Improvement of Unconfined Compressive Strength of Clayey soil using Paper Pulp

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This is to certify that the Final Year project

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DEDICATION

We would like to dedicate our works to our parents, our teachers, our institution NUST, and all our friends. We executed the work with impressive assurance and determination and applied the best of ourselves to the errand at hand.

DECLARATION

It is hereby reverently and truthfully declared that all the work alluded to this thesis is composed by us and it has not been submitted by any institution, in whole or in part in any previous application for a degree. Any references to the work done by any other person or University have been appropriately cited.

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In the name of Allah, the Most Beneficent, the Most Merciful as well as peace and blessings be upon Prophet Muhammad, His servant, and final messenger.

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Moreover, we feel very lucky to have the people around us from our teachers to our friends and family who supported us and had influenced us into becoming who we are today.

Last but not the least, we are grateful to the National University of Sciences and Technology (NUST) for providing us an environment to achieve what we have always dreamt of and enabling us to play our part for the betterment of humanity.

ABSTRACT

The soil in Islamabad, and particularly Bahria Town, is predominantly earth-filled and is subject to clayey characteristics. It has shown tendencies of low strength under load which poses a unique problem and jeopardizes the construction process. This project aims to provide an economically and environmentally feasible utilization of paper pulp in the improvement of the unconfined compressive strength of predominantly clayey soil. Samples were collected from Bahria Town Islamabad and laboratory testing was done to determining soil index properties. 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 low plasticity clay (CL) with sand. The Standard Compaction test was performed to obtain the maximum dry density and the corresponding optimum moisture content which were 1.83 g/cm3 and 15% respectively. The unconfined compression test (UCT) test was then performed using the MDD of this soil with natural soil which gave the unconfined compressive strength of 134 kPa. Then the natural soil was treated with paper pulp additive with increments of 2% up to 8%. The unconfined compressive strength at different percentages of paper pulp was plotted which gave a parabolic curve with peak strength improvement at 6%. The Unconfined compressive strength at 6% additive was 296.1 kPa. There is a 120% increase in strength while the average increase in strength is about 55% at 4% and 8% content of additive. As depicted by the graph plotted by the UCT 6% paper pulp mixed with soil bore the maximum strength, therefore it is considered to be the optimum content of paper pulp as an additive. Moreover, the addition of the pulp induced no compromise in strength whatsoever.

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Chapter-1 Introduction

1.1 Background

Soil improvement is the collective name given to techniques applied to soil to modify and alter its properties in a bid to improve pre-existing soil conditions in its properties such as enhancing strength, reduction in compressibility, and reducing liquefaction potential to keep the pore water pressure minimal. Ground improvement targets can be accomplished utilizing a huge variety of geotechnical construction techniques and advancements that modify and improve below-par ground conditions where soil replacement is not achievable for ecological or specialized reasons, or it is on the costly side. [1]. Various techniques and additives can be applied temporarily during the construction phase on problematic soils or perennially to improve the subject soil properties.

Since the dawn of construction, and as evident from remains found from ancient civilizations such as the Incas, Chinese, and Romans, we have gravitated towards improving pre-existing soil conditions to aid in our construction. Some of these ancient techniques were so effective that roads and buildings from that era still exist and have withstood the test of time. Coming to modern times, in the 60s and 70s, due to varying circumstances different economies in the world had shrunk. This effect trickled into the construction sector, with the frequent scarcity of fuel and aggregate resources that led engineers to start exploring alternatives to available techniques such as swapping the poor soils with more efficient aggregates that are shipped in or transported to the site in question. Since the new techniques were relatively understudied or researched, the result was errors in their applications and relative misunderstandings of their perceived effects on soil, and this led to falling out with soil improvement techniques. After staying on the fringe for a while, soil improvement techniques have yet again become an inevitable need due to industry demand for raw materials, aggregates, and fuel. A slight difference today with that of the 60s and 70s is that engineers are now equipped with modern era research and state-of-the-art equipment at their disposal. [2].

Different techniques include Vibro-flotation, which is the application of a vibrating probe that can penetrate soils up to 100ft in depth. These vibrations cause the movement and realignment of soil grains in the vibrated area, causing them to densify in the process. Another method is dynamic compaction, which comprises launching heavyweights made of steel or concrete from a height of 30-100ft. When a 'working mat' of dry granular soil is utilized at surface level, it is successful up to a depth of 10 m ideally [3]. This facilitates depletion of pore-water pressure and additionally densifies the soil. Insertion of compaction piles can also be a go-to method when it comes to the improvement of soil. These piles are usually made of pre-stressed concrete or timber, and both densify and reinforces the soil. Grouting is a technique that involves the injection of grout, a mixture usually of sand, cement, and water. This generates a bulb-like formation which densifies the surrounding soil. As the grout can be infused at the targeted layers without treating the whole soil segment, this technique is cost-effective and productive for soils containing deep and segregated liquefiable layers. [4]. Other techniques that can be touched upon can be the convenient usage of synthetic or wick drains for drainage of excess pore water pressure depending on soil angle/gradient. In-situ testing is also done to evaluate the liquefaction potential of the soil at hand, and if the chosen improvement technique would suffice.

Nowadays, alternate improvement techniques are preferred in-situ techniques i.e., the addition of different chemical additives and preservatives that enhance soil properties. These are now taking priority over laboratory techniques due to the limitations of laboratory techniques. These additives and admixtures have made life on the site easier, since they are very economical as compared to the others, and their application is relatively easier as compared to some of the other pre-existing soil improvement techniques that are mentioned above. These can include Lime, Fly Ash, and Cement et al [5].

Paper Pulp or simply put, Pulp is a very fibrous material constituting of cellulose fibers that can be both chemically and mechanically separated from wood, waste, crops, vegetables, etc. The interaction through which wood is diminished to a fibrous mass and simultaneously the method for breaking the bond inside the wood structure is called Pulping [6]. It is the most key part of paper manufacturing as it is utilized as part or all of the fiber synthesis in essentially every sort of paper. Its importance can be estimated from the fact that it constitutes roughly 90% of virgin pulp fiber utilized by the world's paper and board industry [7]. Being inherently fibrous and less dense than the type of soil it is likely to encounter, we propose that paper pulp can genuinely be used as a chemical additive in the soil to boost its engineering properties. A study of previous research and works of literature has familiarized us with its usage with cement and water in the form of a product Papercrete, which is a fairly new method. It uses otherwise wastepaper as the additional composite material in its replacement of traditional Portland cement. Around 50% to 60% of wastepaper is contained in the mix for different types of papercrete produced. Concrete and wastepaper are mixed with water to make a paper concrete mash, which is poured into a form, permitted to dry to be used as a tenacious structure material [8].

1.2 Problem statement

Ever since humans throughout their evolutional history have started using land for their construction purposes, due to a combination of natural or artificial factors, they encountered problems in soil that lower their compatibility for constructional purposes. The major and most recurring ones are reduced shear strength, high permeability, and compressibility. Over time different inquisitive brains have come up with different solutions to these soil problems. The purpose of these techniques is to counteract all these problems whilst keeping liquefaction hazards at bay. These existing techniques include compacting the surface, drainage and vibration methods, consolidation, grouting, chemical stabilizations, reinforcements et al. Although these techniques can sufficiently provide improvement to the soils. Bio-mediated strategy for soil improvement has been considered as an innovative and new methodology in geotechnical designing, used to prevent liquefaction and landslide in loose, weak sand which ordinarily brings about failure through foundational deformation [5]. The biochemical response that happens inside a soil mass to create calcite precipitate to alter some engineering properties of the soil is alluded to as the bio-mediated method for soil improvement [5]. One such technique, we purpose can be the option of using paper pulp as an additive to enhance soil properties such as bulk density, simultaneously lowering the liquefaction potential of clayey soil. Fundamentally, cellulose fibers, moisture, and papermaking fillers are mainly composed to make pulp and paper factory residual solids (likewise called sludge) [8]. Due to the presence of silica and magnesium properties, paper sludge starts behaving like cement, which improves the setting of the concrete. [9]. The pulp contains surfaces of fiber composed of hemicelluloses, lignin, and cellulose with compositions that vary, to create stable bonds that have exceptional strength per square meter. The remarkable component of papermaking is that the filaments attach to one another with no paste or adhesive material added to the suspension [10]. All of these could contribute towards improvement in the general characteristics of vulnerable soils.

Recently construction industry and its practices have been a contentious talking point with environmental activists and organizations and have prompted environmental concerns, so legislators are laying more keen emphasis on developing methods that minimize the industry's contribution towards the detriment of the environment. In developed countries (USA, EU, etc.), demand for earth buildings has been increasing in accordance with increased [11]. The recent surge in the popularity of economic, light, and pro-environment materials in the construction industry has brought to light the requirement of an investigation into how the balance between improving the environment and keeping the requirements of the material standard can be achieved. As aggregate natural sources keep on depleting, there should be the urgency to further develop these environment-friendly materials [12]. Critical environmental concerns are raised when the major chunk of abandoned, and wastepaper is collected from countries all over the world. This is where recycled waste such as paper pulp can come in handy. A genuine possibility of a significant reduction in the environmental pollution by paper and lime production wastes and recognizable economization of the construction costs can be initiated by industrial waste usage in civil construction projects [13]. Adding to this that the use of paper-mill residuals in concrete formulations was investigated as an effective and environmentally conscious alternative to landfill disposal [14].

The problem of clayey soil in Bahria Town Phase 8 happened because of the less permeable and low strength soil and the proposal is to use the paper pulp and investigated its impact on subject problematic soil. Clayey soil has many disadvantages as it has low permeability and high expansivity, which means it has slow drainage and the area under review that is Bahria Town in the Islamabad region receives frequent rainfalls and therefore, this slow drainage will result in the pooling of water and consequently affects foundations and any building structure. Paper pulp being cheap and fibrous material is proposed as an additive to study unconfined compressive strength change in this soil. By replacing a portion of soil with paper pulp and mixing the content with soil, it is intended to improve this problem. Geological surveys of the area determined that the majority of samples are sorted poorly, so a portion of the gravel tests contains silt and clay around 18% and a portion of the silty clayey sample which contains around 40.5 percent silt and clay. A portion of the sample finer than 0.42 mm determines the liquid limit, plastic limit, and plastic index, so the properties of matrix sand, silt, and clay are reflected in reported gravel values [15].

1.3 Aim and Objectives

The aim of this research is to improve the unconfined compressive strength of clayey soil from the site and improve the bearing strength of soil using the fibrous paper pulp.

To achieve this aim, need to implement the following objectives:

1- Collect clayey soil samples from different sites in Bahria Town and study engineering properties including Atterberg's limit, compaction parameters, and then performing unconfined compressive strength analysis.

2- Adding the paper pulp to the specimen and performing the UCS

3- To compare untreated and treated specimen results.

1.4 Scope

The scope of the project including:

1- Then determine index soil properties including particle size analysis, Atterberg’s limits (LL, PL, and PI), specific gravity, sieve analysis, and hydrometer analysis.

2- Compact the soil using the standard compaction test to get the maximum dry density (MDD) and optimum moisture content (OMC)

3- Measure the unconfined compressive strength (qu) and undrained shear strength (Cu) using the unconfined compression test (UCT).

4- Determine the hydraulic permeability (k) of the soil using the falling head method.

5- Add the paper pulp and then performing tests to determine the plasticity index, compaction parameters, and undrained compression strength.

6- Interpreting the results of treaded and nontreated soils.

Chapter-2 Literature Review

2.1 Soil Improvement

The need for soil improvement is generated from the inability of soils to support structures in their natural state, and so arrangements need to be made to improve their bearing capacity and decrease foundational settlement. Both modifications aid structural support from the underlying soil. The presence of unsatisfactory soil for supporting designs in building sites, the absence of space, and the economic incentive are essential primary purposes behind utilizing soil improvement techniques with poor subgrade soil conditions as opposed to the deep foundation. Many common methods are used to lessen the post-construction settlement, upgrade the shear strength of the soil system, cause increment in the bearing capacity of the soil, and improve the dam/embankment stability [16] .Proposed division of the soil improvement techniques into four main categories:

- Soil improvement without admixtures (soil substitution, preloading, sand drains, and vertical channels)
- Soil improvement with admixtures or considerations (stone columns, sand compaction heaps)
- Soil improvement utilizing adjustment with additives and grouting strategies (chemical stabilization, deep mixing, jet grouting,)
- Soil improvement utilizing thermal strategies (Heating and Freezing)

2.2 Methods of Soil Improvement

Different methods of soil improvement have been under study by research being carried out. The main focus of all is the obvious increase in soil bearing capacity and decrease in the differential or expected soil settlement. Another key point is economic considerations and keeping expenditures incurred minimal during the process. But there is a paucity of research that considers all factors such as capacity and settlement, foundational and executional costs, etc. Soil improvement by physical and chemical modification techniques is accomplished by using an adhesive that might be as regular soils, waste materials, by-products of industry, or different chemicals which react with each other and the soil and mixing these adhesives and reasonable chemicals in the surface layer or sections of soils all things considered [17]. The stabilization of naturally occurring native soils has been performed for years and years. Before the Christian era started it was familiar that specific geographic zones were presented with surface materials and surrounding conditions that caused hindrance in the men and material movement. These was the early days of stabilization of weak soils to improve their capacity. The Mesopotamians and Romans independently discovered that by blending the weak soils in with a stabilizing agent like pummeled limestone or calcium, it was conceivable to improve the capacity of pathways to carry traffic. A few sections of the roadways that the Romans built are still in remarkably good conditions, despite being 2000 years old [2].

The paradigm shift which the Industrial Revolution brought resulted in the diversification of building materials and the usage of cement and steel in modern construction standards, which became the natural replacement of conventional materials such as earth and wood [18]. The importance of soil to support the constructional loads has thus gradually increased. Scientists, practicing designers, and contractors have built up various techniques and frameworks to fulfill needs for improving beforehand unusable sites as we approach the turn of the millennium since the requirement for inventive and economic ground improvement, foundation, and earth support methods are getting significant. Since the ground improvement field depends heavily on case studies examining past experiences and concentrated research for its progression, this demand ought to stay steady or increase later on as the need to expand on low quality metropolitan urban sites increases and developing nations look for economical alternatives to enable work on problematic zones [19].

Case studies that subsume modern soil improvement techniques, including avant-garde additions of microbial-induced calcite precipitates, use of nanoparticles and calcium chloride/lime, bio-chemical fibrous resins and ceramic, and other industrial waste applications to pre-existing soils have shown promising results. Some of them are mentioned below. To enhance soil design properties through coating and bond arrangement between soil particles, the Microbial induced calcite precipitation (MICP) method uses microorganisms (native or presented) to precipitate calcite [20]. To decline compressibility, increase shear strength, firmness and modify the volumetric behavior of soil are salient features of MICP usage, as studies have shown [21]. Contractor Visser & Smit Hanab applied a Microbially Induced Calcite Precipitate treatment for gravel stabilization to enable horizontal directional drilling (HDD) for a gas pipeline in the Netherlands in 2011 [22]. Other various chemical binding agents have also been used as additives for beneficial purposes. Otoko and Blessing in a bid to improve the strength and compaction of marine clay, utilized cement and lime [23] The unconfined compressive strength were essentially improved, and maximum dry density (ρd max) increased with the cement or lime increase and brought about a relating decrease in the optimum moisture content (Wopt), when the soil was compacted. [24] treated marine earth with 1% ferric chloride ($FeCl3$) and 20% quarry dust which sufficiently lowered the liquid limit and discernibly increased the California Bearing Ratio (CBR) and load-carrying capacity values. Fibrous materials, when added to soil have generally improved existing conditions. Crockford et al. (1993) studied that when fibers are utilized for the chemical adjustment of soils with lime or cement, the clay soil plasticity improves fundamentally, after studying the process thoroughly. Reiterating how environmental and industrial concerns on the plethora of waste material being squandered through dumping and disposal every year, unique methods have been developed. High measures of ceramic waste are aggregated each year in the removal and building construction sites because of the dismissal of all smashed and broken tiles. It is assessed that around 7 to 30% of the ceramic tiles processing plants end up as waste. The utilization of reused clay squashed tiles (RCT) in improving soft soil is viewed as harmless to the ecosystem, affordable and sustainable [25]. Recently, it is known that ash generated from the combustion of rice husk is of promising potential as a pozzolanic substance. In terms of chemical constituents, Rice husk ash is about 80-88% silica, which deems it a sufficient backup of the traditional pozzolanic materials employed in soil stabilization. Where the use of customary cement is limited, monetary and market investigations have shown that the biopolymer binder has high potential as an independent local development cover for earth structures. So modern biochemical remediation techniques are being used more ubiquitously than ever now.

2.3 Paper Pulp Production and Usage

The process of papermaking involves the expulsion of water and subsequently drying the diluted fiber suspension that is generated by mixing with water and then evenly distributed. Paper pulp is the most common and prolific raw material used for the production of all grades of paper. Pakistan produces almost 434k tons of paper to meet a portion of domestic requirements and excess demand is imported [26]. We are considered with its byproduct, the wastepaper pulp. To gain the wastepaper pulp, the chronological order of the steps undergone are shredding, then soaking, mixing, and then drying or dewatering. Manual shredding of waste papers is done in small pieces, and then they are kept immersed in tap water for 24 hours. The soaked paper which is shredded is mixed with aid from a blender until slurry formation, which is then drained off its excess water. A wet state paper pulp is acquired. It can then be used in a wet state or dried at room or oven temperature for further usage and studying of physical characteristics [8].

Paper pulp in itself has very limited usage while it is usage is abundant and diverse as raw material. Paper pulp has numerous applications in the paper industry including paperboard, product packaging, newspaper, toilet paper, tissues, etc. There are different types of paper pulp based on extraction and manufacturing procedures. This includes mechanical pulp, thermomechanical pulp, chemo-thermomechanical pup, chemical pulp, etc. the different methods of pulp extracting, and different sources induce so much variation in type and quality of paper pulp which defines its usage suitability. High-quality and enhanced paper pulp are used to make currency notes [27].

There is another kind of paper pulp called dissolving pulp or dissolving cellulose which is used as raw material to produce regenerated cellulose. Regenerated cellulose is used in the textile industry. It is also used in making cellophane which is abundantly used in packaging [28]. Paper pulp is part of the majority of daily usage products including towels, toilet paper, diapers, hygiene products, fresh food wrappings, paper cups and bags, paper board packaging, books, fabrics and apparel, binding agents in different products, etc. [29].

2.4 Soil Improvement in Pakistan

The landscape of Pakistan is very diverse, and the climate is distinctly different across the regions. As the soil formation depends upon climate, topography, erosion and weathering process, parent rock, etc. therefore, consequently there are different types of soils are located in the different regions of Pakistan. The country has nine different major ecological zones, and these zones have different soil types. For different soil types, there come different construction requirements and problems. Hence, plenty of soil improvement techniques are being employed in Pakistan depending on the type of construction and site requirements [30].

In addition, Islamabad and Rawalpindi are located in a seismically active area, with the MBT fault line running close to them. Due to seismic activity, the consequent generation of force and deformations in the soil in the vicinity induces a vibratory effect in the structure and produces shear in the base, displacement, and moment. The lack of viable construction sites with optimum soil conditions is a bigger concern in Pakistan due to fast-paced urbanization [31].

Different soil improvement additives are being used along with soil improvement techniques. Usually, common additives and soil improvement methods are being used to improve engineering parameters and properties of soil. With the increase in global research and the need for improvisation, newer methods of soil improvement are now being applied in Pakistan. Soil samples obtained from the Kala Shah Kaku area of Punjab were treated with an injection of lime and OPC as additives in changing percentages of 2-8% and 4-15% relative to the soil dry weight [32].

In coastal areas of Pakistan where mostly loose silty sand and clay deposits are, Vibro-compaction is being frequently used. Dynamic compaction and soil replacement are other commonly practiced methods in Pakistan.

As stated in the problem statement the subject area site ‘Bahria town phase 8’ is in the ‘Barani land’ zone which is one of the nine ecological zones and has silt loam, clay loam, and silty clay loam types of soil [33]. Such soil has very low drainage and potentially expansive which is detrimental for the foundation. Such soil causes serious drainage problems when highways and roadways needed to be built. Previously, fly ash is experimented on clayey soil to improve its hydraulic characteristics [34]. Paper pulp being fibrous, cheap, and abundant material can be the source of enhanced engineering properties including improved and enhanced unconfined compressive strength.

Chapter-3 Methodology

3.1 Research Approach

Research is an academic activity for purpose of investigating materials and studying the facts and reaching new conclusions based on investigations. According to Clifford Woody research is meant for redefining problems and is carried out on hypotheses or suggested solutions, analyzing, and evaluating data, and making conclusions [35]. There are two basic approaches to carry out any research, and these are quantitative and qualitative research approaches. The quantitative approach involves the detailed gathering of quantitative data and mathematical analysis of data to reach conclusions. This method includes experimental and simulation approaches to get the final results. However, the latter involves a subjective assessment of behaviors, attitudes, etc. It is more subjective and concerned with non-quantitative data [35]. The subject problem statement requires rigorous quantitative analysis of data and involves experimental procedure to back the results, hence quantitative methodology is adopted to carry the research.

This research involves the background of soil improvement and the discussion of different techniques and materials that have been used for soil improvement. The problem statement is defined to guide the scope of research. To carry out experiments, soil samples from 'Bahria Town Phase-8' are to be collected and different experiments to be carried out to analyze the data. The flow chart in Figure 1 shows the step-wise procedure to carry out the research.

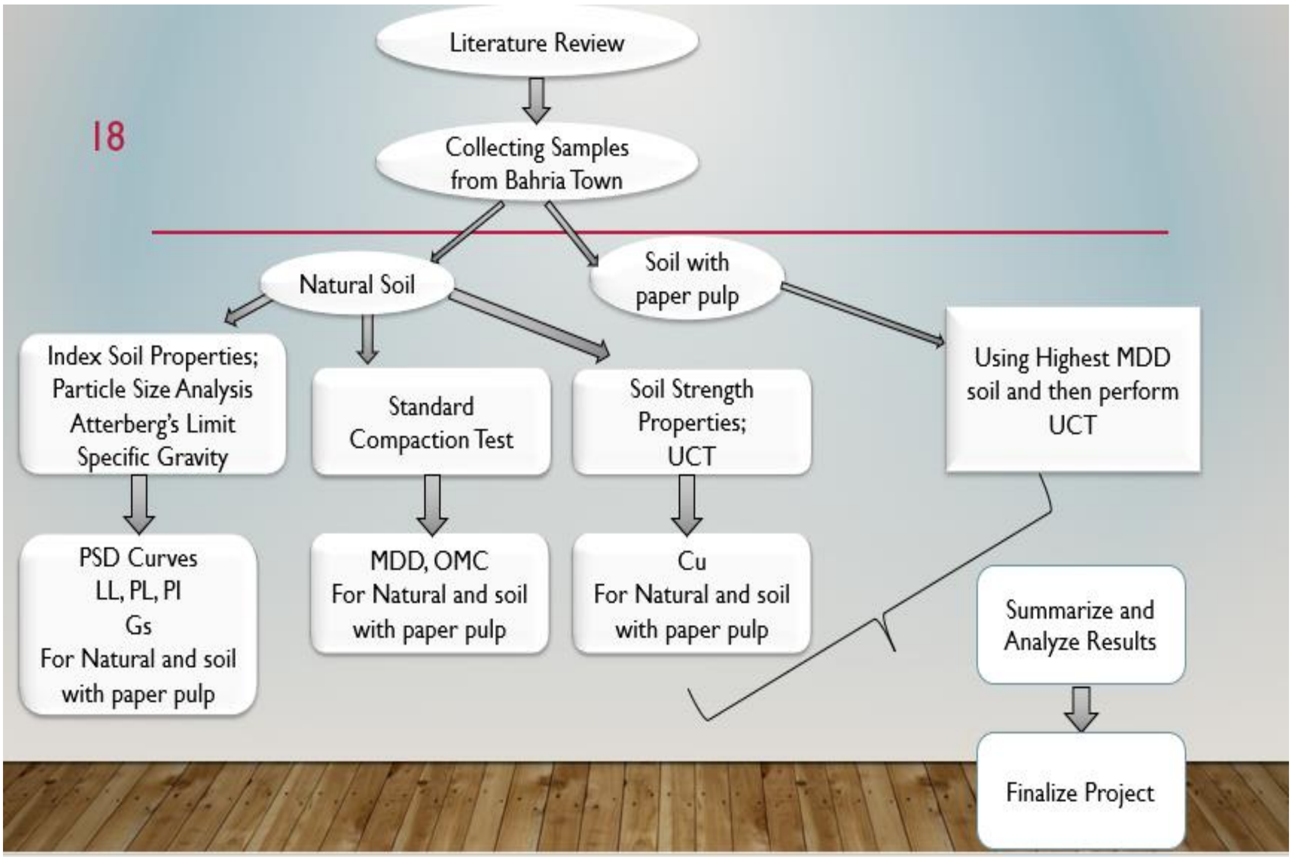

Figure 1 Flow chart

3.2 Geology of the study area

The geology of the study area from various lab tests and assimilation of knowledge from accounts of property buyers and land developers in the area determined that the land was mainly filled land, which is a land area of increased grade via depositions of various rock, soil, silt, gravel et al. These lands have a prerequisite demand for attention in the form of compaction to maintain and regulate safety standards for the beginning of construction process. Filled land is always susceptible to safety problems and construction issues and most often there is an appearance of potholes after a certain amount of time. Homes built on it witness extra settlement due to the emanation of foundational cracks. Different options have been eyed by potential buyers, but the conundrum lies in the finalization of property. Bahria Town undergoes the problem of it being constructed on a hilly terrain which means that the designated plots are filled instead of being leveled due to the steep grade. A plethora of excess material and testing is needed for insurance of structural integrity on plots that are earthfilled.

3.3 Collecting sample area site

First and foremost, a sunny day was chosen for sample collection to know the true soil conditions, and any present organic matter or debris was removed in the vicinity of the area under investigation. Next, a soil spade was employed on the soil surface at about 4-inch depth for sample collection as the true conditions of the soil, including its water content and nutrients, are more attainable at this level. A particular characteristic of a minuscule subsample is denoted by the values acquired from the chemical analysis of the soil [12]. The collection was done in a zig-zag pattern of equal distances in the area. The samples were placed in different zip-top bags and labeled. 20+ samples were collected and brought to the lab for further testing without and then with the addition of paper pulp. The sample weighed about 3-5 kilos in weight.

The location of site collection along with coordinates is Bahria Town Phase-8, Rawalpindi, Punjab, Pakistan. 33°29’31’’N, 73°05’36’’E.

Figure 2 The Site location in Bahria Town

3.4 Lab tests: Brief summary of tests and standards

For the identification and classification of soils to be used in engineering endeavors, the ASTM D-2487-98 has embraced the Unified soil classification system. Three major distinctions of soils are coarse-grained are soils that are with <50% passing the 75 microns IS sieve, fine-grained soils which are soils with >50% passing the 75 microns IS sieve, and highly organic soils and other miscellaneous soil materials being the third major division. Fine-grained soils, the ones that we are concerned with are classified by plotting their values in computations of the liquid limit alongside the plasticity index on the chart, in accordance with the Unified soil classification system [36]. Another technique adopted for particle size analysis is hydrometer analysis. Hydrometer analysis uses Stokes Laws idea to distinguish between coarser and finer particles. What that means is that if all things are kept unchanged, the velocity of a settling grain is based on physical characteristics such as shape, weight, and size of the grain.

In the case of soil, we can say that the denser coarse particles will settle quicker than their finer counterparts. The percentage weights of sand, clay, and silt can be deduced from a soil suspension, aqueous in nature, by virtue of its density with the help of a hydrometer [37]. The specific gravity of a fine-grained soil sample should be between 2.65-2.80. This is determined through a specific gravity test which determines the ratio of the unit of soil particles with the water unit weight. It is important to determine in the sense that we can deduce an understanding of the soil's mineralogy and indicators such as dry and wet density, weathering, and extent of saturation, etc. It is a pivotal property of grain that helps to find other parameters such as void ratio, saturation, and densities for further usage in consolidation and compaction analysis. Therefore, utmost care should be exercised in the laboratory [38]. The process through which a soil experiences mechanical stress and subsequently densifies in the process is referred to as its compaction. Compaction is mainly done to influence strength, compressibility, and permeability parameters. Proctor tests are conducted to determine the degree of compaction of the soil in question and its change of properties with the change in moisture content. These can be of two types namely the Standard Proctor test (SPT) and Modified Proctor test (MPT), with nuanced variances in the procedure, but the objective being the same. Proctor was introduced in 1933 for a specific amount of compaction energy applied on the soil [39]. Soil is compacted into a specific mold when this test is initiated. During successive series of compactions through a rammer, the water content and dry bulk density are noted. This experiment is repeated with varying contents of water to deduce a relationship between water content and dry bulk density through a graph, the highest of which's curve gives the optimum moisture content. Soil is compacted into a specific mold when this test is initiated. During successive series of compactions through a rammer, the water content and dry bulk density are noted. This experiment is repeated with varying contents of water to deduce a relationship between water content and dry bulk density through a graph, the highest of which's curve gives the optimum moisture content [40].

Once the optimum water content is obtained, we move to the unconfined compression test of soil. As the name suggests, this test aids in obtaining the unconfined compressive strength of a specimen since the name stands for the maximum amount of compressive stress applied axially that the specimen sustains under zero confining stress. The test is appropriate for clayey soils with some moisture content, and not for dry sands or clays that are weak or crumbling in nature as the test would fail with the material falling apart without any development in terms of lateral confinement.

In the working of this test, the prepared sample is adjusted between the upper and lower plates of the loading machine. Before initiation, the upper plate is kept in constant connection with the sample and here the deformation is set to zero. The test starts with the application of a 0.5-2% consistent axial strain, per minute. Careful recording of the load and deformation values will provide us with a complete deformation curve with respect to load. This application of load is perpetuated until the value of load remains constant with an increase of strain or decreases, or till 20% of axial strain is reached. The samples are deemed to have failed when this state arrives [41]

Chapter-4 Results

4.1 Results of Lab experiments on Soil

The sieve analysis was performed on the coarse-grained fraction of soil collected from the site while the hydrometer was performed on the fine-grained fraction of the sample. The particle size distribution curve was plotted based on total soil sample. The particle size distribution curve is shown in Figure 3.

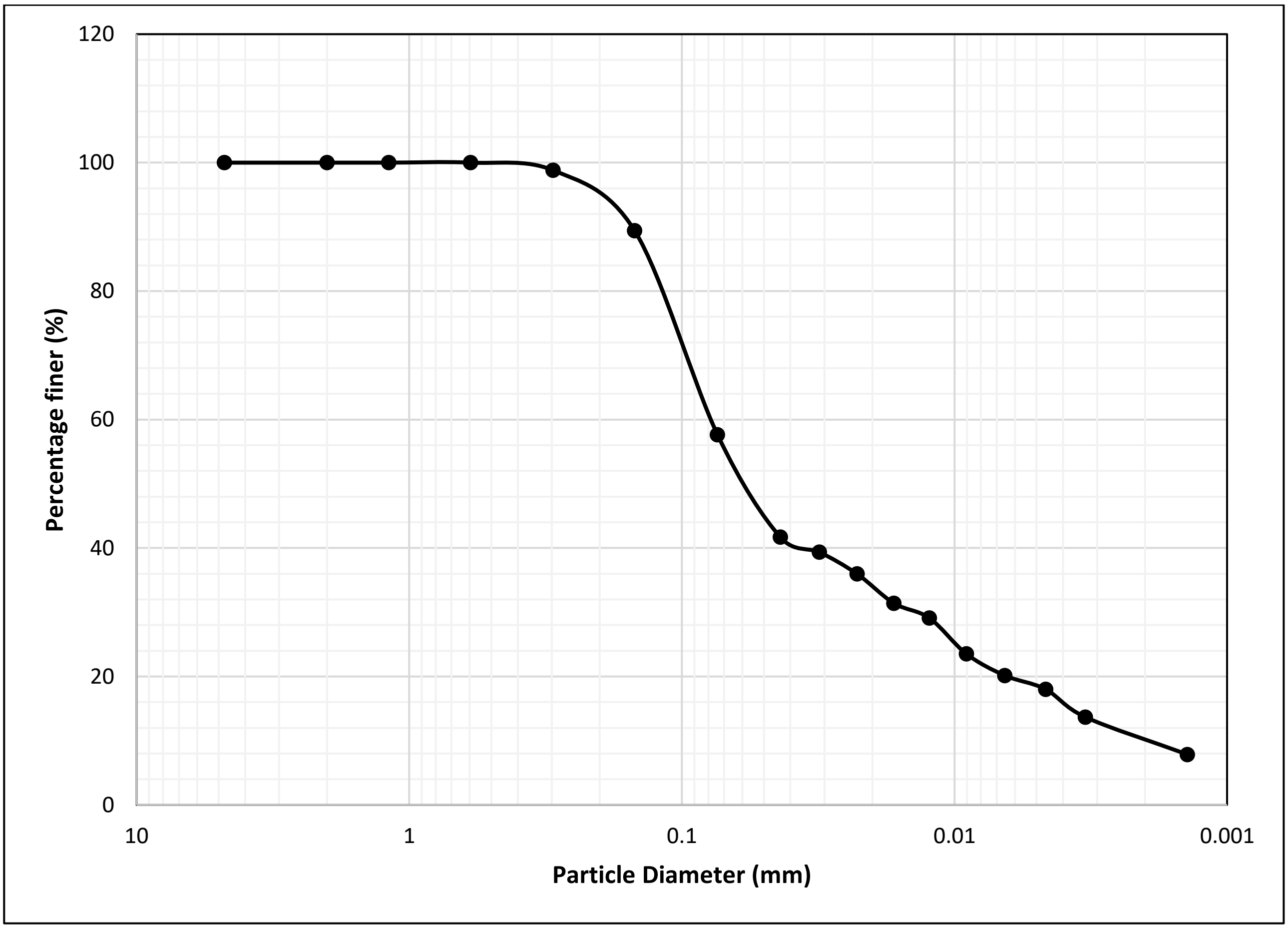

Figure 3 PSD curve based on total soil sample

The specific gravity test was performed which gave the Gs value of 2.669 (see appendix). The Atterberg's limit test was performed to further classify soil. The liquid limit of soil was 26.5% and the plastic limit was 13.5%. The plasticity index was 13% of soil. The soil classification according to USCS was CL with sand fraction.

The standard proctor test was performed to obtain the maximum dry density of soil specimen and the optimum moisture content OMC against that MDD. The compaction curve obtained from the standard proctor test was plotted as the MDD obtained was 1.83g/cm3 against optimum moisture content of 15%.

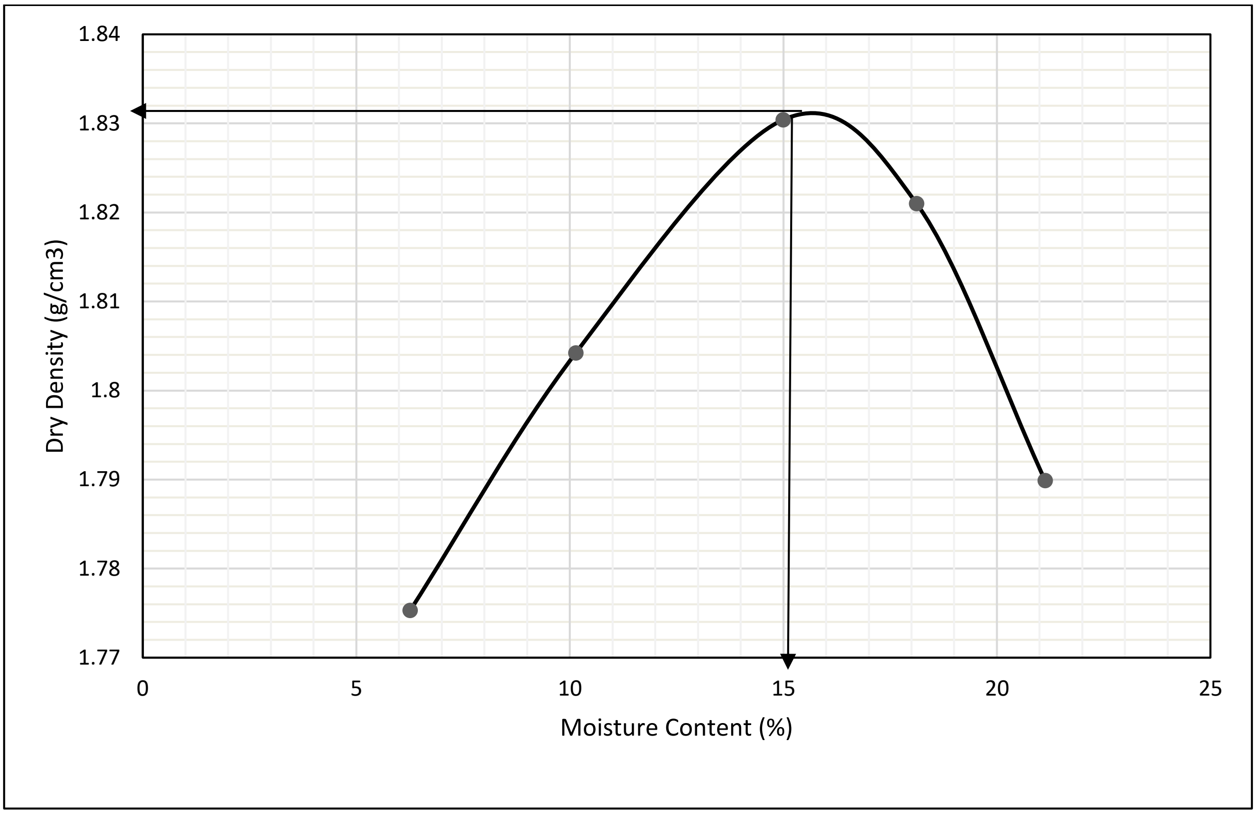

Figure 4 The compaction curve obtained from St. proctor test

The unconfined compression test was performed using a digital UCT machine for the determination of maximum stress and undrained shear strength of the soil. The test was performed on untreated samples with 0% paper pulp and the specimens with different percentages of paper pulp. The undrained shear strength of soil was obtained as half of maximum stress on the soil specimen.

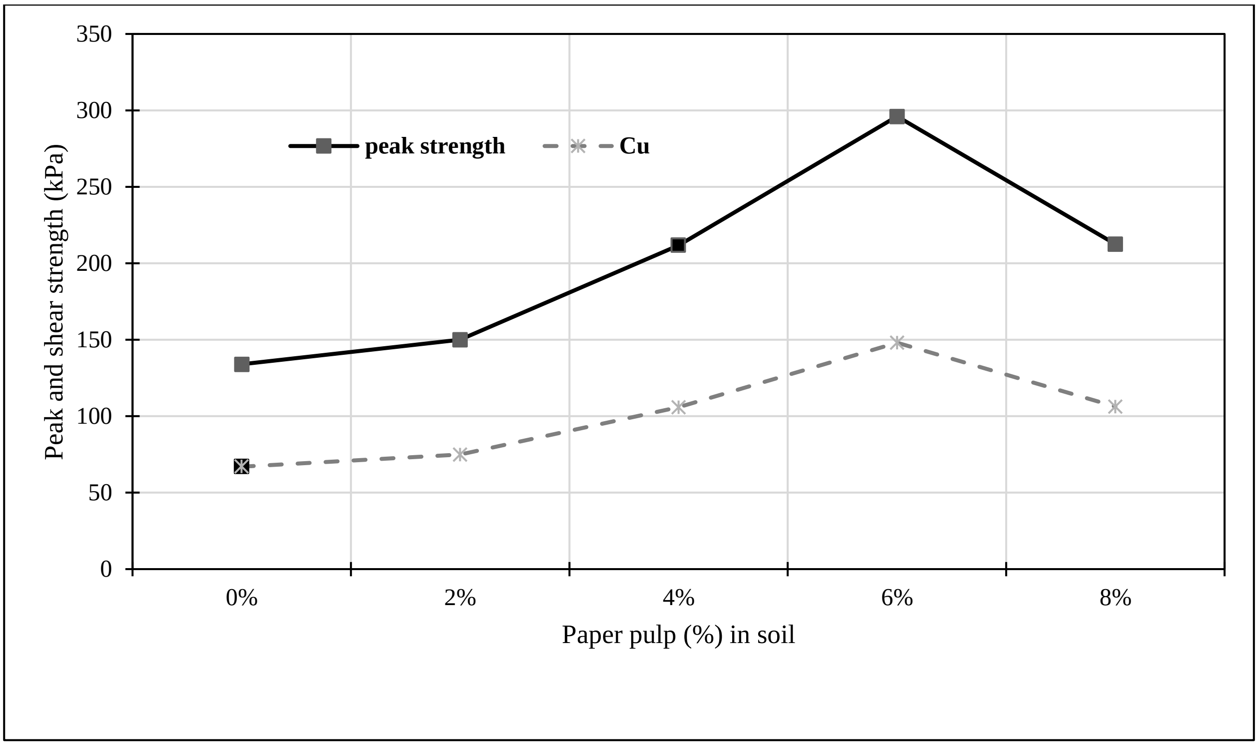

Figure 5 The effect of paper pulp on strength of soil

Chapter 5-Conclusion, Limitations and Recommendations

5.1 Conclusion

The untreated soil sample was tested for Unconfined compressive strength UCS and then a 2% incremental amount of paper pulp was added to see the effect of it on the strength parameters of soil. The UCS test shows that with increasing the paper pulp in the soil, the strength of soil increases significantly until it shows a decrease at 8% paper pulp in the specimen. The soil reached the peak strength of 296 kPa at 6% paper pulp and then decrease with a further increase in paper pulp percentage in the soil.

The stress-strain plot of the UCS test on each percentage of paper pulp is given in the appendices. We can confidently judge the pulp to be increasing the strength of the soil till about 6% and the general trend can be assimilated from the graphs above. We do however believe that further trials and curing in between the trials could be key to obtain a complete picture of paper pulps effect on the soil's strength. This also proves that the addition of paper pulp does not compromise existing soil strength as no sign of a decrease in strength was noted.

5.2 Limitations

There were certain logistic and procurement problems due to COVID-19. We originally planned to test with more percentages of pulp, for which we would have required more quantity of pulp that, due to the protocols in place, was an ordeal. Underestimation of paper pulp moisture content and the resulting problems this would pose in lab experiments was also another factor since the paper pulp is a mixture of blended paper and water, and the water content existing in the mix would have to be accounted for in calculations during experimentation. Time limitation and movement restriction meant the percentage of additive used was limited to 1-8%.

5.3 Recommendations

The improvement of soil strength and its parameters in the construction industry is critical and since the beginning, more and more methods and materials as additives are being employed in the soil. The paper pulp being abundant and cheap can be one of the best alternatives to improve soil strength. The initial testing on the soil for unconfined compressive strength shows significant improvement of strength. Hence, further research on the use of paper pulp is recommended especially the stiffness and permeability study of soil with the addition of paper pulp and its behavior to further confer the results and to see any adverse effects.

The permeability is another important parameter while evaluating soil for construction purposes, hence it is recommended to do further laboratory experiments for permeability analysis of the soil. The adverse or positive effects of paper pulp on the permeability of soil should be evaluated.

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Appendices

5.1 Raw data from sieve analysis

Sieve #	S. opening (mm)	Sieve Mass (A)	A+ Retained sample (B)	Mass of Sample (B-A)	(Rn) Percentage of mass retained on sieve	Comm. Percentage Retained ΣRn	Percentage Finer (100-Rn)
4	4.76	415	415	0	0	0	100
10	2	346	346	0	0	0	100
16	1.19	337	337	0	0	0	100
30	0.595	348	348	0	0	0	100
50	0.297	311	313	2	1.176	1.176	98.824
100	0.149	354	370	16	9.412	10.588	89.412
200	0.074	332	386	54	31.765	42.353	57.647
pan	n/a	296	394	98	57.647	100	0
Σ				170			
					D60	0.08	
					D10	0.002	
					Cu=D60/D10=	40	
					Cc=D30^2/D60*D10	2.5	

Pt based on fine sample	Pt based on total sample	Dia (mm)
	100	4.76
	100	2
	100	1.19
	100	0.595
	98.82	0.297
	89.412	0.149
	57.647	0.074
72.34	41.70188235	0.04355
68.3	39.37294118	0.03133
62.4	35.97176471	0.02276
54.5	31.41764706	0.01669
50.5	29.11176471	0.01237
40.82	23.53152941	0.00904
34.98	20.16494118	0.00654
31.26	18.02047059	0.00463
23.73	13.67964706	0.00331
13.67	7.880352941	0.0014

5.2 Raw data from hydrometer analysis

Time (min)	(R)Hydrometer Reading	Temp. °C	R(cp)	% finer (a*Rcp*100)/50	R(cl)	L'	A'	D (mm)
1	46	17.4	36.5	72.343	47	8.6	0.01485	0.04355
2	44	17.4	34.5	68.379	45	8.9	0.01485	0.03133
4	41	17.4	31.5	62.433	42	9.4	0.01485	0.02276
8	37	17.4	27.5	54.505	38	10.1	0.01485	0.01669
15	35	17.4	25.5	50.541	36	10.4	0.01485	0.01237
30	30	17.8	20.6	40.8292	31	11.2	0.0148	0.00904
60	27	18	17.65	34.9823	28	11.7	0.0148	0.00654
120	25	18.5	15.775	31.26605	26	12	0.01465	0.00463
240	21	19.5	11.975	23.73445	22	12.7	0.0144	0.00331
1440	16	19	6.9	13.6758	17	13.5	0.0145	0.0014

5.3 Raw data from Atterberg's limit test

Atterberg's Limit				
No. of blows (N)	34	23	16	P.L
Container No.	91	79	43	68
Mass of container	12.99	11.54	12.13	11.76
Mass of container+ wet soil (g)	29.26	29.91	26.69	26.71
Mass of container + dry soil (g)	26.06	26.02	23.35	24.93
Moisture Content (%), w	24.4835501	26.8646409	29.7682709	13.5155657
Liquid Limit, L.L (%)	**26.5**			
Plastic Limit, P.L (%)	**13.5**			
Plasticity Index, P.I	**13**			

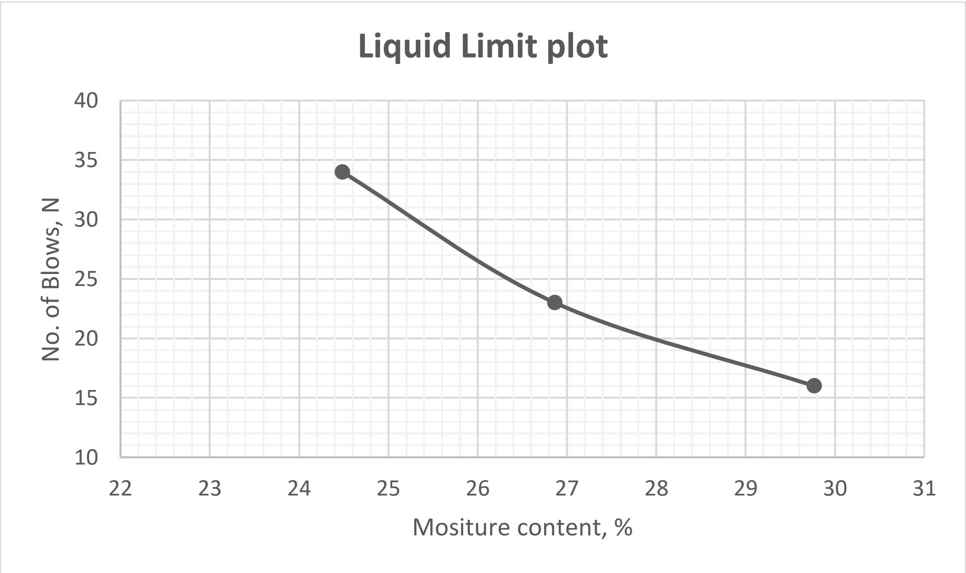

Figure 6 Showing liquid limit plot

5.4 Raw data from specific gravity test

SPECIFIC GRAVITY	
Wt. of flask (g)	100.8
Wt. of flask +dry soil(g)	135.5
Wt. of flask + soil+ water	370.8
Wt. of flask + water	349.1
SPECIFIC GRAVITY, Gs	2.66923077

5.5 Raw data from standard proctor test

Trial	Mass of compacted soil + mold Msm (g)	Mass of mold Mm (g)	Mass of compacted soil (g)	**Wet/bulk unit weight, Yb g/cm3**
A	B	C	D	E
1	3244.00	1482	1762.00	1.88650964
2	3352.00	1496	1856.00	1.98715203
3	3462.00	1496	1966.00	2.10492505
4	3505.00	1496	2009.00	2.1509636
5	3520.00	1495	2025.00	2.16809422

Can ID	Mass of Wet Soil + Can, Mcws (g)	Mass of Dry Soil +Can, Mcs (g)	Mass of Water, Mw (g)	Mass of Can Mc (g)	Mass of Dry Soil, Ms (g)	Moisture Content w(%)	**Dry Unit Weight, Yd g/cm3**
F	G	H	I	J	K	L	M
C 33	87.00	83.72	3.28	31.35	52.37	6.26312774	1.77531913
C 11	65.00	61.87	3.13	31.00	30.87	10.1392938	1.80421716
C 23BCA	79.00	72.74	6.26	31.00	41.74	14.9976042	1.83040774
C 28	83.00	75.15	7.85	31.83	43.32	18.1209603	1.82098384
C 30	85.00	75.58	9.42	31.00	44.58	21.1305518	1.78988223

5.6 Raw data from UCS tests

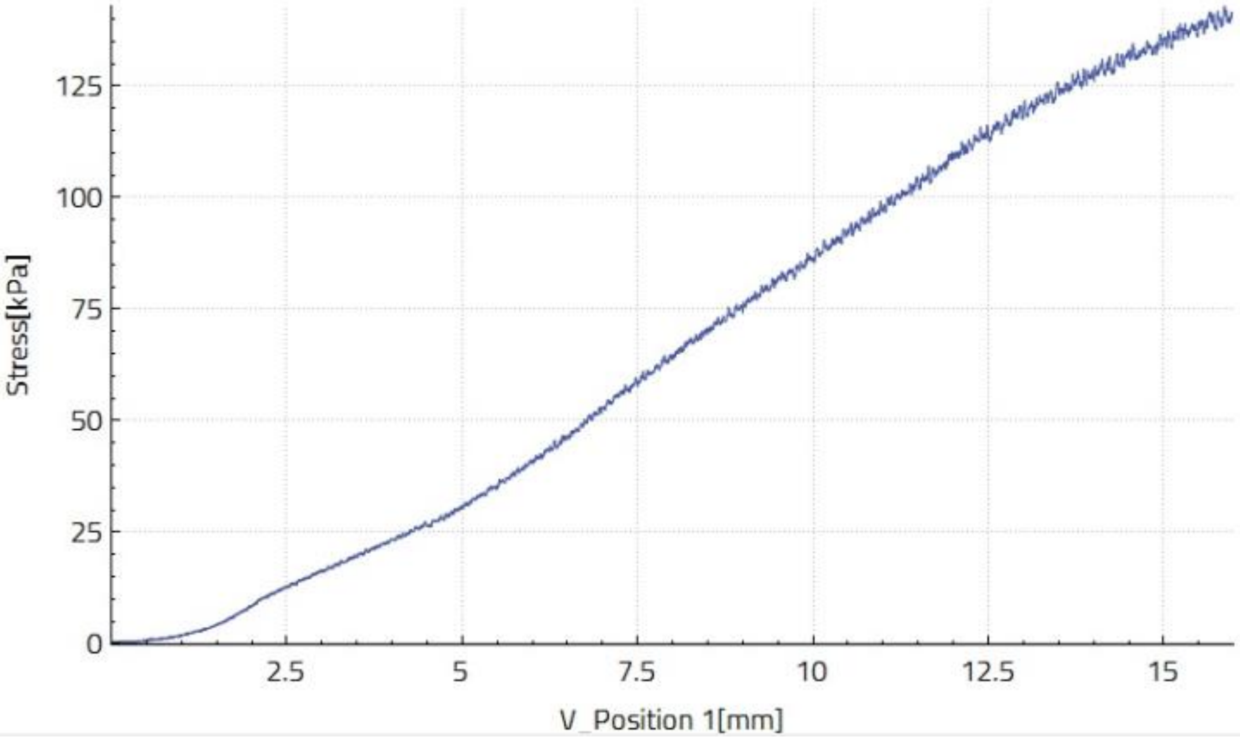

Figure 7 UCS result at 0% paper pulp

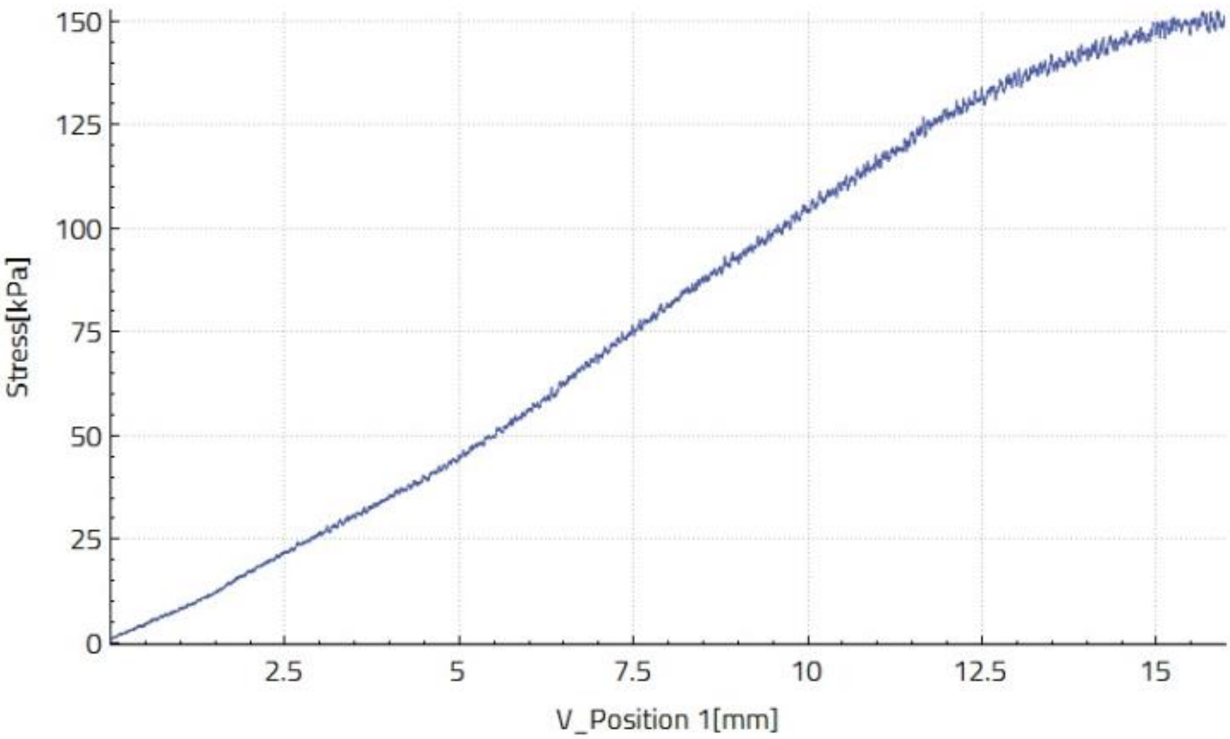

Figure 8 UCS result at 2% paper pulp

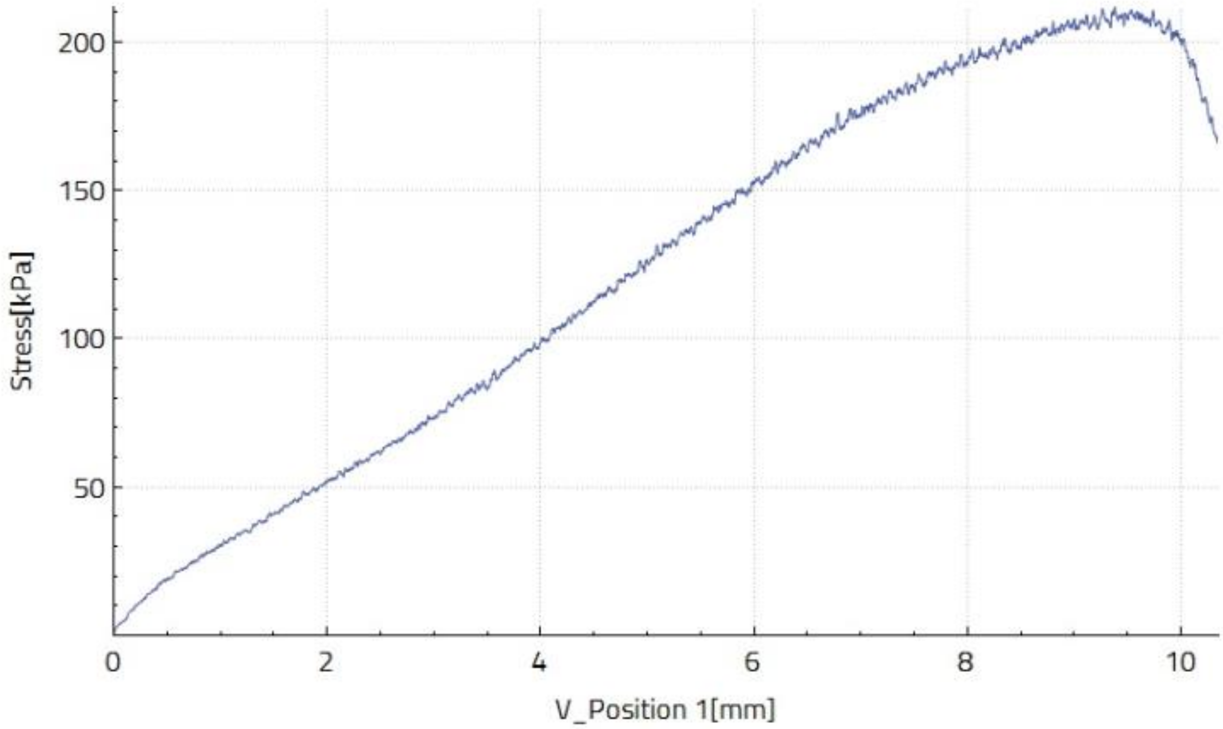

Figure 9 UCS result at 4% paper pulp

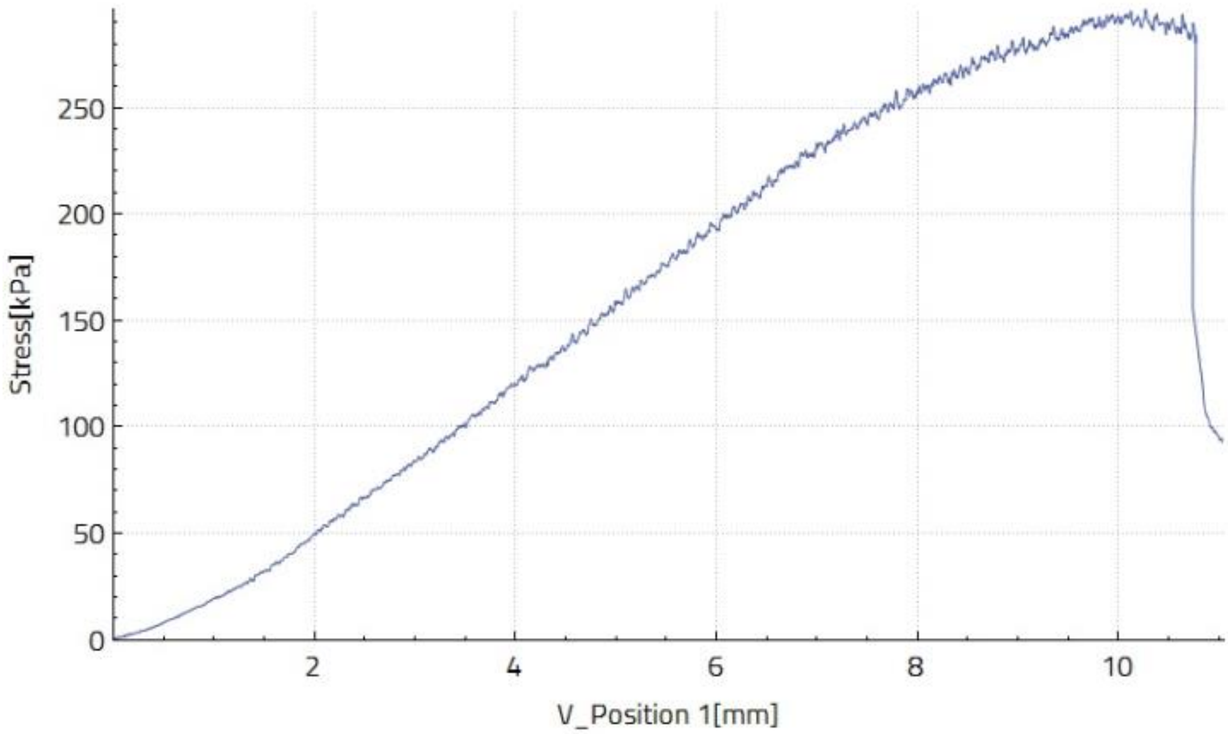

Figure 10 UCS result at 6% paper pulp

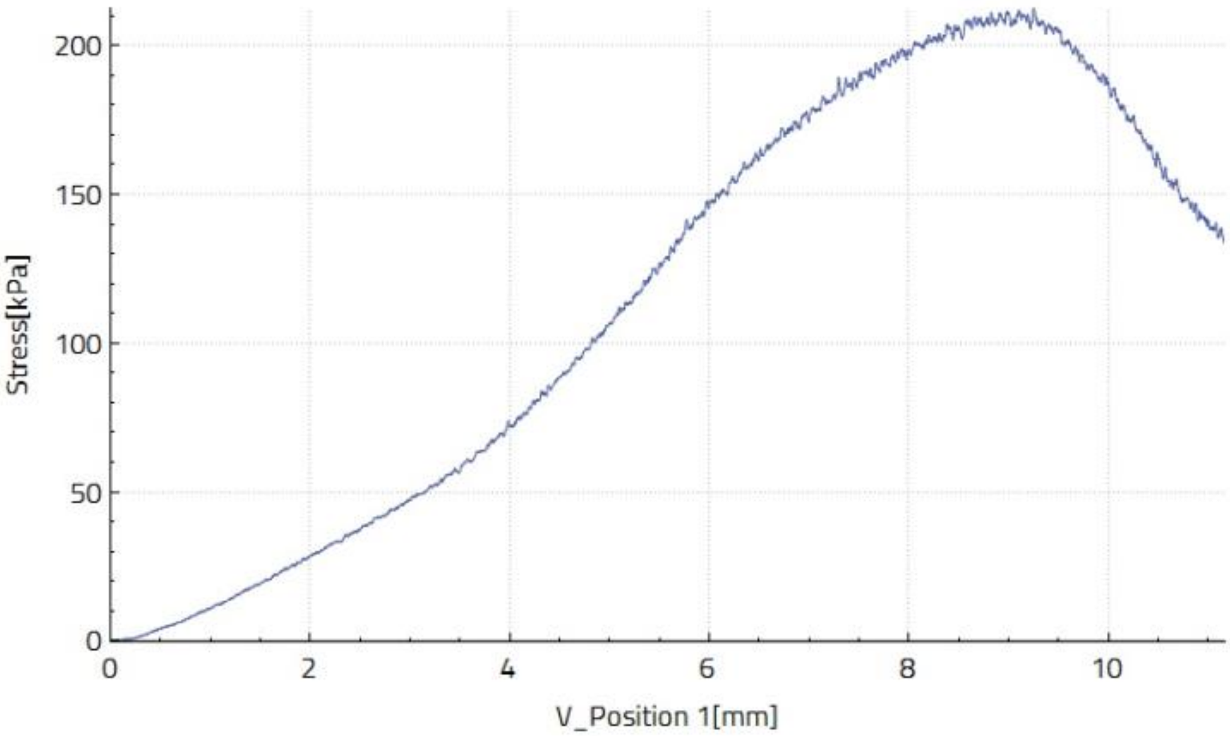

Figure 11 UCS result at 8% paper pulp