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Influence of Short Term Rainfall on the Jamuna River West Bank Protection Flood Embankment Stability at Bahuka, Sirajgonj, Bangladesh--A Case Study

ATM Shakhawat Hossain* &Sayeda Albina Haque. \
Engineering Geology, Geotechnics & Geohazards (EGG) Research Group, Department of Geological Sciences, Jahangirnagar University, Savar, Dhaka-1342, Bangladesh
Corresponding Author: ATM Shakhawat Hossain

Abstract: *In this research, an attempt has been made to evaluate the influence of short term rainfall on the embankment stability with Seep/W & Slope/W numerical finite element software to see the development of seepage pattern and stability condition due to infiltration of rainwater on the embankment slope. Pore water pressure (P.W.P.) development and their influence on the embankment stability are also evaluated by using 2011 monsoonal rainfall data. It is clearly established from these analyses that short term antecedent rainfall event due to recent climate change play an important role on the embankment failure mechanism. It is also observed that there is an influence of suction on the stability &suction value gradually reduced during raining. A variation of thefactor of safety (Fs) value from 1.687 to 0.695 during raining might be responsible for embankment failure and showed significant influence on the stability.*
Findings from this research work clearly infers that short term antecedent rainfall pattern can significantly influence on the embankment stability. It will certainly encourage the geo-engineers and environmental professionals to consider recent climatic influence in the design stage.
Keyword: *Embankment, Stability, Seepage, Suction, Pore water pressure & Factor of safety.*

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I. Introduction

Bangladesh is a low-lying, riverine country and one of the first line victims of ongoing and upcoming threats of climate change. As a riverine country, Bangladesh is suffering from severe riverbank erosion, bank and embankment failure which compels millions of her population to be displaced from their place of origin as an envirnmetal refugees. Flood protection embankments are widely used geo-engineering structures that support houses, roads, cultivable land, rails and so on. Failure of these embankment slopes can cause human casualties as well as negative impacts on a country's economy. Our study area is located in Sirajganj district and embankment failure during monsoonal rainfall is acommon problem in the investigated area. As a result these areas are inundated in flood and destroy everything which directly impacts on the developing economy of Bangladesh. The site was chosen with a view to find out the problem regarding excessive embankment failure during monsoonal period and to see influence of rainfall pattern on the embankment stability.Bangladesh Govt. has taken few steps including constructing revetments to prevent the change of direction of the river but from time to time the soil under the concrete blocks of revetment washed away due to strong current and other natural reasons causing ultimate revetment failure. To protect bank erosion, more than thirty bank protection structures have been constructed along both banks of the Jamuna River.Losses due to the embankment failure in and around Sirajgonj district, Bangladesh is increasing and eroding some flood protection embankments due to recent change of climate causing sudden dangerous flooding in and around Sirajgonj district, Bangladesh. No work has yet been carried out to see the influence of recent climate change on the flood embankment stability .

Most embankment slopes are initially unsaturated prior to any rainfall. Rainfall induced slope failure is a common problem in all over the world. Many rainfall-induced slope failures have been attributed to antecedent rainfalls. Although it has been identified as a cause of rainfall induced slope failure. Antecedent rainfall cycle has been identified as one of the main causes for embankment failures in areas where high annual rainfall is occurred such as Sirajganj area which is lie within tropical monsoonal climate zone. Antecedent rainfall cycle can be responsible for damaging these embankments by reducing the factor of safety values. Antecedent rainfall patterns were applied on soil slopes using Seep/W (2007) software and a transient seepage analysis was conducted. The computed pore-water pressures were used in stability analyses to calculate the safety factor of the slope. Result shows that antecedent rainfall cycle has a direct influence on slope stability. Some consequences of bank and embankment failures in and around Sirajganj district along Jamuna river are shown in

Figure 1.Due to bank erosion and embankments failure, population of this area faces a huge loss and these are mainly appeared as silentdisaster during monsoonal period (June-September).

Every year, the river bank of the Jamuna River erodes the constructed flood protection embankment (earthen embankment). As a result, the water of the Jamuna River enters into the Sirajgonj district during the rainy season and causes enormous flood in the district especially in the Kazipur and Sirajganj Sadar Upazila.

Figure 1 Damaged embankments and bank during rainy season in Sirajganj.

Rainfall, rainfall intensity, soil properties, location of the ground water table, and the slope geometry (angle, height) play a significant role in the rain-induced instability of a slope (Rahardjo et al, 2007). Earthen embankments tend to get washed away by heavy rainfall, flood and strong current. The major causes of failure identified were breach of the embankment cutting by local people, overflow, erosion, seepage and sliding (Mahbub et al, 2013). In case of riverbank failure, the permeability and strength of bank material both decreases rapidly with the increase of water content which associates the bank failure process.

Study area

The location map of the study area is shown in Figure 2. The study area lies between 89°40´ to 89°46´ E longitudes and from 24°34´ to 24°39´ N latitude and is bounded by Kazipur Upazilza in north, Belkuchi upazila in south, Bangabandhu Multipurpose Bridge in east and Kamarkhond upazila in west. This area covers mainly some part of Rangpur platform, large part of Bogra shelf and below Hinge line some part of Faridpur trough. Morgan and McIntyre (1959) noted that the area is tectonically active and evidence of recent tectonic activities is found in different places.

Figure 2 Location map of the investigated area

II. Methods

The present flood embankment is mostly constructed with sandy silt/silty sand (SM-ML, ML-CL). The fine sand in parts of the embankment is very permeable. Surface sealing is usually with clayey silt/silty clay. The analysed embankment slope geometry is measured during site investigations. Rainfall data provided by BMD (Bangladesh Meteorological Department) is used in this analysis.The geo-engineering material properties of soil were determined according to BS 1377 (1990).Bishop (1955), Scott et al. (1993), Sarma (1979) &Maulaand Zhang (2011) studied the embankment stability to see the influence of factor of safety on the stability. Numerical seepage and stability modeling were carried out to investigate the seepage and stability conditions in a saturated embankment under changing hydrological conditions.The commercial geotechnical finite element software Seep/W (2007) & Slope/W (2007) developed by Geoslope International Ltd., Canada was used for all analyses.

III. Results And Discussions

An attempt has been made to determine the short term rainfall influence on the western bank flood protection embankment at Bahuka of Jamuna river . From the analysed data, four distinct seasons 1. Pre-Monsoon Season (March - May) 2.Monsoon Season (June – September) 3.Post-Monsoon Season (October - November) and Winter Season (December-February) are identified in Bangladesh throughout the year. From 1980-2012 (32 years) rainfall data analysis, it is observed that highest amount of rainfall was observed during monsoonal period (June-September) with an increasing trend in study area as shown in Figure 3.It is also observed from rainfall data of 1980-2012 that the maximum amount of rainfall in the study area is observed in 2011. From many years data an attempt has also been made to see the overall rainfall trend for the month of June, July and August separately from 2000-2012. An overall increase of rainfall trend is also observed in August rainfall data (Figure 4).

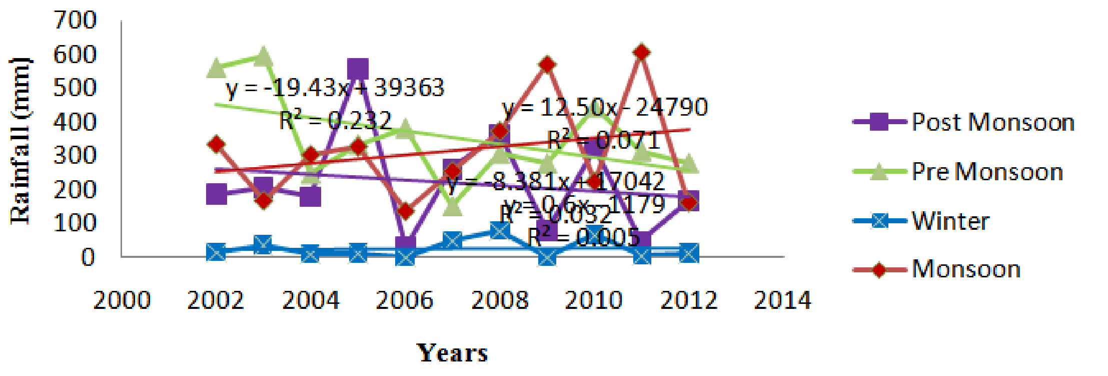

Figure 3 Seasonal variations of rainfall data from 2000-2012.

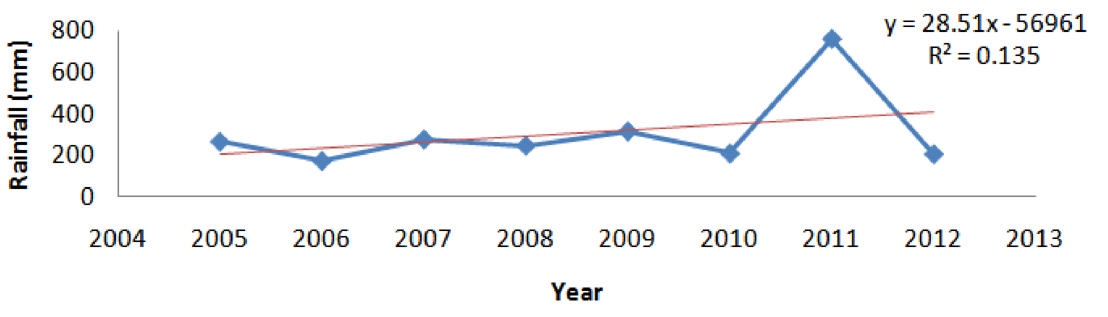

Figure 4 Increasing annual rainfall trend in August from 2005-2012.

Therefore, this August, 2011 data as shown in Figure 5 isused to see the influence of antecedent and major rainfall effect on the embankment failure. From Figure 5, it is identified that there are two (2) antecedentcyclesand one (1) major cycleof rainfall in August, 2011. Different distributions of the rainfall pattern applied on the embankment slope is listed in Table 1.

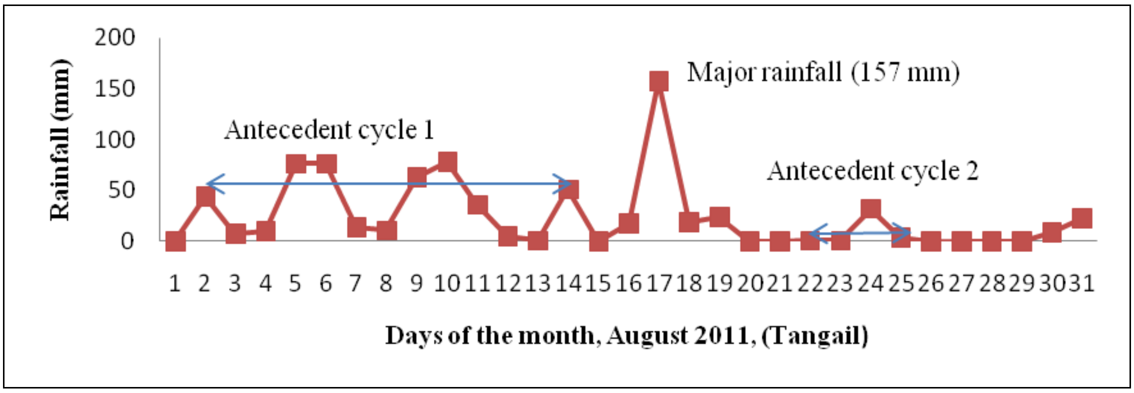

Figure 5 Days of the month versus rainfall curve in August 2011.

Table 1 Different distributions of the rainfall applied on the embankment slope

Antecedent Rainfall (mm)					Major Rainfall (mm)		
Antecedent Cycle	Total amount of antecedent rainfall (mm)	Duration (Hours)	Intensity (mm/day)	Intensity (mm/hr.)	Total amount of major rainfall (mm)	Duration (Hours)	Intensity (mm/hr.)
Cycle 1	473	312 (13 days)	36.38	1.52	157	24 (1 days)	6.54
Cycle 2	218	96 (4 days)	54.5	2.27			

The result of finite element numerical model can be used to interpret the infiltration mechanism of the slope, seepage conditions, effect of hydrological conditions on the pore pressure (P.W.P) changes.Seep/W is capable of modeling saturated/unsaturated and transient flow in two dimensions (2D). The result of the numerical finite element model can be used to interpret the infiltration mechanisms of the slope, seepage conditions, effect of hydrological conditions (including rainfall and evaporation) on the pore water pressure (PWP) changes (Hossain & Toll, 2013).

The P.W.P development due to raining on the slope surface is a complex process. Pore water pressure (P.W.P) might be positive or negative. It is established in this analysis that during raining suction (negative pore water pressure) can play a vital role on the stability. In transient flow the hydraulic head changes as a function of time. In the seepage analysis, a triangular element (1×1mm.) mesh was used. In total this mesh consisted of 859 nodes and 1532 elements. Along the left and right edges, head boundaries were applied in order to define the initial ground water level and initial pore water pressure profile. A zero nodal flow boundary (Q=0) was applied along the base. The precipitation rate was modeled as a unit flux boundary (q) along the nodes at all surfaces of the ground. When solving, Seep/W translates the unit boundary (q) into a nodal boundary (Q) and then calculates the hydraulic head at each node. The slope stability analyses considering the rain infiltration process were carried out to see the seepage conditions on the factor of safety of the slopes. Slope stability analysis were performed using limit equilibrium method. Bishop's simplified method was chosen. The considered embankment height is ± 18 m and inclined at an angle of 50°. Ground water level (G.W.L) is about ± 2 m below the ground level and saturated conditions is considered during analysis. Predicted pore water pressures (P.W.P.) obtained from the Seep/W seepage analyses were used as input ground water conditions for subsequent limit equilibrium analyses.

Material Properties

From grain size analysis result, it is established that the bottom sand layers are mainly uniformly graded very loose to medium fine sands with some silts (Figure 6) and upper clay soils can be classified as intermediate plasticity silty clay (CI) according to their position on soil classification chart.

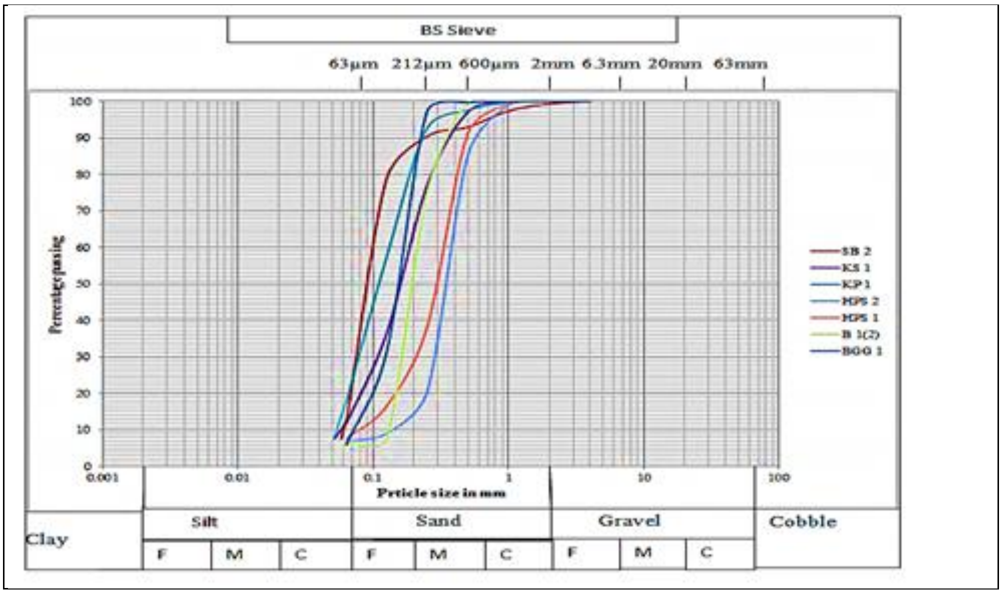

Figure 6 Grain size analysis of silty sand soil

The material properties of soil layer used in the analyses are listed in Table 2.

Table 2 Material properties of soil layer

Soil layer	Soil type/Lithology	γ_{wet} (KN/m²)	c' (kPa)	φ' (°)	K_{sat} (m/sec)
Layer 1 (L-1)	Loose Fine Sand	18	0	27.5	$1e^{-3}$ to $1e^{-4}$
Layer 2 (L-2)	Silty Fine Sand	18	8	17	$1e^{-4}$ to $1e^{-5}$
Layer 3 (L-3)	Dense Fine Sand	20.5	0	27.5	$1e^{-5}$ to 1^{e-6}

Impact of rainfall pattern on embankment stability

Two antecedent rainfall cycles (2nd to 14th August and 22th to 25th August, 2011) and one major rainfall event (17 August, 2011) as shown in Figure 5 were selected as input parameters in numerical finite element software to see the influence of rainfall on the embankment stability.The results of the different scenarios are considered in the following sections

Effect of 1st Antecedent Rainfall Cycle (13 days data) on embankment slope failure

Total amount of rainfall for 13 days was 473 mm. The analyses of initial seepage condition and initial embankment slope by using Bishop's method before rainfall are shown in Figures 7 & 8 respectively. P.W.P. profiles generated by Seep/W for each scenario were used to evaluate the stability conditions. The numerical value shown next to the centre of the failure surface is the calculated factor of safety. Before raining, it provides a negative pore water pressure of -40 kPa (Figure 7) and a factor of safety value of 1.687 (Figure 8) which indicate a stable slope. Seepage conditions of slope was changed after 1st day rainfall and showing a decreasing value of negative P.W.P. -30 kPa from the condition before raining (Figure 9). Factor of safety value was also decreased and it reaches up to 0.814 (Figure 10) which is lower than the value 1.687 of initial day and indicate the unstable condition. Seepage condition of embankment after 2nd days of 1st antecedent cycle is shown in Figure 11, where a more decreasing value of factor of safety 0.710 was observed as shown in Figure 12.With increasing days of antecedent cycle, the factor of safety values gradually decreased to 0.703, 0.697 and 0.695 (Figure 13, 14 & 15) after 3rd, 4th and 5th day respectively. After 5th day no significant change of factor of safety value is observed. All the obtained "Fs" values indicate unstable condition of embankment and up to the end of the test the Fs value remains constant (0.695).

At the end of 1st antecedent cycle , it was observed from the analyzed result that the seepage condition of the embankment was changed from initial condition and a negative pore water pressure -20kPa (Figure 16) is developed at the crest. It infers that during raining , negative pore water pressure is gradually decreased.

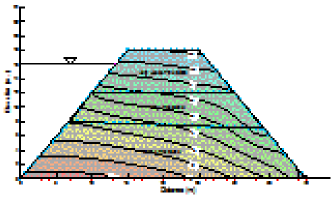

Figure 7 Initial condition of seepage before raining.

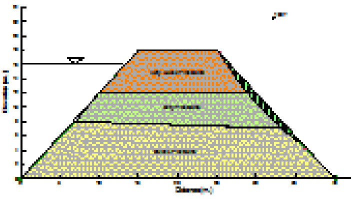

Figure 8 Initial condition of slope before raining (Fs=1.687).

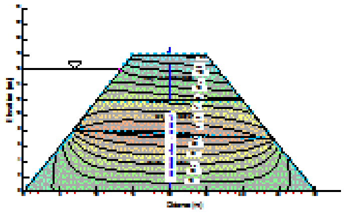

Figure 9Seepage condition after 1 day rainfall (PWP = -30 kPa).

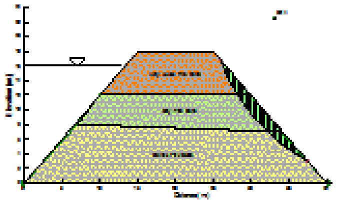

Figure 10 After 1 day rainfall of 1st antecedent cycle (Fs= 0.814).

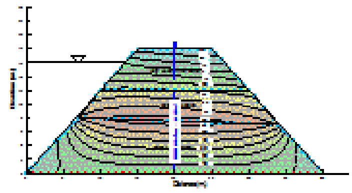

Figure 11 Condition of seepage after 2 day rainfall (PWP = -30 kPa).

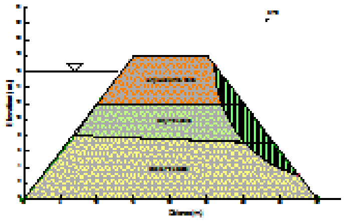

Figure 12 Stability condition after 2 day rainfall (Fs= 0.710).

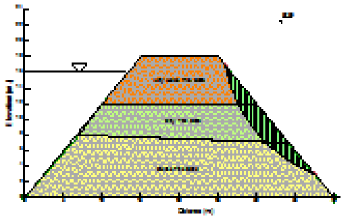

Figure 13 Embankment Stability condition after day 3 rainfall (Fs= 0.703).

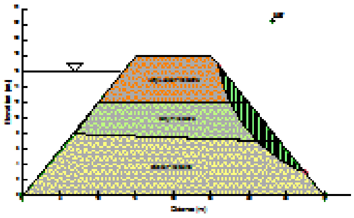

Figure 14 Embankment condition after 4th day rainfall (Fs= 0.697).

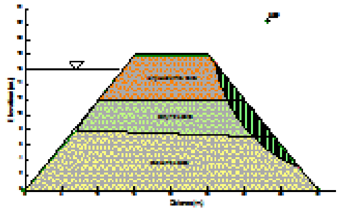

Figure 15 Stability condition after day 5 rainfall (Fs= 0.695).

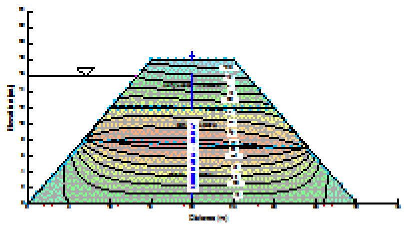

Figure 16 Condition of seepage after 13 day rainfall (Maximum negative PWP = -20 kPa).

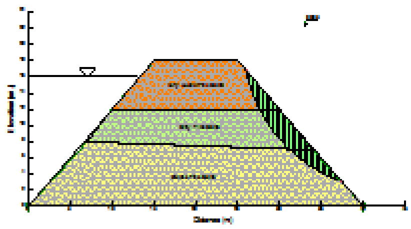

Figure 17 Embankment stability condition after day 13 rainfall (Fs= 0.695).

A drop of negative P.W.P. (suction) value from -40 kPa to -20 kPa clearly indicates that suction might influence on the embankment stability. This can be justified by the corresponding factor of safety values.Slope stability condition at the end of the test provide a factor of safety value 0.695 (Figure 17).

From the 13 days (1st antecedent cycle) data analysis, it is clearly observed that rainfall can influence on the factor of safety values during raining and a value below of 1 (Fs <1) is considered as unstable condition of embankment slope.The change of Fs values with different time steps (2nd to 14th August, 13 days) is shown in Figure 18 and it is clear from this Figure that during antecedent rainfall period significant drop of factor of safety was occurred during 2nd to 5th days and after that almost a steady value is observed up to the end of the test. Significant drop of factor of safety value from 1.687 to 0.695 might be responsible for embankment failure. It infers that antecedent cycle of rainfall event can play vital role in reducing embankment stability. The sequence of dropping of factor of safety values from initial 1.687 to 0.

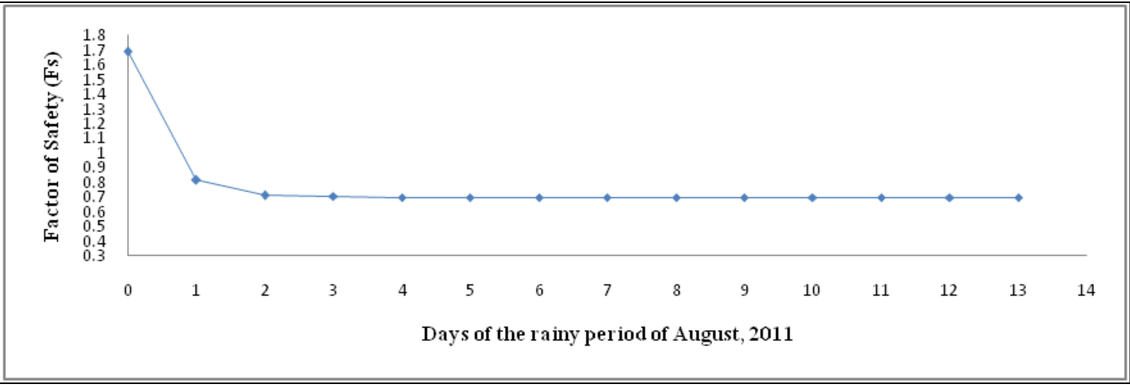

Figure 18 Variation of Factor of safety values with different time of rainfall.

Effect of 2nd antecedent rainfall cycle (4 days) on embankment stability

2nd antecedent rainfall cycle (from 22nd August to 25th August) was also distributed on the embankment slope to see its influence on the stability. Total amount of 2nd antecedent rainfall was 218 mm. and distributed with an intensity of 54.4 mm./day.P.W.P. profiles generated by Seep/W in each case were used to evaluate the embankment stabilityconditions.The embankment stability condition after one day rainfall of 2nd antecedent cycle is shown in Figure 19, a factor of safety 1.570 (Fs=1.570) is encountered which indicate stable condition of slope. The embankment stability conditions after 2nd and 3rd days of rainfall are shown in Figures 20 & 21 respectively, where Factor of safety values decreased up to 1.123 & 1.109. The seepage condition of the embankment slope after 4 days rainfall is shown in Figure 22, a negative P.W.P .-20 kPa is observed near the crest.At the end of 2nd antecedent cycle of rainfall (after 4 days) , a factor of safety value 1.020 is observed (Figure 23). From this analysis, it is established that after distribution of 2nd cycle of antecedent rainfall a drop of Fs value is observed continuously. Although a drop of safety factor is observed, but this amount of rainfall has no significant influence on the failure condition. The slope is marginally stable.

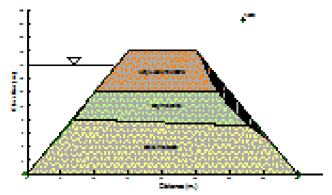

Figure 19 Embankment stability condition after 1 day rainfall (Fs= 1.570).

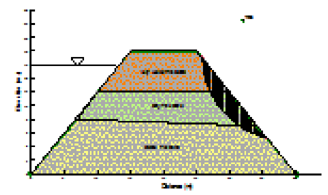

Figure 20Embankment stability condition after 2 day rainfall (Fs= 1.123).

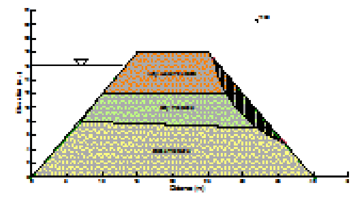

Figure 21After 3 day rainfall of 2nd antecedent cycle (Fs= 1.109).

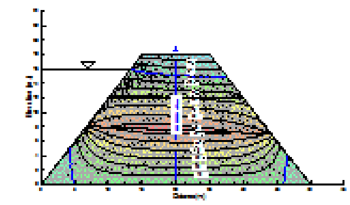

Figure 22 Condition of seepage after 4 days rainfall (Maximum negative PWP = -20 kPa).

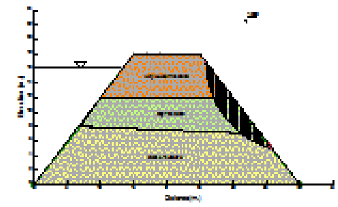

Figure 23 stability condition (after 4 day) at the end of test (Fs= 1.020).

Effects of Major Rainfall Patterns

An attempt has also been made to see the influence of single day major rainfall amount of 157 mm. of 17 August, 2011 on embankment stability which distributed over 24 hours with an intensity of 6.54 mm/hr.

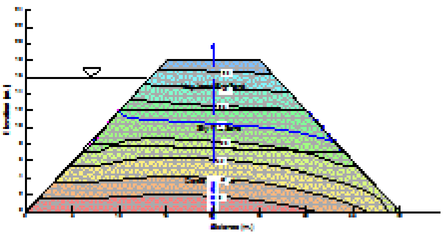

Figure 24 Seepage condition after 1 day major rainfall of 17th August 2011.

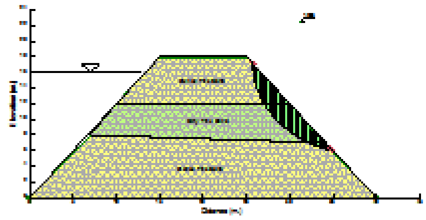

Figure 25 Embankment condition after 1 day major rainfall of 17th August 2011 (Fs=1.233).

The predicted P.W.P. contours are shown in Figure 24 with a suction value -60 kPa near the crest. For this condition, a factor of safety 1.233 is observed (Figure 25). This clearly shows that the single day major rainfall event has no influence on the embankment stability. High suction value –60 kPa might be responsible for the stability condition. The combined effect of any antecedent cycle of rainfall and a single day major rainfall might influence on the stability condition. Hossain & Toll (2013) discussed the combined influence of antecedent and a single day major rainfall event on the landslide hazards of Chittagong.

From many years rainfall data, it is observed that highest amount of rainfall occurs within the June to September monsoon period. In 2011, August showed highest amount of monthly rainfall over 761 mm. it is established from the seepage analysis that during raining negative pore water pressure values gradually reduced and hence soil loses its strength. It is indicating that precipitation causes the suction near the surface to decrease and indeed embankment failures might occur.

IV. Conclusions

The livelihoods of people in Bangladesh are often affected by water-related disasters including floods, riverbank erosion, failure of embankments and such infrastructure. The failure of embankment slope mainly depends on the value of factor of safety. The safety factor above 1 (Fs>1) would be the assurance of soil strength along with the less chance of failure possibility whereas Fs value below 1 indicate more unstable failure condition of slope.

Rainfall data from 1980-2012 have been used to evaluate the climatic scenario of the investigated area. From the analysis, it is established that during monsoonal period (June-September) the amount of rainfall showing an increasing trend from 1980-2012 which showing a consistency with extensive bank failure within this period in the study area reported by national dailies in different years.

From rainfall data of 2002-2012, highest amount of rainfall is observed in 2007 and 2011. This time range 2002-2012 is selected for this analysis because from 2002 the amounts of rainfall patterns are changed than the past. These abnormal rainfall patterns directly indicate the gradual change of climate. Short term rainfall data of August, 2011 was selected as input parameters in software to see the short term rainfall influence on the bank and embankment stability. Two (2) antecedent cycle (2^{nd}-14^{th} August and 22th-25^{th} August, 2011) and one major rainfall event (17^{th} August) are analyzed to see the influence of rainfall on embankment stability. Analysis shows that the factor of safety (Fs) value before raining was 1.687 which indicates of stable condition; in that time maximum negative pore water pressure near the crest was -40 kPa. With increasing days of rainfall cycle, Fs value was gradually decreasing and all values were below 1. And at the end of the Ist antecedent cycle (13 days), factor of safety value reaches up to 0.695 with maximum negative pore water pressure -20kPa at the crest which indicate very much unstable and failure condition of embankment with less suction value. It clearly indicates that short term antecedent rainfall for many consecutivedays has direct influenceon the embankment stability.It is also recommended to locate some free drainage surface within embankment because it prevents to store excess water in embankment.

The 2^{nd} antecedent cycle of 4 days has little influence on embankment stability. A major rainfall event with 6.54 mm./hr. has no effect on embankment stability but in conjunction with 1^{st} antecedent cycle this major rainfall might influence on the embankment stability. 2^{nd} antecedent cycle of 4 days (22^{th}-25^{th}) provide factor of safety value 1.570 after one day rainfall which is stable in condition but with increasing time it was gradually decreasing. At the end of the test (4^{th} day) the factor of safety value reaches upto 1.020 which is very close to 1, it indicates that the embankment slope is marginally stable due to 2^{nd} antecedent cycle of raining.

Single day major rainfall amount of 157 mm of 17 August, 2011 was distributed over 24 hours with an intensity of 6.54 mm/hr. and provide factor of safety value 1.233 with high suction value -60 kPa at the crest.

So, it can be inferred that the 2nd antecedent cycle of 4 days has no influence on embankment stability but in conjunction with any antecedent cycle this major rainfall might influence on the embankment stability.

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