Jordan Journal of Civil Engineering, Volume **10**, No. **4**, **2016**

A Comparative Study of Flexural Fatigue Responses of Lime-Laterite and Lime-Fiber-Laterite Soil Mixtures at Different Densities

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ABSTRACT

Laterite soils, being products of tropical and sub-tropical weathering and chemically ferruginous aluminous in nature, are apparently very complex and controversial materials comprising all stages from parent rock to surface. Popularly, these are known as 'red tropical soils'. There are huge reserves of these soils in different parts of the earth, but there is lack of adequate data on the engineering behaviour of these soils, particularly when they are treated with lime and lime-fiber for the assessment of suitability of these materials compacted at different densities, such as light, medium and heavy, for construction of road base or sub-base. The main purpose of this study is, therefore, to develop data on flexural fatigue responses of lime-laterite and lime-fiber–laterite soil mixtures for their application in road under layers subjected to repetitive flexural loading. Beam specimens at different densities prepared with 5% lime and laterite soils and 5% lime and fiber-laterite soils mixed with 0.6% of 2 cm long fibers cured at 50oC have been subjected to third-point loading for determination of static flexural strength and fatigue flexural response of these mixtures, which are presented in this paper.

KEYWORDS: Laterite soils, Flexural fatigue, Compaction densities, Stress ratio.

INTRODUCTION

Compaction plays a very important role in pavement construction, in the success of soil stabilization and satisfactory performance of bound pavement layers. For compaction, dry of optimum, dry density is a function of both water content and compactive effort and for compaction, wet of optimum, it is mainly governed by water content (Weitzeland Lovell, 1980). Whatever the compaction variables, dry density is the final outcome, and, therefore, it has become traditional to compare compaction on the basis of dry density (Bell, 1977). In other words, dry density is a measure of compaction. Compaction in the present study has been identified at three levels; light, medium and heavy. Standard Proctor Compaction density has been taken as a measure of light compaction and modified AASHTO compaction density as a measure of heavy compaction and the mean of the two as a measure of medium compaction. Test specimens,

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Received on 17/4/2015.
Accepted for Publication on 8/5/2015.

cylinders and beams have been prepared by compacting pre-determined weight of wet materials, lime-laterite and lime-fiber-laterite mixtures, corresponding to moulding water and unit dry weight to given volume by static compaction and classified in any of the above three compaction levels according to the as-molded dry densities.

The specimens have been tested under both static and repeated load. The main purpose of the static load test is to evaluate the improvement that laterite soils may derive out of lime and lime-fiber treatment, thereby identifying the desirable variables for gainful stabilization of the material. The cured lime-laterite cylinders have been subjected to unconfined compression and lime-laterite and lime-fiber laterite beams to flexure to correlate strength with density and to determine the optimum lime percent, fiber length and fiber percent for stabilizing the laterite soils used (Bhattacharya et al., 2014). The flexure test results have also been used to obtain the load-deflection relationship for the purpose of determining the flexural moduli of the materials and also for material characterization.

Fatigue data for lime-soil materials are very much limited and the major reported work is that of Swanson and Thompson (1967). The materials applied in the pavement layers will be subjected to repeated flexural stresses and strains, and, therefore, flexural strength and fatigue response are more important considerations than shear and compressive strength of the materials (Swanson, 1965; Swanson, 1966; Swanson and Thompson, 1967). In view of emphasis having been placed on the investigation of flexural and fatigue flexural aspects of lime-laterite (Bhattacharya and Pandey, 1986) and lime-fiber-laterite mixtures to develop data for design of pavement components with such materials, abundantly available in humid tropical areas of many countries in the world, particularly in South America, Africa, India, Indonesia and Australia (Nixon and Skipp, 1957; Niyogi and Mallick, 1973; Gidigasu, 1976).

Test Materials

Soils

Four laterite soils, designated as A,B,C and D, collected from the well-developed mottled zone from various locations in and around Kharagpur, West Bengal, India (Goswami, 1979) have been used in the testing program. The soils are reddish brown, blocky and sticky with iron nodules fairly distributed. Texturally, A, B and C are loams and D is silty loam. According to the AASHTO classification, they fall in the category of A-6(5), A-4(3), A-4(4) and A-6(9), respectively. The plasticity indices of the soils are 12.58, 10.35, 10.54 and 18.07, respectively. 5% addition of lime reduces plasticity from 7.73 to 6.30. The mean dry densities and the optimum moisture contents of the soils, soils + 5% lime, and soils + 5% lime + 0.6% 2cm fiber, at standard proctor and modified AASHTO compaction levels are respectively: (a) 1920 kg/m^3 and 2055 kg/m^3 at 12.57% and 10.56% of moisture (b) 1877 kg/m^3 and 2011 kg/m^3 at 14.33% and 11.94% of moisture and (c) 1783 kg/m^3 and 1910 kg/m^3 at 15.28% and 12.64% of moisture. Therefore, dry density values have been rounded off to1880, 1940 and 2000 kg/m^3 for lime (5%) + laterite soils and to 1780, 1845 and 1910 kg/m^3 for lime (5%) + 2 cm long fiber (0.6%) + laterite soils to represent light, medium and heavy compaction levels, respectively. The mean specific gravity of the soils is 2.68.

Lime

Commercial grade quick lime, locally procured, slaked, dried and sieved through 75 micron sieve has been used throughout the study. The mean calcium oxide content of the hydrated lime has been nearly 64%. Lime has been mixed at 2.5, 5.0 and 7.5% by weight of dry soil for unconfined compression test specimens. Beam specimens have been prepared with 5.0% of lime only.

It has been revealed by static test results that lime treatment substantially improves the strength of laterite soils yielding high correlation between unconfined compressive strength and dry density for both oven and moist cured specimens (Bhattacharya and Pandey, 1984). Compressive strength increases with dry density and also with days of moist curing. 5% of hydrated lime by weight of oven-dried soil could be taken as the optimum amount needed for stabilization (Bhattacharya and Pandey, 1984).

Air-dried coconut fibers containing 10 to 12% of natural moisture have been used at lengths of 2 cm at 0.2, 0.4, 0.6 and 1.0% and 4 cm at 0.2 and 0.4% for preparation of beam specimens for static flexure tests. For repeated flexure, however, lime-laterite beams have been moulded with 0.6% of 2 cm fibers only. The mean diameter of the fibers is 0.1844 mm and the mean specific gravity is 0.74. The mean elastic strain of the fibers is nearly 1.79% of the mean ultimate strain and the mean ultimate elongation is nearly 10% of the original length. The mean elastic modulus and ultimate tensile strength are respectively 11408 N/mm^2 and 208 N/mm^2.

Specimen Preparation

Mixing

Each batch of soil is weighed according to the requirements of desired dry density and compaction. Lime has been first mixed dry by weight of air-dried soil passing 4.75 mm sieve, then compaction water has been added. In the case of lime-fiber-laterite mixtures, fiber has been added by weight of air-dry lime-soil mixtures in three to four installments with compaction water added each time proportionately. Mixing has been always done by hand wearing rubber gloves. To study the effect of density on strength of cured specimens, samples of different densities have been prepared by varying compaction water over a wide range between 4.96% and 23.46% following the relationship: $W_m = V*\gamma_d*(1+m)$, where, W_m is the weight of the moist material, γ_d is the dry density and m is the compaction water percentage in decimal fraction.

Compaction

The unconfined compression test specimens, 50.8 mm in diameter and 101.6 mm in height, have been prepared by weighing the required amount of moist lime-laterite mixtures into the steel mould in three layers and each layer is duely scarified and tamped 15 times by a rod. Finally, the mixture is compressed to the given volume by means of a hand operated hydraulic jack. The beam specimens, 50 mm in height, 64 mm in breadth and 254 mm in length, have been similarly compacted with the exception that the layers, instead of being tamped, are subjected to 15 blows of a standard proctor hammer per layer. Compaction water added has been both dry and wet of optimum.

Compaction properties of laterite, lime-laterite and lime-fiber-laterite soil mixtures are shown in Table 1.

Since the compaction properties of soils A, B, C and D are close to one another, the representative values of maximum dry density and optimum moisture content of the laterite soils of the study area have been taken as the mean values as shown in Table 1.

Curing

There have been two types of curing; accelerated oven curing for 3 days only at 50^0+ 1^0C and moist curing in desiccators at mean summer laboratory temperature of 30.455^0C for 15, 30, 45 and 60 days. The unconfined compression test specimens have been subjected to both types of curing, while beam specimens have been cured in oven only. For oven curing, the specimens after extrusion have been placed inside polythene bags, the ends of which have been firmly secured to prevent escape of moisture from within and kept in temperature-regulated oven. The purpose of accelerated curing in oven is to work out the equivalent number of days of moist curing at 30.455^0C and to get samples cured in 3 days' time. It has been found that 3 days' oven curing at 50^0C is equivalent to 41 days' moist curing at mean summer temperature of 30.455^0C (Bhattacharya and Pandey, 1984).

Testing

The static tests for unconfined compression and flexure have been carried out in a Universal Testing

Table 1. Compaction properties of laterite, lime-laterite and lime-fiber-laterite soil mixtures

Soil	Lime %	Fiber		Standard Proctor Compaction		Modified AASHTO Compaction	
		Length (cm)	Percent	Max. Dry Density (γ_{dSP}) (kg/m^3)	Optimum Moisture (m_{SP})%	Max. Dry Density (γ_{dMA}) (kg/m^3)	Optimum Moisture (m_{MA})%
A	0	0	0	1926	12.78	2080	10.23
	5	0	0	1884	14.96	2035	11.97
	5	2	0.6	1788	15.34	1930	12.36
B	0	0	0	1945	11.50	2085	9.50
	5	0	0	1878	13.78	2030	10.60
	5	2	0.6	1785	14.85	1910	12.30
C	0	0	0	1910	12.50	2040	10.50
	5	0	0	1875	13.95	2000	12.00
	5	2	0.6	1781	15.40	1910	12.45
D	0	0	0	1900	13.50	2015	12.00
	5	0	0	1870	14.63	1980	13.20
	5	2	0.6	1776	15.55	1890	13.45
Mean Compaction Properties of A,B,C and D	0	0	0	1920	12.57	2055	10.56
	5	0	0	1877	14.33	2011	11.94
	5	2	0.6	1783	15.28	1910	12.64
Mean Comparative Compaction Properties of A,B,C and D	0	0	0	$\frac{\gamma_{dSP}}{\gamma_{dMA}}$	0.934	$\frac{m_{MA}}{m_{SP}}$	0.840
	5	0	0	$\frac{\gamma_{dSP}}{\gamma_{dMA}}$	0.933	$\frac{m_{MA}}{m_{SP}}$	0.833
	5	2	0.6	$\frac{\gamma_{dSP}}{\gamma_{dMA}}$	0.933	$\frac{m_{MA}}{m_{SP}}$	0.827

Machine at a constant deformation of 1.25 mm/min and the repeated flexure test in a Fatigue Testing Apparatus (Bhattacharya and Pandey, 1987) developed in the laboratory for the study at 110 cycles/min with loading to unloading ratio of 1:1 in a cycle length of 0.54 sec. The schematic diagram of the Fatigue Test set-up developed in the laboratory is shown in Fig 1. In both static and repeated flexure tests, the beam samples have been subjected to third-point loading on a simply supported span of 240 mm, 4.8 times the height of the beam. In the repeated flexure study, load and central deflection, δ, of beam specimens are the main items of measurement. Load has been measured by load cell and deflection by LVDT, both being duely calibrated. A two-channel recorder has been used to record the signals from them (Bhattacharya and Pandey, 1987). The selected stress level; that is, the pulsating load, and the consequent deflection remain unchanged during the flexural fatigue study until fracture particularly for lime-laterite materials. For lime-fiber-laterite mixtures also, deflection has remained constant until all on a sudden, it increases considerably when the specimen has been assumed to have failed, although it has some residual strength even at this stage because of the presence of fibers.

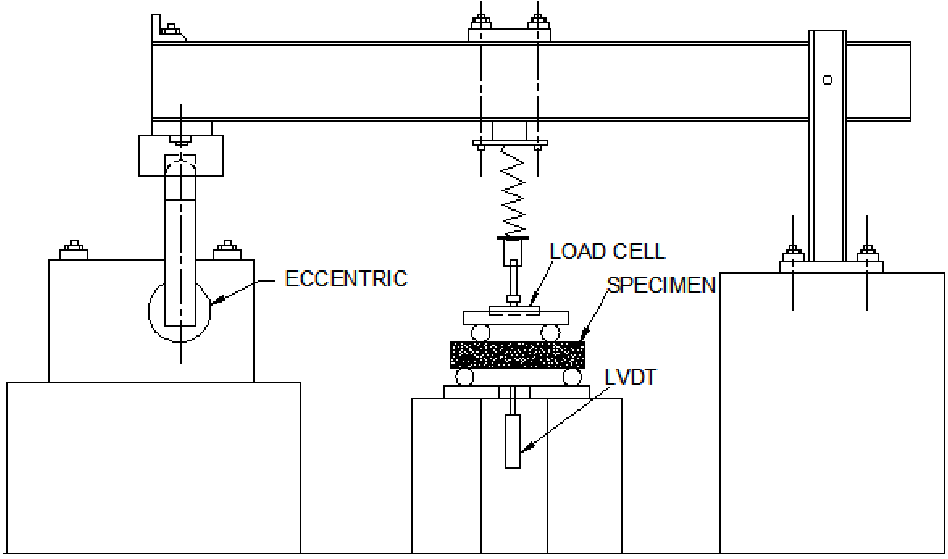

Figure (1): Schematic diagram of fatigue test set-up

Flexural Fatigue Behaviour of Lime-Soil Mixtures As Observed by Swanson and Thompson

Flexural fatigue is the progressive failure of a material produced by repeated flexural stresses which are less than the ultimate strength; that is, modulus of rupture (MR) of the material, and fatigue or flexural fatigue life (N_f) is the accumulated number of load repetitions or stress cycles to cause failure of a test specimen. Flexural stress, also called stress level (σ_f), refers to the applied tensile flexural stress given by the stress amplitude; that is, maximum stress, minimum stress being zero. The stress ratio (S) is the ratio of the applied stress on the beam specimen to its flexural strength (MR). The most notable contribution to study the behaviour of flexural fatigue strength of lime-soil mixtures was made by Swanson and Thompson (1967). They selected four types of soils: loam till, till and two humicgleys, belonging to A- 4 (6), A-6(6), A-7-6 (16) and A- 7-6 (18) according to AASHTO classification, with PI values of 7, 11, 23.5 and 28.8, respectively. A hydrated high-calcium lime containing 96% available calcium hydroxide with 95% passing sieve no. 325 was used in all test mixtures. The primary objectives of their investigation were to evaluate the general flexural fatigue response of the selected lime-soil mixtures and to determine whether the fatigue response would limit the use of these materials in sub-base and base course applications. Their observations were that the S-logN_f plots were typical of fatigue phenomenon in general and that the fatigue response of all lime-soil mixtures would be equivalent. Further, the design stress for sub-base and base with lime-soil mixtures should be selected based on the flexure fatigue response of the materials and must be low enough to allow the design number of load applications before failure. They observed that the fatigue strength of the studied soils at $5x10^6$ N/mm^2 stress application varied from 66% to 40% of ultimate flexural strength with an average of approximately 53%. They prepared test specimens in sizes of (50x50x175) mm to same water content and dry density as nearly as possible and cured in oven at 120^0 F for two days for the loam till and for 1 day for other soils. They applied statistical techniques to obtain the relationships between stress ratio S and log N_f

obtained out of the scatter diagrams of S *versus* the logarithm of the number of cycles to failure N_f. The relationships obtained were as follows:

SoilA-4(6): $S= 0.918 -0.038 \log N_f$, $R = -0.58456$

SoilA-6(6): $S= 0.882 -0.055 \log N_f$, $R = -0.8375$

SoilA-7- 6 (16) : $S= 0.959 -0.083 \log N_f$, $R = -0.85384$

SoilA-7- 6 (18) : $S= 0.936 -0.057 \log N_f$, $R = -0.81816$

The present study, however, in addition to establishing general relationships between stress ratio S and fatigue life N_f, has investigated the effect of density of coconut fiber on flexural fatigue responses of lime-laterite mixtures and made a comparison of the results obtained.

Flexural Fatigue Behaviour of Lime-Laterite and Lime-Fiber-Laterite Soil Mixtures at Different Densities As Observed in the Present Study

Correlation between Flexural Strength and Dry Density

Bending tests on lime-laterite and lime-fiber-laterite soil beams have been conducted at third-point loading to study the relationship between modulus of rupture and dry density for each of the seven groups of beams, plotting modulus of rupture (MR) against dry density in scatter diagram to obtain the least square regression equations shown graphically in Fig. 2. Analyzing the unconfined compression test data (Bhattacharya and Pandey, 1984), 5% of lime by weight of dry soil has been found to be the optimum dose for stabilizing the laterite soils under investigation. 'Least Square Regression' analysis of MR of beams has revealed that for lime-fiber-laterite mixtures, a percentage of 0.6% of 2 cm long fibers increases the MR value (Fig. 2) to its maximum, and, therefore, these values have been taken to prepare test specimens for determination of flexural fatigue behaviour of lime-laterite and lime-fiber-laterite soil mixtures. MR has been calculated using the linear elastic beam formula, $MR= \frac{WxL}{bxh^2}$, where W is the ultimate load, L is the length of the simply supported beam span, b is the breadth and h is the height of the specimen.

The test results have yielded the following regression equations:

MR (for lime 5 % + laterite soil)= $-7.0361+ 4.3 \times 10^{-3}\gamma_d$, R= 0.944, ………….(1)

MR (for lime 5 % + laterite soil + 0.6 %- 2 cm long fibers) = $-15.7717 + 9.2 \times 10^{-3}\gamma_d$, R = 0.9686 ………. (2),

where, MR is the modulus of rupture in MPa, γ_d is the dry density in kg/m^3 and R is the coefficient of correlation.

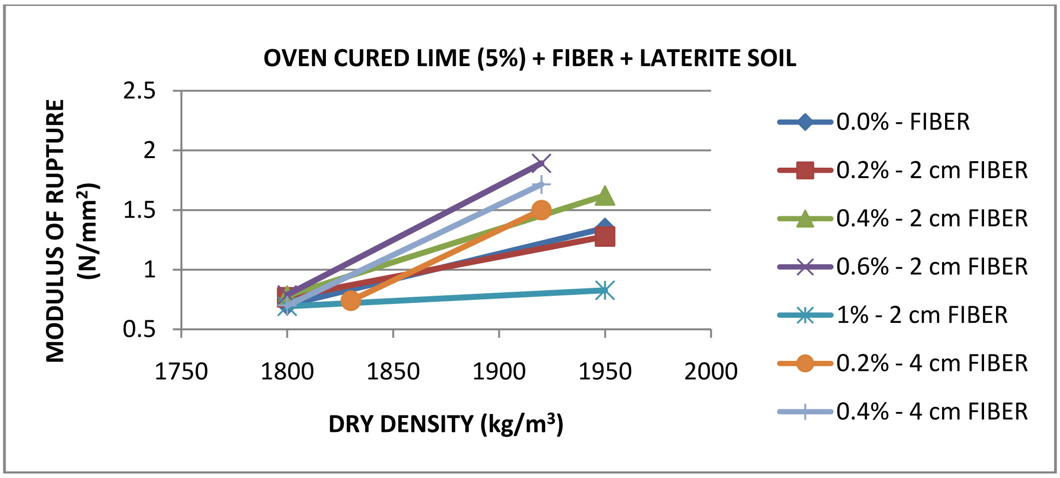

Figure (2): Regression curves showing the relationship between modulus of rupture and dry density for lime-soil and lime-fiber-soil mixtures

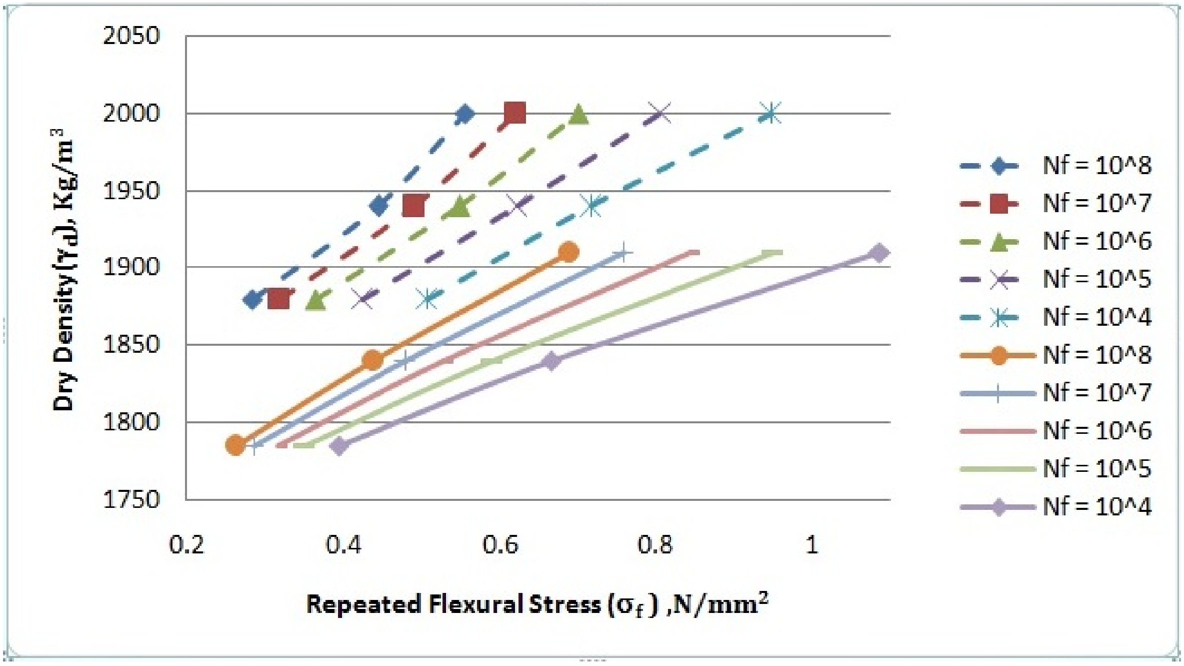

Figure (3): Comparison of fatigue life of lime-laterite and lime - fiber - laterite soil mixtures with dry density and repeated flexural strength

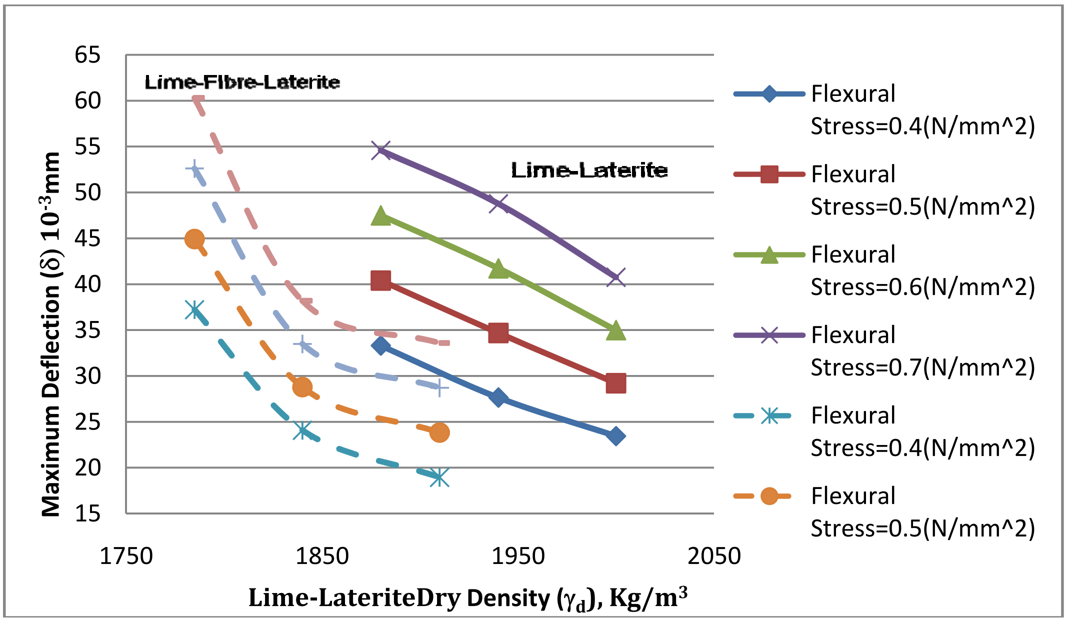

Figure (4): Relationship between deflection, dry density and flexural stress for lime-laterite and lime-fiber-laterite soil mixtures

Correlation between Variables of Flexural Fatigue Characteristics of Lime-Laterite and Lime-Fiber-Laterite Soil Mixtures

The variables of flexural fatigue characteristics considered in the study are: stress ratio S, fatigue life N_f, dry density γ_d, applied stress level σ_f, central deflection δ and dynamic flexural modulus E_{DF} (Bhattacharya and Pandey, 1986).

The lime-laterite and lime-fiber-laterite beam specimens at three dry density levels; light, medium and heavy, have been tested under repeated flexure. The variables have been plotted on scatter diagrams to obtain altogether twenty one equations between (i) S-log N_f , (ii) γ_d/σ_f-log N_f, (iii) σ_f-δ and iv)E_{DF} -γ_d for determination of fatigue characteristics of the material. However, in this paper, the relationship between E_{DF} and γ_d has not been presented. Least square regression technique has been used to develop the regression equations.

The summary of the eighteen equations on flexural fatigue test results excluding three equations between E_{DF} and γ_d are presented in Table 2.

Table 2. Summary of correlation equations on flexural fatigue test results

Material	Compaction	Equation between Variables	Equation No.
Lime 5%+Laterite Soils	Light γ_d =1880 kg/m^3	$S = 0.96 - 0.114 \log N_f$, R = 0.8727	3
		$\frac{\gamma_d}{\sigma_f} = 781 + 730.32 \log N_f$, R = 0.9049	4
		$\sigma_f = -69.67 \times 10^{-3} + 0.0141\ \delta$, R = 0.9842	5
	Medium γ_d = 1940 kg/m^3	$S = 0.95 - 0.099 \log N_f$, R = 0.8779	6
		$\frac{\gamma_d}{\sigma_f} = 1054 + 412.48 \log N_f$, R = 0.887	7
		$\sigma_f = 7.438 \times 10^{-3} + 0.0142\ \delta$, R = 0.978	8
	Heavy γ_d = 2000 kg/m^3	$S = 0.982 - 0.09 \log N_f$, R = 0.888	9
		$\frac{\gamma_d}{\sigma_f} = 619 + 372.57 \log N_f$, R = 0.858	10
		$\sigma_f = 6.687 \times 10^{-3} + 0.01734\ \delta$, R = 0.981	11
Lime 5%+0.6%-2cm Fiber+Laterite Soils	Light γ_d =1785 kg/m^3	$S = 0.974 - 0.085 \log N_f$, R = 0.96	12
		$\frac{\gamma_d}{\sigma_f} = 2263 + 564.3 \log N_f$, R = 0.9626	13
		$\sigma_f = -0.084 + 0.013\ \delta$, R = 0.9082	14
	Medium γ_d =1840 kg/m^3	$S = 0.871 - 0.073 \log N_f$, R = 0.962	15
		$\frac{\gamma_d}{\sigma_f} = 1311 + 361.41 \log N_f$, R = 0.9335	16
		$\sigma_f = -0.11247 + 0.02127\ \delta$, R = 0.9879	17
	Heavy γ_d =1910 kg/m^3	$S = 0.875 - 0.068 \log N_f$, R = 0.8753	18
		$\frac{\gamma_d}{\sigma_f} = 746 + 252.83 \log N_f$, R = 0.898	19
		$\sigma_f = 0.01135 + 0.0205\ \delta$, R = 0.9822	20

Table 3. Comparison of fatigue results of lime (5%) + laterite and lime (5%) + 0.6% - 2 cm fiber + laterite soils

Compaction	**Dry Density (γ_d), kg/m^3**		**Fatigue Life (N_f)**	**$\frac{\gamma_d}{\sigma_f}\frac{kg/m^3}{N/mm^2}$**		**Repeated Flexural Stress σ_f, N/mm^2**		**Deflection δ in microns (10^{-3} mm) at σ_f**		**Remarks**
1	**Lime-Laterite 2**	**Lime-Fiber-Laterite 3**	**4**	**Lime-Laterite 5**	**Lime-Fiber-Laterite 6**	**Lime-Laterite 7**	**Lime-Fiber-Laterite 8**	**Lime-Laterite 9**	**Lime-Fiber-Laterite 10**	**11**
Light	1880	1785	10^5	4433	5084	0.42	0.35	34.73	33.38	Calculated from Equations 4,5,7,8,10 and 11 for lime-laterite and from Equations 13,14,16,17, 19 and 20 for lime-fiber-laterite soils
Medium	1940	1840		3116	3118	0.62	0.59	43.14	33.03	
Heavy	2000	1910		2482	2010	0.81	0.95	46.32	45.79	
Light	1880	1785	10^6	5163	5649	0.36	0.32	30.47	31.08	
Medium	1940	1840		3529	3479	0.55	0.53	38.20	30.20	
Heavy	2000	1910		2854	2263	0.70	0.84	39.98	40.42	

DISCUSSION OF RESULTS

Flexure specimens of lime-laterite and lime-fiber-laterite soil mixtures tested under pulsating load at stresses ranging from 31.5% to 89% of ultimate flexural strength have yielded linear regression relationships between S-log N_f,γ_d/σ_f –log N_f and σ_f - δ with correlation coefficients varying from 0.858 to 0.984 according to Equations 3 through 20. Swanson and Thompson have also obtained linear relationships for flexural fatigue between S and log N_f for four typical lime soil mixtures (Swanson and Thompson, 1967) having different slopes of the regression lines, indicating that fatigue response of lime-laterite materials is not unique and varies from soil to soil. Slope is a measure of the fatigue response of the material, where the greater the slope is, the faster is the rate of damage. Slopes of the fatigue lines as evident from Equations 3,4,6,7,9 and 10 for lime-laterite soils and from Equations 12, 13, 15, 16, 18 and 19 for lime-fiber-laterite soils are higher for lightly compacted soil mixtures, indicating that fatigue damage takes place at faster rates when dry density is comparatively low; that is when compaction is lighter. Further, the slopes of Equations 3, 6 and 9 are greater than the corresponding slopes of Equations 12, 15 and 18, thus there is general improvement of flexural fatigue response of lime-fiber laterite mixtures over plain lime-laterite mixtures.

It has been observed that fiber reduces the density of the soil mix on average by 5.0% for all compaction levels; light to heavy. With addition of 2 cm long fibers, the modulus of rupture initially decreases at 0.2%, then increases and becomes maximum at 0.6% of fiber. Further addition reduces both strength and workability. The variation of MR with dry density and percentage of fiber is shown in Fig.1.

Flexural fatigue life of lime-laterite and lime-fiber-laterite soils compacted at light, medium and heavy levels has been correlated with stress ratios giving linear relations between S and log N_f in the form of $S = a - b \log N_f$, where 'a' is a constant having a value near to 1.0 and 'b' is the slope of the line, similar to the relationships obtained by Swanson and Thompson. Another parameter which has been correlated with log N_f is γ_d/σ_f with the advantage that both γ_d and σ_f are directly measured, whereas in the S-log N_f relationship only one quantity is measured which is σ_f. Therefore, for flexural specimens of lime-soil and lime-fiber-soil composites of varying densities, γ_d/σ_f may be considered as a better parameter for establishing the relationship with fatigue life, N_f. In the relationship between γ_d/σ_f and $\log N_f$, the slope is generally an indication of fatigue response, where the more the slope is, the more is the susceptibility of the material to fail under fatigue; that is the rate of damage is higher. Lime-laterite materials have yielded steeper slopes than lime-fiber-laterite materials for all cases of compaction. The values of the constants have, however, also contributed to determining the fatigue life.

Lime-laterite and Lime-fiber laterite materials show very high correlation between repeated flexural stress and the consequent deflection according to Equations 5,8,11,14,17 and 20 with correlation coefficients varying from 0.978 to 0.9879 with the exception of 0.9082 in the case of lightly compacted lime-fiber laterite materials. The materials may, therefore, be considered as linearly elastic for pavement design. The denser the material is, the less is the deflection at a particular stress, and *vice-versa*.

It is evident from the values given in Table 4 and Table 5 that lime-fiber-laterite soils under heavy compaction develop higher fatigue resistance than plain lime-laterite soils. At heavy compaction, density and static flexural strength of lime-fiber-laterite mixture are respectively 95.5% and 115.1% of those of lime-laterite mixture. The ratios of stresses to which lime-fiber-laterite and lime-laterite mixtures may be subjected vary from 1.135 to 1.254 for N_f varying from 10^4 to 10^8 (Row 9 of Table 4). The ratios of fatigue lives of lime-fiber-laterite and lime-laterite mixtures at heavy compaction vary from 226 to 22.79 for repeated flexural stresses varying from 0.6 to 0.8 N/mm^2. At light and medium compaction, lime-fiber-laterite mixtures do not show any improvement of fatigue resistance. This is also supported by the static flexural strengths of lime-fiber-laterite mixtures, being 62% and 88.5% of those of lime-laterite mixtures at light and medium compaction levels, respectively.

Table 4. Comparison of fatigue flexural stresses of lime (5%) + laterite and lime (5%) + 0.6% - 2 cm fiber + laterite soils at different compactions

Row No. 1	**Description of Mix 2**	**Compaction 3**	**Dry Density kg/m^3 4**	**Modulus of Rupture N/mm^2 5**	**Fatigue Flexural Stresses, σ_f in N/mm^2 for Fatigue Life, N_f of**					**Remarks 11**
					10^4 6	**10^5 7**	**10^6 8**	**10^7 9**	**10^8 10**	
1.0	Lime-Laterite	Light	1880	1.048	0.51	0.42	0.36	0.32	0.28	Read from Fig. 3
2.0	Lime-Fiber-Laterite		1785	0.65	0.39	0.35	0.32	0.29	0.26	
3.0	Ratio of Values of Row 2 to Row 1		0.949	0.62	0.765	0.833	0.889	0.900	0.929	
4.0	Lime-Laterite	Medium	1940	1.306	0.72	0.62	0.55	0.49	0.45	Read from Fig. 3
5.0	Lime-Fiber-Laterite		1840	1.156	0.67	0.59	0.53	0.48	0.44	
6.0	Ratio of Values of Row 5 to Row 4		0.948	0.885	0.93	0.952	0.964	0.980	0.980	
7.0	Lime-Laterite	Heavy	2000	1.564	0.96	0.81	0.70	0.62	0.55	Read from Fig. 3
8.0	Lime-Fiber-Laterite		1910	1.800	1.09	0.95	0.84	0.76	0.69	
9.0	Ratio of Values of Row 8 to Row 7		0.955	1.151	1.135	1.173	1.20	1.226	1.254	

Table 5. Comparison of fatigue life of lime (5%) + laterite and lime (5%) + 0.6% - 2 cm fiber + laterite soils at different compactions and repeated flexural stress

Row No.	**Description of Mix**	**Compaction**	**Dry Density kg/m^3**	**Modulus of Rupture N/mm^2**	**Fatigue Life (N_f) at Repeated Flexural Stresses, σ_f in N/mm^2**					**Remarks**
					0.4	**0.5**	**0.6**	**0.7**	**0.8**	
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1.0	Lime-Laterite	Light	1880	1.048	2.32x10^5	1.2 x10^4				N_f calculated from Equations 4 and 13
2.0	Lime-Fiber-Laterite		1785	0.65	7.9x10^3	207				
3.0	Ratio of Values of Row 2 to Row 1		0.949	0.62	0.034	0.017				
4.0	Lime-Laterite	Medium	1940	1.306	1.59x10^9	7.1x10^6	1.92x10^5			N_f calculated from Equations 7 and 16
5.0	Lime-Fiber-Laterite		1840	1.156	1.26x10^9	3.59x10^6	7.21x10^4			
6.0	Ratio of Values of Row 5 to Row 4		0.948	0.885	0.79	0.50	0.37			
7.0	Lime-Laterite	Heavy	2000	1.564			1.93x10^7	1.02x10^6	1.12x10^5	N_f calculated from Equations 10 and 19
8.0	Lime-Fiber-Laterite		1910	1.800			4.37x10^9	6.94x10^7	3.11x10^6	
9.0	Ratio of Values of Row 8 to Row 7		0.955	1.151			226	68.2	27.8	

CONCLUSIONS

In light of the investigation results, the following conclusions can be drawn.

1. Lime treatment, 5% of hydrated lime by weight of air-dried soil being the optimum requirement, substantially improves the strength of laterite soil. Modulus of rupture (MR) increases with dry density, γ_d with high correlation existing between the variables.
2. Flexural strength, as well as MR of cured lime-laterite and lime-fiber-laterite soil specimens increase with dry density giving good correlation between the variables and can be predicted by Equations 1 and 2. MR values at heavy compaction are respectively 149% and 277% of MR values at light compaction for lime-laterite and lime-fiber-laterite soil beams (Table 5, column 5).
3. Flexural strength of fiber reinforced lime-laterite soil mixture are 62%, 88% and 115% of those of plain mixture at light, medium and heavy compaction levels, respectively (Table 5, column 5).
4. Examination of Equations 3 through 20 reveals that good correlation exists between flexural fatigue life and stress ratio, between flexural fatigue life and ratio of dry density to repeated flexural stress and between deflection and repeated flexural stress of cured specimens. The relationships are all linear and statistically significant.
5. Stress-deflection relationships under repeated flexure indicate that both lime-laterite and lime-fiber-laterite composites are linear elastic materials under cyclic loading. Elastic layered analysis may be applied for computation of stresses in pavements using such materials.

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