculture, cement plants etc. In this report fly ash is utilized for improving various properties of black cotton soil. It is studied that fly ash can be used for improving the basic properties of black cotton soil because of its low specific gravity, cementitious property and high shear strength (Sivapullaiah et al. 1996). Using fly ash as an admixture to the black cotton soil should be taken as a big opportunity to enhance the properties of black cotton soil as well as utilizing the waste material that possesses environmental problems.

Stress-strain behaviour of clay depends on mineralogy, particle shape, compaction, loading, degree of saturation, etc. Settlement in clay during consolidation occurs due to dissipation of pore water from double diffused layer (Bjerrum 1967) and deformation of clay particles (Yin and Graham 1994). When a load increment happens then there is a sudden change in volume called “instant compression” and the change in volume with time is “delayed compression” (Bjerrum 1967). The term ‘creep’ is defined as viscous behaviour of soil during loading stage whereas ‘swelling’ is defined as viscous behaviour of soil during unloading stage (Feng et al. 2017; Graham et al. 1983). When clay comes in contact with water then based on mineralogy, moisture content, dry density and stress history, clayey soils exhibit swelling behaviour and if the swelling is restrained then it exerts swelling pressure. Swelling pressure causes differential settlement in the foundation which is considered dangerous to the structure and it develops cracks. When a sample in oedometer undergoes loading and unloading it shows elastic, elastic-plastic and viscous strain. Elastic strain is a recoverable strain, if elastic and plastic strain occurs simultaneously then combined effect is called elastic-plastic strain and this occurs after the elastic strain in Oedometer condition whereas viscous strain is composed of creep and swelling strain. In the consolidation process, there are two hypothesis A & B. Hypothesis A assumes that creep contributes in the strain after the end of primary consolidation and hypothesis B assumes that creep contributes throughout the consolidation process (Feng and Yin 2016). In this report, hypothesis A is assumed and creep and swelling behaviour of black cotton soil and black cotton soil mixed with different proportions of fly ash is analysed. For analysis, Elastic Visco-plastic model is used including swelling (EVPS) (Yin and Graham 1994; Yin 1999; Yin and Graham 1989; Yin and Tong 2011).

Shear strength of soil is the ability to resist internal and external forces which slide or roll past each other particles. Shear strength have two-component cohesion and angle of internal friction. Shear strength has a significant role in slope stability and lateral earth pressure on earth retaining structure. Shear strength of a soil is affected by soil composition, soil compaction, mineralogy, particle shape etc. It is also affected by the testing process in the laboratory like strain rate and time relaxation or multi-staged tests. Black cotton soil is found to have low shear strength and vast quantities of fly ash had been used in various geotechnical structures for construction of embankments, dams, and as backfill behind retaining walls due to its high shear strength.

In this project, the effect of different proportions (5%, 15%, and 25%) of fly ash in reconstitute black cotton soil on its index properties is studied. The long- term creep and swelling behaviour of black cotton soil and black cotton soil mixed with 5% and 25% fly ash in multi-staged loading and reloading oedometric condition is investigated. Experimental study of shear behaviour of reconstitute black cotton soil mixed with 5% and 25% fly ash for different strain rates under single and multi-staged direct shear test is done.

2. Literature Review

Black cotton soil is generally black or dark in colour due to the presence of organic matter in it (Ramachandran et al. 1959). Effect of fly ash on index properties of black cotton soil has been studied by many researcher and fly ash enhance the basic engineering properties of black cotton soil.

Initially, it was considered that the stress-strain behaviour of clay depends mostly on the loading and unloading amplitude but in the investigation on clayey soils (Crawford 1966) showed that the stress-strain behaviour of clay has a significant dependency on loading duration also, this behaviour is investigated by the Oedometer test which is a one-dimensional test. Elastic-Viscoplastic Model including Swelling (EVPS) model, Perzyana Viscoplastic model, modified cam clay model and many other models are for the analysis of consolidation test. In this project, EVPS model is used for the analysis of consolidation process because it includes elastic, plastic, viscous strain which clayey soil exhibits during the oedometer test. Many researchers have adopted non-linear equation given in EVPS model for creep and swelling behaviour analysis of soil (Kelln et al. 2008; Tong and Jian-Hua 2011).

In oedometer condition, soil undergoes three stages of strain which are viscous strain, elastic strain and elastic-plastic strain (Yin and Graham 1989).

1. Viscous strain:-

Viscous strain occurs during loading and unloading stage. In the loading stage, viscous strain is called creep strain and in unloading stage, it is called swelling strain.

Linear relationship between creep strain and time is given by the following equation (Yin and Graham 1989, 1994)

$$\epsilon_z^c = \frac{\psi^c}{v} \ln\left(\frac{t_0^c + t_e^c}{t_0^c}\right) \tag{1}$$

Here subscript 'c' is used for creep, $(\frac{\psi^c}{v})$ is creep coefficient, t_0^c is time parameter which is taken as the time of end of primary consolidation under loading stage and t_e^c is equivalent time for creep which is defined as $t_e^c = t - t_o^c$ (Yin and Tong 2011).

For the long term, nonlinear relationship between creep strain and time (Yin 1999) proposed the following equation

$$\epsilon_z^c = \frac{\frac{\psi_0^c}{v}}{1+\frac{\psi_0^c}{\varepsilon_z^{cl} v}\ln(\frac{t_0^c+t_e^c}{t_0^c})}\ln(\frac{t_0^c+t_e^c}{t_0^c}) \quad (2)$$

Here ϵ_z^{cl} is creep strain limit

Total strain in the loading stage after the end of primary consolidation is given by the following equation.

$$\epsilon_z = \epsilon_{z_o} + \epsilon_z^c$$

Here ϵ_{z_0} is strain at $t = t_0^c$

Linear relationship between swelling strain V/s time is given by the following equation (Yin and Tong 2011):-

$$\epsilon_z^s = -\frac{\psi^s}{\nu}\ln(\frac{t_0^s + t_e^s}{t_0^s}) \quad (3)$$

Here subscript‘s’ is used for swelling, $(\frac{\psi^s}{v})$ is swelling coefficient, t_0^s is time parameter related to swelling which is taken as the time of end of primary consolidation under unloading stage and t_e^s is equivalent time for swelling which is defined as $t_e^s = t - t_o^s$.

For long term nonlinear relationship between swelling strain and time (Feng et al. 2017) proposed the following equation:-

$$\epsilon_z^s = -\frac{\frac{\psi_0^s}{v}}{1-\frac{\psi_0^s}{\varepsilon_z^{sl}\nu}\ln(\frac{t_0^s+t_0^e}{t_0^s})}\ln(\frac{t_0^s + t_e^s}{t_0^s}) \quad (4)$$

Here ϵ_z^{sl} is swelling strain limit.

Total strain in the loading stage after the end of primary consolidation is given by following equation:-

$$\epsilon_z = \epsilon_{z_o} + \epsilon_z^s$$

Here ϵ_{z_o} is strain at $t = t_o^s$

For determination of creep coefficient, creep strain limit and swelling coefficient, swelling strain limit proposed nonlinear equations are assumed as linear and compared with equation found by experimental data plot.

2. **Elastic strain:-**

Elastic strain is a recoverable strain. Following equation (Yin and Graham 1989) is used for fitting of data.

$$\epsilon_z^e = \epsilon_{z_0}^e + \frac{\kappa}{\nu} \ln \frac{\sigma_z'}{\sigma_{z_u}'} \tag{5}$$

Fig.1 (a) represents the symbolic representation curve for fitting of equation (5). Here subscript 'e' is used for elastic, σ_{z_u}' is initial stress and $\epsilon_{z_0}^e$ is strain at σ_z' =σ_{z_u}' and $\nu = 1 + e_0$, e_0 is initial void ratio.

Rebounding parameter ($\frac{\kappa}{\nu}$) is a material parameter which is defined as the slope of strain v/s effective stress (ln scale) in over-consolidation loading condition.

3. Elastic-Plastic strain:-

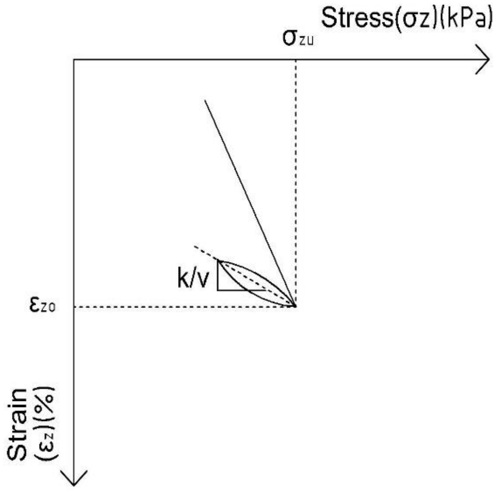
Elastic-plastic strain is not completely recoverable strain. For plastic strain following equation (Yin and Graham 1989) is used for the fitting of data.

$$\epsilon_z^p = \epsilon_{z_0}^p + \frac{\lambda - \kappa}{\nu} \ln \frac{\sigma_z'}{\sigma_{z_0}'} \tag{6}$$

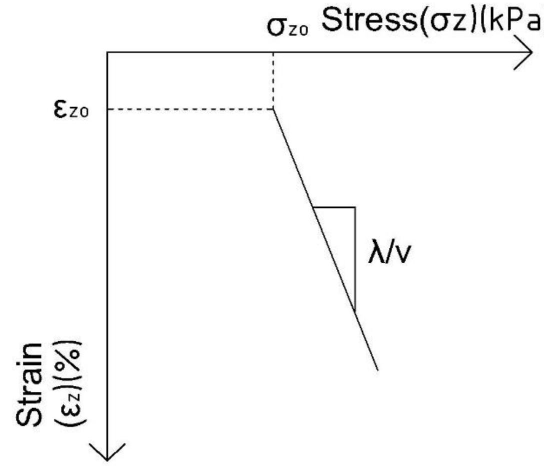
If elastic and plastic strain occurs simultaneously then combined effect is called elastic-plastic strain and this occurs after the elastic strain in Oedometer condition. For elastic-plastic strain following equation is used for the fitting of data.

$$\epsilon_z^{ep} = \epsilon_{z_0}^{ep} + \frac{\lambda}{\nu} \ln \frac{\sigma_z'}{\sigma_{z_0}'} \tag{7}$$

Fig.1 (b) represents the symbolic representation curve for fitting of equation (7). Here subscript 'ep' is used for elastic-plastic and σ_{z_0}' is stress when elastic-plastic strain begins and corresponding strain is $\epsilon_{z_0}^{ep}$. Compression parameter ($\frac{\lambda}{\nu}$) is a material parameter which is defined as the slope of strain V/s effective stress (ln scale) in normal loading condition.



(a)



(b)

Fig.1. Symbolic representation curve for fitting of (a) equation 5 (b) equation 7

(Nakase et al. 1988) presented the average value of ratio of rebounding index and compression index $\frac{C_r}{C_c}$ for reconstitute black cotton soil as 0.144. Rebounding index $\frac{C_r}{v}$ and compression index $\frac{C_c}{v}$ are defined as following

$$\frac{C_r}{v} = \ln(10)\frac{\kappa}{\nu} = 2.3\frac{\kappa}{\nu}$$

$$\frac{C_c}{v} = \ln(10)\frac{\lambda}{\nu} = 2.3\frac{\lambda}{\nu}$$

Shear Behaviour

The most widely used laboratory equipment for investigating the strength and deformation behaviour of soils is either the triaxial or direct shear apparatus. Black cotton soil is found to have low shear strength. Vast quantities of fly ash had been used in various geotechnical structures for construction of embankments, dams, and as backfill behind retaining walls due to its high shear strength. It is found that the shear strength of black cotton soil is higher in dry state but after absorbing moisture its shear strength reduces a lot. Unconfined compressive strength of different proportion of fly ash blended with black cotton soil is studied and it increases with increases of fly ash content up to 10% (Karthick et al., 2018). Cohesion of black cotton soil mixed with fly ash increases as fly ash content increases up to 10% which is determined by direct shear test (Karthick et al., 2018). Shear strength is also affected by strain rate as strain rate decreases shear strength increases. Angle of internal friction of soil is affected by variation in strain rate and it is maximum for intermediate strain of 0.007mm/min (Mamo et al. 2015) in direct shear test. Time relaxation at every 1mm shear displacement of 10-20 min has been given for multi-staged purpose (Borana et al. 2018). Multi-staged direct shear test process has a significant effect on the shear strength of a soil and it is convenient to perform multi-staged test on compacted soil (Hormdee et al. 2012). In multi-staged test due to mechanical relaxation particles of soil specimen undergoes release of force and due to this, movement of particles will slow down and maximum shear stress will increase.

3. Material and Methodology

Black cotton soil and fly ash were used in different proportions as a specimen for various tests conducted. Black cotton soil was collected from IIT Indore campus which is located in Indore, Madhya Pradesh and industrial fly ash generated from coal fibred electric and steam generation plants was used.

Particle size analysis, Specific gravity, Atterberg's limit liquid limit, plastic limit and optimum moisture content-dry density all tests were conducted using guidelines provided in IS Code 2720 Part 4, Part 3, Part 5, Part 7 respectively. Particle size classification table according to Indian standard and particle size distribution curve is presented below.

Table 1. Particle size classification (Indian standard), particle size in mm

	300	80	4.75	0.075	0.002
boulder	cobble	gravel	sand	silt	clay

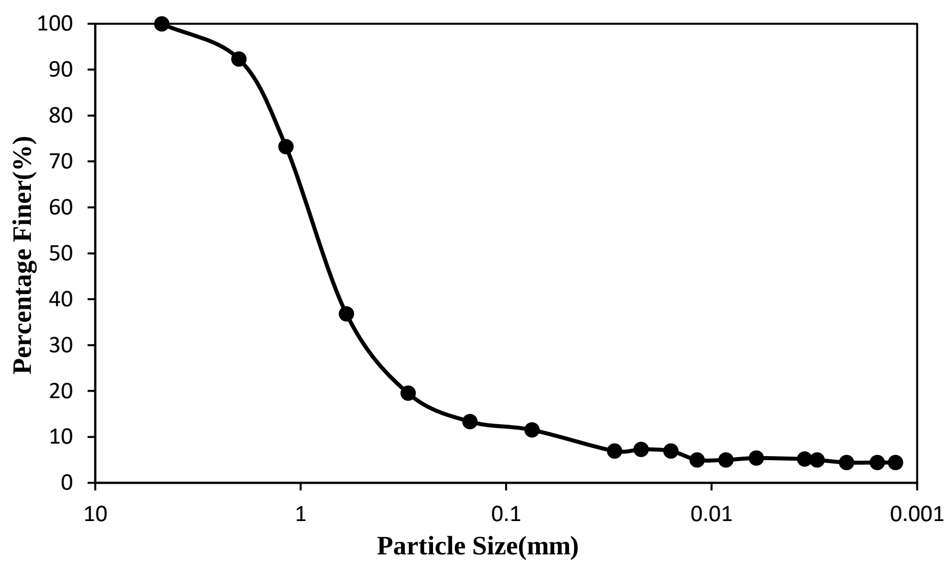


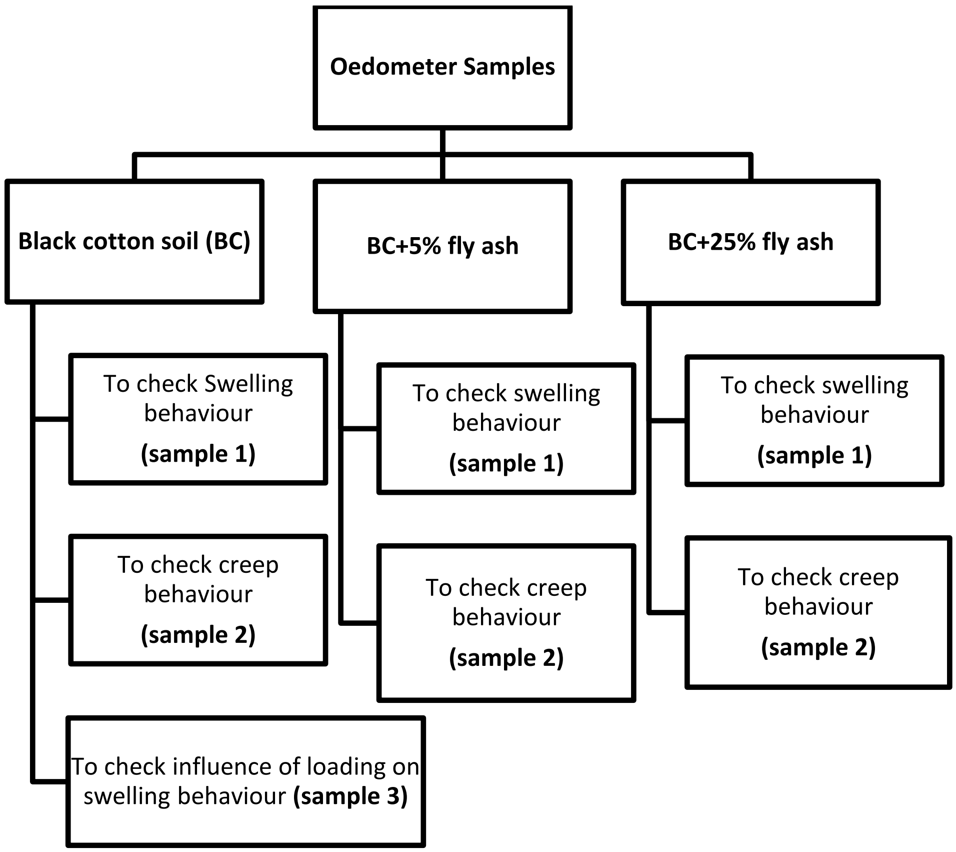
Fig.2. Particle Size Distribution Curve

Fig.3. Density bottle (specific gravity test)

Fig.4. Standard proctor test

3.1 Consolidation Test

Consolidation test is a one-dimensional test conducted in oedometer in saturated condition. In this project, Casagrande's oedometer apparatus was used and multi-staged loading condition was employed. 3 samples of reconstitute black cotton soil, 2 samples of black cotton soil mixed with 5% fly ash (in weight) and 2 samples of black cotton soil mixed with 25% fly ash (in weight) were prepared. All the samples were kept in mould of 20 mm height and 60 mm diameter and dial gauge of 0.01mm least count was placed for measurement of vertical deformation. Samples were prepared at 80% of maximum dry density and the moisture content was taken as their corresponding liquid limit. One wet porous stone was placed at the bottom of the sample and another wet porous stone was placed at the top of the sample. Filter paper was used between the porous stones and sample. Different loading patterns were employed for different aim which are presented in table 2. Following chart (Flow chart 1) represents oedometer samples for consolidation test. Procedures were followed according to IS Code 2720-15. A sitting pressure of 5kPa was applied for 24 hours on every sample.



Flow chart 1. Different types of Oedometer Samples and their aims.

Fig.5. Oedometer apparatus.

Aim: To check Swelling Behaviour		
Order	Loading (kPa)	Duration of Loading (days)
1	5	1
2	10	**7**
3	25	1
4	50	1
5	100	**7**
6	50	1
7	25	1
8	10	7
9	25	1
10	50	1
11	100	1
12	500	1
13	1000	7
14	500	1
15	250	1
16	50	1
17	10	7
18	50	1
19	250	1
20	500	1
21	1000	1
22	1250	7
23	1000	1
24	500	1
25	250	1
26	100	1
27	10	7
28	100	1
29	250	1
30	500	1
31	1000	1
32	1250	7
33	1000	1
34	500	1
35	250	1
36	100	1
37	50	1
38	10	7
Total Days		**92**

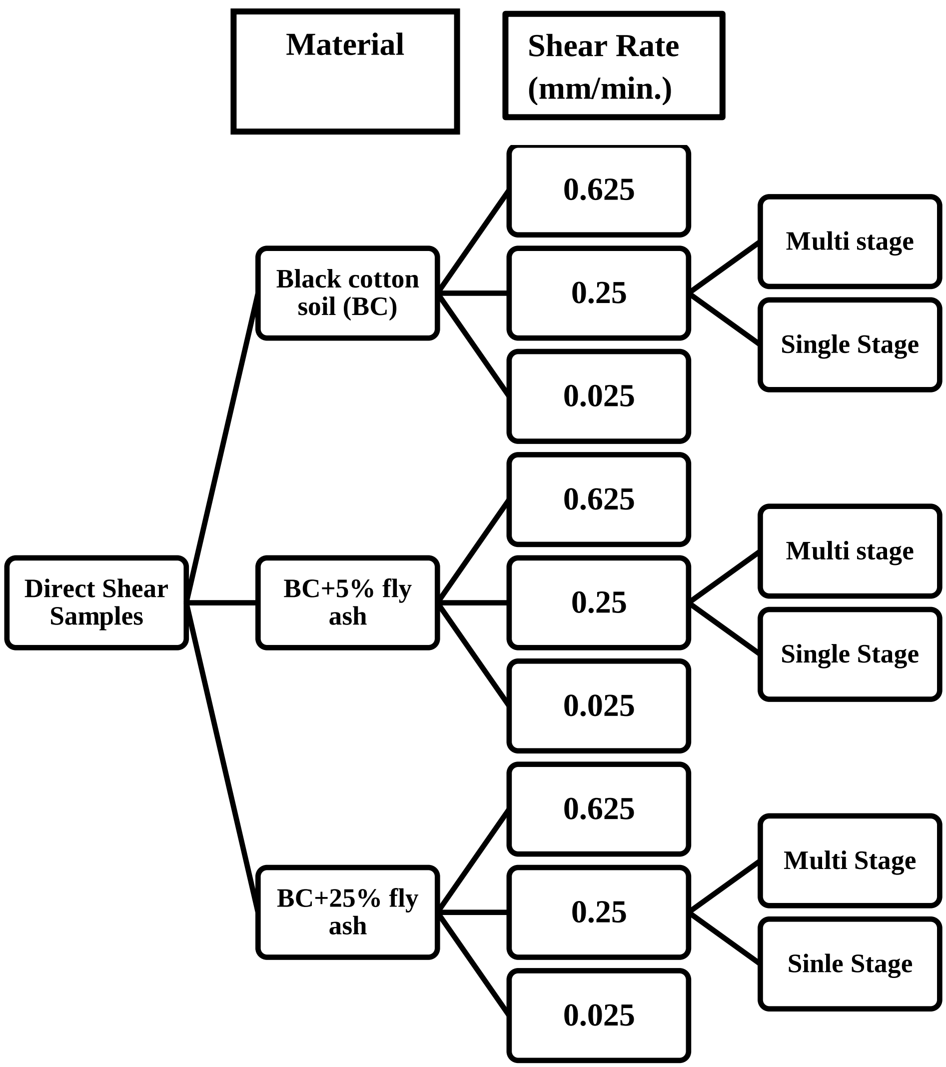
Aim: To check the creep behaviour		
Order	Loading (kPa)	Duration of Loading (days)
1	5	7
2	10	7
3	25	7
4	50	7
5	100	7
6	250	7
7	500	7
8	250	7
9	100	7
10	50	7
11	10	7
12	50	7
13	100	7
14	250	7
15	500	7
16	1000	7
17	1250	7
Total Days		**119**

Aim: To check the influence of loading on Swelling Behaviour with the same amplitude but different stresses		
Order	Loading (kPa)	Duration of Loading (days)
1	5	7
2	10	1
3	25	1
4	50	7
5	25	1
6	10	1
7	5	7
8	10	1
9	25	1
10	50	7
11	100	1
12	250	1
13	500	7
14	250	1
15	100	1
16	50	7
17	500	1
18	1000	1
20	1250	7
22	1000	1
23	500	7
24	1000	1
25	1250	7
26	1000	1
27	500	7
28	1000	1
29	100	1
30	50	1
31	10	7
Total Days		**95**

Table 2. Different Loading Condition for Different aim for oedometer test.

3.2 Direct Shear Test

Shear Strength of soil can be determined using direct shear test, vane shear test, triaxial compression test etc. In this project, direct shear test was adopted for investigation of shear behaviour of soil. Samples were prepared of reconstitute black cotton soil, black cotton soil mixed with 5% fly ash and black cotton soil mixed with 25% fly ash. All the samples were prepared at maximum dry density and optimum moisture content. Sample were made in shear box of dimension 60×60×25mm.



Flow chart 2. Direct Shear Samples for three strain rate and multi or single stage.

(Three normal loading, total 36 samples)

To study the influence of strain rate on shear behaviour, three strain rates were chosen. For the multi-staged test, time relaxation of 10 minutes was given after each shear displacement of 1mm. Flow chart 2 represents different samples for direct shear test. For every strain rate, three normal loadings were applied as 50, 100 and 150kPa. Test procedures were conducted in accordance with IS Code 2720-13.

Fig.6 (a). Direct Shear apparatus.

Fig.6 (b). Shear sample of black cotton soil mixed with 5% fly ash at 100kPa normal loading and 0.25mm/min. strain rate.

4. Result and Discussion

4.1 Index Properties

All the basic engineering properties of black cotton soil and its varying proportion of fly ash was determined in the laboratory for each soil sample viz. specific gravity, liquid limit, plastic limit, optimum moisture content (O.M.C.) and maximum dry density (M.D.D). All these index properties for each sample are presented in table 3.

	B.C. Soil	B.C. Soil +5% fly ash	B.C. Soil +15% fly ash	B.C. Soil +25% fly ash
Specific Gravity	2.2	2.23	2.29	2.44
Liquid limit (%)	69.93	63.13	61.46	61.11
Plastic limit (%)	31.99	32.37	32.83	34.12
Plasticity Index (%)	37.94	30.76	28.63	26.99
O.M.C. (%)	27.02	26.21	24.5	23.68
M.D.D. (g/cc)	1.406	1.432	1.442	1.411
B.C. – Black Cotton				

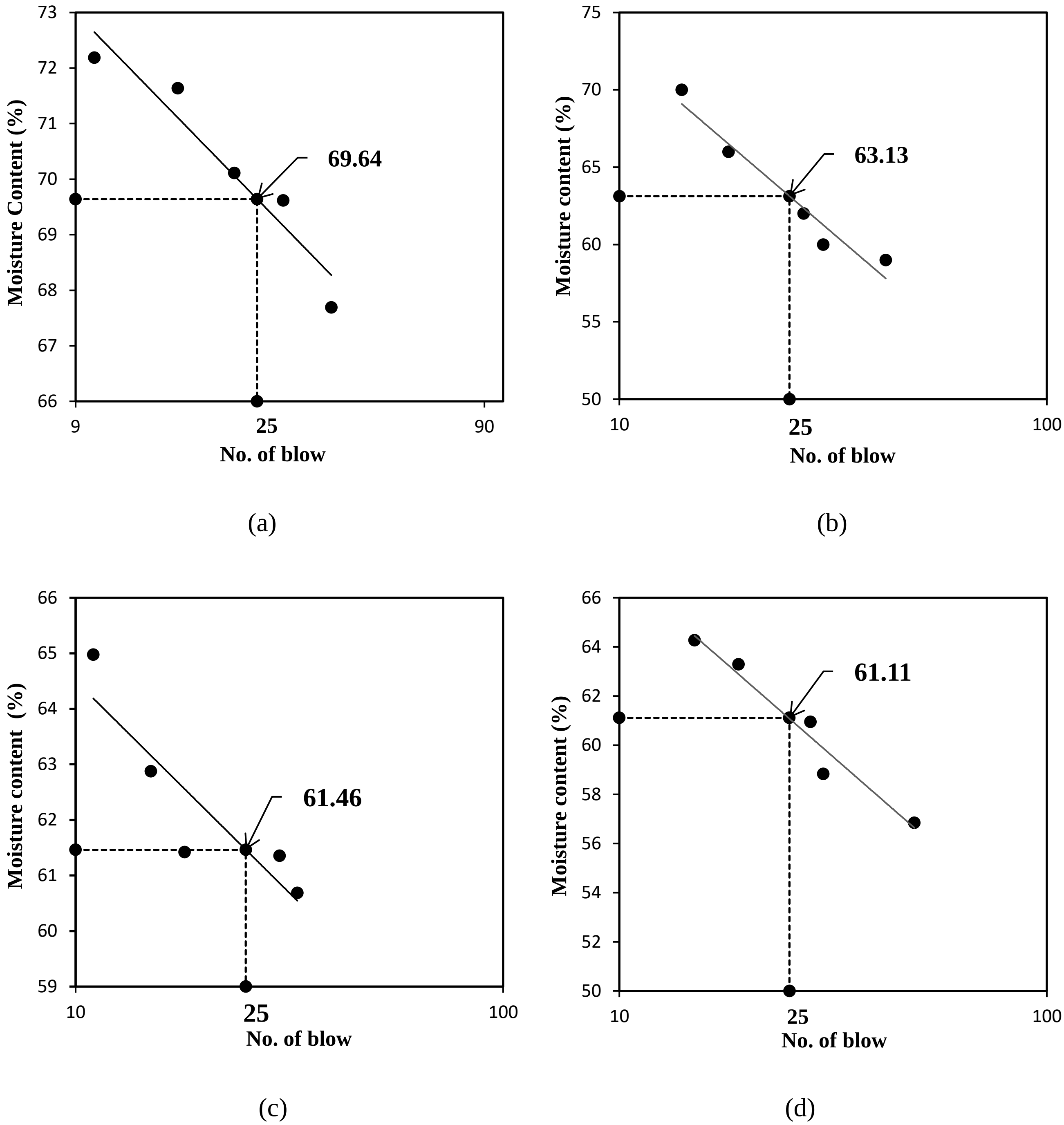
Table 3. Index properties of black cotton soil and black cotton soil mixed with 5%, 15% and 25% fly ash.

4.1.1 Specific Gravity

Specific gravity of soil is defined as the relative density of soil with respect to water. The increase in specific gravity with the addition of fly ash (Table 3) is due to the fine particles like lime, silica, etc. in fly ash which occupies the void space in black cotton soil thus increasing its specific gravity.

4.1.2. Liquid Limit

Liquid limit is defined as minimum moisture content at which soil loses its shear strength and begins to behave like liquid. The flow curve for black cotton soil and black cotton soil mixed with 5%, 15% and 25% fly ash is shown in the Fig.7. The moisture content corresponding to 25 blows on the flow curve is liquid limit for the sample.



(a) (b) (c) (d)

Fig.7. Moisture Content (%) Vs No. of blow for **(a)** Black cotton soil **(b)** Black cotton soil mixed with 5% Fly ash**, (c)** Black cotton soil mixed with 15%fly ash, **(d)** Black cotton soil mixed with 25% fly ash

Liquid limit decreases with increase in the fly ash content up to addition of 25% fly ash (Fig.8) due to the decrease in double diffused layer of soil as clay particles are replaced with fly ash.

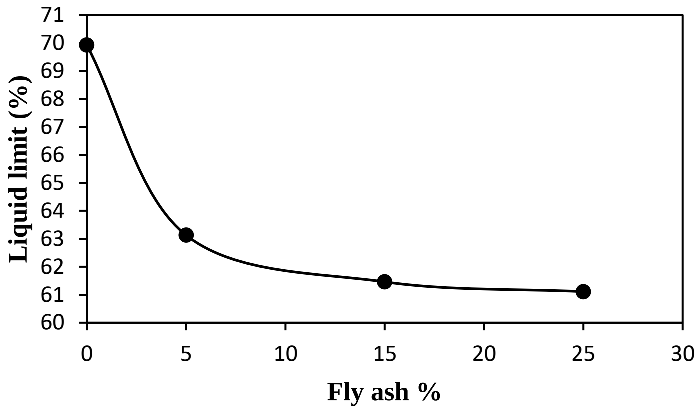


Fig.8. Variation of liquid limit for black cotton soil and black cotton soil mixed with 5%, 15% and 25% fly ash.

4.1.3. Plastic Limit

The moisture content at which the state of the soil just changes from semisolid to plastic is defined as the plastic limit so it represents the moisture content at which soil begins to show plastic behaviour.

The plastic limit of soil sample with more fly ash content tends to increase (Fig.9.) due to the development of shear resistance at interparticle level and the particles require more water to mobilize for rolling crumble.

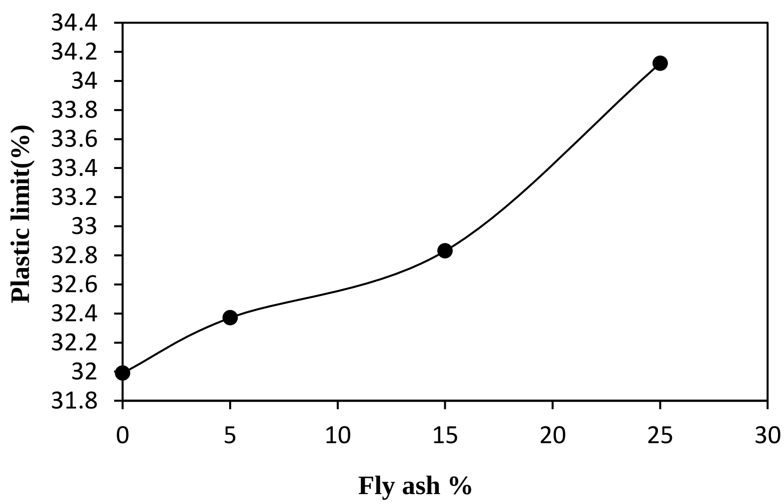


Fig.9. Variation of Plastic limit for black cotton soil and black cotton soil mixed with 5%, 15% and 25% fly ash.

As discussed earlier, liquid limit decreases and plastic limit increases with increase in fly ash content hence plasticity index must decrease for the samples with more fly ash content so it can be concluded that increasing fly ash content will decrease the plastic behaviour exhibited by soil.

4.1.4 Optimum moisture content (O.M.C.) and Maximum dry density (M.D.D.)

Dry density of soil changes with change of moisture content, moisture content at which soil achieve its maximum dry density is called optimum moisture content.

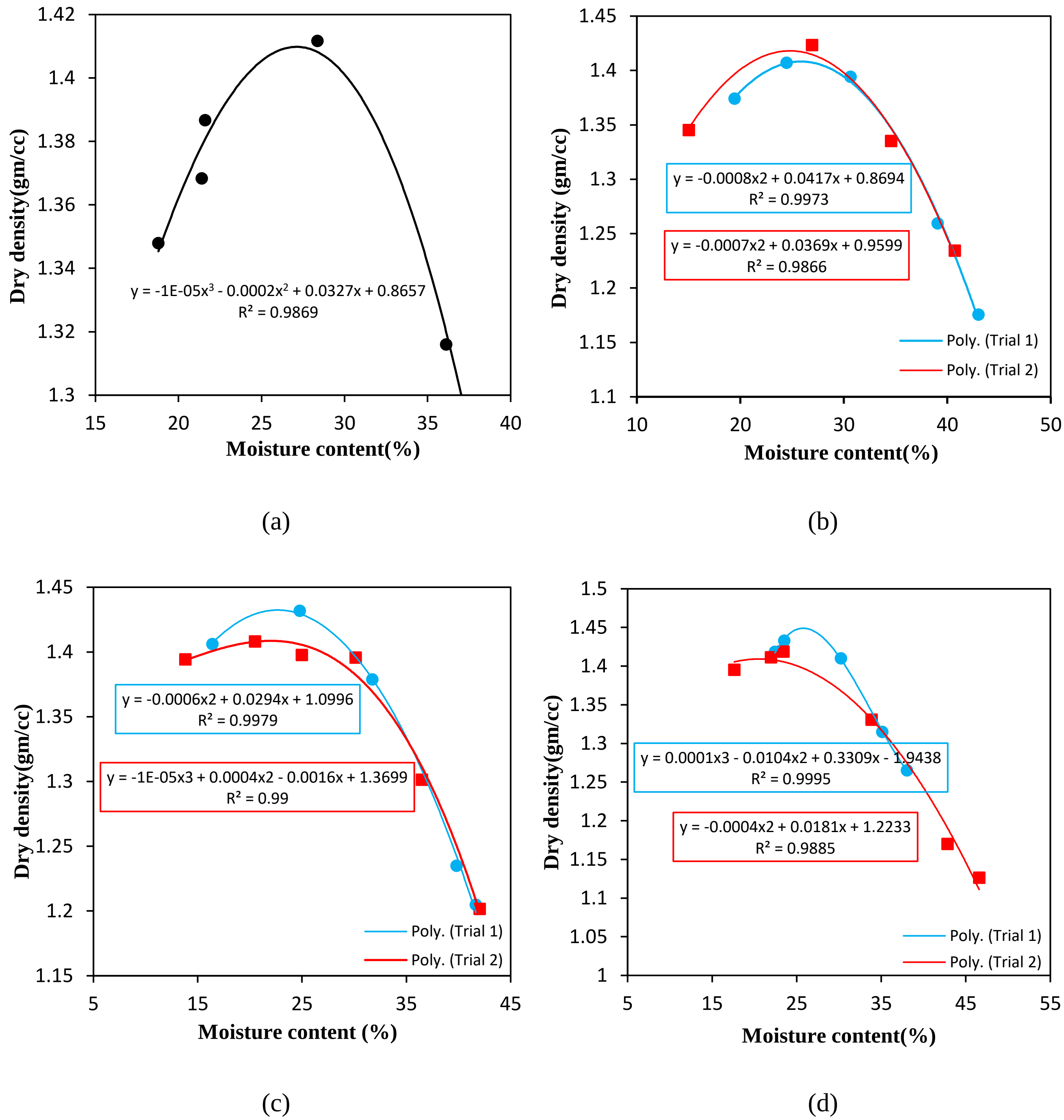


Fig.10. Dry density (gm/cc) Vs Moisture content (%) for (a) B.C. (b) B.C. + 5% fly ash (C) B.C.+ 15% fly ash (d) B.C. + 25% fly ash

It is observed that the O.M.C. of soil decreases with the increase in fly ash content up to addition of 25% fly ash due to the decrease in double diffused layer which eases flocculation and soil can be compacted in less moisture content. The variation of M.D.D with fly ash content is little bit complex trend initially, it increases with more fly ash content but after optimum fly ash content, it begins to decrease (Table 3).

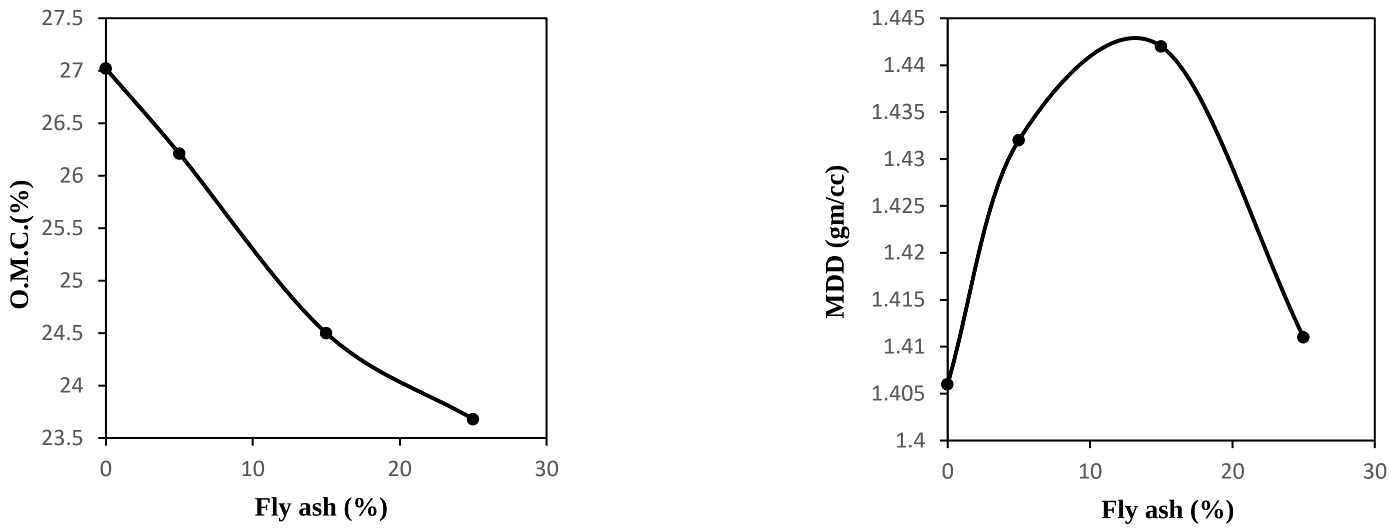


Fig.11. Variation of (a) O.M.C. and (b) M.D.D for black cotton soil and black cotton soil mixed with 5%, 15% and 25% fly ash.

4.2 Consolidation Test

Strain is defined as the ratio of change in dimension and initial dimension of the specimen. Oedometer test is a one-dimensional test in which direction of load is vertical to soil specimen. In this study, different types of loading conditions are applied so that different samples shows different stress-strain behaviour according to the loading pattern applied to it. For illustration, the compressive strain is taken as positive whereas swelling strain is taken as negative in this report. As mentioned earlier, total 7 samples were prepared. Vertical strain versus time (log scale) is plotted for black cotton soil, black cotton soil mixed with 5% fly ash and black cotton soil mixed with 25% fly ash (Fig.13-15 & Appendix A).

During the consolidation process, sample undergoes three stages of consolidation which are initial consolidation, primary consolidation, and secondary consolidation. Initial consolidation, primary consolidation and secondary consolidation occurs due to expulsion of air, due to expulsion of water and due to adjustment of internal structure of soil respectively. For illustration of the consolidation process, vertical strain versus time (log scale) (Fig.12.) of black cotton soil for sample 1 at 50kpa load (Fig.12.) presented.

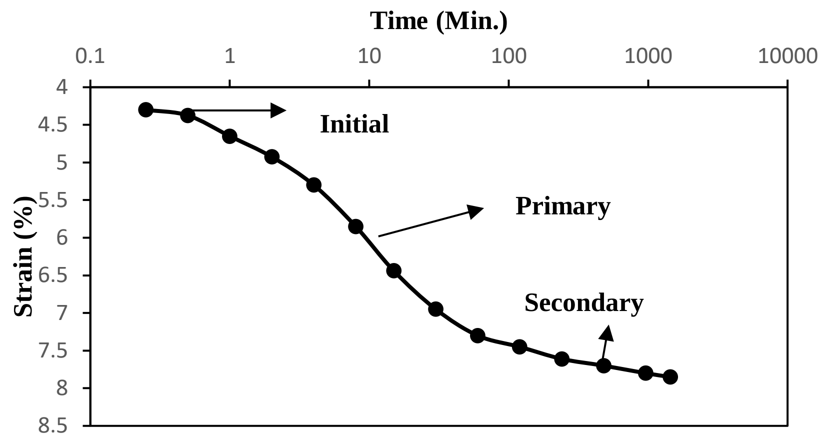
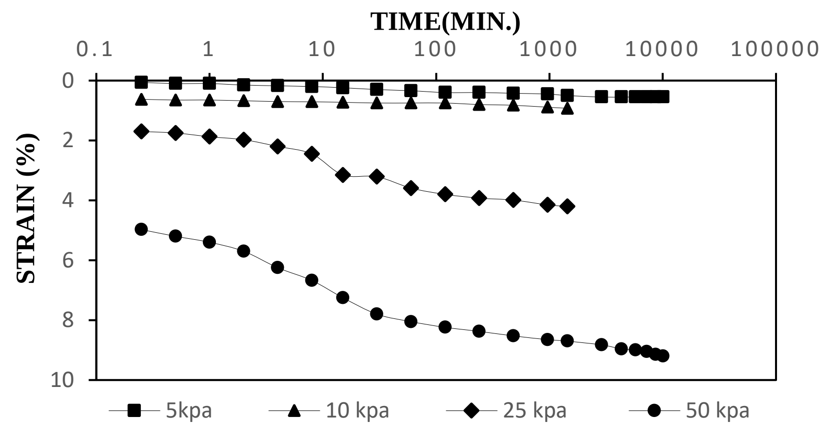
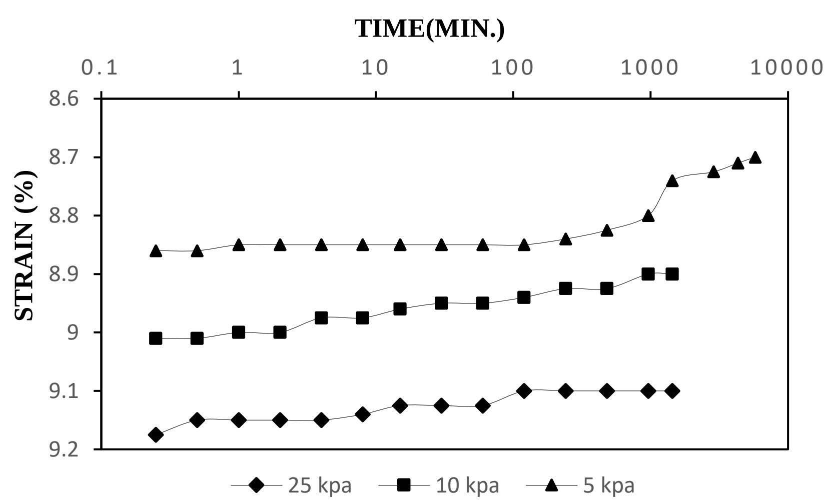


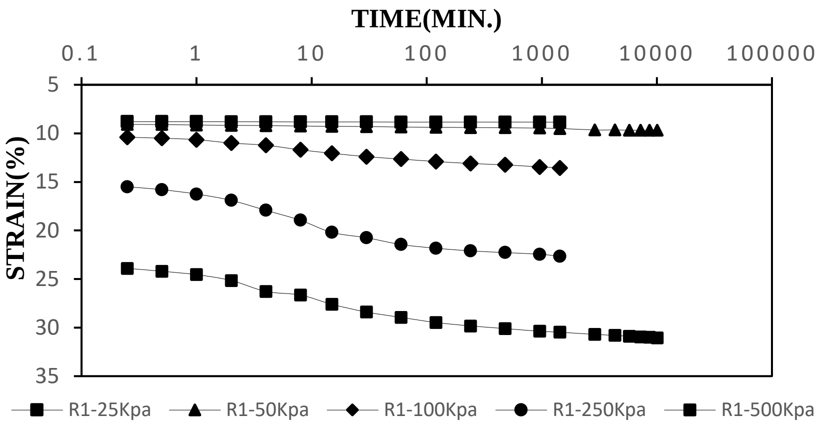
Fig.12. Strain versus time (min.) (log scale) of black cotton soil for sample 1 at 50kpa load



(a)

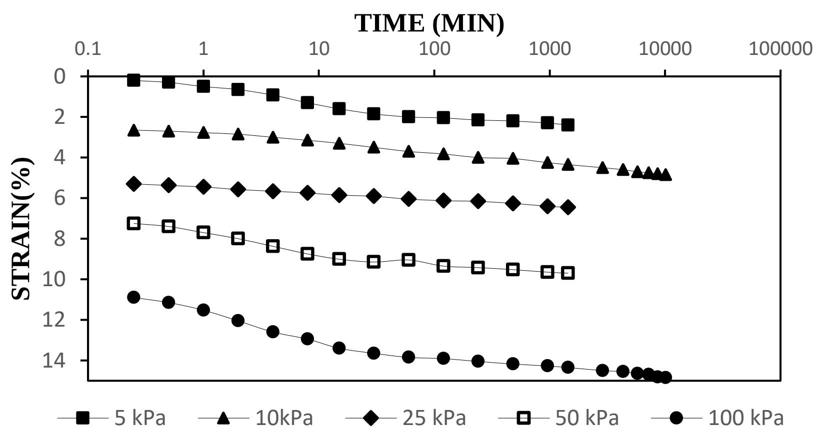


(b)

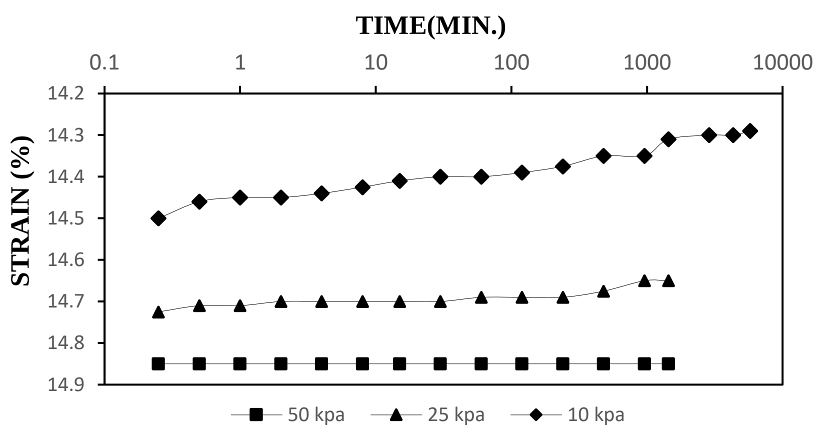


(c)

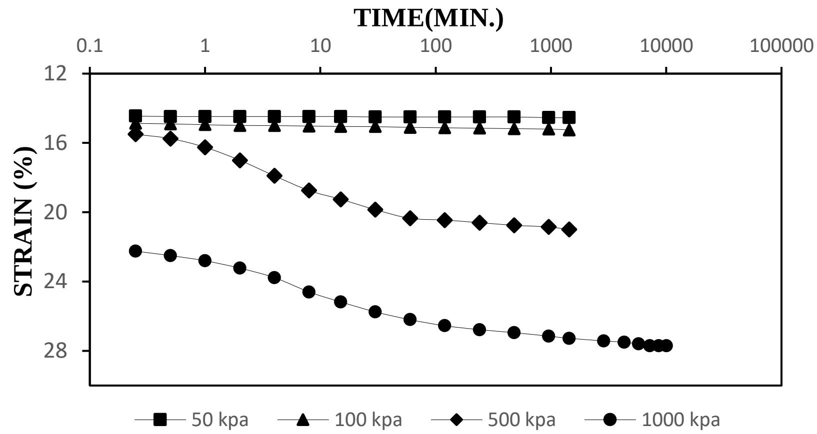
Fig.13. Strain versus time (log scale) of black cotton soil for sample 3 in (a) loading (b) unloading (c) reloading stage.



(a)

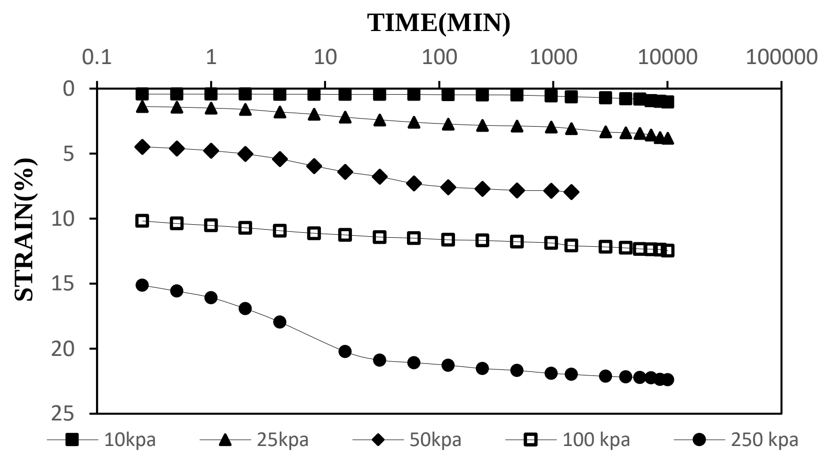


(b)

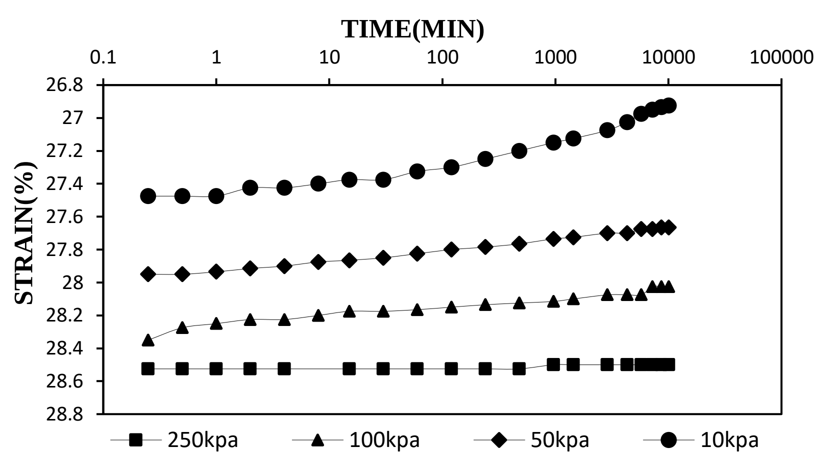


(c)

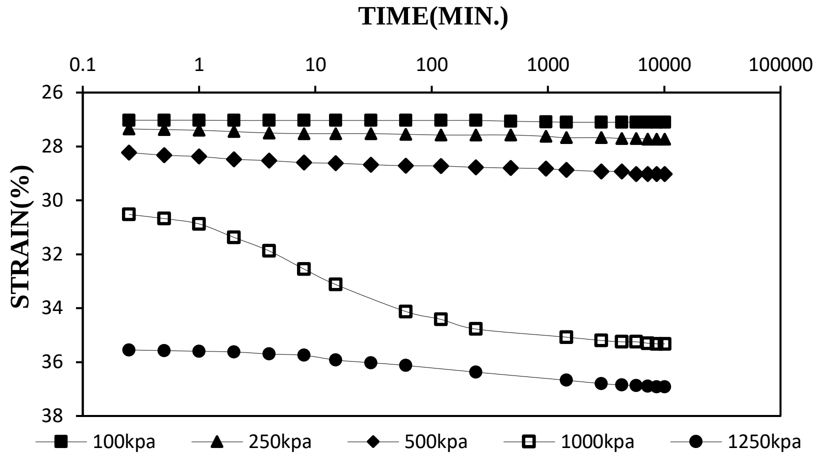
Fig.14. Strain versus time (log scale) of black cotton soil mixed with 5% fly ash for sample 1 in (a) loading (b) unloading (c) reloading stage.



(a)



(b)



(c)

Fig.15. Strain versus time (log scale) of black cotton soil mixed with 25% fly ash for sample 2 in (a) loading (b) unloading (c) reloading stage.

As mentioned earlier, primary consolidation is due to removal of pore water. In this project, Hypothesis A is assumed so creep strain begins after the end of primary consolidation. Time parameter t_o^c and t_o^s are taken as end of primary consolidation in loading and unloading stage respectively so time at which end of primary consolidation occurs is required. Casagrande's log (t) method is applied for determining the time for end of primary consolidation. Fig.16 illustrates the calculation for end of primary consolidation of black cotton soil for sample 1 at 50kPa load in loading stage.

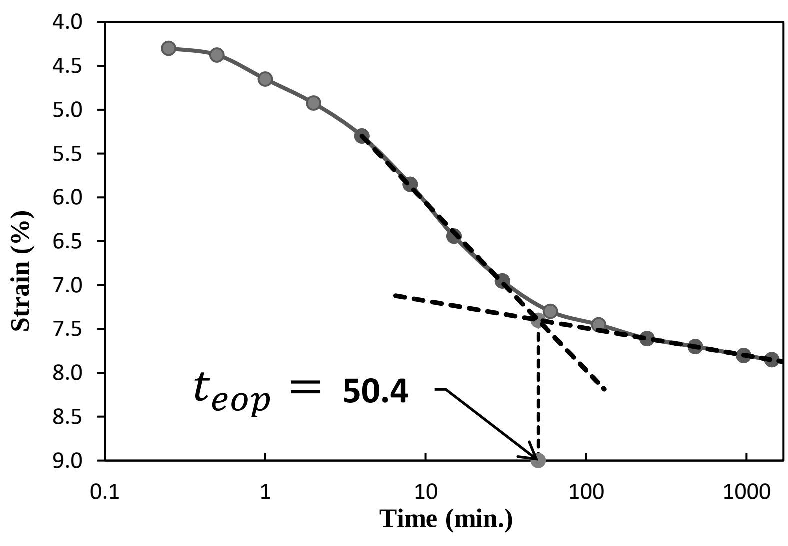


Fig.16. Strain versus time (log scale) of black cotton soil for sample 1 at 50kPa load in loading stage.

Fig.17 represents calculation for end of primary consolidation of black cotton soil mixed with 25% fly ash for sample 1 at 50kPa load in unloading stage for 3rd unloading cycle.

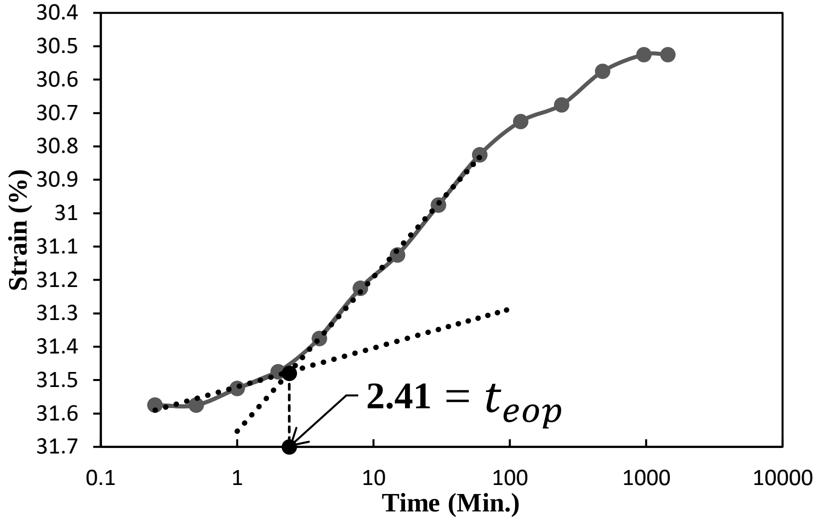


Fig.17. Strain versus time (log scale) of black cotton soil mixed with 25% fly ash for sample 1 at 50kPa load in unloading stage.

Time for the end of primary (t_{eop}) consolidation is calculated for each sample and each aim is illustrated in Flow chart 1for loading and unloading stage. t_{eop} varies for black cotton soil, black cotton soil mixed 5% fly ash and black cotton soil mixed with 25% fly ash from 19-51 minute, 26-45 minute and 29-73 minute respectively whereas in the unloading stage t_{eop} varies for black cotton soil, black cotton soil mixed 5% fly ash and black cotton soil mixed with 25% fly ash from 5-20 minute, 4-15 minute and 2-6 minute respectively which is earlier than the loading stage.

4.2.1 Compression ($\frac{\lambda}{\nu}$) and Rebounding parameter ($\frac{\kappa}{\nu}$)

Compression and rebounding parameter are defined as slope of effective stress (Ln Scale) versus strain curve in normal loading and over-consolidation loading condition respectively. The initial part of the curve (flatter part) represents that the soil sample is in over-consolidated loading condition which means present effective stress on the soil is less than the maximum past effective stress applied and the slope of this part is rebounding parameter (κ/ν) while later on the slope of the curve increases and represents that the soil is in normal loading condition which means present effective stress on the sample is greater than the maximum past stress and the slope of this part is compression parameter (λ/ν). The soil shows elastic behaviour in the over-consolidated condition whereas in normal loading conditions the soil shows elastic-plastic behaviour. In this study, strain is taken as the corresponding stress is applied for 1 day.

Fig.18-20 represent effective stress versus strain for black cotton soil samples, black cotton soil mixed with 5% fly ash and black cotton soil mixed with 25% fly ash respectively

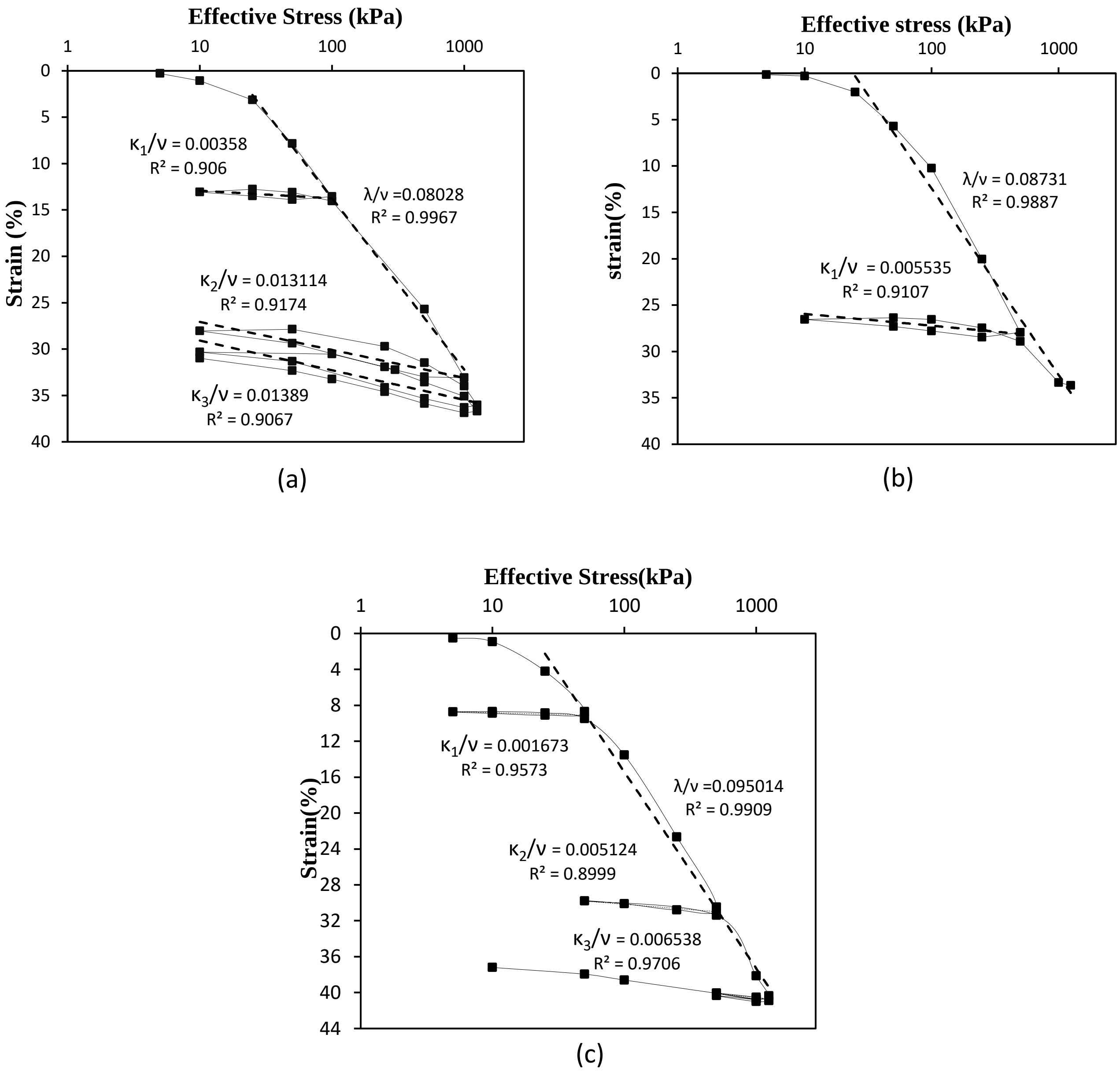


Fig. 18. Effective stress (Ln Scale) versus strain of black cotton soil for (a) sample 1 (b) sample 2 (c) sample 3

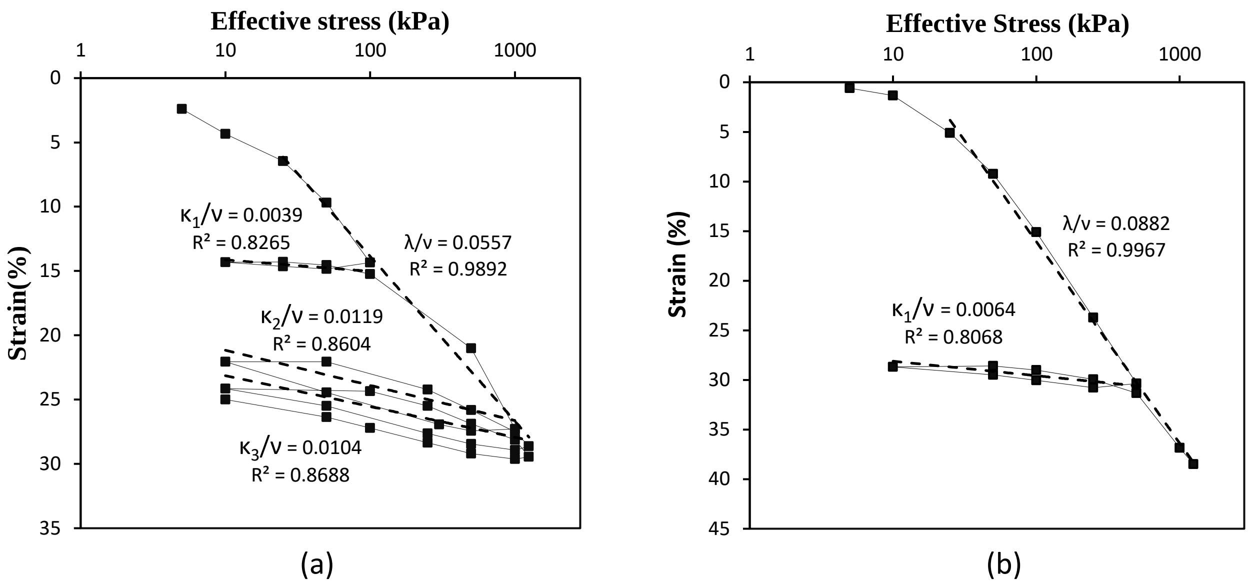


Fig. 19. Effective stress (Ln Scale) versus strain of black cotton soil mixed with 5% fly ash for (a) sample 1 (b) sample 2.

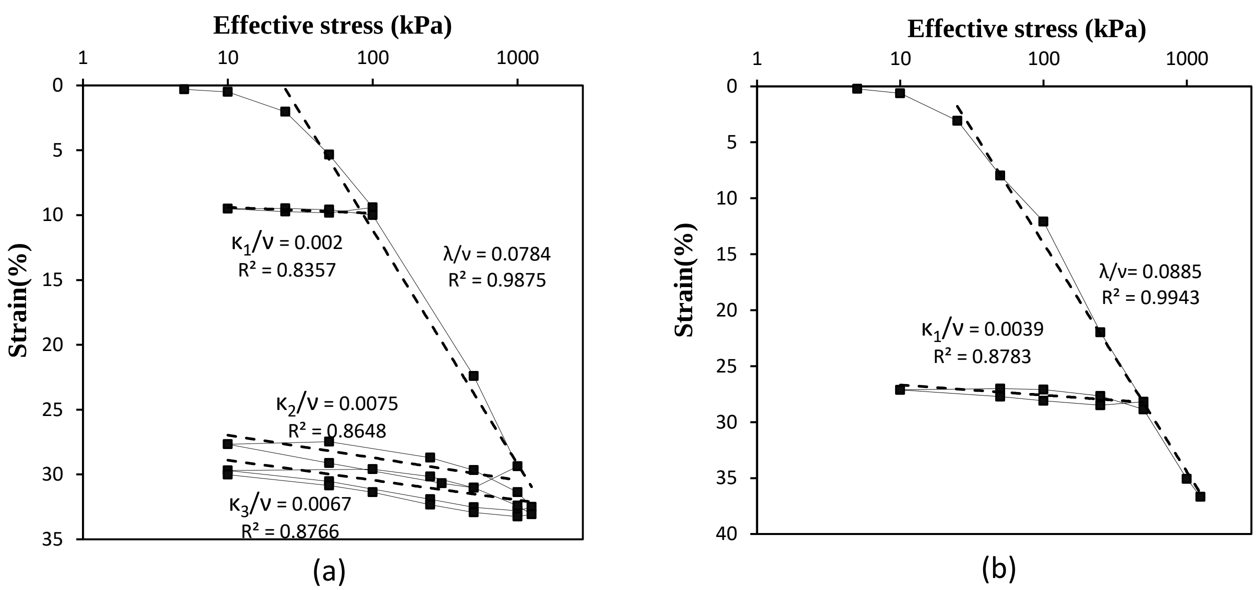


Fig. 20. Effective stress (Ln Scale) versus strain of black cotton soil mixed with 25% fly ash for (a) sample 1 (b) sample 2.

All the values determined of compression and rebounding parameter for all samples are listed in table 4.

Samples	(κ/ν)	(λ/ν)	(C_r/V)	(C_c/V)	$(κ/ν)_{avg}$
B.C. Soil (1)	0.0036 0.0131 0.0139	0.0803	0.00828 0.03013 0.03197	0.18469	0.0102
B.C. Soil (2)	0.0055	0.0873	0.01273	0.20081	0.0055
B.C. Soil (3)	0.0017 0.0051 0.0065	0.095	0.00385 0.01178 0.01504	0.21853	0.0044
B.C. Soil+5% fly ash (1)	0.0039 0.0119 0.0104	0.0557	0.00897 0.02737 0.02392	0.12811	0.0087
B.C. Soil+5% fly ash (2)	0.0064	0.0882	0.01472	0.20286	0.0064
B.C. Soil+25% fly ash (1)	0.002 0.0075 0.0067	0.0784	0.0046 0.01725 0.01541	0.18032	0.0054
B.C. Soil+25% fly ash (2)	0.0039	0.0885	0.00897	0.20355	0.0039

Table 4. Material parameter for each sample of black cotton soil, black cotton soil mixed with 5% fly ash, black cotton soil mixed with 25% fly ash.

Range of compression index varies from 0.18 to 0.21 and rebounding index varies from 0.008 to 0.32 for black cotton soil which is consistent with previous investigation results (Feng et al. 2017). (Nakase et al. 1988) presented that $\frac{C_r}{C_c}$ is 0.144 for reconstitute black cotton soil and the experimental result for $\frac{C_r}{C_c}$ of black cotton soil comes out to be 0.127, which agrees well with Nakase result.

Compression parameter is more for sample with objective of checking creep behaviour than for sample kept for checking swelling behaviour for each type of soil, this is because of the loading conditions in the former one in which every load was kept for longer duration (7 days) hence causing more of plastic strain. Similarly rebounding parameter is more for the samples with the objective of checking swelling behaviour as it involves much higher unloading amplitude and more number of loading-reloading cycles.

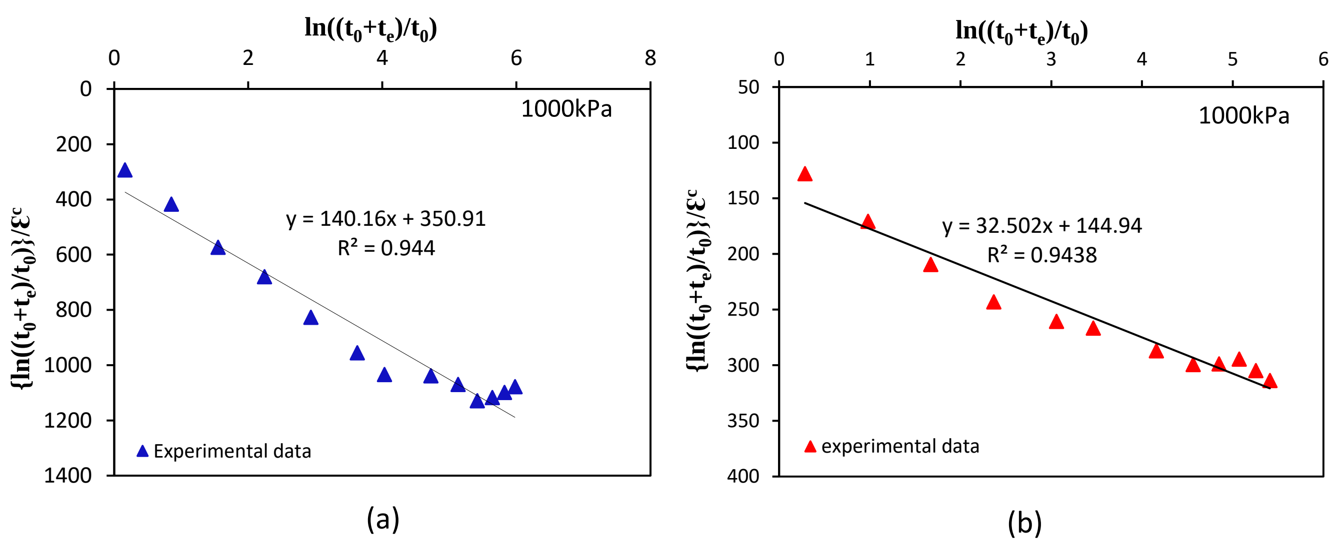
Rebounding parameter is decreasing with increasing fly ash content up to addition of 25% fly ash in black cotton soil which shows that the sample with more fly ash content exhibits less elastic strain.

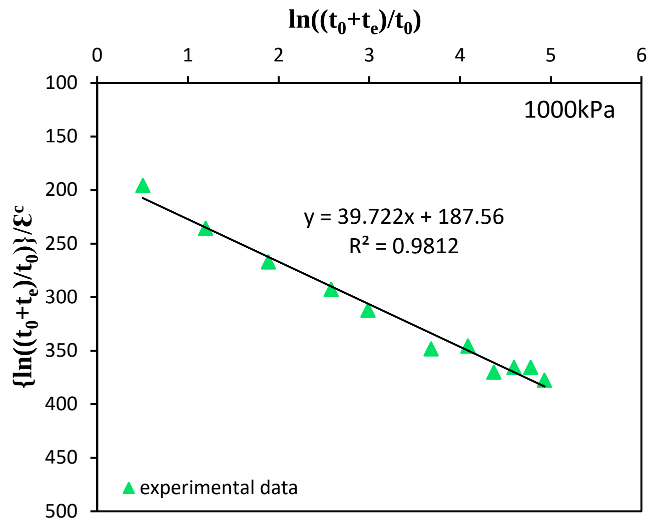
4.2.2 Creep behaviour analysis

Soil specimen shows viscous behaviour during the loading stage which is known as creep. As mentioned earlier, creep strain can be estimated using linear and nonlinear creep equation and creep strain contributes to the total strain after the end of primary consolidation in loading stage. In the linear equation, creep strain will be infinite if load is applied for infinite time which is the drawback of linear equation. Therefore non-linear creep equation is employed to analyse the long term creep behaviour because it consist of creep strain limit for infinite time of load application. In the analysis of creep behaviour using nonlinear equation, creep coefficient and creep strain limit is required. Nonlinear equation for creep strain can be written as

$$\frac{1}{\epsilon_z^c}\ln(\frac{t_0^c+t_e^c}{t_0^c}) = \frac{\upsilon}{\psi_0^c} + \frac{1}{\epsilon_z^{cl}}\ln(\frac{t_0^c+t_e^c}{t_0^c})$$

If $\frac{1}{\epsilon_z^c}\ln(\frac{t_0^c+t_e^c}{t_0^c})$ and $\ln(\frac{t_0^c+t_e^c}{t_0^c})$ are assumed as two variable and experimental data are plotted between these two variable (Fig.24) then above equation will be in $y = a + bx$ format and equation for experimental result is compared. Creep coefficient and creep strain limit will be reverse of intercept and slope of equation obtained for experimental result. It is observed (Table 5) that creep coefficient decreases with increase in effective stress and number of loading cycle. The creep coefficient is found to be more for the sample with objective of checking creep behaviour than for the sample kept for checking of swelling behaviour which is reasonable as the loading duration is more for the former sample. Increase in fly ash content up to addition of 25% fly ash in black cotton soil causes a decrease in creep coefficient for same loading amplitude and loading cycle which means black cotton soil blended with fly ash (up to 25% fly ash) exhibit lesser creep strain.





(c)

Fig.21. Curve fitting for nonlinear equation of creep strain for (a) black cotton soil (b) black cotton soil mixed with 5% fly ash (c) black cotton soil mixed with 25% fly ash.

Sample	Loading (kPa)	Creep coefficient (ψ^c/v)	Creep Strain Limit ϵ_z^{cl}
B.C. Soil (1)	500-1 1000-1 250-2 1000-3	0.018153 0.008927 0.00274 0.001593	0.034382 0.025808 0.002207 0.001593
B.C. Soil (2)	250-0 500-0 1000-1	0.007983 0.006226 0.00285	0.036929 0.032922 0.007135
B.C. Soil (3)	50-0 250-2 1000	0.003571 0.01254 0.000267	0.02962 0.02626 0.004910
B.C. Soil+5% fly ash (1)	500-1 1000-1 250-3	0.011550 0.006899 0.001859	0.018423 0.030767 0.004392
B.C. Soil+5% fly ash (2)	100-0 250-0 250-1	0.004550 0.005801 0.000624	0.036716 0.061706 0.004849
B.C. Soil+25% fly ash (1)	500-1 1000-1 1000-2	0.017581 0.005332 0.001617	0.020924 0.025175 0.005198
B.C. Soil+25% fly ash (2)	250-0 1000-1	0.006899 0.005794	0.028903 0.019486

(Here 0,1,2,3 after load refers to loading, 1st reloading, 2nd reloading, 3rd reloading)

Table 5. Creep coefficient and creep strain limit for black cotton soil, black cotton soil mixed with 5% and 25% fly ash.

In this oedometer test samples were kept for a long time duration of 90-120 days. If the time duration increase then it is more difficult to get the experimental data of creep strain. So linear and nonlinear equation proposed for prediction of creep strain as mentioned earlier. Fig.22-24 represent prediction of strain in the loading stage using linear and nonlinear equation and how these are close to experimental result.

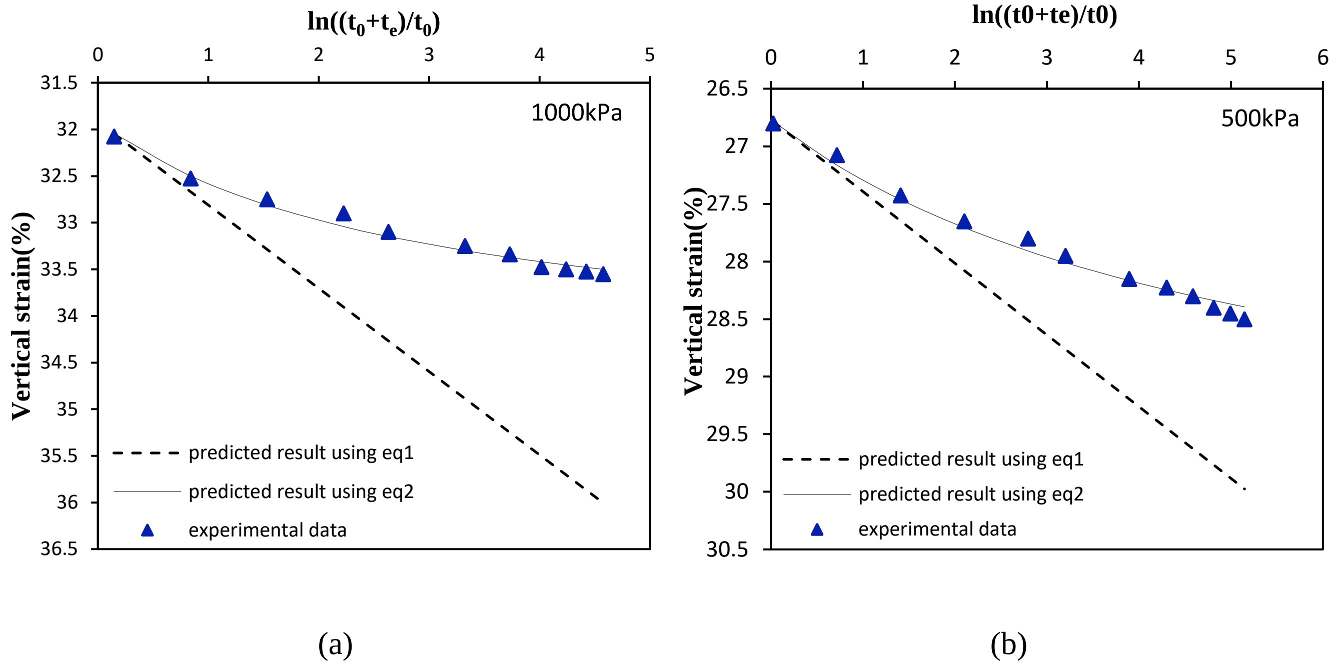


Fig.22. Vertical strain versus $\ln(\frac{t_0^c+t_e^c}{t_0^c})$ of black cotton soil for (a).Sample 1 (b). Sample 2

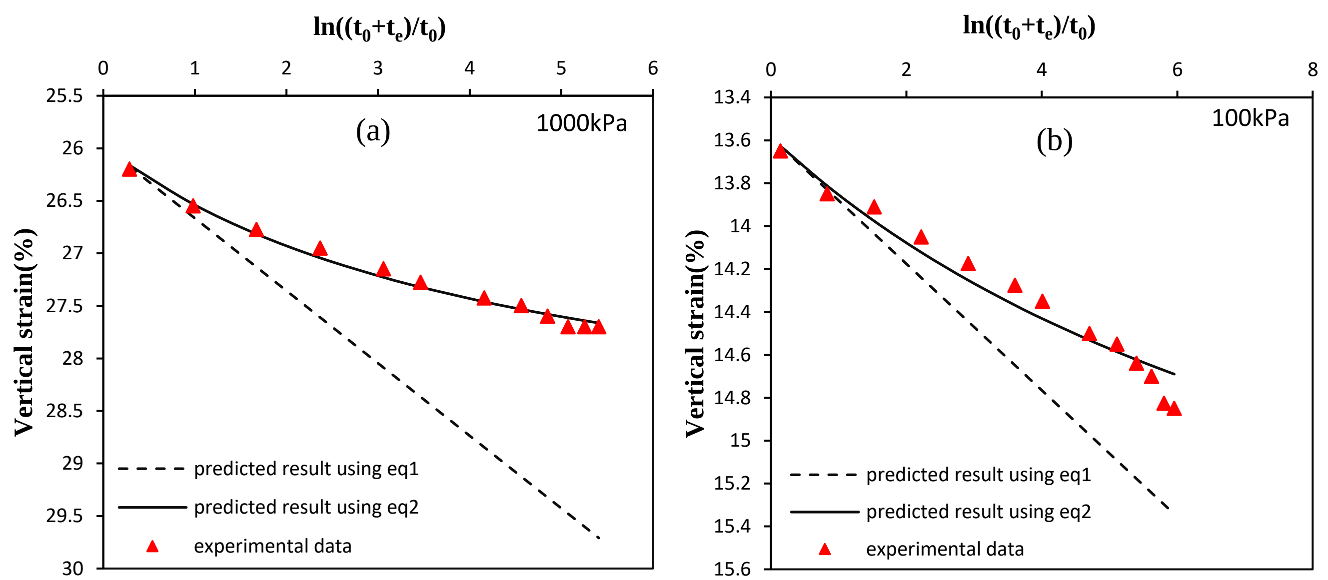


Fig.23. Vertical strain versus $\ln(\frac{t_0^c+t_e^c}{t_0^c})$ of black cotton soil mixed with 5% fly ash for (a) Sample 1 (b) Sample 2

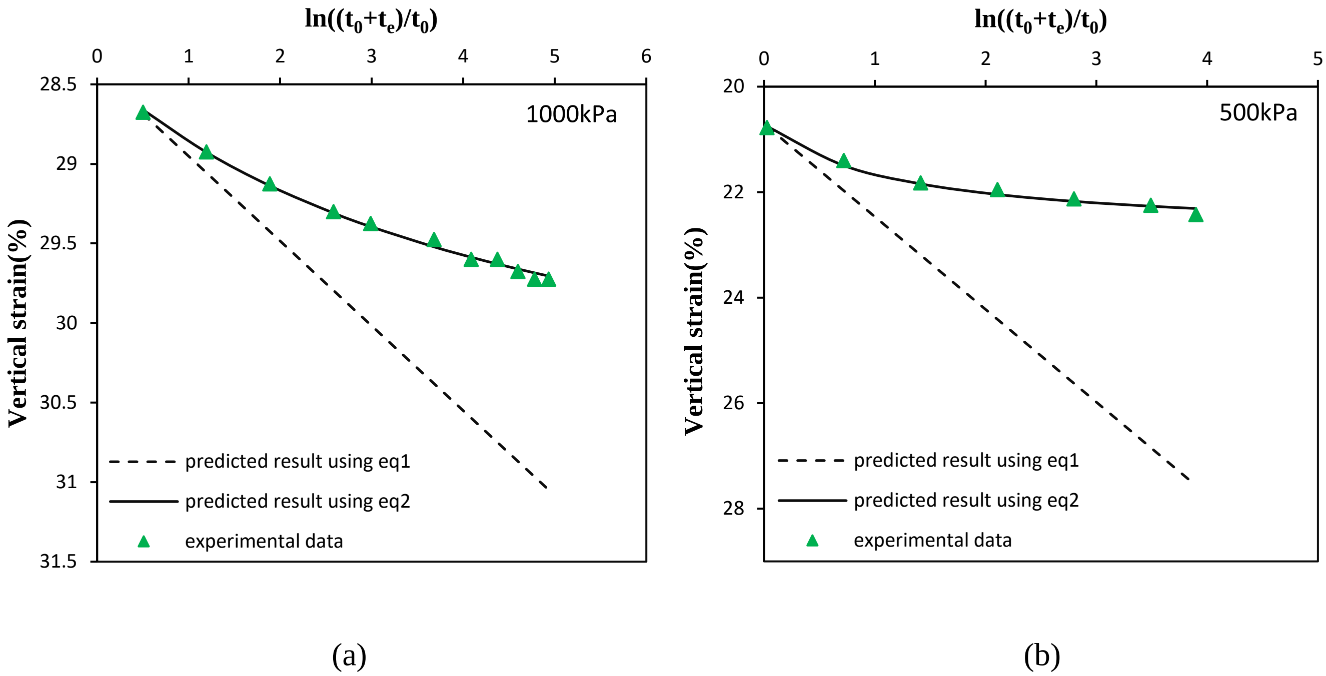


Fig.24. Vertical strain versus $\ln(\frac{t_0^c+t_e^c}{t_0^c})$ of black cotton soil mixed with 25% fly ash for (a) Sample 1 (b) Sample 2

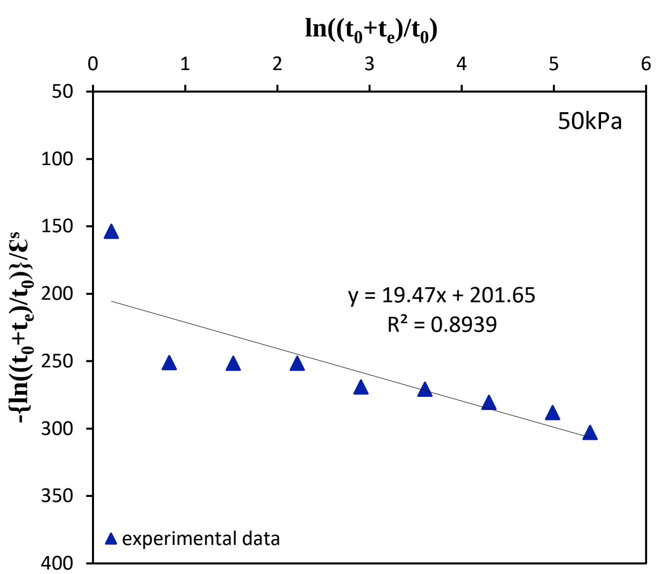
It is evident from the graph that the experimental strain differs significantly from the results predicted using linear creep equation which increases even more with the passage of time whereas experimental data is very close to the results predicted by nonlinear creep equation even for the long duration of loading. Hence nonlinear creep equation is necessary to employ for the analysis of long-term creep behaviour.

4.2.3. Swelling behaviour analysis

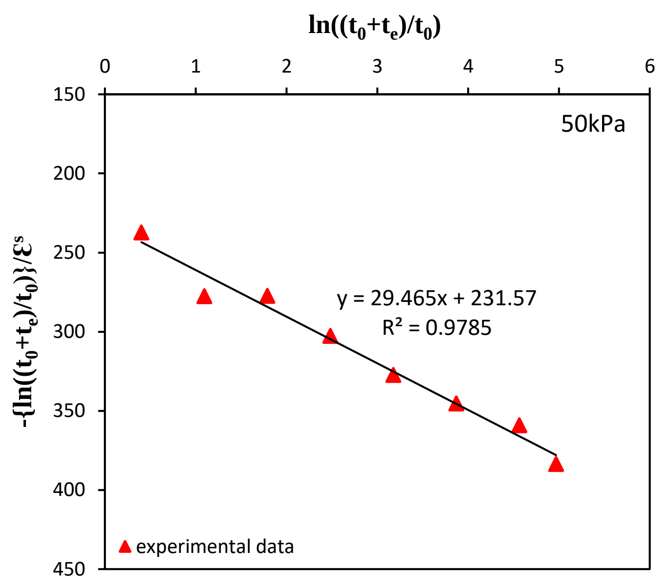
Soil specimen shows viscous behaviour during the unloading stage which is known as swelling. As mentioned earlier swelling strain also can be estimated using linear and nonlinear equation as creep strain and swelling strain contribute in total strain after end of primary consolidation in unloading stage. In analysis of swelling behaviour using nonlinear equation, swelling coefficient and swelling strain limit are required. Swelling strain is presented in negative because of sign convention which is negative for swelling strain. Nonlinear equation for swelling strain can be written as

$$-\frac{1}{\epsilon_z^s}\ln(\frac{t_0^s+t_e^s}{t_0^s}) = \frac{\upsilon}{\psi_0^s} - \frac{1}{\epsilon_z^{sl}}\ln(\frac{t_0^s+t_0^e}{t_0^s})$$

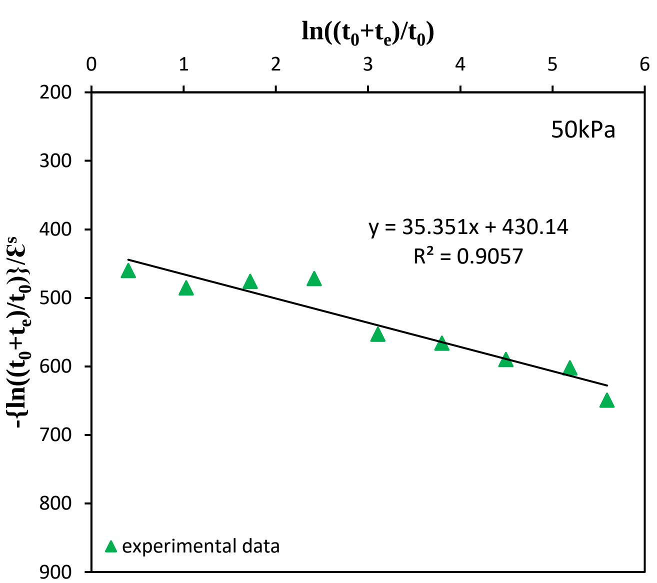
If $-\frac{1}{\epsilon_z^s}\ln(\frac{t_0^s+t_e^s}{t_0^s})$ and $\ln(\frac{t_0^s+t_0^e}{t_0^s})$ are taken as two variable experimental data are plotted between these two variable (Fig.24) then above equation will be in $y = a + bx$ format and equation for experimental result is compared. Swelling coefficient will be reverse of intercept and swelling strain limit will be negative of reverse of slope of equation obtained for experimental result.



(a)



(b)



(c)

Fig.25. Curve fitting for nonlinear equation of swelling strain for (a) black cotton soil (b) black cotton soil mixed with 5% fly ash (c) black cotton soil mixed with 25% fly ash.

Sample	**Unloading (kPa)**	**Swelling Coefficient $\frac{\psi_0^s}{\upsilon}$**	**Swelling strain limit (ϵ_z^{sl})**
B.C. Soil (1)	10-1 50-2 250-3 500-4	0.000582 0.004959 0.001694 0.001579	-0.00663 -0.05136 -0.0274 -0.0116
B.C. Soil (2)	10-1 100-1	0.001196 0.000599	-0.01531 -0.00754
B.C. Soil (3)	100-2 100-5 10-5	0.002592 0.004861 0.002302	-0.004603 -0.02639 -0.03742
B.C. Soil+5% fly ash (1)	50-2 50-3 50-4	0.004318 0.006618 0.001731	-0.033939 -0.018842 -0.018148
B.C. Soil+5% fly ash (2)	100-1 10-1	0.0008 0.0016072	-0.016154 -0.01881361
B.C. Soil+25% fly ash (1)	50-2 10-2 50-3	0.002325 0.002558 0.002237	-0.02829 -0.04907 -0.03515

(Here 1,2,3,4 refers to 1st time, 2nd time, 3rd time, 4th time unloading)

Table 6. Swelling coefficient and swell strain limit for black cotton soil, black cotton soil mixed with 5% and 25% fly ash.

It is observed (Table 6) that swelling coefficient and swelling strain limit increases with increase in unloading amplitude and decreases with increases in number of unloading cycle. Increase in fly ash content up to addition of 25% fly ash in black cotton soil causes a decrease in swelling coefficient for same unloading amplitude and unloading cycle which means black cotton soil blended with fly ash (up to 25% fly ash) exhibit lesser swelling strain.

For prediction of swelling strain linear and nonlinear equation are used. Fig.26-28 shows the prediction of strain in unloading stage using linear and nonlinear equation and deviation of predicted strain from experimental data.

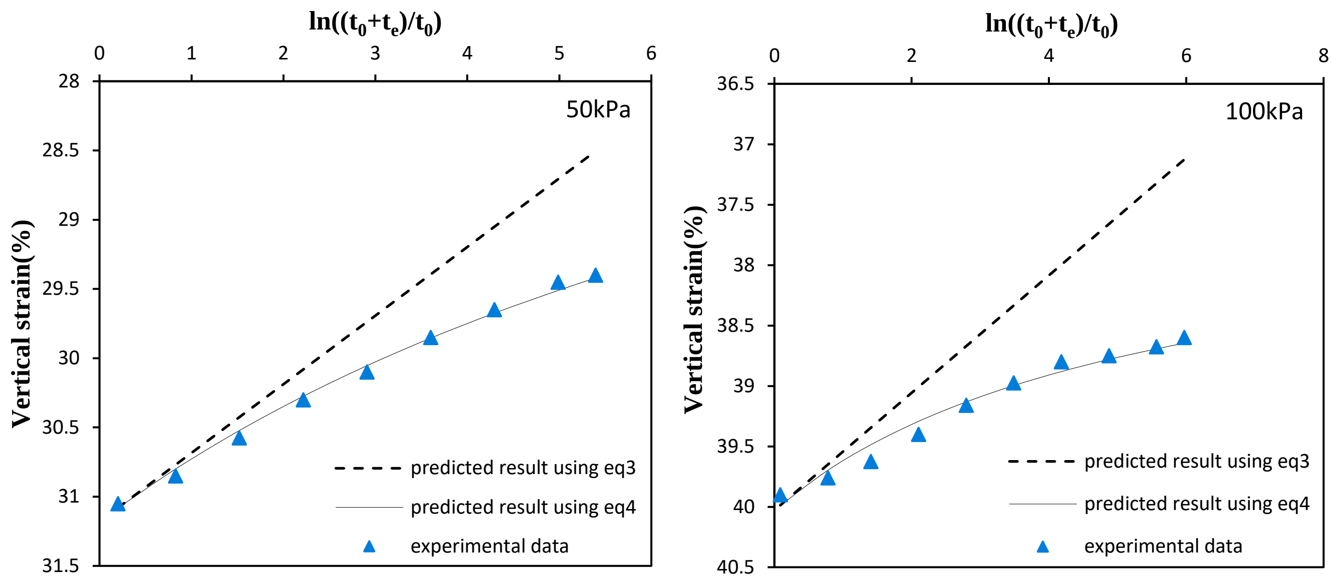


Fig.26. Vertical strain versus $\ln(\frac{t_0^c+t_e^c}{t_0^c})$ of black cotton soil for (a) Sample 1 (b) Sample 2

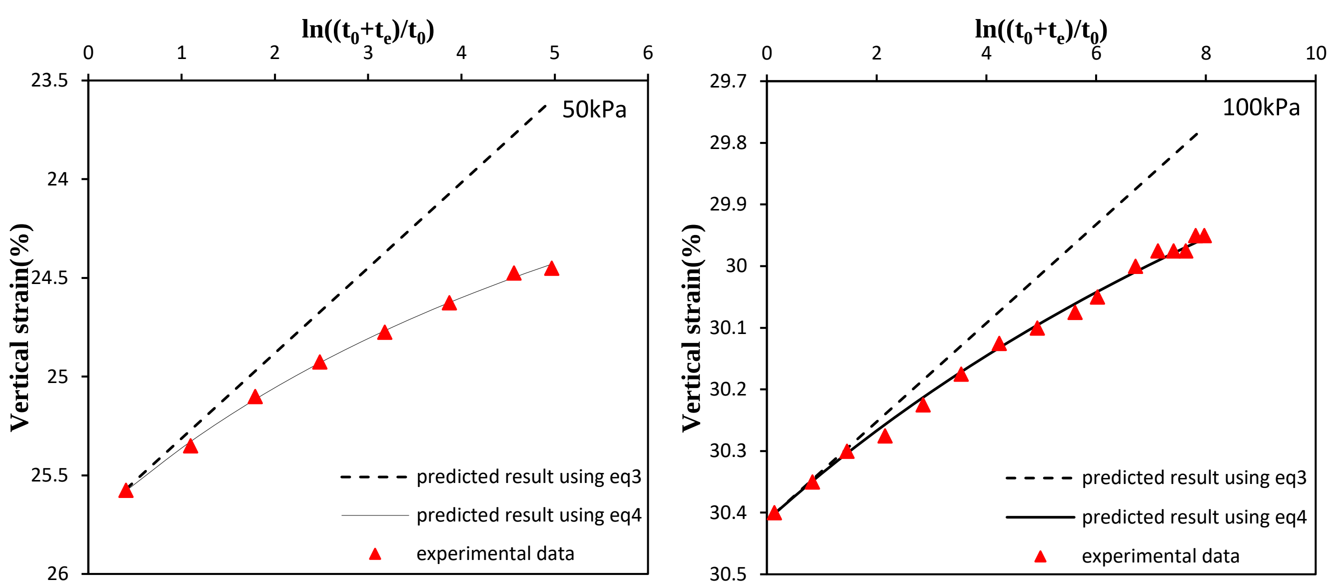


Fig.27. Vertical strain versus $\ln(\frac{t_0^c+t_e^c}{t_0^c})$ of black cotton soil mixed with 5% fly ash for (a) Sample 1 (b) Sample 2

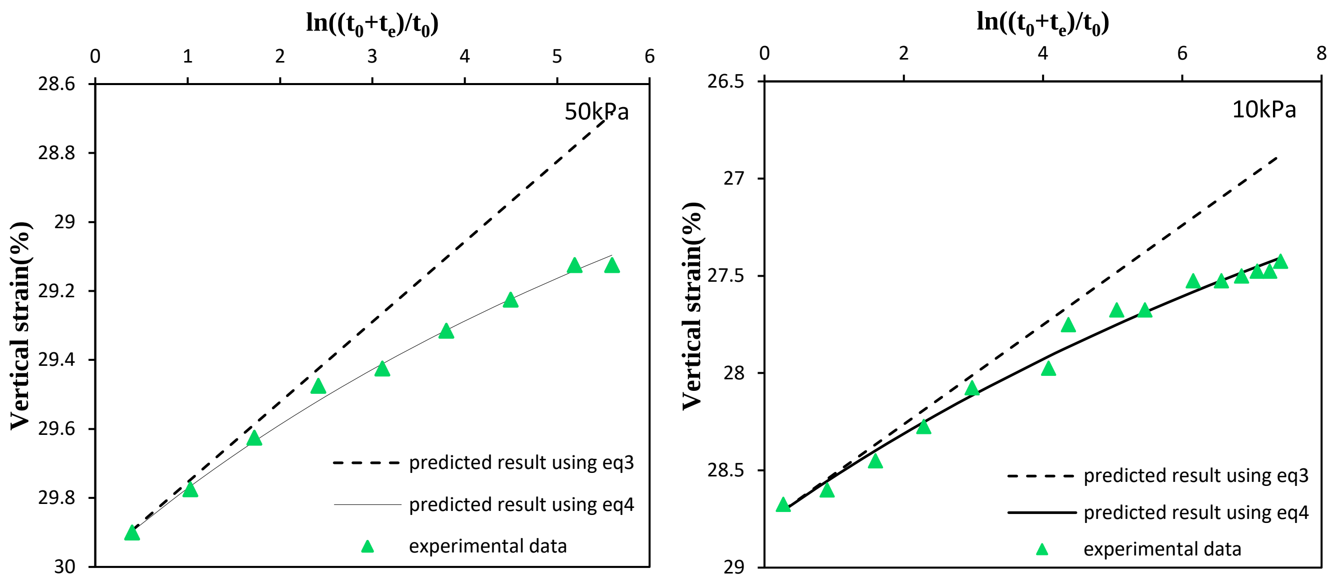


Fig.28. Vertical strain versus $\ln(\frac{t_0^c+t_e^c}{t_0^c})$ of black cotton soil mixed with 25% fly ash for (a) Sample 1

(b) Sample 2

The experimental data for swelling strain during the unloading stage as can be seen from the graph follows results closely predicted from non-linear swelling equation even when the sample was kept for long duration. While the results predicted from the linear swelling equation over-estimates the swelling strain as it doesn't consider any limit to the time-dependent swelling strain which non-linear swelling equation considers well enough. Therefore it is more suitable to use non-linear equation for analysis of swelling.

4.3 Direct Shear Test

Direct shear test is used for the investigation of shear stress and shear displacement. Shear behaviour of black cotton soil, black cotton soil mixed with 5% fly ash and black cotton soil mixed with 25% fly ash is studied for three strain rate which are 0.625mm/min., 0.25mm/min., and 0.025mm/min. corresponding to 50, 100 and 150kPa normal loading. Variation in shear behaviour is also studied for single and multi-staged test at 0.25mm/min. strain rate corresponding to three normal loadings. Fig.29. represents shear behaviour of black cotton soil for different strain rates and multi-staged test at 0.25mm/min. rate.

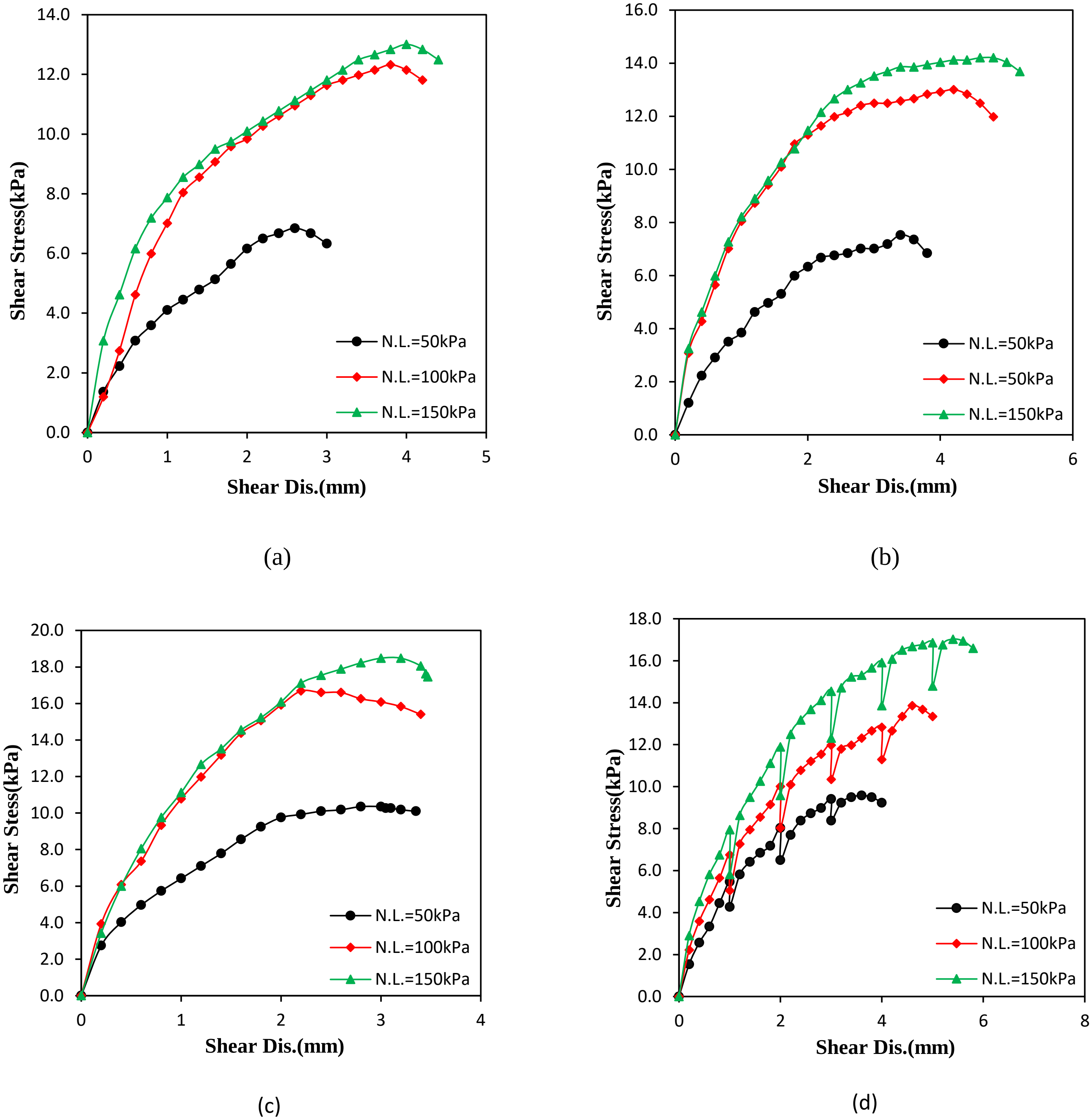


Fig.29. Shear stress (kPa) versus shear Displacement (mm) for black cotton soil at strain rate (a) 0.625mm/min. (b) 0.25mm/min. (c) 0.025mm/min. (d) multi-staged test at 0.25mm/min.

Strain rate affects shear behaviour. To study the influence of strain rate on shear behaviour, test is done for three strain rates to compare for black cotton soil at normal loading 50kPa. Single and multi-staged test results are also compared at normal loading 50kPa.

Fig.30. represents shear behaviour of black cotton soil for different strain rates, also single and multi-staged test results are compared at 0.25mm/min and 50kPa normal loading.

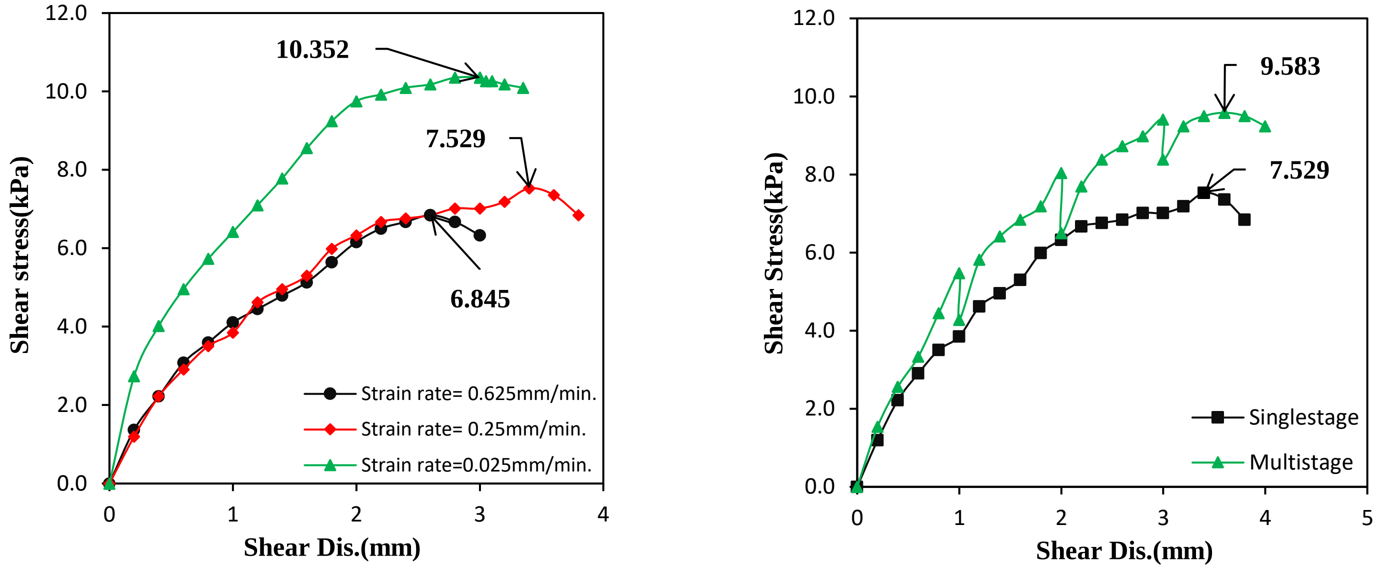


Fig.30. Shear stress versus shear displacement of black cotton soil (a) with change of strain rate 0.625mm/min., 0.25mm/min., 0.025mm/min. at 50kPa normal loading (b) with multi-staged and single-stage test at strain rate 0.25mm/min at 50kPa normal loading.

Shear stress increases as strain rate decreases (fig.30.a). Change in shear stress is less for change in strain rate from 0.625mm/min. to 0.25mm/min. but it is significant for change in strain rate from 0.625mm/min. to 0.025mm/min. which is 25 times less than 0.625mm/min. rate. Shear stress is also affected by single and multi-staged test. For the multi-staged test, time relaxation of 10min. was given and horizontal stress was released. Shear behaviour under single and multi-staged test was studied at strain rate 0.25mm/min. and it is found that under multi-staged process shear strength of black cotton soil is increases considerably.

Fig.31 represents shear behaviour of black cotton soil mixed with 5% fly ash for different strain rates and multi-staged test at 0.25mm/min. rate. Fig 32 represents shear stress versus shear displacement of black cotton soil mixed with 5% fly ash for different strain rate and multi-staged single stage at 0.25mm/min. at normal loading 50kPa. Shear strength increases with decrease of strain rate (fig.32.a) and there is a significant increase in shear strength occurs for multi-staged test.

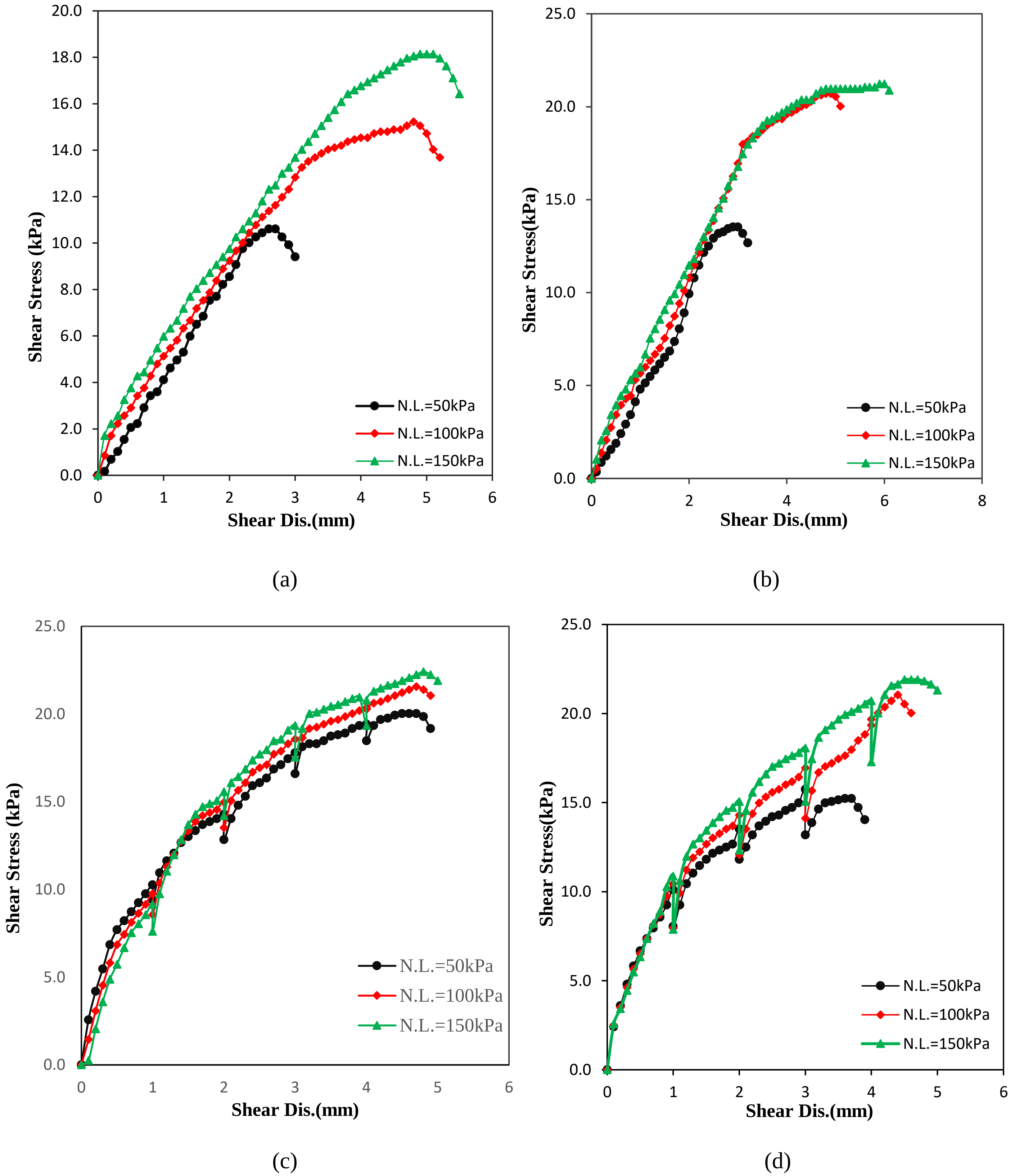
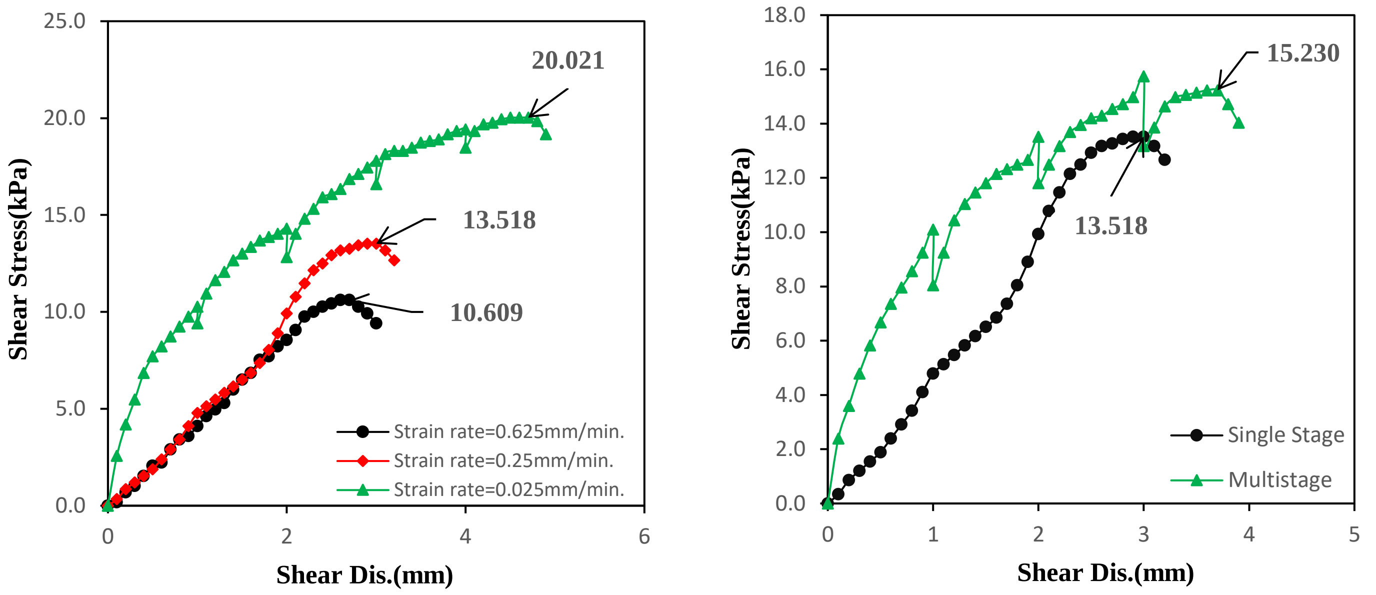


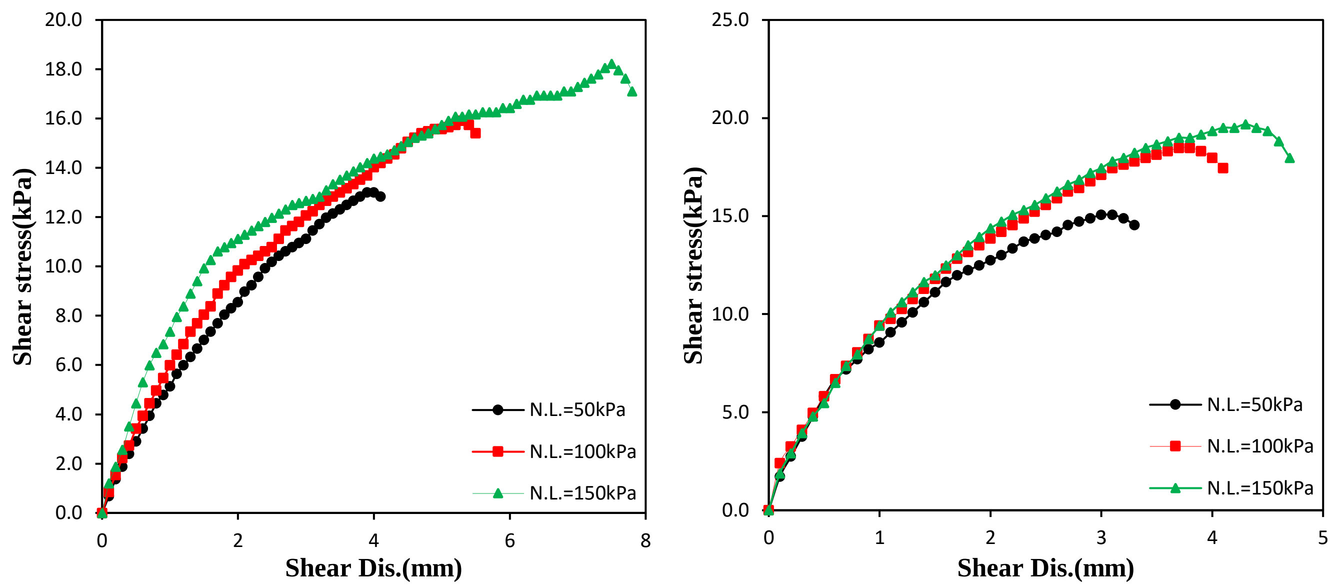
Fig.31. Shear stress (kPa) versus shear displacement (mm) of black cotton soil mixed with 5% fly ash at strain rate (a) 0.625mm/min. (b) 0.25mm/min. (c) 0.025mm/min. (d) multistage at 0.25mm/min.



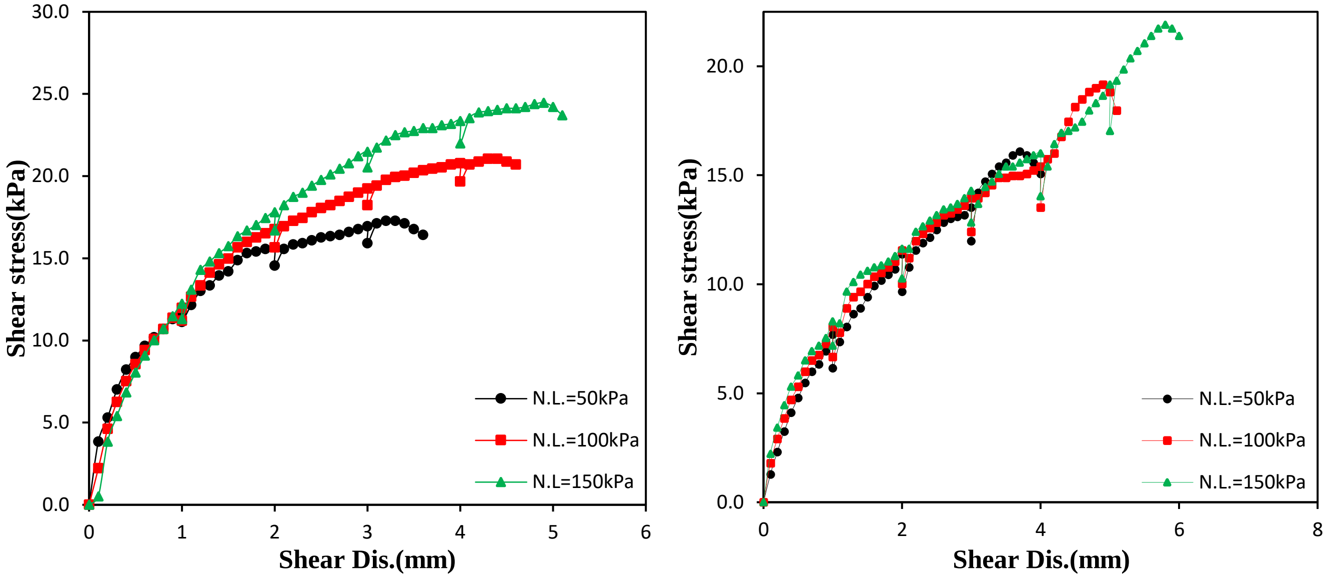
(a) (b)

Fig.32.Shear stress versus shear displacement of black cotton soil mixed with 5% fly ash at (a) change of strain rate 0.625mm/min., 0.25mm/min., 0.025mm/min. (b) multistage and single stage at strain rate0.25mm/min (at 50kPa normal loading).

Fig.33. and Fig.34.represents shear behaviour of black cotton soil mixed with 25% fly ash for different strain rate, multi-staged test at 0.25mm/min. and influence of strain rate and multi-staged test on shear behaviour.



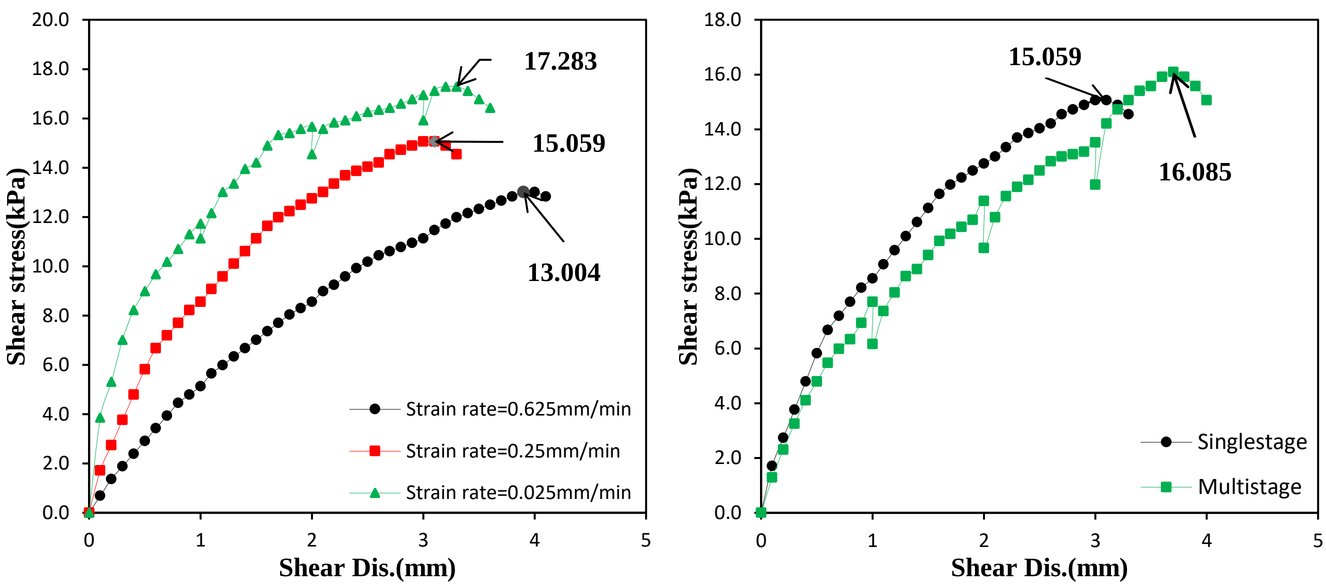
(a) (b)



(c) (d)

Fig.33. Shear stress (kPa) versus shear displacement (mm) of black cotton soil mixed with 25% fly ash at strain rate (a) 0.625mm/min. (b) 0.25mm/min. (c) 0.025mm/min. (d) multi-staged at 0.25mm/min.

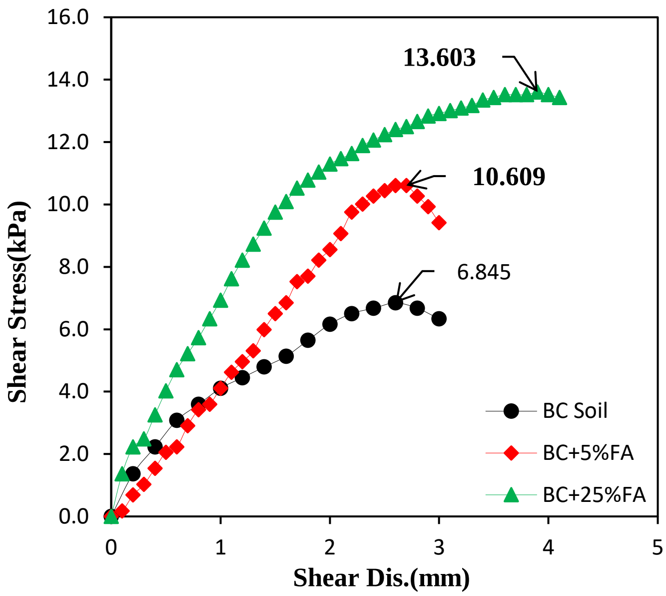
Similar to the results obtained for other samples, shear strength for black cotton soil mixed with 25% fly ash also increases with decrease in strain rate and under multi-staged test (fig.34).



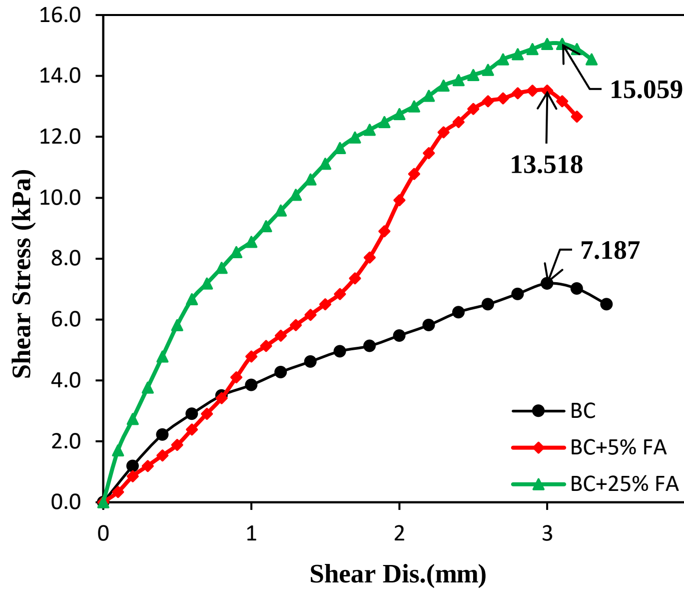
(a) (b)

Fig.34. Shear stress versus shear displacement of black cotton soil mixed with 25% fly ash at (a) change of strain rate 0.625mm/min., 0.25mm/min., 0.025mm/min. (b) multi-staged and single stage at strain rate0.25mm/min (at 50kPa normal loading).

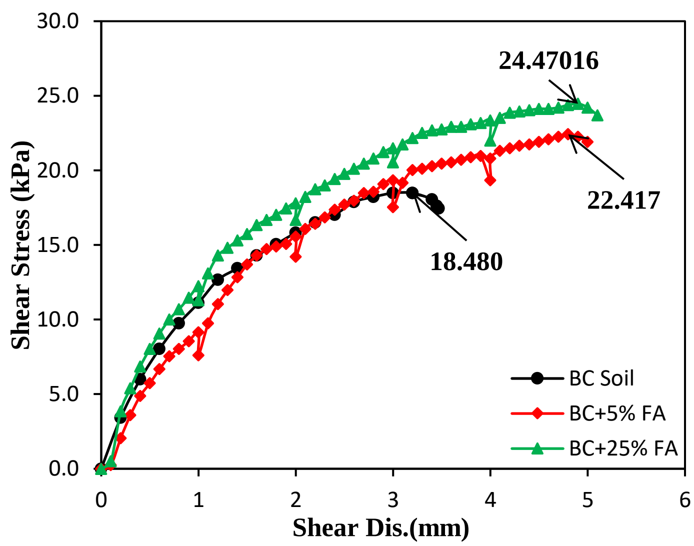
Fig.35 shows shear behaviour of black cotton soil, black cotton soil mixed with 5% fly ash and black cotton soil mixed with 25% fly ash.



(a)



(b)



(c)

Fig.35. Shear stress versus shear displacement of black cotton soil, black cotton soil mixed with 5% and 25% fly ash at (a) 0.625mm/min. strain rate, 50kPa normal loading (b) 0.25mm/min. strain rate, 50kPa normal loading (c) 0.025mm/min. strain rate, 150kPa normal loading.

Shear strength increases with the increase of fly ash content up to addition of 25% fly ash in black cotton soil. Shear strength also increases as strain rate decreases. There is a significant improvement brought out by blending fly ash in black cotton soil as 25% admixture of fly ash results in almost twice the shear strength of black cotton soil.

Sample	Strain rate (mm/min.)	Cohesion (kPa)	Angle of internal friction (ϕ)
B.C. Soil	0.025 (multi-stage)	8.23	4.23º
	0.25 (multi-stage)	6.0462	4.255º
	0.25 (single-stage)	4.9054	3.816º
	0.625 (single-stage)	4.5632	3.525º
B.C. Soil +5%fly ash	0.025 (multi-stage)	18.937	1.375º
	0.25 (multi-stage)	12.72	3.816º
	0.25 (single-stage)	10.781	4.403º
	0.625 (single-stage)	7.1296	4.306º
B.C. Soil +25%fly ash	0.025 (multi-stage)	18.31	2.153º
	0.25 (multi-stage)	13.233	3.331º
	0.25 (single-stage)	13.119	2.645º
	0.625 (single-stage)	11.693	2.645º

Table 7. Represent Cohesion and angle of friction of black cotton soil and 5%, 25% fly ash blended with black cotton soil for different strain rates under single and multi-staged test condition.

Cohesion and angle of friction is found out by comparing Mohr Coulomb's shear equation with experimental data.

$$\tau = \sigma \tan \phi + c$$

Here τ is shear stress at failure, ϕ is angle of internal friction, σ is normal stress and c is cohesion.

Cohesion is the shear strength of soil when there is no compressive force acting on it so it can be said that cohesion is a measure of the very raw shear strength of soil when it doesn't get aided by normal force on it.

From the results obtained, it is observed that cohesion increases as strain decreases from 0.625 to 0.025mm/min and it also increases for multi-staged test. It is found that the increase in fly ash content up to 25% in black cotton soil causes a significant increase in cohesion which indicates that the basic shear strength property is improved by fly ash.

5. Conclusion

Basic engineering properties, consolidation behaviour and shear behaviour of reconstitute black cotton soil and its varying proportion of fly ash is investigated. Multi-staged oedometer test and direct shear test were conducted for creep & swelling behaviour analysis and shear behaviour. Following conclusion are obtained:

1. It is found that fly ash enhances the basic engineering properties of black cotton soil. Plasticity index shows a decreasing trend for black cotton soil mixed with fly ash which concludes that fly ash mixed black cotton soil shows less plastic behaviour. The maximum dry density (M.D.D.) also increases on adding optimum fly ash as admixture while the optimum moisture content (O.M.C.) decreases and soil with fly ash can be compacted easily even with less moisture content.
2. Time of end of primary consolidation in loading stage (t_0^c) found to be increasing with the increase in fly ash content. The creep strain in black cotton soil starts earlier in the loading process than the other two specimens with fly ash content.
3. Total settlement decreases almost 1mm with increases of fly ash content up to addition of 25% fly ash. Fly ash blended with black cotton soil is observed to resist further settlement in reloading.
4. Compression parameter **(λ/ν)** increases on increasing the loading duration on the soil sample. Hence it is evident that not only loading amplitude but also loading duration has a direct impact on elastic-plastic strain which causes to increase it. Using fly ash as an admixture to the soil significantly enhances the elastic and elastic-plastic strain in the soil as **(λ/ν)** and **(κ/ν)** both decreases with fly ash content in the soil hence fly ash mixed black cotton soil exhibits less elastic and plastic strain.
5. Creep coefficient **(ψ^c/ν)** is found to be decreasing with increase in effective stress due to the more stable clay structure. It is observed that **(ψ^c/ν)** and (ϵ_z^{cl}) decreases for black cotton soil mixed fly ash, the sample with 25% fly ash clearly shows less creep strain limit than black cotton soil for the same loading conditions hence it can be said that fly ash mixed samples exhibits less creep property.
6. Unloading amplitude causes an increase in swelling behaviour and increase in unloading cycle causes a gradual decrease in swelling coefficients and swelling strain limit. Soil mixed with more fly ash content clearly shows a decreasing trend in the values of **(ψ^s/ν)** and (ϵ_z^{sl}) which concludes that fly ash improves the high swelling property that black cotton soil possess.
7. For long term creep and swelling behaviour analysis of soil, analytical non-linear equation should be employed instead of linear equation as it gives the best curve fitting.

8. Strain rate and multi-stage direct shear test have a significant effect on the shear behaviour of soil. Shear strength tends to increase when the test is done in less strain rate and in multi-stage process. It is observed that the addition of fly ash as an admixture to the black cotton soil increases its shear strength considerably, shear strength of 25% fly ash mixed black cotton soil is found to be almost twice than of black cotton soil.

6. Scope for future work

Consolidation, creep and swelling behaviour of reconstitute black cotton soil and fly ash blended with reconstitute black cotton soil is studied under oedometer condition. If the boundary condition of sample changes then soil may show different consolidation, creep and swelling behaviour. Effect of boundary condition on consolidation behaviour under oedometer condition is maybe a good thing to study.

In this report, index properties, consolidation and shear behaviour of reconstitute black cotton soil and black cotton soil blended with 5%, 15% and 25% fly ash has been studied. It is found that these properties increases or decreases up to 25% fly ash addition in black cotton soil. Optimum fly ash content for reconstitute black cotton soil may be investigated by examining more samples of black cotton soil with fly ash in different proportions varying at a short interval.

7. References

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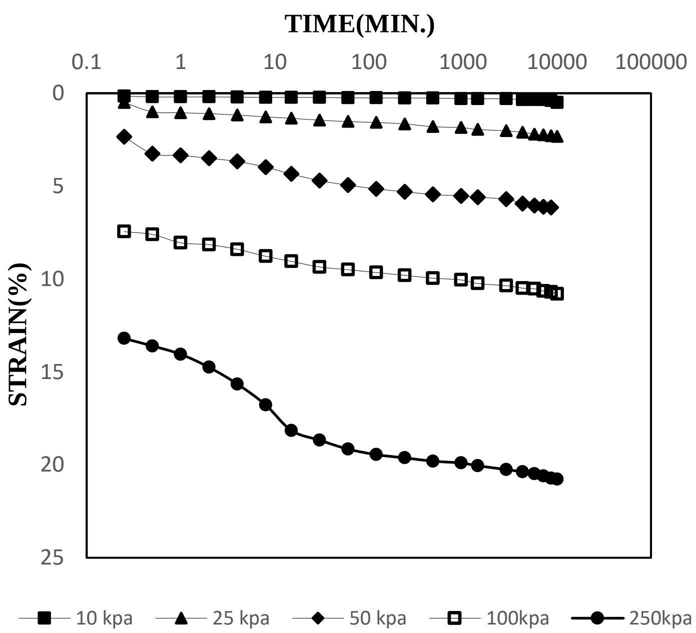
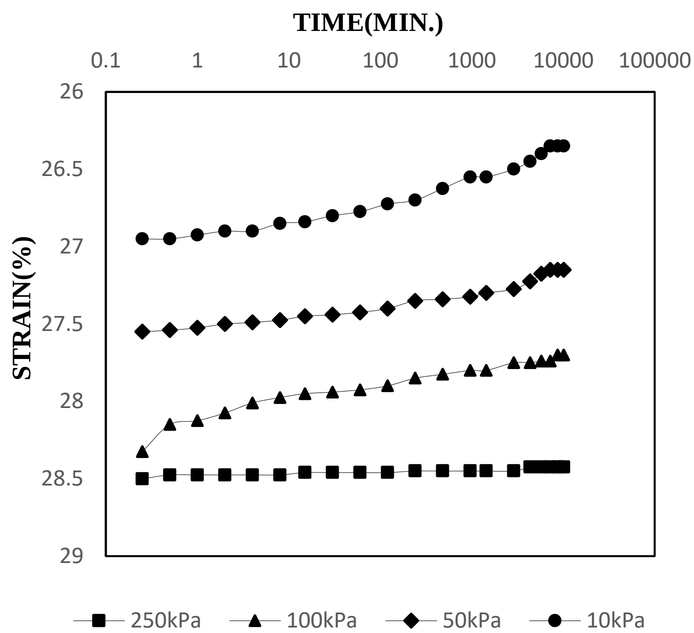
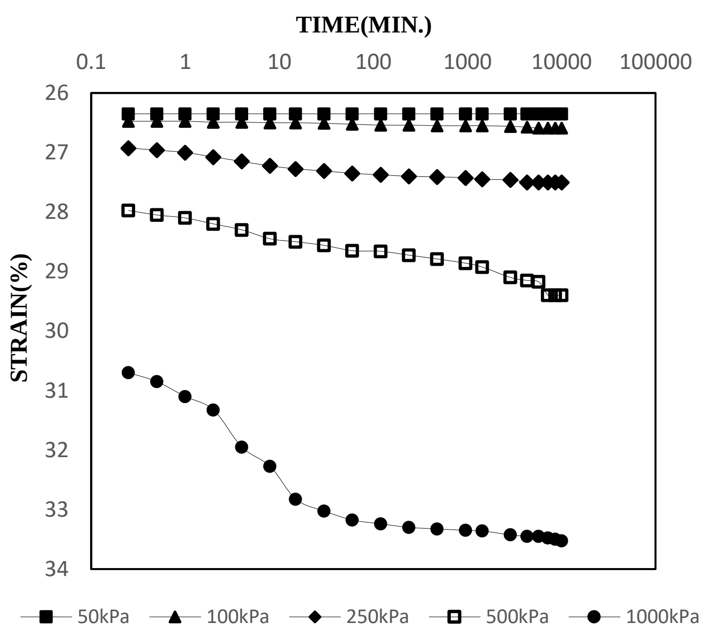
Appendix A



(a)

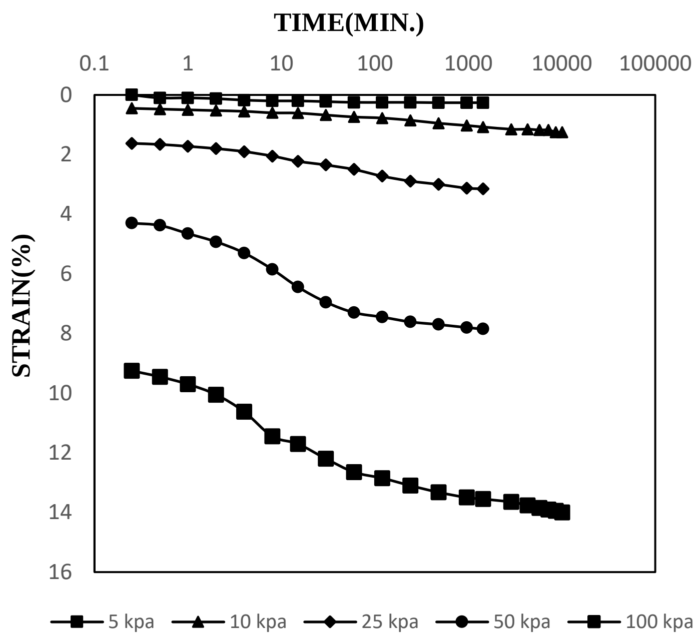


(b)

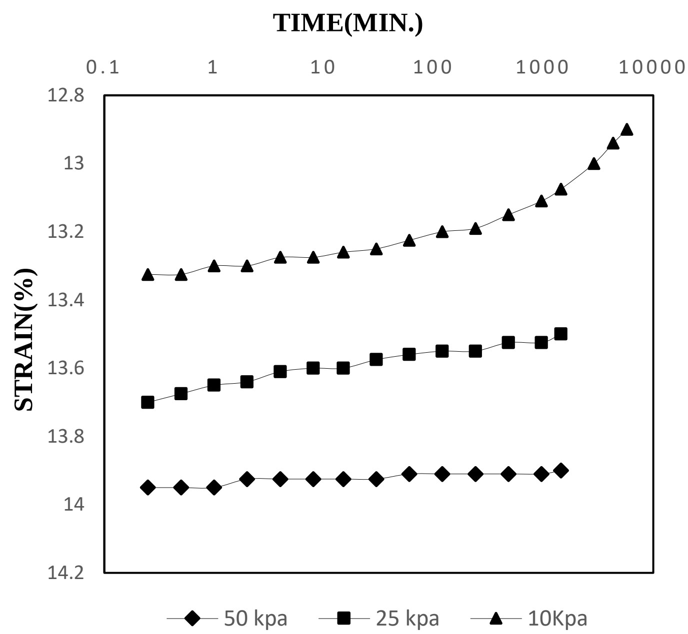


(c)

Fig.36.Strain (%) versus time (log scale) for black cotton soil for sample 2 in (a) loading (b) unloading (c) reloading stage.



(a)



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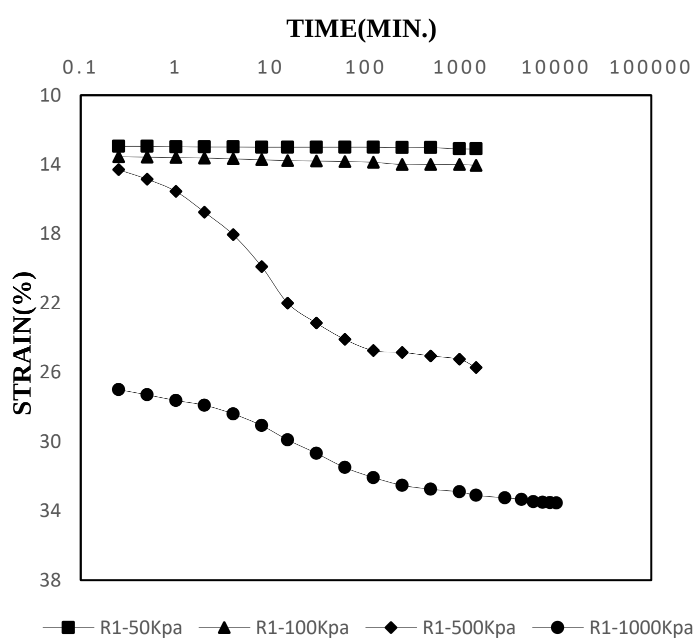
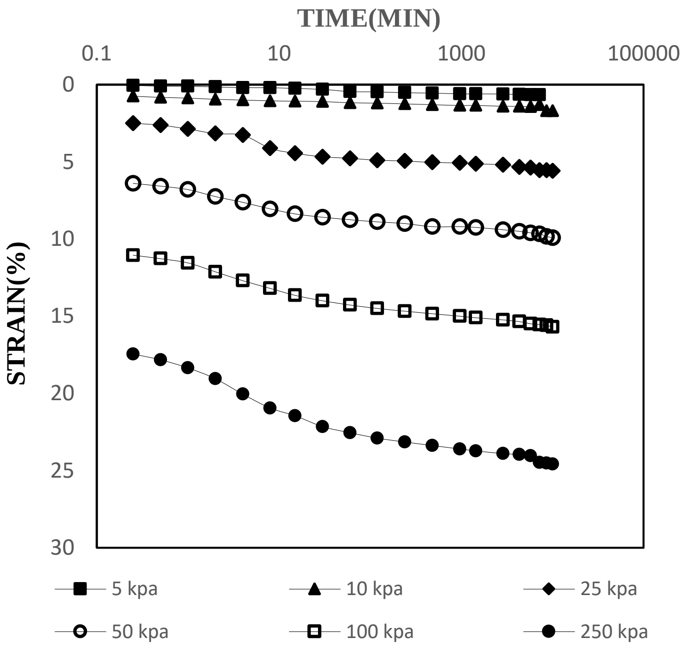
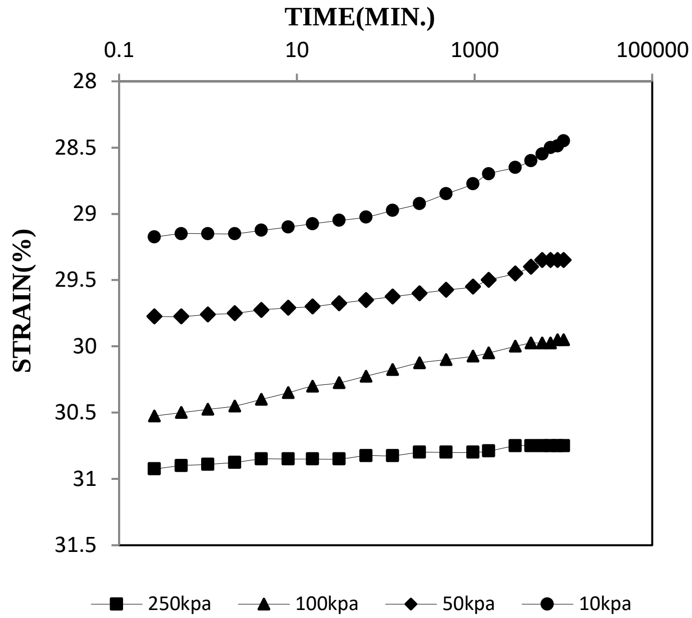


(c)

Fig.37.Strain (%) versus time (log scale) for black cotton soil for sample 1 in (a) loading (b) unloading (c) reloading stage.



(a)



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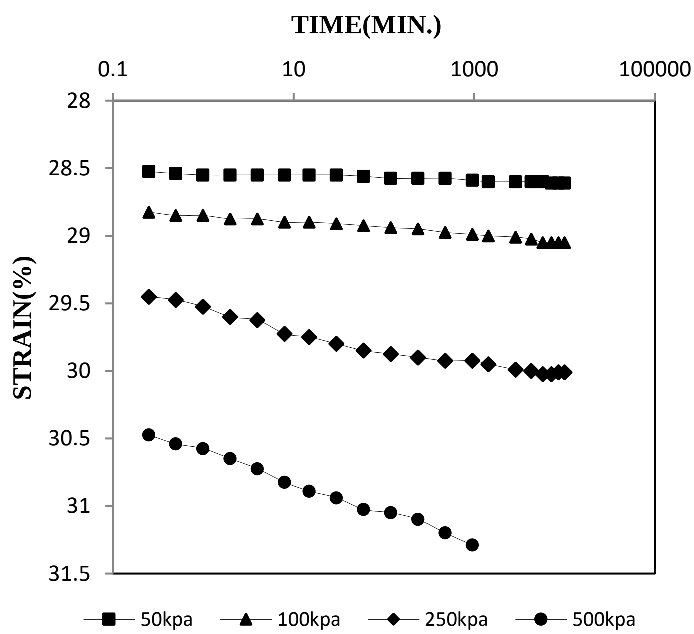

(c)

Fig.38.Strain (%) versus time (log scale) for black cotton soil blended with 5% fly ash for sample 2 in (a) loading (b) unloading (c) reloading stage.

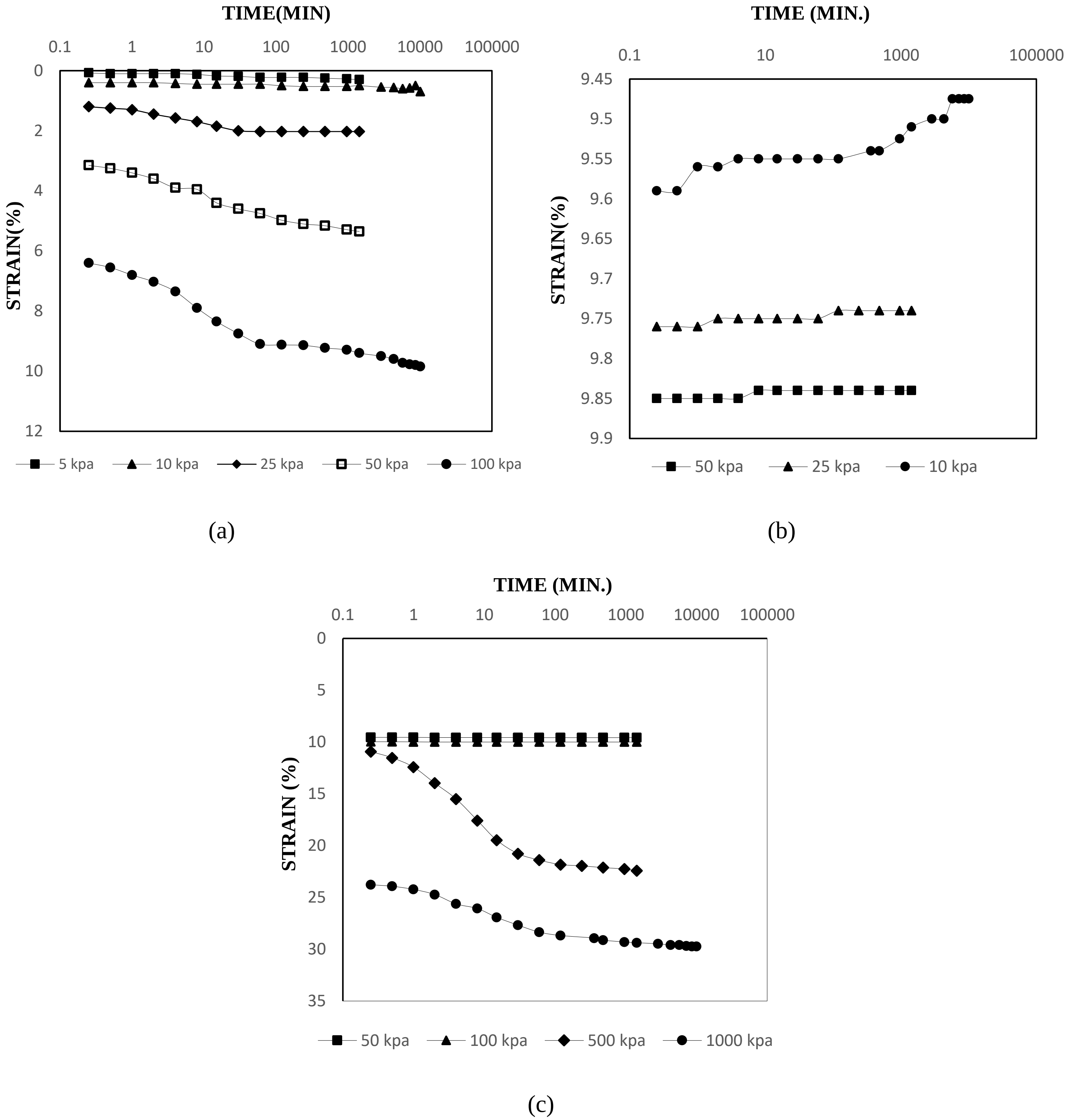

Fig.39.Strain (%) versus time (log scale) for black cotton soil blended with 25% fly ash for sample 1 in (a) loading (b) unloading (c) reloading stage.