Landslide problem in Lalkhan Bazar Area of the Chittagong city, Bangladesh

Md Shofiqul Islam[1*], Mosarraf Hosain[1], Mohammad Shahidul Islam[1], Farjana Hoque[1], A.S. Daiyan Ahmed[1], Shefa Ul Karim[1]

Abstract- Landslides and mudflow after heavy monsoon rains are happening recurrently as the consequences of unwise hill cutting and deforestation in the Chittagong city, causing fatal accident including the loss of lives and property loss. In this paper, we present the main causes for landslide by determining the engineering and geological properties of the in situ soil samples. The analyzed slopes are consisting of two types of formation. Upper part comprises of hard and compact silt/clay layer with high cohesion (1.9-6.82 KPa) and Young modulus (519.4-2627.0 KPa). On the other hand, lower part consists of loose sand with relatively low cohesion (1.53-3.5 KPa) and Young modulus (49.16-55.0 KPa) The mathematical modeling using both liquid equilibrium and finite element method shows that the analyzed slopes are relatively stable (Factor of Safety and Shear Reduction Factor is more than 1) at dry condition. However, in the wet condition most of the slopes are vulnerable for landslide and need support to be stable for saving the people from accidents and injury.

Key words: Landslide, Slope stability, soil sample, Chittagong, Hill, Lalkhan Bazar, Rainfall

1 INTRODUCTION

Landslide or slope instability problem which represents major natural hazards, and which causes significant loss of lives and damages to buildings, properties and lifelines. In the last decades, a significant increase in landslide frequency took place, in response to climate change and the expansion of urbanized areas. It is a complex-disaster event that can be caused by heavy rainfall (typhoons, hurricanes), flood, sustained rainfall, earthquakes, volcanic eruptions, heavy snowmelt, unregulated anthropogenic developments, mining, and others. The gravity is the main driving force for a landslide to take place, whereas other contributing factors that affecting the original slope stability. However, factors affecting slope stability are soil type, strength of the soil, stratification, discontinuities and planes of weakness, ground water tables and seepage through the slopes, external loading, and geometry of the slope. Slope stability is the capability of a slope to resist stress, excess of what is normally bearable for the material property of the soil or rock inherent to the slope. Slope movements, such as translational or rotational slope failures occur when shear stress exceeds the shear strength of the materials forming the slope [1, 2]. Some other factors that contribute to high shear stress, such as lack of lateral support, excessive surcharges, lateral pressures and removal of underlying support [2]. Besides, low shear strength, due to naturally weak materials, soil weathering (swelling, shirking and cracking) and low inter-granular force due to seepage pressure, also enhance slope instability.

In Bangladesh, landslides are typically triggered by heavy rainfall. However, the primary causes of landslide include deforestation, hill cutting, unregulated development work, etc. Moreover, poverty and landlessness force poor people to live in the risky hill-slopes of the Chittagong city. Landslides in the Chittagong city were triggered by heavy rainfalls claimed at least 185 lives in the last seven years or so with 127 in 2007 alone. The disasters took place in Lalkhan Bazar, Motijharna, Tankir Pahar, Batali Hill, Akber Shah, Lebu Bagan (Andhar Manik) and Pahartali areas. On June 17 in 2013, at least 20 people died on three landslides that hit in many areas in the city. Seventeen people died on July 1 in 2011 when a wall collapsed at the Batali Hill in Tiger Pass/Lalkhan Bazar. According to the district administration, there are at least 1,000 families living on and around the twelve hills in Chittagong are at grave risk during the monsoon. People usually live in small tin-roofed hut under the steep hill are vulnerably exposed to a possible landslide. The Chittagong City is highly vulnerable to landslide hazard, with an increasing trend of frequency and damage. The landslides in the study area are classified as 'earth slides' since they consist more than 80% sand and finer particles [2, 3].

There are many techniques used to investigate the landslide or failure plane. Recently, remote sensing techniques represents a powerful tool for landslide investigation, i.e., the mapping of past or active slope failures. Among the techniques used to determine susceptibility of the landslide or slope failure, the laboratory analytical method using in-situ samples along with mathematical analysis is mostly popular. Moreover, some numerical modeling software (e.g., Slide, Phase, Carsole, ABAQUS etc.) lead the analysis more precise with better confidence. These software are based on numerical analysis of liquid equilibrium method or finite element method.
In this study, we aimed to 1) determine engineering properties (unit weight of soil, Poison's Ratio, Young's modulus, Cohesion) of the soil samples, 2) assess the slope stability at dry condition and wet condition, and 3) propose the remedial measures to protect the slope from disaster.

- *1 Department of Petroleum and Mining Engineering, Shahjalal University of Science and Technology, Sylhet 3114 Bangladesh*
- **Corresponding author: sho_fiq@yahoo.com*

2 STUDY AREA AND GEOLOGIC SETTING

The Chittagong City (Fig. 1) of Bangladesh lies between

21°54′N to 22°59′ N latitude and 91°7′ E to 92°14′ E longitude. Chittagong is the second largest city of Bangladesh with about 168sq km area including 4 million populations. The area of Chittagong is situated within the Tertiary hill region of Folded Flank of Bengal Fore deep. The folded part is comprised of the Tipam Sandstone formation and Girujan Clay formation of Pliocene age at the bottom and Dupi Tila formation of Plio-Pleistocene age at the top [4,5]. Tipam Sandstone formation is hard and compact while other sandstones are mostly moderate to loosely compacted and consisted of medium to fine grained with minor amount of silt and clay [5]. The Girujan clay formation comprises mainly of mottled clay with intercalations of sand bands and occasional coal streaks. The Dupi Tila [6] formation comprises of sandstone and shale [5]. The city comprises of the area of small hills and narrow valleys, bounded by the Karnaphuli River to the south, the coastal plain and the Bay of Bengal to the west and the floodplain of the Halda River to the east. The highest level of the hills within the city area is about 60 m above mean sea level [7]. The hills of the study area were cut with slopes of 70°–90° despite the potential threat of landslides because of the newer settlements of slums for the homeless people.

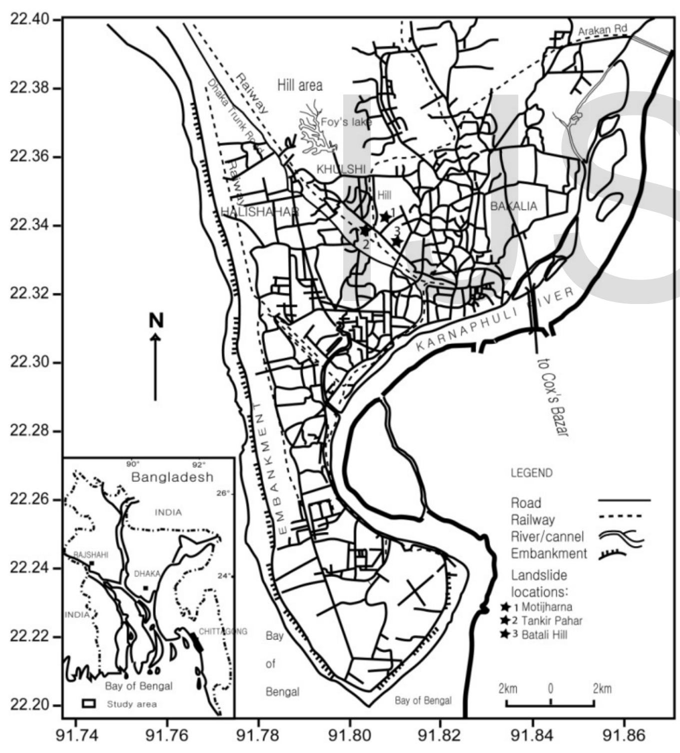

Fig. 1: Location map of the study area (modified after Khan et al. 2012; Islam et al., 2014)

Lalkhan Bazar area has some vulnerable slopes (Fig. 2a-b) that may cause disaster at any time. The slope angle of the slopes are ranging from 65 to 90° with some prominent joint or discontinuities in Matijharna (Lat. 22°20.827′N, Long. 91°48.863′E Fig. 2a-b) and Tankir Pahar (Lat. 22°20.91′N, Long. 91°48.857′E Fig. 2c-f). The upper part of the slopes are comprised of hard clay formation while the lower part consists of mainly loose sand particles (Fig. 2a-b). The upper part of the Tankir pahar area shows the indication (presence of kaolin (Fig. 2e)) of seepage during or after rainfall, which caused instability of the zone. The lower sand zone seems hard in the dry condition but it is very loose at wet condition. This phenomenon is observed during field and sample collection. The Batali Hill area (Lat. 22°20.742′N, Long. 91°48.778′E Fig. 2g-h) is very high with more than 80° slope angle. Some important construction, including telecommunication tower of the Chittagong City Corporation is situated on the top hill. There is a huge population will be living at the base of the slope in the mentioned area with risk.

3 METHODOLOGY

Total twenty four (24) samples have been collected from six (06) points in three (03) different locations (Matijharna, Tankir pahar and Batali Hill) in the Lalkhan Bazar of the Chittagong City (Fig.1). At each point, there are three (03) samples were taken for the direct shear test and one (01) sample was taken for unconfined compressive strength test. The different properties of soils such as unit weight of soil, internal angle of friction, cohesive strength, Poisson's ratio, and Young's modulus were measured using ASTM standard, direct shear measurement, and unconfined compressive strength test. The detail method is already described in Islam et al., [2] and Islam and Hoque, [8]. However, for better understanding of the reader, the method is also described here taken from Islam and Hoque, [8].

3.1 Measurement of unit weight of rock

Weight (W) of the each sample was measured by electronic weight machine using ASTM standard. Unit weight (γ) of the samples were measured using the equation 1

$$\gamma = \frac{W}{V} \qquad (1)$$

Where, V is the volume of the cylindrical sampler. The unit weight values were used to determine factor of safety using SLIDE2®.

3.2 Direct Shear Measurement

The test is carried out on remolded samples as well as in-situ samples in the laboratory of the department of Petroleum and Mining Engineering of Shahjalal University of Science and Technology using motorized direct shear apparatus (EDJ-2 Motorized Shear Appartus). The soil samples were compacted at optimum moisture content in a compaction mold and assembled in the shear box. Then specimen for the direct shear test was obtained using the correct cutter provided. A normal load was applied to the specimen sample and the specimen was shared across the pre-determined horizontal plane between the two halves of the shear box. This procedure was repeated for four times, including one in-situ sample and three remolded samples. Measurements of shear load, shear displacement and normal displacement were recorded. From the results, internal angle of friction and cohesive strength were measured using
Coulomb's shear strength equation (2).

$$\tau_f = c + \sigma_{f\tan\phi} \qquad (2)$$

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Where τf= shearing resistance of soil at failure, c = apparent cohesion of soil, of = total normal stress on failure plane, ϕ = angle of shearing resistance of soil (angle of internal friction). The values of these parameters (cohesion and angle of internal friction) and unit weight were used to determine factor of safety using SLIDE2®.

3.3 Unconfined Compressive Strength test

According to the ASTM standard, the unconfined compressive strength is the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. The test was performed at the Soil Mechanics Laboratory of Civil and Environmental Engineering Department of Shahjalal University of Science and Technology by using unconfined compressive strength tester (ELE International, Model 25-3605). Measurements of strains (%) and stresses were recorded. From the results, Poisson's ratio and Young's modulus were determined. These parameters along unit weight, cohesion and angle of internal friction of samples were used to determine shear stress reduction factor using PHASE2.

3.4 Limit Equilibrium Method

The conventional limit equilibrium methods for investigating the equilibrium of soil mass tending to slide down under the influence of gravity. Transitional or rotational movement is


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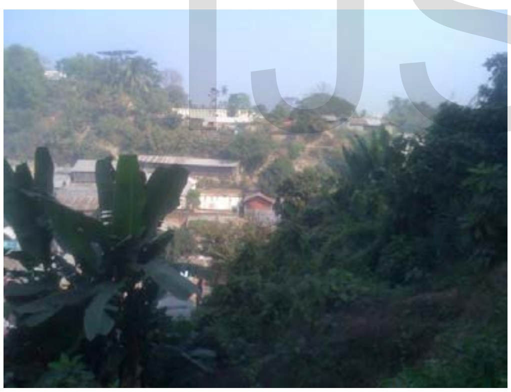
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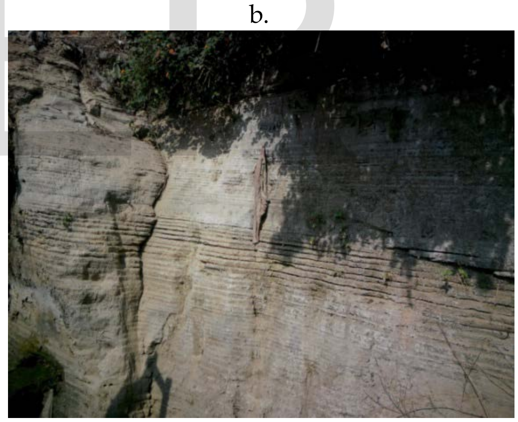
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e.


f.

g.

h.

Fig. 2 Photographs of the study area, a-b) Matijharna, c-f) Tankir pahar, and g-h) Batali Hill

considered on assumed or known potential slip surface below soil or rock mass. In rock slope engineering, these methods may be highly significant to simple block failure along distinct discontinuities. All methods are based on comparison of forces (moments or stresses) resisting instability of the mass and those that causing instability (disturbing forces).

Advantages, Limit equilibrium methods are still mostly used for slope stability studies. These methods consist of cutting the slope into fine slices so that their base can be compared with a straight line, then to write the equilibrium equations (the equilibrium of the forces and/or moments). According to the assumptions made in the efforts between the slices and the equilibrium equations considered, many alternatives were proposed. In most cases, differences between the values of the safety factor obtained with the various methods are generally lower than 6% [9,10]. However, the disadvantages of limit equilibrium are that the factors of safety are assumed to be constant along the potential slope surface and load deformation characteristics are not explicitly accounted.

The Ordinary methods of slices are applicable to non-homogeneous slopes where slip surface can be approximated by a circle and based on the defining equation. The Bishop's modified method is also applicable to non-homogeneous slopes and cohesive soils where slip surface can be approximated by a circle. It is more accurate than the Ordinary Method of slices, especially for analyses with high pore water pressures. Moreover, the Junbu generalized procedure is applicable to non-circular slip surface. This method is also used for shallow long planner failure surfaces that are not parallel to ground surface. Figure 2 shows the generalized force equilibrium of the multislice methods.

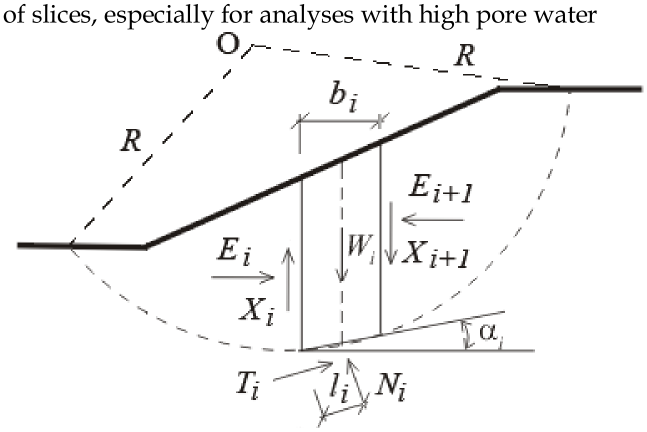


Fig. 3 The most common limit equilibrium techniques are methods of slices where soil mass is discretized into vertical slices.

3.4.1 Bishop's simplified method

Bishop's simplified method [11] is a primary slope stability method where the inter-slice shear forces are neglected and regardless of whether the slip surface is circular or composite that is based on the equation (3)

$$F = \frac{\sum\left[\frac{c'\Delta x + (W + p\cos\beta - u\Delta x\sec\alpha)\tan\phi'}{m_\alpha}\right]}{\sum W\sin\alpha - \frac{\sum M_p}{R}} \qquad (3)$$

Where, Δx is the width of the slice, and m_α is defined by the following equation (4),

$$m_\alpha = \cos\alpha + \frac{\sin\alpha\tan\phi'}{F} \qquad (4)$$

Where, c' and ϕ' is the shear strength parameters for the center of the base of the slice, W is the weight of the slice, α is the inclination of the bottom of the slice, u is the pore water pressure at the center of the base of the slice.

3.4.2 Janbu's Simplified Method

The Janbu's simplified (1956)[12] method is similar to the Bishop's simplified method except that the Janbu's simplified method satisfies only overall horizontal force equilibrium but not overall moment equilibrium.

The Janbu's simplified factor of safety is actually too low, even though the slices are in force equilibrium. Since force equilibrium is sensitive to the assumed interslice shear, as in the Junbu's simplified method, makes the resulting factor of safety too low for circular slip surfaces.

$$F = \frac{\sum[c'l + (P - ul)\tan\phi']\cos\alpha}{\sum P\sin\alpha \pm A} \qquad (5)$$

Where, c' is effective cohesion intercept, ϕ' is effective angle of internal friction, l is the length of the failure surface at the base of the each slice, P is the total normal force on the base of the slice, A is the resultant external water forces, α is the angle between the tangent to the center of the base of each slice and the horizontal.

3.5 Finite Element Method- Shear reduction factor

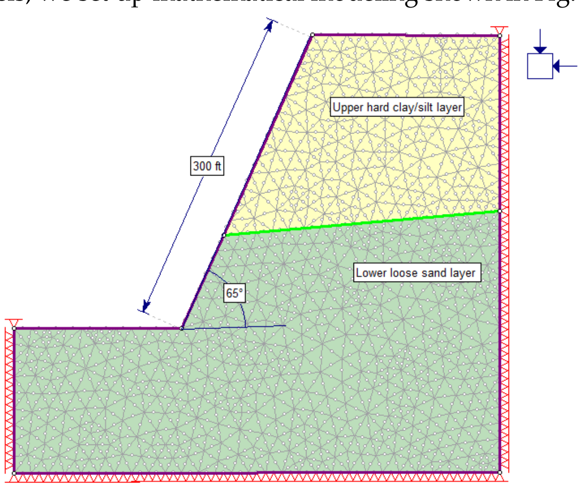
Finite Element (FE) approach to slope stability analysis over traditional limit equilibrium methods where no assumption needs to be made in advance about the shape or location of the failure surface. Failure occurs naturally through the zones within the soil mass in which the soil shear strength is unable to sustain the applied shear stresses. The FE method preserves global equilibrium until failure is reached. If realistic soil compressibility data are available, the FE solutions will give information about deformations at working stress levels. The FE method is able to monitor progressive failure up to and including overall shear failure.

3.5.1 Shear strength reduction method

The shear strength reduction technique for slope stability analysis includes the systematic use of finite element analysis to determine a stress reduction factor or the factor of safety, which brings a slope to verge (end) of the failure. Moreover the shear strengths of all the materials in a FE model of a slope are reduced by the SRF. The conventional method, finite element analysis of this analysis of this model is performed until a critical SRF value which induces instability is attained. Within a specified tolerance a slope is considered unstable in SSR technique when it FE model does not converge to a solution.
Shear strength reduction technique is widely used as it is readily available in many existing finite element softwares (e.g., Phase, Carsole, ABAQUS). It can be expressed in terms of principal stresses or normal stresses. Its linearity allows reduced parameters to be calculated readily while an original shear strength model is reduced by a factor F. Reduction of the shear strength envelope by a factor F, determination of new strength model parameters that conform to the lowered envelope, and use of the new parameters in conventional FE Elasto-plastic analysis.

3.6 Model Setup

On the basis of soil properties determined from the laboratory analysis, we set up mathematical modeling shown in Fig. 4.



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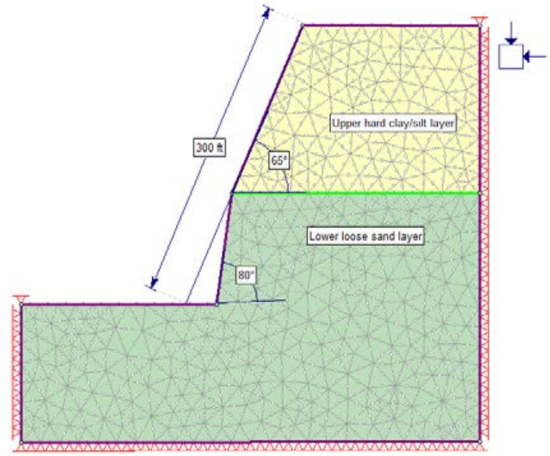

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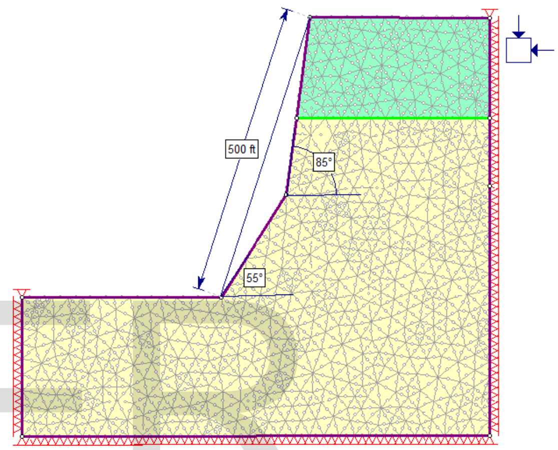

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Fig. 4 Model set up for mathematical modeling of a) Motijharna, b) Tankir pahar, and c) Batali Hills

The cross-section is assumed homogeneous and isotropic elasto-plastic material.

4 Result and Discussion

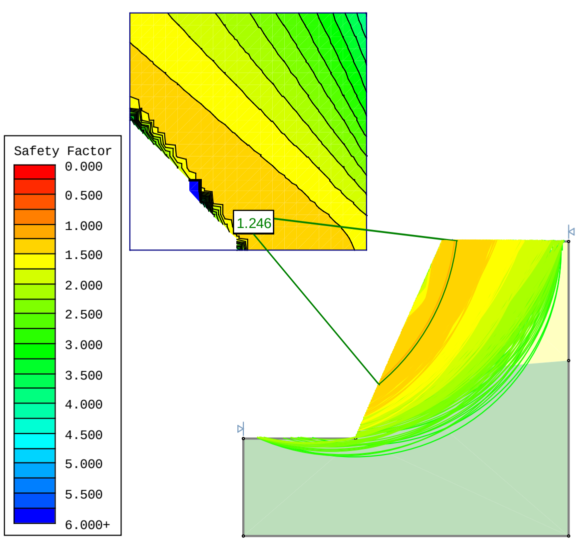
Laboratory measurement shows that the soil samples having unit weight ranging from 9.41 to 12.54 KN/m3 (Table 1). The result also shows that the friction angle, cohesion and Young modulus of the samples decrease significantly at wet than dry condition (Table 1) which is consistent with previous result [2,8, 13]. The main reason for this phenomenon is the rainfall infiltration on slope that could result in changing the soil suction and positive pore pressure, as well as raising soil unit weight, reducing anti-shear strength of rock and soil [14-16]. Some scientific and technical studies also (e.g., [17-20] suggest that rainfall is one of the important triggering factor that causes landslides. The mathematical modeling result show the effect of such condition induced in the landslide at wet condition in the Chittagong City (Fig. 5-7). The result shows that most of the slopes are stable at dry condition with factor of safety and Shear reduction factor values ~1 (Table 2). Moreover vegetation helps to resist landslide at dry condition. However, most of the slopes are vulnerable at wet condition with factor of safety (FS) and shear reduction factor (SRF) values <1 (Table 2). We represent the rigorous analyses of the limit equilibrium technique and finite element method for strength reduction factors of different slopes at better confidence (Table 2). The SRF values are in good agreement with FS values in most cases. Figures (5c-d, 6c-d, 7c-d) show that the deformation vector in the slopes is indicative for greater deformation of the upper part of the slope face.

The main reasons of these hazards are slopes with a steep angle and less shear strength of the material [2]. Islam et al. also opined that the slope would be stable if slope angle is less or equal to the friction angle of the soil at wet condition. Field observation during sample collection seems that unregulated hill cutting by influential greedy, poor and homeless people and deforestation is the main reason for landslide problem in the Chittagong city. The high hills in the city are almost bare and some covered with small herb. Big tree with long root is almost depleted from the hills. Day-by-day the landslide vulnerability is increasing in the Chittagong city from the last decade. To protect the hurt dweller in the foot hill, we should take some remedial measures such as i) landslide vulnerability assessment and zoning, ii) re-location of the foothill slums, iii) proper compliance of existing legal provisions, iv) real time monitoring and early warning, v) enhancement of public awareness, vi) establishment of the emergency response and recovery team and facilities, vii) addressing poverty issue, and viii) strict compliance of zoning and other legal and policy instruments etc..

From the engineering point of view, the slopes can also be made stable with the proper support system. We propose geotextile support with bolting for the slope of Motijharna and Batali Hill area (Fig. 8a-b) which could also be appllied for other slope. Along with previously mentioned remedies, the support system will ensure the safe living of the poor foot hill dweller rather than re-location issue.

TABLE 1 ENGINEERING PROPERTIES OF THE SOIL SAMPLE IN THE CHITTAGONG CITY

Soil condition	Sample location	Unit weight (KN/m3)	Slope angle (°)	Height (ft)	Friction angle (φ, °)	Cohesion (KPa)	Poisson's ratio	Young's Modulus (KPa)
Wet condition	Motijharna upper layer	9.458	65.00	300.0	40.10	1.53	0.42	259.70
	Motijharna lower layer	12.54	75.00	300.0	24.74	1.05	0.34	49.16
	Tankir pahar upper layer	12.54	75.00	300.0	30.00	3.41	0.45	1300.00
	Tankir pahar lower layer	11.95	85.00	300.0	30.66	1.32	0.48	53.12
	Batali Hill upper layer	12.15	80.00	500.0	30.00	3.50	0.44	1300.00
	Batali Hill lower layer	10.15	70/80	500.0	26.00	1.30	0.44	55.00
Dry condition	Motijharna upper layer	9.41	65.00	300.0	47.60	1.90	0.42	519.40
	Motijharna lower layer	10.54	75.00	300.0	45.00	1.83	0.34	98.32
	Tankir pahar upper layer	11.54	75.00	300.0	54.73	6.82	0.62	2627.00
	Tankir pahar lower layer	11.96	85.00	300.0	45.00	1.83	0.48	106.24
	Batali Hill upper layer	11.54	80.00	500.0	60.00	2.70	0.62	2627.00
	Batali Hill lower layer	10.05	70/80	500.0	48.00	6.70	0.44	85.88



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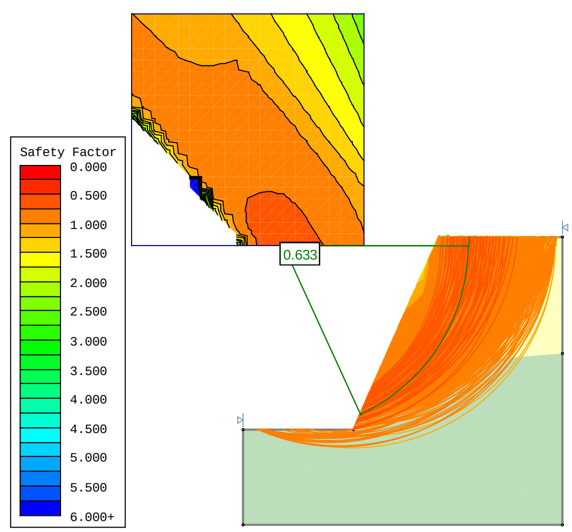

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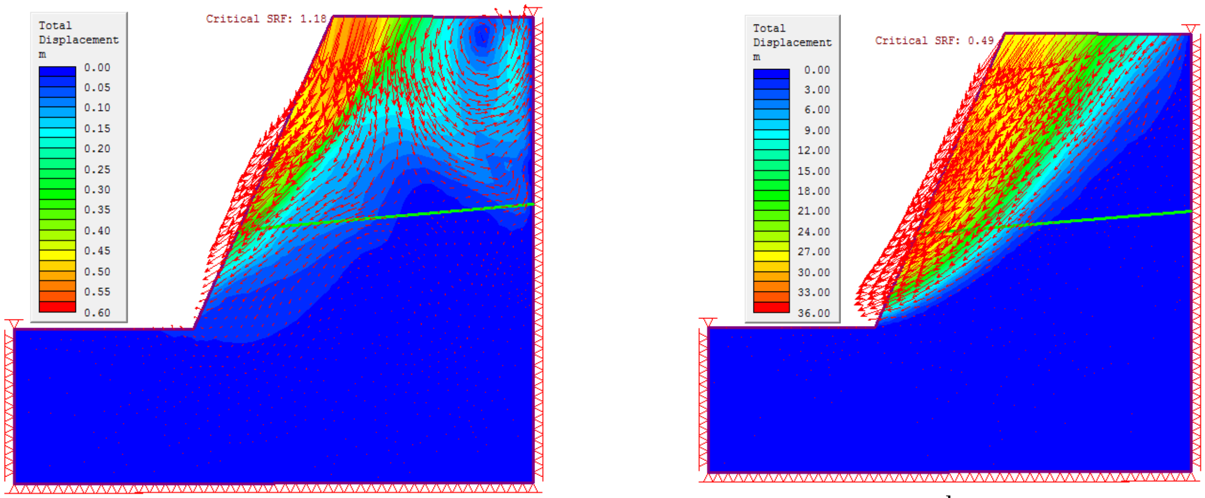
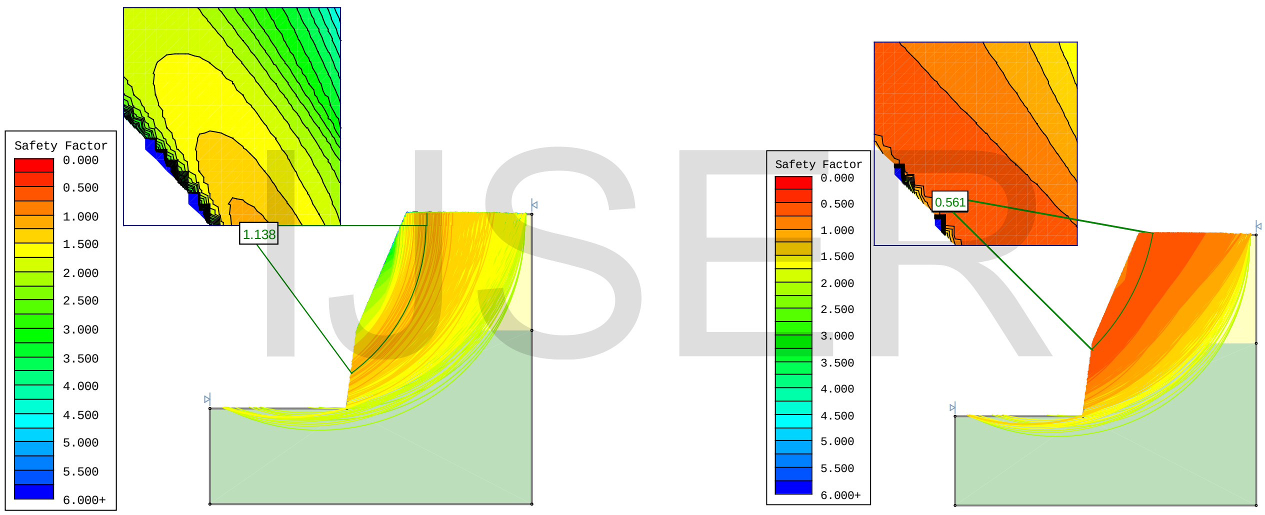


c. d.

Fig. 5 FS value using the Bishop's simplified method at a) dry condition and b) wet condition and SRF at c) dry condition and d) wet condition of the Motijharna area of Lalkhan Bazar of the Chittagong city



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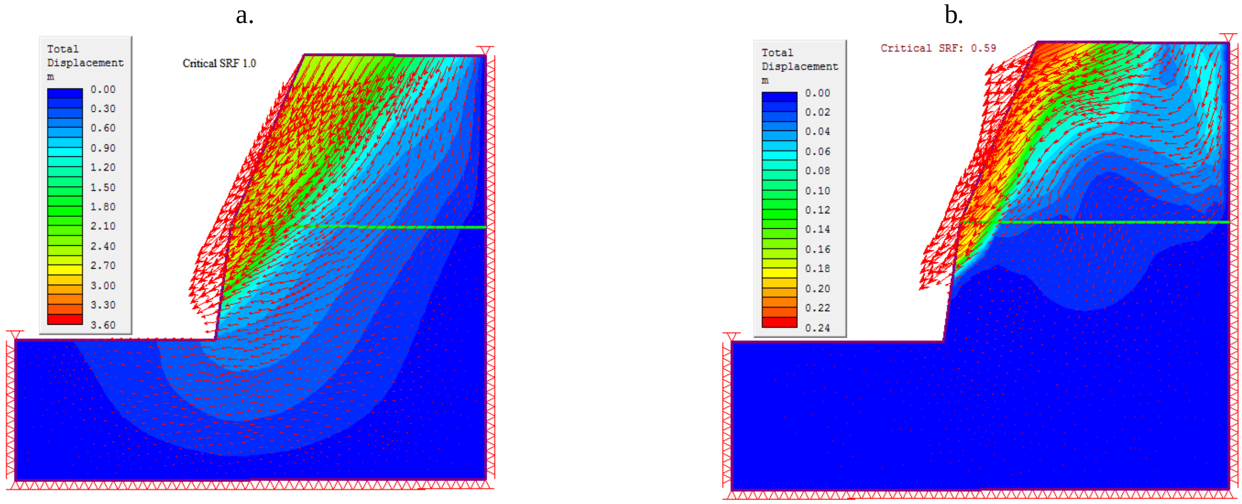


c. d.

Fig. 6 FS value using the Bishop's simplified method at a) dry condition and b) wet condition and SRF at c) dry condition and d) wet condition of the Tankir Pahar area of Lalkhan Bazar of the Chittagong city

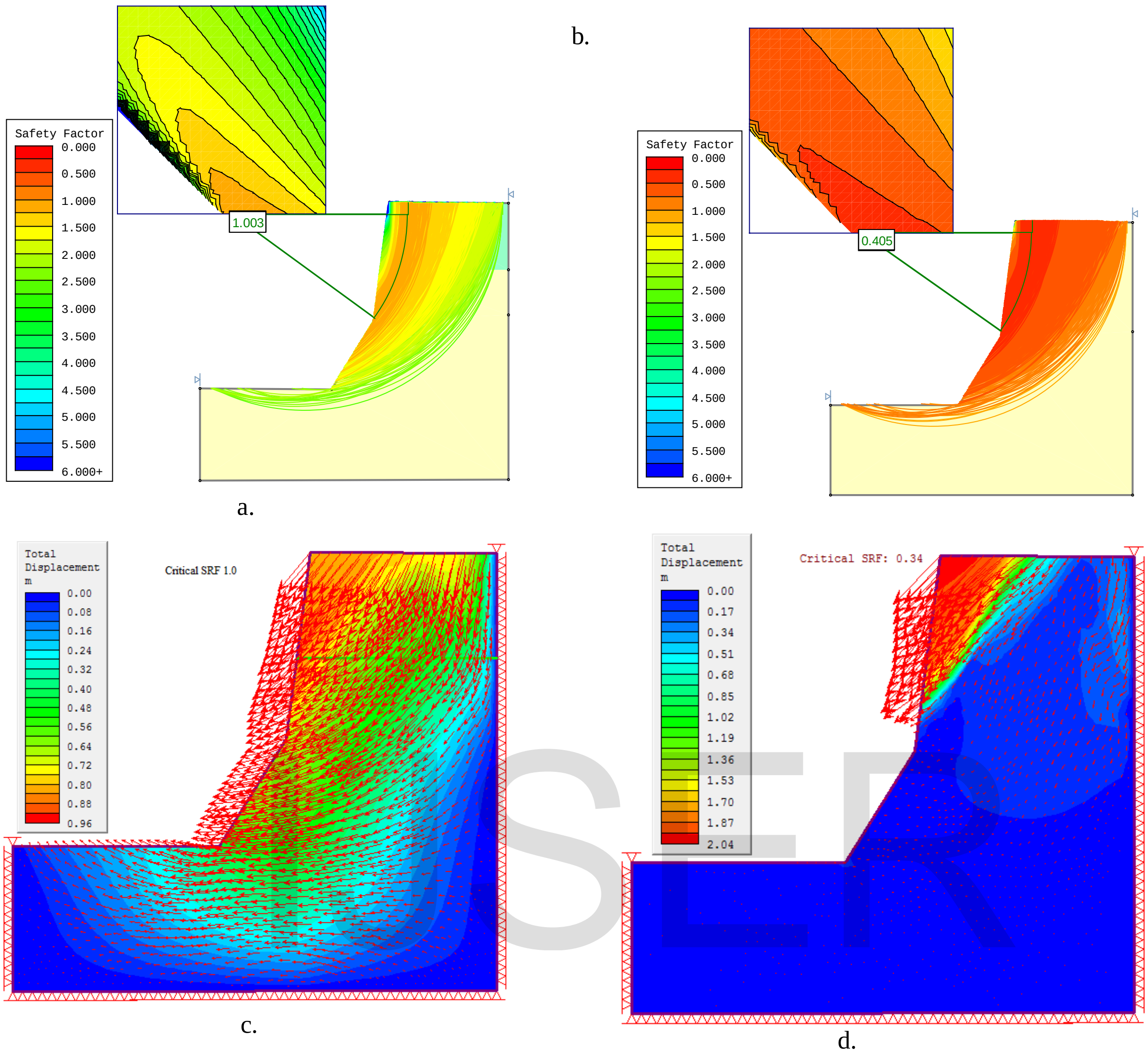
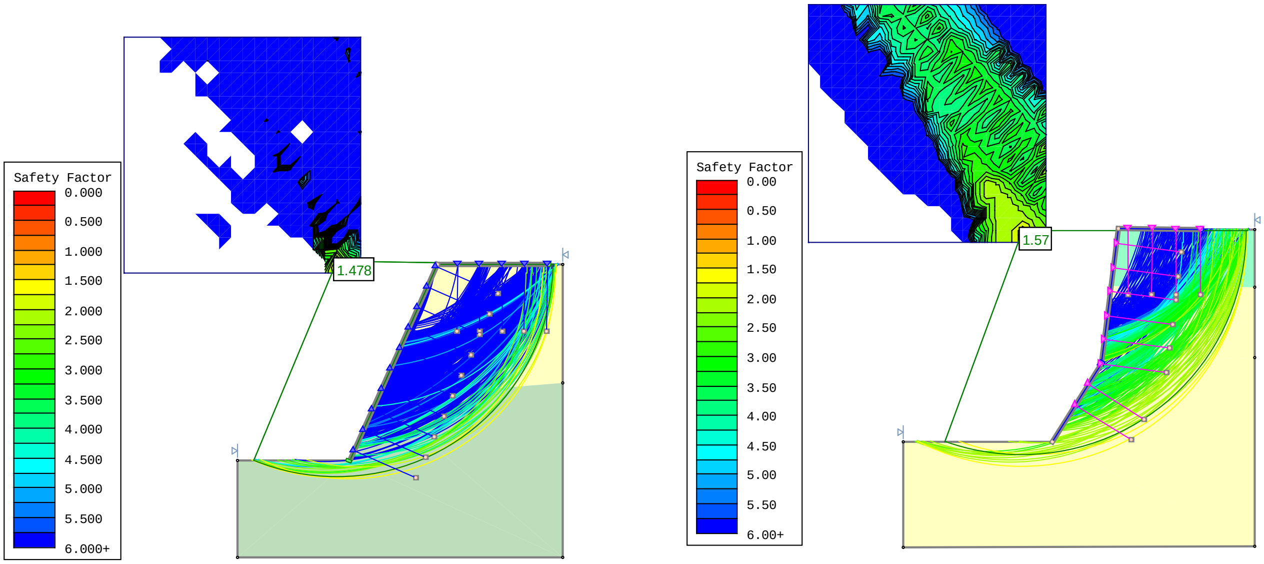


Fig. 7 FS value using the Bishop's simplified method at a) dry condition and b) wet condition and SRF at c) dry condition and d) wet condition of Batali Hill area of Lalkhan Bazar of the Chittagong city

TABLE 2 THE FACTOR OF SAFETY AND SRF VALUES FROM MATHEMATICAL ANALYSIS OF DIFFERENT SLOPES OF THE LALKHAN BAZAR AREA OF THE CHITTAGONG CITY

Location	FS value using Bishop's Simplified method	FS value using Junbu's method	SRF using Finite element method	Soil condition
Motijharna	0.63	0.62	0.59	wet condition
Tankir pahar	0.56	0.54	0.52	
Batali Hill	0.41	0.41	0.39	
Motijharna	1.25	1.18	1.18	dry condition
Tankir pahar	1.14	1.19	1.00	
Batali Hill	1.00	1.16	1.00	



a. **b.**

Fig. 8 FS value at wet condition with support of geotextile and bolts for a) Motijharna and b) Batali Hills of Lalkhan Bazar of the Chittagong city

5 CONCLUSION

Heavy rainfalls in the Chittagong city causing landslides due to unwise hill cutting and deforestation. The mathematical modeling using both liquid equilibrium and finite element method by obtaining engineering and geological properties of the in situ soil samples which show that the analyzed slopes are relatively stable at dry condition. On the other hand, most of the slopes are vulnerable for landslide at wet condition. The major cause is the heavy rainfall infiltration on slopes, increasing saturation and building positive pore pressure, as well as raising soil unit weight, reducing anti-shear strength of soil. However, geotextile with bolt supports are proposed to keep the slope stable, avoiding accidents, injury and even re-locate the poor hut dweller in the foot hill of the city.

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