IMPROVEMENT OF EXPANSIVE SOILS USING ENVIRONMENTALLY FRIENDLY POZZOLANIC MATERIAL

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This is to certify that the Final Year project

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has been accepted towards the requirement
for the undergraduate degree in
Civil Engineering

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Dedication

To our loving parents, who have continuously provided their moral, spiritual, emotional, and material support, have served as a constant source of inspiration and strength during trying times when we were about to give up, and to whom this study is sincerely dedicated. To all of our family members and friends who have offered words of wisdom and motivation to complete this research. For their oversight and direction, which were both provided by our supervisor and co-supervisor and without which this study would not have been possible. Finally, we honour the Almighty God for his fortitude, mental fortitude, protection, abilities, and for providing us with a healthy existence. We are yours to keep, and we will come back to you.

DECLARATION

All work referred to in this thesis was written by us, it is hereby respectfully and truthfully declared, and it has never before, in whole or in part, been submitted by any institution in an application for a degree. Every mention of research conducted by another individual or university has been properly cited.

ACKNOWLEDGEMENTS

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Abstract

Clayey soil with a high degree of flexibility and a poor bearing capacity is always problematic for structures. Montmorillonite is the main component of Nandipur, Gujranwala clay. The activity of the soil is increased by montmorillonite. In order to increase unconfined compressive strength and decrease the activity of clayey soil, this study intends to utilize an environmentally friendly and economically viable material , that is the Ginni Pozzolan. In order to identify the soil index qualities, samples from Nandipur Gujranwala were gathered.These included the Particle Size Analysis, Atterberg Limits, and Specific Gravity tests. The results obtained from the laboratory tests were used to classify the soil by USCS classification as highly plasticity clay (CH). The Standard Compaction test was performed to obtain the maximum dry density and the corresponding optimum moisture content. Untreated clay and clay with additions were tested for their unconfined compression strengths. Additionally, the activities of untreated and additive-added clay were evaluated. After the addition of 1% Ginni pozzolan and 5% lime, soil stability has greatly increased. In addition to laboratory testing, the UCS values of untreated clay and clay with additions were simulated using the Abaqus programme. With the addition of 5% lime and 1% Ginni pozzolan to clay, software also demonstrated an increase in unconfined compressive strength.

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Chapter 1 Introduction

1.1. Background

Engineers working in the construction sector frequently deal with subpar soils, which have inadequate engineering features and are unsuitable for building. In the past, engineers dealt with this problem by replacing these weak soils with good quality soils, and in the process, dumped the weak soil elsewhere. This procedure was not only costly logistically, but also harmful to the environment. However, new approaches were subsequently used, such as a variety of soil stabilisation procedures that improved the engineering and index qualities of the poor soils to make them suitable for use in structures. Both mechanical and chemical techniques can be used to stabilise soil. Among these, chemical stabilization includes the application of conventional stabilizers like cement, lime, and non-traditional stabilizers like ash, slag, and other natural occurring pozzolanic materials (Pourakbar & Huat, 2016). Soils have been stabilised by the use of traditional stabilisers like Cement and Lime in the past. However, they are mostly to blame for significant environmental deterioration due to CO2 emissions, which fuel global warming. According to estimates, the manufacture of cement is responsible for 8% of all global CO2 emissions (Dash & Hussain, 2012). The public's understanding of climate change and the factors causing it has grown in recent years. There is general agreement that environmentally friendly sustainable methods must be employed. Engineers have devised strategies for stabilising soil, such as employing substitute binders that offer effective and environmentally friendly methods of stabilising soil. Pozzolans are materials constituting alumina (Al_2O_3), silica (SiO_2), and ferrite (Fe_2O_3), with the sum of their composition by weight equal or greater than 70%. According to

(ASTM C618-19, 2019), pozzolanic materials can be classified into F and C class: artificial/man-made like fly ash, furnace slag; and N class: Pozzolan derived from natural materials. The pozzolanic reaction takes place when clay minerals are combined with water, lime, pozzolan, silica, and alumina. This produces a variety of sticky gels and cementitious materials. When the pH of the mixture is high enough to allow dissolution for the clay minerals silica and alumina, the pozzolanic reaction will continue until the system has enough calcium or alumina from the pozzolan to combine with silica and alumina (Dos Santos Barreto et al., 2021; Singh et al., 2008). During the hydration of cementitious binders, pozzolanic materials containing silica and alumina are added, it produces cementing components like C-S-H, C-A-H, and C-A-S-H. The equations representing these reactions are mentioned below:

$$2(3CaO \cdot SiO_2) + 6H_2O = 3CaO \cdot 2SiO_2 \cdot 3H2O + 3Ca\,(OH)_2 \text{ – (1)}$$

$$\text{Hydrolysis: } Ca\,(OH)_2 = Ca^{++} + 2(OH)_2 \text{ – (2)}$$

$$Ca^{++} + 2(OH)^{-} + SiO_2 \text{ (pozzolan rich in silica)} = C - S - H \text{ – (3)}$$

$$Ca^{++} + 2(OH)^{-} + Al_2O_3 \text{ (pozzolan rich in alumina)} = C - A - H \text{ – (4)}$$

1.2. Problem Statement

Pozzolans are materials constituting alumina (Al_2O_3), silica (SiO_2), and ferrite (Fe_2O_3), with the sum of their composition by weight equal or greater than 70%, and according to (ASTM C618-19, 2019), pozzolanic materials can be classified into F and C class: artificial/man-made like fly ash, furnace slag; and N class: Pozzolan derived from natural materials. There are two different classifications of Pozzolanic Materials i.e., Artificial and Natural. Artificial Pozzolans like, Low-calcium fly ash and High calcium Fly ash was used to improve the geotechnical properties of Silty clay, Contaminated soil, Clayey soil and other Expansive soils was done by various researchers in the past (Brooks, 2009; Dermatas & Meng, 2003; Edil et al., 2006; Gupta & Kumar, 2017; Horpibulsuk et al., 2013; Kaniraj & Havanagi, 2001; Kolias et al., 2005; Kumar et al., 2007).

The table above lists numerous additional artificial pozzolan varieties. To enhance the geotechnical qualities of the badly graded sand, natural pozzolans like Taftan Pozzolan were employed by (Toufigh et al., 2020). Several other types of Natural pozzolans are given in the table above. Ginni Pozzolan, a natural pozzolan (siliceous in nature), has been discovered in vast quantities in the Ginni, Chilas, Gilgit-Baltistan area. Pozzolan is being mined and processed in preparation for usage in concrete technology. However, we want to look into how it affects soil stability and whether it could eventually replace other environmentally hazardous soil stabilisation chemicals such as cement, lime etc.

1.3. Aim and Objectives

The aim of this project is to investigate the effect of Ginni pozzolan on stabilization ofexpansive soil.

The objectives of this project are to:

- To use the most lime possible, investigate how lime presence affects the expansive soil's index, swelling, and compressive strength behaviour.
- Examine how Ginni Pozzolan, which has a set amount of lime, affects the behaviour of expansive soil's index, swelling, and compressive strength.

- Investigate the long-term effects of Ginni Pozzolan and lime on compressive strength for the treatment of expansive soil.

1.4. Scope

- The impact of pozzolan on the index properties of only one type of soil (silty clay) has been studied. We did not look into other types of soils in this study.
- Our experiment used natural pozzolan that was obtained from a single site. There are unexplored places with different mineralogical characteristics.
- Other features, such as hydraulic qualities, have not been researched; only strength/deformation parameters have been examined.

Chapter 2 Literature Review

2.1. Introduction

Engineers working in the building sector regularly deal with poor quality soils (frail building properties), which is undesirable for development. In the past, engineers dealt with this problem by replacing these weak soils with high-quality soils and then disposing of the weak soil elsewhere. This planning was risky for the environment in addition to being expensive from a strategic standpoint. In any case, gradually new approaches emerged, such as various soil improvement strategies, which alter the designing and recording characteristics of the fragile soils to make them suitable for development. Both mechanical and chemical methods can be used to stabilise soil. Chemical stabilisation includes the use of traditional stabilisers such as cement and lime, as well as non-traditional stabilisers such as cinder, slag, and other naturally occurring pozzolanic materials (Pourakbar & Huat, 2016). Traditional Stabilizers like Cement and Lime have been broadly utilized (Pourakbar & Huat, 2016).

2.2. Chemical improvement of soil

According to (ASTM C618-19, 2019), pozzolans are materials possessing alumina (Al_2O_3), silica (SiO_2), and ferrite (Fe_2O_3), with the sum of their composition by weight equal to or greater than 70%. Following are the materials that are capable of pozzolanic activity while reacting with soils: Cement, Fly Ash, Volcanic Ash, Lime, Slag, Rice Husk Ash. Cement has been widely used to stabilise problematic soils. Cement has a tendency to provide cohesion in low cohesion soil, resulting in increased strength and durability. (Md Ali Ashraf, 2018) experimentally concluded, 8 percent - 10% cement content efficiently increases the unconfined compressive strength 11-12 times more than 0% cement content for any ground condition with a predominance in sand or sand silty. Furthermore, (Solihu, 2020) investigated and confirmed that Cement is a soil stabiliser used in rail track subgrades and highway base and subbase courses to improve the engineering qualities of problematic soils. Low cost and high availability of fly ash are the factors responsible for its high usage. Fly Ash has the capability to strengthen the weak soils at low cost. (Ghais, 2014) experimented and concluded about the stabilizing properties of Sudanese fly Ash on Clayey Soil. The index characteristics and bearing capacity of soil were increased by FA content varying from 0 to 15 percent. Additionally, while MC was decreasing, a drop in LL and PI showed soil stability. (Phani Kumar & Sharma, 2004) studied the impacts of FA on expansive soils. According to the results, 20% FA reduced the plasticity by 50%. Depending on soil type, FA ranging 15-30% can be used as an additive for base and subbase layers' construction of pavements. Also, for the construction of pavements in compressed soils (Phani Kumar & Sharma, 2004). Volcanic eruptions cause volcanic ash to be created. It has been used for a very long time to stabilise soil. According to (Rifa'i et al., 2013), the stability of expansive soils was improved by the addition of VA and lime. It is impossible to overestimate the significance of additives in lowering soil flexibility and swelling potential. Additionally, the soil's strength and bearing capability were improved.(Hossain et al., 2006) conducted experiments to determine the effects of Volcanic Ash on Papua New Guinea's clay. Results indicated that adding volcanic ash increased durability, CBR values, and other index parameters (VA). VA can also be used topically as a binder on slick and unpaved roads. Lime has a substantial effect on soil stabilisation even at low concentrations because of its rapid reactivity rate (Sleep & Masley, 2018). According to (Negi et al., 2013), Lime's ability to stabilise soil has shown great promise. With time, soil's carrying capacity grew, its resistance to shrinking under damp conditions improved, its PI decreased, and its CBR values and compression resistance increased. (Harichane et al., 2011) used Lime in addition to natural pozzolana for soil stabilization. Lime had a greater effect on the properties of the soil than natural pozzolana. With the addition of lime, the soil's PI decreased, its shear strength metrics improved, and its unconfined strength increased. In order to be economical, a small amount of lime is practically blended with a less expensive pozzolanic material. By reducing the soils' ability to collapse, salts have a significant tendency to stabilise failing soils (Abbeche et al., 2010). When NaCl is added to soils, both structural damage and collapse potential are reduced (Abbeche et al., 2016). Salt's propensity to reduce the chance of fragile soils collapsing was strongly demonstrated by potassium chloride (Abbeche et al., 2016). Due to the effect of Rice Husk Ash (RHA) poor cementitious characteristics, it is typically used in conjunction with cement or another cementitious material. The strength of the soil is increased by adding RHA up to an ideal level. (Behak, 2017). Rice Husk Ash ranging 6-8% improved the UCS values of soil. CBR values increased plus swelling potential of soil decreased (Sarapu, 2016).

2.3. Pozzolanic Materials

Pozzolans are siliceous and aluminous minerals with little to no cementitious value, but they react chemically with calcium hydroxide in the presence of water at room temperature to produce compounds with cementitious properties when they are finely divided. In the past, calcined lime and finely ground, active Alumina-silicate compounds were combined to generate an inorganic binder (ASTM C618-19, 2019). Pozzolanic reactions occur upon addition of pozzolanic materials. The pozzolanic reaction turns a silica-rich precursor with no cementing characteristics to calcium silicate, which does. The pozzolanic reaction occurs when calcium hydroxide, also known as Portlandite $Ca(OH)_2$ and Silicic Acid $Si(OH)_4$ or H_4SiO_4). The above reaction can be summarized in abbreviated notation as:

$$CH + SH \longrightarrow C\text{-}S\text{-}H$$

The growth of strength is accomplished by the C-S-H, also known as calcium silicate hydrate. The pozzolanic activity, which is measured in the presence of water, serves as a gauge for the rate of reaction between a pozzolan and calcium hydroxide. The rate of the pozzolanic reaction is controlled by inherent pozzolan properties such as specific surface area, active phase content, and chemical composition (Ogawa et al., 1980; Shi, 2001; Snellings et al., 2012). As a by-product of several operations, artificial pozzolanic materials are produced. There are two key advantages to these pozzolanic materials. First and foremost, they contribute to pollution reduction, secondly, environmental protection, as well as financial benefits like better land conditions, but because these are byproducts, their manufacturing method is extremely dangerous (Pourakbar & Huat, 2016). According to (ASTM C618-19, 2019) artificial pozzolanic materials can be characterized into two classes F and C depending upon the percentages of silica, alumina and ferrous oxide. Artificial pozzolanic materials have been studied, and some are mentioned below with their percentages. When coal is burned for electric generation, two types of fly ash are produced: low calcium and high calcium. In order to strengthen the strength of silty clay, polluted soil, clayey soil, and expansive soil, ashes were added to these types of soils. According to **Table 1**, the composition of low and high calcium fly ash compositions is provided (Brooks, 2009; Dermatas & Meng, 2003; Horpibulsuk et al., 2012; Kaniraj & Havanagi, 2001).

Table 1: Low and high calcium fly ash compositions respectively

Chemical Composition	Percentages (low calcium)	Percentages (High calcium)
SiO_2	55	40
Al_2O_3	26	17
F e_2O_3	7	6
CaO (lime)	9	24
MgO	2	5
So_3	3	3

When sulfuric acid and phosphate rock interact chemically, phospho-gypsum is produced. Investigation on its effects on clayey soil revealed that clayey soil strength was raised in accordance with (Degirmenci et al., 2007). Granulated blast furnace slag, or GGBS, is created in the blast furnace and is used to create pig iron. After studying its impact on contaminated soil, clayey soil, and marine soft clay, it was shown that the qualities did really improve. The composition of granulated blast furnace slag is given in **Table 2** according to (Wild et al., 1998).

Table 2: GGBS composition

Chemical Composition	Percentages
SiO_2	35
Al_2O_3	12
Fe_2O_3	1
CaO (lime)	40
K2O	0.4
SO_3	9
Na_2O	0.3
Loss of ignition	1

Sludge and ash from discarded paper are examples of waste products. Its effects on clayey soil were examined, and it was discovered that it strengthens clayey soil. **Table 3** provides information on the wastepaper sludge's composition according to (Rahmat & Kinuthia, 2011).

Table 3: Wastepaper Sludge composition

Chemical Composition	Percentages
O	15.83
Ca	14.94
Si	60.57
Al	2.06
Mg	3.59
S	1.07
Na	0.22
Fe	0.92
K	0.16

Ceramic waste is produced by bricks, tiles, and burnt clay-based products. The addition improved features, according to an investigation of how it influenced the large soil (Sabat, 2012). A byproduct of the rice processing industry is rice husk ash. After assessing the effects on the remaining dirt and clayey soil after addition, it was discovered that characteristics were improved. Table 4 provides information on the makeup of ceramic waste according to (Yadu et al., 2011).

Table 4: Rice Husk Ash Composition

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	Loss of ignition	SO_3	K_2O
OPC	20.9	4.76	3.41	65.41	1.25	0.24	0.9	2.71	0.35
RHA0	92.0	0.29	0.1	1.28	0.37	0.05	3.4	0.94	2.19
RHA I	92.5	0.28	0.1	1.40	0.20	0.06	3.6	0.93	2.35
RHA2	90.1	0.25	0.1	1.45	0.01	0.18	3.5	0.92	2.42
RHA3	93.2	0.44	0.1	1.10	0.01	0.03	3.7	0.96	1.27

A byproduct of the production of acetylene gas is Calcium Carbide Residue. After studying how it affected silty clay after addition, researchers found that the characteristics had improved (Horpibulsuk et al., 2012). Palm Oil Fuel Ash is a by-product of agriculture. Investigation into the effects of the addition on the clayey soil qualities revealed an improvement. **Table 5** provides the palm oil fuel's composition according to (Sanawung et al., 2017).

Table 5: Palm Oil Fuel Composition

Chemical Constituents	Percentages
SiO_2	53.82
AL_2O_3	5.66
Fe_2O_3	4.54
CaO	4.24
MgO	3.19
Na_2O	0.1
K_2O	4.47
SO_3	2.25
P_2O_2	3.01
LOI	10.49

Natural Pozzolanic Materials are those produced naturally by weathering and other natural processes. According to (ASTM C618-19, 2019), natural pozzolanic materials are classified as class N. Compared to synthetic pozzolans, their composition is far better. Natural pozzolanic material has two key advantages. First and foremost, these contribute to lessening pollution, and secondly, there is environmental protection in addition to an economic benefit, such as bettering land conditions. (Pourakbar & Huat, 2016). There are a few research papers on synthetic pozzolanic materials, some of which are given below with their percentages. Taftan Pozzolan was applied to improve the qualities of badly graded soil, and the results were positive. **Table 6** provides information about Taftan pozzolan's composition according to (Toufigh et al., 2020).

Table 6: Taftan Pozzolan Composition

Composition (% by weight)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Cl	LOI
Taftan Pozzolon	61.7	18	4.93	6.69	2.63	0.1	1.95	1.65	0.04	2.15
Silica Fume	89.2	1.2	2.12	1.87	1.61	-	1.56	0.56	-	2.6

When Tal Shihan's Pozzolan was utilised to enhance the characteristics of fat clay, the results were positive. **Table 7** lists the Tal Shihan pozzolan's chemical makeup according to (al-Swaidani et al., 2016).

Table 7: Tal Shihan’s Pozzolan Composition

Type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	Loss of ignition
Lime	-	-	0.47	93.7	0.53	1.2	-	-	-	3.9
Natural Pozzolan	46.5	19.28	11.22	8.5	5.48	0.14	2.7	3.61	1.88	0.6

It was found that the characteristics of both lean and fat clay were improved when Beni Saf Pozzolan was utilised. **Table 8** lists the Tal Shihan pozzolan's chemical makeup according to (Harichane et al., 2011).

Table 8: Beni Saf Pozzolan Composition

Chemical Composition	Percentage
SiO_2	46.4
Al_2O_3	17.5
Fe_2O_3	9.69
CaO	9.90
MgO	2.42
CaO free	-
SO_3	0.83
Na_2O	3.30
K_2O	1.51
TiO_2	2.10
P_2O_3	0.80
Loss of ignition	5.34

Simba Volcanic Ash was utilised to enhance the qualities of fat clay, and it was found that this was successful. **Table 9** provides the composition of Simba Volcanic Ash according to (Cheng et al., 2018).

Table 9: Simba Volcanic Ash Composition

Type	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	K_2O	Na_2O	P_2O_5	TiO_2	LOI
% Compostion	10.6	11.6	12.4	13.3	43.2	1.29	2.76	0.54	2.85	0.32

Rabaul Volcanic Ash was used for improvement in fat clay and lean clay and concluded that the properties were improved. The composition of Rabaul Volcanic Ash is given in **Table 10** according to (Hossain et al., 2006).

Table 10: Rabaul Volcanic Ash Composition

Chemical Composition	Volcanic Ash percentage	Lime percentage	Cement percentage
CaO	6.1	45	64.1
SiO_2	59.3	12	21.4
Al_2O_3	17.5	1.2	5.7
Fe_2O_3	7.1	0.5	3.5
SO_3	0.7	0	2.1
MgO	2.6	0.7	2.1
Na_2O	3.8	0.2	0.5
K_2O	2.0	0.8	0.6
Loss of ignition	1.0	40	1.1
Fineness(m^2/) kg	242	302	320

2.4. Applications of pozzolanic material

Pozzolanic materials have been in use since around 500-400 BC (Idorn, 1997) at least. Pozzolanic materials have been employed in construction since the Minoan, Greek, and Roman eras. Each of these civilizations utilised them in one form or another. When combined with lime, certain natural elements were found to produce mortars and concrete that could harden underwater. These minerals are known as "natural pozzolans" after the Naples settlement of Puzzoli, where the Romans salvaged some particularly reactive volcanic ashes from Mount Vesuvius (Aïtcin, 2016). A monument to the outstanding craftsmanship and durability of Roman engineers' work and the materials they employed is the structural stability and preservation of some of Rome's most recognisable buildings, like the Pantheon and the Pont du Gard. Following the fall of the Roman Empire, the use of pozzolanic materials decreased due to a lack of practical knowledge and information about them. Pozzolans are extra cementitious elements that are frequently added to Portland concrete formulations during the 20th century (Schneider et al., 2011). The usage of pozzolanic materials and what are known as supplementary cementitious elements is becoming increasingly significant as the endurance of concrete constructions becomes a crucial criterion (Massazza, 2003). The fundamental justification for this is that Portland cement, which is significantly more expensive, may be largely replaced by pozzolan. Less greenhouse gas emissions are the other benefit for the environment. Last but not least, pozzolans are used to boost strength and durability over time. Pozzolans are utilised in concrete, as well as in geopolymer paste mixtures for grouting and filling fissures. Another significant application for pozzolanic materials is the stabilisation of fragile soils. These soils can then be used in a variety of locations, including abutments, foundations, and slope stabilisation. Cementitious compounds, such Portland cement and hydraulic lime, are frequently employed to stabilise poor soils, significantly increasing strength at the expense of environmental costs. It is also a potential idea to use naturally occurring pozzolans and industrial waste products, such as blast furnace slag, fly ash, rice husk ash, and cement kiln dust, to stabilise unstable soils. Numerous studies have been done that demonstrate that naturally occurring pozzolans, in particular, can be used as a practical option for soil stabilisation of weak clayey soils when used in conjunction with an activator like lime, with the added benefit of being significantly more affordable and environmentally friendly than just cement or lime as stabilising agents (al-Swaidani et al., 2016; Cheng et al., 2018; Harichane et al., 2011; Hossain et al., 2007; Toufigh et al., 2020). Future usage of sustainable resources, such as naturally occurring pozzolans for soil stabilisation, is certain given the significance of adopting sustainable methods and materials due to the danger that climate change brings.

2.5. Pozzolanic Material in Pakistan

During the building of the Diamir Basha Dam, a new pozzolanic substance was recently found. It can be situated in Gilgit Baltistan's district Diamir's Ginni neighbourhood. Mountains and natural reserves both include pozzolanic material that occurs naturally. This type of 94 percent siliceous material has not yet been the subject of any studies. Because it reduces the heat of hydration, pozzolanic material is frequently utilised in concrete. The roller-compacted concrete for the Diamir Basha and Dasu Hydro Power Project is now using it. Every study has come to the conclusion that it does enhance the soil's geotechnical qualities. Our study's main objective is to ascertain the effect of Ginni pozzolan, a naturally occurring pozzolanic material, on several soil characteristics. The composition of our material is given in **Table 11**.

Table 11: Ginni Pozzolan Composition

Moisture	%	0.22	MAX 3.00	MAX 3.00	MAX 3.00
LOI (loss on Ignition)	%	0.9	MAX 5	MAX 6.00	MAX 6.00
SiO_2 (Silica)	%	94.4	NOT SPECIFIED		
Al_2O_3 (Alumina)	%	2.2			
Fe_2O_3 (Iron oxide)	%	0.6			
CaO (lime)	%	1.97			
MgO (Magnesia)	%	0.8			
SO_3 (Sulphuric Anhydride)	%	0.12	MAX 2.5	MAX 5.00	MAX 5.00
K_2O (Potassium Oxide)	%	0.35	NOT SPECIFIED		
Na_2O (Sodium Oxide)	%	3.32			
Alkalises Equivalent	%	3.55	MAX 1.5	For low alkali	

Chapter 3 Methodology

3.1. Research Methodology

The soil was sourced from a region in central Nandipur is expansive in nature which not only undergoes significant swelling and shrinkage (E. et al., 2021) but also poses settlement issues when used for construction purposes as well. The purpose of this study is to determine the effects of natural pozzolana on the geotechnical characteristics of Nandipur's expansive clayey soil and whether it can help with settling issues. There has been a significant amount of prior research on the topic of stabilising expansive clayey soils, according to a thorough examination of the literature. However, there hasn't been much research done in the past specifically on the use of natural pozzolana for stabilising expansive clayey soils, and much less has been done on how it affects settlement problems brought on by such troublesome clayey soils. Soil samples were collected from a site in Nandipur (North-eastern part of Pakistan) where issue of poor quality expansive clayey soils is prevalent. Soil samples were analysed using ASTM standardised laboratory procedures to be classified according to USCS. The particles gradation and fines content of the soil were determined through sieve analysis (ASTM D422, 2007). Liquid limit, plastic limit and plasticity index of the soil samples were determined using Atterberg Limit tests (D4318, 2010). Finally, the samples were classified under Unified Standard Classification System (ASTM D2487, 2017). X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF) test was performed on the Nandipur soil and the Ginni Pozzolan to find out their mineralogical quantitative composition. Furthermore, Scanning Electron Microscope (SEM) images of the untreated and treated soil samples were taken to study the changes in mineral and microfabric structure of the soil. Soil sample with varying lime content were tested to get optimum lime content. Untreated soil samples were cured at 0, 14 & 28 days each and tested using UCS test, Consolidation, Compaction test and Atterberg limits tests. Next, soil samples with optimum lime content were cured at 0, 14 and 28 days and then UCS, Consolidation and Atterberg Limits tests were performed. Afterwards, soil samples with optimum lime content and varying natural pozzolan content were cured at 0, 14 and 28 days each and then UCS, Consolidation, Compaction and Atterberg Limits tests were performed. At the end, correlations between a variety of geotechnical characteristics of untreated and treated Nandipur soil samples were formed based on the results of the tests performed. A simplified representation of our research approach has been shown in **Figure 1**.

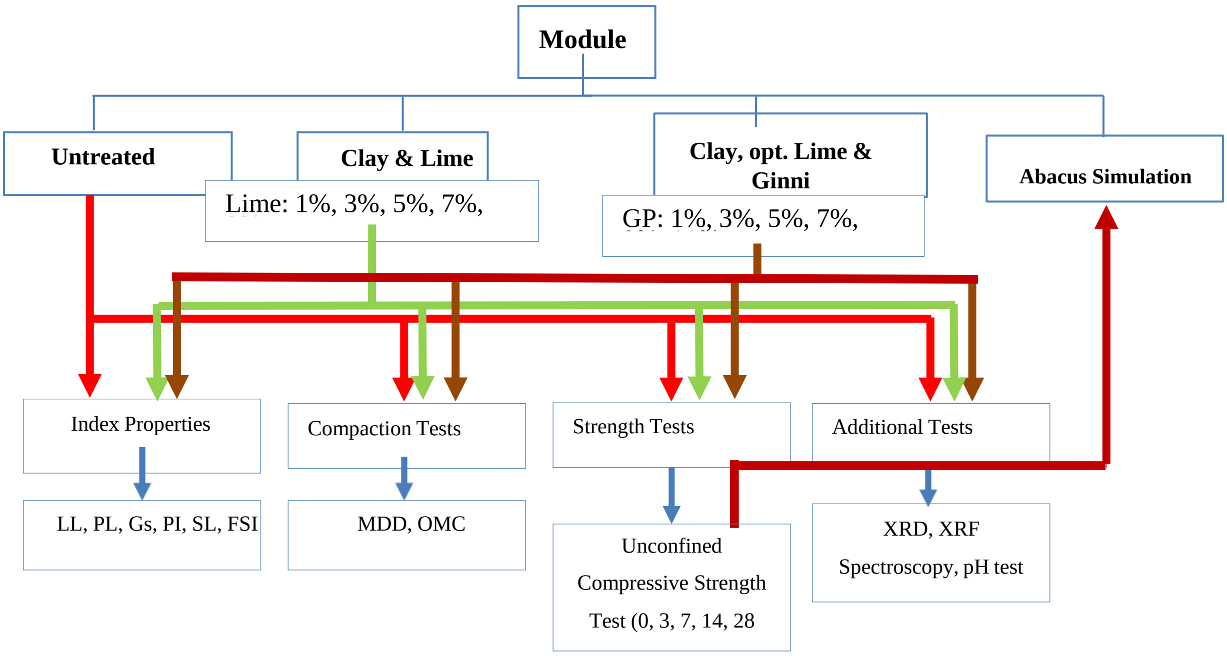


Figure 1 Flowchart for methodology

3.2. Sample Collection

The problem of expansive clayey soil in Nandipur was discovered during a previous geotechnical research of soil in the Nandipur region (North Eastern Pakistan). It was examined that this soil has swelling and shrinkage problems. It was highly plastic soil. Soil samples were collected from a site in Nandipur. To improve quality of this soil, we added Pozzolanic material in it. The Pozzolanic material for a soil improvement was obtained from a place Ginni, District Diamir in Gilgit-Baltistan territory of Pakistan. The natural pozzolanic material, which was in fine crushed form, having particle size 45 micron. We brought 60 kg of soil from Nandipur. Then, we initiated the testing process.

Figure 2 Soil site in Nandipur

3.3. Lab Tests: A summary of tests and standards

The tests that were performed for this research have been mentioned here. A sieve analysis was performed according to (ASTM D422, 2007) to calculate the particle size distribution of soil sample. The grain size distribution curve was then plotted using the particle size distribution data. Atterberg's limits: The Atterberg limits Tests were performed according to (D4318, 2010) to obtain Liquid, Plastic, Shrinkage Limits and Plasticity Index of soil sample. The optimum percentages of Lime and

Ginni pozzolan were added to soil for performing Atterberg's Limit Test. This test helped us to compare index properties of untreated soil with that of stabilized soil. Standard Proctor Test was performed according to (ASTM D698-12, 2021; ASTM D1557-12, 2021) to determine Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of soil. Unconfined Compression Strength (UCS) Test was performed according to (ASTM D2166-06, 2006) standards to calculate unconfined compression strength which was then used to get the un-drained shear strength of soil sample. Test were performed on specimen at different curing ages. The curing time was (0, 3 and 7) days for untreated soil sample and (3 and 7) days for Lime stabilized soil. We cured Lime-Ginni pozzolan stabilized soil samples at (7, 14 and 28) days. X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF) test was performed on the Nandipur soil and the Ginni Pozzolan to find out their mineralogical quantitative composition.

Figure 3 Liquid Limit test being performed

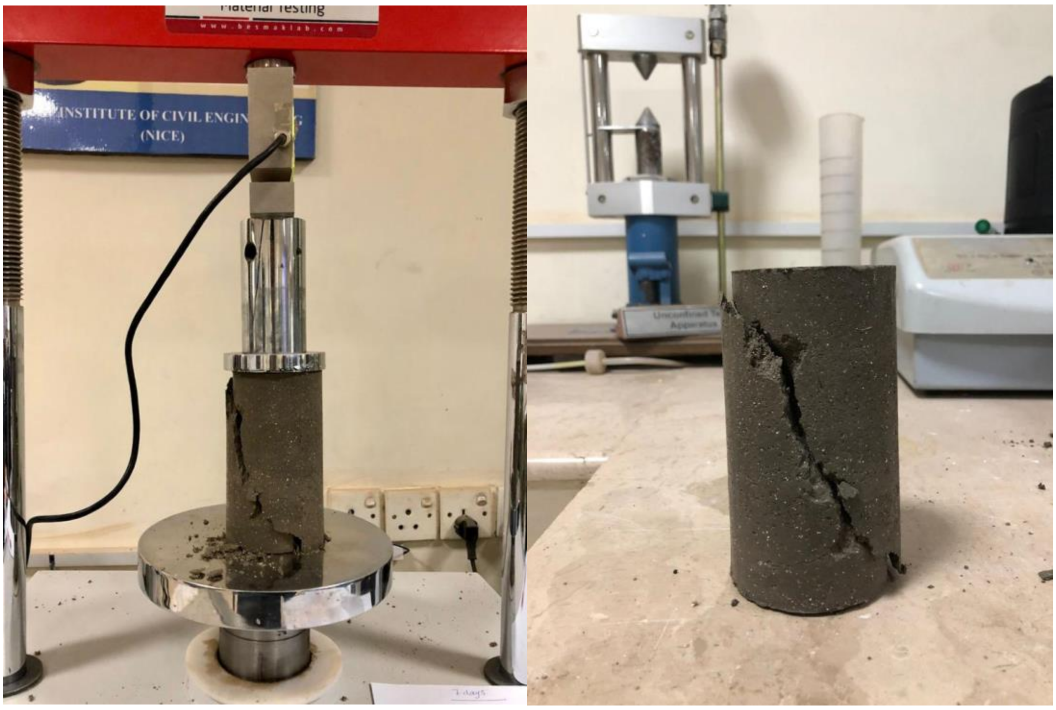


Figure 4 UCS Test being performed

Figure 5 Proctor Test being performed

3.4. Activity

The activity of the soil, defined by Skempton as the ratio of Plasticity Index of the soil to the percentage of particles finer than clay (2μ), was determined for the untreated clay sample using the formula:

Activity = Plasticity index / (% clay content)

The Activity of untreated soil came out to be 0.771 which turns out to be a normally active according to Skempton.

Chapter 4 Results and Discussion

4.1. Atterberg Limits

Untreated soil samples were subjected to Atterberg Limit tests to find out their Atterberg limits. The results showed that the untreated soil samples exhibit a high Liquid Limit and a low Plastic Limit which, consequently, results in a high Plasticity Index. It can be inferred from the high Plasticity Index that it will be highly compressible. The soil samples were then treated with lime for stabilization. Lime was added in increments of 2% starting from 1%. The optimum lime content was determined through these tests which came out to be 5%. Addition of lime above 5% had marginal effect on the Atterberg limits of the soil samples. After lime content had been optimized, the pozzolan content was optimized next keeping the lime content at optimum percentage (i.e., 5%). Pozzolan was also added in increments of 2% starting from 1%. The optimum pozzolan content came out to be 1% when used in conjunction with 5% lime content. **Table 11** lists the Atterberg limits for untreated and treated soil samples with optimal lime as well as optimum lime and optimum pozzolan. A very significant Plasticity Index of 27.05 percent was found in untreated soil. The greater the PI, the greater the amount of water that the soil can absorb and, thus, the greater its ability to swell (Rao, 2006). Addition of 5% lime alone caused a significant reduction in the Plasticity Index from 27.05% to 11.10%. Similar trend was observed by (Harichane et al., 2011) and (al-Swaidani et al., 2016). This is due to the chemical interactions between lime and soil, including ion exchange and related flocculation reactions (Chabrillat & Goetz, 2006). However maximum reduction in Plasticity Index was observed by the combination of 5% lime and 1% Pozzolan used together to treat the soil. This effectively reduced the Plasticity Index from 27.05% to 6.28% which is quite a substantial decrease in Plasticity Index. The workability of the soil would significantly increase as a result of the drop in PI. After stabilisation, the addition of pozzolan and lime is anticipated to significantly improve the expansive soil's plasticity attributes, making such problematic soils usable for the majority of construction operations even in unfavourable environmental conditions like rain (al-Swaidani et al., 2016). A summary of the results of Atterberg Limits tests performed on treated and untreated soil are shown in **Table 12.**

Table 12: Atterberg limits of the untreated soil sample, soil + optimum lime, soil + optimum lime + optimum pozzolan

Sample type	Untreated soil sample	Soil + 5% Lime	Soil + 5% lime + 1% Pozzolan
Shrinkage limit	18.02%	23.01%	28.32%
Plastic Limit	24.18%	26.50%	31.22%
Liquid Limit	51.23%	37.6%	37.5%
Plasticity Index	27.05%	11.10%	6.28%

4.2. Compaction characteristics

Standard Proctor tests were carried out on untreated and treated soil in order to determine the effects of Ginni Pozzolan in conjunction with lime as an activator on the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the investigated soil. First, the untreated clay underwent the standard Proctor Test, which revealed that it had an OMC of 21.38 percent and an MDD of 1.69 g/cm3 on average. The results of the Standard Proctor Test on untreated soil are shown in **Figure 6**. After that, soil samples with various lime amounts underwent Standard Proctor Tests. **Figure 7** depicts the overall pattern that was noticed, which was that the OMC increased simply by adding lime and that the MDD decreased with increasing lime content. In comparison to adding 0% lime, adding 5% lime to the soil increased the OMC from 21.38 to 25.20 percent while lowering the MDD from 1.69 to 1.60 g/cm3. In the case of lime-stabilized clayey soils, a similar pattern has been seen in earlier works (al-Swaidani et al., 2016; Harichane et al., 2011; Hossain et al., 2007). These elements are believed to be responsible for this behaviour: First, lime increases particle aggregation, which alters the effective grading of soils. Second, lime often has a lower specific gravity than the soil being tested. Third, the pozzolanic interaction between the lime and the soil's clay generates an increase in OMC (Harichane et al., 2011). Last but not least, samples with various Ginni Pozzolan concentrations underwent the Standard Proctor Test while keeping lime fixed at 5%. **Figure 9** illustrates the results, which show that adding Pozzolan to a fixed lime concentration of 5% results in a decrease in MDD from untreated soil but an increase in MDD from soil with 5% lime. The OMC also increases when compared to untreated soil but decreases when compared to soil treated with 5% lime. The ideal ratio of pozzolan to lime was found to be 1 percent to 5 percent, producing an OMC and MDD of 24.12 percent and 1.64 g/cm3, respectively. The Ginni Pozzolan has a specific gravity of 2.4, which is less than untreated soil, which has a specific gravity of 2.67, but more than lime, which has a specific gravity of 2.3, explaining why MDD decreases when compared to soil that hasn't been treated and increases when compared to soil that has only 5 percent lime.

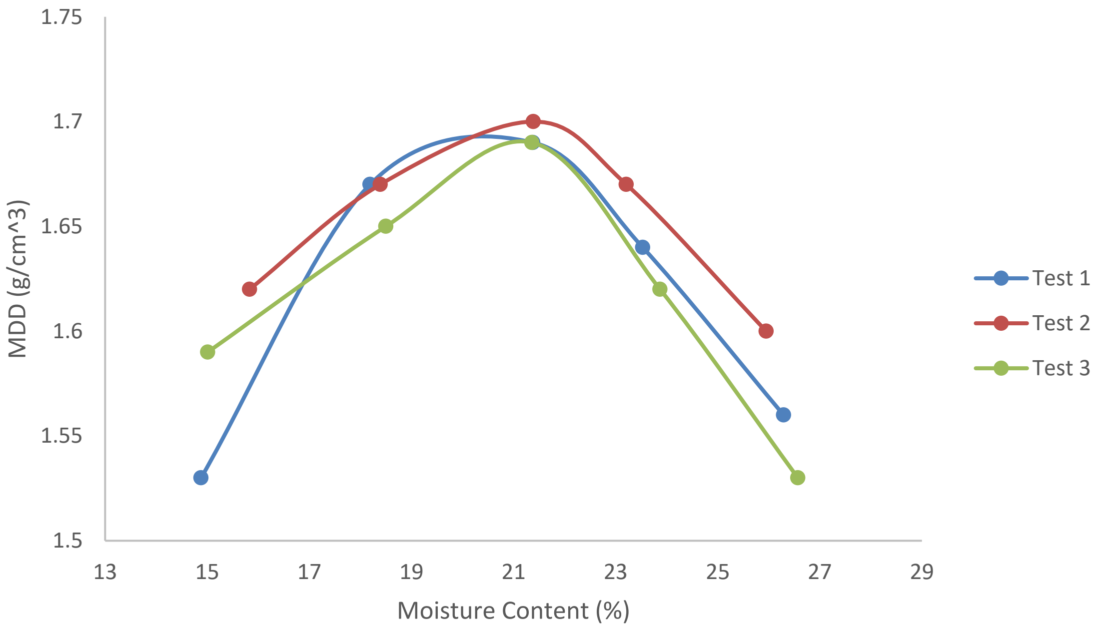


Figure 6 Standard Proctor Test on untreated soil

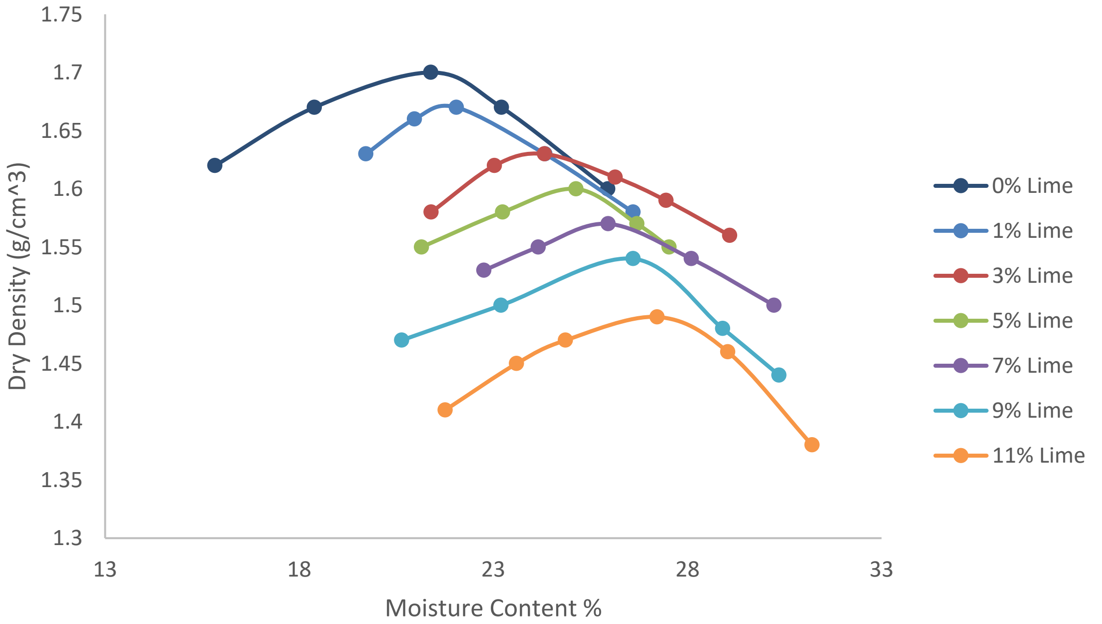


Figure 7 Standard Proctor Test on soil samples with different percentages of lime content

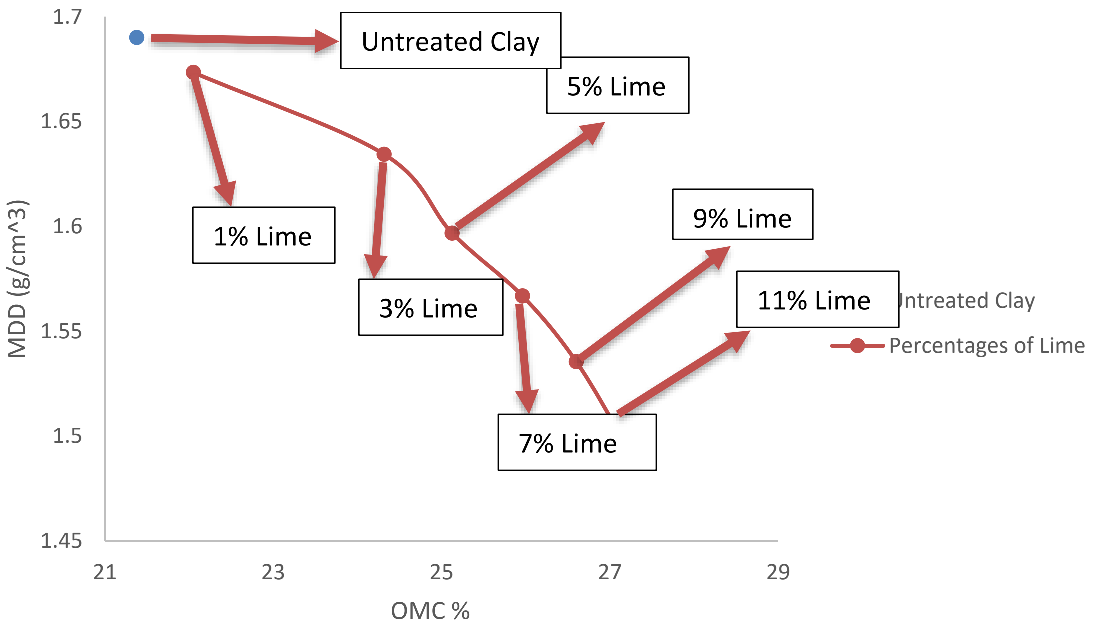
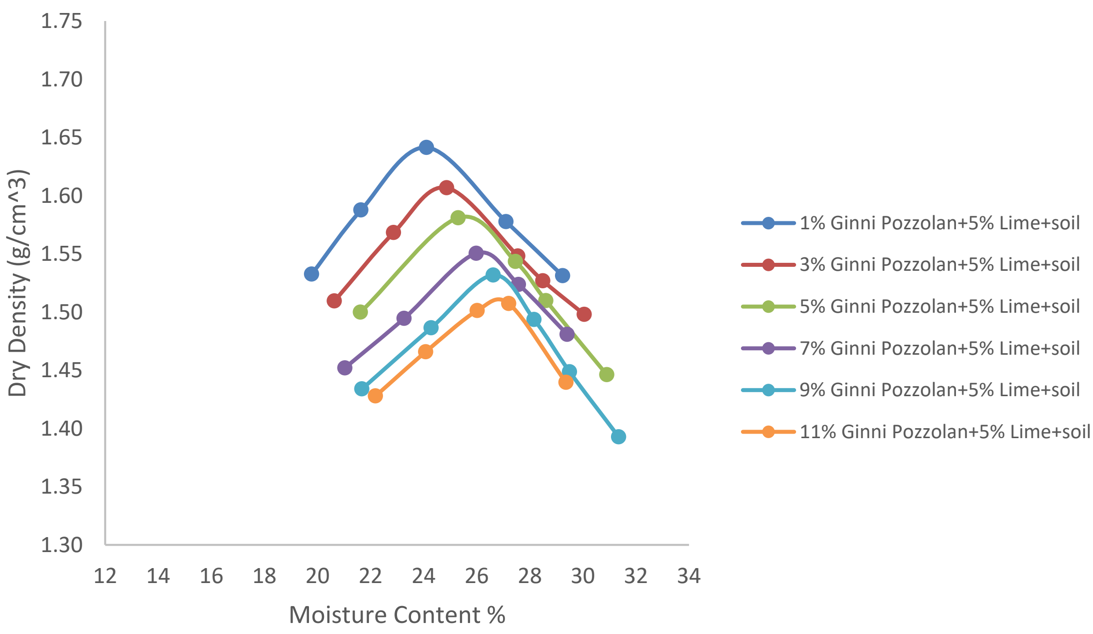


Figure 8 MDD and OMC% comparison of untreated clay with clay treated with lime



sFigure 9 Standard Proctor Test on soil samples with different percentages of Ginni Pozzoloan and 5% lime

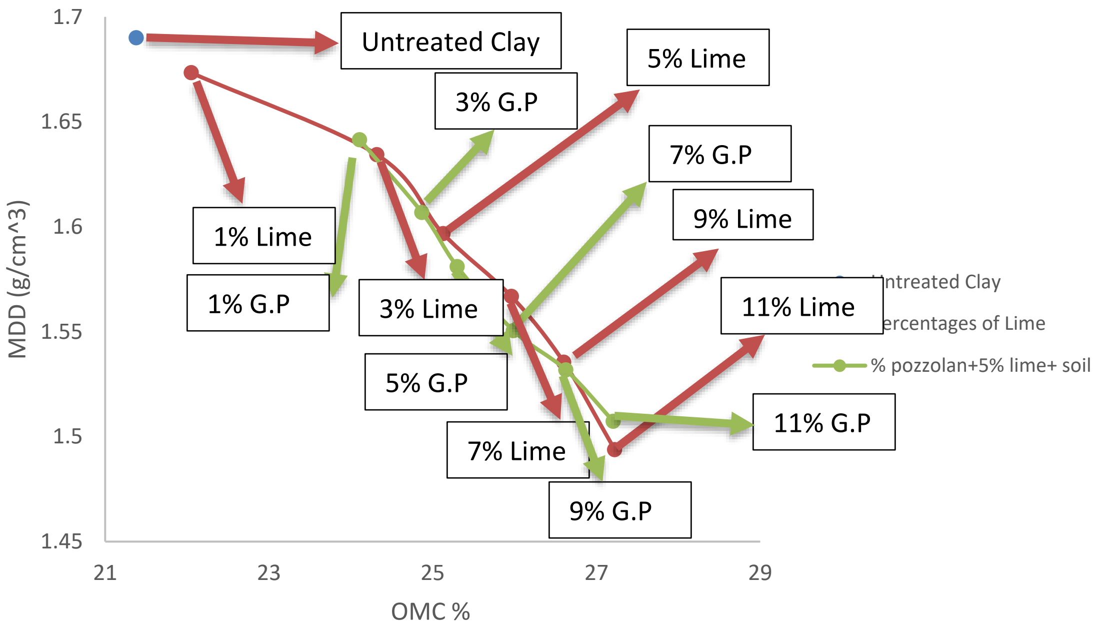
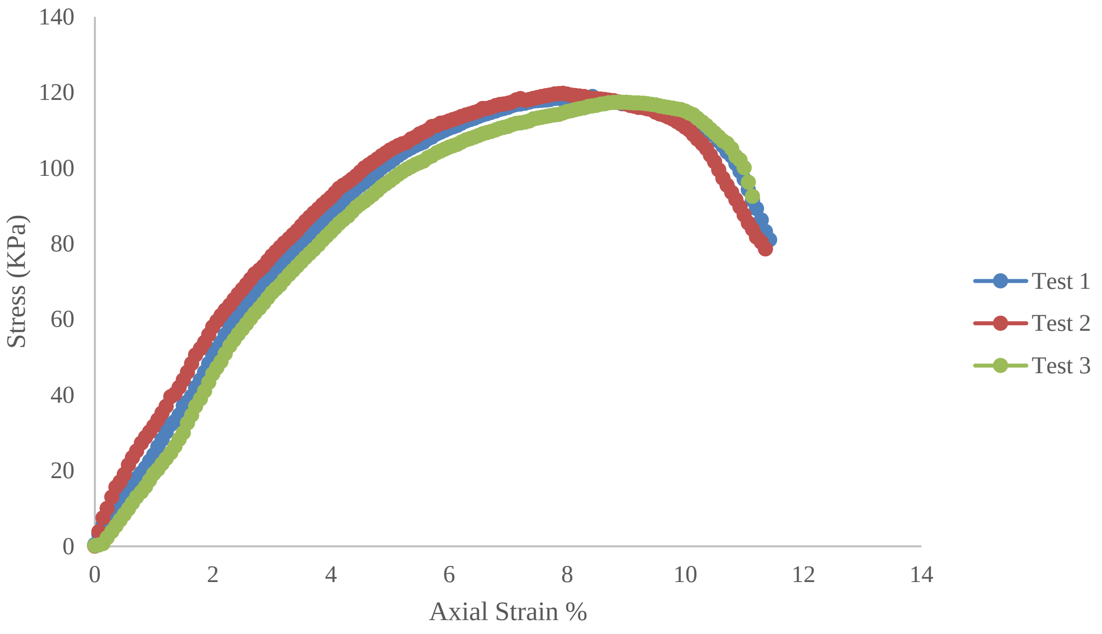


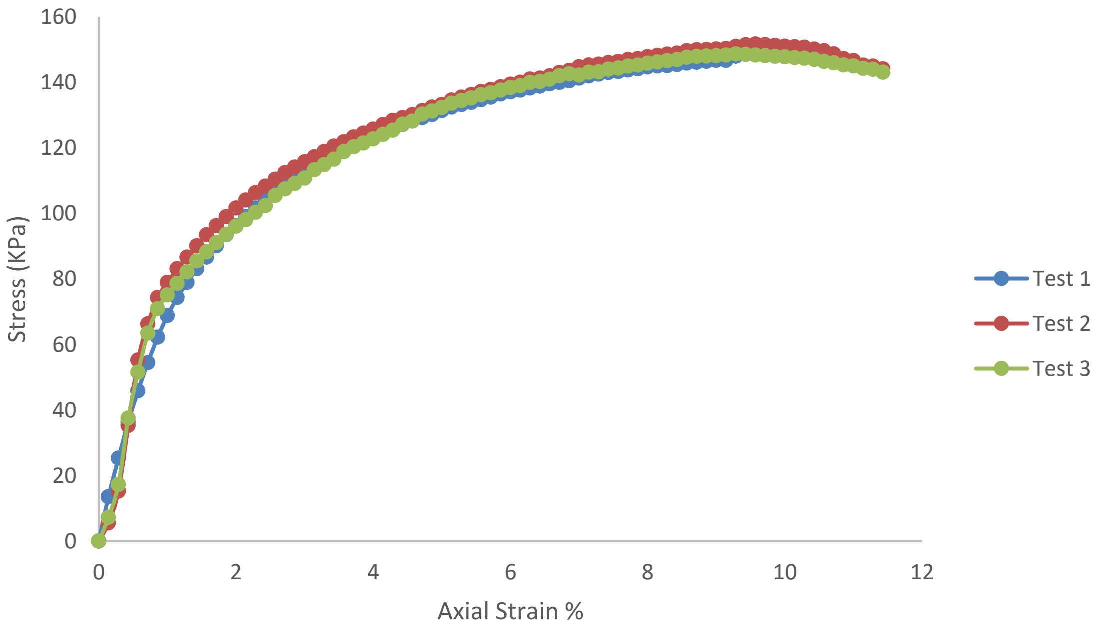
Figure 10 Comparison among untreated clay, different percentages of lime and different % of pozzolan

4.3. Unconfined compressive strength Test

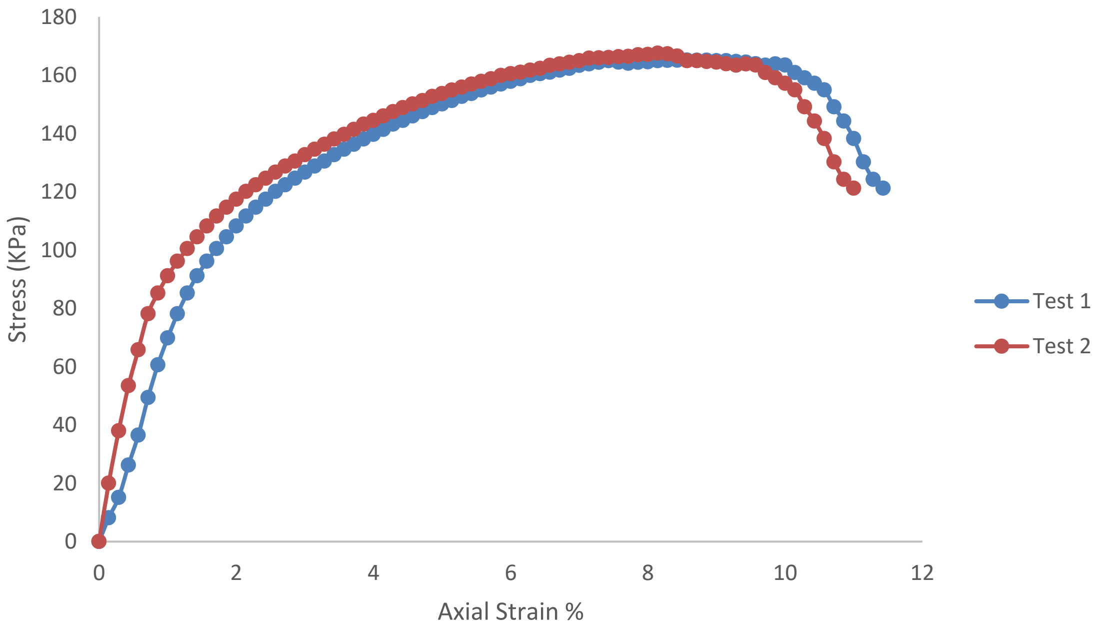
On untreated soil, soil stabilised with lime, and soil treated with lime-Ginni pozzolan, experiments on unconfined compressive strength were conducted. Different curing ages of the specimen underwent tests. To prevent moisture loss, specimens were preserved in plastic bags. The untreated soil sample required 0, 3, and 7 days to cure, while stabilised soil required 3 and 7 days. At 7, 14, and 28 days, we cured soil samples stabilised with Lime-Ginni pozzolan. **Figure 11** displays UCS test trends on untreated clay at various curing days. The graphs clearly show that as the curing period increases, the strength of the soil sample also increases.



(a) Untreated soil for 0 day



(b) Untreated soil for 3 days



(c) Untreated soil for 7 days

Figure 11 Clay - UCS Test Results (0, 3, 7 Days)

In **Figure 12,** unconfined compressive strengths at different days are compared. At 0 days, strength is120 KPa and after 7 days, the strength is 40 times increased.

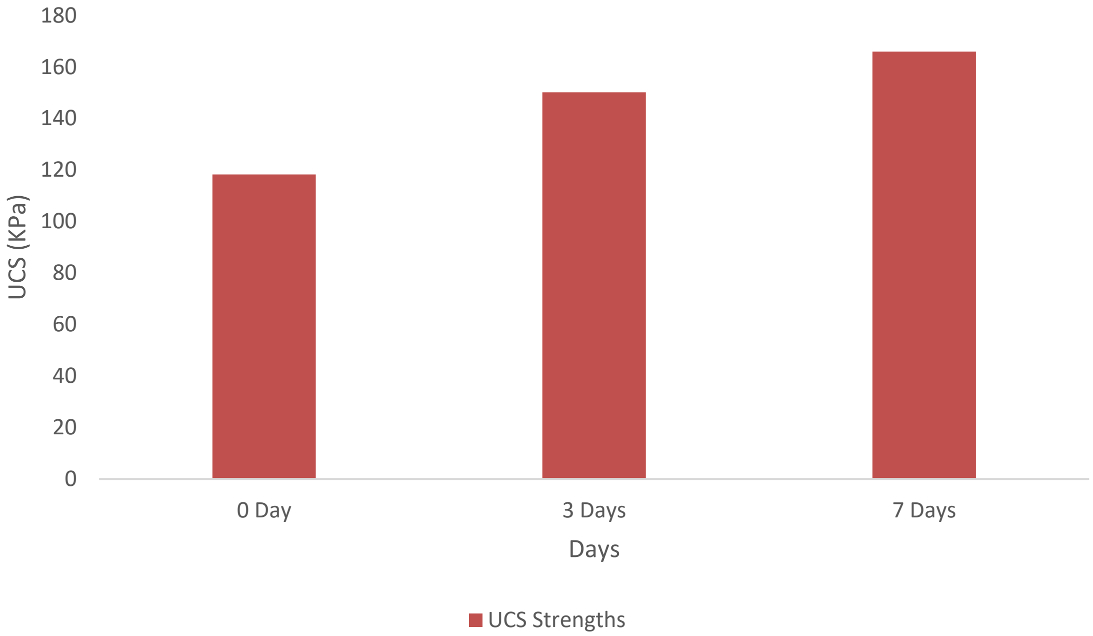
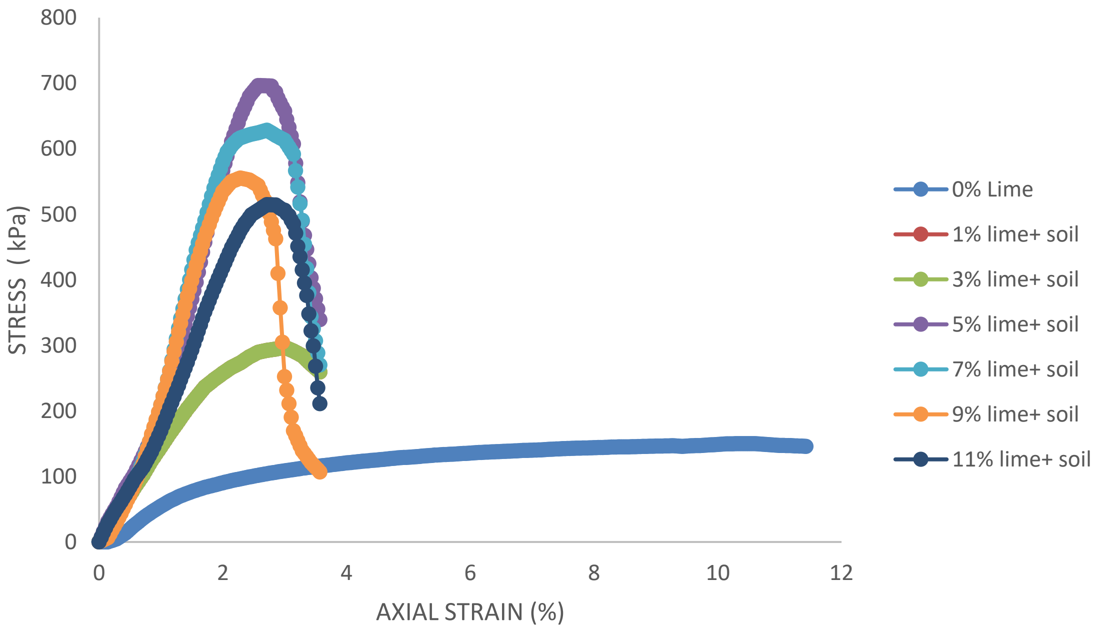
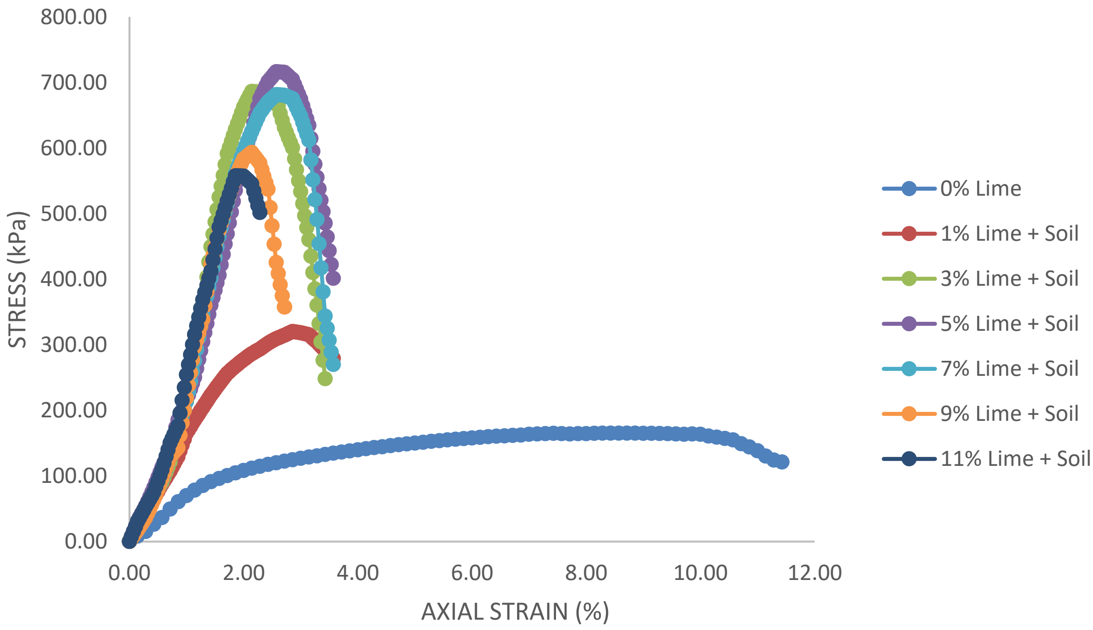


Figure 12 The comparative summary of UCS test on untreated soil

Figure 13 depicts the trend of unconfined compressive strength values for lime-stabilized soil at varying lime concentration percentages. Figure 13 shows that the strength of soil improves up to a specific lime percentage as the quantity of lime in the soil increases. If the lime percentage is increased above the ideal amount, the soil's strength starts to decline. Due of its ability to cement together soil particles, lime primarily increases soil strength. If lime particles, which have a larger surface area than soil, had been used in place of the soil, the cementation process would have been more successful. The cementitious compounds calcium-silicate-hydrates (C-S-H) and calcium-aluminate-hydrate are created when significant concentrations of calcium react with silica and aluminium in lime (CAH). After the lime % reaches its maximum, the soil's strength starts to decline. The key contributing factor is the replacement of soil with smaller lime particles, which reduces soil MDD and, as a result, soil strength. Additionally, **Figure 13** demonstrates that as the curing age of the soil increases, so does its UCS strength.



(a) Lime treated soil for 3 days



(b) Lime treated soil for 7 days

Figure 13 Clay and Lime- UCS Test Results (3, 7 Days)

The results show that lime-stabilized soil has maximum strength at 5 % optimum lime content. The comparative summary of UCS test on Lime stabilized soil at different lime percentages and curing time is shown in **Figure 14.**

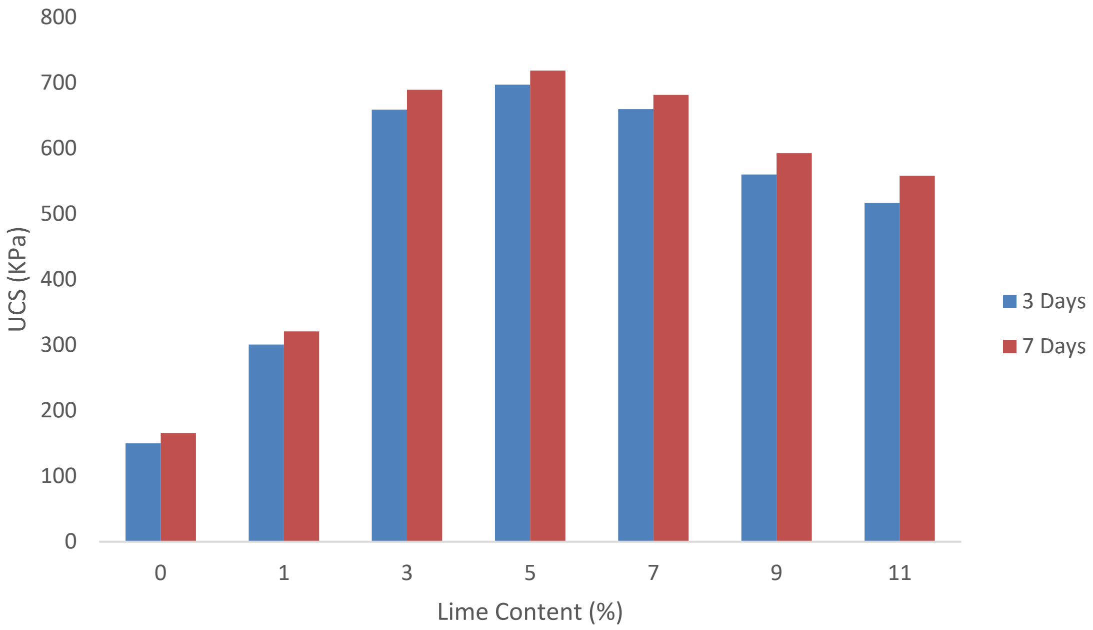
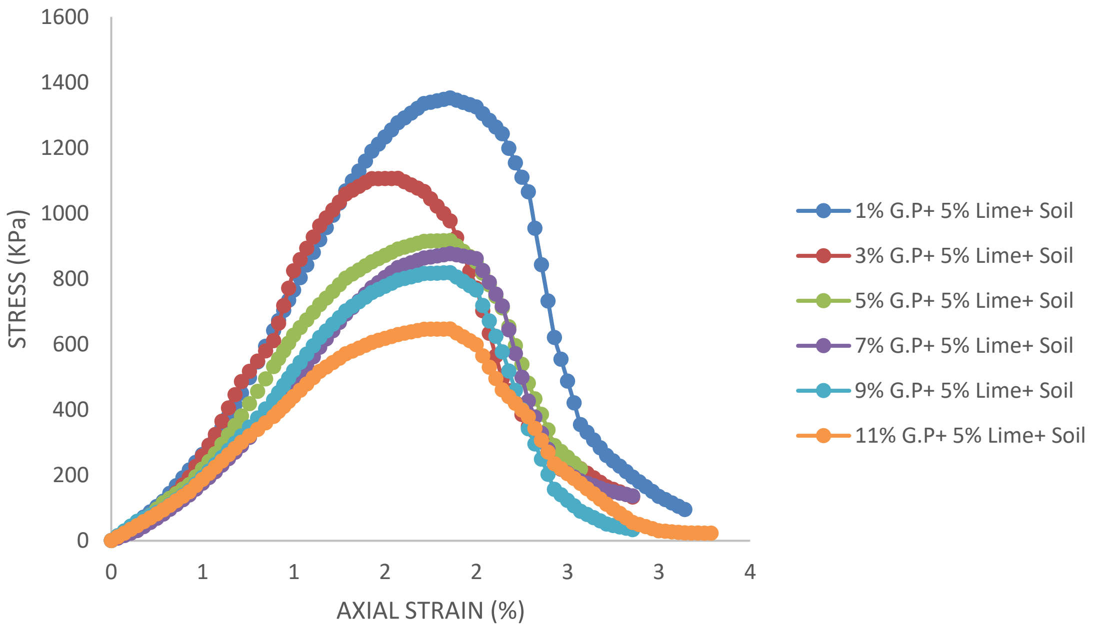
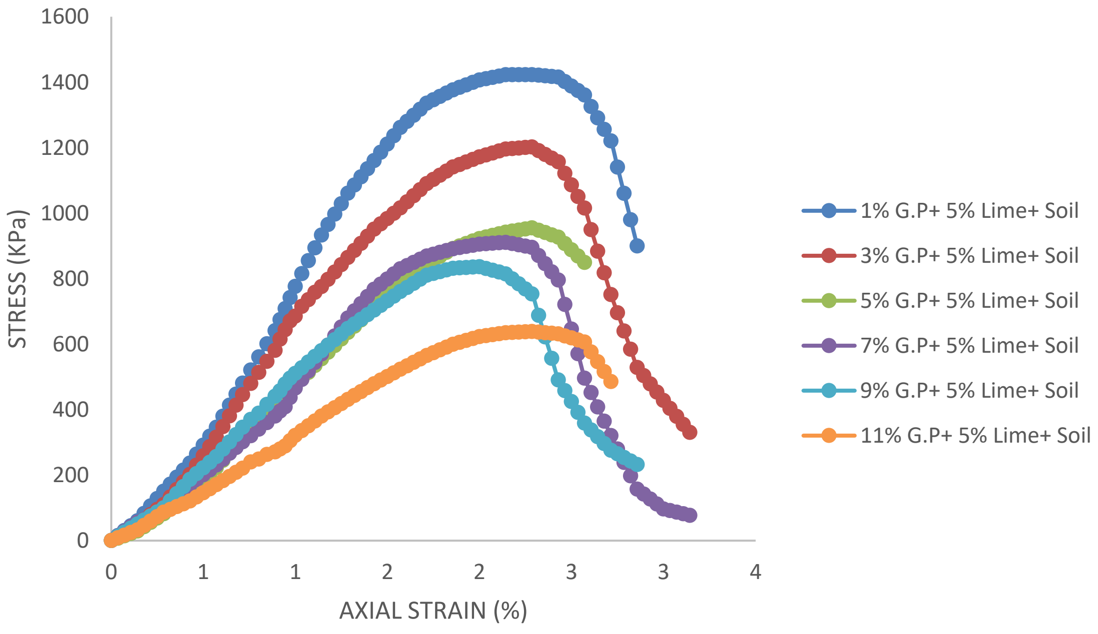


Figure 14 The comparative summary of UCS test on Lime stabilized soil

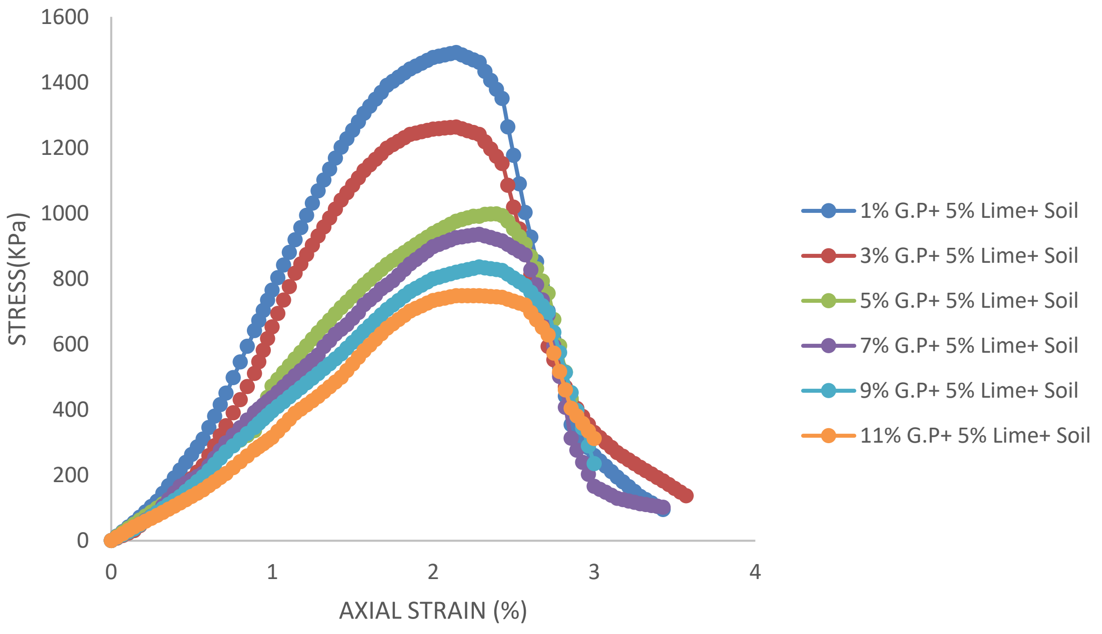
The strength of the soil is increased by the addition of 1% Ginni pozzolan and 5% optimal lime content. The strength of the soil starts to deteriorate if Ginni pozzolan is added in excess of 1%. The readily available silica and alumina from the pozzolan react with the calcium to create binding elements that bind the soil particles together when 1 percent of the best Ginni pozzolan and 5 percent lime are added. The replacement of heavier soil particles by lighter Ginni pozzolan particles, which reduces MDD, results in a drop in soil strength as the Ginni pozzolan percentage is increased further. **Figure 15** depicts the trend of unconfined compressive strength values of lime-Ginni pozzolan stabilised soil at various Ginni pozzolan content percentages. **Figure 15** further demonstrates that when the curing age grows, the UCS strength of soil increases.



(a) Lime (5%) + pozzolan treated soil for 7 days



(b) Lime (5%) + pozzolan treated soil for 14 days



(c) Lime (5%) + pozzolan treated soil for 28 days

Figure 15 Clay, Lime and Ginni Pozzolan- UCS Test Results (7, 14 and 28 Days).

The analysis's finding indicated a soil stabilised with lime and Ginni pozzolan at a 1 percent optimum Ginni pozzolan content with a 5 percent lime content had the highest strength. **Figure 16** depicts the comparative summary of the UCS test on Lime-Ginni Pozzolan stabilised soil at various pozzolanic percentages and ages.

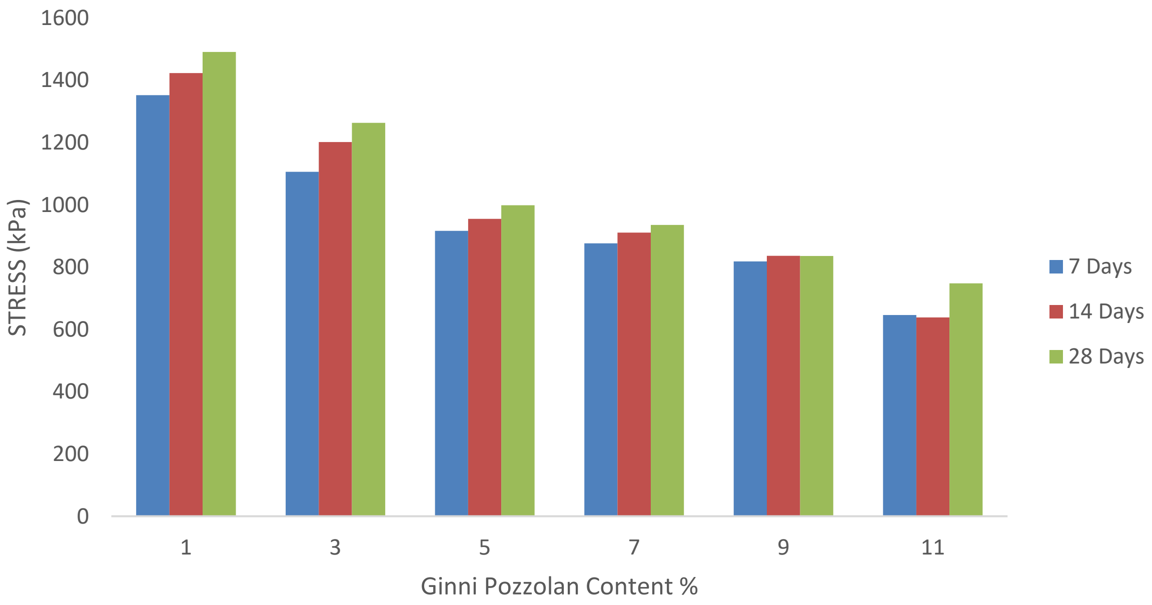


Figure 16 Comparative summary of UCS of clay + 5% lime + 1% pozzolan

4.4. Free Swell Test

The interlayers of montmorillonite absorb water when it is introduced to expansive soils. The absorption increases as its proportion increases. This will cause voids to be filled by swelling Montmorillonite, increasing the amount of soil (Komine & Ogata, 1996). Because it becomes unstable when exposed to water, earth with a high swell potential is unsuitable for supporting a structure (Thomas et al., 2000). To determine how much soil would swell with the addition of water, a free swell test was conducted. Swell index is dramatically decreased from 40% to 16.12 percent with the addition of 5% lime and 1% Ginni pozzolan in fat clay. Swell potential is reduced by around 60%, indicating that these additions can reduce volume changes in soil when it comes into contact with water.

4.5. Computational Analysis

Calculation of E50 values:

E50 values are calculated using stress-strain graphs of UCS tests. Firstly, the ultimate strength is halved to get the unconfined shear strength. The secant slope of this resultant value gives the E50 value. E50 value of every sample i.e., untreated clay, clay plus opt. lime and clay plus both opt. pozzolan and lime is calculated.

Software simulation:

ABAQUS is used for computational analysis to examine how additives affect clay stability. A block with infinite dimensions is drawn to represent soil, and a 100 kPa load is placed at a point of symmetry. Block is meshed to include more accurate results. For computational analysis, the following methodology is used.

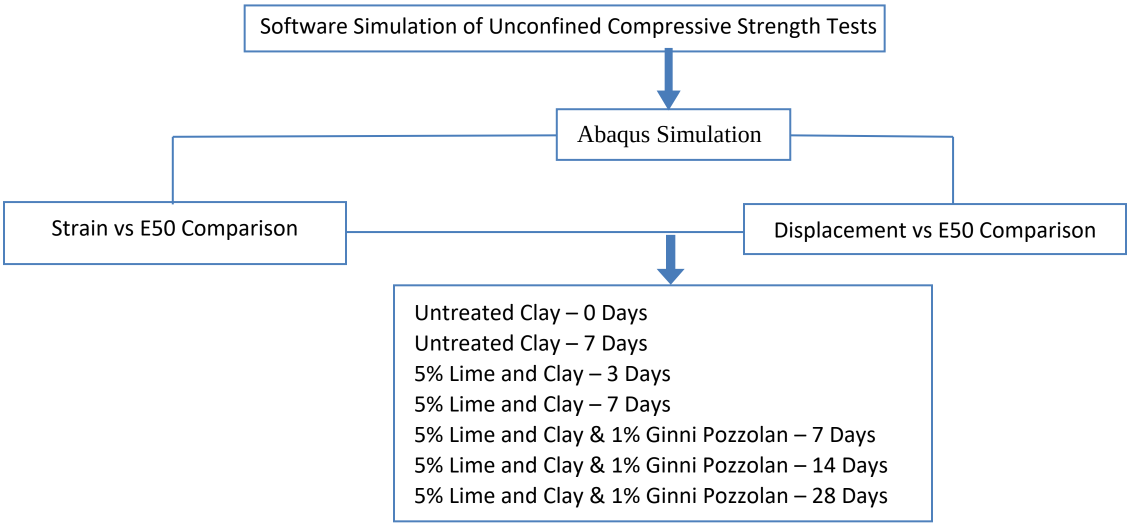


Figure 17 Flowchart for software simulation using Abaqus

4.6. Strain Analysis

At different depths, results **Figure 18, 19, 20** showed that after the addition of 5% lime and 1% Ginni pozzolan in fat clay, strain value is significantly reduced. Strain is further reduced with the incorporation of curing effect.

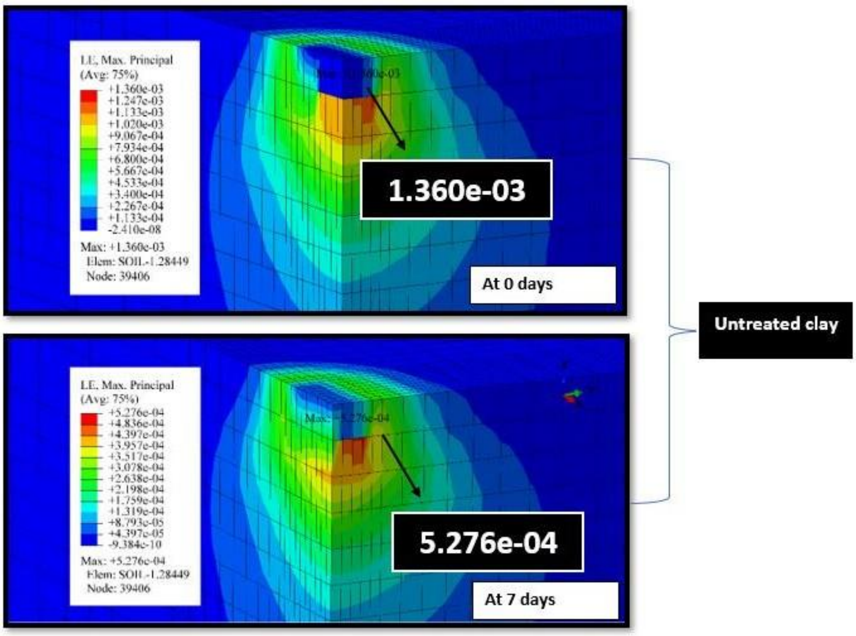


Figure 18 Strain Analysis on untreated clay (0, 7 days) using Abaqus Software

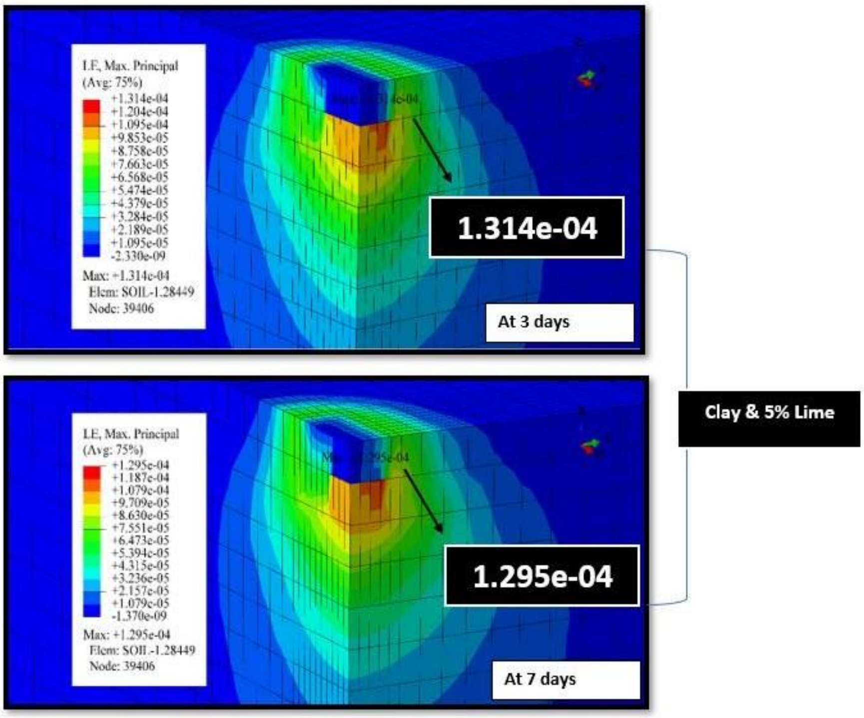


Figure 19 Strain Analysis on lime stabilized clay (3, 7 days) using Abaqus Software

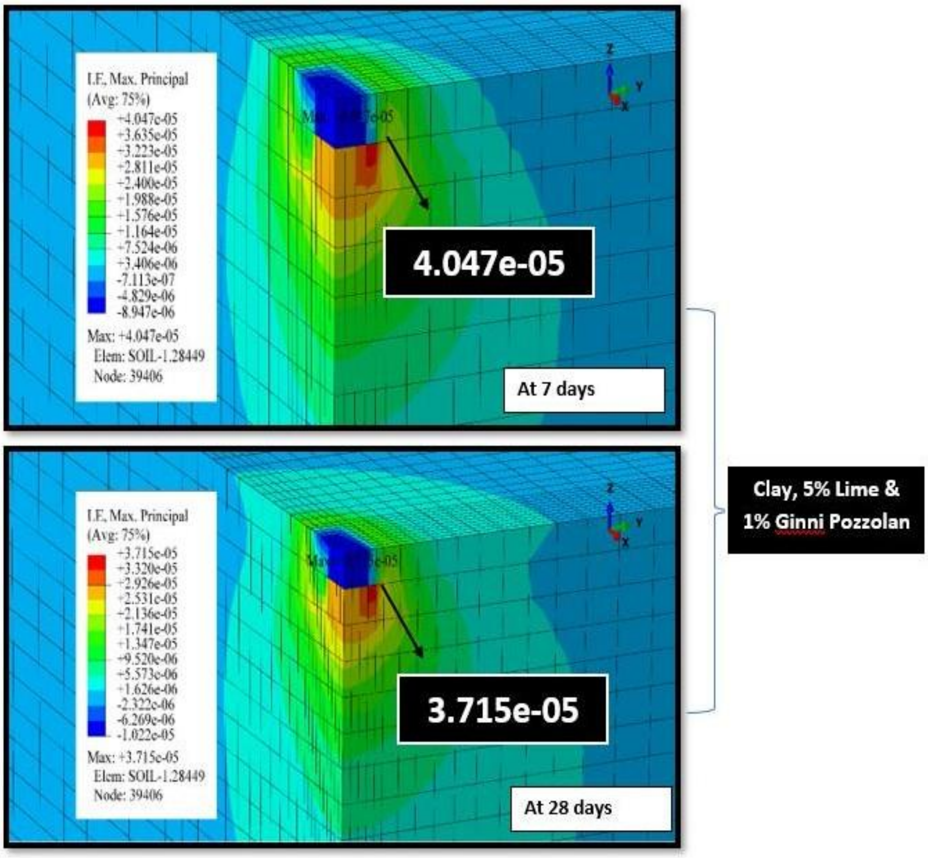


Figure 20 Strain Analysis on lime and pozzolan stabilized clay (7, 28 days) using Abaqus Software

Following Strain vs E50 graph **Figure 21** shows that after the addition of additives and increasing curing time, strain is decreased. Reduction in strain results into increment of stability of soil sample.

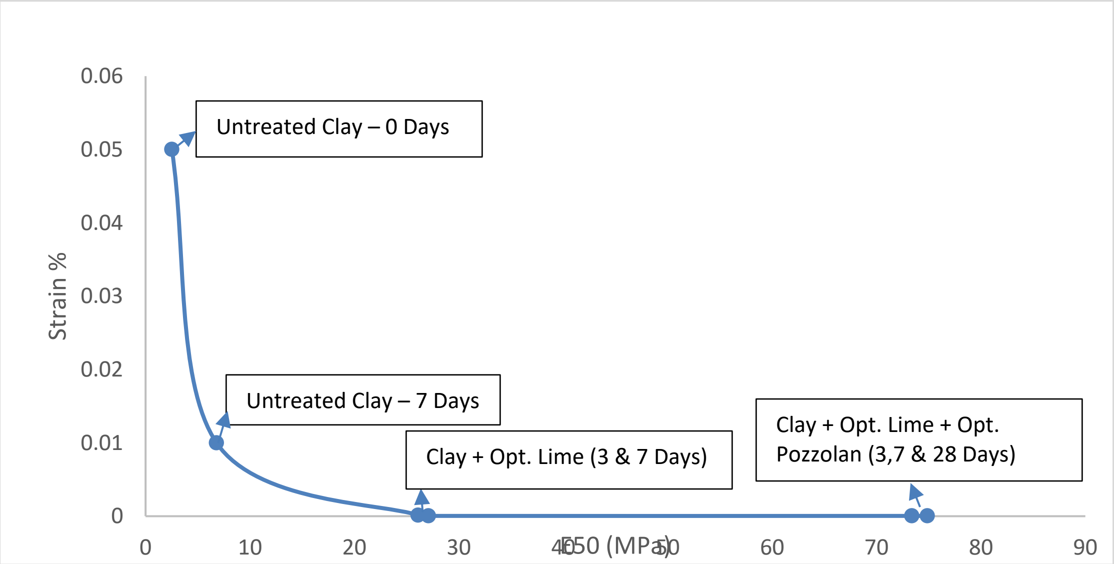


Figure 21 Strain vs E50 Graph Using Abaqus Software

4.7. Displacement Analysis

With the input of E50 values, software provided the displacement values at different depths. Results in **Figure 22, 23 and 24** show that after the addition of 5% lime and 1% Ginni pozzolan in fat clay, displacement value is significantly reduced. Displacement is further reduced with the incorporation of curing effect.

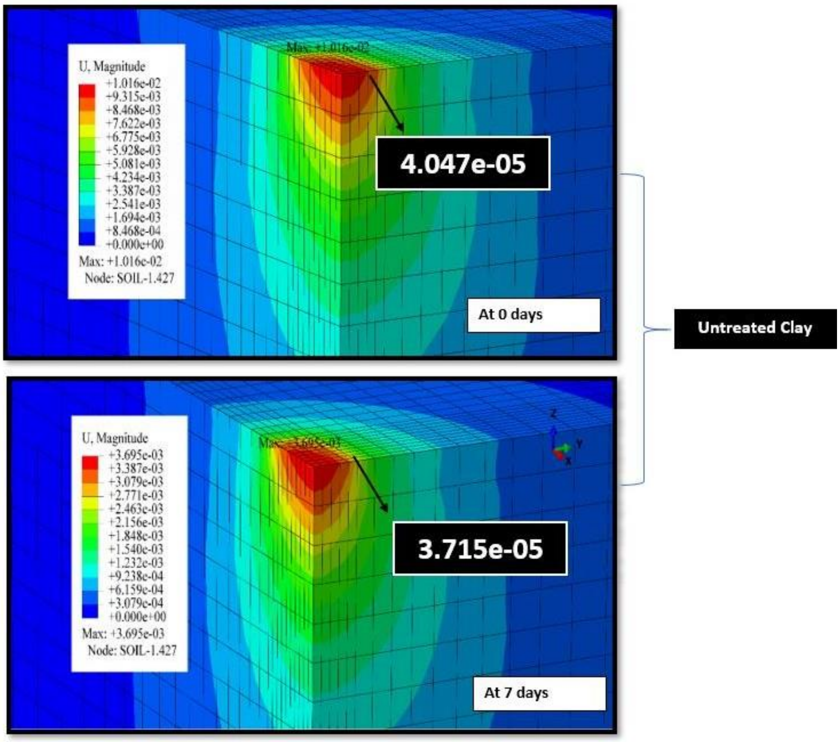


Figure 22 Displacement Analysis on untreated clay (0, 7 days) using Abaqus Software

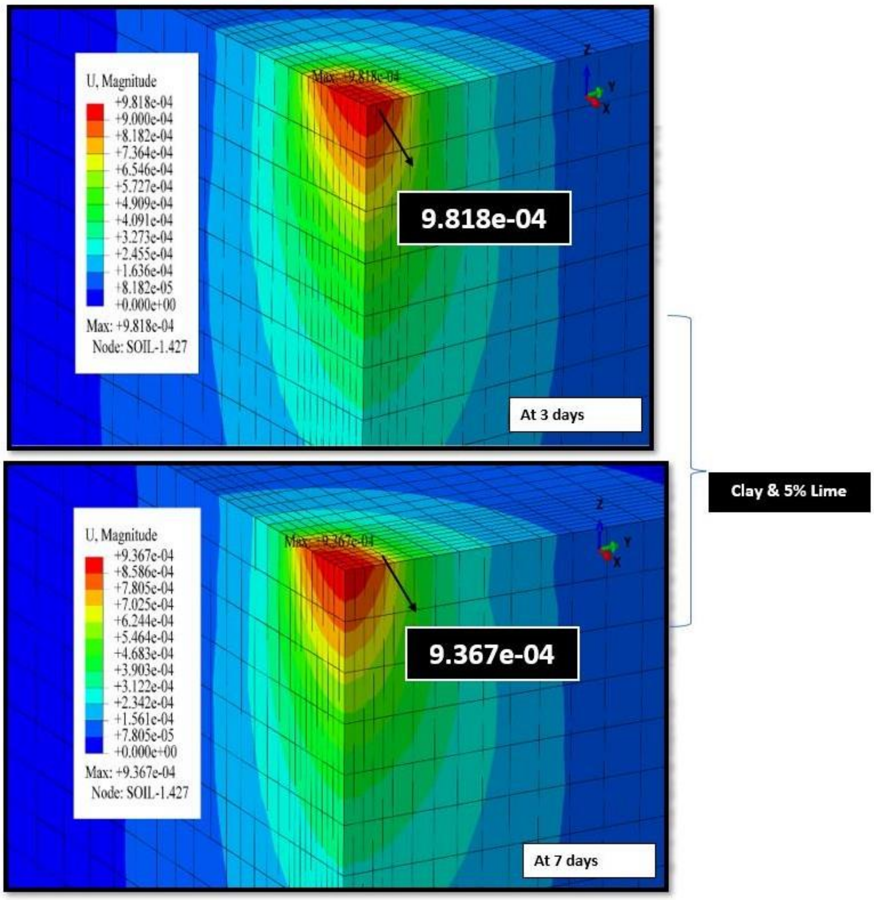


Figure 23 Displacement Analysis on lime stabilized clay (3, 7 days) using Abaqus Software

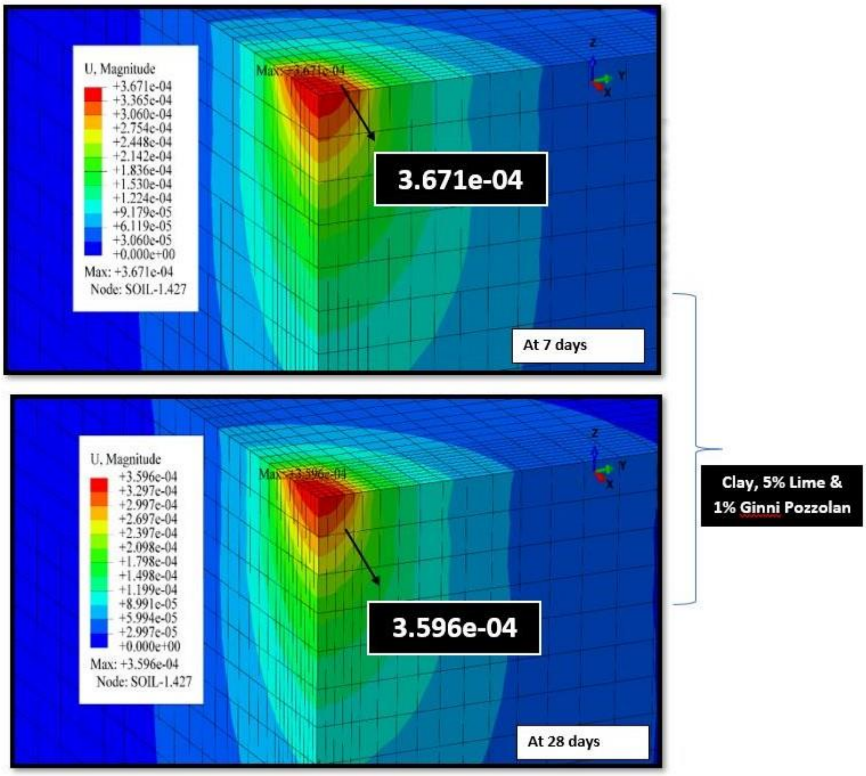


Figure 24 Displacement Analysis on lime and pozzolan stabilized clay (7, 28 days) using Abaqus Software

Following Displacement vs E50 graph **Figure 25** shows that after the addition of additives and increasing curing time, strain is decreased. Reduction in displacement, results into increment of stability of soil sample.

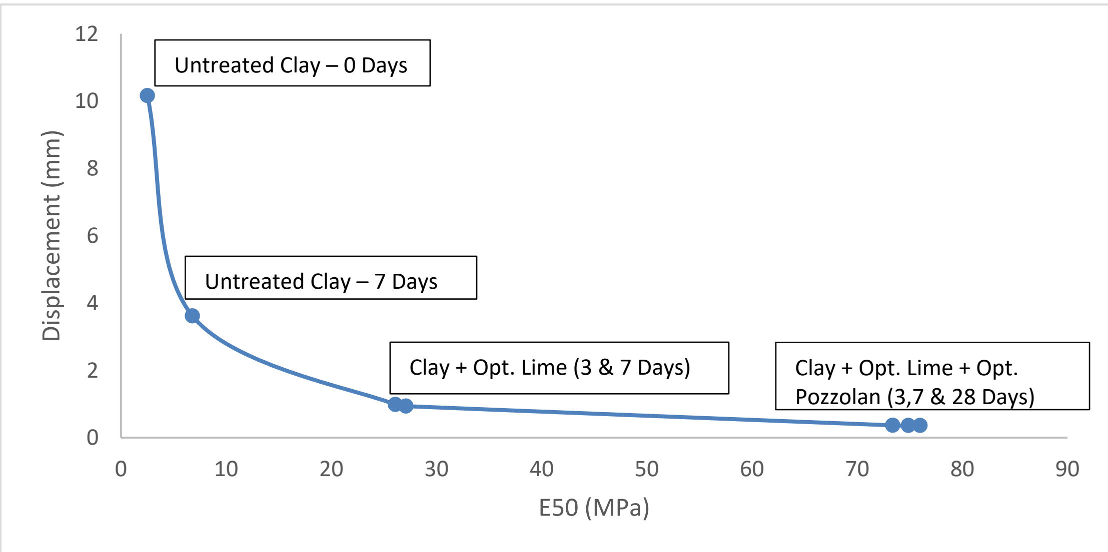


Figure 25 Displacement vs E50 Graph Using Abaqus Software

4.8. pH Test

The beginning of the reactivity is indicated by the PH test, which measures the pH change in the sample. This test was carried out to determine the time at which the pozzolanic reaction started. From **Table 13**, it is evident that pozzolanic reaction started after 14 days of curing.

Table 13: pH value of clay samples at opt. amounts of lime and pozzolan (0, 3, 7, 14, 28 days)

Type - Days	**pH**
Virgin Clay – 0 day	8.35
Clay + 5% Lime – 3 Days	9.2
Clay + 5% Lime – 7 Days	11.2
Clay + 5% Lime + 1% Pozzolan – 7 Days	11.35
Clay + 5% Lime + 1% Pozzolan – 14 Days	12.02
Clay + 5% Lime + 1% Pozzolan – 28 Days	12.32

Chapter 5 Conclusion

This study examines how lime, naturally occurring Ginni pozzolanic material, and their mixtures affect expansive soil compaction, Atterberg limits, and unconfined compressive strength. The following conclusions can be made in light of the test findings we conducted:

- In stabilised soil using Ginni pozzolan in conjunction with the ideal amount of lime, the ideal moisture content of the soil increases when compared to untreated soil, but decreases when compared to lime stabilised soil. On the other hand, the MDD from untreated soil decreases when Pozzolan is added, whereas the MDD from lime stabilised soil increases.
- When lime is added to soil that has already been stabilised with lime, the OMC rises and the MDD falls as the lime content rises.
- In comparison to untreated and lime-stabilized soil, the plasticity index of soil stabilised using the best lime-Ginni pozzolan drops. In a similar vein, soil treated with lime-Ginni pozzolan has a higher shrinkage limit than untreated or lime-stabilized soil. In comparison to lime-stabilized and untreated soil, the swelling potential is reduced more with the addition of a lime and Ginni pozzolan combination. This proves that adding the right amount of lime-Ginni pozzolan improves the soil's index qualities.
- The unconfined compressive strength was strengthened by the addition of lime. The unconfined compressive strength can be significantly increased by combining lime and Ginni pozzolan.

- The software modelling of UCS testing reveals that clay treated with the ideal amount of lime-Ginni pozzolan experiences less displacement and strain, increasing soil stability.
- In comparison to other conventional soil stabilising materials, Ginni pozzolan and lime are more environmentally benign when employed as an activator. In contrast to prior research, which reveal that over 12 percent cement is used in the field for expansive soil stabilisation, here only 1 percent Ginni pozzolan and 5 percent lime are used. Cement is a concern to the environment since it contributes to CO2 emissions into the atmosphere.

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