

Slope stability, rainfall, infiltration

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**1. Introduction**

This paper relates the concern of landslides and slopes stability issues in the Bujumbura city in Burundi located in the African tropical region of intense rains. During heavy rains, torrential flows are observed in the rivers. The intermittent rivers flows are subjected to water level fluctuation. Every year the phenomenons repeat, what results in rivers banks failures in which a progressive failure of river banks manifests with steep slopes. In upstream and mid-course along their passages, the rivers currents cause a lot of problems to the normal civilian and damages to the city infrastructures. The case study consists of the Ntakangwa river, one of the four main rivers that crosses the Bujumbura City.

**2. Materials and methods**

**2.1. Case study overview**

The river bank top is 12.6m long from the slope top, 4.7m high from the river bed and inclined of 85°. The river slope model is shown in Fig.1.

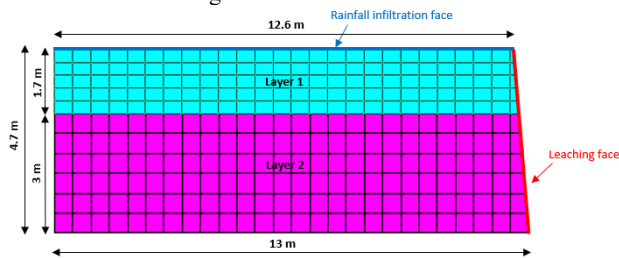


Fig.1. Slope shape and analysis model

**2.2. Methodology**

The methodology flowchart is shown in Fig.2

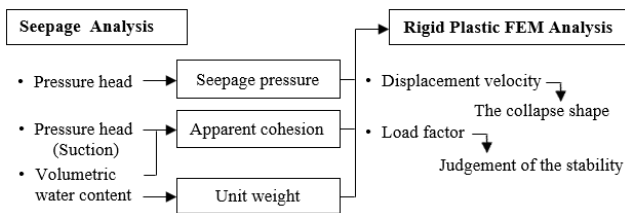


Fig.2. Analysis Methodology

The constitutive model of the soil is the Mohr Coulomb failure criterion. The effective stress of unsaturated soil being given by the Bishop relation in which the parameter depending on the suction is used. The soil water retention characteristics standing for the relation between degree of saturation and suction is given by the combination of Mualem and Van Genuchten models. Furthermore, the Van Genuchten model is also used to determine the effective saturation.

The normal rainfall event in Bujumbura area has 67.7 mm/h and 14.4mm/h as maximum and minimum intensities, respectively as shown in Fig.3.a). In the

analysis, the maximum intensity is to occur earlier in one case in order to investigate its effect, the Fig.3.b) shows its pattern.

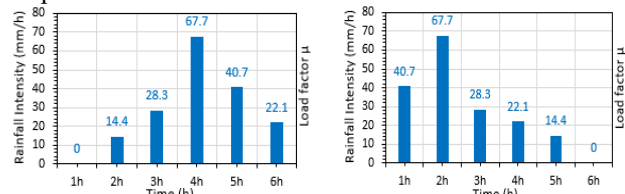


Fig.3. Rainfall event in Bujumbura area; a) pattern 1, b) pattern 2

**2.3. Slope model and Soils properties**

The Fig.1. shows the mesh consisting of 286 elements and 324 nodes. The layer 1 counts 130 rectangular elements of 0.50m x 0.34m whereas the layer 2 counts 156 square elements of 0.50m x 0.50m. The thicknesses of layers are 1.7m and 3m for layer 1 and layer 2, respectively. The layers 1 and 2 are silty sand and sandy silt soils, their soils properties are listed in Table 1, respectively.

Table 1. Soils properties

	$\gamma_d$ (kN/m <sup>3</sup> )	$k_s$ (m/s)	$c'$ (kN/m <sup>2</sup> )	$\phi'$ (°)
Layer 1	14.6	$8.25 \times 10^{-5}$	16	24.8
Layer 2	17	$6.94 \times 10^{-7}$	27	30.3

**3. Seepage analysis**

The assessment of the slope stability is performed at the slope conditions related to the plenty rain period where soils layers have small suctions and large volumetric water contents. This state can be convenient for assessing the slope stability of the Ntakangwa river banks. The Fig.4. presents the distribution of unit weight and cohesion when the rainfall pattern 1 is used without ground water level (GWL) at moments corresponding to the maximum intensity occurrence and the last step of rainfall, 4h and 6h, respectively.

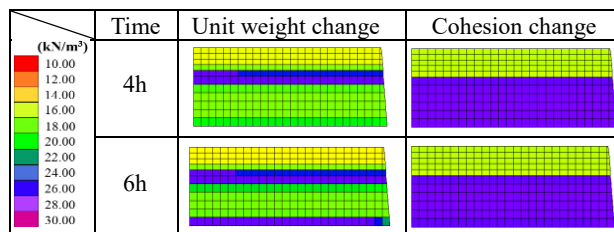


Fig.4. Distribution of Unit weight and cohesion with rainfall pattern 1

The Fig.5. compares the distributions of unit weight whereas the Fig.6. compares that of cohesion, with and without GWL when the rainfall pattern 2 is used. The outputs are presented at 2h and 4h for elapsed times corresponding to the moment of the maximum intensity

and the moment after slope failure, respectively.

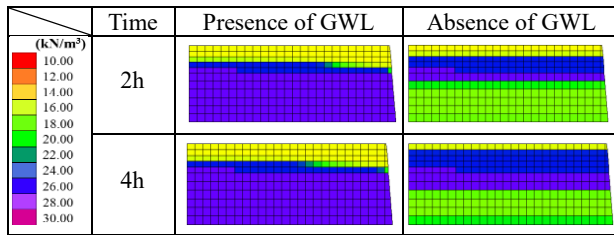


Fig.5. Distribution of Unit weight with rainfall pattern 2

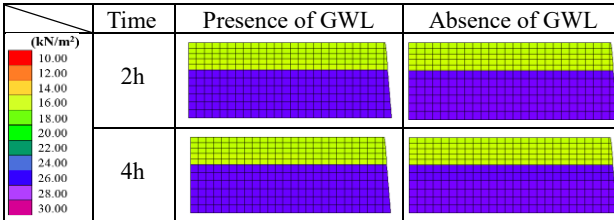


Fig.6. Distribution of cohesion with rainfall pattern 2

At 2.5m of GWL due to the river flow rise, a major number of soils elements are saturated, the cohesion exhibits a decrease whereas the unit weight increases significantly along the course of the shower. The changes in cohesions are small and with the scale calibrated with respect to the soils layers cohesions values does not make the changes clearly visible. Thus, the rainfall infiltration induces the loss of soils layers strengths and the reduction of the effective stresses and a great increase in unit weight.

#### 4. Slope stability analysis

The results of seepage analysis are introduced in the rigid plastic FEM slope stability analysis in which the load factor is obtained, the load factor standing for the safety factor. On river bed, nodes of soils elements are fixed vertically and horizontally whereas nodes of soils elements within the massif are free to move vertically; the rest of elements nodes are free of movement in both directions. The Fig.7. shows the boundaries conditions of the Ntahangwa river bank.

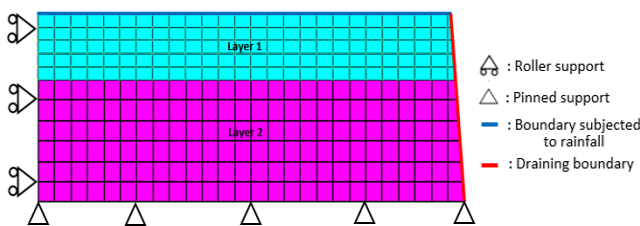


Fig.7. Boundaries conditions

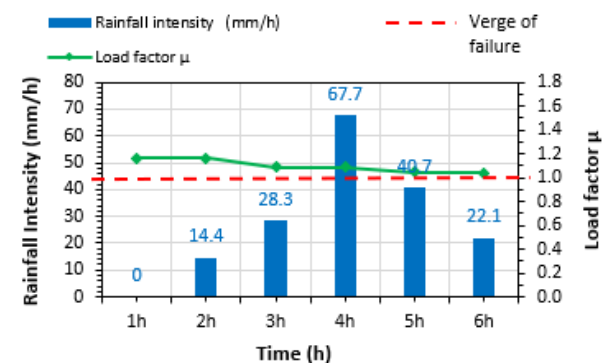


Fig.8. Load factor obtained with rainfall pattern 1 when no GWL exists

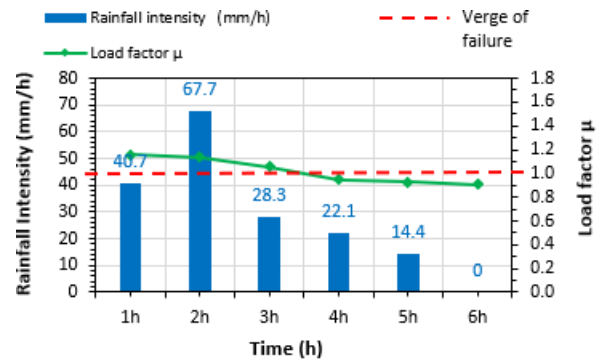


Fig.9. Load factor obtained with rainfall pattern 2 when no GWL exists

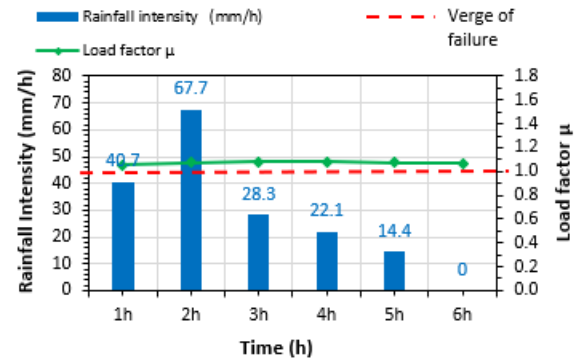


Fig.10. Load factor obtained with rainfall pattern 2 when GWL exists

The slope becomes unstable when the load factor is less than 1. In Fig.9, case where the rainfall pattern 2 is used, the failure occurs after 3.5h of shower with respect to the Fig.8 using the rainfall pattern 1. A comparison of load factors curves obtained with the rainfall pattern 2, with respect to the Fig.9. where no GWL exists, the Fig.10. that accounts for the presence of the GWL, the load factor significantly decreases and becomes almost constant.

#### 5. Results discussion

The rainfall pattern has effect on the failure occurrence. In the Fig.9, the case of the rainfall pattern 2, the failure instant happens after 3.5h of rain with respect to the case of the rainfall pattern 1 in Fig.8. Thus, a shower starting with a strong intensity accelerates the collapse mechanism under rainfall infiltration.

Along the course of the shower, the load factor goes down as time passes and the failure happens after the maximum intensity have been reached. In the case of the GWL existence, the load factor curve trend may be influenced by the fact that the layer 2 that contains more silt is less permeable; furthermore, the calculation assumes a constant ground water level where no flow out is allowed below the water table what makes the rainfall infiltration and drainage easier in the upper layer.

#### 6. Conclusion

The existence of the GWL in the slope accelerates the decrease of the load factor  $\mu$  but does not change the load factor curve shape. Therefore, the load factor  $\mu$  becomes almost constant.

The trend of the load factor change curve displays a decreasing shape at which the  $\mu$  value goes down less than 1 when the maximum intensity has been reached. A

good observation of load factor change can be made on the case where no GWL exists.

The rainfall is the most important factor in triggering the slope destabilization where the position of the strong intensity has been revealed being the factor accelerating the sliding mechanism for the slope.

## **7. References**

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