Stabilization of high plastic and low plastic soil using Terrazyme®

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Abstract. Clays being expansive in nature poses a great challenge in civil engineering. When encountered with water they undergo volumetric changes; not only damaging the super structure but also experiences a sudden loss in strength leading to ultimate failure. Terrazyme an enzyme has been used to improve the strength properties and reduce swelling of high plastic clayey and low plastic clayey soil obtained from Ballewala, Nandipur, Pakistan. Hight plastic soil was made by mixing low plastic soil with 25 % of bentonite. Terrazyme increased Maximum Dry Density (MDD), California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS) and reduced the swell potential of both clays. For Atterberg limits, Liquid Limit reduced, and Plastic Limit increased for both soils. Addition of Terrazyme produced cations in soil, this decreased Cation Exchange Capacity (CEC) of soils. A significant improvement in CBR and UCS validated the successfulness of Terrazyme as a non-traditional additive for the selected soils.

1 Introduction

In civil engineering, soil plays an important role as a load bearing material. Roads, bridges, buildings, and dams etc., ultimately transfer their load to the soil. Physical and chemical properties of clay have a great impact on the life and functionality of structure constructed over it. Expansive clays have damaged many types of structures around the world, e.g, airports, highways, railways, and buildings etc. Alone in the USA it caused a damage of 2,225 million dollars per year [1]. This property of clay is greatly governed by its mineralogical composition, i.e, CEC, surface area, particle thickness, etc. Most commonly occurring clay minerals are Kaolinite, Illite, and Montmorillonite. Ground improvement is the method to improve soil properties as per the project requirement by changing its natural conditions, instead of changing the design in response to the soil natural limitations [2]. Ground improvement techniques have a very long history. About 2000 years ago lime was used in Rome for road improvement [3]. About 500 years ago Chinese made soil and lime proportions for improvement of soil as a foundation material [4]. Around 1400 BC people of Iraq used horizontal drains made up of reed to accelerate the consolidation process of soil [2]. Soil improvement is a combination of physical and chemical methods for improving the characteristics of soil when it is used as a construction material [5]. Ground improvement has been categorized into four groups which are as follows [6]:

1. Mechanical Modification. This technique purely uses mechanical methods of modification. For example, compaction, deep dynamic compaction, vibro compaction etc.
2. Hydraulic Modification. In this technique, the excess pore water is expelled out of soil usually to accelerate the process of consolidation. The main methods for hydraulic modification are PVDs, vacuum consolidation, sand columns etc.
3. Modification by Inclusion and Confinement. This type of technique uses soil reinforcement methodology to enhance its strength, e.g., are geo-grid, mesh and bars, MSE etc.
4. Chemical Modification. It is the process of physically adding and mixing certain additives in soil to enhance its properties for, e.g., bio-enzymes, lime, cement etc. The rest of the paper is organized as follows: section 2 discusses about the existing works in this field, section 3 discusses about the methods used to address the research questions. While results have been described in the section 4. Section 5 onwards, we elaborate about the related discussion and detailed around the achieved results in precise.

2 Literature review

2.1 Stabilization mechanism of Terrazyme®

Terrazyme is a patent enzyme product of NaturePlus® Inc. USA. Extracted from sugarcane and vegetable extracts, Terrazyme is nontoxic, non-corrosive and an environmental friendly soil stabilizer [7]. Terrazyme

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when applied to soil, accelerates the process of cation exchange, which in result reduces the double layer [8]. Terrazyme reacts with the adsorbed layer and reduces its thickness, causing the close orientation of particles as shown in Fig. 1 [9]. The electrical charge of water is reduced by Terrazyme, this causes other metal cations to come and adsorb on clay particle causing densification in the matrix [10]. Terrazyme causes permanent alteration in soil particles, hence even it is biodegradable, but it doesn't affect the improved properties of soil [11]. Terrazyme maintains soil moisture, improves cohesion and adds cementing properties to the soil, this also makes it water resistant [12]. It improves the mechanical benefit of compaction and creates a permanent matrix of soil which doesn't reabsorb water after proper curing [13]. Terrazyme is available in concentrated, hence dilution in water is required prior to application to the site [14].

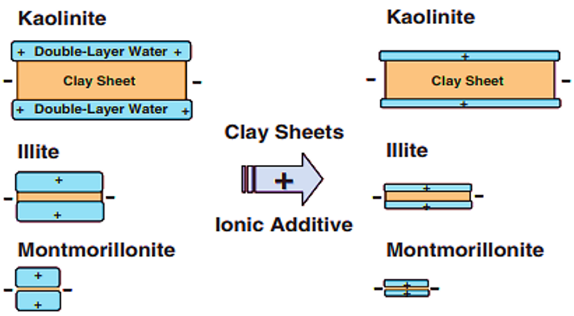

Fig. 1. Reduction in double layer after exchangable cations replaces water from clay surface [15].

2.2 Feasibility of Terrazyme®

As cations adsorb only on fine particle, hence there should be at least 10 % of clay-size fraction in soil [16]. For Liquid limit between 50 to 70 % and Plastic Limit 20 to 35, a significant improvement can be seen in soil [8]. Terrazyme works properly in slightly acidic conditions, i.e., around pH of 5-9 [7]. As enzymes are sensitive to temperature, hence the operating temperature of Terrazyme must be between 16 to 50°C [8]. In an organic solvent, it is much stable and resistive to external changes [17].

2.3 Previous works on stabilization

Findings concluded that the with addition of 30 % of Cement Klin Dust (CKD) in Sabkha soil, its MDD reduced by 4 % and Optimum Moisture Content (OMC) increased by 18 %. UCS was improved by 85 %. The soaked as improved by 177 %. Phosphoric acid was used to stabilize A-7-6 soil. It was reported that it increased the density of soil by 2 % and reduced OMC by 7 %. On addition of phosphoric acid, the UCS increased by 200 %. Addition of Terrazyme increased the shear strength of CL soil from 5.39 kPa to 27.5 kPa. Same percentage of Terrazyme increased CBR from 3.93 to 8.03 almost 104 % increase in value. Triaxial results showed that Terrazyme increased the soil cohesion by 463 %. Calcium chloride powder was used to improve the properties of high plastic clayey soil. It was observed that, addition of 15 % of additive reduced swelling and plasticity by 70 and 60 % respectively. Improvement in shear strength was around 5 %. The addition of calcium chloride increased the UCS by 50 %. Rubber tire was used to improve MDD and CBR of low plastic clayey soil. It was concluded that addition of rubber tire shred decreased OMC by 14 % and decreased MDD by 10.05 %. Highly compressible silt with grounded blast furnace slag and fly ash was stabilized. It was concluded that UCS value increased by 176 % at 28 days of curing. CBR Plus was used to improve the properties of sandy soil. A significant increase in MDD was observed with increase in OMC. The UCS value was increased by around 87 %. Renolith was used to stabilize black cotton soil, at optimum dosage it reduced the liquid limit of soil by 23.63 % and increased CBR by 627 %. An enzyme Dz-1X was used to improve CH soil. Dz-1X improved UCS from 10.8 kPa to 49.05 kPa. It increased CBR from 3.93 to 8.03. Triaxial test showed that shear strength of soil was increased by 450 %. Saw dust ash (SDA) was used to stabilized low plastic soil. It was concluded that with addition of SDA, UCS increased by 26 %, while undrained shear strength increased by 26 %.

3 Materials and methods

3.1 Soil

Low plastic soil was bought from Ballewala, near Nandipur, Pakistan. As this soil is famous for the making of cricket pitches, local people sell it, hence sample batches were obtained from a local vendor. The high plastic soil was artificially formed by mixing 25 % bentonite with low plastic soil obtained from Ballewala as shown in Fig. 3.
Fig. 2 shows the location of site. Site coordinates are as follows: Lat: 32.26638 °, Lon: 74.23570 °, EPSG: 3857.

Fig. 2. Site location map.

Fig. 3. Collection of soil sample in batches.

3.2 Terrazyme

Terrazyme was directly imported from NaturePlus® Inc.U.S.A. the bottle is shown in Fig. 4 Dosage was made by diluting 10 ml of Terrazyme in 3000 ml of distilled water making a dilution of 1:300. Dosage selection of Terrazyme is listed below:

D0 → No additive

D1 → 200 ml / 3.0 m^3

D2 → 200 ml / 2.5 m^3

D3 → 200 ml / 2.0 m^3

D4 → 200 ml / 1.5 m^3

The dosage of Terrazyme is selected by keeping Terrazyme volume constant i.e., 200 ml while changing soil volume i.e., 3.0 m^3 to 1.5 m^3.

Fig. 4. Bottle of Terrazyme.

4 Results and discussions

In this section, we provide detailed elaborations concerning our results along with the corresponding discussions that further strengthen our hypothesis. Table 1 states that the properties of untreated soils along with the indexed properties of the soils. This has provided further rigor to the results that have been later described in several Figures and corresponding comparative analysis. Table 1 Shows the properties of untreated soils.

4.1 Atterberg limits

The Atterberg limits test was done as per ASTM D 4138-10. For low plastic clay, LL was 49.6 % and PI of 27 % Fig. 5. while high plastic clay had LL of 61.9 % and PI of 31.9 % Fig. 6. It has been observed that with the addition of Terrazyme the liquid limit of CL reduced from 49.6 to 45 %, and in case of CH, the liquid limit reduced from 61.9 to 54.2 %. The loss in LL is due to replacement of double layer with exchangeable cations.

4.2 Cation exchange capacity

CEC value has been determined using correlation provided by [18].

$$CEC = e^{2.63 + 0.02LL} \quad (1)$$

With addition of Terrazyme CEC of CL decreased from 37.4 to 34.1 (meq / 100 g) Fig. 7, and for CH it decreased from 47.8 to 41.0 Fig. 8. The reason for reduction in CEC is because as Terrazyme released exchangeable cations in soil, these cations then started to adhere the soil particle, hence reducing its CEC.

Table 1.Index properties of soils.

Property		Ballewala soil	Ballewala soil +25 % bentonite
Passing # 200 (%)		96	99
Clay Size Fraction < 0.002 mm (%)		26	28
Specific Gravity (Gs)		2.67	2.70
Index category		CL	CH
AASHTO Classification		A-7-6	A-7-6
USCS Classification		Lean Clay	Fat Clay
LL (%)		49.6	61.9
PL (%)		22.6	30
PI (%)		27	31.9
MDD (g/cc)		1.84	1.80
OMC (%)		11.8	12.5
UCS (kpa)		1861.6	3151.6
CBR (%)	Soaked	2.2	1.2
	Unsoaked	3.6	15.8
CEC (meq/100g)		37.4	47.8
Swell Potential (%)		5.58	7.30

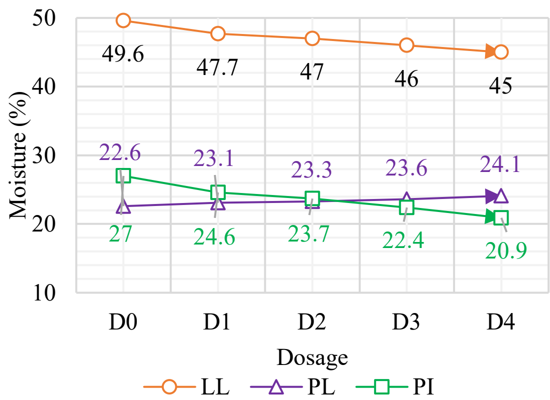

Fig. 5. Change in Atterberg Limits with addition of Terrazyme in low plastic soil.

4.3 Moisture-density relation

Modified Proctor test was done as per ASTM D 1557-12. It has been observed that in untreated form, CL has MDD of 1.84 g/cc and 11.8 % OMC Fig. 9, while CH has MDD of 1.80 g/cc and 12.5 OMC Fig. 10. For CL as the dosage of Terrazyme increased from D0 to D1 the MDD increased from 1.84 g/cc to 1.865 g/cc while

OMC increased from 11.8 % to 12.5 %, further increment in dosage i.e. D1 to D4 the MDD decreased from 1.865 g/cc to 1.824 g/cc while OMC kept on increasing. Trends are summarised in Fig. 11 and Fig. 12.

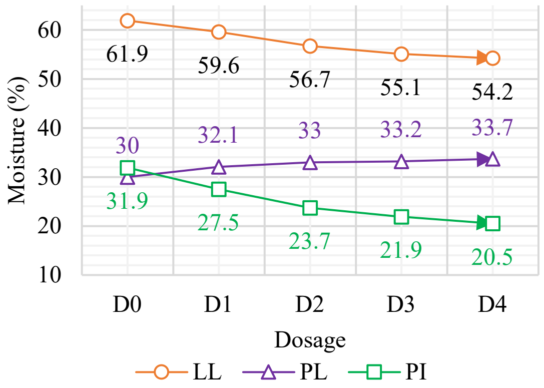

Fig. 6. Change in Atterberg Limits with addition of Terrazyme in high plastic soil.

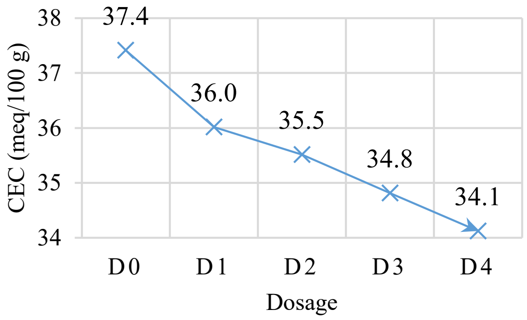

Fig. 7. Reduction in CEC of CL with addition of Terrazyme.

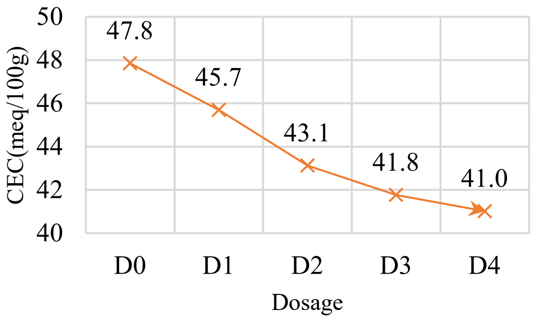

Fig. 8. Reduction in CEC of CH with addition of Terrazyme.

For CH as the dosage of Terrazyme increased from D0 to D1 the MDD increased from 1.80 g/cc to 1.825 g/cc while OMC increased from 12.5 % to 14 %, further increment in dosage i.e. D1 to D4 the MDD decreased from 1.825 g/cc to 1.78 g/cc while OMC kept on increasing, i.e, 14 % to 15 %. Trends are summarised in Fig. 11 and Fig. 12.

The optimum dosage where soil gave maximum value of MDD is D1 and D2 for CL and CH soil respectively. The increase in density is because as Terrazyme produces exchangeable cations in soil which replaces water from clay mineral and reduces double layer causing densification of soil particles.

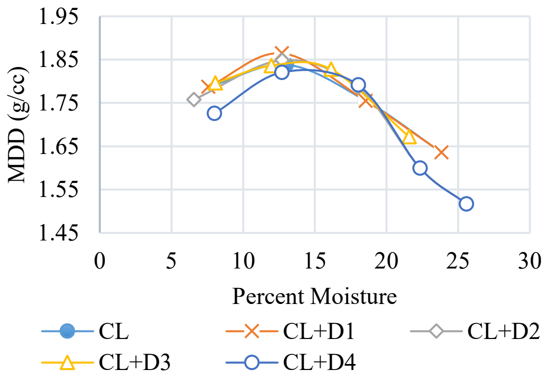

Fig. 9. Compaction curves for CL soil at all dosages of Terrazyme.

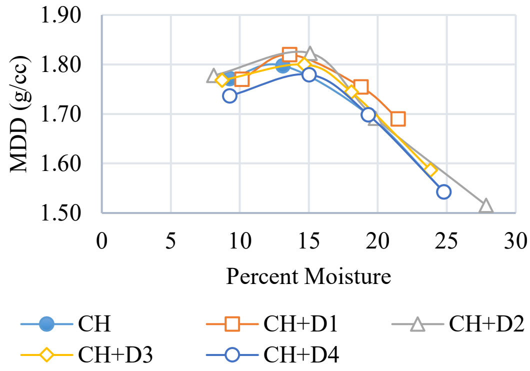

Fig. 10. Compaction curves for CH soil at all dosages of Terrazyme.

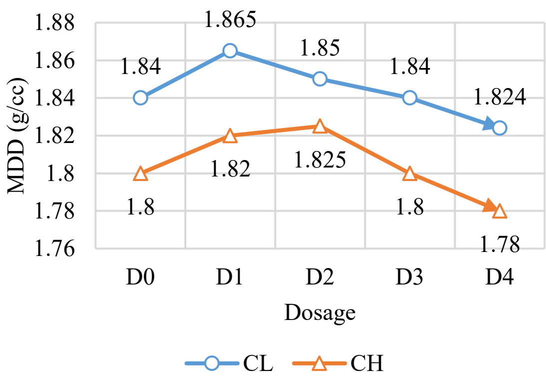

Fig. 11. Trends in MDD with addition on Terrazyme.

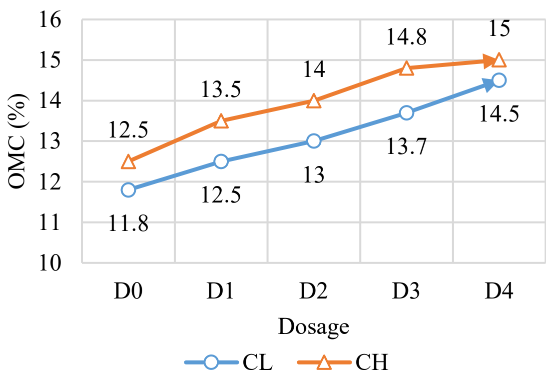

Fig. 12. Trends in OMC with addition of Terrazyme.

4.4 Unconfined compressive strength

This test was performed at 95 % of MDD and OMC of respective soil. Untreated UCS (no curing and soaking) for CL is 270 psi (1861.6 kPa) and for CH is 457.1 psi (3151.6 kPa) as shown in Fig. 13. This change in strength is due to extra cohesion in CH soil due to bentonite particles. UCS test samples were prepared for all four dosages of Terrazyme for both soils. UCS samples were wrapped and set for curing for 4 hours so enzyme could start its action. For CL, UCS increased from 270 psi (1861.6 kPa) to 465 psi (3206.1 kPa) and on further addition of Terrazyme, this value decreased to 311.4 psi (2147 kPa).

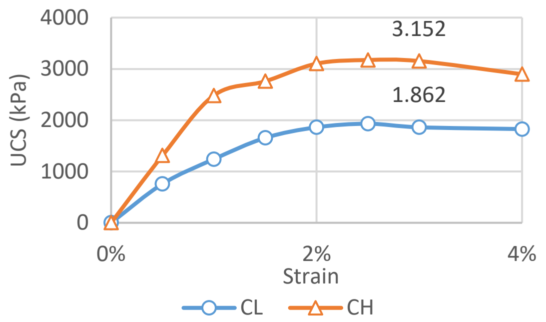

Fig.13. Stress strain curves for untreated CL and CH soil.

It has been observed that UCS values were maximum at dosage D1 and D2 for CL and CH respectively as shown in Fig.14. This is because at that dosage maximum density was obtained, moreover Terrazyme also imparts cementation between soil particles which improves UCS of soil.

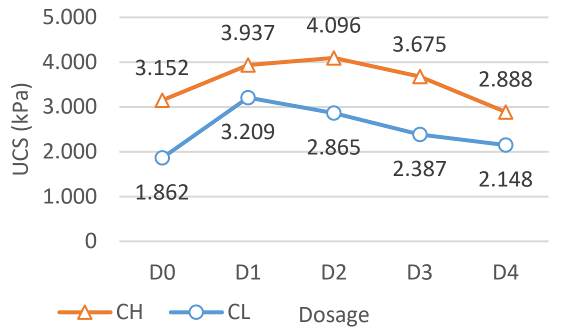

Fig. 14. Trends in UCS value with addition of Terrazyme for CL and CH soil.

4.5 California bearing ratio

CBR test was performed as per AASHTO T-193 standards. CBR for soils was tested at OMC and MDD obtained previously. For both soils soaked and unsoaked CBR was evaluated. From Fig. 15 the unsoaked CBR for CL came out to be 3.6 % while in the soaked condition it reduced to 2.2 %. For CH, CBR for unsoaked condition was 2.7 % and in the soaked condition it reduced to 1.2 % as shown in Fig. 16.

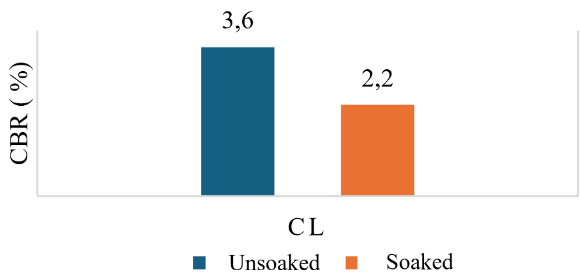

Fig. 15. Unsoaked and soaked CBR value for CL.

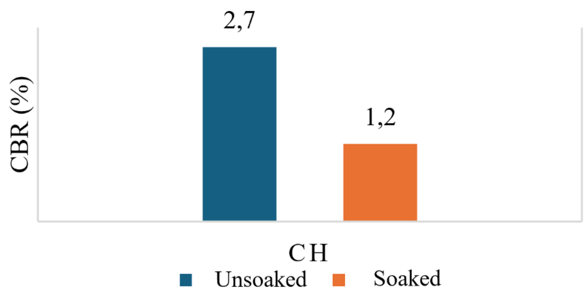

Fig. 16. Unsoaked and soaked CBR value for CH.

4.6 Swell potential

The swell potential was calculated as per AASHTO T-193 by soaking CBR samples mould in a water tank for 96 hours, the samples were subjected to surcharge load of 5.0 kg. After 96 hours the change in height to the original height of soaked sample gives the swell potential of the soil.

5 Properties of optimized soil

Modified proctor test was performed to find dosage of Terrazyme where soils gave maximum density. Base on result obtained same densities were used to carry further testing.

5.1 Unconfined compressive strength

Curing samples were prepared, wrapped in plastic wraps and cured for 2, 7, 14 and 28 days in a desiccator at 30^{o}C. For soaked conditions, samples were first cured and then soaked for 2, 7, 14 and 28 days in vacuum impregnation chamber. The process through which an enzyme spreads into a soil structure is called diffusion and is greatly governed by the difference in concentration of enzyme in different areas of soil structure [19].

5.1.1 Curing

From Fig.17 at optimum dosage of Terrazyme the first two days of curing showed a significant increase in UCS of CL soil, i.e., 270 psi (1861.6 kPa) to 522.8 psi (3645.9 kPa), afterward it increased gradually up to 786.8 psi (5424.8 kPa), 28 days of curing the strength increased with decreasing rate, showing the completion of Terrazyme action in the soil, hence no further curing was done because a significant change was not seen. For high plastic clay at optimum dosage of Terrazyme the first two days of curing showed a significant increase in UCS of soil, i.e., 457.6 psi (3155 kPa) to 643.4 psi (4436.1 kPa), afterward it increased gradually up to 1190.0 psi (8204.8 kPa) as shown in Fig. 18.

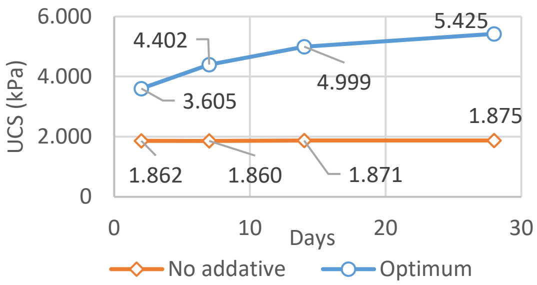

Fig. 17. Effects of curing period oer UCS of optimized and untreated CL soil.

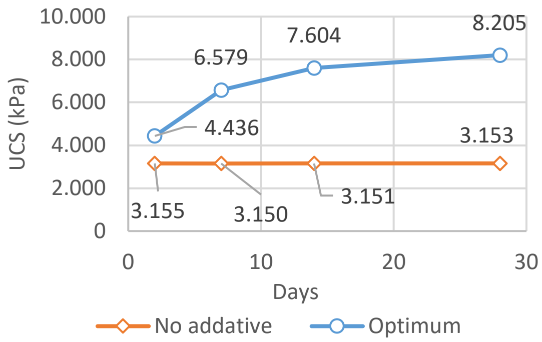

Fig. 18. Effects of curing period oer UCS of optimized and untreated CH soil.

5.1.2 Soaking

In soaked conditions soil experiences swelling, decrease in density, causing an overall loss in compressive strength of soil. To imitate these conditions untreated soil was subjected to 2 days of soaking so to compare it with stabilized soil. Samples were first cured at 2, 7, 14 and 28 days. After curing samples were un wrapped and wrapped again into cotton wire gauze and left for soaking in vacuum impregnation setup. In soaked condition soil with no additive lost its UCS after 2 days i.e., from 270 psi (1861.6 kPa) to 100 psi (689.5 kPa). At optimum dosage of Terrazyme UCS at 2 days of soaking increased from 270 psi (1861.6 kPa) to 478.7 psi (3300.5 kPa). However soaked UCS value at optimum dosage increased to 650 psi (4481.6 kPa) in 28 days as shown in Fig.19. Soaking for CH soil was done in similar way as for CL soil. In soaked condition UCS was reduced after 2 days i.e., from 457.1 psi (3151.6 kPa) to 127 psi (875.6 kPa). However soaked UCS value at optimum dosage increased to 1000 psi (6894.8 kPa) in 28 days the trend can be seen in Fig.20.

5.2 California bearing ratio

CBR value of soil greatly depends upon the density of soil. In this test, CBR mold was prepared using an optimum dosage of Terrazyme at OMC. A significant increase in CBR value has been observed. This is due to the increase in MDD with the addition of Terrazyme. Soaking is done to check the durability of stabilized soil in worst conditions.

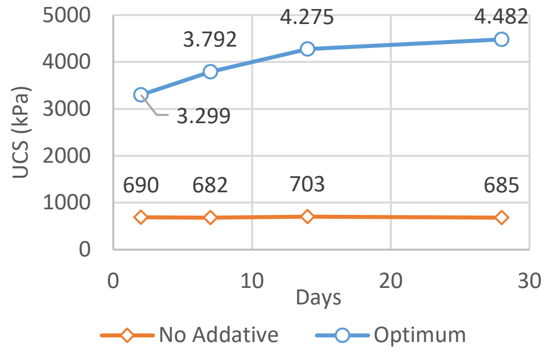

Fig. 19. Effects of soaking period over UCS of optimized and untreated CL soil.

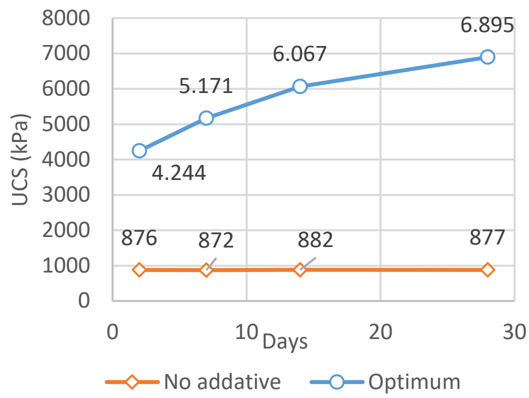

Fig. 20. Effects of soaking period over UCS of optimized and untreated CH soil.

5.2.1 Low plastic clay

At optimum dosage of Terrazyme i.e., D1, unsoaked CBR improved from 3.6 % to 11.9 % and in soaked conditions it improved from 2.2 % to 6.5 %.

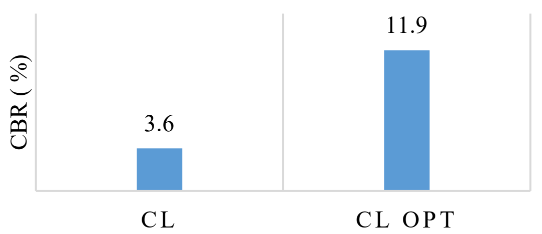

Fig. 21. Improvement in CBR with addition of optimum Terrazyme dosage in unsoaked conditions.

5.2.2 High plastic clay

At optimum dosage of Terrazyme i.e., D2 unsoaked CBR improved from 2.7 % to 10.6 % and soaked CBR improved from 1.2 % to 4.8 %.

5.3 Swell potential

A significant reduction in swell potential of both soils has been observed with the addition of Terrazyme at optimum dosage. As Terrazyme with help of exchangeable cations permanently reduces the double layer around the soil, so on the addition of water, the soil experiences reduced the amount of swelling as compared to untreated conditions. The swell potential for low plastic clay reduced from 5.58 % to 2.83 %. For high plastic clay, the swell potential decreased from 7.30 % to 4.72 %.

6 Summary of results

Below table summarizes the results obtained from testing soils at optimum dosage and with no additive at all.

Table 2. Summary of stabilized soil.

Property		Condition	CL	CH
LL (%)		No additive	49.6	61.9
		Optimum	47.7	56.7
PL (%)		No additive	22.6	30
		Optimum	23.1	33
PI (%)		No additive	27	31.9
		Optimum	24.6	23.7
MDD (g/cc)		No additive	1.84	1.80
		Optimum	1.865	1.825
OMC (%)		No additive	11.8	12.5
		Optimum	12.5	14
UCS (kPa)	28 days soaking	No additive	1861.6	3151.6
		Optimum	4481.6	6894.8
	28 days curing	No additive	1861.6	3151.6
		Optimum	5424.8	8204.8
CBR (%)	Soaked	No additive	2.2	8.8
		Optimum	6.5	12.7
	Unsoaked	No additive	3.6	15.8
		Optimum	11.9	18.8
CEC (meq/100g)		No additive	37.4	47.8
		Optimum	36.0	43.1
Swell Potential (%)		No additive	5.58	7.30
		Optimum	2.83	4.72

7 Conclusion

This study investigated Terrazyme stabilization of CL and CH soils to identify the optimum dosage for maximum improvement. Properties evaluated included Atterberg limits, UCS, CBR, compaction characteristics, and swell potential. At optimum dosage (D1 for CL, D2 for CH), MDD increased by ~1.4 % for both soils. LL and PI decreased by 3.83 % and 8.9 % (CL) and 8.4 % and 25.7 % (CH), while CEC reduced by 3.7 % and 9.8 %, respectively. UCS improved by 72 % (CL) and 30 % (CH), rising further after 28 days of curing (189.3 %; 160.2 %) and soaking (384.7 %; 686.2 %). Unsoaked CBR improved by 231 % and 293 %, soaked CBR by 195 % and 300 %, for CL and CH soils respectively. Swell potential reduced by 49 % (CL) and 35.3 % (CH).

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