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Resilient Response of Mechanical-Cement Stabilized Laterite Gravel

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Abstract. Rapid economic growth is leading to ubiquitous expansion in highway projects around the world. Utilization of natural aggregate resources for the construction of flexible pavement has led to uncontrollable quarrying in the state of Kerala, India. The recent landslides in Kerala is the aftermath of extensive quarrying activities. Utilization of treated native soil in the subbase and base layers of flexible pavement can widely avert the danger associated with ecological imbalance due to quarrying. In this study, engineering properties of mechanical-cement stabilized laterite gravel were investigated for their effective utilization as a subbase course material in flexible pavements. The effects of cement content and the curing period on the resilient modulus and permanent strain of laterite gravel-stone chips-cement (LSC) mixes were investigated. A mix of 70% laterite gravel + 30% stone ships stabilized with 7% cement was obtained as the optimum mix. The optimum LSC mix with a 28-day curing period exhibited 55% higher resilient modulus and 78% lower permanent strain than the conventional granular subbase (GSB). On the basis of finite element analyses of flexible pavement, it was found that the pavement with optimum LSC mix in subbase exhibited a design life ratio of 1.13 and 1.29 with respect to that of pavement with conventional granular subbase corresponding to rutting and fatigue failure criteria.

Keywords: Laterite soil, cement, unconfined compressive strength, resilient modulus, California bearing ratio.

1 Introduction

The depletion of natural aggregate resources triggered new technologies for the implementation of marginal materials in road construction. Use of native soil in the base and subbase layers of flexible pavement is an innovative technology to minimize the exploitation of the natural aggregate resources, especially in an environmentally fragile state like Kerala. Several researchers have done various studies on both the mechanical and chemical stabilization of laterite soil.

Joel and Agbede found that partial replacement with 45% sand significantly improved the gradation of the laterite soil [1]. The 55% laterite and 45% sand mix when stabilized with 6% cement resulted to a stiff cemented mix of UCS value > 3 MPa. The compaction characteristics of laterite were significantly improved by the addition of cement [2]. In another study, 8% crushed steel slag were added to laterite for increasing the maximum dry density [3]. Laterite stabilized with 8% crushed steel slag gave a CBR value of 30%, indicating that it is suitable for subbase layers of flexible pavement. Laterite soil stabilized with 3% cement resulted to a CBR value of 90% after 7 days curing and 4 days soaking, which is 9 times greater than that of untreated soil [4]. Cement stabilized laterite-steel slag mix can be used as a potential alternative for granular base or subbase of flexible pavement [5]. Even though several studies emphasized on the strength and the gradation characteristics of stabilized laterite soil, very few studies are performed on the resilient behavior of such innovative mixes which is essential for a pavement material.

In this study, native laterite soil is mechanically stabilized with stone chips by partial replacement to improve the strength as well as gradation. Stone chips which are scrap from quarries and marble/granite industries are not recommended as a construction material due to their poor gradation and smaller size (< 6 mm). The stone chip waste can be a useful ingredient to improve the gradation and strength of laterite gravel. The laterite-stone chips mix is further stabilized with cement to develop a cemented subbase suitable for flexible pavement as per the requirements of IRC. The focal point of this research is to study the resilient response of the innovative cemented mix, by comparing its resilient modulus and permanent deformation with that of conventional granular subbase. The objectives of this study are as follows:

- Find the optimum laterite gravel – stone ships – cement (LSC) mix from various trial mixes based on gradation and UCS value.
- Determine the resilient modulus and permanent deformation of the optimum LSC mix and compare with that of conventional granular subbase (GSB).
- Based on finite element analyses using Plaxis 2D, determine the design life ratio of the pavement constructed with LSC mix and compare with that of conventional pavement.

2 Experimental Program

2.1 Materials & Mix proportion

The laterite gravel for the study is obtained from South Kalamssery, Ernakulam District, Kerala. The physical properties of laterite gravel are given in Table 1. Stone chips of 6 mm to 4.75 mm size were obtained from a quarry in Ernakulam District. 43 grade Portland pozzolana cement from a local cement manufacturer is used to stabilize laterite – stone chips mix.

In order to achieve a well graded mix, laterite soil was replaced by 10%, 30%, 50% and 70% stone chips by dry weight. Even though the coefficient of uniformity (C_u) of the laterite soil as well as the laterite + stone chips mixes was > 4, the coefficient of curvature (C_c) was in the range of 1 to 3 only for 30% and 50% stone chips content, improving the poorly graded (GP) native laterite soil to well-graded gravel (GW). A well graded mix results to a mechanically stable and well compacted layer in the field [6]. In order to promote bulk utilization of native soil in pavement layers and to minimize the transportation cost of the quarry waste, it was desired to choose 70% laterite + 30% stone chips mix for stabilizing with cement. The particle size distribution curves of laterite soil and 70% laterite + 30% stone chips mix are shown in Fig. 1. The laterite – stone chips mix was stabilized with 3%, 5%, 7% and 9% cement by dry weight.

Table 1 Physical properties of laterite gravel

Property	Value
Color	Brick red
Specific gravity	2.76
Grain size distribution (%)	
Gravel (20 mm to 4.75 mm)	52.5
Sand (4.75 mm to 0.075 mm)	46.1
Fines (<0.075 mm)	1.4
Coefficient of uniformity (C_u)	15.5
Coefficient of curvature (C_c)	0.93
Modified compaction characteristics	
OMC (%)	14.2
MDU (kN/m^3)	17.2
Soaked CBR (%)	12
IS Classification	GP

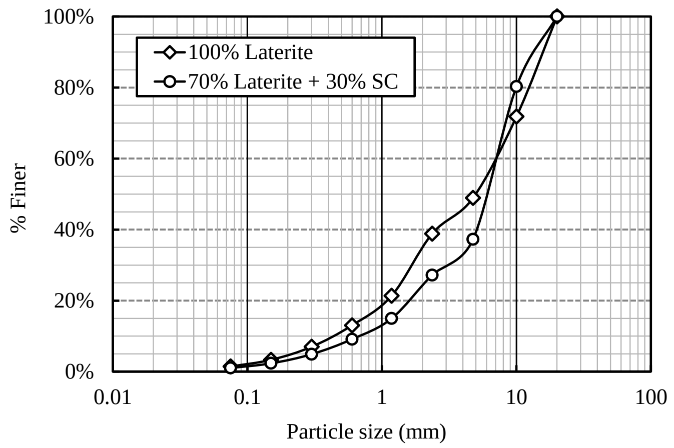

Fig. 1 Particle size distribution curve for 100% laterite gravel and 70% laterite gravel + 30% stone chips

2.2 Laboratory Investigation

The optimum moisture content (OMC) and maximum dry unit weight (MDU) of the laterite soil – stone chips – cement mixes (LSC) were obtained by performing the heavy compaction test as per IS 2720-Part 8 and presented in Table 2 [7].

Table 2 Compaction characteristics for various cement contents added to 70% laterite + 30% stone chips mix

Cement content (%)	OMC (%)	MDD(kN/m^3)
3	11.3	17.9
5	11.0	18.1
7	10.6	18.3
9	10.1	18.4

On the basis of these compaction characteristics, cylindrical specimens of 100 mm diameter and 200 mm height were prepared for various cement contents. The specimens were wrapped and sealed in polythene and kept for curing for 7, 14 and 28 days at a temperature of 27°±2°C. Unconfined compressive strength test and cyclic triaxial test were performed on the cured LSC specimens [8]. The resilient modulus test was conducted on the optimum LSC mix according to the stress levels stipulated by AASHTO T 307 [9].

3 Results and Discussion

3.1 Unconfined compressive strength

The variations of UCS values with cement content and curing period are presented in Fig. 2 and Fig. 3. Both the increase in cement content and curing period had significant improvement in the strength of the LSC mixes.

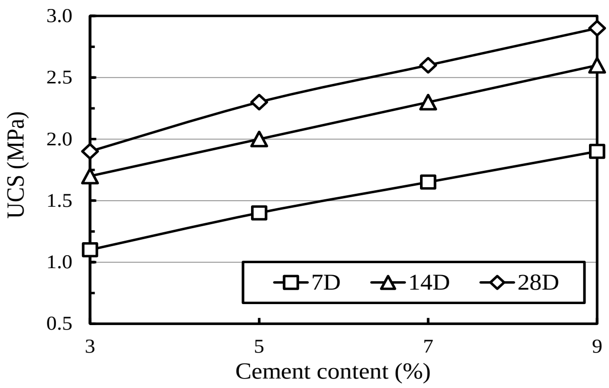

Fig. 2 Variation of UCS values of laterite-stone chips-cement mix with cement content

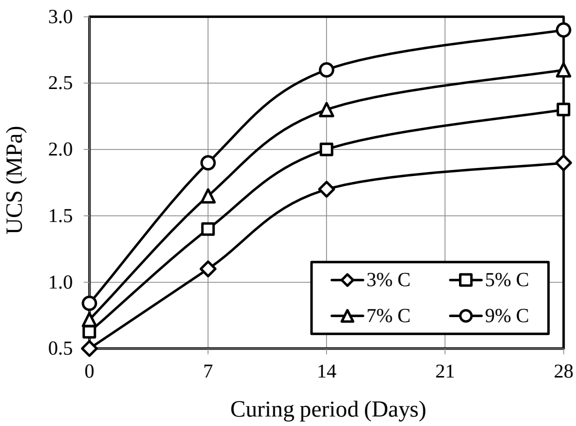

Fig. 3 Variation of UCS values of laterite-stone chips-cement mix with curing period

The strength gain is steady up to 14 days of curing and later on it slows down giving an indication that major pozzolanic reactions take place within the first 14 days. The strength gain is mainly due to the formation of binding gel (calcium silicate hydrate C-S-H) formed due to the hydration of cement, which serves as a matrix phase in the stabilized mix. LSC mixes with 7% and 9% cement content satisfied the IRC criteria of UCS > 1.5 MPa after 7 days curing for use as a cemented subbsase in flexible pavement [10]. In order to reduce the environmental impact of using greater cement content and for additional economic benefits, LSC mix with 7% cement content was chosen as the optimum mix.

3.2 Resilient modulus

The effect of confining stress (σ_3) and deviator stress (σ_d) on the resilient modulus (M_r) of 28 days cured LSC mix is shown in Fig. 4. Steady increase was seen in the M_r value with increase in σ_3 and σ_d. The lateral strain in the specimen reduces with increase in confining stress leading to lower axial deformation. This reduces the recoverable axial strain subsequently giving higher M_r. The applied σ_d for various stress levels is significantly lower than the UCS value of the specimen and this results in strain hardening of the cemented LSC mix. The increase in M_r with increase in σ_d is due to this strain hardening.

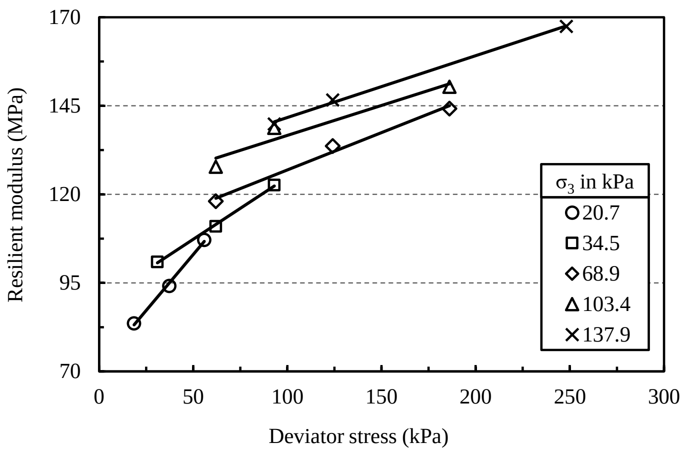

Fig. 4 Effect of deviator stress and confining stress on resilient modulus of optimum LSC mix cured for 28 days

In Fig. 5, the M_r of optimum LSC mix for various curing periods is compared with that of GSB at a constant confining stress of 34.5 kPa. For all the curing periods, LSC mix exhibited higher M_r than that of GSB. As the base and subbase layers of flexible pavement experience a confining stress and deviator stress of around 35 kPa and 100 kPa in the field, the M_r of LSC mix corresponding to σ_3 = 34.5 kPa and σ_d = 93.1 kPa is compared with that of GSB. The 28 days cured LSC mix exhibited M_r of 122.6 MPa which is 1.78 times that of GSB. The variation of M_r with bulk stress is shown in Fig. 6. The increase in bulk stress increased the M_r for LSC mix as well as GSB.

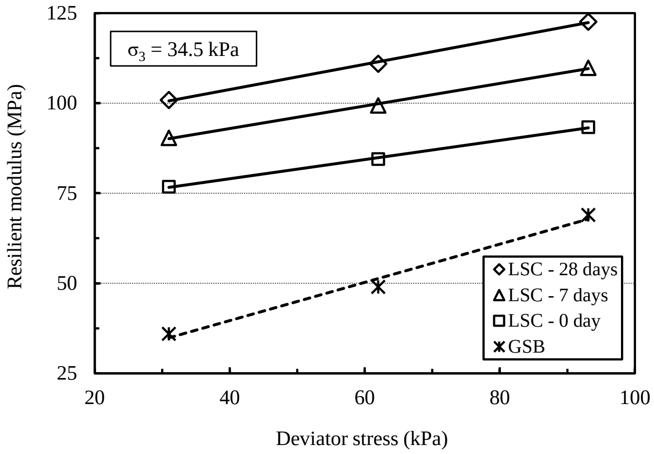

Fig. 5 Comparison of resilient modulus of optimum LSC mix for various curing periods with GSB at a constant cell pressure of 34.5 kPa

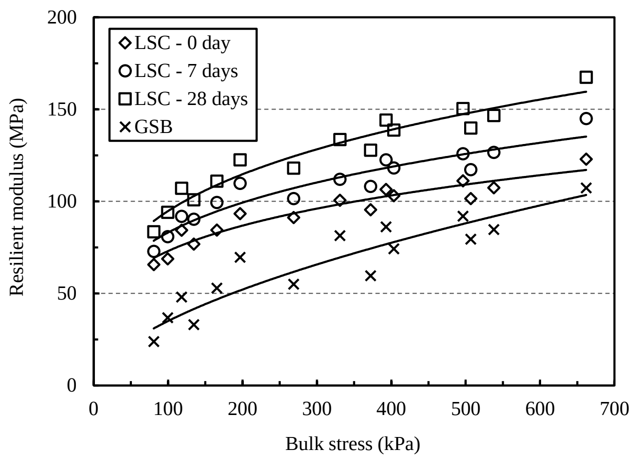

Fig. 6 M_r vs bulk stress for LSC mixes and GSB

The permanent strain of optimum LSC mix corresponding to $\sigma_3 = 34.5$ kPa and $\sigma_d = 93.1$ kPa is compared with that of GSB for 10,000 cycles and shown in Fig. 7. The figure clearly indicates that the permanent strain significantly reduces with increase in curing period. The 28 days cured LSC mix exhibited the lowest permanent strain, which is 78% lower than that of GSB. The increase in the quantity of binding gels with increase in curing period led to lower permanent strain for the LSC mixes.

3.3 Design life ratio

In order to compare the critical strains in the flexible pavement crust comprising LSC mix with that of GSB, finite element analysis was performed using Plaxis 2D. The thickness of the layers of flexible pavement were adopted from the template given in IRC 37, 2018 for a subgrade CBR of 5% and traffic intensity of 50 million standard axles (msa) [11]. The pavement was modelled as a 2D axis-symmetrical model. As the stresses induced in every layers of a flexible pavement due to the impulse traffic loading are significantly lower than the strength of the layers, all the layers are assumed as linear elastic during the analysis [12]. To simulate the traffic loading of 40 kN, a stress of 566 kPa was applied at the center on a circular contact area of 300 mm diameter on top of the pavement.

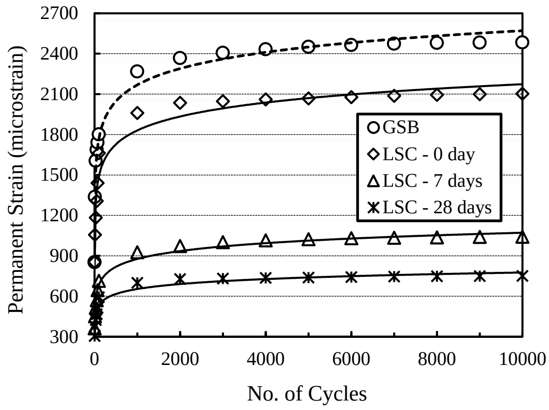

Fig. 7 Permanent strain of LSC mixes and GSB

Table 3 Parameters used for finite element analyses of flexible pavement [11, 12]

Parameters	Subgrade	Granular subbase (GSB)	Optimum LSC mix subbase	Wet mix macadam (WMM)	Dense bituminous mix (DBM)	Bituminous concrete (BC)
Resilient modulus (MPa)	50	70	123	150	2000	2000
Poisson's ratio	0.35	0.35	0.35	0.35	0.35	0.35
Unit weight (kN/m^3)	17.7	21.4	18.3	21.8	22.6	23.3
Thickness (mm)	500	200	200	250	130	40

The parameters adopted for the analysis are shown in Table 3. While performing the analysis, the resilient modulus of GSB was replaced by that of LSC mix to compute the critical strains. The design life ratio (DLR) corresponding to the two most important failure criteria of flexible pavements, rutting and fatigue are determined using the Eq. 1 and Eq. 2 [12].

$$DLR_{rutting} = \left(\frac{\varepsilon_{z1}}{\varepsilon_{z2}}\right)^{4.5337} \quad (1)$$

$$DLR_{fatigue} = \left(\frac{\varepsilon_{t1}}{\varepsilon_{t2}}\right)^{3.89} \quad (2)$$

Where, ε_{z1} and ε_{t1} are the maximum compressive strain developed at the top of subgrade and maximum tensile strain developed at the bottom of DBM of pavement with GSB. And, ε_{z2} and ε_{t2} are the maximum compressive strain developed at the top of subgrade and maximum tensile strain developed at the bottom of DBM of pavement with LSC mix in subbase. For the pavement section with GSB, ε_t of 187 με and ε_z of 331.5 με and that with LSC mix in subbase, ε_t of 175 με and ε_z of 322.4 με were obtained. The DLR for the pavement with LSC mix in subbase with respect to that of pavement with GSB corresponding to rutting and fatigue criteria were obtained as 1.13 and 1.29.

These higher design life ratios clearly indicate that the optimum LSC mix chosen in this study can be considered as a potential alternative for granular subbase of flexible pavements without compromising the life of the pavement.

4 Conclusions

Resilient response of laterite – stone chips – cement mixes were evaluated in this study for their effective utilization in the subbase layer of flexible pavement. Following conclusions were drawn from this study.

- The gradation of the laterite gravel was improved from GP to GW by replacement with 30% and 50% stone chips. In order to maximize the utilization of native laterite soil and to reduce the transportation cost of the stone chips, it was intended to stabilize 70% laterite gravel + 30% stone chips mix with cement.
- LSC mixes with 7% and 9% cement content satisfied the IRC criteria of UCS > 1.5 MPa after 7 days curing for use as a cemented subbsase in flexible pavement. In order to reduce the environmental impact of using greater cement content and for additional economic benefits, LSC mix with 7% cement content was chosen as the optimum mix.
- The strength gain in the LSC mixes is mainly due to the formation of C-S-H gels formed due to the hydration of cement, which bind the laterite-stone chips mix to form a stable mass.
- The 28 days cured LSC mix exhibited M_r of 122.6 MPa, which is 1.78 times that of GSB. Increase in confining stress and deviator stress led to increase in M_r. The reduction in the recoverable axial strain with increase in the confining stress and strain hardening in the specimen due to lower applied deviator stresses than the strength of the mixes during the cyclic loading is the reason for the increase in M_r.
- The 28 days cured LSC mix exhibited 78% lower permanent strain than that of GSB. The increase in the quantity of binding gels with increase in curing period led to lower permanent strain for the LSC mixes.
- The DLR for the pavement with optimum LSC mix in subbase with respect to that of pavement with GSB corresponding to rutting and fatigue criteria were obtained as 1.13 and 1.29, thus indicating that the LSC mixes can be a potential alternative for GSB.

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