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Evaluation of Empirical SPT N-Vs Correlations Using 1D Site Response Analysis and Improving the Shear Strength of Expansive Soil in Islamabad, Pakistan

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ABSTRACT

In this study, a suite of SPT-N profiles from Islamabad, Pakistan is used and a set of renowned empirical SPT-N and Vs correlations are applied to construct the corresponding shear wave velocity profiles. A suite of one-dimensional seismic site response analysis is then performed on the developed shear wave velocity profiles. Site response outputs are compared with the code-based design spectra of BCP (2007). Based on a comparative analysis, the empirical correlations suitable for engineering practice in the context of current seismic design of Pakistan are recommended. Furthermore, this study investigated the shear strength of expansive soils before and after their stabilization to improve their shear strength. Direct shear tests and unconfined compression tests were carried out on non-stabilized and stabilized soil specimens in different conditions using different percentages of sugar bagasse and nominal percentages for improvement of shear strength of soils were recommended.

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Chapter 1

INTRODUCTION

1.1 Background

Pakistan is an earthquake-prone country. Geologically, Pakistan is situated in the Eurasian and Indian plates. The capital city of Pakistan, Islamabad is located on the outskirts of the Potohar Plateau at 33.43N, 73.04 E. Islamabad was hit by a strong earthquake with a moment magnitude (Mw = 7.8) on October 8, 2005. More than 250 people were buried alive and over 74000 people died as a result of that deadliest earthquake[1].

Understanding earthquake hazards is crucial for Pakistan's sustainable development. Ground response analysis is usually performed to predict the surface motions. Shear wave velocity (Vs) is an essential parameter required to perform seismic ground response analysis. Additionally, Vs is also a fundamental soil parameter used in seismic site classification. The building codes around the world are primarily based on Vs30[1], the required information pertains to the time-weighted shear wave velocity of the top 30 m. Vs is typically measured by using in-situ seismic non-destructive tests. However, there is a lack of such tests in Pakistan due to cost limitations. Therefore, the empirical correlations between in-situ standard penetration test measurements (SPT-N) and Vs are utilized to resolve the shear wave velocity.

Expansive soil is a type of soil that displays volume changes in response to fluctuations in moisture content. Water is absorbed by the expansive soil, causing it to swell, and it is dried out, leading to its shrinkage. This poses a significant problem for geotechnical engineering as the soil's swelling and shrinking behavior can cause substantial damage to buildings, roads, and other infrastructure built on top of it. Arid and semi-arid regions are typically where expansive soils are found, where they form due to the weathering and erosion of specific types of rock such as shale, limestone, and clay.

One of the most challenging properties of expansive soils is their high clay content, which gives them their unique swelling and shrinking behavior. When the soil absorbs water, the clay particles absorb moisture and swell, pushing against each other, causing the soil to expand. Conversely, when the soil dries out, the clay particles contract and the soil shrink.

Expansive soils also tend to have low shear strength, which makes them susceptible to cracking and fracturing under load. This can cause significant damage to buildings and infrastructure, including the formation of cracks in walls, floors, and foundations. Moreover, the soil's swelling and shrinking behavior can lead to heaving, settlement, and differential movement of the soil, which can cause further damage to buildings and infrastructure.

Working with expansive soils poses several challenges for engineers. For instance, designing foundations and other infrastructure on expansive soils requires careful consideration of the soil's properties and behavior. Engineers must also account for the effects of climate and weather patterns on the soil, as well as the potential for changes in moisture content over time.

Many researchers such as[2] have reported and widely revealed in previous findings that significant estimates are made for the average annual cost of structural damage associated with light structures and footings constructed on expansive soils. The projected yearly expense resulting from this destruction amounts to around $US 15 billion, significantly surpassing the total cost of damage to residential buildings and infrastructure caused by various natural disasters like floods, hurricanes, tornadoes, and earthquakes. ASCE (the American Society of Civil Engineers) reports that expansive soils cause significant structural damage, with roughly a quarter of all houses in the United States suffering some form of damage.

Shear strength is an essential variable to consider while dealing with expansive soils as it measures the soil's capacity to resist forces that may cause it to deform or collapse. The significance of shear strength in expansive soils arises from their inherent low shear strength, which can result in structural instability and failure. This instability can severely damage buildings and infrastructure, characterized by foundation movement, deformation, and cracking. Therefore, the shear strength of expansive soils is crucial to be improved to ensure the stability and safety of structures constructed on such soils. Enhanced shear strength also increases the longevity of structures, reducing the need for frequent maintenance or expansive repairs.

In geotechnical engineering, the strength of soil is a crucial variable in the design of systems, alongside cost and ease of construction. To strengthen the soil properties, conventional materials like cement, lime, and bitumen have been utilized. However, these materials can be expensive and inaccessible, particularly for civil projects in rural areas[3]. As a result, further research is necessary to discover more innovative and cost-effective methods of improving the engineering characteristics of soil. One of these innovative ways is reinforcing soil with bagasse fiber, which could also have the added benefit of reducing its environmental footprint.

Sugarcane bagasse ash (SCBA) and limestone dust (LSD) are two cost-effective and eco-friendly materials that can potentially enhance the expansive soil's shear strength. A by-product of the sugarcane industry is sugarcane bagasse ash, produced by burning sugarcane bagasse, the fibrous residue left after juice extraction. Limestone dust, on the other hand, is a by-product of the quarrying process, produced by crushing limestone rocks.

Both materials have unique properties that make them suitable for soil stabilization. Sugarcane bagasse ash is rich in silica and pozzolanic compounds, which, when combined with calcium hydroxide in the soil, create cement-like substances that enhance the soil's strength and stability. Limestone dust, on the other hand, contains high levels of calcium carbonate, which reacts with soil acids to neutralize them and improve the soil's pH and strength.

One of the advantages of using these materials is their availability. Both sugarcane bagasse and limestone are abundant in many regions of the world, making their production and distribution relatively easy and cost-effective. Additionally, the utilization of these materials for soil stabilization can help in reducing waste and minimizing the environmental impact of their production.

1.2 Problem Statement

The occurrence of anomalous damage during earthquakes in the region highlights the necessity for a well-organized site characterization to improve seismic design procedures. To improve seismic design methods and reduce the likelihood of unusual damage, a comprehensive comprehension of the site's geotechnical properties and seismic response characteristics is crucial. This is achieved through a well-organized site characterization process. Furthermore, we know that one of the most common soil types in the world is clayey soil, and it is frequently utilized in building and other construction applications. Instability and failure in structures constructed on or with clayey soils can be caused by their poor shear strength. The current understanding of expansive soils highlights the distinct characteristics of these soils that pose challenges for geotechnical engineering projects. Designing structures on expansive soils demands a thorough understanding of their properties and behavior to ensure stability and durability. Clays and silts that have low shear strength need to be stabilized. Similar soils are being found in many areas in arid and semi-arid regions of Pakistan including Islamabad, so there is a need for soil improvement in such areas. Despite the significant research that has been carried out in this field, there is still a gap in the search for practical and sustainable solutions that are cost-effective in enhancing the shear strength of expansive soils. This study is of utmost importance as it aims to identify sustainable and cost-effective solutions to enhance the shear strength of expansive soils, which could significantly benefit the construction industry and the environment.

1.3 Key questions

The research on sugarcane bagasse-reinforced soils was guided by several key research questions. These questions helped to provide focus and direction for the study and included:

- How can a well-organized site characterization process enhance seismic design procedures?
- What are the critical geotechnical data required for accurate seismic hazard assessments?
- How can tailored seismic design procedures improve the resilience of structures in earthquake-prone regions?
- What is the shear strength behavior exhibited by expansive soils?
- Is it possible for sugarcane bagasse ash to be utilized in order to improve the engineering properties of soils?
- What is the optimum amount of bagasse ash required to achieve the maximum enhancement in the shear strength parameters of soils?
- How does the addition of sugarcane bagasse ash in combination with limestone dust affect the shear strength of expansive soils?
- What is the optimum percentage of SCBA-LSD to use in improving the shear strength of expansive soils?
- How can the findings of this research be applied to real-world geotechnical projects?
- What are the potential environmental impacts of using sugarcane bagasse ash and limestone dust in expansive soils?

1.4 Aims and Research Objectives

- To evaluate the empirical SPT N-VS correlations using 1D site response analysis.
- Evaluate and compare various existing empirical SPT N-VS correlations available in the literature. Analyze their applicability to different soil types and geological conditions.
- To use agricultural waste, sugarcane bagasse, an application managing waste sustainably, for the stabilization of expansive soil.
- Improving engineering characteristics of expansive soil using industrial waste and solving the problem of waste disposal.
- Knowledge of the shear strength, which is essential for design consideration and Improvement in the geotechnical design of the foundation.
- Recommendations after a comprehensive site response and shear strength analysis.

1.5 Scope of Research

The scope of the study is to evaluate the empirical Standard Penetration Test (SPT) N-VS correlations using one-dimensional (1D) site response analysis. The focus is on understanding the relationship between the SPT N-values and shear wave velocity (Vs) profiles to assess the seismic site response characteristics. The study will utilize a suite of SPT-N profiles from Islamabad, Pakistan, and apply renowned empirical correlations to construct corresponding shear wave velocity profiles. The soil serves as the foundation for the structure, providing support from underneath and effectively distributing the load. Inadequate soil stability can result in structural failures such as settlement, cracks, and other forms of damage. The primary objective of this study is to examine the shear strength of expansive soils both prior to and subsequent to their stabilization, with the aim of enhancing their shear strength. In all the developing residential societies of Pakistan where cut and fill processes are employed for the construction of commercial buildings, residential houses, and roads. This study will help the industry understand soil's shear strength characteristics using a sustainable waste application and its stabilization. We will be conducting direct shear tests and unconfined compressive tests on both non-stabilized and stabilized soil samples. These tests will be performed under various conditions, using different combinations of sugarcane bagasse ash and limestone dust. From this, we can make recommendations after comparing the results and concentrating on future use. Furthermore, the experimental setup will be simulated in the PLAXIS software, and the results will be compared with to help the Pakistan construction industry in its geotechnical design.

1.6 Novelty

The novelty of this research lies in its approach of evaluating empirical SPT N-Vs correlations using 1D site response analysis and its focus on improving the shear strength of expansive soil in Islamabad, Pakistan. By combining these two aspects, the study aims to provide valuable insights into the behavior of expansive soil under seismic conditions and proposes potential measures to enhance its shear strength, which can be crucial for infrastructure stability and safety in the region prone to earthquakes. This research contributes to a better understanding of soil dynamics and offers practical solutions for mitigating the risks associated with expansive soils in Islamabad, ultimately benefiting the construction and engineering industries in the

1.7 Research Outline

The research is structured into five chapters outlined as follows:

Chapter 1: In Chapter 1, we provide an introduction to the research topic, focusing on seismic site characterization for enhanced seismic design and sustainable soil stabilization using SCBA and LSD. We discuss the background information on seismic hazards in the region and emphasize the importance of site characterization in seismic design and geotechnical stability. Additionally, we present an overview of current seismic design procedures and challenges, highlighting the need for sustainable soil stabilization techniques to improve the geotechnical properties of expansive soil, background information on expansive soil and its properties, as well as an overview of the use of sustainable materials in geotechnical engineering.

Chapter 2: In this chapter, we conducted a comprehensive literature review, exploring geophysical and geotechnical methods utilized for site characterization, with a specific focus on the Standard Penetration Test (SPT) and its significance in obtaining shear wave velocity profiles for seismic analysis. We examine empirical SPT-N and Vs correlations, crucial for seismic site response analysis. Additionally, we review prior studies concerning the use of SCBA and LSD as soil stabilizers, analyzing their impact on soil properties, particularly in enhancing shear strength. Furthermore, we investigate sustainable practices in geotechnical engineering, emphasizing the utilization of waste materials for environmentally-friendly and resource-efficient solutions.

Chapter 3: In this chapter we present comprehensive details on data collection and analysis. We outline the collection of SPT-N profiles from Islamabad, Pakistan, and their subsequent utilization in constructing shear wave velocity profiles through empirical correlations. Additionally, we conduct one-dimensional site response analysis using numerical simulations. Furthermore, we provide specifics on soil sample collection and characterization procedures. We describe the mixing techniques employed to incorporate SCBA and LSD into the soil, as well as the testing methods utilized to evaluate shear strength and geotechnical properties. This chapter serves as a crucial foundation for our research, enabling us to assess the seismic response characteristics and improve the geotechnical properties of expansive soil using sustainable stabilizers.

Chapter 4: In this chapter we present the results and engage in a comprehensive discussion. We showcase the site response outputs, comparing them with code-based design spectra to evaluate their accuracy. Through residual analysis, we assess the suitability of empirical correlations for engineering practice. Additionally, we discuss key findings related to seismic site characterization and their implications for enhancing seismic design. Moreover, we present experimental results of soil improvement using SCBA and LSD, and conduct a comparative analysis of different stabilization approaches. Finally, we thoroughly discuss the effectiveness of the combined use of SCBA and LSD in stabilizing the soil, highlighting their potential as sustainable solutions for geotechnical stability.

Chapter 5: In this final chapter, we provide a concise conclusion and valuable recommendations. We summarize the research findings concerning seismic site characterization and sustainable soil stabilization using SCBA and LSD. We offer practical recommendations for the application of empirical correlations in seismic design, as well as guidance for the effective use of SCBA and LSD in soil stabilization. Moreover, we emphasize the importance of integrating seismic site characterization and soil improvement techniques to achieve comprehensive geotechnical stability in earthquake-prone regions. Additionally, we highlight future research directions, including seismic site characterization, seismic design enhancement, and sustainable soil stabilization, with broader implications for geotechnical engineering practices and environmental impact.

Chapter 2

LITERATURE REVIEW

2.1 Empirical Correlation Evaluation

Extensive research has been performed in this regard resulting in the development of a number of empirical correlations. Most of the empirical correlations have been developed using uncorrected SPT-N values.[4]

In Pakistan, some studies have utilized the SPT N – Vs correlations for ground response analyses.[5] used the empirical correlation of[6] to study the one-dimensional site response of the Margalla tower collapse in Islamabad.[7] used a suite of empirical correlations to study the site-specific ground response at the cultural museum, Peshawar.[8] used empirical correlation of to develop a functional form for VS30 with depth.[9]used the correlation of[6] to evaluate the site amplification factors of Islamabad, Pakistan.

In all the above-mentioned study, the evaluation of different empirical correlations was not performed. There is a need to evaluate the existing correlations in context to the building code of Pakistan[10]. In this study, two different correlations were used to develop the Vs profiles from SPT-N values. A suite of 1D nonlinear site response analyses was performed on both sets of profiles and the calculated amplification factors are compared with those in the[10]. The discrepancies were discussed.

2.2 A review of Building code of Pakistan (BCP 2007):

The current building code of Pakistan includes provisions related to seismic safety [10] have been taken from Chapter 16 of Uniform Building Code[11]. Based on Probabilistic Seismic Hazard Analysis (PSHA), Pakistan is divided into five seismic zones. Islamabad lies in the seismic zone 2B. Sites are classified into five classes based on VS30. Soil classification is summarized in Table 2.1. The characterization of design spectrum is illustrated in Figure 2.1.

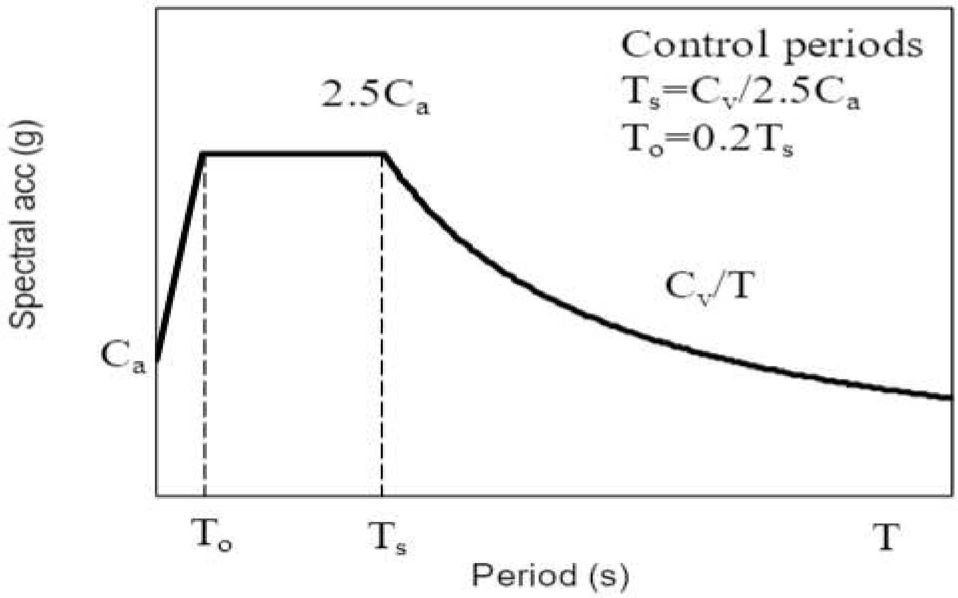

Figure 2.1. Characterization of design spectrum in[10]**.**

Table 2.1. Seismic site classification according to BCP (2007)[10]

Site	Description	V_{S30} (m/s)	SPT N	Undrained shear strength, Su (kPa)
S_A	Hard rock	> 1500	-	-
S_B	Rock	750 - 1500	-	-
Sc	Very dense soil/Soft rock	360 - 760	>50	>100
S_D	Stiff soil	175 - 350	15 - 50	50 - 100
S_E	Soft soil	< 175	<15	<50
S_F	Soil requires site-specific evaluation			

2.3 Expansive Soil: Challenges and Implications

One of the most common soil types in the world is clayey soil, and it is frequently utilized in building and other construction applications. Instability and failure in structures constructed on or with clayey soils can be caused by their poor shear strength. Expansive soils refer to soils that exhibit significant swelling and shrinkage upon variation in moisture content. This type of soil is found in many parts of the world, and its high swelling potential can pose a significant challenge to the construction industry. Expansive soils can cause substantial destruction to buildings and infrastructure due to their tendency to undergo alternating wetting and drying periods, leading to foundation movement, deformation, and cracking, which can compromise the stability and safety of structures. As such, it is crucial to enhance the shear strength of these soils to maintain the integrity of buildings and infrastructure.

Shear strength is an essential parameter to consider while dealing with expansive soils as it measures the soil's capacity to resist forces that may cause it to deform or collapse. The significance of shear strength in expansive soils arises from their inherent low shear strength, which can result in structural instability and failure. This instability can severely damage buildings and infrastructure, characterized by foundation movement, deformation, and cracking. Therefore, it is crucial to enhance the shear strength of expansive soils to ensure the stability and safety of structures constructed on such soils. Enhanced shear strength also increases the longevity of structures, reducing the need for frequent maintenance or expensive repairs.

2.4 Previous Studies on Sugarcane Bagasse Ash and Limestone Dust

Prior research has been done on the use of agro-industrial wastes such as rice husk, fly ash, silica fume, and bagasse fiber, in engineering applications[12]. Many researchers have studied the potential use of sugarcane bagasse ash (SCBA) and limestone dust (LSD) to improve the shear strength of expansive soils. A study conducted by[13] explored how incorporating bagasse ash and limestone dust affected the geotechnical characteristics of expansive soil. The findings demonstrated that adding these materials enhanced the soil's strength and reduced its swelling potential. And its plasticity while the SCBA-LSD combination also improved unconfined compressive strength UCS recorded at an optimal stabilizer content of 10%. In a separate study conducted by[14], it was found that as the content of SCBA-LSD increased from 0% to 25%, there was an 80% increase in the unconfined compressive strength. Similarly, as reported by[15], [16] SCBA and LSD can improve the geotechnical properties of various soils like silty, low to high plastic clay, and expansive soils potentially to be used as a pozzolanic material for binders in building material and from 0 to 25% stabilizer content enhances engineering properties and diminish linear shrinkage.

Furthermore, a study done by[17], [18] concluded that the peak shear strength exhibited a non-linear increase with the increase in SCBA content, reaching its highest point at a fiber content of 1.4%. However, beyond this point, the shear strength started to decrease. Likewise, a study conducted by[19] explored the impact of polypropylene fiber (PPF) on the characteristics of clay soil stabilized with bagasse ash-cement. The study concluded that the addition of PPF to the SCBA increased the soil mixture's properties, reaching an optimal fiber content of 0.75%. Beyond this optimal value, the properties began to decline. As also reported by[20] the UCS of expansive soil increases till a particular percentage of stabilizer SCBA and then decreases thereafter.

In Pakistan research has been done on the use of agro-industrial wastes in the shear strength improvement of expansive soils. A study conducted by[14] examined the effect of adding rice husk ash to expansive soil on its shear strength. The study observed a notable enhancement in the soil's shear strength due to the inclusion of rice husk ash. Similarly, a study conducted by[21] investigated the effect of adding marble industrial waste and bagasse ash to expansive soil on its shear strength. The study found that the addition of marble industrial waste and bagasse ash resulted in an improvement in the soil's shear strength and a reduction in its swelling potential. Typically, an optimal range of 8 to 10% of moisture-induced swelling inhibitor (MIW) and 5 to 7% of bagasse ash (BA) demonstrates effective results in reducing plasticity index (PI), minimizing volumetric shrinkage, enhancing unconfined strength, and mitigating swell potential. These findings signify a clear and significant improvement in the overall performance of the material. A study conducted by[22] investigated the effect of adding sugarcane bagasse ash and marble waste to expansive soil. The study found that the addition of sugarcane bagasse ash and marble waste resulted in a significant improvement in the soil's geotechnical properties.

2.5 Sustainable Solutions for Soil Improvement

The production of conventional stabilizers like cement and lime is costly and energy-intensive, which can result in greenhouse gas pollution and environmental damage[23]. A solution for sustainable soil stabilization can be found in the sugarcane industry which can be an alternative to traditional additives[15]. Agricultural waste products are also inexpensive and easily accessible, which makes them a practical choice for soil stabilization in developing nations like Pakistan. The agriculture sector is considered to be one of the most important production sectors globally. Generating a significant amount of agricultural waste poses a major challenge for waste management[20]. Concurrently, alternative researchers have conducted experimental studies aimed at enhancing clayey soil through the utilization of recycled waste materials. Studies have shown that well-burnt bagasse ash (BA), which contains amorphous silica, can be used with lime to enhance concrete's engineering properties. These studies reveal that up to 20% of the cement content in concrete admixtures can be effectively replaced by BA without any adverse impact on the concrete's physical and mechanical properties. Researchers have recently developed a keen interest in exploring the potential utilization of bagasse ash (BA) in construction technology, including areas such as compacted clay bricks and the creation of recycled construction materials such as geo-polymer. However, there remains a scarcity of comprehensive studies conducted by researchers concerning the possible applications of BA in clay soil stabilization[13][13][15], [24]. Furthermore, it was indicated by an experimental investigation the utilization of both bagasse ash (BA) waste and cement for the enhancement of soft clay has demonstrated the capability to achieve comparable strength levels to those obtained by treating soft clay solely with cement when 20% of cement was replaced with BA[25].

Currently, several traditional additives, such as cement, cement kiln dust, and lime, are utilized for stabilizing expansive soil. The production of conventional stabilizers like cement and lime is costly and energy-intensive, which can result in greenhouse gas pollution and environmental damage[23]. A solution for sustainable soil stabilization can be found in the sugarcane industry which can be an alternative to a traditional additives eco-friendly and sustainable substitute for conventional soil stabilizers like cement and lime provided by agricultural refuse. Agricultural waste is widely accessible and frequently regarded as a waste product that needs to be disposed of. However, these refuse products have characteristics that can be helpful for soil stabilization. Agricultural waste products abundant in silica, such as rice husk ash, bagasse ash, sawdust ash, and wheat straw ash, can be used to strengthen and stabilize soil. The calcium silicate hydrate, a substance that can increase soil strength and durability, can be created by these materials, by reacting with calcium hydroxide, a byproduct of the cement manufacturing process. Agricultural waste products are also inexpensive and easily accessible, which makes them a practical choice for soil stabilization in developing nations like Pakistan. The agriculture sector is considered to be one of the most important production sectors globally. The generation of a significant amount of agricultural waste poses a major challenge for waste management also[20].

The solution to ecological challenges arising from the disposal of agricultural and industrial waste lies in their utilization within the construction sector. The utilization of sugarcane bagasse ash, a by-product obtained from crushed sugarcane, has been studied to explore its potential in improving soil properties like compaction, shear strength, permeability, and more. This research aims to address environmental issues caused by improper agricultural waste management and its impact on air, water, and soil pollution[13].

Other researchers have conducted experimental investigations into the enhancement of clayey soil using recycled waste materials. Notably, industrial waste like bagasse ash (BA) has a significant amount of amorphous silica. When combined with lime, it can replace up to 20% of cement in concrete admixtures, improving the concrete's engineering properties without negative effects. Additionally, BA's potential application in construction technology, such as compacted clay bricks and recycled construction materials like geo-polymer, has become a subject of research interest. However, there is a scarcity of comprehensive studies conducted by researchers on the potential utilization of BA in clay soil stabilization[23], [24], [26].

2.6 Key Findings and Limitations of Existing Research

Expansive soils are a common problem in many parts of the world, including in Pakistan, particularly in areas such as Islamabad, Rawalpindi, and Lahore, where a significant proportion of the soil is composed of expansive clay. One of the key challenges in dealing with expansive soils is their low shear strength, which can lead to instability and failure of structures built on them. Despite extensive research on various methods for improving the shear strength of these soils, there is still a need for effective and sustainable solutions that are suitable for local conditions in Pakistan.

Chapter 3

MATERIALS, SAMPLE PREPARATION AND TESTING

3.1 Introduction

A total of 4 SPT profiles are utilized in this research. The selected profiles have depth to bed rock (H) < 30 m. Stratigraphy, testing method and other characteristics of SPT profiles are detailed in[9]. The empirical SPT N – Vs correlations of[6], [27] hereafter referred to as L90 and AEA15 respectively, are used to develop the Vs profiles. The reason of selecting these two correlations is their wide use in the amplification studies of Pakistan.

In this chapter, we will also present an extensive explanation of the materials employed, the techniques utilized for sample preparation, the laboratory tests conducted, and the procedures implemented throughout this research project. A comprehensive description of the testing setups and apparatus employed will also be provided to facilitate comprehension and interpretation. All experimental tests for this investigation were conducted at NUTECH, the National University of Technology, Islamabad.

3.2 Materials

3.2.1 Expansive Soil

Once the visible organic materials, such as leaves and tree rootlets, were removed, the soil samples were gathered and transported to the testing laboratory. Table 3.1 and Table 3.2 display the mechanical, physical, and chemical characteristics of expansive soil, respectively. The soil is classified as low plasticity silt (ML) according to unified soil classification system (USCS), maximum dry density obtained was 1895.75 kg/m3 and the optimum from Islamabad, Capital Smart City region, Pakistan within coordinates 33.6839° N, 72.9887° E). The soil samples were obtained by hand auger at a depth ranging from 1 to 3 meters. Subsequently, the collected soil was air-dried and stored in bags within the laboratory. To determine the index properties of the soil, ASTM standards were followed. The air-dried soil was thoroughly crushed, and its moisture content was measured at 13.91%.

Analysis of Atterberg's limits revealed a liquid limit (LL) of 22.75 and a plasticity index (PI) of 3.71, indicating that the collected soil belonged to the category of expansive soil. Sample collection site is shown in Figure 3.1. It is important to note that during the preparation of soil samples (as depicted in Figure 3.2), particles larger than 2.36 mm were removed to ensure more consistent samples.

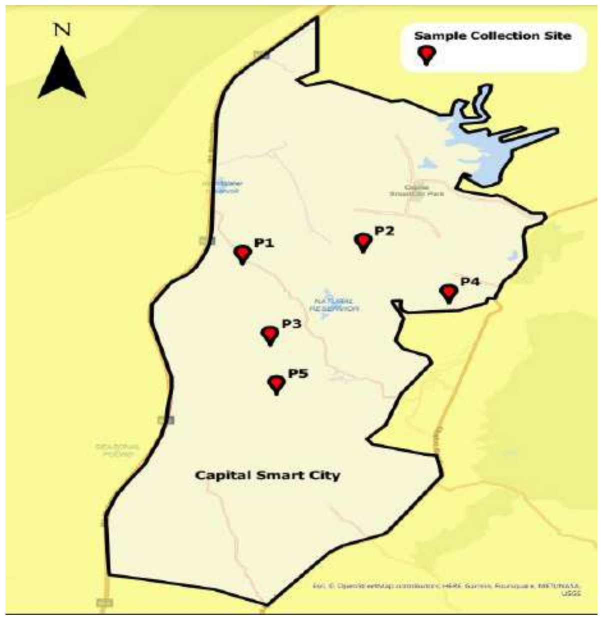

Figure 3.1. Sample collection site

Table 3.1. Index properties of natural soil sample

Properties	Soil Sample
AASHTO Classification	A-4
USCS	Low plasticity silt
MDD	1895.76 kg/m3
OMC %	13.91
LL	22.75
PL	19.05
PI	3.71

Table 3.2. Chemical composition of natural soil

Chemical Composition	Components Content (%)
Mgo	2.2
Al2O3	22.98
SiO2	63.26
CaO	4.06
FeO	8.25
K2O	3.6
Na2O	3.39

Figure 3.2. Oven dried natural soil sample.

3.2.2 Stabilizers

Limestone Dust (LSD) and Sugarcane Bagasse Ash (SCBA) were employed individually and in combination to enhance the geotechnical characteristics of soil. The LSD was sourced from a mining location in Rawalpindi, Pakistan. The SCBA was obtained from a local provider in Islamabad's market (Noon Sugar Mills Limited Bahawal, Sargodha Pakistan). The stabilizers underwent a sieving process using a 200 mm sieve, after which they were carefully stored in airtight bags. The basic properties of stabilizers are shown in Table 3.3 and chemical composition in Table 3.4. Figure 3.3 and Figure 3.4 shows the stabilizers used in this research.

Table 3.3. Basic properties of stabilizers.

Stabilizer	Specific Gravity
LSD	2.6
SCBA	1.9

Table 3.4. Chemical properties of stabilizers.

Mineral	SCBA %	LSD %
Al2O3	6.2	3.35
SiO_2	76.6	1.10
CaO	2.8	54.6
Fe2O3	6.1	3.04
K_2O	2.1	–
MgO	2.3	3.06
Na_2O	1.1	–
P2O5	2.02	–
$CaCO_3$	–	96.69
TiO_2	3.36	3.02
LOI	1.0	43.55

Figure 3.3. Limestone dust (LSD).

Figure 3.4. Sugarcane bagasse ash (SCBA).

3.3 Methodology

The study encompasses a combination of field and laboratory testing. A total of 4 SPT profiles are utilized in this research. The selected profiles have depth to bed rock (H) < 30 m. Stratigraphy, testing method and other characteristics of SPT profiles are detailed in[9]. The empirical SPT N – Vs correlations of[6], [27], hereafter referred to as L90 and AEA15 respectively, are used to develop the Vs profiles. The reason of selecting these two correlations is their wide use in the amplification studies of Pakistan. A total of nine input ground motions were selected from NGA-west 2 and scaled to a peak ground acceleration of 3.2g.

The study encompasses a combination of field exploration and laboratory testing to assess the strength properties of the soil both before and after treatment with additives. The stabilization of the expansive soil was achieved by introducing the stabilizers, following the mix proportion outlined in the provided Table. Each stabilizer was utilized individually as well as in combination. In total, 18 different mix proportions were prepared and subsequently tested. Tests conducted on the matrix in Table 3.5 include Atterberg’s limits, particle size distribution, dry density, Unconfined compressive test, and direct shear test.

Table 3.5. Experimental matrix.

Sample	Soil %	SCBA %	LSD %	Total Additives %	Designation
A	100		0	0	Natural soil
B	95	0	5	5	LSD
C	90		10	10	LSD
D	95		0	5	SCBA
E	90	5	5	10	SCBA-LSD
F	85		10	15	SCBA-LSD
G	90		0	10	SCBA
H	85	10	5	15	SCBA-LSD
I	80		10	20	SCBA-LSD
J	85		0	15	SCBA
K	80	15	5	20	SCBA-LSD
L	75		10	25	SCBA-LSD
M	80		0	20	SCBA
N	75	20	5	25	SCBA-LSD
O	70		10	30	SCBA-LSD
P	75		0	25	SCBA
Q	70	25	5	30	SCBA-LSD
R	65		10	35	SCBA-LSD

3.4 Testing Methods and Procedures

3.4.1 Mixing of Materials

The natural soils were carefully mixed with sugarcane bagasse as and limestone dust at different ratios are presented in Table 3.5. The target water content was then added to the mixtures by the dry weight of the soil while the combinations were constantly mixed as shown in Figure 3.5, until they were uniform. It is important to note that a number of the first USCS experiments on stabilized soil specimens were conducted by varying the combination ratio of bagasse ash to lime, and the results led to the best SCBA-LSD combination ratio. The best compressive strength can be attained by using the ideal SCBA-LSD combination ratio for soil stabilization. As a result, using a mechanical blender, the expansive soil was fully mixed with SCBA, LSD, and water.

Figure 3.5. Mixing of materials.

3.4.2 Particle Size Mechanical Analysis

The scope of the experiment is to classify soil by size, the test is performed according to ASTM D 422-63. The particle sizes and their relative distribution for particles larger than 3.075 mm are determined through mechanical analysis. This analysis is carried out by stacking sieves on top of each other as shown in Figure 3.6, pouring a measured weight of soil onto the top sieve, and separating soil particles by size using stacked sieves and shaking them in a particular way. The outcomes are shown on a graph, where particle sizes are represented on a logarithmic scale on the x-axis, and the percentage of particles is shown on a regular scale on the y-axis.

Figure 3.6. Sieve set.

To analyze the particle size distribution of a soil sample, we take a 500-gram oven-dry soil sample and put it in a series of sieves (No. 4, 10, 40, 50, 100, 200, and a pan). The sample is sieved with a mechanical shaker for 5 to 10 minutes. If the sieves don't fit in the shaker, we shake them by hand until we can remove the top few sieves. Then, we put the remaining stack in the mechanical shaker. After sieving, we weigh the material retained on each sieve and add up the weights. Finally, we compare this sum to the original weight of the sample taken. If the loss of residual material is more than 2%, we consider it unsatisfactory and repeat the test.

To calculate the percentage retained on each sieve, the weight retained on each sieve is divided by the original sample weight. To determine the percentage passing, the calculation begins with 100% and subtracts the cumulative percentage retained for each sieve.

3.4.3 Particle Size Hydrometer Analysis

The scope of the test is to classify the fines which pass through sieve no 200 and is performed according to ASTM D7928 standard. Hydrometer analysis is used for determination of the particle size of the soil sample having size less than 3.075mm. In hydrometer, analysis sample is dispersed in water and allow settling down freely. It is based on the principle that particles having larger diameter will settle down quickly as compared to smaller diameter particles. A reading of less than zero (i.e., a negative reading) on the hydrometer indicates that the soil particles have settled out of suspension and are resting on the bottom of the cylinder. In such a case, the percent finer cannot be accurately determined using the hydrometer method. Therefore, it is important to ensure that the hydrometer reading is always above zero during the test.

To accurately determine the percent finer using the hydrometer method, it is necessary to apply corrections to the hydrometer reading. Correction factors are presented in Table 3.6. Correction factor 'a' for unit weight of solids.and Table 3.7. Temperature correction factor (Ct). This is because the depth to which the hydrometer sinks is directly related to the reading R, regardless of the amount of soil in suspension. Corrections need to be applied to the actual reading in order to ensure an accurate measurement of the suspended soil particles and facilitate the necessary computations for determining the percentage of finer particles. Table 3.8 shows values of k for several unit weights of soil solids and temperature combinations

To conduct a hydrometer analysis test, a 50-gram sample of well-pulverized, oven-dried soil is taken and mixed with 125 cubic centimeters of a 4% sodium metaphosphate solution. The mixture is allowed to stand for approximately one hour before being transferred to a malt mixer cup. Tap water is added to the cup until it is two-thirds full, and the mixture is mixed for a duration of three to ten minutes. Subsequently, all the contents are carefully transferred to a sedimentation cylinder, ensuring no loss of material. First, the cylinder is filled with tap water until it reaches the 1000 cubic centimeter mark. Then, a control jar is prepared with tap water and 125 cubic centimeters of either a 4% sodium metaphosphate solution or an equivalent amount of a sodium silicate solution used in the initial step. The cylinder is capped with a No. 12 rubber stopper, and the mixture is agitated for at least one minute. Hydrometer readings are taken at intervals of 1, 2, 3, and 4 minutes, and the temperature is recorded. We started by taking a meniscus reading from the control jar and replacing the stopper. Then, we agitated the suspension and repeated the hydrometer readings at 1, 2, 3, and 4 minutes until we had two sets of readings that agreed within one unit. Next, we took another set of readings and compared them to the previously accepted 4-minute readings. When they showed satisfactory agreement, we utilized the averaged 4-minute readings as the initial four readings.

Afterward, we continued to collect more hydrometer and temperature readings at elapsed times of 8, 15, and 30 minutes, followed by 1, 2, 4, 8, 16, 24, and 96 hours. If the hydrometer readings dropped below 5 before 96 hours had elapsed, we terminated the test. Throughout the test, we stored the hydrometer in the control jar, except when taking readings. Figure 3.7 depicts the distribution curve for expansive soil.

Table 3.6. Correction factor 'a' for unit weight of solids.

Unit Wt. of soil Solids (g/cm^3)	A
2.95	0.94
2.90	0.95
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.03
2.45	1.05

Table 3.7. Temperature correction factor (Ct).

T (°C)	Ct
15	-1.10
16	-0.90
17	-0.70
18	-0.50
19	-0.30
20	0.00
21	0.20
22	0.40
23	0.70
24	1.00
25	1.30
26	1.65
27	2.00
28	2.50
29	3.05
30	3.80

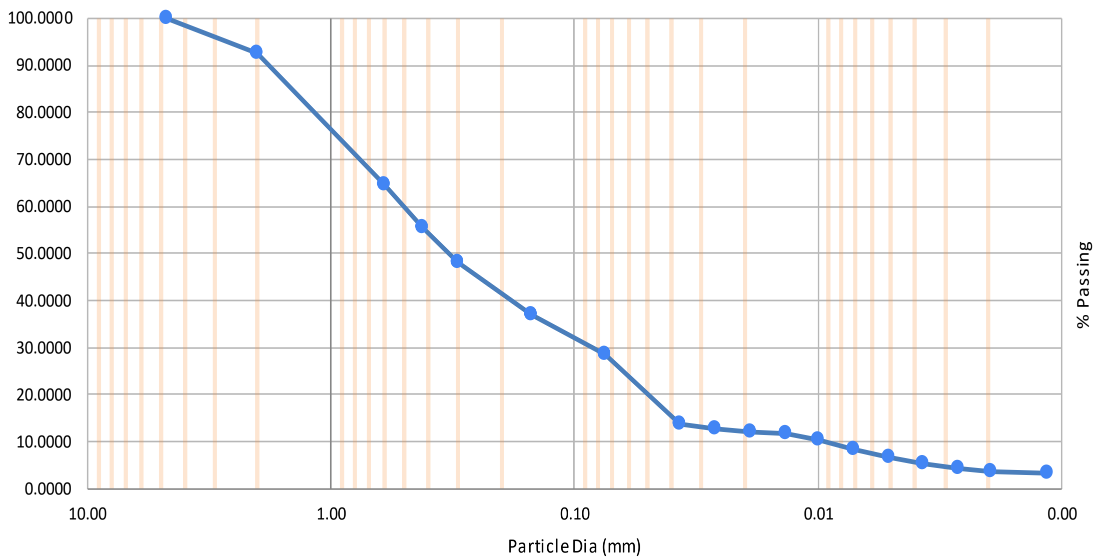

Figure 3.7. Particle size distribution curve for expansive soil.

Table 3.8. Values of k for several unit weights of soil solids and temperatures.

T (ºC)	Unit Weight of Soil Solids (g/cm^2)								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01510	0.01480	0.01460	0.01440	0.01410	0.01390	0.01370	0.01360
17	0.01511	0.01490	0.01460	0.01440	0.01420	0.01400	0.01380	0.01360	0.01340
18	0.01492	0.01480	0.01440	0.01420	0.01400	0.01380	0.01360	0.01340	0.01320
19	0.01474	0.01450	0.01430	0.01400	0.01380	0.01360	0.01340	0.01320	0.01310
20	0.01456	0.01430	0.01410	0.01390	0.01370	0.01340	0.01330	0.01310	0.01290
21	0.01438	0.01410	0.01390	0.01370	0.01350	0.01330	0.01310	0.01290	0.01270
22	0.01421	0.01400	0.01370	0.01350	0.01330	0.01310	0.01290	0.01280	0.01260
23	0.01404	0.01380	0.01360	0.01340	0.01320	0.01300	0.01280	0.01260	0.01240
24	0.01388	0.01370	0.01340	0.01320	0.01300	0.01280	0.01260	0.01250	0.01230
25	0.01372	0.01350	0.01330	0.01310	0.01290	0.01270	0.01250	0.01230	0.01220
26	0.01357	0.01330	0.01310	0.01290	0.01270	0.01250	0.01240	0.01220	0.01200
27	0.01342	0.01320	0.01300	0.01280	0.01260	0.01240	0.01220	0.01200	0.01190
28	0.01327	0.01300	0.01280	0.01260	0.01240	0.01230	0.01210	0.01190	0.01170

3.4.4 Atterberg's limit test (liquid limit and plastic limit)

The objective of the test is to determine the liquid limit and plastic limit of the soil in accordance with the ASTM D 423-66 standard. The liquid limit represents the moisture content at which the soil transitions from a semisolid state to a liquid state, while the plastic limit indicates the moisture content at which the soil changes from a solid to a semisolid state. These limits play a significant role in the characterization and classification of soil.

To conduct the liquid limit test, we need a representative sample of approximately 250 grams of soil that has passed through a No. 40 sieve. We adjust the height of the liquid limit device's fall to precisely 1 cm using the 1 cm calibration block. We mix the soil with distilled water using a spatula, gradually adding water until we achieve a blow count of 30 to 40 blows, closing the standard groove of ½ inch.

Next, we place a portion of the soil paste in the brass cup of the liquid limit device and create a clean, straight groove using the grooving tool. We turn the crank of the device at a rate of two revolutions per second while counting the number of blows needed to close the groove.

We collect approximately 20-40 grams of soil from the closed part of the groove for subsequent determination of water content and place it in a pre-weighed moisture content container. We repeat this process at least four times using the same soil sample, adding small increments of distilled water each time, and keeping the blows count between 10 and 53.

After collecting the soil for water content determination, we remove the remaining soil from the brass cup, return it to the container, and then clean and dry the cup before starting the next test.

To determine the plastic limit of a soil sample, approximately 20 grams of air-dried soil that has passed through a No. 40 sieve is taken and mixed with distilled water on a glass plate as shown in Figure 3.8 until it reaches a plastic consistency suitable for shaping into a ball. We allow the plastic soil mass to mature for a period of time. Then, we take about 8 grams of the plastic soil and roll it between our fingers and a glass plate with enough pressure to form a thread of uniform diameter throughout its length. We then knead and roll the specimen again until the diameter of the thread decreases to 1/8 inch and crumbles. The crumbled soil thread is collected in a container for water content determination. We repeat the test three to four times, and we record the average value of these readings.

Figure 3.8. Plastic limit determination.

3.4.5 Standard Compaction Test

The maximum dry density (MDD) and the optimum water content (OMC) for the soil sample were determined through a standard compaction test, following the guidelines of AASHTO T: 99. To perform a standard compaction test on a 3 kg representative sample of air-dried soil that passes the U.S No. 4 sieve, the soil sample is first mixed with a percentage of water by dry weight determined from an inspection of the soil specimen, is about 7% for sandy soils and about 10% for clayey soils. The soil is placed in an airtight container and kept for 20 hours to undergo maturation. The compaction mold as shown in Figure 3.9, including the collar and base plate, is weighed and measured to determine its volume. The soil is compacted in three equal layers, with each layer being subjected to 25 blows from a 5.5 lbs rammer dropped from a height of 12 inches. The collar is then removed, and the compacted soil cylinder is struck with a straight edge to eliminate any excess material. The mold is cleaned and weighed with an accuracy of one gram, and the soil cylinder is extruded from the mold, split, and a sample is extracted for moisture determination. The sample is subsequently reduced to a No. 4 sieve size and mixed with 2% water relative to the original sample weight. Steps 5 to 9 are repeated until a peak value, followed by two slightly lesser compacted weights, is achieved based on wet weights.

Figure 3.9. SPT sample preparation.

3.4.6 Unconfined Compression Test

The shear strength of the soil is determined using the unconfined compression test, as outlined in ASTM D-2166 and AASHTO T-208. This test is considered the simplest, easiest, and most cost-effective method. It is similar to the triaxial compression test, but it differs in that no confining pressure is applied, and a cylindrical soil specimen is subjected to a vertical (axial) load. Figure 3. shows the UCC setup. Since there is no lateral support in the unconfined compression test, the soil specimen must be capable of standing alone in the form of a cylinder. Therefore, this test is typically limited to cohesive soils. In the unconfined compression test, the unconfined compressive strength (qu) is determined as the maximum load per unit area or the load per unit area at 15% axial strain, whichever occurs first during the test. The undrained shear strength (s_u) or cohesion (c) of cohesive soil is considered to be half of the unconfined compressive strength (q_u). Figure 3.10 shows the selected soil sample and Figure 3.11 illustrates sample failure.

Figure 3.10. UCC setup.

Figure 3.10. Selected soil sample prepared for testing.

Figure 3.11. UCC sample failure.

3.4.7 Direct Shear Test

The direct shear test is a common geotechnical laboratory test used to determine the shear strength parameters of soils and rock materials. It involves applying a shear force to a specimen of soil or rock along a predefined plane, known as the shear plane. The test measures the shear stress required to cause failure or sliding along this plane, allowing engineers and geologists to evaluate the stability and behavior of the material in different engineering applications. The direct shear test provides crucial information for designing foundations, analyzing slopes, determining soil stability, and assessing the suitability of materials for various construction projects. It is a fundamental and widely used test in geotechnical engineering and plays a crucial role in ensuring the safety and efficiency of structures and infrastructures. The testing setup and selected sample is shown in Figure 3.12 and Figure 3.13 respectively.

Figure 3.12. Direct shear apparatus.

Figure 3.13. Soil sample for direct shear test.

3.5 Summary

In this chapter, we evaluated empirical correlations between Standard Penetration Test (SPT) N-values and Shear Wave Velocity (VS) using 1D site response analysis. The study involves collecting relevant data, applying 1D site response analysis to estimate the VS profile, and comparing the estimated VS values with those predicted by the selected correlations. The findings contribute valuable insights into the performance and limitations of these correlations, aiding geotechnical and seismic engineers in making informed decisions for site-specific assessments and seismic hazard analyses. Also, the influence of sugarcane bagasse ash and limestone dust additions on the geotechnical properties of expansive soil is investigated. The materials, sample preparation, and detailed experiment programs and procedures are presented. The preparation of stabilized soil specimens involved varying the content of SCBA from 0% to 25%, along with combinations of 0%, 5%, and 10% LSD content based on the dry weight of the expansive soil. Different mix ratios were used in a series of laboratory experiments, including Atterberg's limits, UCC tests, and direct shear tests. The outcomes of these experimental investigations were analyzed and discussed to gain a better understanding of how SCBA, LSD, and their combination affect the geotechnical properties of the soil.

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

The results of the testing program, conducted in accordance with the testing methods and procedures specified in Chapter 3, are presented in this chapter. The objective is to collecting relevant data, applying 1D site response analysis to estimate the VS profile, and comparing the estimated VS values with those predicted by the selected correlations. Furthermore, Influence of sugarcane bagasse ash and limestone dust additions on the geotechnical properties of expansive soil is also examined. The preparation of stabilized soil specimens involved modifying the SCBA content from 0% to 25%, along with combinations of 0%, 5%, and 10% LSD content based on the dry weight of the expansive soil. Multiple series of laboratory experiments, including Atterberg's limits, UCC tests, and direct shear tests, were carried out with varying mix ratios. The outcomes of these experimental investigations were analyzed and discussed to enhance the performance and limitations of these correlations, aiding geotechnical and seismic engineers in making informed decisions for site-specific assessments and seismic hazard analyses and understanding of how SCBA, LSD, and their combination affect the geotechnical properties of the soil. A total of 18 UCC samples, 54 samples for Atterberg's limits, and 54 samples for the direct shear test were prepared and tested.

4.2 Experimental Results and Discussion

The properties of the profiles developed from both empirical correlations are summarized in Figure 4.1 and the profiles developed are shown in Figure 4.1.

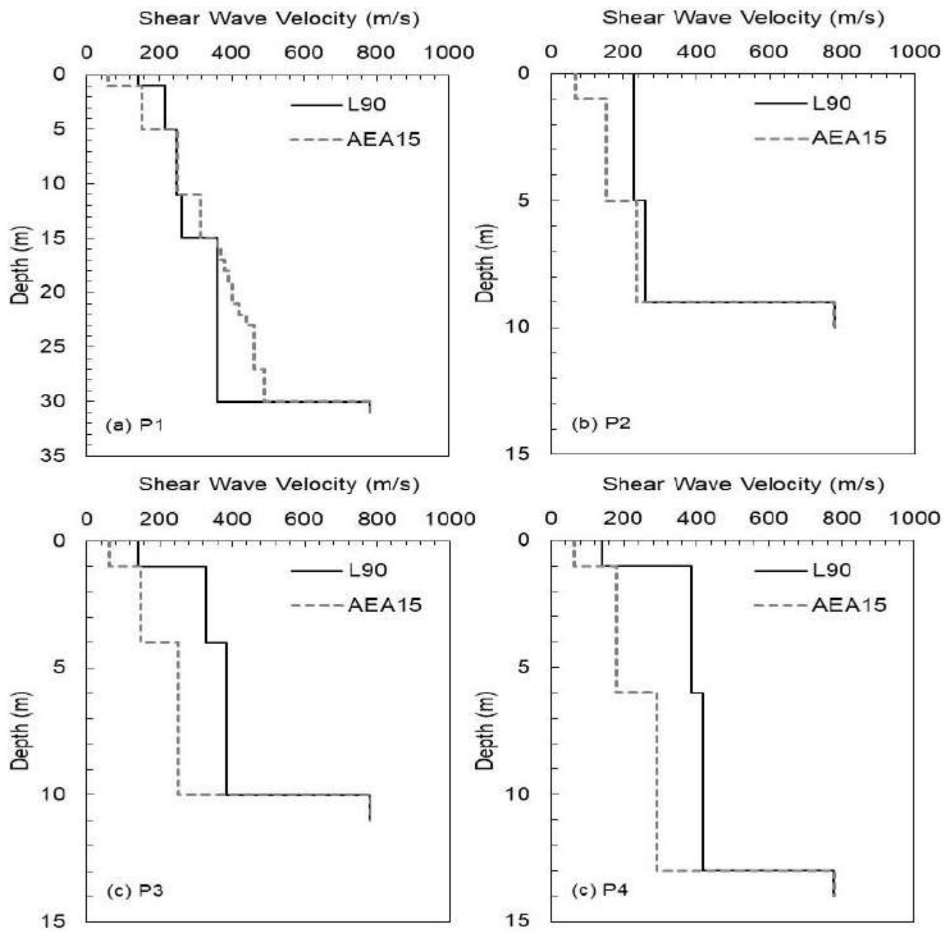

Figure 4.1. Developed Vs profiles using selected empirical correlations.

Table 4.1. Characteristics of developed Vs profile.

Profile	V_{S30} (m/s)	T_G (s)	Depth to bedrock (m)	Site class
P1 (L90)	284	4.44	31	D
P2 (L90)	466	4.15	9	C
P3 (L90)	522	4.12	10	C
P4 (L90)	512	4.14	13	C
P1 (AEA15)	267	4.47	31	D
P2 (AEA15)	352	4.23	9	C
P3 (AEA15)	384	4.24	10	C
P4 (AEA15)	334	4.27	13	D

4.3 Site Response Analysis

A total of nine input ground motions were selected from NGA-west 2 databases. The details are summarized in

Table 4.2. Summary of input ground motions. The ground motions were scaled to a peak ground acceleration (PGA) of 4.2 g. The selected ground motions and their scaling is consistent with the study of[9] for amplification characteristics in Islamabad. Figure 4.2 illustrates the suite of ground motions.

A total of 72 1D nonlinear site response analyses were performed using DEEPSOIL[9]. The pressure-dependent Modified Kodner-Zelasko (MKZ) model was used. Nonlinear modulus reduction (G/Gmax) and Damping curves of [28]used. Rayleigh damping formulation was used to model the small-strain damping. The 1st and 5th modes were used to calculate the coefficients of Rayleigh damping[1].

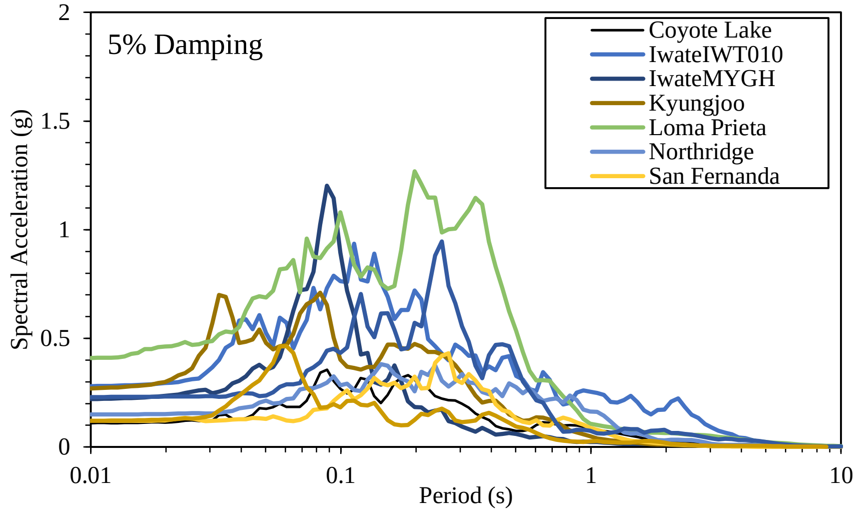

Figure 4.2. Suite of unscaled input ground motions.

Table 4.2. Summary of input ground motions.

No	Earthquake Name	Year	Station Name	Magnitude	Mechanism	R_{rup} (km)	V_{S30} (m/s)
1	Loma Prieta	1989	Gilroy Array 1	6.9	Reverse Oblique	9.6	1428.14
2	Northridge	1994	LA - Wonderland Ave	6.7	Reverse Oblique	24.3	1222.52
3	Coyote Lake	1979	Gilroy Array 1	5.7	strike slip	14.7	1428
4	Tottori	2000	SMNH 10	6.6	strike slip	15.6	967.27
5	Iwate	2008	IWT010	6.9	Reverse	16.3	825.83
6	San Fernanda	1971	Pasadenaold	6.6	Reverse	21.5	969.07
7	Tottori	2000	OKYH07	6.6	strike slip	15.2	944.2
8	Iwate	2008	MYGH04	6.9	Reverse	44.4	849.83
9	Kyungjoo Korea	2016	MKL	5.8	-	13.0	

4.4 Comparison of Site Response Analysis

This section presents the comparison of site response analysis results from Vs profiles obtained using two sets of empirical correlations, as mentioned in the previous section. Site response analyses results were used to calculate the seismic coefficients. To this end, short-period amplification factor (Fa) was first calculated in the period range of 4.1 – 4.5 s, whereas the long-period amplification factor (Fv) was calculated in the period range of 4.4 – 2.0 s. The seismic coefficients Ca and Cv in the code were then calculated using Fa, Fv and zone factor (Z) of 4.2 for zone 2B, according to the[29]. Figure 4.3 illustrates the calculated seismic coefficients of both sets of profiles. It is demonstrated that the Vs profiles developed from AEA15 results in a lower Ca than that of L90, whereas Cv is higher. This is attributed to the stiff nature of profiles developed from the L90 correlation resulting in a higher short-period amplification and lower long-period amplification.

4.5 Comparison of PGA Profiles

Figure 4.4 illustrates the comparison of mean PGA profiles calculated from the two sets of Vs profiles. Typically, the PGA increases in both sets of profiles when the surface is approached, however, a sharp amplification portion is observed for AEA15 in the fill layer. This is attributed to a low Vs value of fill layer calculated by AEA15. These trends are consistent in all the profiles.

4.6 Comparisons of Design Spectra

Figure 4.5 shows the comparison of design spectra from two sets of profiles with that of[10]. P1 obtained from both correlations is compared with SD design spectrum of[10]. P2 and P3 are compared with SC design spectrum. The design spectra of P4 (AEA15) and P4 (L90) are compared with SD and SC respectively. It is demonstrated that the profiles developed from AEA15 are well compared with the code design spectrum. Site profiles developed using L90 results in overestimation of the response at short periods ($T < 1.0$ s), whereas the response is underestimated at long periods. AEA15 underestimates the response at short periods, however, the extent of underestimation is very small, whereas a good match with the code spectrum is depicted at long periods.

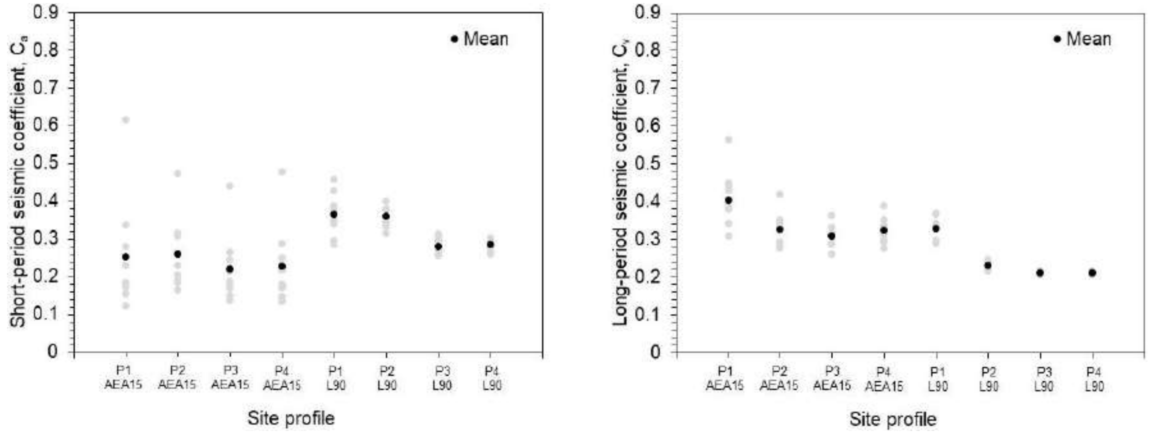

Figure 4.3. Comparing seismic coefficients from two profile sets.

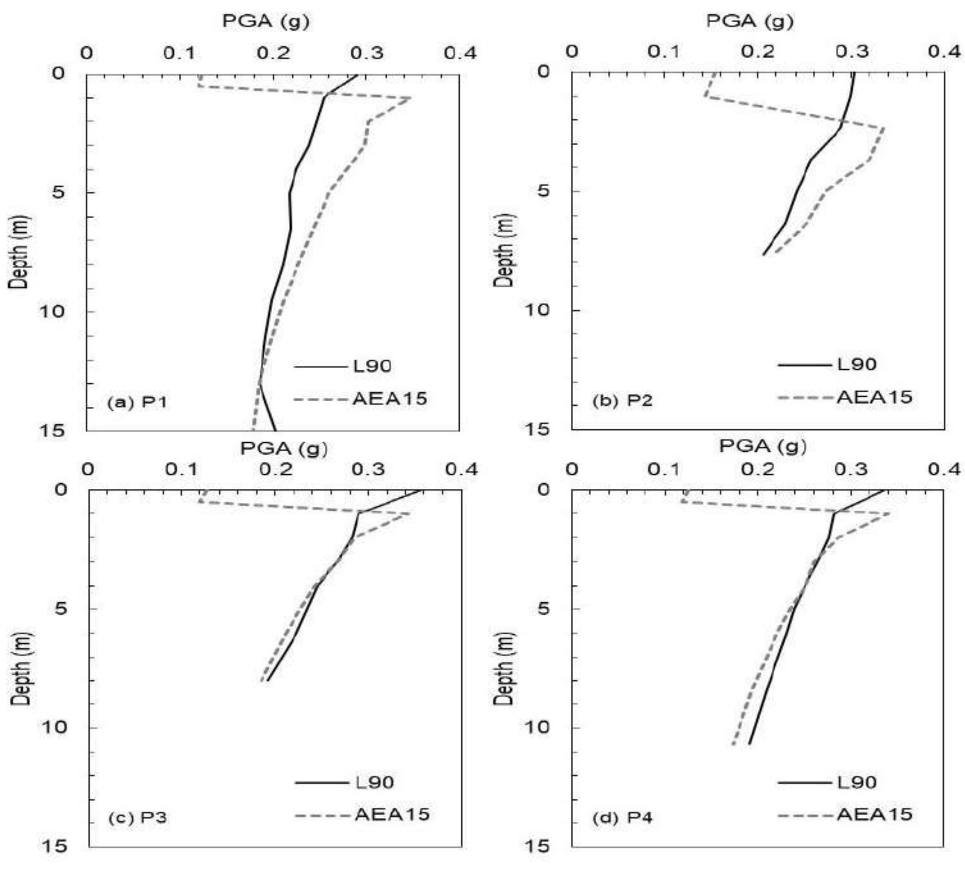

Figure 4.4. Comparison of PGA profiles.

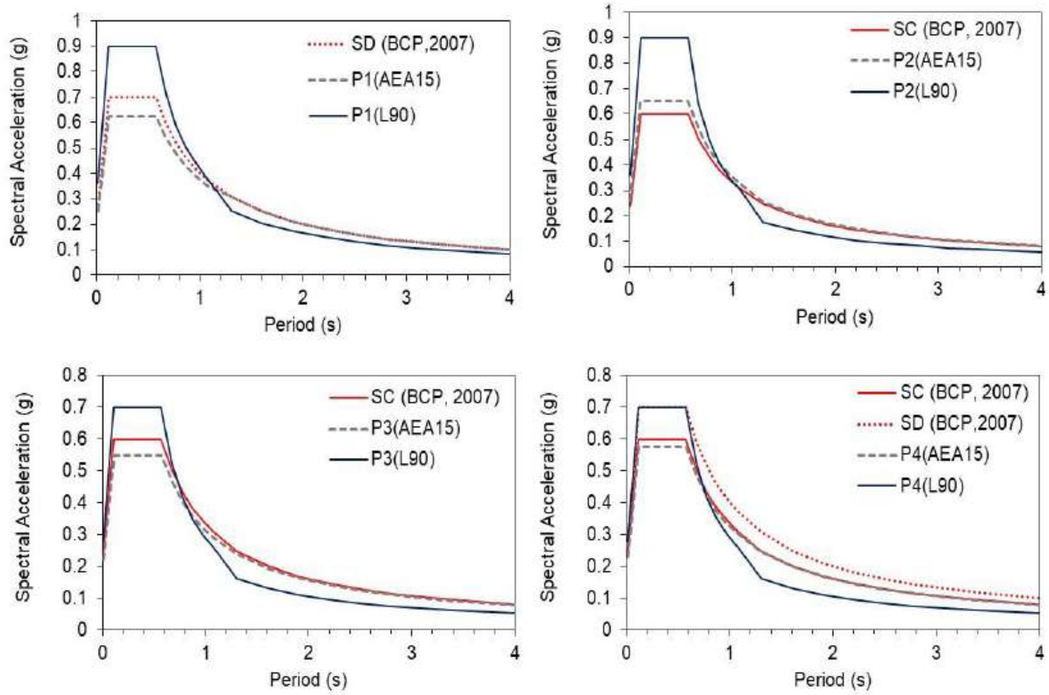

Figure 4.5. Comparing design spectra: site response outputs vs. code's spectrum.

4.7 Sieve Analysis

The results obtained from sieve analysis are presented in Table 4.3. Figure 4.6 Gradation curve for expansive soil shows the gradation curve for expansive soil.

Table 4.3 Results obtained from sieve analysis

Sieve Number	Diameter (mm)	Soil Retained (g)	Accumulative Retain (gm)	% Mass Retain	% Passing
#4	4.75	0	0	0.0000	100.0000
#10	2.00	37	37	7.4000	92.6000
#30	0.60	139	176	35.2000	64.8000
#40	0.42	46	222	44.4000	55.6000
#50	0.30	37	259	51.8000	48.2000
#100	0.15	56	315	63.0000	37.0000
#200	0.075	43	358	71.6000	28.4000
Pan	0.0368	142	500	100.0000	13.859
	0.0266				12.723
	0.0190				12.155
	0.0135				11.587
	0.0100				10.451
	0.0071				8.179
	0.0051				6.475
	0.0037				5.339

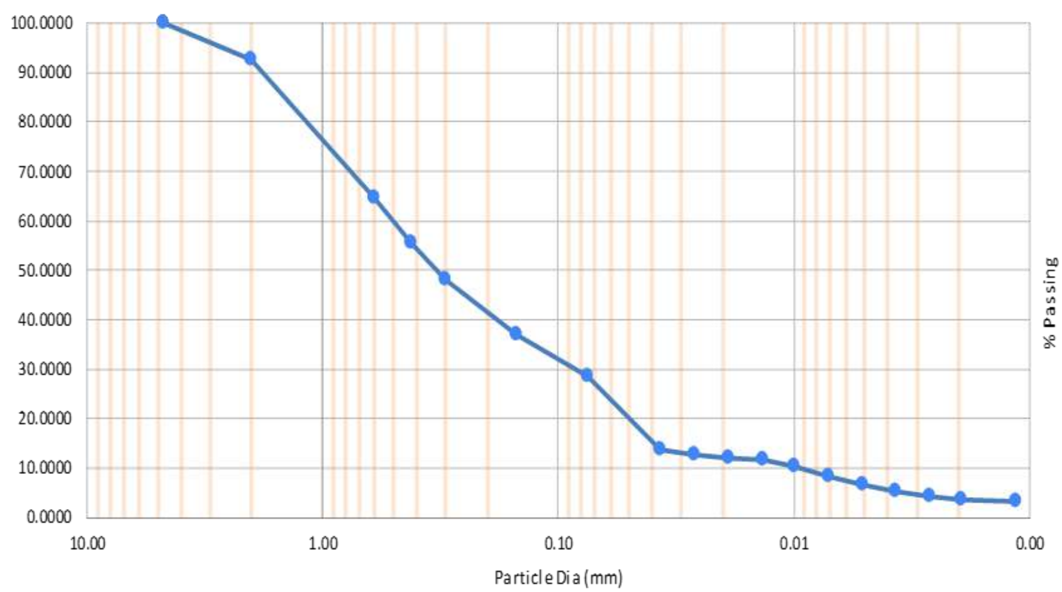

Figure 4.6 Gradation curve for expansive soil

4.8 Effect of SCBA and LSD on Atterberg's limits

The index properties of the existing soil are presented in Table 4.4 and liquid limit results are presented in

Table 4.5 for stabilized soil. The influence of the stabilizers on the Atterberg's Limits indices is shown in Figure 4.7. The decrease in liquid limit observed after adding stabilizers, particularly LSD-SCBA, can be attributed to cation exchange. The addition of stabilizers promotes a chemical process that leads to the reduction in the liquid limit by 8.7% as reported by[13] resulting from the interaction of divalent calcium-silicate ions.

Table 4.4 Index properties of soil

Plastic limit	19.05
Liquid limit	22.76
Plasticity index	3.71
USCS	Low plasticity silt (ML)

Table 4.5 Liquid limit results

Stabilizers %	**Liquid Limit**
0	23.28
5	21.53
10	17.7
15	15.3
20	13.5
25	12.5

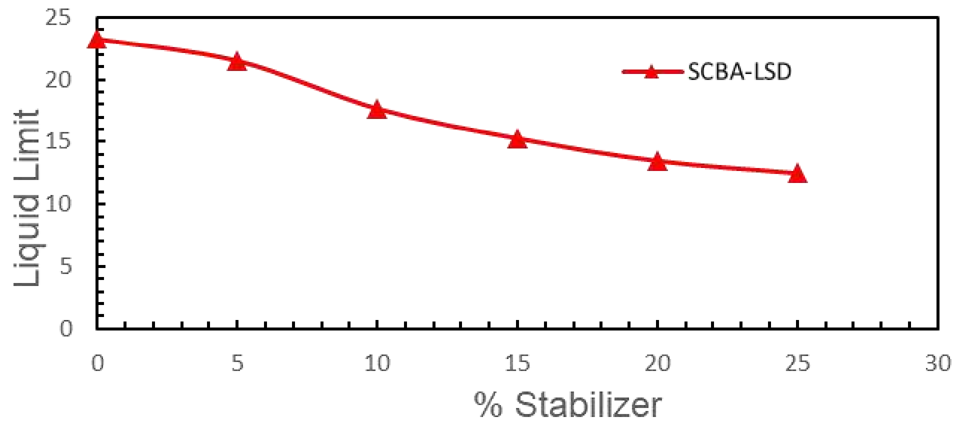

Figure 4.7 Influence of stabilizers on liquid limit

4.9 Influence of stabilizers on UCS values

The UCS value represents the maximum stress that an expansive soil can withstand under compression without lateral support. However, expansive soils often exhibit low UCS values, which can limit their applications in various construction projects, therefore we have added different percentages of stabilizers as per our experimental matrix to enhance its strength. Each mix ratio of stabilizer interacts with the soil in different ways, leading to changes in its UCS values. Understanding the influence of stabilizers on UCS values is crucial for engineers and researchers involved in geotechnical and civil engineering projects. By analyzing and quantifying the effects of stabilizers on the UCS of soils, it becomes possible to optimize the design and construction processes, select appropriate stabilizers, and ensure the long-term stability and performance of engineered structures. Testing sample details are presented in Table 4.6. The results clearly demonstrated that the stabilizers had a significant impact on improving the UCS values of the soil as shown in Figure 4.8.

As the percentage of stabilizers increased, there was a noticeable improvement in the UCS values. Optimum performance was achieved with 25% SCBA and 10% LSD, which resulted in the highest enhancement of UCS values. The increase in unconfined compressive strength (UCS) can be attributed to changes in the gradation of the matrix resulting from the addition of LSD, potentially leading to a reduction in porosity. On the other hand, the decrease in strength observed with increasing SCBA content may be due to inadequate calcium content in the soil to compensate for the excess silica introduced by the additional SCBA as reported by[13]. A decrease in strength can also be influenced by the grain size effect and specific gravity. This agrees with the conclusion of[13], who recommended that Bagasse ash was ineffective as a “stand-alone” stabilizer.

Table 4.6. UCC sample detail

Total length	100mm
Dia	50mm
Area	4.00196
MDD	1804.97 kg/m3
OMC	13.21%
Mass of sample	353 g

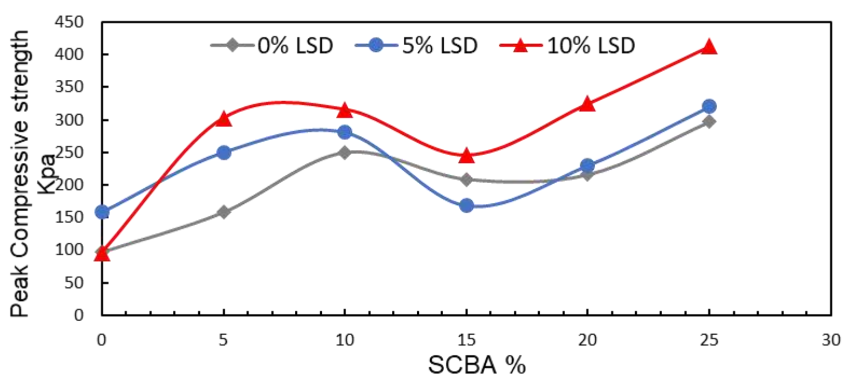

Figure 4.8. Influence of stabilizers on UCC strength.

4.10 Influence of stabilizers on failure strains

The investigation focused on evaluating the influence of stabilizers, namely sugarcane bagasse ash (SCBA) and limestone dust (LSD), on the failure strains of expansive soil. The objective was to analyze how the varying percentages of stabilizers, as well as their combination, affected the failure strains of the soil. The results clearly demonstrated that an increase in the content of stabilizers effectively reduced the failure strains of the soil.

Notably, as the percentage of stabilizers increased, there was a significant decrease in the failure strains observed. The interaction between the two stabilizers enhanced the soil's stabilization mechanisms, resulting in enhanced resistance to strain and deformation during failure.

These findings have significant implications for practical applications in dealing with expansive soils. Increasing the content of stabilizers, particularly SCBA and LSD, effectively reduces the failure strains of expansive soil as shown in Figure 4.9.

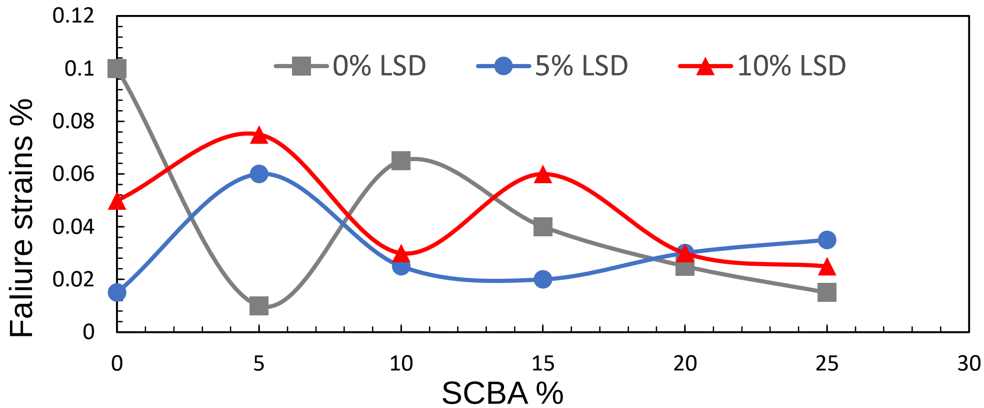

Figure 4.9. Influence of stabilizers on failure strains.

4.11 Influencers of Stabilizers on Shear Strength

The present study focused on improving the shear strength of expansive soil by incorporating stabilizers, specifically sugarcane bagasse ash (SCBA) and limestone dust (LSD). The objective was to investigate the effects of varying stabilizer percentages and their combination on enhancing shear strength properties. Notably, it was observed that as the percentage of stabilizers increased, the strength of the soil improved. The optimum strength was achieved with 25% SCBA and 10% LSD. We have tested our samples at 25 kpa, 50 kpa and 100 kpa.

The results demonstrated that the addition of SCBA alone yielded favorable outcomes in terms of shear strength improvement. The performance of SCBA as a stabilizer was particularly notable, with significant enhancements observed in shear strength properties as shown in Figure 4.10. This suggests that SCBA has inherent characteristics that positively influence the shear strength of expansive soil.

These findings have important implications for the practical application of stabilizers in expansive soil. The results suggest that the addition of SCBA, either alone or in combination with LSD, can effectively improve the shear strength of expansive soil. The optimized percentages of

25% SCBA and 10% LSD proved to be the most effective in achieving the desired shear strength enhancement which is 51.7 KN/m^2. For LSD-SCBA admixtures, the shear strength exhibited an initial increase, reaching a maximum of 48.31 KN/m2 at a stabilizer content of 15%, followed by a gradual decrease. This improvement in shear strength can be attributed to the effects of suction and changes in gradation, which contribute to enhancing the properties of the subgrade soil. The combination of SCBA and LSD in the soil induces a cementation effect and pozzolanic reaction, leading to an increase in soil shear strength. This process strengthens the bond between soil particles. However, the decrease in shear strength observed with increased bagasse ash content can be attributed to the reduced availability of calcium in the soil for reacting with the alumina and silica present in SCBA, as well as the specific gravity of bagasse ash. It is worth noting that these results align with previous studies highlighting the potential of SCBA and LSD as stabilizers for expansive soils. The current research further confirms their efficacy and provides valuable insights into their combined application, offering a practical approach to address the challenges posed by expensive soil.

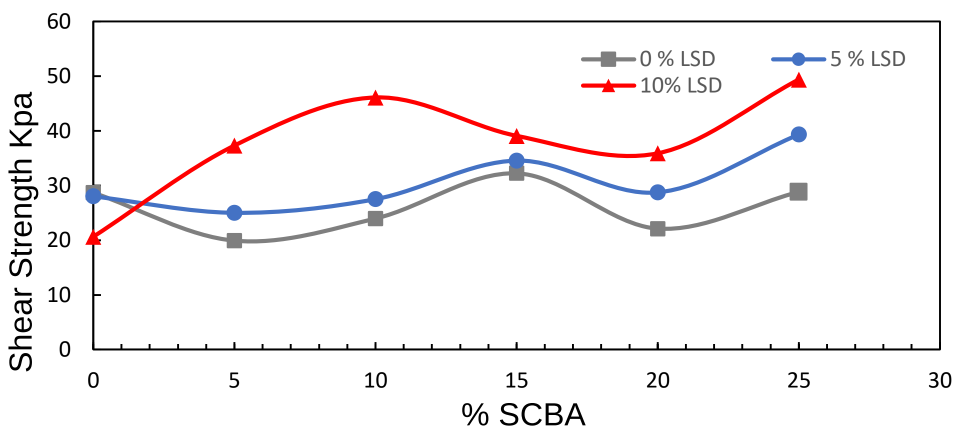

Figure 4.10. Influence of stabilizers on shear strength.

4.12 Optimizing Strength

The strength comparison for different mix ratios is presented in Figure 4.11

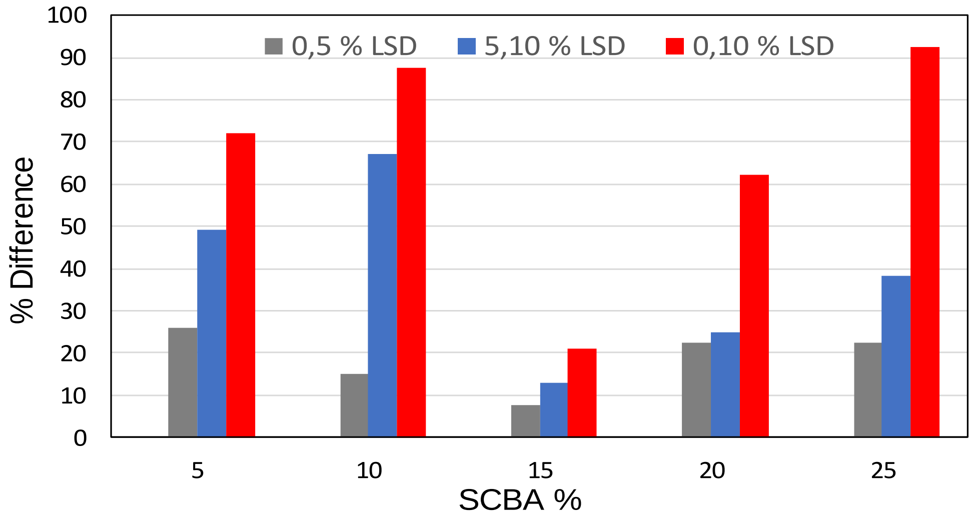

Figure 4.11. Comparison between SCBA-LSD for Maximum Performance.

4.13 PLAXIS Model Analysis

The PLAXIS model allowed for a comprehensive analysis of the settlement behavior of the footing on expansive soil and on stabilized soil. By incorporating the parameters specific to expansive soil, such as its expansive potential and swell-shrink behavior, the model accurately simulated the real-world conditions. Additionally, the properties of the stabilized soil were incorporated into the model to assess the impact of stabilizers on settlement. The objective was to investigate the settlement characteristics of the footing and compare the deformation between the untreated expansive soil and the soil treated with stabilizers.

4.13.1 Settlement of Footing on Expansive Soil and Stabilized Soil

The results clearly indicated that the stabilizers played a crucial role in improving the strength of the soil and reducing deformation and settlement. The addition of stabilizers effectively increased the soil's resistance to deformation, resulting in reduced settlement under the footing. This observation suggests that stabilizers have the potential to mitigate the detrimental effects of expansive soil on structural foundations.

By comparing the settlement behavior of the untreated expansive soil with the stabilized soil in Figure 4.12 and Figure 4.13, it was evident that the stabilizers significantly contributed to the reduction in settlement. The stabilized soil exhibited notably lower settlement values, indicating improved load-bearing capacity and enhanced stability of the footing.

These findings have significant implications for practical applications in dealing with expansive soil. The utilization of stabilizers in soil stabilization techniques proves to be an effective strategy for mitigating settlement issues associated with expansive soil. The PLAXIS model results provide valuable quantitative data on the reduction in deformation and settlement achieved through soil stabilization.

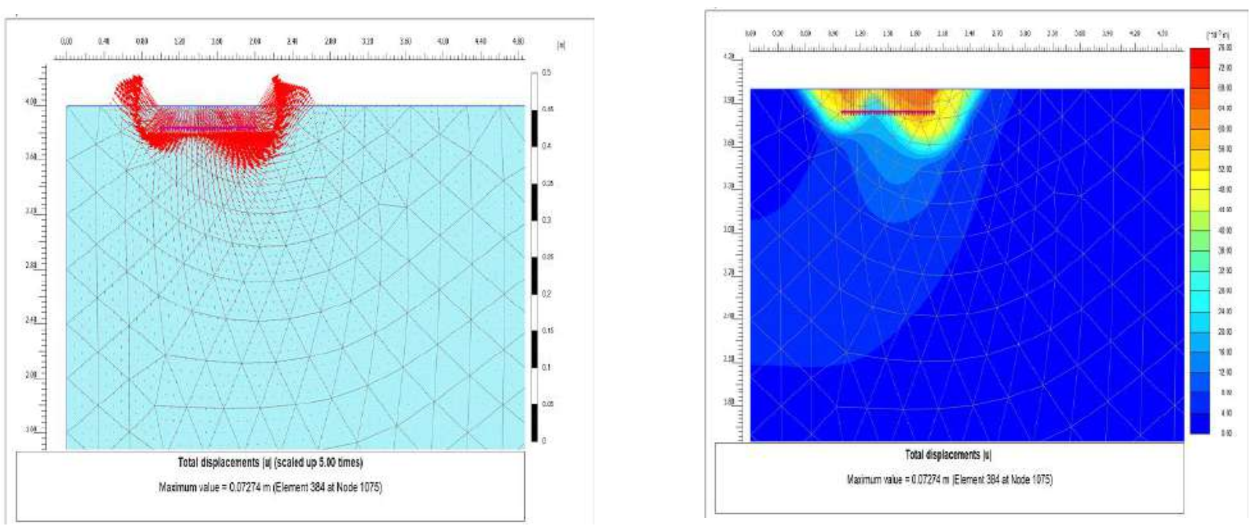

Figure 4.12. Settlement of footing on expansive soil.

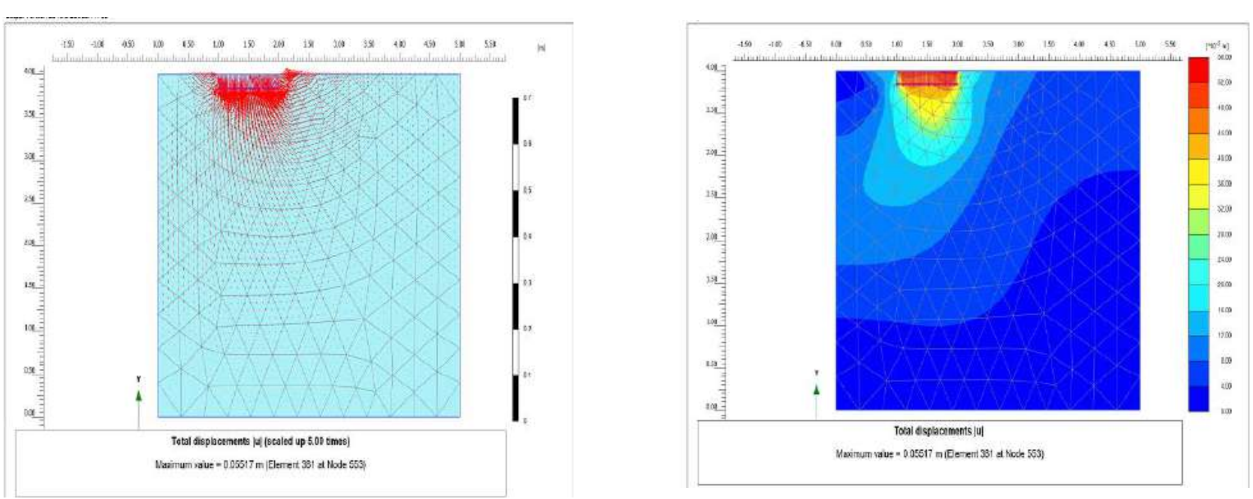

Figure 4.13. Settlement of footing on stabilized soil

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Key Conclusions and their Significance

Comparison of SPT N – Vs Correlations for Shallow Bedrock Conditions

This study evaluates two SPT N – Vs correlations for shallow bedrock conditions in Islamabad, Pakistan by using 1D site response analysis. A suite of 1D nonlinear site response analyses is performed. The empirical correlation proposed by AEA15 results in a lower short-period seismic coefficient as compared to that of L90, whereas it results in higher lng-period seismic coefficient. Due to a lower estimation of Vs in the fill layer, AEA15 results in a reduction of PGA at the fill layer. When compared with the design spectra of BCP, 2007, it is revealed that the spectrum developed from L90 outputs results in overestimation of the response at short periods, whereas an underestimation is observed at long periods. It is concluded that AEA15 better predicts the code spectrum at short periods as well as long periods.

Stabilizers effectively reduce the liquid limit:

The liquid limit of soil refers to its moisture content at the boundary between the liquid and plastic states. Stabilizers, such as sugarcane bagasse ash (SCBA) and limestone dust (LSD), have been found to effectively reduce the liquid limit of expansive soil. This reduction in the liquid limit indicates that the soil becomes less susceptible to excessive moisture and exhibits improved plasticity, making it more stable and less prone to swelling and shrinkage.

The combination of stabilizers with SCBA-LSD increases unconfined compressive strength

Unconfined compressive strength (UCS) is a measure of a soil's ability to resist compressive forces without confinement. When stabilizers, specifically SCBA and LSD, are combined, they have a synergistic effect on enhancing the UCS of expansive soil. The addition of stabilizers increases the bonding and interlocking of soil particles, resulting in increased strength and resistance to compression. This combination of stabilizers has been found to significantly improve the UCS values of expansive soil, indicating its enhanced load-bearing capacity.

Optimal stabilizer content of 25% with 10% LSD yields the highest UCS; strength declines beyond this point: Through experimental observation, it has been determined that the optimum content of stabilizers for achieving the highest UCS in expansive soil is 25% SCBA combined with 10% LSD. Beyond this optimal point, further increases in stabilizer content may lead to a decline in strength. This could be attributed to factors such as excessive particle aggregation, which could adversely affect the soil's structure and reduce its overall strength. Therefore, it is important to identify and maintain the appropriate content of stabilizers to ensure maximum UCS values in expansive soil.

SCBA-LSD combination improves the shear strength of expansive soil:

Shear strength refers to a soil's ability to resist deformation or failure under shear forces. The combination of SCBA and LSD has been observed to enhance the shear strength of expansive soil. The interaction between these stabilizers leads to improved stabilization mechanisms within the soil, resulting in increased resistance to shear deformation. This combination has proven to be particularly effective in addressing the challenges posed by expansive soil, as it significantly enhances the soil's shear strength properties.

These observations and findings highlight the positive effects of stabilizers, specifically SCBA and LSD, on various soil properties. The reduction in liquid limit, the increase in unconfined compressive strength, and the improvement in shear strength demonstrate the efficacy of these stabilizers in enhancing the geotechnical characteristics of expansive soil. These results have practical implications for engineering practices aimed at stabilizing and improving the performance of expansive soil in various construction projects.

5.2 Recommendations and Future Research

Incorporate stabilizers for stable structures: Stabilizers, such as sugarcane bagasse ash (SCBA) and limestone dust (LSD), play a crucial role in ensuring the stability of structures built on expansive soil. By incorporating stabilizers into the soil, the adverse effects of expansive soil, such as excessive swelling and shrinkage, can be mitigated. Stabilizers help to improve the structural integrity of the soil, reducing settlement and potential damage to the foundations.

Incorporating stabilizers is therefore essential for achieving stable and durable structures in areas with expansive soil.

Optimize stabilizer content for strength, which is 25% SCBA with 10% LSD: It is important to determine the optimal content of stabilizers for achieving the desired strength in expansive soil. Through research and experimentation, it has been determined that an optimized combination of stabilizers consists of 25% SCBA and 10% LSD. This specific composition has been shown to yield the highest strength and resistance to compression. It is crucial to carefully consider and maintain the appropriate content of stabilizers to ensure optimal performance and structural stability of the soil.

Embrace sustainable materials for greener construction: In addition to their engineering benefits, stabilizers like SCBA and LSD offer the advantage of being sustainable materials. SCBA is a byproduct of the sugarcane industry, while LSD is a waste product from limestone mining or processing. By utilizing these materials as stabilizers, construction projects can embrace sustainable practices and contribute to greener construction. The use of such materials helps reduce waste and environmental impact by repurposing industrial byproducts. Embracing sustainable materials not only enhances the performance of the soil but also aligns with the principles of sustainable development and responsible construction practices.

By incorporating stabilizers, optimizing their content for strength, and embracing sustainable materials, construction projects can achieve stable structures while reducing the environmental footprint. The use of stabilizers ensures the long-term stability and performance of structures on expansive soil, minimizing potential risks and maintenance requirements. Furthermore, the adoption of sustainable materials contributes to the overall sustainability and eco-friendliness of the construction industry. It demonstrates a commitment to responsible construction practices and fosters a greener and more sustainable built environment.

For future research, it is recommended to investigate the performance of stabilizers in diverse soil types, assess long-term durability and aging effects of stabilized soils, and evaluate the environmental impact of stabilizer utilization through life cycle assessments and environmental impact studies.

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Originality Certificate

We, the undersigned members of the capstone design project group, hereby confirm that the group project titled "**Evaluation of Empirical SPT-N -Vs Correlations Using 1D Site Response Analysis and Improving the Shear Strength of Expansive Soil in Islamabad, Pakistan** has been undertaken and completed by us as a collaborative effort. The project report is prepared by the undersigned group members. Any external sources, including published or unpublished works, have been appropriately acknowledged and referenced in accordance with the guidelines provided by NUTECH University.

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