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Application of bioenzymatic soil stabilization in comparison to macadam in the construction of transport infrastructure

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Abstract

Over ninety percent of roads and highways are paved with asphalt as it is less expensive, flexible and easy to construct and repair in comparison to concrete. The increasing effect of climatic change and cost of construction materials have forced to consider environment friendly methods to build roads. One economically feasible solution for achieving these objectives is use of enzyme soil stabilization. Use of bioenzymes is known to improve the stability of aggregates and soil materials in the roadways and other pavement structures. The present study was designed to introduce environment friendly TerraZyme to increase engineering qualities of soil for road construction. Soil classification and earth work characteristics were analyzed for two soil types representing pulverized local and transported soil with and without TerraZyme. Obtained results confirmed that treatment with TerraZyme increased engineering characteristics as indicated by increase in CBR values from 10.47 to 16.28 with 55 % improvement, increase of 4.28 % and 2.20 % in dry density and decrease of 18.13 % and 6.17 % in moisture content for untreated and treated soils, respectively. TerraZyme constructed roads will be effective for cost saving upto 15-20 % and maintenance cost reduction of 60 % as compared to normal water bound Macadam road.

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Introduction

For many years road engineers have used a wide variety of materials as additives for soil stabilization such as lime, cement, cement kiln dust, fly ash, sodium silicate and macadam (Thomas, 2007). The environmental hazards of using lime and lime based products for soil stabilization are alarming because these cause leaching of hazardous compounds into the groundwater (William, 1996), and also transform pH of the area highly alkaline. Water (bound macadam) as a medium allows infiltration of lime by altering the micro flora in soil and water table affects the aquatic life. Modern methods of road construction were first developed in the 18th century. Innovations from time to time included waterproof surfaces and better drainage systems. Engineers at that time used variety of materials and techniques to build roads that could handle high volumes and stress of heavy automobiles (Hindley, 1972). Bituminous pavement is cheaper and easier to construct but it requires more maintenance. Concrete pavement lasts for a very long time but is more expensive and time-consuming (Gupta, 2000). Weather and seasonal changes can cause roadways and the earth below them to rise or fall slightly. These natural phenomena cause bituminous pavements on the road surface to bend or flex slightly without breaking. Over ninety percent of all the roads and highways are paved with asphalt as it is less expensive and flexible in comparison to concrete (Kriech and Anthony, 1990). Use of asphalt where water is involved leaches hazardous compounds e.g., polynuclear aromatic hydrocarbons (PAHs) (Anthony, 1992) into the groundwater (William, 1996). Macadam in Scotland (Finch and James, 1960) was introduced as improved methods for creating roads made up of stone. Macadam's method (Harrison, 1955) stressed the need to keep the subsoil dry by including adequate drainage and waterproof covering. The decreasing availability and increasing cost of construction materials along with the uncertain economic circumstances force engineers to consider more economical methods to build roads using locally available materials, which are beyond the existing specifications. One economically feasible solution for achieving these objectives is the use of enzyme soil stabilization.

Bio-enzymes are chemical, organic and liquid concentrated substances used with increasing frequency to improve the stability of aggregates and soil materials in the roadways and other pavement structures (Jester and Thomas, 1995). Bio-enzymes application procedures are not complicated and do not require specialized equipments (Duggal, 1998). TerraZyme is non-toxic in nature and environment friendly. TerraZyme biodegrades in the soil after usage while soil retains its strength because of the alteration of the clay particles, which is permanent (Sheldon, 2000). A good road (paved or unpaved) requires a suitable foundation, which in turn requires soil stability. The degree of stability is primarily a function of the road material resistance to lateral movement or flow (U.S. Department of Transportation, 1976). Different types of road material employ different mechanisms for resisting lateral movement. In general, granular soils count on their particle sizes, angularity and interlocking ability to develop the internal friction required to resist lateral flow. However, in fine-grained soils such as clay soils, the stability is very much moisture dependent. There are many varieties of soil available for road construction. However, many of the soil deposits do not naturally possess the requisite engineering properties to serve as a good foundation material for roads and highways. As a result, soil-stabilizing additives or admixtures are used to improve the properties of less-desirable road soils (American Road Builders Association, 1976). These stabilizing agents can improve and maintain soil moisture content, increase soil particle cohesion, and serve as cementing and waterproofing agents (American Road Builders Association, 1976; Gow *et al.,* 1961). Unpaved road having dust suppressants are considered soil additives because they produce changes in soil characteristics that influence soil stabilization (Gow *et al.,* 1961; Ross and Woods, 1988). Many factors influence soil stabilization. The most notable factors are the physical and chemical properties of soil and nature of chemical additives. The stabilization effect of a soil additive is measured in terms of increase in shear strength (Kezdi, 1979) of soil-additive mixture. Petry and Little (2002) reviewed so the advances of soil stabilization over the past 60 years. Traditional (Transportation Research Board, 1987; American Concrete Institute, 1990; American Coal Ash Association, 1995) and byproduct stabilizers affect stabilization through calcium exchange, whereas non-traditional stabilizers (Santoni *et al.*, 2002) rely on hydrogen ion penetration of sulfonated oils into a clay lattice.

Pakistan, being a developing country, has an extended network of road structures used for transportation of vehicles, goods and other purposes. Total length of roads and highways in the country is 250,000 km and 8759 km respectively. However, the paved and unpaved pathways cover an area of 141,252 km and 106,559 km respectively (National Transport Research Centre, 1999). Pakistan is an agro economy based country and huge amount is invested to improve the conditions of its agricultural sector. It has modernized the old setup and improved the strength of roads, but the cost of introducing soil additives has also increased causing environmental pollution as well. So, there is an urgent need to combat with the scenario through some economical and environment - friendly methods. Sustainable development has been globally recognized under depleting non-renewable resources (petroleum, natural gas, coal, minerals, etc.), regulations for using synthetic materials, growing environmental awareness, and economic considerations (Kamm and Kamm, 2004). A balanced road performance and compliance to environmental regulations is an increasing challenge. Dust control and sediment control for roads and unpaved surfaces continue to tighten. Moreover, common amendments such as gravel and well graded soil for upgrading road structures are becoming less available and increasingly expensive.

Introduction of new technology for using liquid enzyme soil stabilizers is truly cost effective and has been used with excellent and consistent results in more than thirty countries of the world. This advancement resulted more durable roads with improved mechanical qualities of local soil. The use of soil stabilizer also permits direct application of the product to the *in situ* native material.

Compaction of aggregates near the optimum moisture content by construction equipment produces desired high densities characteristics of shale. The resulting surface has the properties of durable shale produced in a fraction of time that required millions of years by the nature. The idea of using enzyme stabilization for roads has been developed from the enzyme products used for treatment of soil to improve horticultural applications. A modification to the process produced a material, which was suitable for stabilization of poor ground for road traffic. When this material is added to a soil, the enzymes increase the wetting and bonding capacity of soil particles. The enzyme allows soil materials to become more easily wet and more densely compacted. It also improves the chemical bonding that helps to fuse the soil particles together, creating a more permanent structure that is more resistant to weathering, wear and water penetration. Wright-Fox (1993) carried out a study to assess the stabilization potential of enzymes and concluded that enzymes provide additional shear strength. However, soil stabilization with enzymes should be considered for various applications, but only on case-to-case basis (Fox *et al*., 1993).

In the light of the above, the present study was designed to introduce the environment friendly TerraZyme to increase the engineering qualities of soil for road construction. Bioenzyme was selected for the present study for the following reasons: It lowers the construction, maintenance and life cycle cost of the road infrastructure. It provides more ecological benefits in comparison to the water bound macadam. TerraZyme biodegrades in soil after usage, while the soil retains its strength. It reduces the entrance of pollutants into food cycle, as well as reduce the mining pollution. Thus, its introduction will be a environment friendly technique in Pakistan.

Materials and Methods

Sampling : Two soil samples (one meter thick) were collected from Site I (Project side of sectors I and J, principal road Phase 1) and Site II (Mechanical Pool office) of Islamabad, representing pulverized local and transported soils respectively. The two soil types were designated as A-6 and A-4, respectively. Soil classification and earth work characteristics were determined for local and transported soils with and without TerraZyme following the American Association of State Highway and Transportation official (AASHTO) standards (AASHTO M-145, ASTM D-3282) (AASHTO M-145-91, 2000 Modified) (Hogentogier and Terzaghi, 1929). Representative samples of known mass of each pulverized local and transported sieved soil were washed with water and oven dried for 24 hrs at 98°C as per ASTM D-2216 method. Each dried sample was then passed through a set of sieves numbering 4,10,40,100 and 200 having pores of 4.75 mm, 2.00 mm, 425 µm, 150 µm and 77 µm respectively (ELE International) with a pan at the bottom and lid at the top. The samples were shaken horizontally for 15 mins and the weight retained on each sieve was noted using triple beam balance.

Physico-chemical characterization of TerraZyme : Each sample was subjected to azeotropic distillation with benzene. Different fractions and the neat sample as reference were subjected to FTIR, carbon and proton NMR spectral analysis. The presence of different compounds was identified through series of TLC using different solvents like Chloroform (100%), Methanol (100%) and Chloroform: Methanol (1:1) for elution, whereas spray of sulphuric acid and iodine vapors were used as locating agents.

Compaction test (ASTM D-1557) : Dried samples of local and transported soils were placed on a glass plate of Casagrands apparatus pre-adjusted at 1 cm height for the Liquid Limit test. The soils were thoroughly mixed with distilled water until thick paste was obtained. A portion of this paste was levelled in brass cup of the apparatus and straight groove was placed in the center of the soil pat to divide it into two parts. The crank of the apparatus was rotated at a rate of 2 revolutions per second. The number of blows was counted till the two soil parts came into intimate contact.

Atterberg limit (ASTM D-4318) : A known portion of each soil type was analyzed for moisture content and plastic limit. The Plasticity Index (PI) is a measure of a soil's cohesive property and is indicative of the amount and nature of clay in the soil. PI was calculated by the following formula:

Liquid Limit – Plastic Limit = Plasticity Index

Modified proctor tests were carried out for local and transported soil with and without TerraZyme on samples passing through sieve 4. Different volumes of water were added to each soil sample to fill the compaction mold in fine equal layers. Each layer comprise of 25 blows. The mold was weiged to determine maximum dry density and optimum moisture content. The same procedure was repeated for the TerraZyme. TerraZyme (5%, 7%, 9%, 11%) diluted in water in 1:400 ratio was added to soil samples.

Expansion test (ASTM D-3877) : A direct measure of the expansive properties of soil is able to bear without serious consequence or adverse effect in soaking and swelling portion of the California Bearing Ratio (CBR) test. Oven dried samples of local and transported soils on which the modified proctor compaction test were performed were taken for CBR test. Optimum moisture content was added to the samples and CBR mould was filled in fine equal layers and each layer was compacted by applying 10, 30 and 65 blows. Moulds were soaked in water for 96 hrs after which the samples were drained for 15 minutes. The moulds were finally placed in CBR machine and reading of the load dial gauge for each 0.25 inch penetration was recorded. The same procedure was repeated for TerraZyme in water (1:400) for 10, 30 and 65 blows.

Results and Discussion

TerraZyme material safety data sheet (Mathias, 1998) identified the material as N-Zyme with none of the hazardous ingredients, fire explosion hazard and health hazard either through inhalation, skin contact or ingestion. Its boiling point is 212°F and specific gravity is 1.05. It is brown in color, not transparent and has sweet smell. TerraZyme is freely soluble in water and gives oily layer in methanol acetone and chloroform. The chemical composition shows that the enzyme produces a high concentration of protein and observations suggest that enzyme behaves like a surfactant which affects its stabilization performance.

The physico-chemical characterization of TerraZyme showed that it is an organic, non-toxic product manufactured from plant/vegetable extract. FTIR peaks showed hydroxyl groups and alkyl chain. These functional groups confirmed by carbon and proton NMR. Sieve analysis of transported and local soil showed soil passing percentage through different sieves ranges from 71.6 % - 95.5% and 96% - 99.7%, respectively (see Table 1).

It is evident that transported soil showed a wider variation of grain size distribution in comparison to local soil. A maximum decrease of 24 orders of magnitude is noted for transported soil passing through sieve # 200. According to classification of American Association of State Highway and Transportation Officials (1993), local soil was designated as clayey of A-6 type and transported soil as silty of A-4 type. Furthermore, local soil was rated as sub-grade (poor), unsuitable for road construction, whereas transported soil was rated as sub-grade (fair) and may be used for road construction having more portion of silt as compared to clay.

The bio enzymatic stabilization showed little improvement in dry density of both soils however, the increase is insignificant, especially in the case of transported soil. An average increase of 0.107 and 0.076 was observed in four samples each from local and transported soil respectively. Results of the present study are in conformation with another study conducted by Shankar *et al.* (2009). This little improvement is related to the chemical constituents of the soil, which showed low reactivity with bioenzyme. The results of Atterberg Limit test for the two soils revealed relatively higher percentage of Liquid Limit, Plastic Limit and Plasticity Index (PI) value for local soil as compared to transported soil sample.

The calculated PI was 13.11 % and 8.28 % for local and transported soils, respectively. A substantial reduction of PI in transported soil indicates an improvement in the volume change characteristics and modification of soil into more stable and workable material (www.griffinsoil.com/assets/Manual.htm). Results of modified proctor tests are graphically presented in Fig. 1.

Table 1 : Sieve analysis for local and transported soil

Sieve No.	Soil retained (g)	Soil retained (% age)	Accumulative Retained (% age)	Soil passing (g)	Soil passing (% age)
Local Soil (500 g)					
# 4	1.46	0.292	0.292	498.54	99.7
# 10	0.72	0.144	0.436	497.82	99.6
# 40	1.66	0.332	0.768	498.16	99.2
# 100	8.52	1.704	2.472	487.64	97.5
# 200	7.82	1.564	4.126	479.82	96
Transported Soil (400 g)					
# 4	19.5	4.875	4.487	380.5	95.513
# 10	1.6	0.4	4.887	378.9	95.113
# 40	17.9	4.475	9.362	361	90.638
# 100	44.5	11.125	2.487	316.5	79.513
# 200	31.7	7.925	28.412	284.8	71.588

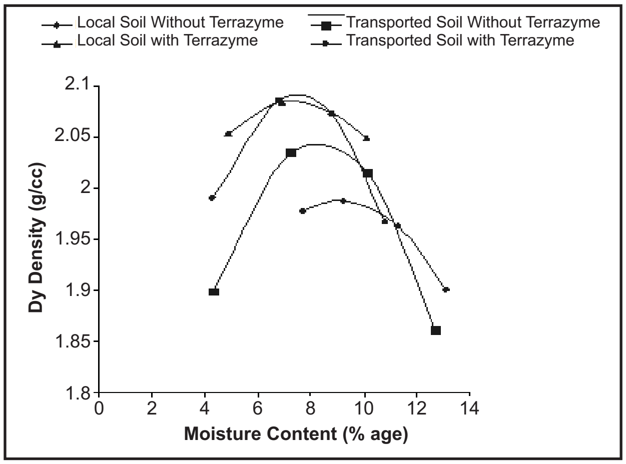

Fig. 1 : Moisture Content and maximum dry density of local and transported soil with and without TerraZyme

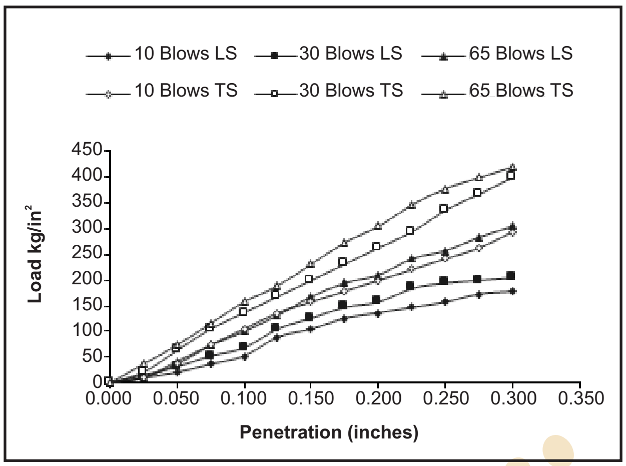

Fig. 2 : CBR Test without TerraZyme on Local and Transported Soil

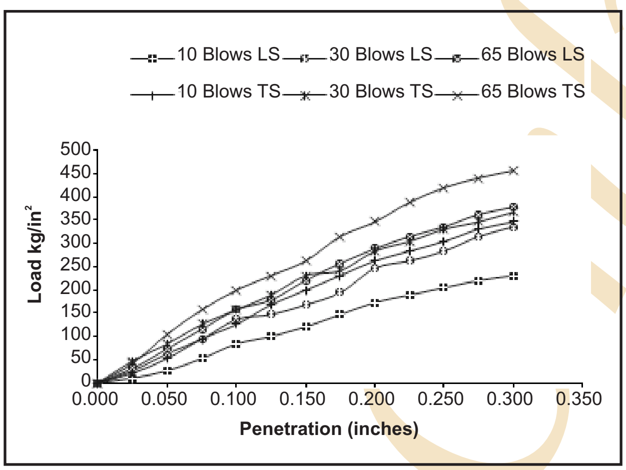

Fig. 3 : CBR Test with TerraZyme on Local and Transported Soil

Comparison of untreated and treated soils clearly showed a decrease of 18.13 % and 6.17 % in moisture content. Reduction in the degree of saturation is associated with an increase in metric suction values (Escario and Juca, 1989), leading to non-linear increase in the shear strength of unsaturated soils (Vanapalli *et al.*, 1996). The results also indicate that local soil was relatively more positively impacted by treatment with TerraZyme as compared to transported soil. The CBR tests were initially performed on the un-treated local and transported soil samples at different penetrations ranging from zero inches to 0.30 inches to determine its baseline values. The results indicated that correction in terms of treatment was required for only 0.1 inch and 0.2 inch penetration (Fig. 2 and Fig. 3).

The data showed that with increasing penetration, CBR (load in Kg in^{-2}) increased for both soils irrespective of number of blows. An increase of 109, 83, 79 and 149, 128, 105 Kg in^{-2} in load was noted for local and transported soil, respectively, that moved from 0.1 to 0.2 inch penetration However, this increase was more significant in transported soil as compared to local soil. It was also noted that less was the number of blows lower was the compaction load. A considerable increase in the CBR values was found when soil samples were treated with TerraZyme solution. So, it can be inferred that the CBR value of local and transported soil increased from 6.28 to 9.90 with an improvement in CBR of 58 % and in case of transported soil it increased from 10.47 to 16.28 with an improvement in CBR of 55 %. Hitam and Yousaf (1998) carried out a study in Malaysia on roads constructed with soil stabilization. They specified that roads that normally needed re-building several times per year have remained in excellent condition after four monsoon seasons. It can be concluded that TerraZyme increased the engineering characteristics of both silty and clayey soils rendering them suitable for road construction.

The present study also attempts to carry out the assessment of conventional material (water bound Macadam) and the TerraZyme in terms of design, machinery and material cost. The results are summarized in Table 2.

The crust thickness of TerraZyme was found significantly lower than the conventional Macadam. It may be due to the fact that the former increased the stiffness and strength parameters than the later and supports the reduced use of material in case of bio-enzyme. In addition, California Bearing Ratio and Compaction density of TerraZyme layer was higher. It may be related to the structural differences of two materials. Large molecular structures have active sites which assist bonding and interactions (Hitam and Yusof, 1998). TerraZyme has a semi rigid monolithic structure in comparison to firm surface of Macadam. The preference of

Table 2 : Comparison of conventional road with TerraZyme Road

Thickness comparison of conventional road with TerraZyme road				
Layers (5 meter wide road)	**Conventional Road**		**TerraZyme Road**	
	Thickness (mm)	**Unit (m^3) km^{-1}**	**Thickness (mm)**	**Unit (m^3)/km**
Granular Sub Base	300.00	1500.00	0.00	0.00
Granular Base	225.00	1125.00	0.00	0.00
Dense Bituminous Macadam	100.00	500.00	300.00	1500.00
TerraZyme Layer	0.00	0.00	75.00	375.00
Bituminous Concrete (mm)	60.00	300.00	30.00	150.00
Mix Seal (mm)	40.00	200.00	20.00	100.00
Total	725.00	3625.00	425.00	2125.00

Material comparison between the Conventional and TerraZyme road				
Description	**Conventional Road**		**TerraZyme Road**	
	Km (5 m wide) Volume (m^3)	**Volume (m^3) Thickness**	**Km (5 m wide) Volume (m^3)**	**Volume (m^3) Thickness**
Soil	1500.00	0.300	1500.00	0.300
Metal	1125.00	0.225	300.00	0.060
DBM	500.00	0.100	375.00	0.075
BC	300.00	0.060	150.00	0.030
MS	200.00	0.040	100.00	0.020
Total Thickness	0.725	-	0.485	

Machinery comparison between Conventional and TerraZyme road			
Description	**Unit**	**Conventional Unit km^{-1}**	**TerraZyme Unit km^{-1}**
Rotovator	Hours	0.00	16.00
Water Tanker	Hours	20.00	12.00
Grader	Hours	15.00	6.00
Roller	Hours	10.00	4.00
Labour (15 member team)	Days	5.00	2.00

TerraZyme roads is due to non-granular base and sub-base that reduce the mining cost as well. The effectiveness of TerraZyme on sub-base and sub-grade soil was also been reported earlier (Lacuoture and Gonzalez, 1995). Furthermore, less labor, less machinery and less construction time is required for TerraZyme road. A ratio of 2:5 days is accessed for construction of TerraZyme and conventional road, respectively (Table 2). Cost effectiveness of 15-20 % and reduction of 60 % in maintenance has been calculated for TerraZyme road. Enzymes have also been successfully used to stabilize roads in Malaysia, China and Western USA at low cost. The improvement in strength of soil due to bio-enzymatic stabilization is also supported by Shankar *et al.* (2009) that ensures the durability aspects and free maintenance of pavements. The use of TerraZyme for the construction of Transport Infrastructure is expected to lead a sustainable development and better environment. Several studies consider bioenzymes as environment-friendly material (Rubens and Sheldon, 1999). Its economic feasibility provides more realistic features for a stable and economical design of pavements. TerraZyme can also be successfully used for secure landfills and as dust control agent on roads rather than using PCB's oil. It is supported by the fact that compaction additives based on enzymes reduce dust (http://international enzymeslv.com/). Cumulative impact of TerraZyme is an improvement in environmental aspects controlling deforestation and possibility of minor landslides (Gray and Leiser, 1982).

TerraZyme road takes two days for construction, whereas, conventional roads need five or more days. Cost effectiveness of 15-20 % and reduction of 60 % in maintenance is calculated for TerraZyme roads. A considerable increase in CBR values of soil samples was found on treatment with Terra Zyme solution. Terra Zyme provides more ecological benefits and economic feasibility in comparison to the water bound macadam. Thus its introduction is economical and an environment friendly technique in Pakistan.

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