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RESEARCH ARTICLE

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SLOPE STABILITY STUDIES OF EXCAVATED SLOPES IN LATERITIC FORMATIONS, INCLUDING EROSION STUDIES ON LITHOMARGIC CLAYS

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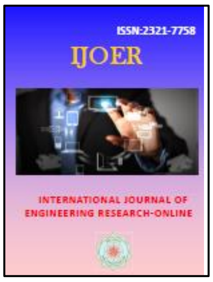


ABSTRACT

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 products of laterization, sandwiched between the hard and porous weathered laterite crust at the top and the hard granite or granitic gneiss underneath. Laterization is a chemical weathering process, of the parent rock, due to intense tropical weather conditions i.e. high temperatures and rainfall. Shedi soils of coastal Karnataka generally classify, based on grain size distribution, as silty sands or sandy silts, with very little clay size particles. Even the behavior of the fine fraction (75 micron down soils) is nowhere near to the clay behavior.

This coastal area receives copious amount of rainfall and a lot of developmental activities are taking place. Excavated slopes for railway and highway projects in such lateritic formations pose serious erosion and slope stability problems, especially, due to the presence of these shedi soils and seepage pressures from stagnated water at top. In the first 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 results on 60 degree slope showed that with increased ponding depths during precipitation, the factor of safety reduces slightly. In the second stage of this study, laboratory erosion studies are conducted by using the hole erosion test apparatus on controlled shedi soil samples. From the whole erosion test (HET) conducted erosion rate decreased with increased hydraulic shear stress confirming that no progressive erosion has taken place for fully compacted soils. Erosion observed in the HET conducted is mainly accelerated due to slaking irrespective of dispersive nature of the soil.

Keywords: Lithomargic clay, Slope stability, Precipitation, Ponding, Erosion, Hole erosion test.

1. INTRODUCTION

Slopes either occur naturally or are engineered by humans. Slope stability problems have been faced throughout history whenever the delicate balance of nature has been disturbed by any kind of internal or external forces. The forces with in nature like heavy rainfall leading to erosion and landslides constitute an important example of internal disruptive forces while the external forces mainly human activities such as excavation and filling of slopes have also caused the slide. Excavated slopes being devoid of natural cover and protection becomes more susceptible to erosion during heavy rainfall. Erosion can be easily categorized in to surface erosion especially caused by running water on slope surface or internal erosion occurring within the structure. Erosion, over a period of time can lead to geometric changes of slope with subsequent major distress finally causing the failure. While studying slope stability, attention has been given to geology, groundwater flow and seepage and shear strength of soils. Stability of slopes is also affected by presence or absence of vegetation (turning or trees) on slopes.

Hydrological factors like intensity of rainfall, run off etc. will also be studied briefly in this section as to understand their relation with erosion on slopes. In rainy season, the effect of precipitation results in to a situation of water becoming almost stagnant in the top layers near to the crest referred to as ponding. This might possess a threat to the long term stability as the water might seep through it due to the porous nature of top layer and could cause changes in pore pressure over time. This has been common in the Dakshina Kannada District where the laterite holds high positions with in top 3m and the very soft lithomargic clay below and the stability problem referred above wereinvestigated using Plaxis 2D software for a particular geometry varying the cut slope angle. Erosion problems were also dealt with using a stabilizer, Calcium Lignosulfonate 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 ground water below. The optimum amount of this stabilizer was added to the erodible layer, lithomargic clay in their varying compositions obtained by altering the quantity of fines and erosion test was conducted to study the erosion potential of the soil.

2. LITERATURE REVIEW

Kandiah and Arulananthan (1974) studied the mechanism of erosion of saturated and unsaturated soils by examining the effect of initial water content on the critical shear stress required to initiate erosion. Erosion tests on saturated and unsaturated soils were carried out in a rotating cylinder and a flume apparatus respectively.In the case of partially saturated soils, erosion may also be accelerated by a process called slaking.Slaking rate studies on compacted samples of a silty clay indicate that the slaking is significant when samples are compacted on the dry side of optimum moisture content. The slaking rates decreased with increase in water content. The slaking rate was negligible at water contents greater than 5 per cent above the optimum water content for the compaction energy used in the study. They reasoned that the swelling of soils decreased with an increase in the placement water content which ultimately lead to an increase in the critical shear stress and decrease in the erosion rate.

Sherard et al (1976) developed the pinhole test todirectly measure the dispersibility of compacted fine grained soils in which water is allowed to flow through a small hole of 1mm diameter in a soil specimen to stimulate water flow through a crack or other concentrated leakage path in the impervious core of a dam or other structure. Distilled water is percolated through the hole in the sample under the heads of 50, 180, 380 and 1020 mm for periods of 5 minutes to 10 minutes at each head. The outflow is measured continuously using a flask and the colour of outflow is observed through the side of the column in the flask and vertically through the column of fluid in the flask. The soil is classified into 6 groups ranging from highly dispersive clay to completely erosion resistance clay based on the cloudiness of the effluent and the size of hole at the end of test. The principle differentiation between dispersive and non-dispersive soils is given by the test results under 50 mm of head.

Lewis and Schmidt (1977) conducted an investigation to determine the influence of dry density and initial water on the erosion of a compacted dispersive clay using the pinhole test. When the soil specimens, compacted to densities representative of standard and modified proctor effort were eroded under a roughly constant erosional shear stress, it was found that a minimum amount of erosion occurred at a water content about 2 to 3 per cent wet of optimum water content. It was also found that, at the same water content, the amount of erosion tended to decrease with an increase in the dry density.

Sargunan (1977) conducted a laboratory test to study the dispersive behaviour of selected clay systems when subjected to disruptive action of flowing water using a rotating cylinder apparatus. Results from this test showed that total content of salt in the pore water has an important effect on dispersibility. For soils with very low salt concentration, a lesser sodium percentage is required to cause the soil to become dispersive than for soil with a normal or higher salt content.

Shaikh et al (1988) studied the erosion rates of unsaturated compacted sodium and calcium montmorillonite clays that were measured under a range of tractive stresses from surface flows in a rectangular flume. The calcium montmorillonite is treated with additives calcium chloride and sodium carbonate to obtain samples with different chemical compositions. The tractive stress ranges from 1.67-12.9 Pa. The erosion rate of calcium montmorillonite (a nondispersive clay) is two orders of magnitude higher than that of sodium montmorillonite (a dispersive clay). It was pointed out that with unsaturated compacted clayey soils, slaking was the major cause of erosion, not dispersion. This result contradicted the findings of other investigators (e.g. Sherard et al 1976b) which demonstrated that dispersive soils are highly erodible. Shrestha and Arulananthan (1989) commented on these results and explained that the Calcium montmorillonite was in a higher state of flocculation than Sodium montmorillonite and therefore slaked faster.

Atkinson et al (1990) questioned the reliability of the crumb test and pinhole test, all of which considered soil under unsaturated conditions. He pointed out that internal erosion of the soil was governed by true cohesion of soil, which was defined as the strength of soil at zero effective normal stress. Hence a rise in effective stress because of suction in unsaturated soil could influence the results of pinhole and crumb test.A new test, the cylinder dispersion test, has been developed to investigate true cohesion and dispersion in soils.

3. EXPERIMENTAL STUDY

Testing Methodology: The project work can be mainly categorized in to two main portions. The first one included mainly the numerical analysis done in the FEM softwatre, Plaxis 2D 2015 targeted at solving the slope stability problem where various boundary conditions for flow due to the effect of precipitation was considered. The second one included the experimental part mainly the Hole Erosion Tests (HET) conducted on different controlled shedi soil samples with and without the addition of Calcium Lignosulfonates to examine their erosion potential.

Initially, controlled shedy soil samples were prepared with varying percentage of fines i.e 90% fines, 70% fines and 50% fines with remaining portion sand (passing through 1.18mm) is mixed . These soil samples are named F1,F2 and F3 for their simplicity. These untreated samples are then mixed with the optimum amount of calcium lignosulfonates to obtain the treated soil samples F1T,F2T and F3T. Hence we have 6 different combinations in total. A series of hole erosion tests are carried out on all these samples after compacting to their maximum dry density and moisture content with the suitable maximum range of head possible in the apparatus (normally around 60cm). A set of Falling head permeability tests are also conducted on all the samples to find out the value of coefficient of permeability (horizontal)as it being an important parameter governing flow in soils. This would be used as an input in Plaxis 2D in later part of the work for any stimulation associated with flow or erosion.

The optimum amount of lignosulfonate to be added was found from the UCC tests conducted in the laboratory. Other tests included the basic tests to determine index properties like grain size distribution, atterberg limits etc for the untreated soil. SEM tests were conducted on the treated samples to understand the stabilization mechanism.

Atterberg Limits: The tests were performed according to IS 2720-Part 15, (1985) on soil passing 425µ sieve. For saline water, this test was performed at different concentrations.

Specific Gravity: The Specific gravity (G) of the soil has been determined by exploited some density bottle and pycnometer as per the guidelines provided by IS 2720-Part 3, (1980). The average value has been taken from the three trials was obtained and the result as shown in the table.

Standard Proctor Compaction Test: The soil sample was oven dried at 110^{O}C for about 24 hours. Later, as per standards, the soil is mixed with the various concentrations (0.001 M, 0.01 M and 0.05M) of salt in weight and then this mix has been compacted in three equal layers with each set of experiments with increasing the water content. Later, based on the compaction curves plotted for the different mix, optimum moisture content (OMC) and maximum dry density (MDD) for each test specimens were obtained.

UCC Test: The unconfined compressive strength of the cylindrical shaped specimens (38 mm diameter and 76 mm length) was determined according to IS: 2720-Part 10, (1991). The cylindrical specimen was placed on the base plate and the load frame has been fixed without any stress application upon the specimen. Set the dial gauge reading and proving ring to zero. Axial load increment was applied at a strain rate of 1.5 mm/min. Noted the proving reading value at regular intervals of the dial gauge reading.

Hole Erosion Test: ASTM. 2007. Standard D5852. Standard test method for erodibility determination of soil in the field or in the laboratory by the jet index method. American Society for Testing and Materials.

Index Properties

Table 1: Properties of the selected material

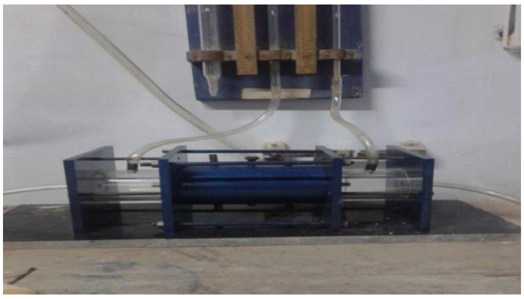
parameter	90% fines + 10% sand (F1)	70% fines + 30% sand (F2)
G (specific gravity)	2.55	2.60
Plastic Limit (%)	34.1	29.4
Liquid Limit (%)	50.2	41.2
Plasticity Index(%)	15.9	11.8
Optimum Moisture Content(OMC)	27.10	22.73
Maximum Dry Density (γ_{dmax}) (g/cc)	1.45	1.60
Clay size (%)	36.2	28.7

TESTS CONDUCTED:

Hole Erosion Test

Specimen preparation: Test specimens were prepared at maximum dry density and optimum moisture content.The dry density of a test specimen was controlled by controlling the total mass of soil of known water content to be used for forming the compacted test specimen. Known amount of soil was compacted to a pre-calculated thickness (160mm, the height)in a mould of 83 mm diameter corresponding to the desired dry density. Finally, the mass of the completed test specimen was measured so as to calculate the actual dry density of the specimen. The treated samples FIT, F2T and F3T were prepared by the addition of optimum amount of lignosulfonates that is found to be 0.6% of the dry weight of the soil. This optimum amount of lignosulfonates 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.

Test procedure



Hole Erosion Test(HET) apparatus (without water circulation)

The test procedure can be briefly explained in the following steps

1) Drill the prepared soil samples using a 6 mm diameter rod to the axial direction and at the center of the sample.

2) Fill the upstream chamber with 20 mm gravels in order to regulate the speed of water at the upstream side of the sample.

3) Place the soil sample between the upstream and downstream chambers. Also, tighten the sample mold with rubber rings to avoid any leak.

4) Adjust the level of constant head container to the level appropriate for the prepared soil sample, ranging between 50-1200 mm

5) Open the valve and maintain the water head in the constant head container with an appropriate amount of water.

6) Connect all the other pipes one by one in such a way that each connection is made whenever the chamber is full of water so that the air bubbles are removed to the maximum extent possible.

7) Increase the water head until progressive erosion is initiated. This is a tough step to exactly identify the point and sometimes does not happen even at the maximum head available.

8) Measure the flow rate at the downstream side of the apparatus and at different time intervals (with in

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every 30 seconds) during the test until 45 min 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 monitor the pressure drop to obtain the hydraulic gradient with time as the downstream head is continuously rising because of accelerating flow rate.

9) The specimen of eroded soil is then retrieved out of the device and melted paraffin is poured into the eroded hole. After the paraffin solidifies, the specimen is cut out and the candle is prudently extracted. This candle represents the shape of the final eroded hole. The volume of the candle (V_{can}) allows the calculation of the final average radius of the eroded hole R_f and the total mass of dry soil eroded during the test $M_{So\text{-}er.}$

$R_f = (V_{can}/\pi L)^{1/2}$ and $M_{So\text{-}er} = \pi L \rho_s[(R_f)^2 – (R_i)^2]$

10) Clean the apparatus from remained soil particles and prepare it to be used for the next test.

Falling Head Permeability test: A Falling head permeability test was conducted to find the horizontal permeability of both the treated and untreated soil samples. The water is allowed to flow horizontally through a saturated soil sample so that any drop in volume of water in the stand pipe is equal to the discharge that comes out of the soil sample. This forms the basis behind the falling head permeameters commonly used in the laboratories for finding the coefficient of permeability of fine grained soils of intermediate and low permeability consisting mainly of silt and clay.

A mould was specially prepared for conducting this test. The inner mould diameter is 82 mm and length was length is 81.5 mm. The samples were first prepared at their maximum dry density and optimum moisture content using this mould. It was then put to saturation for 1 or 2 days till some water comes out at the other end. It is then connected to a main stand pipe which is under observation. The permeability value in this test is given by the following equation.

$$k = (aL/At) * \ln (h_1/h_2)$$

Here 'a' and 'A' refers to the cross sectional area of stand pipe and soil specimen respectively. 'L' is the length of the soil specimen and 't' is the time taken for head to drop from a water level of h_1 to h_2. Both these water levels h_1 and h_2 are measured from the reference datum which corresponds here to the central longitudinal axis of the specimen. Before starting the experiment, it is important to ensure that the soil specimen is fully saturated and for this it is kept in another set up where high heads are available so that water movement is made fast inside the soil specimen (flow velocity is increased due to large hydraulic gradients) .Usually a 1mm drop takes atleast 5-10 minutes during the experiment conducted. Therefore the time for the water level to drop from h_1 to h_2, differing by exactly 1mm was noted against the usual convention of measuring the head drops for a fixed time interval. However, the time for dropping from h_1 to $(h_1 h_2)^{1/2}$ and $(h_1 h_2)^{1/2}$ to h_2 was observed and found to be the same as suggested by IS 1720 (part 17) – 1986. Consistent values of coefficient of permeability, k is obtained and presented in Table 3.4.The observations and calculations of untreated samples are given in the appendix.

Sample	Horizontal Coefficient of Permeability (cm/s)
F1	2.22×10^{-7}
F2	2.41×10^{-7}
F3	4.93×10^{-7}
F1T	1.43×10^{-7}
F2T	1.91×10^{-7}
F3T	4.10×10^{-7}

RESULTS AND DISCUSSIONS

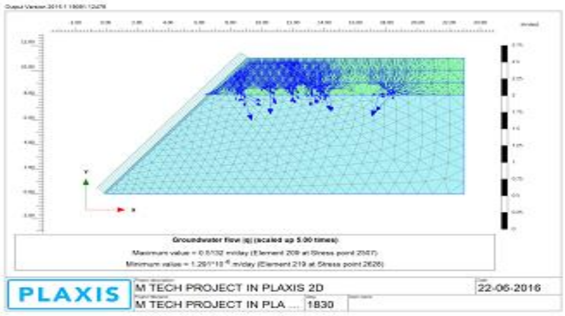
Unconfined Compression tests

Table.3.4.Horizontal coefficient of permeability of all the treated and untreated samples.

Percentage of LS added	UCC strength (kPa) of F1	UCC strength (kPa) of F2	UCC strength (kPa) of F3
0	324.67	355.03	301.83
0.4	347.50	408.62	320.69
0.6	387.52	480.67	323.22
1	289.53	329.71	272.10
2	320.10	402.67	271.87

RESULTS ASSOCIATED WITH FLOW AND DISPLAMENTS

Groundwater flow and Degree of saturation



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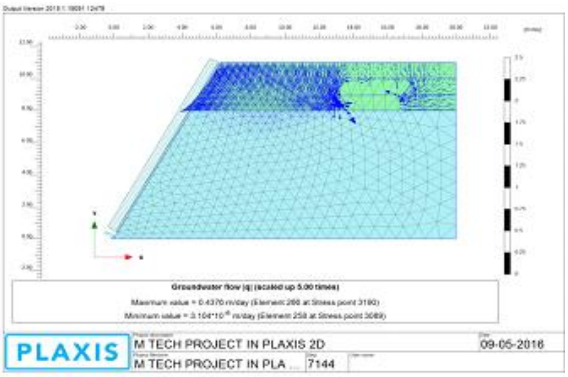

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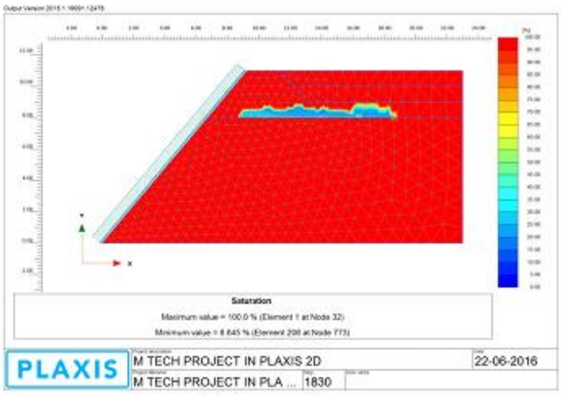

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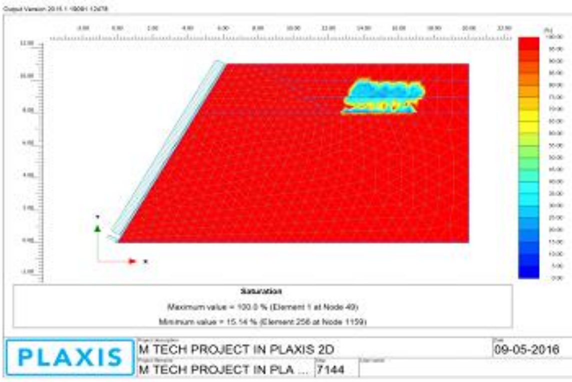

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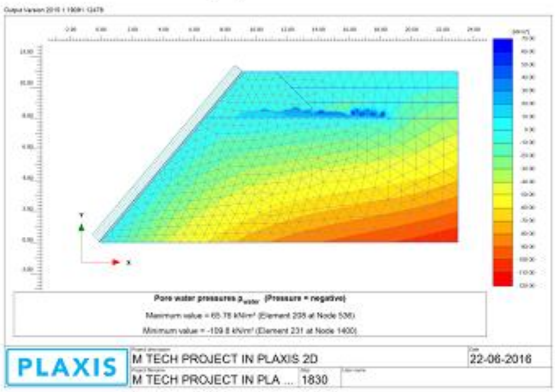

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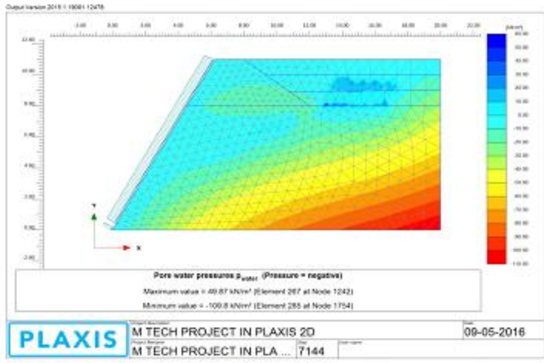


(F)

(A) Direction and Magnitude of Groundwater flow for a slope of 50 degree shown by arrows.

(B) Direction and Magnitude of Groundwater flow for a slope of 60 degrees shown by arrows.

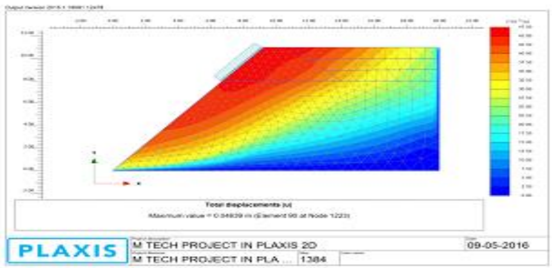
(C) Direction and Magnitude of Groundwater flow for a slope of 60 degrees shown by arrows.

(D) Degree of saturation shown by different colors with red indicating 100% saturation on 50 degree slope

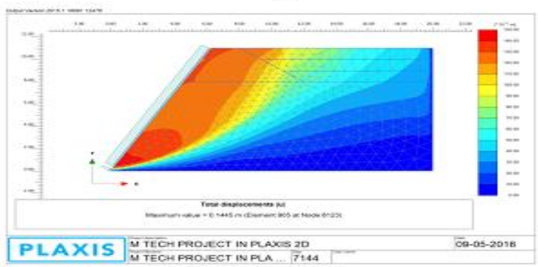
(E) Pore water pressures (sum of steady state and excess pore pressures) generated on a 50 degree slope as when precipitation was allowed

(F) Pore water pressures (sum of steady state and excess pore pressures) generated on a 60 degree slope when precipitation was allowed

TOTAL DISPLACEMENTS



(A)



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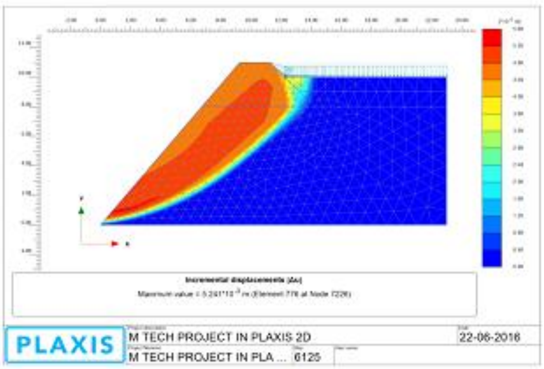

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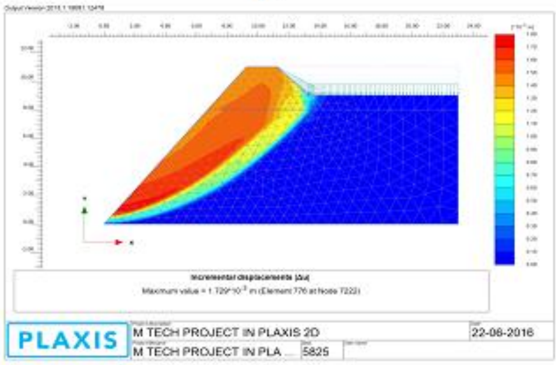

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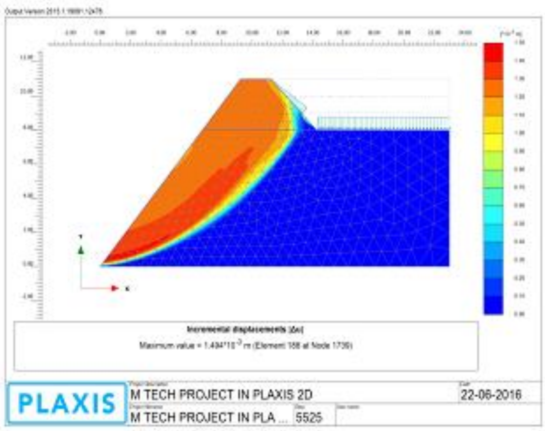


(E)

Incremental Displacements along with their safety factors

(A)Total displacements in a 50 degree slope is shown with varying colors to indicate the range of values

(B)Total displacements in a 60 degree slope is shown with varying colors to indicate the range of values.

(C)Incremental displacements on 50 degree slope when ponding depth = 1m. (FOS = 1.340)

(D)Incremental displacements on 50 degree slope when ponding depth = 2m. (FOS=1.345)

(E)Incremental displacements on 50 degree slope when ponding depth = 3m. (FOS=1.370)

HET RESULTS.

HET results on untreated Soil specimens.

Soil sample F1 (90% Fines + 10% Sand)

OBSERVATIONS	
Dry Weight of compacted soil mass (g)	1239
Initial diameter of the drilled hole(mm)	6
Dry Weight of compacted soil mass after drilling the hole(g)	1229
Final average diameter of soil sample after erosion(mm)	25
Final mass (dry)of soil sample after erosion(g)	1123
Total Mass of soil eroded during the test(g)	106
Initial Downstream head in the acrylic tank (Table level as datum)	27.8
Upstream head maintained in the constant head container (Table level as datum)	109.6
head causing flow	81.8
length of the sample	16
initial hydraulic gradient	5.11

Soil sample F2 (70% Fines + 30% Sand)

OBSERVATIONS	
Dry Weight of compacted soil mass	1368g
Initial diameter of the drilled hole(mm)	6
Dry Weight of compacted soil mass after drilling the hole(g)	1356
Final average diameter of soil sample after erosion(mm)	11.3
Final mass (dry)of soil sample after erosion(g)	1338
Total Mass of soil eroded during the test(g)	18
Initial Downstream head in the acrylic tank (Table level as datum)(cm)	27.8
Upstream head maintained in the constant head container (Table level as datum)(cm)	99.6
head causing flow	71.8
length of the sample	16
initial hydraulic gradient	4.49

Soil sample F3 (50% Fines + 50% Sand)

OBSERVATIONS	
Dry Weight of compacted soil mass	1486g
Initial diameter of the drilled hole	6mm
Dry Weight of compacted soil mass after drilling the hole	1476g
Final average diameter of soil sample after erosion	8.9mm
Final mass (dry)of soil sample after erosion	1466.5g

Total Mass of soil eroded during the test	9.5g
Downstream head fixed in the acrylic tank (Table level as datum)	27.8cm
Upstream head in the constant head container (Table level as datum)	88cm
head causing flow	60.2cm
length of the sample	16cm
Initial hydraulic gradient	3.76

General comments on the test results of untreated soil samples

It was observed that the F1 sample has shown considerable erosion as the mass eroded is high (106g). The hole diameter in this case increased to about 25mm from the initial 6mm. The hydraulic shear stress has shown to reach about a value more than 200kPa. The F2 sample lost a mass of about 18g while its hole diameter changed to 11.3mm and F3 sample lost only about 9.5g while its hole diameter changed to 8.9mm. 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%). 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.

HET results on treated soil samples.

Soil sample F1T (90% fines + 10% sand + 0.6% LS)

OBSERVATIONS	
Dry Weight of compacted soil mass	1244g
Initial diameter of the drilled hole	6mm
Dry Weight of compacted soil mass after drilling the hole	1232g
Final average diameter of soil sample after erosion	7.2mm
Final mass (dry)of soil sample after erosion	1229g
Total Mass of soil eroded during the test	3g
Downstream head fixed in the acrylic tank (Table level as datum)	27.8cm
Upstream head in the constant head container (Table level as datum)	96.6cm
head causing flow	68.8cm
length of the sample	16cm
initial hydraulic gradient	4.3

Soil sample F2T (70% fines + 30% sand + 0.6% LS)

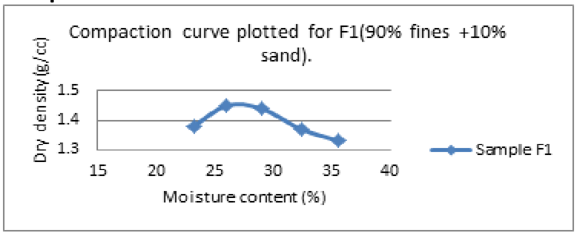
OBSERVATIONS	
Dry Weight of compacted soil mass	1382g
Initial diameter of the drilled hole	6mm
Dry Weight of compacted soil mass after drilling the hole	1366g
Final average diameter of soil sample after erosion	7.52mm
Final mass (dry)of soil sample after erosion	1359g
Total Mass of soil eroded during the test	6.55
Downstream head fixed in the acrylic tank (Table level as datum)	27.8cm
Upstream head in the constant head container (Table level as datum)	91.2cm
initial head causing flow(in cm)	63.4
length of the sample (in cm)	16
Initial hydraulic gradient	3.96

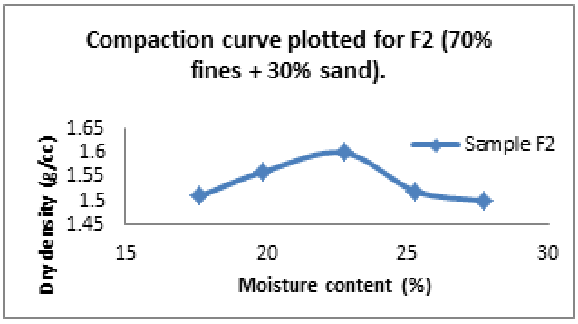
Soil sample F3T (50% fines + 50% sand + 0.6% LS)

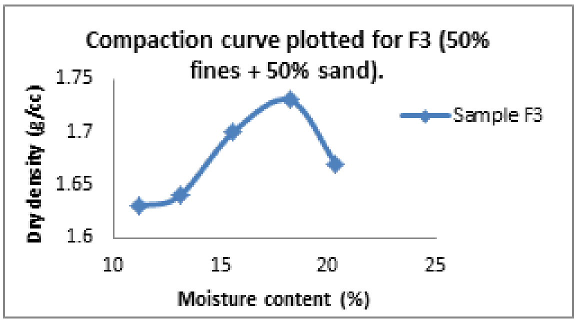
OBSERVATIONS	
Dry Weight of compacted soil mass	1488g
Initial diameter of the drilled hole	6mm
Dry Weight of compacted soil mass after drilling the hole	1476g
Final average diameter of soil sample after erosion	8mm
Final mass (dry)of soil sample after erosion	1470g
Total Mass of soil eroded during the test	6g
Initial Downstream head in the acrylic tank (Table level as datum)	27.8cm
Upstream head maintained in the constant head container (Table level as datum)	94.6cm
head causing flow	66.8cm
length of the sample	16cm
initial hydraulic gradient	4.17

GRAPHS

Compaction characteristics of the untreated samples



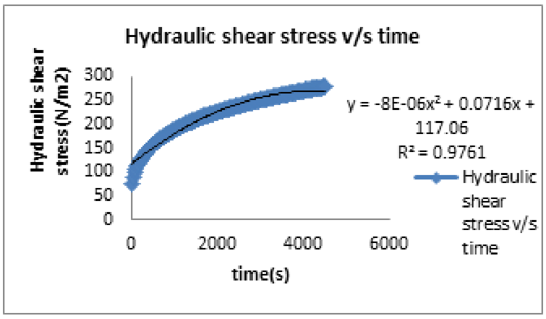


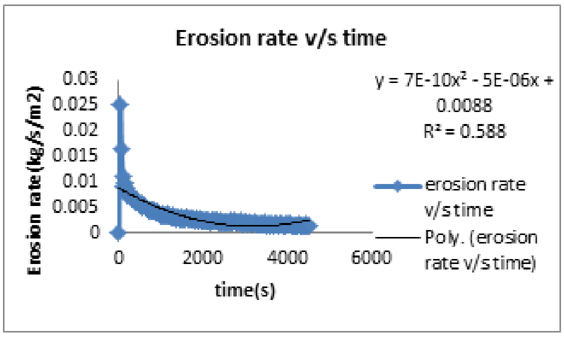


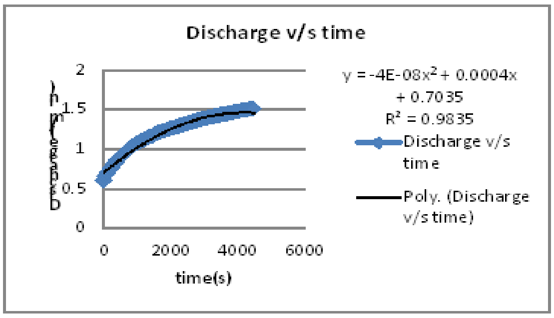
HET TEST RESULT GRAPHS

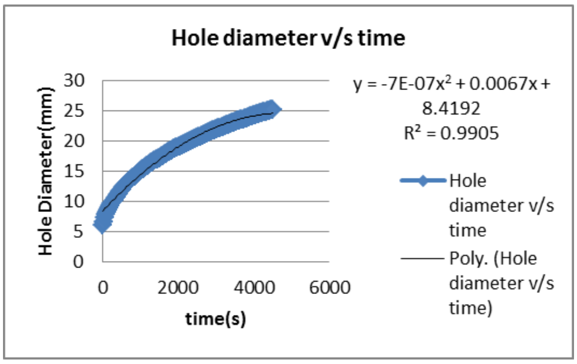
HET RESULTS ON UNTREATED SOIL SPECIMENS GRAPHS

SOIL SAMPLE F1 (90% FINES + 10% SAND)

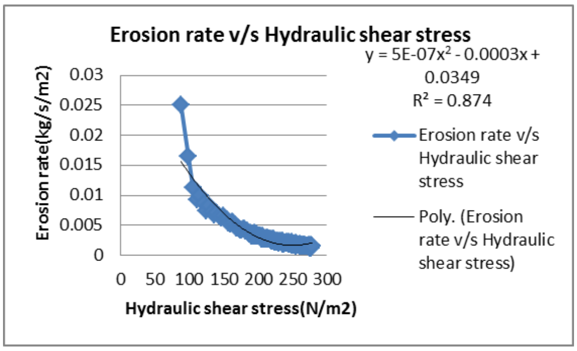


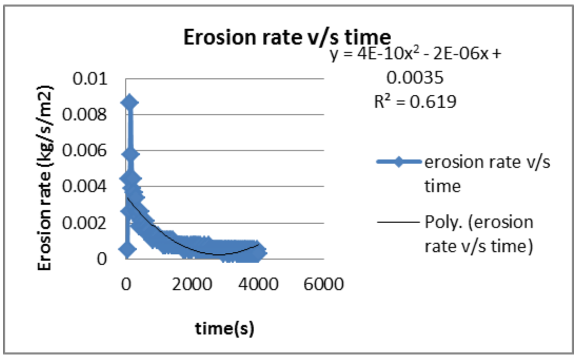


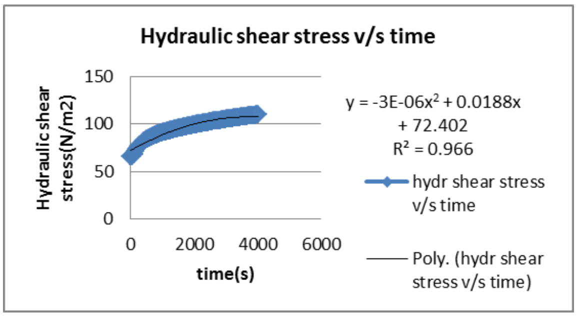


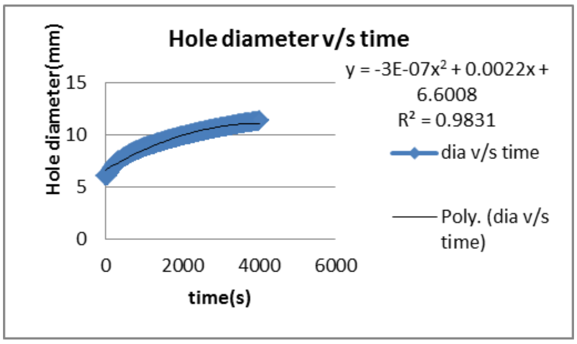


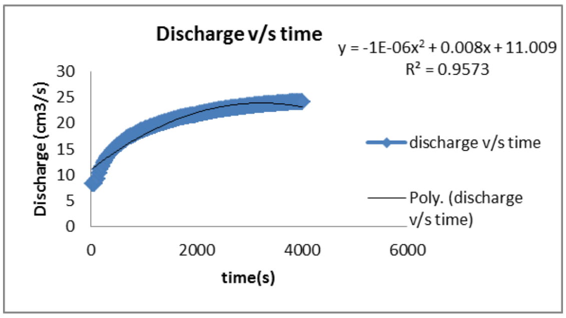
SOIL SAMPLE F2 (70% FINES + 30% SAND)



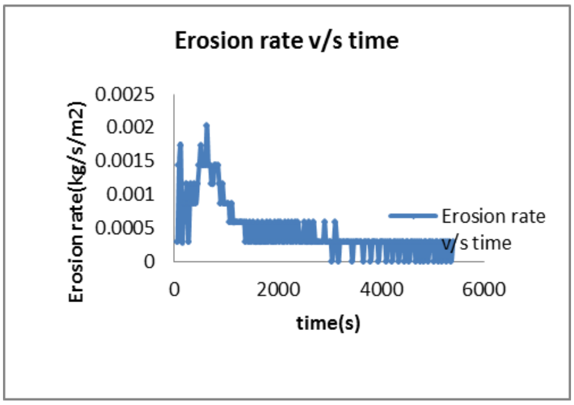


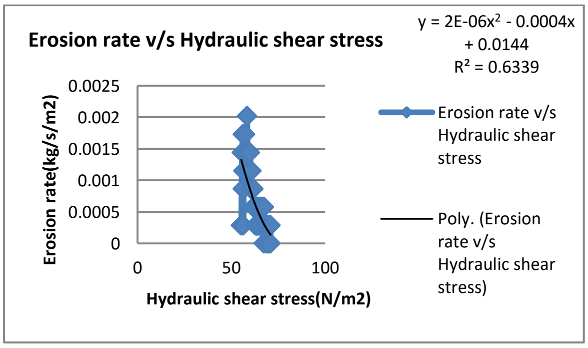


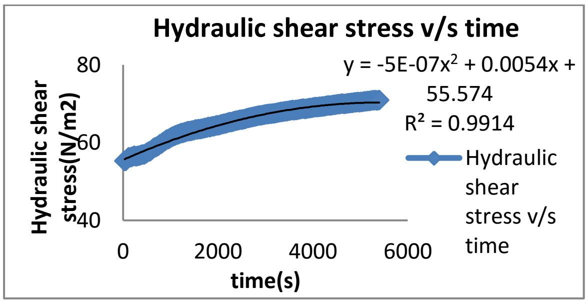


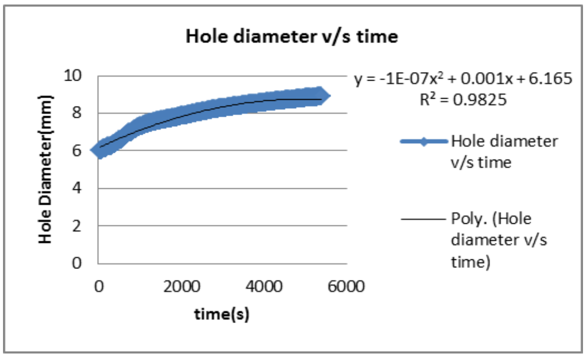


SOIL SAMPLE F3 (50% FINES + 50% SAND)



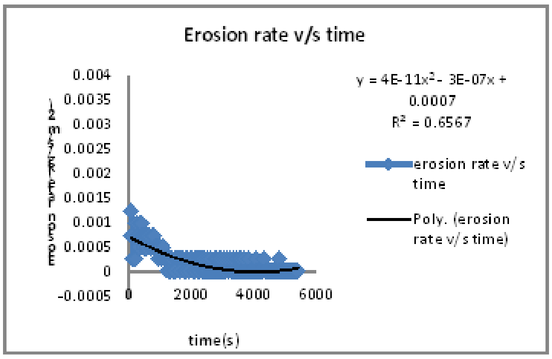


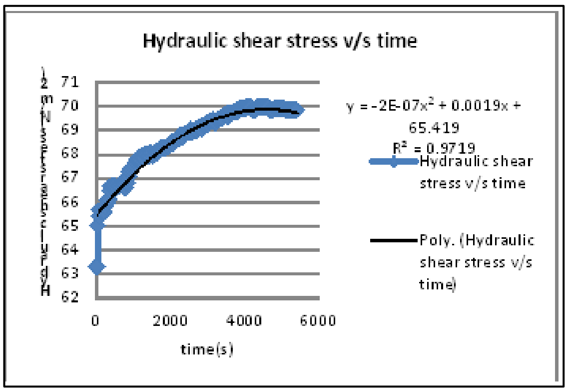


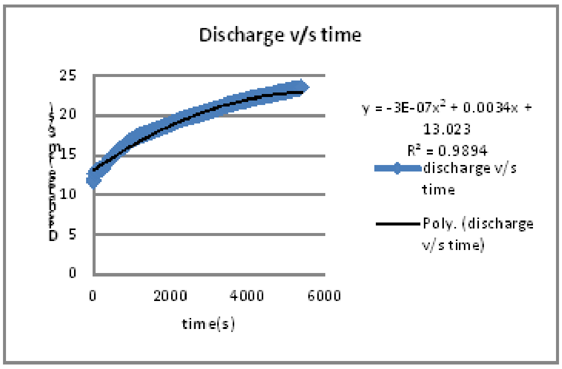


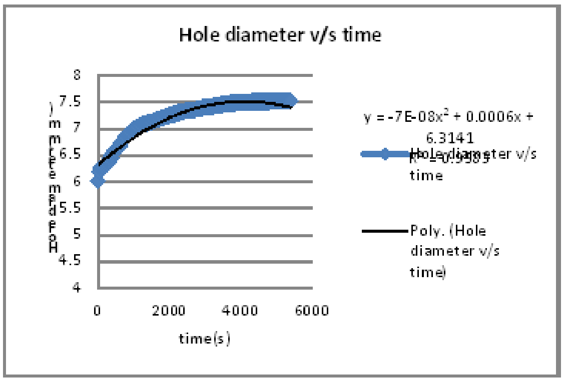
HET RESULTS ON TREATED SOIL SAMPLES GRAPHS

SOIL SAMPLE F1T (90% FINES + 10% SAND + 0.6% LS)









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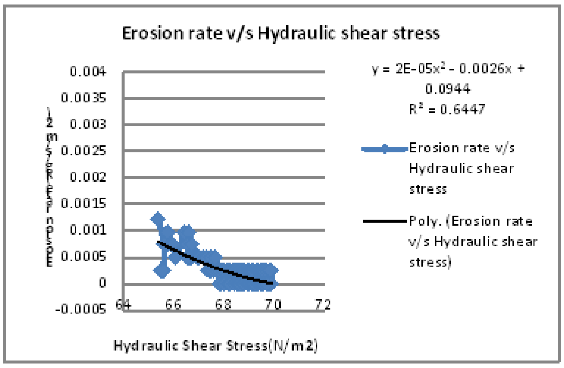
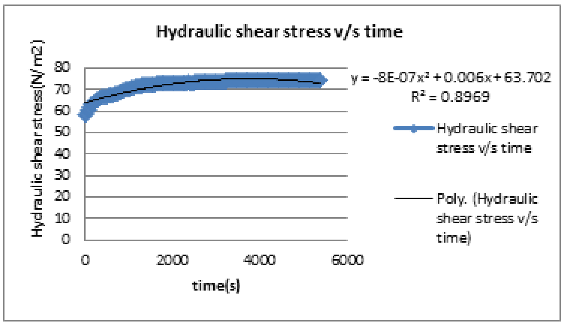
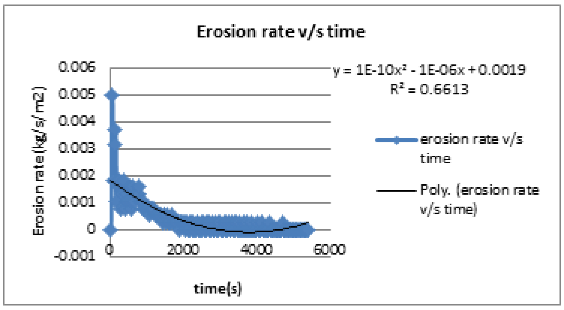
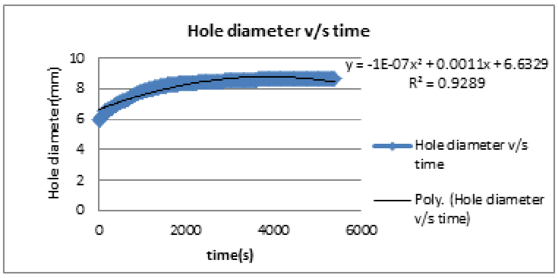
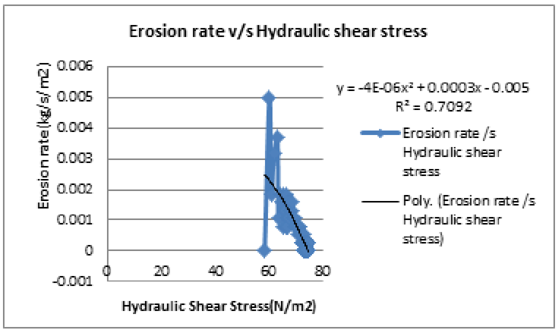


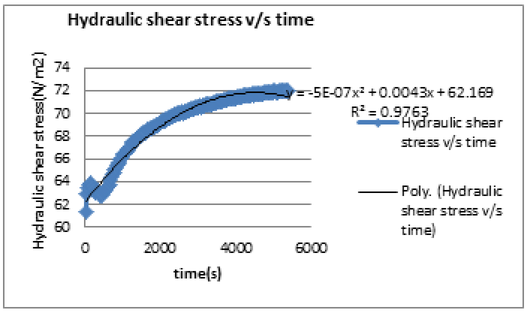


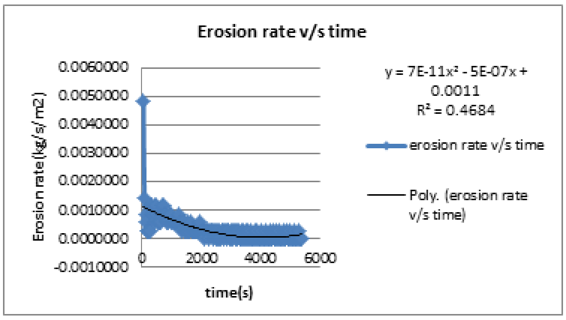


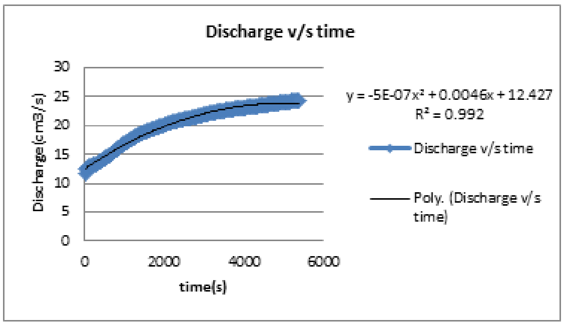


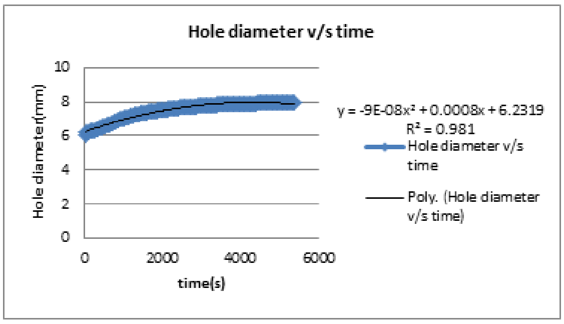


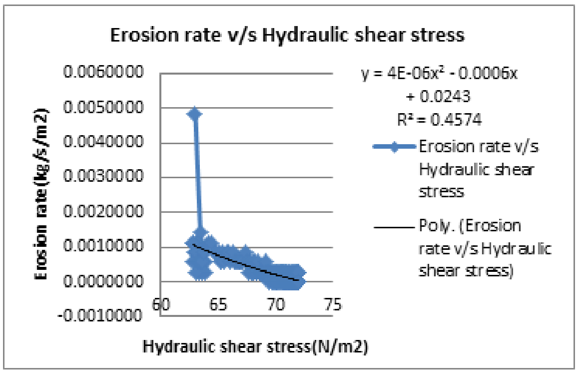
SOIL SAMPLE F3T (50% FINES + 50% SAND + 0.6% LS)











CONCLUSIONS

The following are the conclusions drawn from the present study

1. From the UCS tests conducted with varying percentages of Lignosulfonates, (i.e 0%,0.4%,0.6%,1%,2%) it is observed that the UCS strength decreased slightly when the percentage of LS exceeded 0.6% i.e the optimum percentage of LS is 0.6%.
2. Horizontal permeability tests were conducted for all the six soil samples and it is observed that horizontal permeability decreased with addition of LS. Horizontal permeability test conducted without addition of LS showed that the coefficient of permeability decreased with increase in percentage of fines.
3. From the HET tests conducted, critical shear stress and IHET could not be calculated since progressive erosion was not observed in any of the soil samples for the given compaction and head conditions.
4. Erosion rate decreased with increased hydraulic shear stress confirming that no progressive erosion has taken place 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 erosion. Under higher hydraulic gradient or poorer compaction, progressive erosion could occur and thus is suggested for further detailed study.
5. Erosion observed in the HET conducted is mainly accelerated due to slaking irrespective of dispersive nature of soil.
6. 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.
7. Addition of optimum percentage of LS to the untreated samples has resulted inhigh increase in its erosion resistance and this increase is specifically seen in F1 soil sample.
8. From slope stability analysis, it is observed that slopes with slope angle steeper than 70 degree could pose considerable instability problems and result is failure.
9. The results on 60 degree slope showed that with increased ponding depths during precipitation, the factor of safety reduces slightly.
10. However, the ponding had little effect on both the slopes in the analysis considered where factor of safety values did not vary much.

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