

Laterite as a base and subbase material for flexible pavement – a review.

Laterita como material de base y subbase para pavimento flexible: una revisión.

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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. The recent landslides in Kerala which took the lives of many people is the aftermath of extensive quarrying activities. Utilization of treated native soil in the structural layers (Subbase and base) of flexible pavement can widely avert the danger associated with ecological imbalance due to quarrying. The main objective of this review article is to enlighten the researchers and practicing engineers about the key advances developed in the last 10 years for utilizing native laterite soil in the base and subbase layers of flexible pavement. On the basis of various researches, laterite soil treated with lime, cement and other additives showed considerable enhancement in the compaction characteristics, unconfined compressive strength (UCS) and California Bearing Ratio (CBR). As stipulated by MORTH (Ministry of Road Transport and Highways), for a layer to be suitable as a subbase material in flexible pavement, minimum CBR value must be 30%. From the extensive review, it was found that the treated laterite soil satisfied the MORTH criteria for use as a subbase layer in flexible pavement.

Keywords: Ferrocement, cyclic loading, flexural behavior, precast ferrocement wall, dynamic analysis, static analysis.

RESUMEN

El rápido crecimiento económico está dando lugar a una expansión ubicua en los proyectos de carreteras en todo el mundo. La utilización de recursos naturales agregados para la construcción de pavimento flexible ha llevado a canteras incontrolables en el estado

de Kerala. Los recientes deslizamientos de tierra en Kerala que se cobraron la vida de muchas personas son las secuelas de extensas actividades de extracción de canteras. La utilización de suelo nativo tratado en las capas estructurales (subbase y base) del pavimento flexible puede evitar ampliamente el peligro asociado con el desequilibrio ecológico debido a la explotación de canteras. El objetivo principal de este artículo de revisión es informar a los investigadores e ingenieros en ejercicio sobre los avances clave desarrollados en los últimos 10 años para utilizar suelo de laterita nativa en las capas de base y subbase de pavimento flexible. Sobre la base de diversas investigaciones, el suelo de laterita tratado con cal, cemento y otros aditivos mostró una mejora considerable en las características de compactación, resistencia a la compresión no confinada (UCS) y California Bearing Ratio (CBR). Según lo estipulado por MORTH (Ministerio de Transportes por Carretera y Carreteras), para que una capa sea adecuada como material de subbase en pavimento flexible, el valor mínimo de CBR debe ser del 30%. A partir de la revisión exhaustiva, se encontró que el suelo de laterita tratado cumplía con los criterios de MORTH para su uso como capa de subbase en pavimento flexible.

Palabras clave: Ferrocemento, carga cíclica, comportamiento a flexión, muro de ferrocemento prefabricado, análisis dinámico, análisis estático.

INTRODUCTION

India has a road network spanning 5.6 million km and is the second largest in the world. A challenging problem in the construction of highways is the increasing demand of good quality natural aggregates leading to their fast depletion. Also, the overall construction cost of flexible pavement is increasing drastically due to the scarcity of natural aggregates location of the quarries which are far away from most of the highway projects. Non-conventional pavement construction approach is widely practiced throughout the world. However, due to the lack of codal provisions and specific guidelines, ambiguities in the end results and the performance of pavements throughout its design life, such types of constructions are still practiced very rarely in India.

Even though laterite soil is a marginal material, it is widely used as a base/subbase material in flexible pavements when modified suitably according to the required strength criteria. Suitability of laterite for base/subbase material depends on various factors such as grading characteristics, physical characterization and chemical and mineralogical composition, as well as onsite conditions where they are used. Even though laterite has been successfully used in road construction, usually it fails to meet the strength requirements due to poor quality control and improper treatments. Such practices compel the contractors to switch towards conventional construction leading to large scale exploitation of aggregate resources. To meet the requirements for laterite to be used for pavement applications,

various treatments are done to improve plasticity characteristics, alteration of grain size distribution, increase in mechanical strength and durability by partial replacement of aggregates, industrial wastes such as steel slag, fly ash etc. and addition of cementing agents like cement, lime etc. and sometimes both. Many researchers have turned their attention towards the use of geopolymer as a sustainable soil stabilizer, especially for building materials [Phummiphan et al, 2016]. Steel slag can also be used as a partial substitution for improving the strength characteristics of weak soils [Akinwumi et al, 2012].

This review delves into various researches on the feasibility of using locally available laterite as a potential replacement for natural aggregates in road base/subbase construction which will avert the ecological imbalance due to fast depleting natural aggregates. Also, this paper highlights the effect of adding stabilizers on the crucial geotechnical properties of native laterite, namely, particle size distribution, compaction characteristics, unconfined compressive strength (UCS), California Bearing Ratio (CBR), resilient modulus (M_r) etc. which will be a one stop solution for practicing pavement engineering.

PHYSICAL PROPERTIES OF THE STABILIZED LATERITE

Laterite is usually classified as poorly graded sand (SP), according to most of the soil classification standards. This is because of the absence of sand sized and silt sized particles. Laterite alone does not always satisfy the national as well as most international specifications for unbound granular base or subbase materials because of its poor gradation. Important physical properties of native laterite and that of stabilized laterite is shown in Table 1.

Table 1
 Physical Properties of Native and Stabilized Laterite
 [Akinwumi et al, 2012],[Joel and Agbede, 2011]

Properties	Native laterite		Stabilized laterite	
Material	Lateritic Soil	Lateritic Soil	55% laterite +45% sand + 6% cement	Laterite+ 8% crushed steel slag
Soil Classification	poorly graded GP (AST 1992)	Lean clay CL (USCS)	Grade A (TRL, 1993)	--
Specific gravity	3.1	2.65	2.4	2.8
Liquid Limit (%)	41.07	40.8	17.43	35
Plastic Limit (%)	24	26.5	11.43	23
Plasticity Index	17.07	14.3	6	12
Permeability (cm/s)	-	1.68×10^{-4}	-	2.23×10^{-4}
Optimum Moisture Content (%)	9	17.5	10.5	18.5
Maximum Dry Density (kN/m ³)	17.45	18.2	17.65	14.5

The addition of pulverized steel slag reduced the plasticity of lateritic soil having the nature of sandy clay and thereby improved its workability, and reduced its moisture-holding capacity and swell potential [Akinwumi et al, 2012]. The partial replacement of laterite by 45% sand moved the particle size distribution curve from zone “B” grading envelope to grade “A” of the Transport Research Laboratory (TRL) (1993) which is the recommended particle-size distribution for lateritic gravel road bases [Joel & Agbede, 2011].

COMPACTION CHARACTERISTICS

Compaction Characteristics of Stabilized Laterite is shown In Table 2.

Table 2
 Compaction Characteristics of stabilized Laterite

Material	Optimum Mix	Application	MDD (KN/m ³)	OMC (%)
Laterite + Cement [Caro et al, 2018]	Laterite + 4% cement	Low Medium volume roads	23	8.4
Laterite + fly ash + alkali activated CCR [Phummiphan et al, 2016]	60% laterite + 30% fly ash + 10% CCR [activated by Na ₂ SiO ₃ :NaOH (50:50)]	Subbase	19.5	18
Laterite + crushed steel slag (SSC) [Akinwumi et al, 2012]	Laterite+ 8% SSC	Subbase Course	14.5	18.5
Laterite + cement/lime [Portelinha et al, 2012]	Laterite+3% binder (cement/lime)	Subbase and Base	14.5 - 15	28 - 27
Laterite + sand + cement [Qian et al, 2015]	50% laterite + 50% sand + 4% cement	Base Course	22.2	10

Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of stabilized laterites are shown in Table 2. Soil-cement mixtures showed higher MDD than the untreated soil, while soil-lime presented lower values when compared to that of untreated soil [Portelinha et al, 2012]. The addition of lime led to increase in OMC and the result was reverse in the case of cement. Flocculation and cementation due to addition of lime make the soil more difficult to compact, thereby reducing the maximum dry density that can be

achieved with a particular compaction effort. The compaction curve for lime treated clayey soils is generally flatter, making moisture control less critical and reducing the variability of the density produced. Whereas, the hydration of cement leads to the reduction in the OMC of the soil-cement mixes. Similar studies proved that MDD of around 23 KN/m^3 can be achieved for 4% cement content [Caro et al, 2018], [Qian et al, 2015]. For a particular alkaline activator ($\text{Na}_2\text{SiO}_3:\text{NaOH}$) ratio and calcium carbide residue (CCR) content, the dry unit weight of the lateritic soil-fly ash-CCR increases with increasing liquid alkaline activator content until the MDD is attained at an optimum liquid content (OLC) [Phummiphan et al, 2016]. Beyond this optimum value, the unit weight decreases as the alkaline activator content increases. The maximum dry unit weight of the soil slightly increased with higher steel slag contents and for 8% steel slag content, MDD of 14.5 KN/m^3 was obtained at an OMC of 18.5% [Akinwumi et al, 2012].

STRENGTH CHARACTERISTICS

A. California Bearing Ratio

The CBR values of the stabilized laterite for optimum mixes by various researchers are shown in Table 3. Increase in CBR with addition of cement was clear from the various studies [Joel & Agbede, 2011, Portelinha et al, 2012, Qian et al, 2015]. The higher strength of these mixes 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. 7-day CBR of 218.75–338.54% was obtained when lateritic gravel was treated with 2–6% cement [Portelinha et al, 2012, Qian et al, 2015], which came close to the value of 40% lateritic gravel + 60% sand + 6% cement recommended by Joel and Agbede (2011). The specimens were cured for 6 days unsoaked under controlled conditions (i.e., at a temperature of $25 \pm 2^\circ\text{C}$ and a relative humidity of 100%) and later immersed in water for 1 day before testing, as recommended by the Nigerian General Specification, 1997 [Joel & Agbede, 2011].

The unsoaked CBR value for the soil progressively increased from 51% for the 0% slag content to 91% for 8% slag content [Akinwumi et al, 2012]. The soaked CBR value initially decreased from 49% for the 0% slag content to 25% for 5% slag content before a progressive increase to 30% for 10% steel slag content. The clay particles of the soil became rearranged with addition of steel slag (flocculation), producing a soil mixture with more crumbly characteristics, especially when in contact with water. This accounts for the sharp initial decrease in the soaked CBR value for increasing steel slag content up to 5%. The subsequent increase of the soaked CBR value for higher steel slag contents, results from the fact that the percentage of clay particles within the lateritic soil that becomes rearranged reduces with increasing steel slag content.

Table 3
 CBR of Stabilized Laterite

Material	Optimum mix	Application	CBR (%)
Laterite + sand + Cement [Joel and Agbede, 2011]	55% laterite + 45% sand + 6% cement	Base Course	230
Laterite + sand+ Cement [Qian et al, 2015]	50% laterite + 50% sand + 4% cement	Base Course	475
Laterite +Steel Slag [Akinwumi et al, 2012]	Laterite + 8% SSC	Subbase	91(uns soaked) 30 (soaked)
Laterite + cement/lime[Phumm iphan et al, 2016]	Laterite + 3% binder (cement/lime)	Subbase Base	90 (Cement) 35 (Lime)

B. Unconfined Compressive Strength

The UCS values of various stabilized laterite for optimum mixes by various researchers are shown in Table 4. Various studies proved the increase in strength with cement stabilization [Joel & Agbede, 2011, Portelinha et al, 2012, Qian et al, 2015]. Specimens were cured in sealed plastic bags to prevent loss of moisture by evaporation for 6, 13, and 27 days, and later immersed in water for 1 day before being tested with mechanical pressure [Qian et al, 2015]. Comparing the effect of cement and lime stabilization of laterite soil, a higher UCS of 1.1 Pa for 28 days curing was obtained with cement stabilization, when compared to that of lime, which is only 0.9 MPa. Hence the use of low contents of cement showed to be more effective than lime to improve the lateritic soil strength [Portelinha et al, 2012].

Table 4
 UCS of Stabilized Laterite

Material	Optimum mix	Application	UCS (MPa)
Laterite + sand + cement [Joel and Agbede, 2011]	55% laterite + 45% sand +6% cement	Base Course	2.1 (7days), 3.5 (28 days)
Laterite + Cement [Biswal et al, 2016]	Laterite + 6% cement	Base Course	3.2 (7days), 3.8 (28 days)
Laterite + Cement +Sand [Qian et al, 2015]	50% laterite + 50% sand + 4% cement	Base Course	1.5 (7days), 3.7 (28 days)
Laterite + fly ash + alkali activated CCR [Phummiphan et al, 2016]	60% laterite + 30% fly ash + 10% CCR [activated by Na ₂ SiO ₃ :NaOH (50:50)]	Subbase	7.5 (7days), 9 (28days) 18.8 (90 days)
Laterite +Steel Slag [Akinwumi et al, 2012]	Laterite + 8% SSC	Subbase	1.7 (28 days)
Laterite + Cement, Laterite + Hydrated Lime [Portelinha et al, 2012]	3% cement and lime	Subbase and Base	0.8 (Laterite + Lime for 28 days), 1.1 (Laterite +Cement for 28 days)

Phummiphan et al. (2016) examined the UCS of soaked lateritic soil-fly ash-CCR samples after curing periods of 7, 28, 60, and 90 days. The geopolymer paste with high Ca(OH)₂ exhibited high UCS at early stage but the value decreased after 28 days of curing [Phummiphan et al, 2016]. The unconfined compressive strength (UCS) of the natural soil at its OMC and MDD, increased with slag content, from 104.0 kN/m² for 0% slag content to 170.7 kN/m² for 8% slag content [Akinwumi et al, 2012]. However, with further increase in the slag content, there was a sharp decrease in the UCS value. This could be due to the less availability of higher valence cations which did not neutralize the lower valence cations which are in excess.

CONCLUSION

From the comprehensive examination following conclusions were drawn;

- Laterite alone does not satisfy all the requirements for subbase and base material. Variation of properties of laterite with stabilization are remarkable
- The sesquioxides (Fe_2O_3 and Al_2O_3) are the major in the fraction of lateritic gravel. Low contents of fine-grains clay minerals in lateritic gravel resulted in the ineffectiveness of the cement reactions between lateritic gravel and cement. But the addition of cement to lateritic gravels would ultimately bring about the compact intersection of interlaced lateritic particles, if curing periods were long enough. Therefore, high-grade cement, such as P.O.42.5, or solidification agents that could accelerate the process of the cement hydrating reactions, are recommended when using cement-lateritic gravel.
- The impact of cement stabilization on laterite is noteworthy even for the lowest cement content of 2%. Various experimental results showed that soil workability and mechanical strength changed even with the addition of 2% and 3% of lime or cement
- The high-calcium FA-based geopolymer with CCR as a promoter can also be used with marginal lateritic soils instead of using conventional PC as a sustainable as a green stabilizer
- Reduction in the plasticity of lateritic soil, increase in workability, and reduction in moisture-holding capacity and swell potential are obtained by the addition of pulverized steel slag to native laterite.

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Received: 15th February 2021; Accepted: 18th May 2021; First distributed: 18th May 2021.

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Received: 15th February 2021; Accepted: 18th May 2021; First distributed: 18th May 2021.