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ORIGINAL CONTRIBUTION

Experimental Study on the Effects of Freeze-Thaw Progressions and Performance of Soil with Non-Toxic Bio-Enzyme

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***Abstract*— The Yakhtangay (Cold Valley) in District Shangla is encountering severe freeze-thaw cycles due to its elevated location and cold weather conditions. Repeated cycles of freeze-thaw action on soil cause it to lose strength, leading to settlement and a decrease in compressive strength. The objective of the study is to investigate the potential of terrazyme in enhancing the compressive strength of soil subjected to freeze and thawing cycles. Terrazyme, a bio enzyme obtained from plants and soluble in water, can reduce the water content from the soil while increasing inter-particle cohesion, leading to improved soil strength. The laboratory tests were conducted on both treated and untreated soil samples, and their properties were compared. The experimental study also included performing tests such as grain size distribution, Atterberg's limits, compaction, and compressive strength on the soil samples. Unconfined Compression Samples (UCS) were prepared and tested for freeze and thaw cycles in treated and untreated forms. The research utilized the optimal amount of Terrazyme, reducing water moisture content from 13% to 11%. Furthermore, using Terrazyme significantly increased soil compressive strength, with an improvement of 40%. Based on the study's results, terrazyme is proposed as a highly effective soil admixture that can significantly enhance soil properties—particularly its resistance against the negative impact of freeze-thaw cycles. This study can be implicated practically to avoid freeze-thaw problems in the soil of cold regions and can be proved fruitful for the researchers to study on the particular and related topics.**

***Index Terms*— Clayey soil, Compressive strength, Freeze and thaw, Terrazyme**

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I. INTRODUCTION

The occurrence of freeze-thaw cycles (FTCs) in soil on the earth's crust is generally subjected to natural phenomena climate change, precipitation, temperature changes, etc. When temperatures regularly drop below freezing, leading to both physical and chemical alterations in materials such as soil, rocks, and concrete. Freeze-thaw can change the size and shape of soil particles, as a result increasing the soil volume and causing fragmentation and aggregation of soil mineral particles, affecting the soil structure, which, in turn, affects the soil properties [1, 2]. Generally, the movement of the soil moisture in the liquid or gaseous state is driven by the water potential of the soil during the FTC process [3, 4]. Usually, freezing occurs on the soil's surface and gradually extends downwards[5]. This process causes cracking in the soil. On the other hand, when the temperature rises, the soil moisture starts melting, resulting in swelling in the formation of empty spaces, which gradually become filled under loading and self-weight and result in thaw weakening and settlement of the soil [6]. These alternate freezing and thawing cycles affect the compressive strength of the soil. The compressive strength of soil reduces as the number of freeze and thaw cycles increases with time [7]. The variation in the soil organic matter under FTCS conditions has been affected by physical, chemical, and biological actions [8, 9]. The strength of the destructive action is related to factors such as surface freezing temperature, freezing depth, freezing duration, and winter snowfall [10, 11]. Generally, lower surface temperatures, deeper freezing depth, longer freezing duration, and larger winter snowfall make the damage more severe[12]. Therefore, for this, we are using admixture terrazyme to check the variation in the compressive strength of the soil. Terrazyme is a bio-liquid, non-toxic, non-corrosive, non-flammable natural organic material formed and extracted from vegetables and fruits [13]. It improves soil quality, such as CBR and durability while decreasing the optimum moisture content and plasticity index [14]. The effect of terrazyme on the soil is permanent and becomes a bio adjective in nature.

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The reason behind the permanent improvement in the soil properties is the catalytic exchange capacity of the clay. Terrazyme provides a protective coating around the clay particles and makes them clay particles water repellent [15]. These organic enzymes are also found in liquid form, perfectly soluble in water. The color of terrazyme is dark brownish, and it smells like molasses. In some cases, eye irritation may occur, but handling these is very easy by using glasses, while gloves and masks are typically unnecessary. The mechanism of providing terrazyme to soil is very simple. Terrazyme reacts with the water layer absorbed by soil particles, causing a decrease in their thickness. This results in reduced voids between the particles and closer orientation, leading to less compacted soil shown in Figure 01. As a result, of this process, soil's swelling capacity is reduced, and its permeability is decreased [16]. The use of Terrazyme provides a significant advantage in that it enhances soil strength and stiffness, reducing maintenance costs by 30 to 50%. Additionally, it reduces the plastic properties of the soil. The addition of Terrazyme allows for a reduction in pavement thickness by up to 30-50%, while also reducing construction time by 50% and increasing the soil's load-bearing capacity.

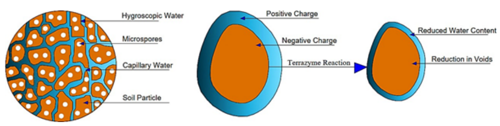

Fig. 1. Soil and water mechanism with terrazyme

Terrazymes may lose their properties if the temperature rises above 55ºC, so it is essential to keep the temperature under control [17]. This bio-organic liquid is stable, and the risk of decay becomes less or negligible. The boiling point of terrazyme is 212°, a specific gravity that ranges from 1 to 1.09, a vapor density of 1, a pH value that varies from 4.30 to 4.60, and it appears as a clear, brown liquid. The properties of treated soil depend upon the soil mineralogy, type, amount of admixture used, and compaction effort. Terrazyme was the admixture utilized in this study. A review was conducted on the stabilization of terrazyme and the various factors that can affect the mechanism of stabilization. It is understood that FTCs of clay soils can cause alterations in their volume, strength, compressibility, density, moisture content, bearing capacity, and microstructure. Freezing of soil moisture increases the volume and stiffness of soil, which results in cracking of the pavement structure. On the other hand, thawing melting of ice occurs, which results in consolidation settlement [8, 18]. Frost-susceptible soils meet the condition of frost susceptibility; that is, the particle size should be more than the limit of 3% finer than 20 mm. Frost action causes heaving in soil, which is the vertical displacement of the soil due to freezing and the freezing of soil moisture, also known as in-situ freezing [19]. There are two main types of cold regions: permafrost regions, where the soil remains frozen throughout the year, including summer, and seasonal frost regions, which experience freezing in winter and thawing in summer. Frost actionoccurs in areas where the soil is in direct contact with free water, causing the formation of ice lenses. The ice lens size depends on free water availability [20, 21]. As water temperature approaches freezing, the water molecules form a unique hexagonal structure due to the strong hydrogen bonding that develops with decreasing temperature. This hexagonal structure causes an increase in the volume of water in its frozen state [22]. Different trials were done to check the effect of freeze-thaw cycles on the shear strength of the soil. Samples were prepared by mixing illite clay with a plastic limit of 23% and a liquid limit of 57% taken from Deutschland. The water was mixed with clay until it reached a water content of 34%, a dry unit weight of 16.4 kN-m3, and a void ratio of 0.62. Each sample's unit weight was measured FTCs the cylinders were chopped to a size between 50 and 100 mm. Afterward, the sample was put into a watertight container to prevent moisture from escaping throughout the freeze-thaw cycle. A thermoelectric device supplies the temperature needed for freezing and thawing. The sample was considered frozen when the temperature was below - 2.50°C for at least 1 hour and completely thawed when the temperature reached or exceeded 30°C for 1 hour. The temperature and number of cycles were controlled automatically. The frozen samples were placed in a triaxial machine and lowered by the loading piston. The machine is filled with water at a temperature of 17°C, allowing the sample to thaw action for at least 6.5 hours. The standard method for unconsolidated undrained triaxial compression test for cohesive soil was used to determine the shear strength of the thawed sample at a pressure of 400 kPa and a loading rate of 0.1 mm-min-1. The sample exhibited softening behavior and a decrease in peak shear strength after undergoing a single freeze-thaw cycle. Following the freeze-thaw cycle, the stiffness of the sample decreased, and after the third cycle, the stiffness was reduced by approximately half when compared to an unfrozen sample. The stiffness of the sample continues to decrease until the 7th cycle when the formation stabilizes the sample and an increase in stiffness occurs. By the 20th cycle of freeze-thaw cycles, the initial behavior of the soil remains unchanged, but there is a significant increase in residual shear strength. The decrease in soil stiffness is due to structural changes in the soil. When the samples freeze slowly, they exhibit larger cracks and lensing in both horizontal and vertical directions. On the other hand, when the samples freeze faster, they show smaller cracks and lensing in both vertical and horizontal directions. The failure plane typically corresponds to the plane with the larger ice formation. The shear strength of the soil is primarily determined by the thickness of the ice lenses at freezing temperatures. Freeze-thaw cycles induce changes in soil water content, bulk density, porosity, permeability, modulus of compressibility, shear strength parameters, and other geotechnical properties [23].

Lanzhou University of Technology conducted a study utilizing soil samples extracted from the back hill, specifically excavated to a depth of 6-6.5 meters below the natural ground surface. The soil's water content and dry unit weights are 7.63% and 1.62 gcm3, respectively. The remolded loess is bound with ordinary Portland cement. The samples are prepared according to the specifications of the soil test by the Ministry of Water Resources and PRC. First of all, the wind-dried loess was crushed into powder form, and then the loess powder was shaken in a sieve with a hole diameter of 5 mm. The desired water is added to the dried soil sample to achieve the required water content. The moisture is stored overnight in an airtight container to allow it to equilibrate, and then it is packed in a mold-covered rigid jacket and tamped 20 times. Then the cylindrical specimens with a diameter of 61.8 mm and a thickness of 20 mm are prepared in cutting rings. The water content is 7.0 %, 16%, and 30%, while the cement content is 0.10 %, 2.0%, and 5.0%, respectively. The samples are covered with rubber sleeves to prevent the evaporation of water. The cutting rings filled with freeze and thaw samples are then placed in a freezing cabinet at -15 C and frozen quickly for 24 hours; then, the sample is thawed quickly for 24 hours at room temperature in a closed case. The first freeze and thaw cycle will affect the physical and mechanical properties of soil effect of bio-enzyme stabilization on the unconfined compressive strength of expansive soil. Earlier research studies show that as the number of freeze-thaw cycles increases, the compressive strength of soil decreases. Lime was used as a stabilizing agent in this research study to improve the strength of the soil. Lime stabilization is one of the older methods of improvement in civil engineering practices like footings, embankments, roadbeds, piles, etc. Most research studies show that lime-treated soil significantly increases strength and other engineering properties. The soil is exposed to a freeze-thaw cycle in cold regions at least once a year. Clayey soil exposed to freeze-thaw cycles shows volumetric change, change in strength, compressibility, densification, bearing capacity, and microstructure. During freezing conditions, the subsoil moisture forms a frozen layer, forming certain structures on micro and macro scales. The thawing phase results in the melting of the ice layers. Another research study concerns the different laboratory apparatuses used for freeze-thaw laboratory testing. The devices mostly differ based on the diameter and length of the cylindrical cell. ASTM D5918 and LTU apparatus are presented in this study comprehensively. The LTU apparatus, specially designed for freeze-thaw phenomena, is more focused in this research study. Another research study focused on the compressive strength of expansive soils, such as black cotton soils, constituting a significant portion of central India and primarily comprising

basalt. These soils usually possess high plasticity and consist of montmorillonite minerals, which are very unstable and thus result in high shrinkage and swelling. Such soils did not possess the capacity to support the loads imposed upon them for better performance of structures built upon such soils. The strength of these soils can be enhanced with bio-enzymes, which are organic substances used to improve pavement strength [24]. Terrazyme is a natural, liquid-form bio-enzyme that is nontoxic and environmentally friendly. Mixing soil with terrazyme can alter the engineering properties of the soil, and the extent of this change depends on the type and amount of terrazyme used. Terrazymes can decrease the voids between soil particles and enhance water distribution for optimal compaction. Terrazyme can work as a form protective layer that repels water and enhances the soil's weather resistance. The Unconfined Compressive Strength (UCS) test was conducted at various dosages, with curing periods of one and seven days. The results have shown that increasing the dosage of terrazyme leads to an improvement of the unconfined compressive strength by 200%. Treatment with seven days of curing results in higher strength. The optimum terrazyme, which gives the maximum UCS result, is 1 ml/5 kg of soil [21]. The research aims to investigate the changes in the compressive strength of soil caused by repeated cycles of freezing and thawing in colder regions. The research is to assess the effectiveness of terrazyme in improving and stabilizing soil properties. In addition, to compare the results obtained with terrazyme in a similar environment. Finally, to evaluate how the soil is influenced by the freeze-thaw process.

II. PROPOSED STUDY AREA

Yakhtangay (cold valley) is located in the district of Shangla, one of the top tourist attractions due to its fresh water and lush green mountains. The geographical coordinate trace between latitudes of 34, 31 to 33°, 08° N longitude, and 72, 33 to 73°, 01° E longitude. The average elevation is 3164 m above sea level, with a total area of 1586 square kilometers, shown in Fig. 2. The area receives heavy snowfall in winter. The snowfall season starts in December and continues until the end of February. The extreme temperature in the summer ranges between 25 and 38 °C, while in the winter, it drops to -2 to -5 °C, and in some locations, it drops to -10 °C [19], in addition. As a result, the area receives significant damage during harsh weather conditions, including building and infrastructure failure, soil erosion, and the formation of slippery icy snow surfaces, leading to numerous accidents. Most of the issues in the area are caused by soil or sub-grade failures and occasionally by foundation problems.

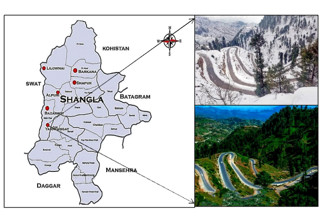

Fig. 2. Geographical location of Yakhtangay (cold valley) in the District Shangla

[25] In regions with seasonal FTCS, these cycles can change the characteristics of the soil on the surface of a slope, particularly those that affect soil stability, and heavy rainfall can greatly increase soil erosion [22, 26]. As construction activities continue to grow rapidly, it is crucial to enhance the compressive strength of soil against freeze-thaw cycles. The impact of freezing and thawing on the engineering properties of soil differs based on soil type, local climate, and site conditions [27, 28]. Therefore, a comprehensive study is needed to investigate the effect of freeze and thaw cycles on the compressive strength of soil in the treated and untreated forms. In this study, terrazyme was used to improve the compressive strength of the soil.

III. MATERIALS AND METHOD

The materials being used the details of the tests performed, and the preparations of soil specimens for the tests are discussed briefly in this section. All the tests were conducted according to the ASTM standards. The soil used in this study is clay soil with 90% fine particles. The soil samples were collected from the Yakhtangay (cold valley) district, Shangla, KP, Pakistan. The soil was collected from the area where the phenomena of freeze and thaw significantly occur. The entire testing was performed on oven-dried soil throughout the research. Preliminarily the experiment was conducted in four phases.

A. Phase 1: Properties of untreated soil

The first step in this research was to find the properties of untreated soil by performing Atterberg limits, modified proctor tests, and unconfined compression (UCS) tests. The soil was obtained from the Yakhtangay (cold valley), which was vulnerable to freezing and thawing phenomena and received significant snowfall in the winter, with temperatures dropping to -10 degrees.

1) Sieve analysis

TABLE I
RESULT OF GRADATION

S. No.	Titles	Values
1	Weight of soil sample	350gm
2	Percent passing through #200 sieve	90.92%
3	Percent retained on #200 sieve	9.08%

Sieve analysis performed according to ASTM standards. The washing method of sieving was used during the test. The main aim was to check the amount of soil passing through the No. 200 sieve.

2) After Berg's Limit

Atterberg's limits are a set of standardized tests used to determine the water content of fine-grained soils such as clay, silt, and loam. These three limits are used to classify soils into four categories: Solid (or dry) state, plastic state, liquid state, and semi-solid state (also known as the plasticity index). These limits are important in soil mechanics because they provide a measure of the consistency and compressibility of the soil. Engineers and geologists use this information to design foundations, evaluate the stability of slopes and embankments, and assess the potential for settlement or heave of structures built on the soil.

B. Phase 2: Effect of freezing and thawing cycle on untreated soil

Untreated soil can become more vulnerable to erosion, settlement, and other forms of damage because of the repeated freezing and thawing cycle. Therefore, engineering techniques like soil stabilization, such as using lime or cement, are often used to improve the performance of untreated soils in cold climates. Additionally, soils with high moisture content are more vulnerable to damage from freezing and thawing cycles than dry soils because the water in the soil can expand as it freezes, causing more significant changes to the soil's structure. Therefore, we studied in this phase; UCS tests were performed on untreated soil samples to check their behavior during freezing and thawing. The test is usually performed by loading a cylindrical.

soil sample axially at a constant rate until the sample fails or undergoes a specified deformation. The unconfined compressive strength of soil is an important parameter for geotechnical engineers because it provides information about the soil's shear strength and load-bearing capacity. The unconfined compressive strength test is relatively simple and inexpensive to perform, which makes it a popular choice for evaluating the strength of soils in the field.

C. Phase 3: Optimization of terrazyme content

Terrazyme is a type of enzyme-based soil stabilizer used in construction to improve the strength and durability of soil. Once the UCS sample was created, the soil was allowed to cure, enabling terrazyme to react fully with the soil particles. The UCS samples were tested after a week of curing to determine the maximum value that could be used moving forward. This phase of the study involved determining the appropriate amount of terrazyme to be used for enhancing the strength of the soil. The amount of terrazyme to be used in the soil sample depends upon the soil's plasticity index and Maximum Dry Density (MDD). Typically, 1 liter of terrazyme content was used for 25 to 40 m-3 of soil. Based on MDD and PI of soil samples collected from the field, the amount of terrazyme to be added is selected. A 1:100 dilution factor is used, which results in a 1.6 factor that is to be multiplied by the amount of soil taken in kg. This will give the amount of terrazyme to be used in ml. A trend was developed by testing the UCS at different factors. The selected factor was 1.6 to get the optimum terrazyme content, so UCS was conducted at different factors below and above 1.6. After performing UCS and modified proctor tests at 1.5, 1.6, 1.7, and 1.8, the optimum value was obtained at 1.7.

D. Phase 4: Properties of treated soil

Treated soil refers to soil that has been modified or stabilized using various techniques, such as the addition of chemical additives or the use of geosynthetic materials. Treated soil can offer a range of benefits over untreated soil, including increased strength, durability, and stability, as well as improved drainage and reduced settling and deformation. However, the specific properties of treated soil will depend on the treatment method used and the soil's conditions. As the optimization phase was completed, the researchers calculated the optimum amount of Terrazyme to be used. That calculated amount was further used to treat the soil for the improvement of soil properties. The UCS test was performed in this phase according to the ASTM standards. The UCS samples were made so that the calculated amount of terrazyme was dissolved in the optimum water as obtained from the modified proctor test. The dissolved terrazyme was then mixed with the soil and calculated according to the size of the mold. This phase consists of several freezes and thaw cycles, each cycle comprising 24 hours of freezing followed by 24 hours of thawing. The temperature for freezing was -10°C, and the

samples were kept at room temperature for the thawing phase. Three samples were made for each freeze and thaw cycle to obtain accurate results, and the average value was used. In this manner, twenty-one samples were treated with terrazyme and evaluated for improvements in strength while also examining the effects of minimizing freeze and thaw.

IV. RESULTS AND DISCUSSIONS

This section presents the experimental findings of various tests, including Atterberg's limits, modified compaction, and UCS, which assist in defining parameters to optimize the dosage of Terrazyme required for soil treatment. This test was carried out to determine the relationship between water content and dry unit weight. The trials were conducted as the moisture content increased. The moisture content at which maximum dry unit weight (maximum dry density) was achieved is called OMC. The MDD achieved was 116.52 lb-FTCs-3, obtained at 13% moisture content, as shown in Figure 03. The liquid limit is the amount of moisture content present in the soil. According to Atterberg's limits test results for consistency, it can be concluded that the soil sample is of low compressibility and consists of silty soil. As the moisture content increases, the number of blows/revolutions required decreases. The liquid limit value from this test is 27.5%, obtained at 25 blows of the Casagrande apparatus, as shown in Fig 3. The plastic limit is the moisture present in the soil at which a thread of soil just crumbles when rolled to a diameter of 1/8 inch. The moisture content was determined from the crumbled pieces. The moisture content obtained was 20%, which is the value of the plastic limit of the soil. It is the difference between the liquid limit and the plastic limit. The value obtained was seven. The results of the Standard Proctor test indicate that the higher the amount of terrazyme, the greater the maximum dry density and the lower the optimal moisture content.

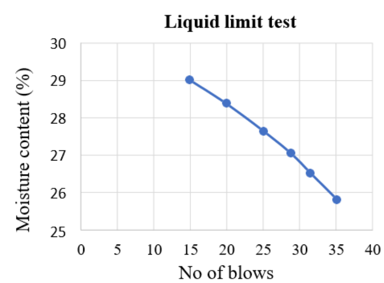

Fig. 3. Liquid limit test

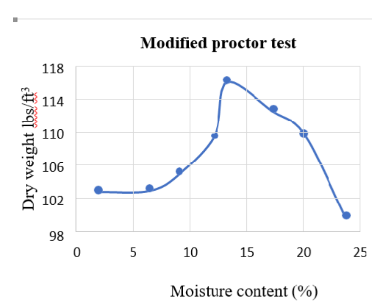

Fig. 4. Modified proctor test

1) *Unconfined Compressive Strength (UCS)*

The unconfined compressive strength of soil samples was determined in untreated form. The strength value is obtained as the load value shown by the dial gauge divided by the area of the specimen. The shear strength is also computed as half of the value of unconfined compressive strength, as shown in (Figure. 5).

A. Phase II: Effect of freeze and thaw cycles on untreated soil

The value of compressive strength against every freeze and thaw cycle was computed. Every freeze and thaw cycle continues for 24 hours with a freezing temperature of -10 degrees and a thawing temperature of 25 degrees. The compression values for every cycle are shown (F-T Cycle I to F-T Cycle IV). The graphs show the effect of freezing and thawing on the strength of the soil. Each cycle shows a decrease in compressive strength. It is obvious from the above graphs that freeze and thaw cycles on soil reduce its strength. To minimize the effect of freeze-thaw cycles, terrazyme is used for improvement.

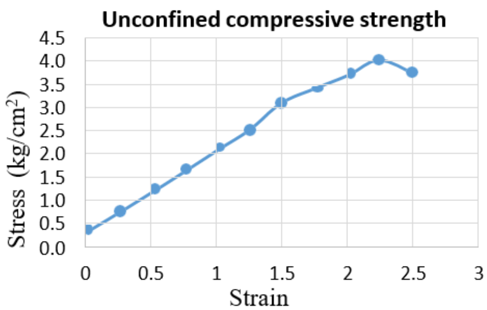

Fig. 5. Unconfined compressive strength

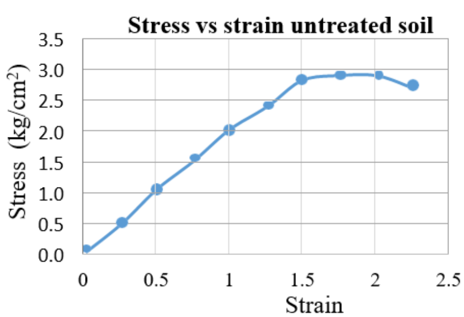

Fig. 6. Stress vs strain untreated soil (F-T Cycle - I)

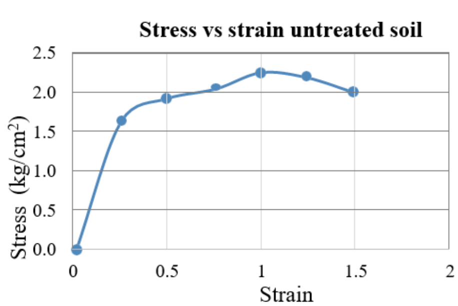

Fig. 7. Stress vs strain untreated soil(F-T Cycle-II)

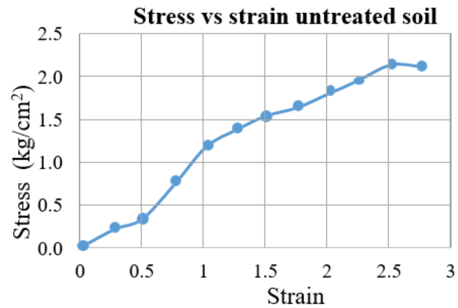

Fig. 8. Stress vs strain untreated soil(F-T Cycle-III)

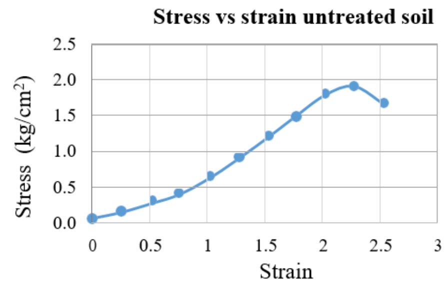

Fig. 9. Stress vs strain untreated soil(F-T Cycle-IV)

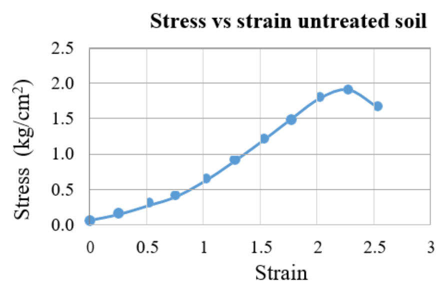

Fig. 10. Stress vs strain untreated soil(F-T Cycle-V)

B. Optimization of terrazyme content

The optimization of terrazyme content depends on several factors, including the type of soil, the desired strength and durability of the soil, and the environmental conditions of the proposed area. Typically, the goal is to achieve the maximum level of soil stabilization with the lowest possible amount of terrazyme to minimize costs and potential environmental impact. The actual amount of terrazyme used to improve strength and minimize the effect of freeze and thaw cycles is obtained by optimization of terrazyme. The optimum value to be used was selected from the tables below. The tables are based on the plasticity index and percent fines present in the soil. The volume of soil to be treated with terrazyme is selected, and based on volume and density; a factor is selected from the following tables [29, 30].

The amount of terrazyme depends upon the soil's fine content and plasticity index. (Table 2) shows the volume of soil that is to be treated with one liter of terrazyme based on the plasticity index and fines present in the soil. A factor is selected from the second table based on soil density and volume of soil per liter that is to be treated with terrazyme. The selected factor is then multiplied by the weight of soil in Kg, which will give the amount of terrazyme used.

1) Optimization for modified proctor test

A modified proctor test was conducted for the factors selected from the table.

TABLE II
TERRAZYME FACTOR AGAINST MDD AND VOLUME

Terrazyme Conc. (m3 soil) / Liter		27	28	29	30	31	32	33
	1400	2.65	2.55	2.46	2.38	2.3	2.23	2.16
	1500	2.47	2.38	2.3	2.22	2.15	2.08	2.02
	1600	2.31	2.23	2.16	2.08	2.02	1.95	1.89
Soil Density (Kg-m-3)	1700	2.18	2.1	2.03	1.96	1.9	1.84	1.78
	1800	2.06	1.98	1.92	1.85	1.79	1.74	1.68
	1900	1.95	1.88	1.81	1.75	1.7	1.64	1.59

A trend line is set around that factor to calculate maximum dry density and optimum moisture content. The factor that gives maximum values was selected for the UCS test. Modified compaction test values for different factors are shown in (Table 4).

TABLE III
OPTIMIZATION FOR MDD AND OMC DIFFERENT FACTORS

[1] S. No.	[2] Factor	[3] MDD(lb./FTCs^3)	[4] OMC (%)
[5] 1	[6] 1.5	[7] 114.63	[8] 10.43
[9] 2	[10] 1.6	[11] 116.52	[12] 11.81
[13] 3	[14] 1.7	[15] 115.04	[16] 11.06

The factor (1.6) gives maximum values for MDD and OMC, so this factor is used further for the preparation of UCS samples.

2) Optimization for UCS Test

Factor 1.6 was further optimized for UCS, and a trend line was set at different factors of terrazyme, one above and one below the selected value, to calculate the exact amount of terrazyme. The factors that give maximum strength results were further used for terrazyme amounts. (Figs. 13 to 16) show the strength values of UCS samples at different factors. The UCS samples were crushed after seven days of curing.

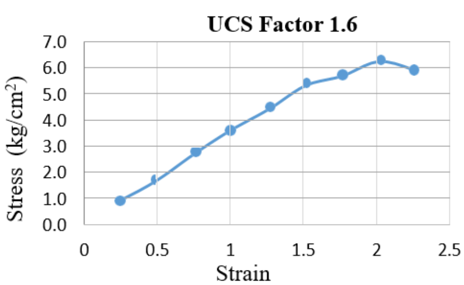

Fig. 11. UCS Factor 1.6

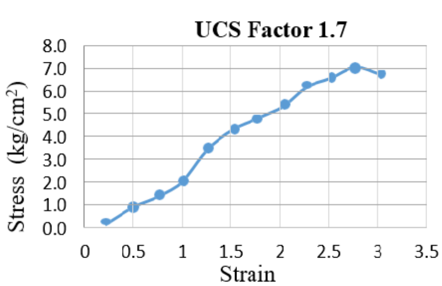

Fig. 12. UCS Factor 1.7

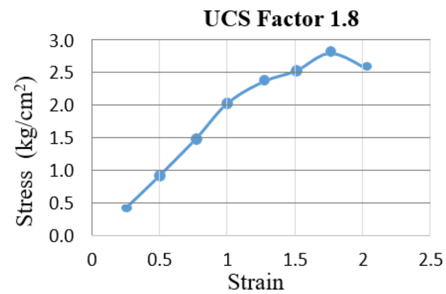

Fig. 13. UCS Factor 1.8

The maximum average value of UCS from (Table 4) against the given factor was used as the optimum amount of terrazyme. The UCS value is greater at factor 1.7, so this factor is further used for the next phases. The Figures of the UCS for different factors are given below.

TABLE IV
OPTIMIZATION FOR UCS AT DIFFERENT FACTORS

S. No.	Factor	Trial #01	Trial #02	Average value
1	1.5	6.01	5.41	5.71
2	1.6	5.75	6.78	6.26
3	1.7	6.15	7.94	7.04
4	1.8	2.43	3.15	2.79

C. Phase IV: Properties of treated soil

The soil was treated with the desired amount of terrazyme, and UCS samples were made for freeze and thaw cycles. This phase is completed in several freeze-thaw cycles, each lasting 24 hours of freezing and 24 hours of thawing at room temperature. The improvement of soil strength was determined, and each effect is shown in (Figs. 15 to 21).

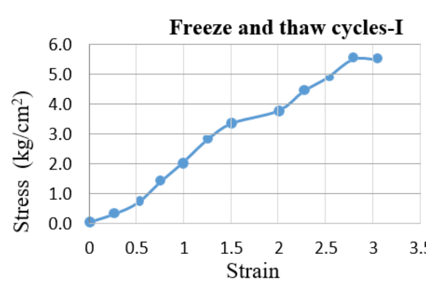

Fig. 14. Freeze and thaw cycles-I

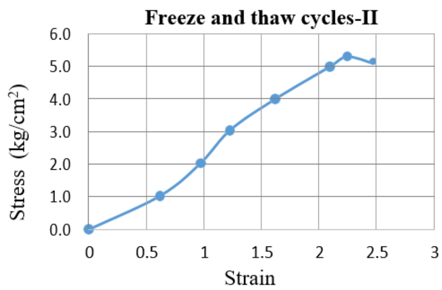

Fig. 15. Freeze and thaw cycles-II

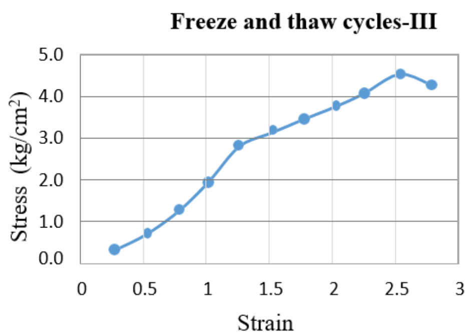

Fig. 16. Freeze and thaw cycles-III

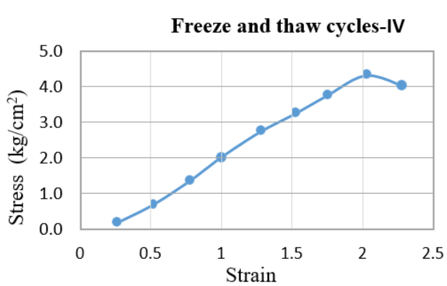

Fig. 17. Freeze and thaw cycles-IV

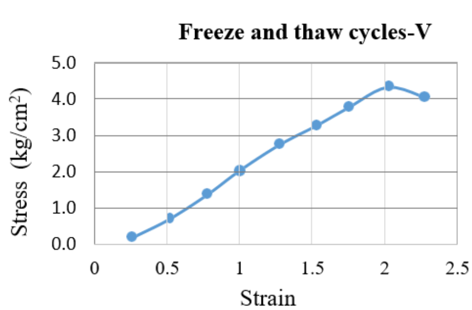

Fig. 18. Freeze and thaw cycles-V

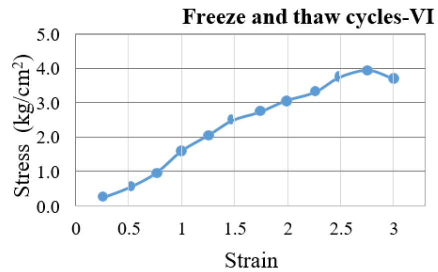

Fig. 19. Freeze and thaw cycles-VI

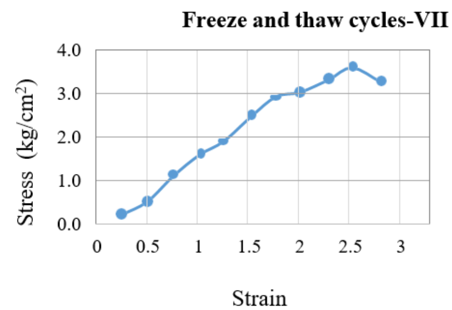

Fig. 20. Freeze and thaw cycles-VII

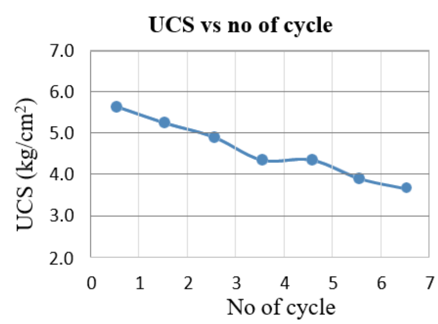

Fig. 21. UCS vs no of cycle

The selected factor is then multiplied by the weight of soil in kg to get the amount of terrazyme in ml. The optimum amount of terrazyme was treated with soil, and UCS samples were made for the freeze-thaw cycles. The treatment phase was completed in seven cycles, and each cycle comprised 24 hours of freezing at -10 degrees followed by 24 hours of thawing at room temperature. Terrazyme has several disadvantages that must be taken into consideration before using it for soil stabilization. Firstly, its chemical content can contaminate the soil and groundwater, leading to harmful effects on nearby plants and animals. Additionally, it can be expensive, especially for larger construction projects, and may not be available everywhere. Furthermore, Terrazyme is only effective in stabilizing clay soil and may not prevent soil erosion. Moreover, it requires a specific amount of time to take effect. Although Terrazyme can improve the immediate stability of soil, its long-term durability is uncertain and may not prevent long-term issues that affect soil stability, such as soil erosion. Therefore, it is important to consider all these factors before deciding whether to use Terrazyme for soil stabilization purposes.

V. CONCLUSION

The research was conducted in four stages to examine the improvement of compressive strength by using Terrazyme. The basic soil classification was carried out, and soil properties such as sieve analysis, Atterberg's limits, compaction, and compressive strength were determined. The compressive strength was evaluated after subjecting the samples to freeze-thaw cycles. The experimental results show that the compressive strength value decreases as cycles increase. The soil was subjected to seven freeze-thaw cycles, which decreased compressive strength from 3.99 kg-cm-2 to 1.53 kg-cm-2, reflecting a 38.34% decrease in strength. Therefore, terrazyme was utilized to balance the loss of strength. The modified proctor test and unconfined compressive strength were optimized through the use of Terrazyme. The maximum factor of 1.6 from the modified test was optimized for the UCS test. The final factor for the optimum amount of terrazyme addition for UCS samples was selected as 1.7. The results show that the compressive strength of the soil treated with terrazyme was improved as compared to the untreated soil. The unconfined compressive strength of treated soil was improved by 40%. Comparing both treated and untreated soil also shows that the soil, when treated with terrazyme minimizes the effect of freeze-thaw cycles on the soil compared to that of untreated soil. The results also demonstrate that the use of terrazyme led to a decrease in optimum moisture content while maximum dry density increased. The research study found that freeze-thaw activity on soil reduces its compressive strength by 38.34%. However, applying terrazyme resulted in a 40% improvement in unconfined compressive strength (UCS).

A. Future recommendation

The study can further be done by increasing or decreasing the Freeze-Thaw (F-T) cycles in the areas of colder and hotter than this particular site which could ultimately cause changes in compressive property and stress-strain graphs. The modification in the terrazyme content may bring the more positive changes.

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