Lowland Technology International 2020; 21 (Issue 4): 205-214
International Association of Lowland Technology (IALT): ISSN 1344-9656
Special Issue on: Engineering Geology and Geotechniques for Developing Countries

Research Paper

Laterites and Lateritic Soils: Geology, Engineering Properties and Problems

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ARTICLE INFORMATION

Article history:

Received: 18 October, 2019
Received in revised form: 25 November, 2019
Accepted: 28 November, 2019
Publish on: 06 March, 2020

Keywords:

Lithomargic soil
Erosion
Hole erosion test
Lateritic formations
Slope stability

ABSTRACT

Lateritic soils are abundantly available in the Konkan belt in the western coast of peninsular India, in the four southern states namely - Kerala, Karnataka, Goa and Maharashtra. Along with heavy rainfall (annual rainfall of 2000mm - 4000mm), the region is characterised by high humidity and little variation in temperatures. The typical stratification in lateritic areas consists of soft to hard lateritic crust at the top – about 3m thick, underlain by a layer of lithomargic clay (8 to 10m thick) underlain by parent rock, which is granitic gneiss. This paper briefly discusses the following aspects of lateritic soils (a) geotechnical properties, including those of laterites, lithomargic clays, lateritic lithomarges and lithomargic laterites (b) erosion studies from hole erosion tests (c) slope stability problems of excavated slopes in lateritic formations (d) role of vegetation i.e. turfing and/or trees on slopes in the stability of slopes. It is concluded that lateritic soils, especially lithomargic clays and lateritic lithomarges (1) behave somewhat like dispersive soils. (2) They are highly erosive by nature, especially lithomargic clays with higher content of sand and silt (3) Stability of both excavated and embankment slopes depends on good drainage control. Providing berms and vegetation on slopes adds to stability of slopes.

1. Introduction

Slope stability problems have been faced throughout history when human beings or nature have disrupted the delicate balance of natural soil slopes. The increasing demand for engineered cut and fill slopes in construction projects has only increased the need to understand all factors affecting its stability and various analytical methods, investigative tools, and stabilization methods to solve slope stability problems. Stability of slopes is also affected by presence or absence of vegetation (turfing or trees) on slopes, hydrological factors like intensity of rainfall, surface flow etc. Vegetation directly influences on the soil both at the surface, protecting and restraining the soil, and at depth, increasing the strength and competence of the soil mass. Effects of these may be adverse or beneficial, depending on the circumstances, and most have direct engineering relevance (Coppin and Richards, (1990)).

The study area considered here is coastal Karnataka in India, where the soil is mainly comprised of laterites and lateritic soils. This coastal area receives copious amount of rainfall and a lot of developmental activities are taking place. The soil stratification in lateritic areas

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Note: Discussion on this paper is open until September 2020

consists of lithomargic clays, which are products of laterization, sandwiched between the hard and porous weathered laterite crust at the top and the hard parent rock of granite or granitic gneiss underneath. These lithomargic clays which are extensively used in construction purposes behave as dispersive soils and are found to be highly erosive in nature. These lithomargic clays are locally called as ‘shedi soils’. Excavated slopes for railway and highway projects in such lateritic formations pose serious erosion and slope stability problems (Sabhahit and Rao, (2004)), especially, due to the presence of these shedi soils and seepage pressures from stagnated water at top. Caving – in of the lithomargic layers in excavated slopes is a common sight along NH 66 and along Konkan rail route, right from Trivandrum in south to Mumbai in north.

The present study is mainly categorized into two parts. In the first portion, hole erosion tests (Wan and Fell, (2002); Wan and Fell, (2004); Benahmed and Bonelli, (2012)) have been conducted to study the erodibility characteristics of the shedi soil. A number of hole erosion tests are conducted on controlled lithomargic clay samples with varying percentage of fines. The influence of moulding water content, head causing flow and percentage silt content on the erosion characteristics of controlled lithomargic clay samples are being studied. In the second portion, slope stability analysis is conducted using Plaxis 2D considering the effect of vegetation (trees and turfing) on and near slope, precipitation, ponding at top and seepage through the excavated slope.

1.1 Laterite and Lateritic Soils

The term "laterite" was coined by a Scottish scientist Dr. Francis Buchanan in 1807 in India, from a Latin word "later" meaning brick (Makasa,1998). From the geological point of view laterite also can be defined as, “A kind of vesicular rock composed essentially of mixture of hydrated oxides of aluminum and iron with small percentage of other oxides such as manganese or titanium” (Gidigasu, 1976). It is defined as soil layer that is rich in iron oxide and derived from a wide variety of rocks that weather under strongly oxidizing and leaching conditions. It forms in tropical and subtropical regions where the climate is humid. Lateritic soils may contain clay minerals; but they tend to be silica-poor, for silica is leached out by waters passing through the soil.

According to Aleva and Creutzberg (1994) laterite (or rather some varieties of it) is formed by a process, by which certain rocks undergo superficial decomposition, with the removal in solution of combined silica, lime, magnesia, soda, potash, and with the residual accumulation, assisted, no doubt, by capillary action, metasomatic replacement, and segregative changes of a hydrated mixture of oxides of iron, aluminium, and titanium, with more rarely, manganese. These oxides and hydroxides of iron, aluminium, titanium, and manganese are designated the lateritic constituents. This residual rock is true laterite, and the presence of any considerable proportion (> 10 percent) of non-lateritic constituents requires expression in the name, as it always indicates want of completion in the process of lateritization. True laterite contains, then, 90 to 100 percent of lateritic constituents. There is often a gradation in composition between true laterite as defined above and lithomarge which is taken as the amorphous compound of composition $2H_2O.Al_2O_3.2SiO_2$, corresponding to the crystalline mineral kaolinite of the same composition. For rocks intermediate between laterite and lithomarge the terms ‘lithomargic laterite’ and ‘lateritic lithomarge’ are available, The former being applied to forms containing 50-90 percent of lateritic constituents, and the latter to forms containing only 25 to 50 percent of lateritic constituents.

Laterites have been long known in India, where they occupy large areas of Deccan Peninsula. High level laterites cap the summit of hills and plateau on the highlands of central and Western India. Low level laterite is found in long bands along both coasts of Deccan Peninsula.

A large number of cuttings in laterite soils are encountered during the implementation of large projects like Konkan Railway Project, Varahi canal Project, highway projects etc. The depth of the cuttings varies from 1 to 20 m and various geotechnical methods have been adopted to stabilize the excavated slopes. Laterite formations in this area consist of top hardened vesicular layer that is highly porous, followed by lithomargic clay layer over the weathered residual soil and parent rock. The Konkan belt falls on the windward side of the southwest monsoon and, thus, witnesses heavy rainfall, which often leads to boulder falls and soil slips in the region. Due to the porous nature of laterites present, water seeps into the underlying clay soil. This increases the density of the rocks and decreases their hold in the soil base, which becomes soft due to water absorption, resulting in boulder falling and soil slippage from slopes, cuttings, and tunnels.

Lithomargic clays, are a problematic soil, since they lose much of their strength when they come in contact with water and behave like dispersive soils. In addition to loss of strength of lithomargic clays due to saturation, erosion (both internal erosion and external erosion) has also contributed to instability of slopes in the region. Slope and embankment failures in lithomargic soils have resulted in enormous economic losses, especially during the monsoon season. Various stabilization methods using cement, quarry dust, GBFS, lime, sand and coir (Nayak and Sarvade, (2012); Sekhar et al., (2017); Ravi Shankar et al., (2012); Shivashankar et al., (2015)) have been adopted with lithomargic clays to improve their strength behavior. SEM and XRD studies (Darshan and Sitaram, (2017)), electrical resistivity studies (Vincent et al., (2017)) have also been conducted on stabilized lithomargic clays. Very few research studies have been reported on the erosion characteristics of lithomargic clay and its impact on stability of excavated slopes in lateritic formations.

2. Erosion studies on lateritic lithomarge soils (lithomargic clays)

In the present study, the influence of various parameters; such as moulding water content, head causing flow and percentage silt content on critical shear stress and erosion rate index (I_h) of lithomargic clay are carried out by conducting hole erosion tests.

2.1 Materials Used

Two lithomargic clay samples were procured from two nearby sites from depths of 2-3m below ground level, below the laterite layers. These lithomargic clay samples had particle sizes finer than 150µ sieve size. The first procured sample (C0 sample) had higher percentage of clay fraction and second procured sample (M0 sample) had higher percentage of silt fraction. Both these samples were blended in the laboratory with different percentages (10%, 20%, 30% and 40%) of river sand (passing 1.18mm sieve) to prepare controlled samples. These samples are designated as C10, C20, C30, C40 (for C0 blended samples) and as M10, M20, M30, M40 (for M0 blended samples) respectively. Controlled soil samples thus prepared were then studied for both geotechnical and erosion properties.

2.2 Samples Tested

A series of hole erosion tests are carried out on all the ten samples at various water contents (namely at 50% of OMC, at OMC and at full saturation) with the suitable range of head (within the laboratory constraints). The basic geotechnical properties of all the C and M soil samples are listed in Table 1 and Table 2 respectively.

Table 1 Geotechnical properties of C samples

Parameter		C0	C10	C20	C30	C40
Specific gravity (G)		2.56	2.57	2.61	2.63	2.65
Maximum Dry Density (γ_{dmax}) (kN/m^3)		14.2	14.3	14.8	15.7	15.9
Optimum Moisture Content (OMC) (%)		27.0	26.4	24.3	23.0	19.6
Void ratio (at γ_{dmax})		0.77	0.76	0.73	0.64	0.63
Plastic Limit (%)		30.0	29.0	26.0	25.0	24.0
Liquid Limit (%)		53.0	50.0	45.0	41.0	39.0
Plasticity Index		23.0	21.0	19.0	16.0	15.0
Fine fraction (Dusty fraction) (%)	Clay fraction	55.3	49.8	44.2	38.7	33.2
	Silt fraction	42.7	38.4	34.2	30.7	26.3
Coarse fraction (%)	Sand fraction	2.0	11.8	21.6	30.6	40.5
	Gravel fraction	0.0	0.0	0.0	0.0	0.0
Unified Soil Classification		MH	MI-MH	CI	CI	CI

Table 2 Geotechnical properties of M samples

Parameter		M0	M10	M20	M30	M40
Specific gravity (G)		2.49	2.50	2.52	2.54	2.58
Maximum Dry Density(γ_{dmax}) (kN/m^3)		13.2	14.0	15.2	15.4	16.6
Optimum Moisture Content (OMC) (%)		27.2	24.6	20.2	18.8	16.4
Void ratio (at γ_{dmax})		0.81	0.76	0.63	0.61	0.53
Plastic Limit (%)		36.0	31.0	25.0	23.0	22.0
Liquid Limit (%)		48.0	46.0	41.0	36.0	31.0
Plasticity Index		12.0	15.0	16.0	13.0	9.0
Fine fraction (Dusty fraction) (%)	Clay fraction	16.6	13.3	13.2	12.3	7.4
	Silt fraction	79.9	74.5	64.1	55.1	51.0
Coarse fraction (%)	Sand fraction	3.5	12.2	22.7	32.6	41.6
	Gravel fraction	0.0	0.0	0.0	0.0	0.0
Unified Soil Classification		MH	MI	CI	CI	CL

2.3 Hole Erosion Test (HET)

2.3.1 Experimental Setup

The experimental setup consists of a constant head tank, an inlet chamber, the mould along with the specimen (thickness of 105mm and 83mm diameter), an overflow container, a collecting tank and a weighing balance. The constant head upstream tank is provided with a continuous water supply. The inlet chamber is connected to the constant head tank. It is filled with 20mm coarse aggregates to reduce the impact of water on the soil specimen. An air valve is provided in the inlet chamber to remove air bubbles (if any) during the experiment. The plate in between the inlet chamber and the specimen is provided with a hole of diameter 5cm to ensure uninterrupted flow of water through the specimen. A wire mesh is fixed on the plate to avoid the coarse aggregates from disturbing the specimen. The hole erosion test apparatus is shown in Fig. 1.

Fig.1 Hole Erosion Test apparatus (without constant head tank)

The weight of the overflowing water is continuously measured. The discharge at various time intervals was calculated from the weight and the head was obtained by measuring the vertical distance between the water level in the overhead tank and the free water surface at the downstream end. The test is terminated (by closing the downstream valve) upon observing one of the following conditions i) several minutes of accelerating flow, no significant erosion in one hour at maximum test head, ii) extreme erosion with hole enlargement, reaching the walls of the mould (Luthi, 2011).

2.3.1 Test Procedure

A hole of 6mm diameter was drilled along the central longitudinal axis of the specimen. The inlet chamber is filled with 20mm gravels in order to regulate the flow of water on the upstream side of the sample and also to reduce the impact of water on the specimen surface. The soil sample is placed between the inlet chamber and overflow container. The flow rate at the downstream side of the apparatus was measured at different time intervals during the test. The final hole diameter is noted after the test. According to Wan and Fell (2002, 2004), the erosion rate (ε) changed linearly with the hydraulic shear stress (τ_t). The coefficient of soil erosion C_e is the slope of the straight line obtained from plotting ε against τ_t. The critical shear stress, τ_c can be obtained graphically by extrapolating the plot of ε versus τ_t to zero.

The rate of erosion of a soil can be represented by an erosion rate index' "I_h" which can be derived from the results of the hole erosion test as:

$$I_h = -\log (C_e)$$

The rate of progression of erosion is classified as per Table 3. Soils that erode rapidly have lower I_h values than soils that erode slowly.

Table 3 Qualitative relation of representative erosion rate index and progression of internal erosion as recommended by Wan and Fell (2002, 2004)

Group number	Erosion Rate Index (I_h)	Progression of internal erosion
1	Less than 2	Extremely rapid
2	2-3	Very rapid
3	3-4	Moderately rapid
4	4-5	Moderately slow
5	5-6	Very slow
6	Greater than 6	Extremely slow

2.4 Hole Erosion Test Results

2.4.1 Determination of Critical Head

All the C samples underwent progressive erosion from a head of 110cm. Tests were conducted on C specimens at heads of 110cm, 125cm, 140cm and 155cm. Test results indicated slaking for C samples when tested at various heads ranging from 50cm to 100cm. In contrast, all the M samples underwent progressive erosion from a head of 30cm. Tests were

Fig.2 (a) Sample before test with 6mm hole (b) Sample(C10) which showed very less surface erosion after HET when coated with wax on its surface (c) Cross section of a sample after HET

conducted on M specimens at heads of 30cm, 40cm, 60cm and 70cm. At higher heads the specimens were washed off. The soil samples at different stages or conditions of HET are shown in Figs.2 (a) to (c).

2.4.2 Influence of Change in Moulding Water Content

C samples **-** The variation of erosion rate index (I_h) of C samples with head causing flow at different moulding water contents are shown in Fig. 3 (a) to (c). At 50% OMC condition, it can be observed that the original lithomargic clay sample C0 has the maximum rate of erosion and sample C40 is having least erosion rate and therefore is more stable. C0 has the highest void ratio and hence is the most erodible while C40 has the least void ratio. In addition, the sand fraction in the C40 sample adds stability to the soil structure.

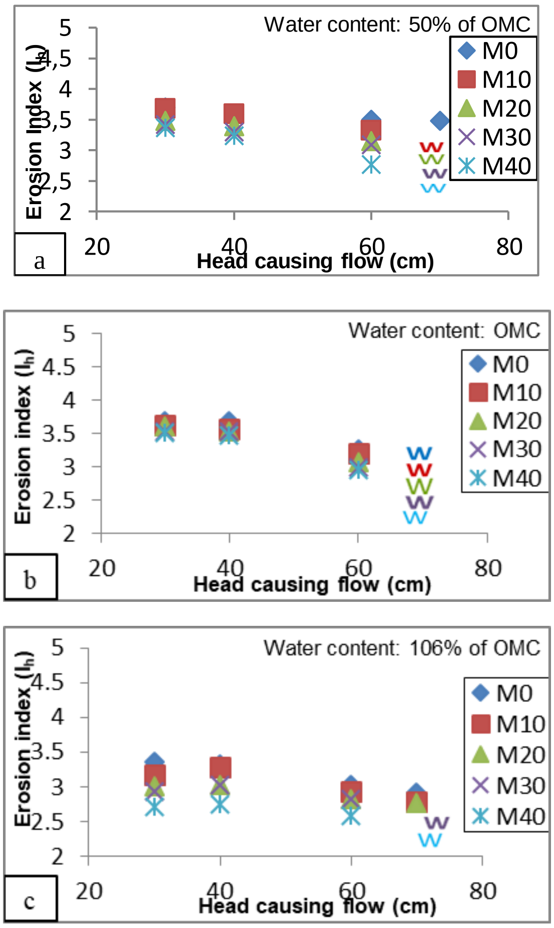


Fig.4 Variation of Erosion rate index of M samples compacted at a) 50% of OMC b) OMC c) 106% of OMC (Saturation condition) {Note: W denotes wash off occurred beyond this head}

At OMC condition, the C40 sample is seen to be more stable than C0 sample. At 110% of OMC (fully saturated condition), C0 sample which had more cohesion due to high percentage of fine fraction of soils was more stable. In C0 sample, it was observed that the fines eroded as individual particles and not as lumps. At higher heads, samples containing higher sand content were washed off.

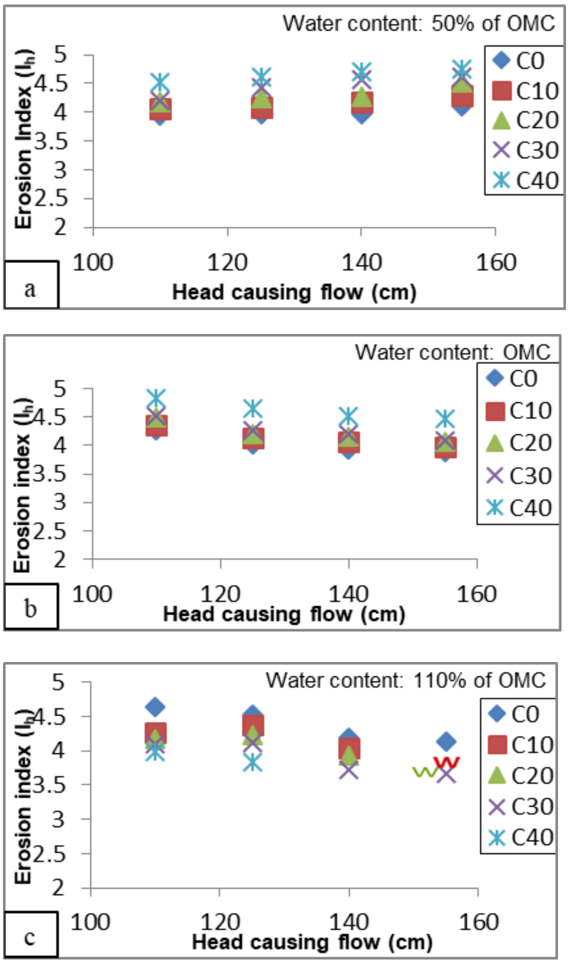


Fig.3 Variation of Erosion rate index of C samples compacted at a) 50% of OMC b) OMC c) 110% of OMC (Saturation condition) {Note: W denotes wash off occurred beyond this head}

M samples **-** The variation of erosion rate index (I_h) of M samples with head causing flow at different moulding water contents are shown in Fig. 4 (a) to (c). At 50% OMC condition, it can be observed that the M40 sample (M0 sample + 40% sand) has lower I_h value and thus has the maximum rate of erosion. The original lithomargic soil sample (sample M0) has higher I_h value and so is the most stable. At OMC condition, M0 sample had maximum cohesion due to the increase in water content and hence was more stable. At 106% of OMC (fully saturated condition), M0 sample had fullest cohesion due to the highest degree of saturation and hence was more stable.

2.4.3 Critical Shear Stresses

Critical shear stress is defined as the minimum stress to be applied on the soil surface to initiate progressive erosion. In general it is found that at optimum moisture content condition, the soil is most stable and shows a higher value of critical shear stress. Figure 5(a) to (b) shows the critical shear stress variation of samples at different moulding water contents for C and M samples. In the case of C samples, critical shear stress varies from 200N/m^2 to 400 N/m^2. At 110% OMC, since C0 sample was most stable it has the highest value of critical shear stress. At OMC and 50% OMC conditions, C40 sample being more stable shows a higher value of critical shear stress. In the case of M samples, critical shear stress varies from 45N/m^2 to 125N/m^2. At all the initial moulding water content, M0 sample shows a higher value of critical shear stress. It can be clearly observed that soils with higher silt content (M samples) show a lower critical stress than those of soils with higher clay content (C samples).

2.4.4 Variation of erosion index with silt fraction

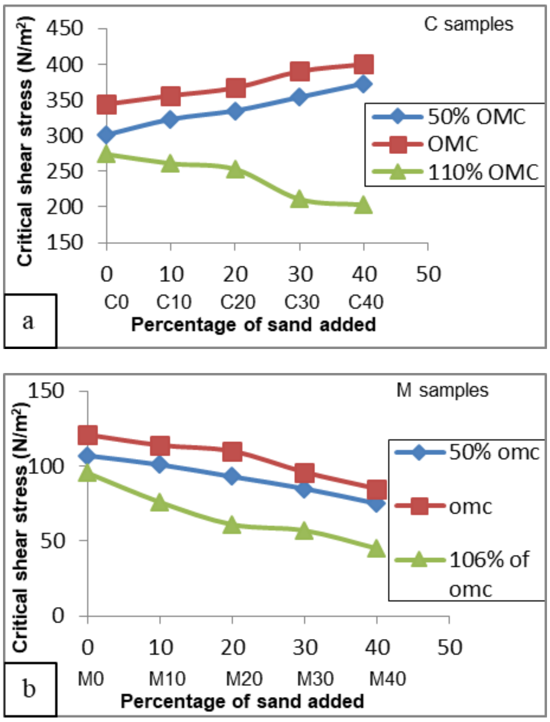


Fig.5 Critical shear stress variation of samples at different moulding water contents for (a) C samples (b) M samples

A comparison of erosion rate indices is studied for the M samples (having comparatively higher silt content) and C samples to understand the influence of silt content on erosion index values. Figures 6 (a) to (c) show the variation of erosion index with silt content for different conditions of moulding water content.

It is observed that the C samples have lower erosion rate when compared to the M samples which have higher silt content. Since the M samples have higher silt fraction, the structure of soil mass is less stable. However, in the C samples, as silt content is less, the structure of soil mass is more stable with the fine clay particles filling the voids of the coarser particles leading to higher inter-particle shearing resistance and higher stability of the C samples.

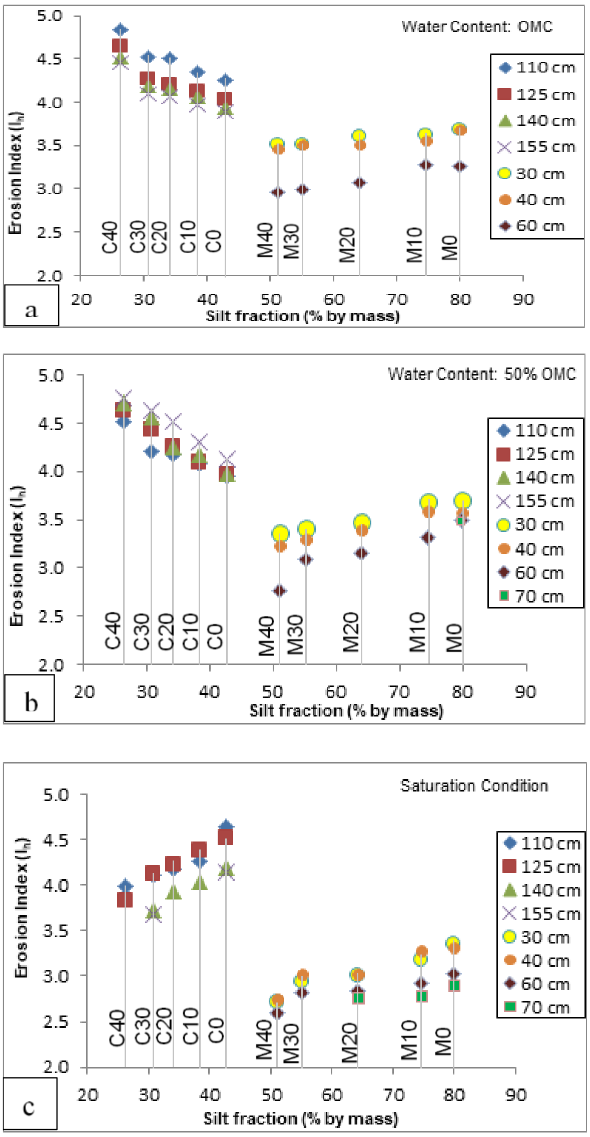


Fig.6 Variation of erosion index with silt content for (a) OMC (b) 50% of OMC (c) Saturation condition

3. Numerical Analysis On Excavated Slopes In Lateritic Formations Considering Vegetation

3.1 Methodology

Slope stability analysis is a complex problem. It does not involve just geotechnical factors, but also very much influenced by hydrological factors (precipitation, ponding, seepage), and biological factors (vegetation and turfing). However, since it is difficult to study the influence of all the factors together, the influence of these various factors are studied separately.

The slope stability analysis is conducted to simulate a situation that occurs both during the months of heavy rainfall in which the ground water table rises to ground level (undrained condition) in a vegetated and excavated slope. The slope considered consists of laterite for the top 3m underlain by lithomargic clay and a hard rock (granitic gneiss) below it. Water gets accumulated on the top hard laterite near to the crest (ponding) for a considerable width and for varying depths (i.e. 1m, 2m and 3m respectively in different cases) for a period of 3 days was considered. Tree is provided at toe, mid and crest (top) position of the slope. Cut slope angles for the excavated slope were varied as 30, 40, and 45 degrees for slopes of height 11m, and 8m. A berm of 3m width was provided at mid- height of the slope. Effect of turf vegetation is also included as a layer of soil of 3m thickness, along the slope, with 30% increased cohesion than the original soil layer (Shivashankar et al. (2014)). Spacing between each tree (typically a neem tree is considered) is considered to be 3m and height of tree is taken as 10m. Height of crown is 5m, wind velocity is around 15kmph and drag coefficient is 0.2 to 0.5 for moderate wind. The wind force (direction is upward of the slope) developed on the tree top (Coder Kim, 2010) per metre length was obtained as 7kN/m. Fig.7 shows the geometric profile of the slope.

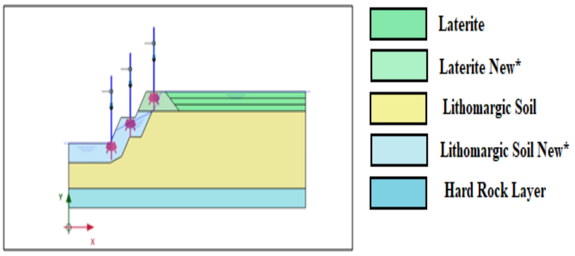


Fig.7 Geometric profile of the slope

Table 4 Properties of laterite and lithomargic soil

Properties	Laterite	Lithomargic Soil	Laterite New*	Lithomargic Soil New*
Material type	Drained	Undrained	Drained	Undrained
Young's Modulus (E) kN/m^2	4000	2000	4000	2000
Poisson's Ratio (μ)	0.3	0.3	0.3	0.3
Cohesion (c) kN/m^2	35	35 at 3m depth	45	45 at 3m depth
Angle of internal friction (ϕ) in degrees	30	0	30	0
Hydraulic Conductivity (k) m/day	0.1	0.0035	0.1	0.0035
Incremental shear strength	0	5kN/m depth	0	5kN/m depth

*Lithomargic Soil New, Laterite New- Properties of soil in which effect of turfing (30% increased cohesion) is considered

Table 5 Properties of roots used in slope stability analysis

Properties	Tap root	Branch root
E (kN/m^2)	6957000	6957000
Self-weight (kN/m^3)	10	10
Diameter (m)	0.3	0.2

Table 6 Properties of tree used in slope stability analysis

Properties	Tree
Material type	Elastic
EA(kN/m)	491000
Flexural rigidity, EI (kNm^2/m)	2766
Poison's ratio	0.35

The calculation used is fully coupled flow deformation analysis (Hamdhan and Schweiger, (2011)) in which the full interaction between deformations, consolidation and groundwater flow is solved simultaneously in the same phase. The safety analysis is carried out by phi-c reduction method. The slope is analysed as a plane strain model and Mohr-Coulomb model is selected as the material model. The tree is simulated by plate element and roots by embedded beam row element. Table 4 shows the properties of laterite and lithomargic clay. The properties of plate element (tree) and embedded beam row element (tap roots and branch roots) are shown in Tables 5 and 6 respectively (Coder Kim, 2000; Shivashankar et al. 2014).

3.2 Defining the Calculation Phases

The calculation phase has been divided into 4 phases to simulate the situation for a particular geometry with fixed slope angle. The geometric profile of slope for phase 1 to phase 4 are shown in Fig. 8 (a) to (d)

Initial phase- The excavated slope geometry and water table at ground level are defined in the initial phase, assuming the slopes are almost fully saturated during the months of June and July in the study area. The trees and turfing were introduced in this phase.

First phase- In this phase precipitation was introduced on a fully saturated slope. To simulate this, infiltration rate was applied at each of the surface boundaries. An ideal case of assumption considered in this study was that the rainfall rate is not greater than the potential infiltration rate or no surface ponding occurs. This was done to arrive at the condition that all rainfall will infiltrate into the soil without runoff and thus the actual infiltration rate is the rainfall rate (independent of time). Hence, even though the infiltration rate could be slightly less or equal to the saturated hydraulic conductivity, worst case of infiltration rate equal to saturated hydraulic conductivity was adopted. The effect of rainfall for a period of 3 days was considered. Wind load on trees (upward of slope) are activated from this phase.

Second phase- The effect of ponding (probably due to some siltation) is introduced along with the precipitation and wind load in the second phase. Ponding was provided for a depth of 1m at a distance of 2m from the crest for a period of 3 days and an additional boundary condition of seepage behavior is also added in the groundwater flow boundary condition.

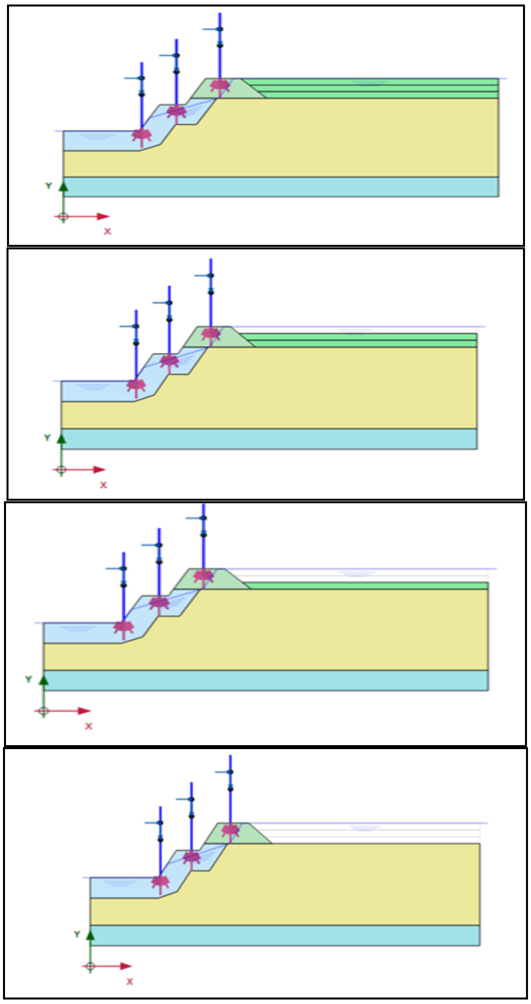


Fig.8 Geometric profile of the slope for a) Phase 1 b) Phase 2 c) Phase 3 d) Phase 4

Third phase- This phase starts from the second phase. The procedure is repeated with ponding depth increased to 2m. Hence the analysis is carried out for the next 3 days as for a comparison.

Fourth phase- This is the final phase in which the ponding depth covers whole of the top lateritic layer i.e 3m and the effect on the slope stability was carried out as done in other phases. It is to be remembered that every one of these phases, including this last phase has the precipitation and wind effect.

3.3 Percentage Variation in Factor of Safety With Respect to Tree Position

As the slope angle increases, the effect of tree at the toe of slope is more i.e. percentage increase in factor of safety when compared with bare slope is increasing. This is because the root penetration in resisting zone is more in case of steep slopes.

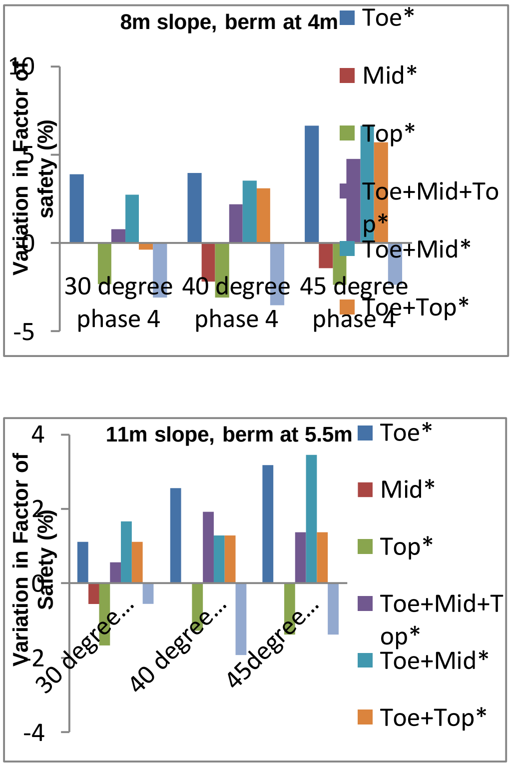
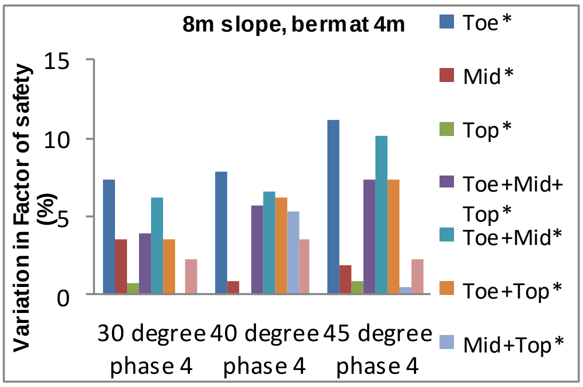


Fig.9 Percentage variation in factor of slope with tree at different position for a) 8m slope with berm at 4m b) 11m slope with berm at 5.5m (*Tree position)



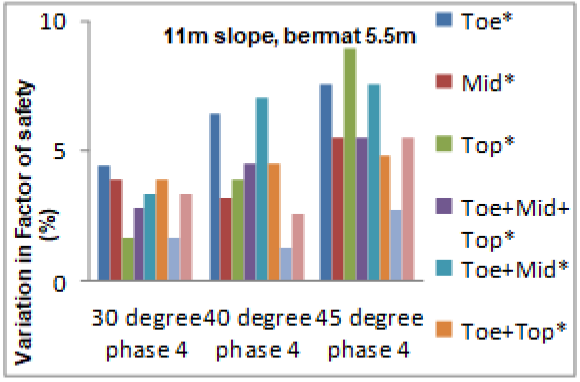


Fig.10 Percentage variation in factor of safety of turfed slope with tree at different positions for a) 8m slope with berm at 4m b) 11m slope with berm at 5.5m (*Tree position)

An increase of factor of safety is observed when tree is at toe and a 5% decrease in factor of safety is observed when tree is at Mid+Top. When the tree is placed near the mid and top a decreasing factor of safety is observed. This is due to the fact that tree weight contributes to the driving force leading to decrease in FOS. When you consider tree position at Toe+Mid+Top, Toe+Mid, Toe+Top the factor of safety increases. Figures 9 (a) to (b) shows the percentage variation in factor of safety with respect to tree position when compared with bare slope.

3.4 Percentage Variation in Factor of Safety With Respect to Turfing

A percentage increase up to 12% is obtained when turfing is provided in slopes along with the trees in undrained conditions. Figures 10 (a) to (b) shows the percentage variation in factor of safety with respect to turfing when compared with bare slope.

4. Conclusions

Lithomargic soil samples containing higher clay fraction (C Samples) and higher silt fraction (M Samples) were subjected to hole erosion tests to study its erosion characteristics. From the HET tests conducted, the C samples underwent progressive erosion after a head of 100cm whereas in the case of M samples progressive erosion was observed from a head of 30cm. Soils containing higher clay fraction showed higher resistance to erosion with critical shear stress varying from 200N/m^2 to 400N/m^2 whereas in the case of soils with higher silt fraction lower erosion resistance was observed, with critical shear stress varying from 45N/m^2 to 125N/m^2. Lithomargic clays with higher clay fraction could be classified under moderately slow erosion, whereas soils with higher silt fraction indicated very rapid to moderately rapid erosion.

From slope stability analysis, it is observed that the wind load has very little effect on factor of safety when it acts on a body of trees together. Higher factor of safety was observed when both trees and turfing were provided on the slope. Vegetation increases the apparent cohesion of the soil, thus increasing the stability and decreasing soil erosion. However, the excavation and ponding had little effect on both the slopes in the analysis considered where very less variation in the factor of safety is observed.

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