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EFFECTS OF AN ENZYME ON THE PERFORMANCE OF SUBGRADES

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An efficient transportation system requires a good network of roads provided with pavements that can withstand both the heavy and frequent traffic demands and environment variations while requiring minimal maintenance. However, roads are sometimes built where the sub-grade soil does not comply with the specifications and needs to be replaced with an acceptable soil that satisfies these requirements. To minimize the construction cost and the impact on the environment that the road construction would have, stabilizing agents (lime, cement or fly ash), are commonly used to improve the characteristics of in-situ soils. However, this process adds to the cost of road construction and maintenance. Therefore, alternative, environmental-friendly solutions have been investigated to reduce these costs. In recent years, enzymes have been used successfully to stabilize mostly fine-grained soils. This paper reports on an on-going research program on the use of various stabilizing agents to improve the properties of in-situ sub-grades for rural roads. Two locally-sourced soils were used in this investigation. The effects of cement, cement-fly ash mix and Perma-zyme binders on the properties of the selected soils were investigated. A series of tests was performed to establish the strength, stress-strain and deformation characteristics of the supplied soils. The results were compared to establish if Perma-zyme is suitable as stabilizing agent for the supplied soils.

Keywords: Cementing binder, Flexible pavement, Laboratory investigation, Nontraditional additive, Road foundation durability, Stabilizing agent.

1 INTRODUCTION

The economy of modern societies relies heavily on transportation. An efficient transportation system requires roads with pavements that can withstand both the heavy and frequent traffic demands and environment variations while requiring minimal maintenance. In Australia, unsealed roads are constructed to reach remote areas, due to their relative lower construction costs. These roads represent about two-thirds of the country's road network (ARRB 2009a). In Victoria, more than half (> 57%) of the total road length constructed is represented by unsealed roads (ARRB 2009b). However, only approximately 53% of these roads are formed and surfaced with a 50-mm gravel layer placed on the top of the sub-grade. To lower construction costs, local councils may use the existing subgrade soil, which is often not suitable for road construction, and marginal or non-standard materials supplied from local natural deposits (Austroads 2018). Also, the absence of a seal exposes the subgrade to the environmental conditions, leading to increased maintenance costs or premature failures. Hence, the maintenance of Australia's road network constitutes a significant portion of its budgetary spending (Stevenson 2014).

Various mechanical and chemical stabilizing methods are commonly used to improve road performance and minimize maintenance costs. While some of these methods, such as mechanical compaction and granular modification, may be less costly, they are not always efficient (Ionescu 2006). In recent times, enzymes have been used for subgrade stabilization (Agarwal and Kaur 2014, Renjith *et al.* 2017). However, the evidence to support their effectiveness is mainly based on manufacturers' claims. Since enzymes catalyze very specific chemical reactions, it is difficult to discern a general stabilization mechanism for them (Tingle *et al.* 2007). Furthermore, Milburn and Parsons (2004) reported that silty soils treated with enzymes provided no improvement in the performance of soils tested, whereas Tingle *et al.* (2007) reported significant and accelerated improvement in strength. Hence, there is a need for independent assessment of the performance of enzyme-stabilized soils. Consequently, this paper compares the effects of two traditional stabilizers and an enzyme stabilizer on two locally-sourced subgrade soils.

2 PAVEMENT REQUIREMENTS

Flexible pavements must be strong enough to support the traffic load and reduce the stress on the subgrade. Often, the in-situ subgrade does not meet the desired strength (CBR) and stiffness requirements (ARRB 2009a). Hence, chemical stabilization of the in-situ soils is carried out to improve their performance and prolong the pavement life. The type of chemical additive used depends on the percentage of fines in the surface material of the subgrade, climatic conditions, traffic volumes and construction logistics (ARRB 2012).

3 EXPERIMENTAL WORK

The physical characteristics of the materials used in this study were determined in accordance with the relevant Australian Standards (primarily AS1289 2005). The governing factors were the compliance with current specifications and the feasibility of obtaining an acceptable material.

3.1 Soils Classification

Representative soil samples were supplied from two sites in Victoria, Australia. One soil sample (S1) was sourced from Colac East, in the Colac Otway Shire, south-east Victoria. The second soil sample (S2) was obtained from Denyer's Pit, approximately 15 kilometres west of Kerang, in the Gannawarra Shire, north Victoria. Particle size distribution (PSD) plots and grading characteristics for the two materials are presented in Figure 1 and Table 1, respectively. The consistency characteristics of the soil fractions finer than 0.425 mm are summarized in Table 2. Soil S1 can be described as poorly-graded gravelly sand with non-plastic silt (SP-SM), whereas S2 is classified as a low plasticity silty sand-gravel poorly-graded mix (SM). The supplied soils have a silt content of 10-14%, and closely fit the enzyme treatment envelope, rendering them suitable for enzyme stabilization.

Table 1. Grading characteristics of the supplied materials.

Material	Particle shape	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	D_{max} (mm)	C_u	C_c
S1	sub-angular	0.07	0.75	2.6	19.0	37.1	3.1
S2	sub-rounded	0.06	0.2	2.7	63.0	45.0	0.2

Table 2. Consistency characteristics of supplied soils.

Materials	Atterberg Limits			Linear
	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Shrinkage (%)
S1	40	-	NP	0.4
S2	21	24	3	1

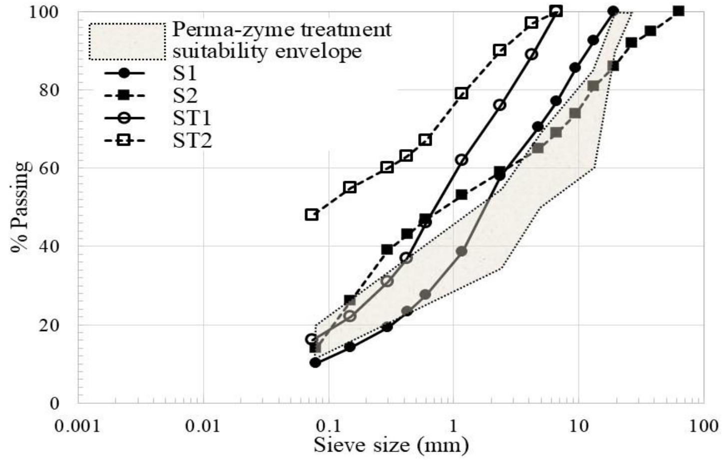

Figure 1. Particle size distributions of soils used in the current study.

3.2 Stabilizing Agents

Cement has been used to stabilize silty soils and provides the most significant improvement of any traditional stabilizer (AustStab 2011). Furthermore, cementitious blends provide satisfactory stabilization of non-plastic silty soils (Austroads 2002). Hence, for the purpose of comparisons, three stabilizing agents were used in this study, namely a cement, a cement-fly ash (50/50) blend and an enzyme (Perma-zyme). The general-purpose cement (GP), the Class F (non-self-cementing) fly ash (FA) and Perma-zyme (PZ) were locally supplied. The enzyme used is a low-energy, sustainable by-product that is non-toxic and non-flammable, and it is produced during the natural fermentation process of cane sugars and other organic compounds. This enzyme is an environmental-friendly and biodegradable natural organic compound that acts as a catalyst. It lowers the surface tension of water, which promotes fast and thorough penetration and dispersal of moisture, resulting in an increased compaction rate, as well as higher density for clays and silts.

3.3 Soil Samples Preparation

The supplied soils were oven dried at 40ºC, and then they were subjected to stabilization and left to cure at 25º C for different lengths of time, as per the manufacturer's specification (Vicroads 2012). Table 3 summarizes the soil samples used to determine the dry density-moisture content relationship.

Table 3. Soil samples used during the testing procedure.

Treatment type	Tests performed					
	Compaction test samples		CBR test samples		Triaxial test samples	
Modified PSD	No	No	No	No	Yes	Yes
None	S1	S2	S1	S2	ST1	ST2
3% cement	S1-GP	S2-GP	S1-GP	S2-GP	ST1-GP	ST2-GP
3% cement-fly ash mix	S1-GP-FA	S2-GP-FA	S1-GP-FA	S2-GP-FA	ST1-GP-FA	ST2-GP-FA
1 mL enzyme to 300 mL water	S1-EZ	S2-EZ	S1-EZ	S2-EZ	ST1-EZ	ST2-EZ

A standard triaxial cell was used for the CU tests. The sample size ratio is defined as the diameter of the triaxial specimen (38 mm) divided by the maximum particle dimension. It has been argued that the sample size effects become negligible as the sample size ratio approaches six (Marachi *et al.* 1972, Ionescu 2004). Hence, parallel gradations to the PSD of the supplied soils were used for the triaxial specimens. These gradations, PT1 and PT2, shown in Figure 1, have a have a maximum particle dimension of 6.7 mm and a corresponding sample size ratio of 5.7. Prior to testing, the soil samples were subjected to treatment in the same manner as for the compaction tests. The list of soil samples used during the CU triaxial tests is summarized in Table 3.

4 RESULTS AND DISCUSSION

4.1 Effect of the Additives on Compaction

Standard compaction curves are presented in Figure 2. Soil S2, having a larger number of fractions, attained better compaction at a lower moisture content when compared with the compaction results for soil S1. The untreated soils achieved a maximum dry density (MDD) of 1.73 t/m^3 at an optimum moisture content (OMC) of 12% for S1, whereas S2 achieved a higher MDD (1.86 t/m^3) at a lower OMC (11%). The results of the compaction tests summarized in Table 4 fall in the typical range for non-plastic/low plasticity silty sand-gravel poorly-graded soils. Overall, independent of the soil used, the stabilized soil required more water (9% to 40%) to reach the MDD, although the increase in MMD was insignificant. Cement stabilization produced the best result for soil S1 (MDD = 1.76 t/m^3, OMC = 17%), closely followed by the cement-fly ash mix stabilization. There was no improvement in the MMD for S1 treated with the enzyme. However, a 33% higher moisture content was required to achieve the MDD. Enzyme stabilization resulted in slightly larger compaction for soil S2 at the same OMC, whereas the cement and cement-fly ash blend stabilization produced similar results as for the compaction of the untreated soil. These results contrast to some extent with the expected results, e.g., a lower OMC for enzyme treated soils. Also, the overall improvement of the compaction of the supplied soils due to the additives is insignificant, and more water was required for compaction. These findings agree with Milburn and Parsons (2004), who reached inconclusive results for enzyme-stabilized soils.

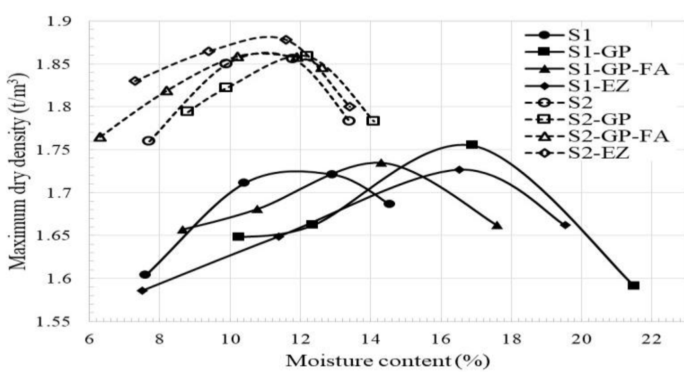

Figure 2. Maximum dry density-moisture content relationship for untreated and treated soils.

4.2 Effect of the Additives on Shear Strength

The shear strength characteristics of the naturally occurring and treated soils were estimated from a series of consolidated undrained (CU) triaxial tests. Constant confining pressures of 100, 200 and 400 kPa were used at a strain rate of 0.02%/s. The triaxial test specimens were prepared at the OMC estimated from the compaction tests. During the preparation of the specimens, a split cylinder was used to support the silicone membrane. The material was placed inside the cylinder in five lifts, with each lift being subjected to a predetermined number of blows from a tamping hammer to achieve the MDD. The relative compaction attained using this method was 95-98% of the MDD. A summary of the physical characteristics of the triaxial test specimens is presented in Table 5. The porosity of the triaxial test specimens was around 33-34% (e_o = 0.5-0.52), and the specimens classified as medium dense (35% < ID < 65%), based on the relative density estimated for the compaction level assumed.

Table 4. Compaction results for the naturally occurring and treated soils.

Parameter	**S1**	**S1-GP**	**S1-GP-FA**	**S1-EZ**	**S2**	**S2-GP**	**S2-GP-FA**	**S2-EZ**
MDD (t/m^3)	1.73	1.76	1.74	1.73	1.86	1.86	1.86	1.88
OMC (%)	12	17	14	16	11	12	11	11

The critical state friction angle (ϕ'_{cs}) was back-calculated using Bolton’s (1986) dilatancy index and its values are summarized in Table 5. Soil ST1 stabilized with cement-fly ash blend (ST1-GP-FA) displayed the highest values for the critical state friction angle, with about 10% improvement of the shear strength of untreated soil ST1. Stabilization with cement and enzyme of soil ST1 resulted in 5-15% lower values for ϕ'_{cs}. Soil ST2 stabilized with cement (ST1-GP) displayed the highest values for the critical state friction angle, with about 11% improvement in the shear strength of untreated soil ST2, followed by soil stabilized with cement-fly ash blend (ST2-GP-FA) with only a 4% increase in ϕ'_{cs}. Stabilization with the enzyme of soil ST2 produced a 3% decrease in the ϕ'_{cs} value. This correlates well with the degree of packing for the two soils and the Milburn and Parsons (2004) findings from triaxial tests on enzyme-stabilized soils.

Table 5. Triaxial test specimen characteristics and results for the naturally occurring and treated soils.

Parameter	**ρ_d (t/m^3)**	**ρ_{bd} (t/m^3)**	**S (%)**	**e_o**	**I_D (%)**	**ϕ'_{cs} (°)**
ST1	1.73	2.6	82.0	0.51	57.8	34.8
ST1-GP	1.74	2.6	83.7	0.50	64.7	33.2
ST1-GP-FA	1.73	2.6	83.3	0.50	63.4	38.2
ST1-EZ	1.71	2.6	90.0	0.52	50.4	29.8
ST2	1.76	2.65	84.1	0.50	44.1	27.2
ST2-GP	1.75	2.65	83.0	0.51	39.3	30.2
ST2-GP-FA	1.76	2.65	84.2	0.50	44.4	28.5
ST2-EZ	1.77	2.65	84.8	0.50	46.7	26.3

Note: ρ_{bd} = density of oven dried particle

5 CONCLUSIONS

The effects of different stabilizing agents on the performance of two sub-grades were presented in this paper. The effect of stabilizing agents on the compaction performance was minimal, although it seems that the stabilized soils are less sensitive to changes in water content. There was not a definite trend regarding the shear strength of the stabilized soils. It appears that the cementing additives increase the shear strength of the tested soils, although the effect is not the same for each soil. Despite the lower cost for the enzyme, it appears that the enzyme did not improve the performance of the studied soils. These results agree with some past research, although they contradict other results. It is believed that the curing time specified by the manufacturer is far too short, and longer curing time may be required to achieve better performance. Moreover, the change in the PSDs of the soil used in the triaxial tests may not be representative of the gradation of naturally-occurring soils.

Further investigation is required to evaluate the effects of the selected stabilizing agents for longer curing times. In addition, large-scale triaxial cells may need to be used during the testing program to better evaluate the shear strength of the supplied soils.

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