SLOPE STABILITY STUDIES OF EXCAVATED SLOPES IN LATERITIC FORMATIONS

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ABSTRACT: The study area for this paper is coastal Karnataka in India, which has laterites and lateritic soils. The soil stratification in this area mainly consists of lithomargic clay, which is a product of laterization, sandwiched between the hard and porous weathered laterite crust at the top and the hard granite or granitic gneiss underneath. This lithomargic clay, locally called as 'shedi soil' behaves as dispersive soil and is also highly erosive. In the first stage of this study, laboratory erosion studies are conducted by using the hole erosion test apparatus on controlled shedi soil samples. Erosion observed in the HET is accelerated due to slaking irrespective of dispersive nature of the soil. Erosion problems were also dealt with using a stabilizer, calcium lignosulfonate and resulted in high increase in its erosion resistance. In the second stage of this study, slope stability studies of excavated slopes in lateritic formations are conducted considering intensity of rainfall, ponding and seepage, apart from the usual geotechnical parameters. The slopes steeper than 60 degrees are not stable in the case of shedi soil considered here.

KEYWORDS: lithomargic clay, erosion, hole erosion test, slope stability

1 INTRODUCTION

The present study area considered is the coastal Karnataka in India. The soil stratification in this area, consists of hard (vesicular layer) and highly porous laterite at the surface followed by lithomargic clay. This lithomargic clay is locally called as 'shedi soil'. There are excavated slopes being devoid of natural cover and protection becomes more susceptible to erosion during heavy rainfall.

In the present study hole erosion tests (Wan and Fell (2002, 2004), Benahmed and Bonelli(2012)) have been conducted to study the erodibility characteristics of the shedi soil. The erosion resistance of controlled shedi soil samples is also studied after treating it with calcium lignosulfonate (Indraratna et.al.(2013)) that could score over the traditional stabilizers like cement and lime as it does not alter the pH of soil or affect the quality of groundwater below. Slope stability analysis is conducted using the software Plaxis 2D considering the effect of precipitation and ponding at the top of excavated slopes for varying cut slope angles.

2 EXPERIMENTAL INVESTIGATION

2.1 Preliminary Investigation

Controlled shedi soil samples were prepared by mixing varying percentage of fines i.e. 90% fines, 70% fines and 50% fines (passing through 150μ sieve) with river sand (passing through 1.18 mm) and were designated as F1, F2 and F3 respectively. The basic geotechnical properties of these soil samples are listed in the Table 1.

Table 1 Properties of controlled shedi soil samples

Parameter	F1	F2	F3
Specific gravity	2.55	2.60	2.63
Plastic Limit (%)	34.1	29.4	25.0
Liquid Limit (%)	50.2	41.2	33.5
Plasticity Index (%)	15.9	11.8	8.5
Optimum Moisture Content(OMC)	27.1	22.7	18.2
Maximum Dry Density (g/cc)	1.45	1.60	1.73
Clay size (%)	36.2	28.7	21.2
Silt size (%)	53.8	41.3	28.8
Sand size (%)	10	30	50

The soil samples treated with optimum amount of 0.6% calcium lignosufonate by dry weight of soil are referred as F1T, F2T and F3T respectively. The optimum amount of lignosulfonate to be added was found from the UCC tests conducted in the laboratory. A series of hole erosion tests were then performed on both treated and untreated samples to measure their erodibility.

2.2 Hole Erosion Test

2.2.1 *Experimental Setup*

The HET assembly comprises of three parts i.e. the upstream water tank, eroding unit and the downstream water tank. The eroding unit comprises of three chambers: a) inlet chamber b) erosion chamber c) outlet chamber.

The inlet and the outlet chambers are made up of an acrylic tube of 8cm diameter and 8cm length and are connected to the upstream and downstream tanks respectively. They are also connected to standpipes to measure the hydraulic gradient. The erosion chamber consists of a MS split mould of 8.3cm diameter and 16cm length. The entire eroding unit were kept inside an acrylic tank of size 60cm x 40cm x 40cm which acts as the downstream tank. All the three chambers of the eroding unit are connected together by using steel plates (having 6mm hole drilled at the centre) which in turn are connected by steel rods.

2.2.2 *Specimen preparation*

Test specimens were prepared at maximum dry density and optimum moisture content of the untreated soil. The treated samples were prepared by the addition of 0.6% of lignosulfonate (LS). The LS is first mixed with water and then added to the dry soil. Both the treated and untreated samples were then kept for curing in a desiccator for 7 days.

2.2.3 *Procedure*

A hole of 6mm diameter was predrilled along the central longitudinal axis of the soil sample. The sample is then placed into the test apparatus in which water flows through the hole under a constant hydraulic head for up to 45 minutes. The flow rate is measured at the downstream side of the apparatus and at different time intervals during the test until 45 minutes from the initiation of the erosion. This may have to be continued more depending on the level of flow rate and the progression of piping. Simultaneously, the pressure drop is also monitored to obtain the hydraulic gradient with time as the downstream head is continuously rising because of accelerating flow rate.

The specimen of eroded soil is then retrieved out of the apparatus and melted paraffin is poured into the eroded hole. After the paraffin solidifies, the specimen is cut out and the paraffin is carefully extracted. This paraffin represents the shape of the final eroded hole. The volume of the paraffin is used for the calculation of the final average radius of the eroded hole and the total eroded mass of dry soil during the test.

2.2.4 *Results*

The hydraulic shear stress in case of sample F1 has shown to reach a value more than 200kPa. It can be noted that as the percentage of fines increased from about 50 to 90%, the eroded mass has increased about 10 times under the corresponding test head conditions and compaction level (relative compaction = 100%)(Table 2). This could be due to the presence of high amounts of silt in the fines of shedi soil which is easily eroded even under low hydraulic shear stresses.

In the case of treated specimens, it has been found that all the samples have shown resistance to erosion after treating it with optimum amount of 0.6% of LS. There has been considerable improvement especially in case of F1 sample as F1T sample showed very little erosion (3g). It is also noted that the lignosulfonate treatment is effective when there are large quantity of fines, and especially clay. In the case of F3 sample there was good binding that occurred between the coarse sands and fine fraction as the fines have filled the spaces between the coarse particles and good interlocking is obtained when compacted at maximum dry density and optimum moisture content. The cumulative masses eroded and final hole diameters of both treated and untreated samples are shown in Table 2.

Table 2 Cumulative mass eroded and final hole diameter of both treated and untreated samples

Sample	Cumulative mass eroded(g)	Final diameter(mm)
F1	106	25
F2	18	11.3
F3	9.5	8.9
F1T	3	7.2
F2T	8.26	7.5
F3T	6	8

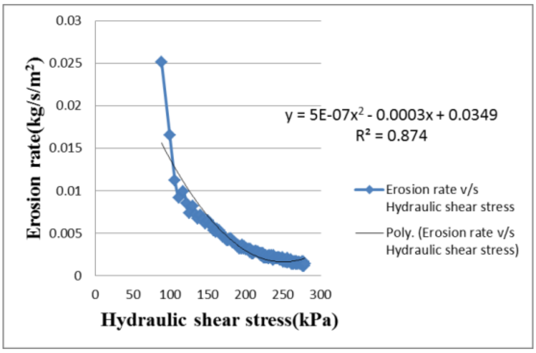

Fig. 1 Erosion rate v/s hydraulic shear stress for F1 sample

For both treated and untreated samples the decrease in erosion rate with increasing hydraulic shear stress (Fig. 1) suggests that critical shear stress has not been exceeded or the applied hydraulic shear stresses are still below the critical stress necessary to initiate progressive erosion. The cumulative mass eroded with time indicated that erosion has decreased with the decrease in the percentage of fines. However the mechanism of erosion has been complicated and further accelerated by slaking. Slaking is the breakdown of unconfined soil after exposure to air and subsequent immersion in water and no external confining pressure is assumed to act over the soil prior to immersion. One of the important characteristics associated with slaking is that it can occur under low hydraulic shear stresses. The F1 sample showed considerable slaking along with dispersion.

3 NUMERICAL ANALYSIS ON EXCAVATED SLOPES CONSIDERING PRECIPITATION AND PONDING

The analysis is conducted to simulate a situation in excavated slope that occurs during the months of heavy rainfall during which the slope becomes fully saturated. The slope comprises of laterite for the top 3m, underlain by lithomargic clay for a depth of 8m and a hard rock (granitic gneiss) below it. Ponding for a considerable width and for varying depths (i.e. 1m, 2m and 3m respectively), each for a period of 3 days are considered. The cut slope angles for the excavated slope were varied as 50, 60 and 70 degrees with the ponding situation described above was separately analysed. Fig 2 shows the geometric profile of the slope.

The kind of calculation used for this study is fully coupled flow deformation analysis (Hamdhan and Schweiger (2011)) in which the full interaction between deformations, consolidation and groundwater flow are solved simultaneously in the same phase. The safety analysis is carried out by phi-c reduction method. The slope was analysed as a plane strain model and Mohr-Coulomb model is selected as the material model. Table 3 shows the properties assigned for laterite and shedi soil respectively.

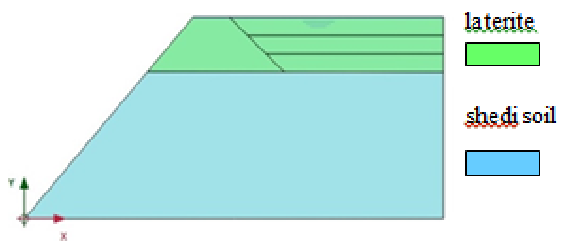

Fig. 2 Geometric profile of the slope

Table 3 Properties of laterite and shedi soil

Properties	Laterite	Shedi soil
Young's Modulus	40000kPa	10000 kPa
Poisson's Ratio(μ)	0.33	0.33
Cohesion(c)	35 kPa	27 kPa
Angle of internal friction(ϕ)	30º	20º
Material type	Drained	Undrained
Hydraulic Conductivity(k)	0.1 m/day	0.00321m/day

3.1 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.

3.1.1 *Initial Phase*

The initial phase was defined with the excavated slope geometry and assuming the slopes are almost fully saturated during the months of June and July in the district. Initial stresses are generated in this phase using the gravity loading.

3.1.2 *First Phase/Precipitation Phase*

In this phase, precipitation is brought into picture on a fully saturated slope. To simulate this, infiltration rate was applied at each of the surface boundaries. The effect of rainfall for a period of 3 days was given. On the sloping surface, precipitation is modelled perpendicular to the surface and a value $q\cos\theta$ is applied where θ is the angle of slope and q the infiltration rate on a horizontal surface (i.e. θ =0). At first, surface ponding effects on the horizontal ground surface is neglected considering the porous and free draining nature of the laterite soils, the water might easily move out through the sloping part rather than accumulating over the surface.

3.1.3 *Second Phase(1m ponding)*

In the second phase, the effect of ponding is introduced along with the precipitation. Ponding was provided for a depth of 1m at a distance of 2m from the crest for a period of 3 days.

3.1.4 *Third Phase(2m ponding)*

The procedure was repeated with ponding depth increased to 2m. The analysis was carried out for the next 3 days.

3.1.5 *Fourth Phase(3m ponding)*

This is the last and final phase in which the ponding depth almost 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 noted that all these phases including this final phase has got the precipitation effect.

3.2 Results

The study done in PLAXIS 2D 2016 has given an insight to the effect of precipitation, ponding and also to the slope angle beyond which stability is a concern especially in excavated slopes during the peak rainfall periods. Three excavated slopes with different cut angles of 50, 60 and 70 degrees were analysed.

In the precipitation phase, from the incremental displacements obtained for the cut slope angles of 50 and 60 degrees, it can be seen that there is much tendency of the failure surface to extend deeply in to the weak lithomargic clay layer leading to a progressive failure of the entire excavated slope. Reduction by around 40% in the safety factor are seen in the both cases due to the rainfall infiltration affecting the saturated slope. However when the precipitation was provided on a 70 degree slope whose initial safety factor came out to be 1.75 in the saturated state failed (i.e safety factor less than 1)after the precipitation phase (Table 4).

Table 4 Factor of Safety in the Precipitation phase

Cut slope angle	Initial FOS when slope is fully soaked	FOS after the precipitation phase
50	2.35	1.43
60	2.02	1.18
70	1.75	< 1(slope failed)

Table 5 Factor of Safety for 50 and 60 degree slope including ponding effect and precipitation

Phase	FOS for 50 degree slope	FOS for 60 degree slope
2nd phase	1.340	1.185
3rd phase	1.345	1.155
4th phase	1.370	1.150

After the introduction of ponding, the safety factors (Table 5) have not altered much from the precipitation phase in both the 50 and 60degree slopes. The steeper slope has more chances of failing in the presence of precipitation and higher ponding depths which is expected and observed from the analysis. Also in the case of 50 degree slope, there was more flow in to the inner lithomargic clay layer during the initial ponding phase (ponding depth = 1m) making it weaker and the failure surface had a tendency to widen creating more displacement resulting in a lesser factor of safety. It is always seen that the critical failure surface moved with advancement in ponding depth.

4 CONCLUSIONS

From the HET conducted, critical shear stress could not be calculated since progressive erosion was not observed in any of the soil samples for the given compaction and head conditions. Erosion rate decreased with increased hydraulic shear stress confirming there is no progressive erosion under the given compaction and head conditions. By this we can conclude that in case of a well compacted shedi soil there will be no progressive erosion. Under higher hydraulic gradient or poorer compaction, progressive erosion may occur. Erosion observed in the HET is accelerated due to slaking irrespective of dispersive nature of soil. Among the untreated samples, Soil F1 showed more erosion than F2 and F3 which occurred mainly due to slaking process. This is mainly due to the presence of higher percentage of clay in F1 sample when compared to other samples. Addition of LS to the untreated samples has resulted in high increase in its erosion resistance and this increase is specifically seen in F1 soil sample.

From slope stability analysis, it is observed that slopes with slope angle steeper than 60 degrees could pose considerable instability problems and result is failure. The ponding had little effect on the slopes in the analysis considered where factor of safety values did not vary much.

References

Benahmed, N., and Bonelli, S. (2012) 'Investigating Concentrated Leak Erosion Behaviour of Cohesive Soils by Performing Hole Erosion Tests', *European Journal of Environmental and Civil Engineering, Taylor and Francis,* 16(1), pp43–58.

Hamdhan, I. N., and Schweiger, F. H., (2011) 'Slope stability analysis of unsaturated soil with fully coupled flow-deformation analysis', IAMG, Salzburg, Austria. pp1133-1150.

Indraratna, B., Athukorala, R., and Vinod, J. (2013) 'Estimating the Rate of Erosion of a Silty Sand Treated with Lignosulfonate', *Journal of Geotechnical and Geoenvironmental Engineering, ASCE,* (5)139, pp701–714.

Wan, C.F. and Fell, R. (2002) 'Investigation of internal erosion and piping of soils in embankment dams by the slot erosion test and the hole erosion test', UNICIV Report, no. R-412.

Wan, C.F., and Fell, R. (2004) 'Laboratory tests on the rate of piping erosion of soils in embankment dams', *Geotechnical Testing Journal*, 3(27), pp295–303.