Evaluation of Shear Strength of Collapsible Soils by Toner Stabilization Method

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Abstract: The research is oriented to investigate the improvement in the shear strength of soil after the addition of the toner which is usually used in printing machines. Soil is the most important component in the construction industry as every structure has to be built on the soil. The most widely explored aspect in the construction industry is how the soil should be stabilized. Various techniques are being applied all over the world in the soil during construction which enhances the soil stabilizing. The soil stabilization includes different materials such as cement waste, lime, lime and cement mixture, and high-density polyethylene particles. Toner is a relatively new material to be used as an additive for soil stabilization. The presence of pigment and iron-oxides present in toner helps in increasing the strength of the soil. In this study, toner was added in different percentages of the total quantity, and various tests of soil to determine the strength of soil were performed like Sieve analysis, Atterberg limits, California bearing ratio, and Modified proctor tests. The results obtained from performed tests suggest the toner is a promising admixture for soil stabilization.

Keywords: Soil Stabilization, HDPE, Toner, Pigment, Atterberg Limits, Proctor test.

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1. Introduction

Soil is a substance that is accessible all over the world and can be utilized in a variety of earthen construction, such as cob, rammed earth, or stabilized slush blocks. Lower strength, continuity, high compressibility, bulking-shrinking characteristics of the over-consolidated or high-swelling soils spectacle significant geotechnical challenges in the building. An important barrier to properly imposing green structure systems can frequently be found in the poor soil conditions on their parcels. Erstwhile, deciding to employ soil as the enclosing material in a construction design, a significant challenge is to determine how much soil is adequate for cost-effective stabilization [1]. Constructing a structure's foundation on compressible soil results in settlement. From a design standpoint, understanding the pace at which soil density occurs is crucial. The soil's properties, such as plasticity, compressibility, and shear strength, always have an impact on the design of the building. Construction errors may result due to a lack of understanding of the soil's qualities. It is advisable to base an assessment of a soil's suitability for a given purpose on its technical features rather than relying on a graphical inspection or an apparent similarity to other investigated soils. The loading capacity is the function of soil type. Generally, fine-granulated soils have a lesser bearing capacity than soils with larger grains [1]. The plasticity index and liquid limit are the two most important factors that help an engineer comprehend the uniformity or plasticity of clay. Although shearing strength decreases for all clays at plastic limits, strength remains constant at liquid limits. According to Karsten et al., the shear strength of soils is one of the crucial factors for determining and resolving stability issues [2]. This makes it particularly applicable to geotechnical soil [3].

1.1 Types of Soils

1.1.1 Sandy Soil

Although sandy soils are generally considered to have certain well-defined physical characteristics, being simple is far from them. This might be true in the case of sandy soils in the tropics, where they are subjected to periodic cycles of watering down and drying up. Fine sand has higher porosity, water retention, and penetration resistance, but coarse sand shows decreased permeability. When the variety of the sand particle distribution increases, porosity decreases, which raises penetration resistance and lowers permeability. Due to variations in the mineralogy, different physical qualities can be found. In contrast to other soil types, tillage techniques eventually damage the basic fabric of sandy soils. However, these systems are incredibly unstable, and if lower porosity can be induced through tillage activities, contraction by wheels, or other actions, can result in the production of a stable structure [3].

1.1.2 Silty Soil

The silt particles in silty soil exhibit physical characteristics in between sand and clay particles. Silty soil has higher fertility ratings than sandy and clay soils. Medium-sized and better able to retain moisture and nutrients are silty soil particles. For gardening, silty soil is lightweight and easy to work with. The silt particles range in size from 0.002 to 0.05 mm, making them more significant as compared to clay soil, even being smaller than sand particles. The silt is left behind by erosion caused by ice, rain, and wind. Silt is slippery rather than gritty while wet, and it has a lovely, fluffy texture when dry [4].

1.1.3 Clayey Soil

With a size of less than 0.002mm, clay particles are the smallest of all soil particles. When moist, clayey earth rolls like plasticized and feels extremely sticky. Clay particles can hold more water than the majority of other types of soil, and even though only nearly half of this absorbed water is accessible to plants which causes this limited supply of water is one of the reasons behind the failure of crops. These soils can undergo some remodelling depending on the amount of rainfall because they expand when wet and contract when dry.

1.1.4 Loamy Soil

Loamy soil is a mixture of clay, sand, and silt. The properties of these three different surfaces promote water retention, air circulation, waste, and maturity. This type of soil is easy to work with and has excellent seepage. They can be either sandy or clay loam, depending on their transcendent composition. Due to the collaboration of other ingredients, the soil is created. For instance, soil that contains 30% clay, 50% sand, and 20% silt may be sandy clay soil, with the soil type "loam" written in the arrangement where their constituent parts are most prevalent in the soil. The terms "clay loam," "silt loam," and "sandy loam" refer to soils that are fundamentally made up of a higher percentage of prefix components [5].

1.2 Soil Stabilization

The natural, chemical, or mechanical change of the properties of soil is known as soil stabilization. Soil stabilization may be a tactic used in deferential designing to improve the properties of soils. These properties include toughness, adaptability, compressibility, penetrability, and mechanical quality. Perfunctory advancement is common but some intellectuals are inclined to utilize the term 'stabilization' about chemical changes within the soil properties by including chemical intermixtures. Soil stabilization includes the understanding of material characteristics that are involved in the mix and the desired result after mixing of that material. It examines the effects of this process on the surrounding structures and their conditions. Soil stabilization has the major advantage of negligible environmental and climatic effects [6].

1.3 Methods & Materials of Soil Stabilization

Soil stabilization is broadly classified into three classes which are mechanical, chemical, and biological as shown in Fig. 1. The common materials employed in chemical stabilization are synthetic polymers, cement, lime, emulsions, synthetic resins, bitumen, and recycled waste products. Likewise, biological stabilization involves seedlings, seeds, hydro-seeding mixtures, and hydro-mulch mixtures. The strategy of stabilizing soils could be a commonly attempted strategy within the development of landing strips, stopping parcels, landfills, banks, streets, watercourse organization, horticulture, and mining locales. The type of stabilization technique that may be applied, depends on location. It may be a single strategy or a combination of the two [6].

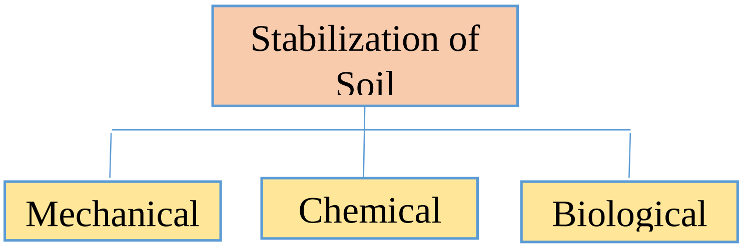

Figure 1 Stabilization Methods for Soil

1.4 Persistence for Stabilization of Soil

Stabilization makes soil more stable by decreasing the porousness, and compressibility and with increment in shear strength. It makes the soil steadier, hence upgrading the bearing capacity of the soil. For proper development and lifetime solidity, structures need a stable foundation. A constructed structure must eventually settle on the ground, dealing with the complete load of the structure. If a weak soil base is used for construction, it will eventually compact and solidify, causing the structure to settle unevenly. Structures may split as a result, which could have devastating effects. Stabilized soil achieved by different techniques should be taken into consideration in fragile soil to keep a strategic distance from uncertain problems. There are numerous reasons for soil stabilization, substituting poor soils with superior ones having more ideal building properties. Enrichment of the strength and bearing capability of the soil. Control of dust for a better working environment. Preservation of common or artificial structures by using waterproofing. To advance the utilization of waste geo-material in developments. Finally, upgrading the characteristics of the soil on location.

1.5 Toner Powder

Toner is a type of powder that is typically used with a toner cartridge for creating printed text and images in laser photocopiers. Finely ground polyester, a kind of plastic, makes up the majority of toner. Toner, as a waste product utilized in this study is presented in Fig. 2.

Figure 2 Toner Waste Product Used for Soil Stabilization

2. Literature Review - Soil Stabilization

By adding admixtures like cement, lime, fly ash, etc., we can enhance the engineering properties of soil. It is crucial to improve the soil's properties as needed, such as its bearing capacity and shear strength. Streets, rest areas, site improvement projects, airports, and a variety of other places where sub-soils are not suitable for development can all benefit from soil stabilization [6].

2.1 Toner Powder

The term "toner" refers to the powder mixture found in the toner cartridge of a copier. It is the method that enables laser printers to print. Toner, which is contained in a sizable plastic cartridge, is used by a huge number of commercial laser printers and picture copiers in office settings. The primary components of toner are fine powder and pigment, while various other additives accentuate these elements. To enhance the printed quality, the carbon was melt-mixed with a polymer. The heat from the fuser melts the toner particles, which then bond to the paper. Depending on the specific requirements of the copier, each toner cartridge has different ratios of its constituent parts. When it comes into contact with the moving drum of the copier, this incredibly thin powder, which has a consistency similar to talcum powder, acquires an electric charge. The charge is subsequently removed from the previously charged portions of the drum by the copier's laser beam, freeing up some regions of the drum for toner application. A sheet of paper that has been partially coated in toner by the drum as it rolls over it produces an image. Various mixed ingredients compose toner powder, in turn making up miniscule particles generally ranging in size from five to 15 microns a millionth of a meter around.

2.2 Plastic

The toner powder's composition is made up of heat-sensitive plastic powder particles which contribute to its 60% of composition. During the laser printing process, tiny bits of plastic melt, enabling the toner to cling to the paper and produce an image.

2.3 Iron Oxide

The Smart Computing Encyclopaedia states that iron oxide is made of toner powder which is typically about 40%. Rust is the term used to describe this reddish-brown material. This metal powder serves as a "transferor" to ensure that the toner clings to the appropriate areas on the rotating drum by assisting in the creation of the magnetic charge required to oppose the charge of the other toner powder particles. Rust is present in copier toner.

2.4 Pigment

A type of powder component called pigment is what gives the toner its color. All of the blended ingredients in toner powder are given different shades by pigment. It makes up a large portion of the base of the toner powder, together with plastic and pigment.

2.5 Types of Soil Stabilization

2.5.1 Biological Soil Stabilization

The main goal of biological soil stabilization is to control the disintegration of soil particles, and it is achieved through planting or afforestation. Compositional, morphological, physiological, and biotic root properties, play a key role in both the physical and compound development of soils, supporting the fundamental soundness of the dirt. This method is suitable for landscapes subject to the effects of water and wind, which are not implied for buildings.

2.5.2 Mechanical Soil stabilization

It is the expansion or reduction of specific soil sections to change the molecular size and pliancy of the soil to modify its actual qualities. The alteration of soil porosity and inter-particle rubbing or interlock is known as mechanical soil stabilization. Compaction is frequently used in soil adjustment and removes air gaps from the mass of soil using mechanical means so that the soil can withstand loading in this way without any additional immediate pressure. Stabilization and its impact on soil shows how implied technique affects strength, how it helps to increase and maintain soil moisture content, and how it might be used in construction methods.

2.5.3 Chemical Soil Stabilization

Chemical soil stabilization may be done by using both traditional and unconventional expertise. When compared to the most recently formed specialists, the two classes differ due to the older and more established additional ingredients. Lime, concrete, and asphalt are examples of calcium-based traditional synthetic stabilizers which have been incorporated in amounts of 3%, 5% & 7% respectively [7]. Modern synthetic resins and derived materials are examples of modern chemical soil stabilizers.

2.5.4 Lime Soil Stabilization

According to Saldanha L. et al., searching for alternatives to natural materials is crucial for a more sustainable society and pertinent to development and infrastructure projects [8]. In the above-mentioned study, a dense waste with a high calcium carbonate content, eggshells, could replace limestone. When compared to traditional limes, the results demonstrate that eggshell limes have a lesser impact on the earth's ecosystem, as two cycles (limestone quarrying and limestone improvement) have been reduced. The tensile strength and solidity of the soil were increased by the ground glass (pozzolan) that the two limes finally produced in response [9]. Amu et al., have achieved the subgrade soil stabilization by adding the lime in different percentages, however, the plasticity indices of soil samples have been decreased [10].

2.5.5 Lime & Cement Soil Stabilization

Portilinha et. al. used hydrated lime or Portland concrete to support the asphalt layers in the soil stabilization technique [11]. Their results revealed that 2% and 3% of lime or concrete expansion was adequate to alter the utility and mechanical strength of the soil. Additionally, tests confirmed that the dirt adjustment process, when used in asphalt base layers, is a significant practice with low flexible strains in the black-top layer. In 2011, Cuisinier et al. explored the effect of synthetic mixes such as nitrates, phosphates, and chlorides on soil in the presence of lime and concrete. The outcomes showed that the properties of soil are not only the function of additives but also the type of soil in which the additives were incorporated [12].

2.5.6 Waste Material Soil Stabilization

In 2021, Parthiban et al. reviewed industrial waste (such as steel slag, silica fume, and fly ash) for stabilizing weak expansive soil as a promising technique owing to an increase in strength which is also eco-friendly [13]. It was also found that geo-polymers obtained as industrial wastes are good additives for soil stabilization having nearly negligible environmental impact. Shah et al. improved the soil's strength by integrating characteristics with alum sludge [14]. The use of waste material improved the cohesive properties of the soil. It was also discovered that the strength gain was maximum at an optimal level of 8%. Alum sludge, as a soil stabilizer, facilitated the enhancement of soil strength, even at lower compaction. Gonzaga de Oliveira et al. studied the utilization of textile sludge which is a waste material for soil stabilization the limitation of this technique is if the malfunction occurs during the treatment process of sludge it may cause negative environmental impacts [15].

2.5.6 HDPE & Glass Soil Stabilization

The usage of High-Density Polyethylene (HDPE) and Glass as material stabilizers in Kuantan clayey soil stabilization was explored by Fauzi et al. The addition of HDPE and glass in the soil in different proportions resulted in the enhancement of soil stabilization [16].

2.5.7 Fly-ash Soil Stabilization

Khadka et al. used fly ash extracted from alumina-silicate with a combination of metakaolin for the stabilization of high sulfate expansive soil. The technique enhanced the swelling and shrinkage properties of high sulfate expansive soil. Of two other geo-polymers by restricting the formation of ettringite [17].

3. Resources and Approaches

3.1 Introduction

Three sites were initially selected for preliminary studies in Nandipur (District Gujranwala, Pakistan), and only two sites were adopted for the detailed investigation. Representative samples were collected for laboratory investigations. The methods of sampling and sample preparation as well as tests conducted are discussed.

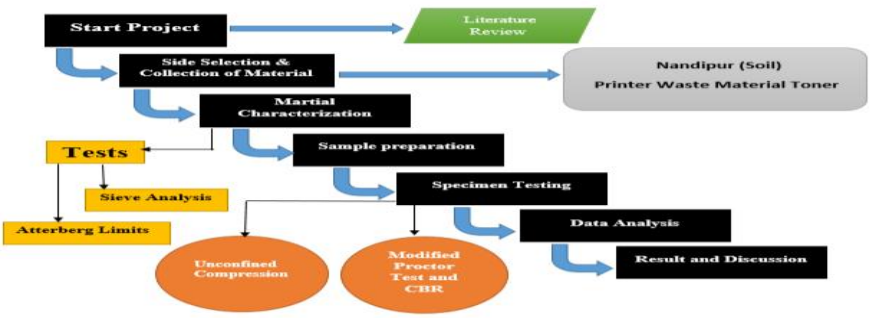

Figure 3 Research Methodology

3.2 Study Materials

3.2.1 Soil Sample Collection

The expansive soil samples (both disturbed and undisturbed) were collected from selected sites of Nandipur (Gujranwala, Pakistan) from 3m deep soil. The mentioned site is located 400 kilometres away from Multan. These soil samples were greyish-black in color and highly plastic clay.

3.2.2 Toner

Samples of locally available toner were collected from waste containers, and carefully transferred to certain locations using sealed plastic bags to avoid contamination from dust and water. The chemical composition of toner consists of granulated plastic, carbon powder, and iron oxide, however, most recent mixtures for triboelectrification showed the presence of polypropylene (a thermoplastic polymer), fumed silica (also known as pyrogenic silica), and different minerals.

3.2.3 Rating of CBR Values

The results of the CBR experiment are presented in Table 1. These results show a maximum load of 3600 kg.

Table 1 Penetration Load of CBR

Penetration of Plunger		**Standard Load**	
(mm)	(inch)	(kg)	(lbs)
2.5	0.1	1370	3000
5	0.2	2055	4530
7.5	0.3	2630	5800
10	0.4	3180	7011
12.5	0.5	3600	7937

Table 2 Rating of CBR Values

CBR (%)	**Level**	**Objective**	**System of Classification**	
			USCS Classification	**AASHTO Classification**
0-3	Very poor	Sub-grade	OH, CH, MH, OL	A5,A6,A7
3-7	Poor to fair	Sub-grade	OH, CH, MH, OL	A4,A5,A6, A7
7-20	Fair	Sub-base	OL, CL, ML, SC, SM, SP	A2,A4,A6, A7
20-50	Good	Base or Sub-base	GM, GC, SW, SC, SM, SP	A1,A-2-5,A3, A-2-6
>50	Excellent	Base	GW, GM	A1,A-2-4,A3

3.2.4 Unconfined Compression Strength:

Table 3 Typical Values of Unconfined Compression Strength of Cohesive Soil.

Type of soil	Value of Unconfined Compressive strength in kPa
Very soft	<25
Softs	25-50
Medium	50-98
Stiff	98-196
Very Stiff	196-392
Extremely Stiff	>329

4. Results and Discussions

The natural and treated/stabilized soil samples were tested independently for the different engineering parameters of the soil. In addition to the California bearing ratio (CBR), the tests also include Atterberg limits, and moisture density relationship (compaction test). The compression tests on unconfined samples cured at 1 day, 3 days, 7 days, 14 days, and 21 days were conducted. Likewise, unconfined compressive tests for uncured samples were also conducted [18].

4.1 Natural/Untreated Soil

The tests were carried out to identify the soil and determine its natural qualities. The soil is a dark greyish-black hue. The findings of the sieve study show that almost 97.11% of the soil may pass through sieve number 200, with a liquid limit of 54%, a plastic limit of 25%, and a plasticity index of 29%. The standards define a low liquid limit as less than 35%, a medium limit as between 35% and 50%, and a high limit as between 50% and 70%. As a result, the soil is classified as CH (high plastic clay) by the USCS soil classification system. The soil class that makes up our soil is A-7-5. Soils in this category are categorized as being poor materials for usage as sub-grade materials in engineering The maximum dry density for the soil is 19.45 KN/m, while the ideal moisture level is 17.6%. The UCS value for the I-day sample is 22.09 psi, 47.45 psi at 3 days, 57.85 psi at 7 days, 70.64 psi at 14 days, and 85.95 psi at 21 days of curing. Natural soil has a CBR value of 5.44 (using the 1-point technique).

4.2 Sieve Analysis

The distribution of various grain sizes affects the engineering qualities of soil. Grain size analysis provides the distribution of grain sizes, which is required for classifying the soil. As shown in Table 4, the weight retained at particle sizes 10mm, 40mm & 100mm is the highest as compared to other sieve sizes showing the fine nature of soil, similar trends can be seen in Table 5 showing the higher percentage of clay which are the finer particles as compared to gravel and sand. The graph of sieve analysis is shown in Figure 4. The type of particles (percentage) present in the soil are shown in Table 5.

Table 4 Sieve Analysis Results

Sieve no.	Sieve Size (mm)	Weight Retain (g)	Cumulative Weight Retain (g)	Percentage Retain	Percentage Passing
3/4"	19.05	0	0	0	100
4	4.75	0	0	0	100
10	2	2.35	2.35	0.58	99.42
40	0.425	3.02	5.37	1.35	98.75
100	0.15	4.23	9.6	2.4	97.6
200	0.075	1.97	11.57	2.89	97.11

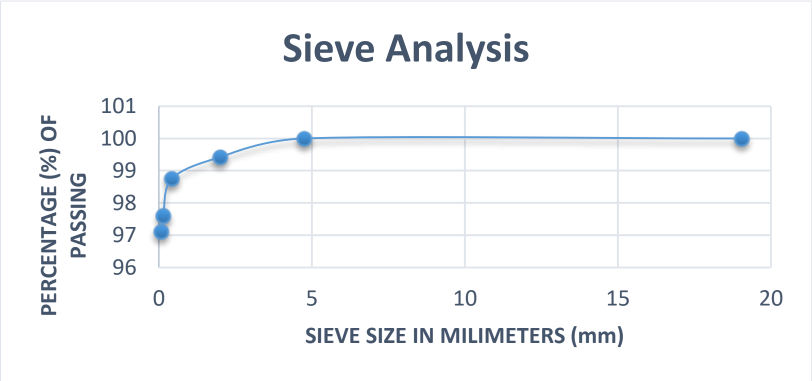

Figure 4 Sieve Analysis Graph

Table 5 Soil Type's Percentage obtained from Sieve Analysis

Gravels	Passing from Sieve # 4 and Retained on Sieve # 100	0%
Sand	Passing from Sieve # 4 and Retained on Sieve # 200	3%
Clay or Silt	Passing from Sieve # 4 and Retained on the pan.	97%

4.3 Atterberg Limits:

Only two of the seven "limits of consistency," the liquid and plastic limits, were explored in the current study due to their utmost importance in the engineering field. The moisture level of the soil affects the Atterberg. The liquid limit determines the minimum moisture content at which the soil behaves as a liquid. The shrinkage limit is the moisture content at which the soil volume will not continue to change even if the moisture content is decreased. The impact of printer waste toner on the wild soil's plasticity index whether it has been treated or not. Typically, a fairly noticeable drop is seen as the molasses content increases. The liquid limit, Plastic limit, and Plastic index of soil treated by wasted toner of the printing market have been shown in Table 6. Similarly the Liquid limit, Plastic limit, and plastic index University toner-treated soil have been shown in Table 7. The liquid limits, plastic limits, and Plasticity Indices of Soil treated by wasted toner in the printing market as well as treated by wasted toner of university printers are shown with the help of graphs in Figure 5, Figure 6 & Figure 7 respectively. These Atterberg limits show the common trends that the limits of soil treated by university wasted printers have higher values as compared to the soil treated by wasted toner of the market. This might be due to the reason that toner obtained from wasted market printers was exposed to contamination as compared to the toner obtained from university printers as a result these contamination particles have reduced the results.

Table 6 Atterberg Limits Results of Soil Treated by Wasted Toner of Printing Market

Percentage (%)	Liquid Limit	Plastic limit	Plasticity index
0%	54	28	26
2%	48	29	19
4%	46	30	16
6%	44.6	31.2	13.4
8%	43.1	30	13.1

Table 7 Atterberg Limits Results of Soil treated by Wasted Toner of University Printer

Percentage (%)	Liquid Limit	Plastic limit	Plasticity index
0%	54	28	26
2%	49.2	29.4	19.8
4%	45	30.5	14.5
6%	43	31.4	11.6
8%	42	30.1	11.9

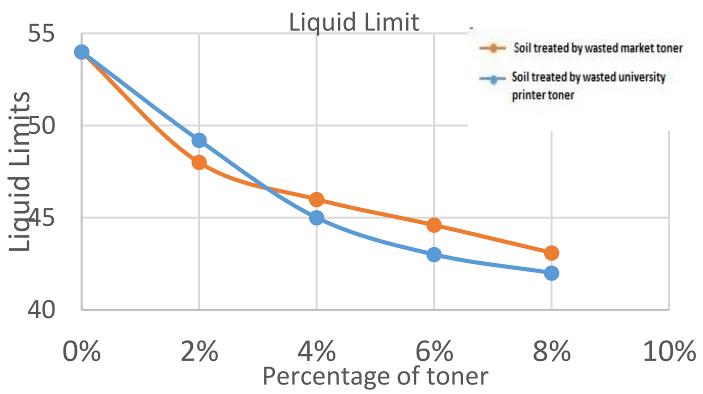

Figure 5 Liquid Limit of Soil treated by Different Toners at different Percentages

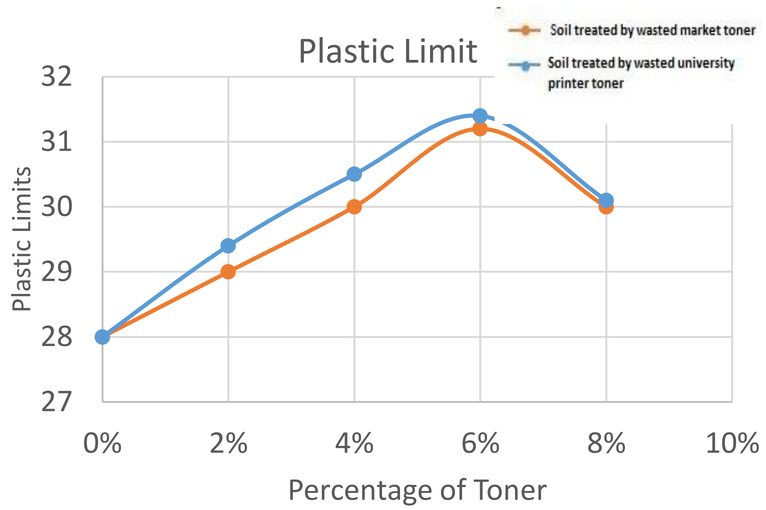

Figure 6 Plastic Limit of Soil treated by Different Toners at different Percentages

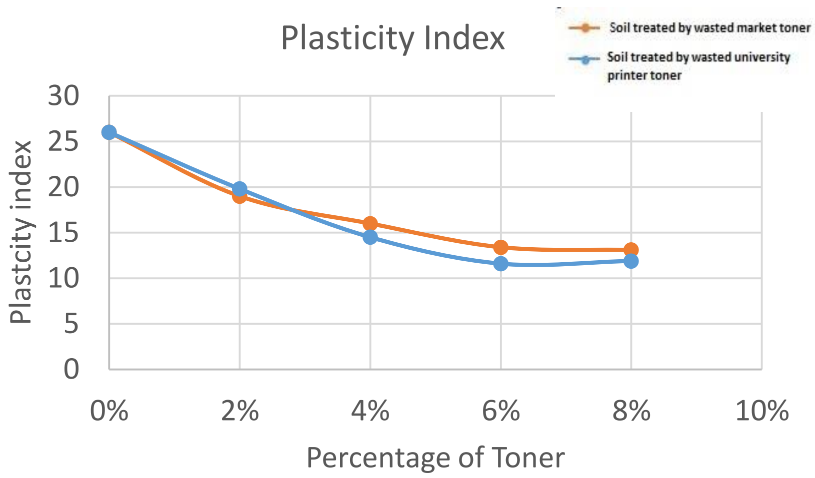

Figure 7 Plasticity Indices of Soil treated by Different Toners at different Percentages.

4.4 Modified Proctor Test:

The relationship between a soil's dry density and moisture content was investigated in the laboratory experiment. The compaction is the quantity of mechanical energy required to compact the soil mass. Numerous methods, such as tamping, kneading, vibrating, and static load compaction, are used in the field to compact soil. The Proctor test is another name for it. Two types of compaction tests are routinely performed. The first one is the Standard Proctor Test (SPT), and the second one is the Modified Proctor Test (MPT).

4.4.1 Results of MPT of Untreated Soil:

The result of MPT conducted on untreated soil has been shown in Table 8 and graphically represented in Figure 8. These values show the typical clayey soil behavior of soil.

Table 8 Bulk density and Dry density of untreated soil obtained by MPT

Sr #	Mass of MPT Mould + Mass of Moist Soil (grams)	Mass of Moist soil (grams)	Bulk Density (KN/m^3)	Dry density (KN/m^3)
1	3772	1716	16.8	15
2	3890	1823	19.1	16.4
3	3986	1930	21.3	17.5
4	4063	2007	21.1	17.2

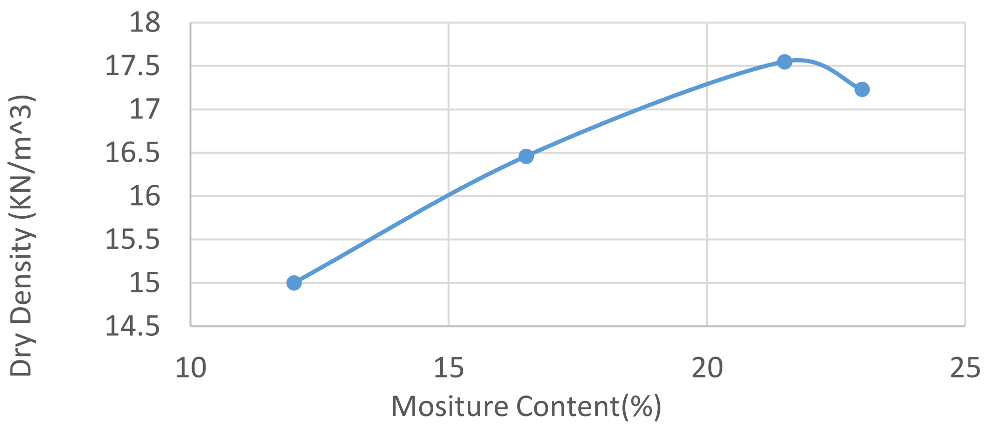

Figure 8 Dry Density of Untreated soil Vs. Moisture Content (%)

4.4.2 Result of MPT of soil at Addition of 2% toner:

On adding 2% toner to the soil the results were nearly similar to untreated soil as shown in Table 9 and graphically represented in Figure 9. So, further tests were performed after increasing the percentage concentration of toner in the soil which is discussed in the next section.

Table 9 Bulk density & Dry density of Soil with the addition of 2% Toner.

Sr #	Mass of MPT Mould + Mass of Moist Soil (grams)	Mass of Moist soil (grams)	Bulk Density (KN/m3)	Dry density (KN/m3)
1	3822	1766	17.3	15.3
2	3940	1873	19.6	16.7
3	4036	1980	21.5	17.8
4	4113	2057	21.3	17.3

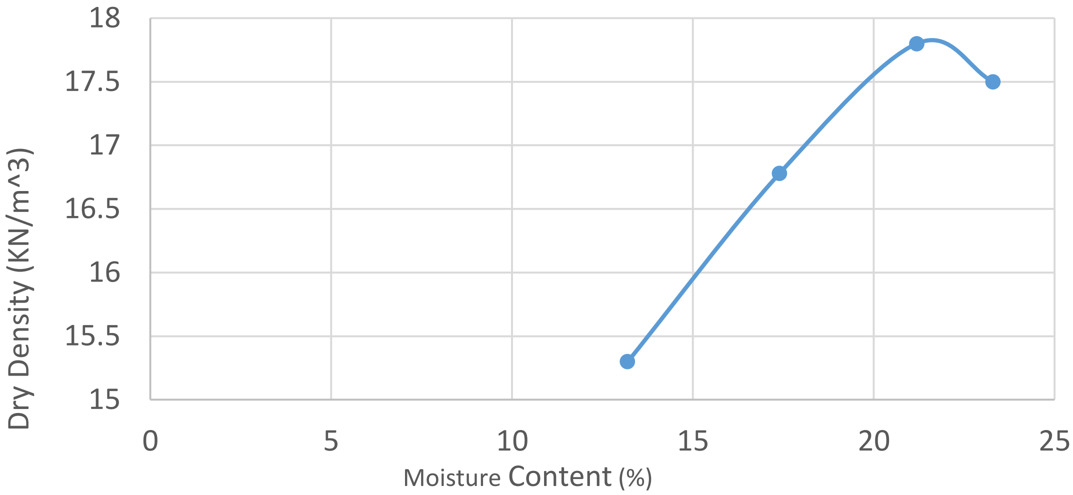

Figure 9 Dry Density of Soil treated with 2% of toner Vs. Moisture Content (%)

4.4.3 Results of MPT of the soil with the addition of 4% toner:

After the addition of toner with a concentration of 4% in soil mass, the dry density has been increased as shown in Table 10 and graphically shown in Figure 10. If we compare the maximum bulk density of untreated soil which is 21.3 KN/m^3 with the bulk density of the maximum bulk density of soil treated with 4 % toner which is 22.6 KN/m3, a slight increase in the bulk density has been observed. This slight increase in the bulk density as well as dry density of soil suggests a further increase in the concentration of toner in the soil as a promising technique. From Figure 10, it is clear that Optimum Moisture Content lies around 19.2 %.

Table 10 Bulk density & Dry density of Soil with addition of 4% Toner.

Sr #	Mass of MPT Mould + Mass of Moist Soil (grams)	Mass of Moist soil (grams)	Bulk Density (KN/m3)	Dry density (KN/m3)
1	3802	1746	18.5	16.5
2	3920	1853	21.6	18.6
3	4016	1960	22.6	19.2
4	4093	2037	22.5	18.8

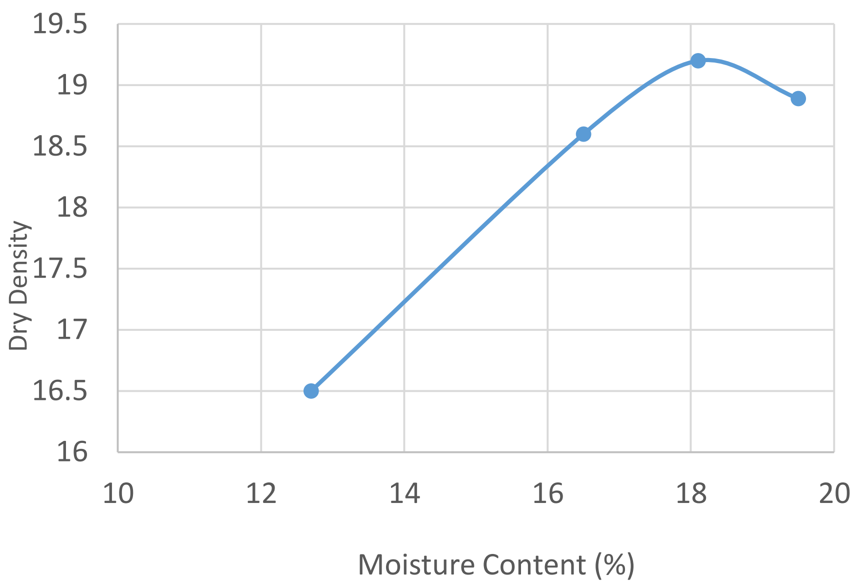

Figure 10 Dry Density of Soil treated with 4% of toner Vs. Moisture Content (%)

4.4.4 Results of MPT of the soil with the addition of 6% toner:

At a 6% concentration of toner, the maximum bulk density achieved is 21.8 KN/m3 as shown in Table 11 which is lesser than a 4% concentration of toner i.e., lesser than 22.6 KN/m3. This suggests that on further increase in the concentration of toner, the bulk density is being decreased. So, a 4% concentration of toner might be the Optimum level of concentration for soil stabilization. As indicated by Figure 11 the optimum moisture content is around 18 %.

Table 11 Bulk density & Dry density of Soil with addition of 6% Toner.

Sr #	**Mass of MPT Mould + Mass of Moist Soil (grams)**	**Mass of Moist soil (grams)**	**Bulk Density (kN/m^3)**	**Dry density (kN/m^3)**
1	3812	1756	18.1	16.3
2	3930	1863	20.5	17.8
3	4026	1970	21.8	18.1
4	4103	2047	21.5	17.5

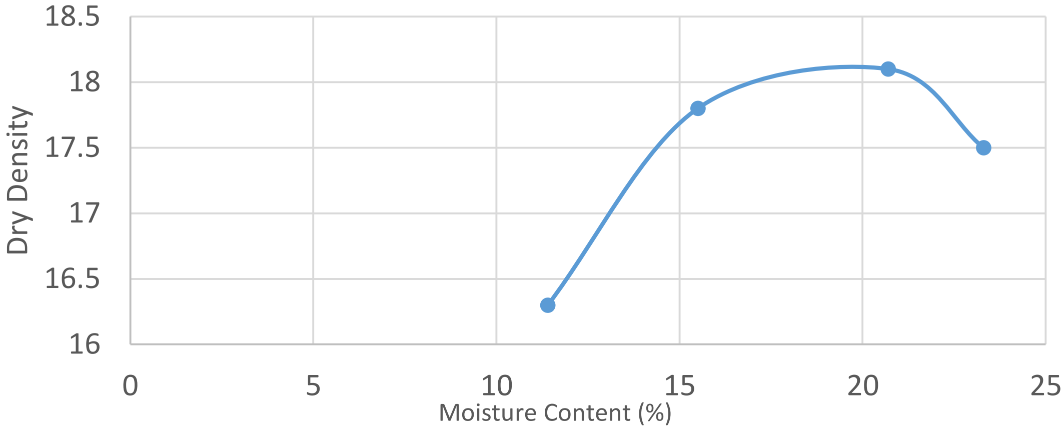

Figure 11 Dry Density of Soil treated with 6% of toner Vs. Moisture Content (%)

4.5 California Bearing Ratio

One of the most popular techniques for determining the strength of a subgrade soil, sub-base, and base course is the CBR test, which is also used to determine the thickness of highway and airport pavement. The CBR test comprises inserting a standard piston with a diameter of 50 mm (1.969 in) into the soil at a standard pace of 1.25 mm/minute. The ratio decreases, and although the force increases with penetration depth, it usually does not increase as quickly as it does for the typical crushed rock. There are times when the ratio at 5 mm is greater than that at 2.5 mm. If this occurs, the 5 mm ratio ought to be used. To determine the ideal mixture design, soil samples were subjected to the Standard Compaction and California Bearing Ratio (CBR) tests. The samples were created by combining soil samples with different stabilizer contents at the ideal water content.

4.6 CBR Test Results of Untreated Soil

Following the AASHTO-required California Bearing Ratio (CBR) test on untreated soil to determine CBR at the ideal moisture content. The detailed results are shown in Table 12 whereas these results are graphically presented in Figure 12. It is clear from the results that in untreated form, the soil was capable of supporting a maximum load of about 525 lbs.

Table 12 CBR test Values of Untreated Soil

Penetration (inch)	Gauge Reading (56 Blows)	Load (lbs.)
0	0	0
0.025	18	54
0.05	33	96
0.075	41	120

0.1	49	144
0.125	57	168
0.15	64	192
0.175	75	219
0.2	82	244
0.225	90	267
0.25	98	291
0.275	107	318
0.3	115	342
0.35	130	390
0.4	148	444
0.5	177	525

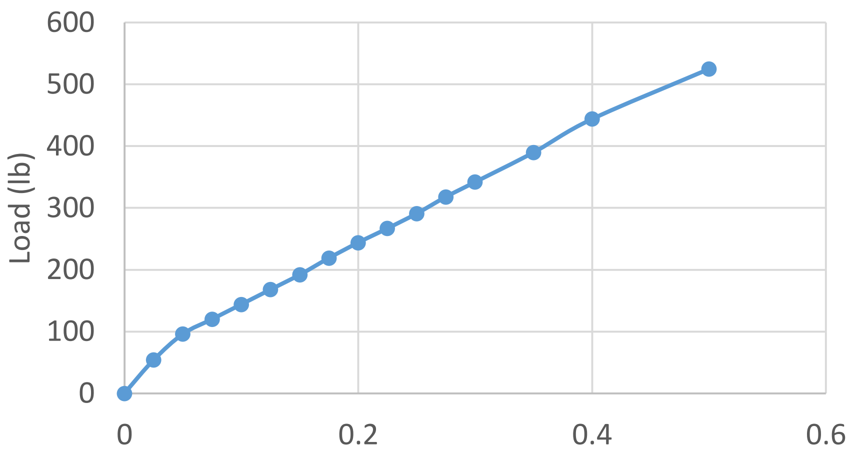

Figure 12 CBR Test Values of Untreated Soil, Load Vs. Penetration

CBR test Results of soil with the addition of 2% Toner:

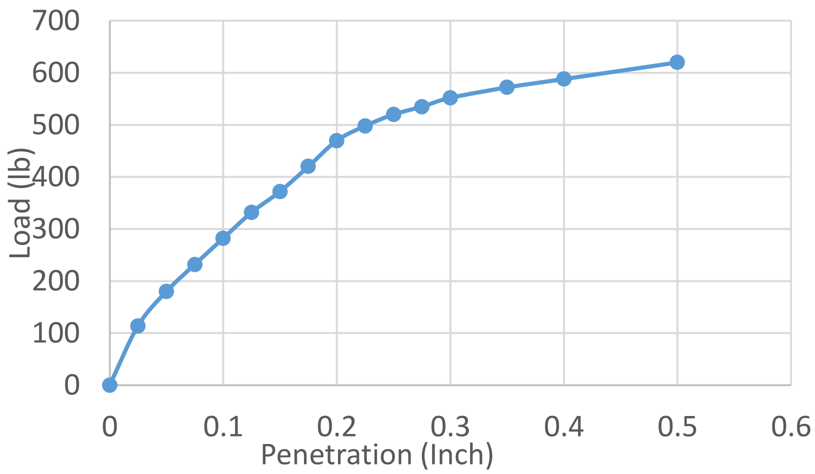

Figure 13 CBR Test Values of Soil treated with 2% toner, Load vs. Penetration

After performing the CBR test with the addition of 2% toner at the optimum moisture content according to the AASHTO standard. The results are given below in Table 13 and graphically represented in Figure 13. It can be noted that the maximum load resisted by soil is 620 lbs. which is slightly higher than the load resisted by untreated soil. This slight increase in load suggests the further increase in concentration of toner in soil could result in a further increase in resistance.

Table 13 CBR of Soil treated by 2% addition of Toner

Penetration (inch)	**Gauge Reading (56 Blows)**	**Load (lbs.)**
0	0	0
0.025	39	114
0.05	56	180
0.075	67	232
0.1	79	282
0.125	102	332
0.15	125	372
0.175	138	420
0.2	156	469.8
0.225	172	498
0.25	181	520
0.275	194	535.5
0.3	199	552
0.35	205	572
0.4	215	588
0.5	227	620

4.6.1 CBR test Results of soil with the addition of 4% Toner

After performing the CBR test with the addition of 4% toner at the optimum moisture content according to the AASHTO standard. The results are resented in Table 14 in detail and graphically shown in Figure 14. The results show the maximum load of 1178 lbs. which is far more than the maximum load resisted by untreated soil i.e., 525 lbs. It is clear from the results that a 4 % addition of toner is the optimum percentage for soil stabilization.

Table 14 CBR of Soil treated by 4% addition of Toner

Penetration (inch)	Gauge Reading (56 Blows)	Load (lbs.)
0	0	0
0.025	43	121
0.05	59	190
0.075	72	240
0.1	94	375
0.125	120	467
0.15	145	531
0.175	167	601
0.2	199	670.005
0.225	210	740.2
0.25	234	811.3
0.275	251	888
0.3	271	925
0.35	288	1012
0.4	296	1115
0.5	300	1178

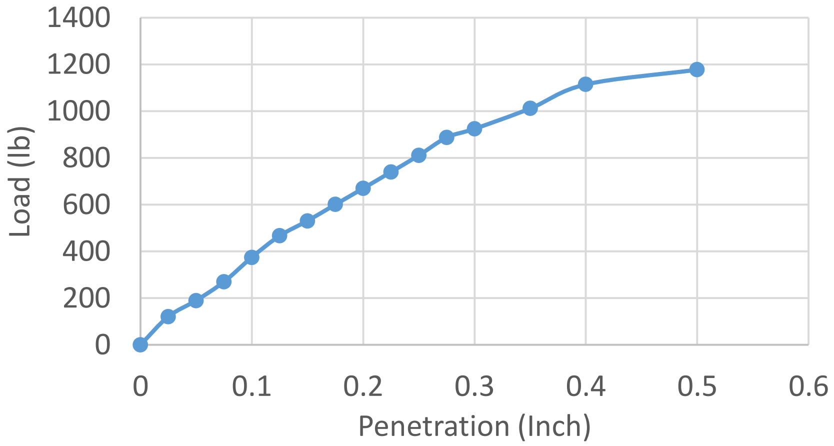

Figure 14 CBR Test Values of Soil treated with 4% toner, Load vs. Penetration

4.6.2 CBR test Results of soil with the addition of 6% Toner

After performing the CBR test with the addition of 6% toner at the optimum moisture content according to the AASHTO standard. The results are given below in Table 15 in detail and graphically represented in Figure 15. The maximum load resisted in soil is 655 lbs. which is higher in untreated soil (i.e. 525 lbs.) but lower than soil treated with 4% toner (1175 lbs.). This decrease in capacity shows that further increase may cause a drastic decrease in soil stabilization. Hence no further tests were performed by increasing the toner concentration above 6%.

Table 15 CBR of Soil treated by 6% addition of Toner

Penetration (inch)	Gauge Reading (56 Blows)	Load (lbs.)
0	0	0
0.025	18	60
0.05	33	98
0.075	41	140
0.1	49	165
0.125	57	201
0.15	64	240
0.175	75	302
0.2	82	355.05
0.225	90	398
0.25	98	445
0.275	107	522
0.3	115	578
0.35	130	609
0.4	148	640
0.5	177	655

4.6.3 Unconfined compression strength of soil at different percentages of toner

The analysis of the unconfined compression strength of soil shows a 4% concentration of toner as the optimum concentration. Above 4 % percent of toner, the unconfined compression strength started decreasing. The rate of increase and decrease in strength showed nearly similar trends in all concentrations.

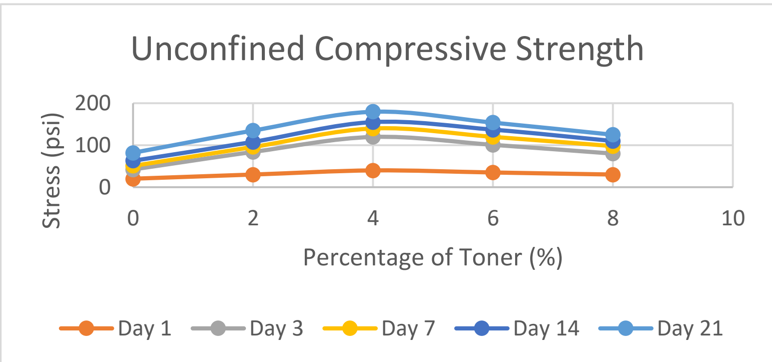

Figure 15 Unconfined compression strength Vs. Percentage of Toner

4.7 Discussion

As the percentage of toner in soil increases:

1. Liquid limit decreases, from which an increase in the CBR value can be judged.
2. The plastic limit can be increased up to a point of a specific toner percentage and then decreased if further toner is added.
3. The plasticity index decreases.
4. Decrease in Optimum Moisture content.
5. Increase in maximum dry density up to a certain point, then decrease with the addition of further toner.
6. California Bearing Ratio increases up to a specific point, then decreases with further addition of toner.
7. Unconfined compressive strength increases up to a certain point and then decreases with the addition of further toner.
8. The optimum value of toner percentage is 4%.

5. Conclusion and Recommendations

5.1 Conclusion

The subsequent conclusions are pinched based on the test results and synthesis of the research work within the scope of the study.

1. The engineering qualities of the expanding clay soil under study are not acceptable to be employed as a sub-grade and/or embankment fill material, as it can be inferred from the geotechnical test results of the natural soil unless its unfavorable properties are modified.
2. When the expanding clay soil is stabilizing, the inorganic elements, in particular the Fe2O3 that is present in the copier toner used for the study, are actively producing a chemical reaction involving cation exchange.
3. According to the PH values, adding molasses causes the slightly alkaline soil to become slightly acidic.
4. When molasses is added to soil, the CEC values increase. Since there is a direct correlation between CEC and soil LL, the same is true for LL value. The ideal stabilizer content in soils treated with Toner was found to be 4% of the dry weight of the soil. UCS and CBR strength test pick values are at this %. And the strength decreases by 6%.
5. The comparative investigation indicates that, in comparison to lime, cement has a considerably greater impact on the mechanical behavior of soil. Additionally, the samples

that had been cured for 28 days showed compressive strengths that were roughly four to six times higher than those of the untreated specimen.

6. The aforementioned instance demonstrates that to achieve the best results, the typical laboratory test techniques that disturb soil aggregation cannot be performed straight to toner-treated soils. Therefore, more precise testing methods should be developed.
7. In general, curing has little impact on the stabilized soil's engineering qualities.
8. Reduction in plasticity index with an increase in content of toner.
9. With each increase in molasses concentration, the ideal moisture content decreased and the maximum dry densities increased.
10. Toner easily dissolves in water, making it easier to apply the stabilizer during construction. The dirt particles that were flocculated and agglomerated because of a toner's adhesive characteristic, however, decomposed since it was easily washed away by water. Losses in strength resulted from the agglomeration of coarser particles, which decreased the soil's colloidal concentration and made it harder for the toner to properly mix and connect with finer particles.

    If the required precautions are taken to prevent water infiltration, Toner could be employed as a stand-alone soil stabilizer in the scenario above. For instance, it could be applied to enhance inadequate expansive subgrade and underlying sub.

1.2 Recommendations:

1. Given the minimal change and enhancement in the naturally expanding soil's engineering qualities, the toner may be used in conjunction with other stabilizers. Additionally, toner delays the cement's immediate setting, as some literature supports. Mixing with the soil promotes and improves workability. Toner can therefore be added to cement as an additive during soil stabilization.
2. Geotechnical testing should be done in carefully chosen sites of an extended soil trial section to examine the impact of seasonal fluctuation on toner and/or toner-cement-stabilized soil.

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