EFFECT OF VARIATION OF WATER LEVEL AND GEOMETRY ON THE STABILITY OF THE PADMA RIVERBANK SLOPE FOR DIFFERENT SOIL PROPERTIES

Anika T Abha*[1], Azizul Islam[2], Eqramul Hoque[3] and Ferdousul H Shikder[4]

[1]*Graduate in Civil Engineering, Bangladesh University of Engineering and Technology, Bangladesh, e-mail: anikatabha@gmail.com*
[2]*Assistant Professor of Civil Engineering, Bangladesh University of Engineering and Technology, Bangladesh, e-mail: aziz.buet@gmail.com*
[3]*Professor of Civil Engineering, Bangladesh University of Engineering and Technology, Bangladesh, e-mail: ehoq@ce.buet.ac.bd*
[4]*Graduate in Civil Engineering, Bangladesh University of Engineering and Technology, Bangladesh, e-mail: hsferdous95@icloud.com*

***Corresponding Author**

ABSTRACT

Natural riverside slopes are often hampered by the variation of water level. This study aims toinvestigate the stability of the riverbank of Padma due to the variation of water level as well as variation of geometry by using PLAXIS-2D software based on Finite Element Method (FEM). Undisturbed soil samples at different depths were collected from the selected two locations called Paschimchor and Moinotghat which are two riverbanks of the Padma river. Four undisturbed samples were collected from field using Shelby tube. Then the samples were subjected to direct shear test to determine the strength parameters which were later used as input parameters in the software. Grain size analysis and specific gravity test indicated that the sample collected from Paschimchor was MC or clayey-silt (4.5% sand, 7.5% clay and 88% silt) and the sample collected from top layer of Moinotghat was SM or silty sand (56.8% sand, 37.2% silt and 6% clay) and sample collected from bottom layer of Moinotghat contains 23% clay and 76.4% silt. Considering different slope geometry (slope angle 30°, 35°, 42°, 53°, 58°) slope stability analysis had been performed for different water level (high water table, dry condition and rapid draw down) for riverbank slope of Moinotghat and Paschimchor. From the analysis, it had been observed that maximum factor of safety was found for high water table condition and minimum factor of safety was found at rapid draw down condition considering the same geometry and soil property. On the other hand, soil properties specially the cohesion, angle of friction and coefficient of permeability also had a great impact on stability of the slope considering same geometry. Considering different water level, relation of factor of safety with the geometry of the slope (slope angle) has been represented here also. As the steepness of the slope increases, factor of safety decreases. Steepness of the slope has different effect on factor of safety considering rapid draw down, high water table and dry condition for sandy soil and silty soil.

Keywords: *Slope-stability, Water-level, Geometry, Cohesion, Plaxis-2D.*

1. INTRODUCTION

Slope failure has become an acute problem at Dohar, one of the banks of Padma River and it leads to a huge erosion of land every year. People living around the riverside areas become homeless for this reason. Waterfront slopes are affected by water-level fluctuations originating from as well natural sources (e.g. tides and wind waves), as non-natural sources; in this study, three different approaches used for hydro-mechanical coupling in FEM-modelling of slope stability, have been evaluated. A fictive slope consisting of a till-like soil material has been modelled to be exposed to a series of water-level fluctuation cycle (Johanson, J., 2014). Development of stability, vertical displacements, pore pressures, flow, and model-parameter influence, has been investigated in this study. Factor of safety changes with the change of water level, specially the factor of safety decreases at rapid draw down condition (Fatema & Ansary,2014). In that research work, the soil sample was collected from Basuria in Sirajgonj near the bank of Jamuna river; the soil sample was SW-SM and numerical analysis in performed here using software STBN2010. Another research presented examines the effect of declining water levels on the stability of riverbank slopes. Where climatic factors, geometry of the slope, material properties of the soil and time taken to vary water level all influenced the stability of the slope (Schiller & Wynne 2010). To make reasonable estimates of slope performance, it is necessary to have knowledge of expected changes in pore water distributions within the earth mass (Allen, Deen & Hopkins, 1975). This research work aimed to establish a correlation between some function of resistivity and a corresponding measure of moisture content. Some research works briefly discussed the way of numerical analysis like Finite Element Method, using a software as calculation tool. In this study Mohr-Coulomb yield criterion and Drucker-Prager yield criterion were converted to equivalent area circle yield criterion, at the same time strength reduction technology combined with convergence criterion, catastrophe criterion and plastic zone penetrability criterion was used (Zhang, H., 2012). Some research works have distinguished the numerical analysis done by FEM and LEM (Mamun & Rahman, 2016). These research works show that analysis done by FEM method shows more conservative result to some extent.

2. METHODOLOGY

For this study four soil samples have been collected. Sample – 1 has been collected from riverbank of Paschimchor (Latitude 23°34'21" and Longitude 90°8'42"). The sample was collected from the depth of 2.5ft from the top surface of the riverbank. Sample – 2 has been collected from riverbank of Moinotghat (Latitude 23°43'5.11" and Longitude 90°4'5.89"); the sample was collected from the depth of 1ft from the top of the surface. The sample – 3 has been collected from bottom layer of the Moinotghat (Latitude 23°37'4.6" and Longitude 90°4'6.65") at the depth of 5.5ft from the top surface of the riverbank. Sample – 4 has been collected from Moinotghat (Latitude 23°37'15.1" and Longitude 90°3.54'4.48") at the 7ft from the top surface of the riverbank. All the samples were collected by using Shelby tube; these four samples were subjected to specific gravity test, grain size analysis test and direct shear test.

2.1 Specific Gravity Test

The specific gravity test was performed for soil of Paschimchor (sample – 1), Moinotghat top layer sample (sample – 2) and Moinotghat bottom layer sample (sample – 3 and sample – 4). Volumetric flask was weighed and 50g soil sample was placed in the pycnometer. Then water was poured into the pycnometer and was filled upto ¾ of total volume. Then the sample was allowed 10 minutes for soaking. Then the sample wass boiled until the soil-water mixture started to boil. Vacuum was applied for 10 minutes during boiling of soil water mixture. Then the pycnometer containing the soil water mixture was removed and the sample was allowed for cooling. The following day the pycnometer was weighed. The sample was removed and then pycnometer was filled with water up to the mark. The specific gravity of the soil samples is listed in Table 1.

Table 1: Specific gravity of collected soil samples

Soil Sample	Specific Gravity
Soil of Paschimchor riverbank (sample - 1)	2.745
Soil of top layer of Moinotghat riverbank (sample - 2)	2.683
Soil of bottom layer of Moinotghat riverbank (sample - 3)	2.742
Soil of bottom layer of Moinotghat riverbank (sample - 4)	2.703

2.2 Grain Size Analysis Test

In unified classification system soil is basically classified into two groups: Coarse Grained and Fine Grained. Besides these, there are two additional classes: Organic Soil and Peat Soil. On the basis of Unified Classifications coarse grained soils are classified according to grain size and fine grained are to their plasticity characteristics.

If more than 50 percent of soil material of total mass retains on # 200 sieve which means if more than 50 percent of soil material is coarser than 0.75µm, then the soil is known as coarse grained soil. If 50 percent or more than 50 percent of soil material passes through # 200 sieve, then the soil is known as fine grained soil. If coarse grained soil has less than 5% of materials passing through # 200 sieve, according to USCS classification system, the soil may either be GW, GP, SW, SP. If the coarse-grained soil has greater than 12% finer material than 0.75µm (# 200 sieve), then the soil sis classified as GM (silty gravel) or SM (silty sand). Soils having between 5 percent to 12 percent passing through # 200 sieve classified by dual symbol. First part of dual symbol describes whether the coarse fraction of the soil is well graded or poorly graded. The second part describes the nature of fineness. A soil classified as GW-GC indicates it is well graded gravel with 5% to 12% clay materials.

The fine-grained soils are subdivided into two class: silt and clay depending on plasticity characteristics. They are further qualified by their degree of compressibility (plasticity). Here liquid limit and plastic limit is identified by the portion of soil passing through # 40 sieve. This is expressed in

Figure **1** (ASTM D2487-17, 2017).

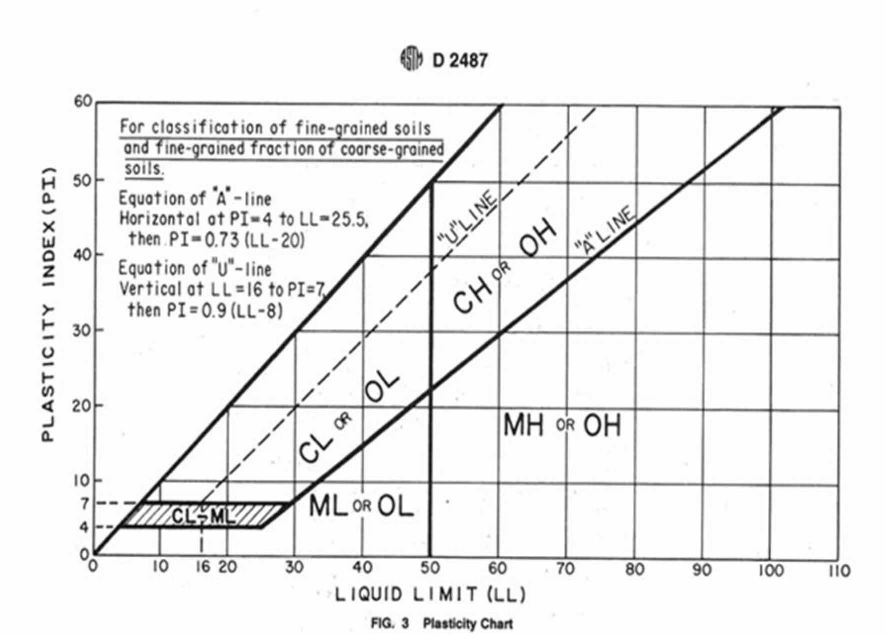


Figure 1: Plasticity Chart

2.2.1 Sieve Analysis and Hydrometer Test

The sample – 1 which was taken from the riverbank at Paschimchor is taken for sieve analysis. For this purpose, the soil is oven-dried and broken into as fine as possible. Then 100gm sample is taken and washed on # 200 sieve and the residue is kept oven-dry. Wash sieve method ensures that little dust will adhere to larger particles and reducible lumps will water softened and the clay and silt particles are washed through sieve. The following day the oven-dried sample is measured it weighs 4.5 gm. As 95.5 gm out of 100 gm soil passes through # 200 sieve which means more than 50% soil material passes through # 200 sieve, the soil is fine grained soil. In the same procedure sample 2,3,4 collected from Moinotghat is subjected to sieve analysis test. For sample-2, As 43.2gm out of 100 gm soil passes through # 200 sieve which means more than 50% soil material retains on # 200 sieve, the soil is coarse grained soil. For sample 3, As 95.9 gm out of 100 gm soil passes through # 200 sieve which means more than 50% soil material passes through # 200 sieve, the soil is fine grained soil. For sample 4, As 99.4gm out of 100 gm soil passes through # 200 sieve which means more than 50% soil material passes through # 200 sieve, the soil is fine grained soil.

Then Hydrometer test has been performed. Hydrometer analysis is widely used method of obtaining an estimate of distribution of soil particle size from no. 200 (0.075mm) sieve to around 0.001mm. Soils where more than 10 to 12 percent passes through # 200 sieve, hydrometer analysis is performed. Hydrometer analysis utilizes the relationship among velocity of fall of spheres in a fluid, the diameter of the spheres, specific weights of the spheres and that of fluid. The rate at which particles settle in a fluid media is an indicator of their size. The hydrometer analysis is based on Stock's law which states that particles in suspension settle out at a rate which varies with their size and settling of the particles is influenced by the viscosity of the fluid.

Here sample – 1, 2, 3 and 4, collected respectively from Paschimchor and Moinotghat, are subjected to hydrometer test as all samples do have more than 12% finer particle than # 200 sieve.

The soil of Paschimchor was basically fine-grained soil as 95.5% soil grains passed through # 200 sieve as shown in Figure 2. From grain size analysis it has been seen that there are 7% clay, 88% silt and 4.5% sand in the soil sample.

From grain size analysis, it can be seen that, soil collected from top layer of riverbank of Moinotghat was basically coarse-grained soil as 43.2% of soil grains which is less than 50%, passed through the # 200 sieve. From grain size analysis, it can also be seen that soil sample contains 56.8% sand, 37.2% silt and 6% clay. This can be visualised from

Figure **3**.

Soil sample collected from bottom layer of Moinotghat was basically fine-grained soil and 95.9% soil grains passed through # 200 sieve as shown in

Figure **4**. From grain size analysis it has been seen the soil sample contains 5% clay, 4.1% sand and 90.9% silt.

Soil sample collected from bottom layer of riverbank of Moinotghat was basically fine-grained soil and 99.4% soil grains passed through # 200 sieve, which is shown in

Figure **5**. From grain size analysis it has been seen that the soil sample contains 23% clay and 76.4% silt and 0.6% sand.

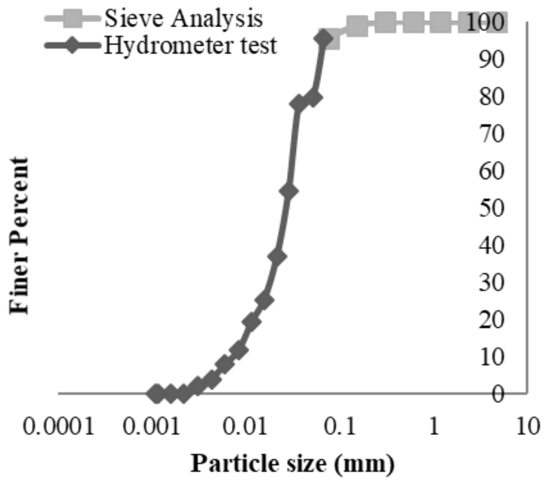


Figure 2: Grain size analysis for soil of Poschimchor riverbank (Sample – 1)

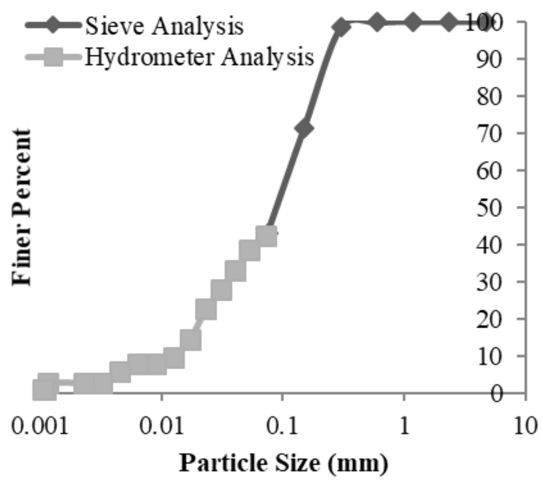


Figure 3: Grain size analysis for soil of top layer of Moinotghat (Sample - 2)

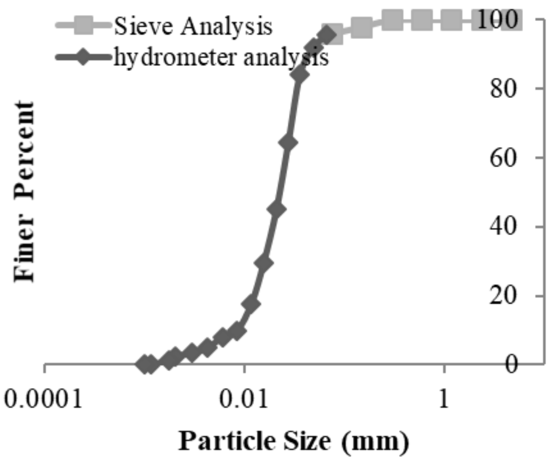


Figure 4: Grain size Analysis of Soil of Bottom Layer of Moinotghat (Sample - 3)

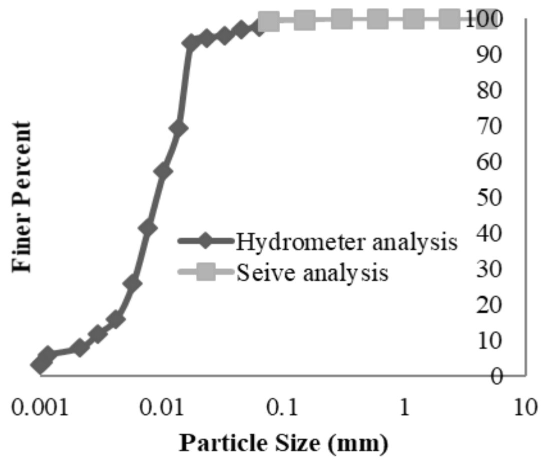


Figure 5: Grain size analysis of soil of bottom layer of Moinotghat (Sample – 4)

2.2.2 Atterberg Limit Test

From grain size analysis it has been seen that the soil of Paschimchor and that of bottom layer of riverbank at Moinotghat is fine grained soil. To differentiate between clay and silt, Atterberg limit test and plasticity test were performed for sample – 1 and sample – 4. But this test could not be done successfully as the soil could not be grooved.

2.2.3 Direct Shear Test

To determine the shear strength parameters of soil samples, direct shear test was conducted in the laboratory. Here, sample – 1 which was collected from Paschimchor, was subjected to direct shear test. The specific gravity of the sample was 2.72 and the sample was collected from 2.5 ft depth from the top surface. So, the soil sample was subjected to a normal pressure of 48.09 KPa. So, in laboratory, the soil was subjected to 8 kg, 16 kg and 32 kg normal load only. The test outcomes are shown in Figure 6 and Figure 7.

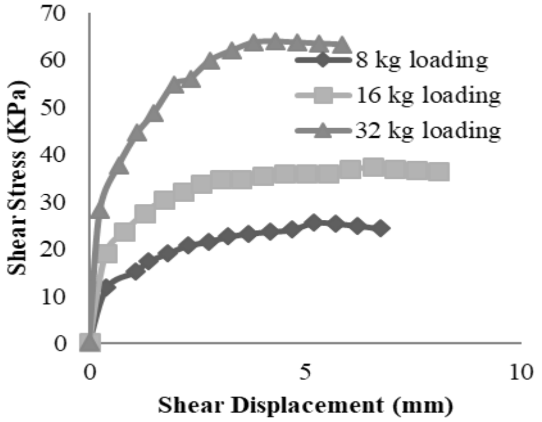


Figure 6: Shear Displacement Vs Shear Stress for Soil Sample of Paschimchor

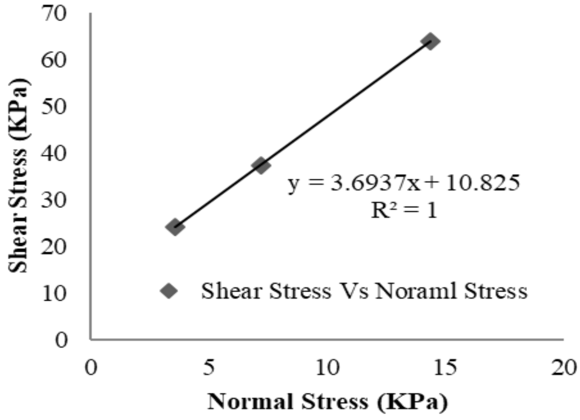


Figure 7: Failure envelop for soil sample of Paschimchor (Failure Envelope)

Soil sample – 2 was collected from the river bank at Moinotghat at 1ft depth from the top layer. As the soil sample was subjected to 24.77 KPa normal load at that place, the direct shear test was performed using 4kg, 8kg and 16 kg normal load in the laboratory. The test outcomes are shown in Figure 8 and Figure 9.

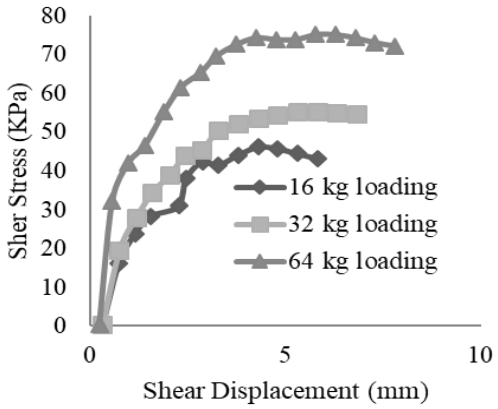


Figure 8: Shear Stress Vs Shear Displacement for Moinotghat Bottom Layer

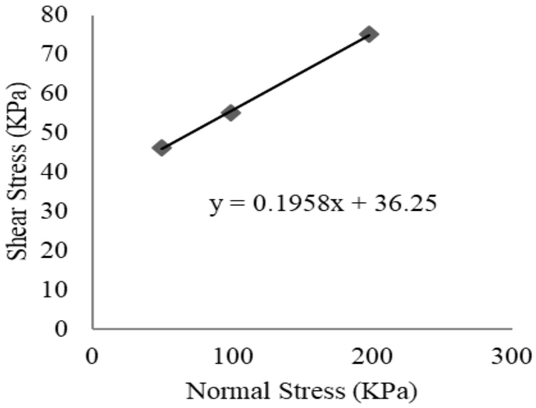


Figure 9: Shear Stress Vs Normal Stress for Moinotghat Bottom Layer (Failure Envelop)

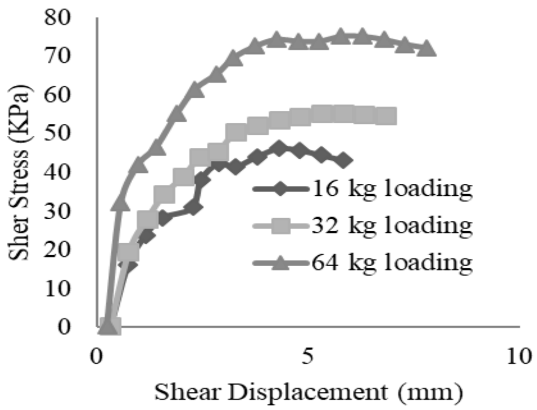


Figure 10: Shear Stress Vs Shear Displacement for Moinotghat Bottom Layer

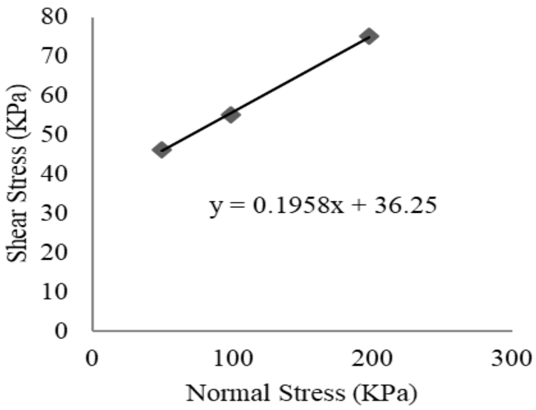


Figure 11: Shear Stress Vs Normal Stress for Moinotghat Bottom Layer (Failure Envelop)

Soil sample – 4 was collected from riverbank of Moinotghat at 7 ft depth from top surface of the riverbank. The soil sample was subjected 68.2 KPa normal load. So, in laboratory, the test was performed using 16 kg, 32 kg and 64 kg normal load. The test outcomes are shown in Figure 10 and Figure 11.

3. SOFTWARE ANALYSIS AND RESULTS

For analysis the problem of slope stability certain steps should be followed. If the geometry of the slope is known, and phreatic level of the slope is known any problem of slope stability can be analysed by Plaxis-2D.

3.1 Riverbank at Poschimchor

Soil of riverbank of Paschimchor was clayey-silt (7% clay, 88% silt and 4.5% sand). The model is done using Plaxis - 2D maintaining the slope angle of 30°, 35°, 42°, 53°,58° for high water table, dry condition and rapid draw down condition.

The model is kept using plain strain 15 node element. The material was clayey silt and unsaturated unit weight was 13.69 KN/m^3 and saturated unit weight was 17.69 KN/m^3. Coefficient of permeability was kept 0.001cm/sec which is converted to m/day as 0.021 m/day along x direction and 0.001 m/day in vertical direction. The c was kept 14.15 KPa (gained from direct shear test) and φ value was kept 38° and V_s and V_p value was used as 46.97 m/s and 98.78 m/s. And E value was used as 12000 KPa and poison's ratio was kept 0.33 and interface was kept manual and R_{inter} was kept 0.5 (Das, B, M., 2017). The factor of safety is calculated in strength reduction procedure which is shown in Table 2. From Figure 16, it can be seen that, the factor of safety decreases with increasing slope angle. It can also be seen that, the factor of safety follows a polynomial model with slope angle in these three conditions.

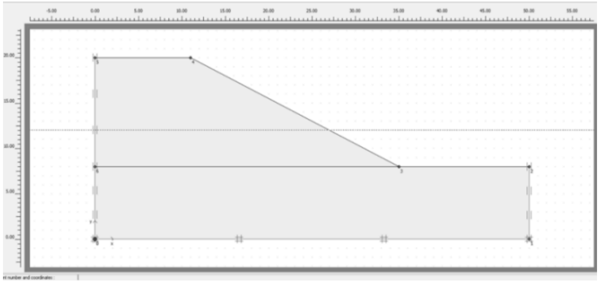


Figure 12: Slope geometry for slope of 30° for riverbank of Paschimchor

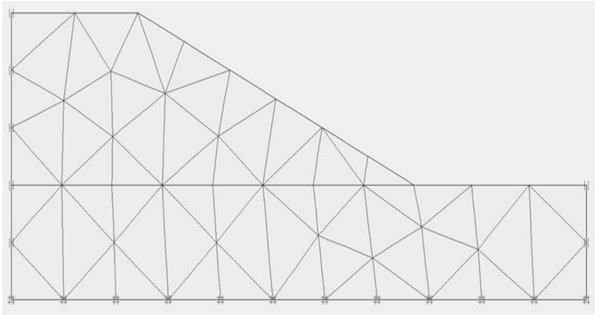


Figure 13:Meshing of the slope

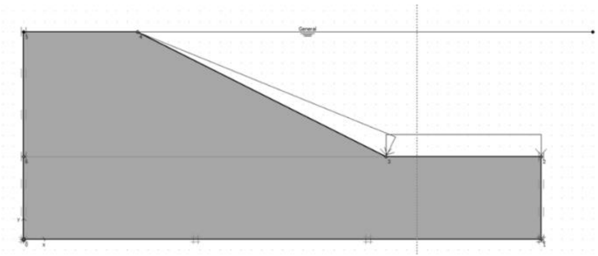


Figure 14: Defining phreatic level

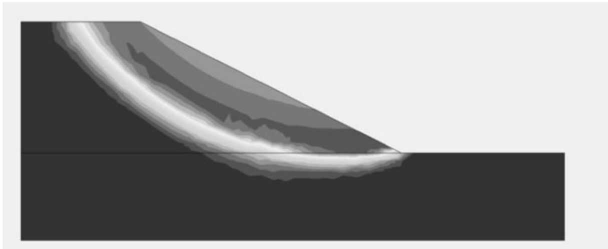
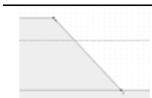


Figure 15: Total displacement (showing most applicable rupture surface of failure) at high water table

Table 2: Variation of Stability of Slope of Riverbank at Paschimchor with change of Geometry (slope Angle) and Water Level

	Change of Slope Geometry (Slope) Angle)	**Factor of Safety for High Water Table**	**Factor of Safety at Dry Condition**	**Factor of safety at Rapid Draw Down**
	11	4.4	3.35	2.45
	35	4.02	3.02	2.25
	42	3.35	2.56	1.71
	53	2.75	2.15	1.38
	58	2.25	1.78	1.26

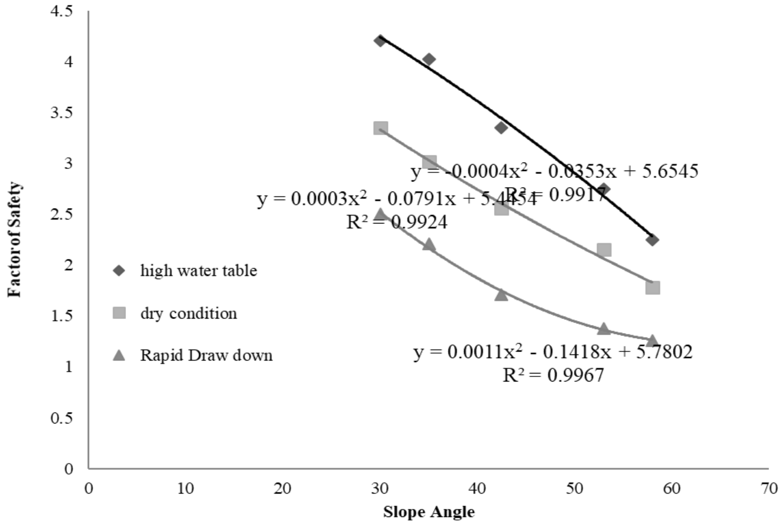
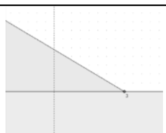
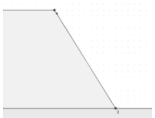


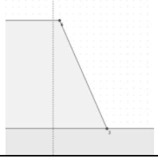
Figure 16: Factor of Safety Vs Slope Angle Considering Different Water Level for Riverbank at Paschimchor

3.2 Riverbank at Moinotghat

The riverbank of Moinotghat of two kind of layer of soil; upper layer is consisted of (silty-sand (contains 56.8% sand, 37.2% silt and 6% clay) and bottom layer is consisted of clayey-silt (5% clay, 4.1% sand and 90.9% silt). The model is kept using plain strain 15 node element. Unsaturated unit weight was kept 13.46 KN/m^3 and saturated unit weight was 17.28 KN/m^3. Coefficient of permeability was kept 0.01 cm/sec which is converted to m/day as 7.645 m/day along x direction and 0.001 m/day in vertical direction. The c was kept 5 KPa (gained from direct shear test) and φ value was kept 38° and V_s and V_p value was used as 51.93 m/s and 108.1 m/s respectively. And E value was used as 10,000 KPa and poison's ration was kept 0.35 and interface was kept manual and R_{inter} was kept 0.5 (Das, B. M. 2017). This is shown in Table 3.

Table 3: Variation of Stability of Slope of Riverbank at Moinotghat with change of Geometry (slope Angle) and Water Level

	Change of Slope Geometry (Slope) Angle	**Factor of Safety for High Water Table**	**Factor of Safety at Dry Condition**	**Factor of safety at Rapid Draw Down**
	30	2.56	2.2	1.35
	35	1.98	1..65	1.22
	42	1.45	1.25	0.99
	53	1.28	1.07	0.61

	Change of Slope Geometry (Slope) Angle	Factor of Safety for High Water Table	Factor of Safety at Dry Condition	Factor of safety at Rapid Draw Down
	58	1.2	0.95	0.5

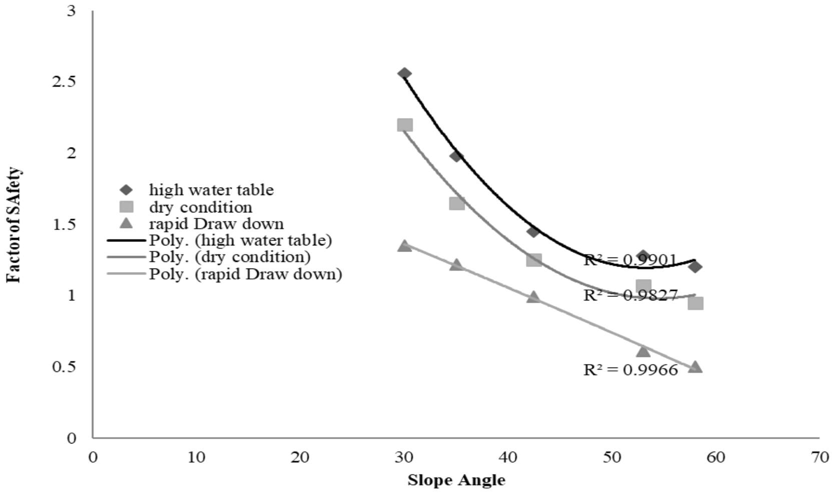


Figure 17: Factor of Safety Vs Slope Angle Considering Different Water Level for Riverbank at Moinotghat

4. CONCLUSIONS AND RECCOMENDATIONS

This study has been run focusing on the impact of water level and slope geometry on the stability of slope using software PLAXIS-2D based on finite element method for soil of different properties such as different shear strength parameter and coefficient of permeability. From above study it has been observed that for all type of geometry (considering varying slope angles) the highest factor of safety occurs at high flood level. This is because at high flood level there is water pressure on the both side of the slope and this balancing force increases the stability of the slope. The lowest factor of safety has been found at rapid draw down condition for all type of geometry (considering varying slope angles) due to the seepage force which acts as suction force on the slope and stability of the slope is reduced to a great extent by this phenomenon. As the steepness of the slope increases, the stability decreases. It has been also being seen that the type of the soil has a great impact on stability of the slope. The riverbank at Paschimchor has greater factor of safety than the riverbank of Moinotghat considering the same water table and geometry as the soil of Paschimchor was clayey silt and the soil of top layer of riverbank of Moinotghat was silty sand. As the clayey silt has greater cohesive force and less coefficient of permeability than silty sand, the slope of the riverbank of Paschimchor is much more stable than slope of riverbank of Moinotghat. So, slope protection measures should be taken for the riverbank at Moinotghat. It has been also observed that stability of the slope decreases linearly with the increase of steepness of the slope for clayey silt for high water table and dry condition where the stability of the slope decreases maintaining a power function with the steepness of the slope considering high water table and dry condition for silty sand.

In this research work, the relationship of deformation with time at rapid draw down condition is not shown here using software Plaxis-2D and it is the limitation of this research work. In this research work, no necessary measures have been mentioned to stabilize the riverbank. The relation between factor of safety and slope geometry considering different water level is represented here graphically but it could be better research work if this relationship was expressed in linear or non-linear equation.

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