Slope Stability Problem and Bio-engineering Approach on Slope Protection: Case Study of Cox's Bazar Area, Bangladesh

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ABSTRACT: The slope stability problem of the six (06) locations in the Cox's Bazar district, Bangladesh were analyzed through laboratory measurement of the engineering properties of the soil samples, tensile strength of roots and numerical modeling using both limit equilibrium and finite element method. The modeling results show that the slopes are stable (FS value greater than 1) at the dry condition and the wet condition unless rocks are weathered. At the wet condition most of the slopes with loos soil are vulnerable for landslide and need supports to stabilize. We suggested the vegetal support (tap-rooted tree) to stabilize the vulnerable slopes of the study area. The experimental result shows that the roots of the local growing tap rooted trees (e.g., Chapalish, Korai, Gorjon, Telsur) grew linearly within a few years. The roots reached their length of 3-5 m within 4/5 years, yielding tensile strength of 70-80 MPa that enough to avoid the slope failure.

KEYWORDS: Slope stability, Slope angle, Cohesion, Factor of safety, Root tensile strength, Cox's Bazar

1. INTRODUCTION

Slope failure is an incident that a slope collapses abruptly due to weakened self-retain the ability of the earth under the influence of a rainfall or even due to the gravitational force. It also causes for the orientation of bedding planes, slope steepness, water and drainage, **s**oil composition**, v**egetation, joints and fractures and by the **s**udden tremors. Some other factors that contribute to the slope failure are the high shear stress, lack of lateral support or removal of support, weathering and low intergranular force due to seepage pressure. Other factors that also contribute to the slope failure are the high shear stress, lack of lateral support or removal of support, weathering and low intergranular force due to seepage pressure. Because of sudden collapse of slope, many people fail to escape from it if it occurs near a residential area, thus resulting in a higher rate of fatalities such as deaths, injuries, property damage and adversely affects a lot of resources. The damage of the transportation routes, utilities, buildings and other side effects are also caused by slope failure. The negative economic effects of the slope failure include the cost to repair structures, loss of property value, medical costs in the events of injury and other indirect costs. Environmental degradation can also be caused by the slope failure. It has become a very common occurrence in the recent years in the Cox's bazar, Chittagong and other hilly areas in the country which is a threat to the people living near the hills. According to the news published on 27 July 2015 to daily star 5 people were killed, including three women and a six-year-old child by a landslide triggered by incessant rain in Cox's Bazar town in the Hilltop Circuit House area in early Monday. It seems that landslide of the study area is due to the anthropogenic effect such as hill cutting, deforestation etc.

Through the slope stability analysis one can assess the stability of the slopes under the specified conditions and to evaluate the possibilities of the slope failure. In this study, we have performed the slope stability analysis of vulnerable location or locations where failure was occurring. This analysis helped us to understand the failure mechanisms and to obtain the in-situ material properties. Various types of analyses, including the behavior of slopes, failure mechanism of the slopes, safe designing on the slopes, and designing of remedial measures have been done. Many techniques, methods were used to conduct research work on slope stability problem. Recently, numerical modeling techniques for the analysis of the slopes have become famous as a result of improved computational efficiency. Recently, some research works have been conducted on the Chittagong city (Islam et al. 2014; Islam et al. 2015) and the Surma river bank (Islam and Hoque 2014) of the Sylhet city using the numerical techniques by the first author. However, there is no work has been conducted in the Cox's Bazar district. In this study, combination of laboratory analysis of engineering properties and numerical modeling techniques was used to analyze the slope stability problem of Cox's Bazar district to 1) determine engineering properties (unit weight of soil, Poison's Ratio, Young's Modulus, Cohesion) of the soil samples, 2) determine the slope stability (safety factor) at dry condition and wet condition, and 3) propose the remedial measures to protect the slope from failure by vegetation.

1.1 Bioengineering approach

Vegetation refers to the ground cover, provided by plant communities. It also means the plantation in which plant helps to stabilize the mass of soil via hydrological and mechanical means. The effects of vegetation on the soil depend on the overall root growth, architecture and its mechanical function. The plant roots provide a strong interlocking network to hold unconsolidated materials together and prevent the slide. It is very effective in removing water from the soil, thus increasing the shear strength as a result increase stability of a slope (Saifuddin and Osman 2014). Different types of vegetation such as grasses, herbs, shrubs and trees are used to stabilize the slope stability and reinforcement of the soil. Grasses are quick to establish, versatile and cheap and have a wide range of tolerance, with dense cover but shallow rooting requiring regular maintenance. Herbs have deeper roots, nitrogen fixers, compatible with grasses, but they have expensive seed, difficult establishment and winter dieback. Shrubs have deeper roots and robust and cheap requiring low maintenance. Trees have substantial rooting, low maintenance, but require long time to establish and are slow growing. However, the growth of vegetation is extremely beneficial as it is environment-friendly and helps in the development of sustainable ecosystem. The vegetation cover and slope stability are interrelated by the ability of the plant growing on slopes and the interaction of root and soil.

Now-a-day, scientists are thinking about the best root architecture for stabilization of slopes or for control of soil erosion by water. Styczen and Morgan (1995) classified rooting patterns into five types, of which the H- and VH-types are considered for slope stabilization and H- and M-types for soil erosion control (Figure 1).

The VH type roots (Figure 1) are also called tap root. It is a primary root that grows vertically downward and gives off small lateral roots or the central element or position in a line of growth or development a main root of a plant that grows straight down and gives off smaller side roots (Reubens et al. 2007). Large trees can increase the shear stress required for sliding by 2.5 kPa and that their removal can promote landslides (Bishop and Stevens 1964). The main features of roots architecture/morphology that are taken into account when considering root contribution to soil stability are (1) root biomass, i.e. root system mass, (2) root length, (3) root spread, (4) rooting depth, and (5) root distribution. However, the magnitudes of root contribution are controlled by geology, climate, topography, soils, water table, stand density and age of the tree (Watson et al. 2016).

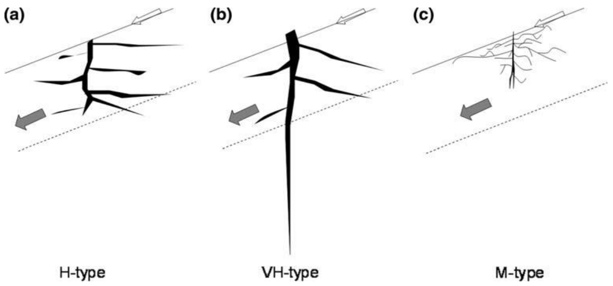


Figure 1 Rough representation of root classification (Styczen and Morgan 1995)

1.1.1 Roots as slope reinforcement material

The effect of vegetation roots on soil shear strength can be taken as part of the cohesive strength component of the soil-root system (Wu et al. 1979). Figure 2 showing the mechanisms of root reinforcement of grass, plants and tree. Assuming that the phreatic surface is at the soil surface and the location of the potential shear plane is the z distance below the soil surface, the safety factor (the minimum possible shear strength / the maximum possible shear stress) for a vegetated infinite slope is given by equation below;

$$FS = \frac{[c^{/}+\Delta c+z\,cos^2\,\alpha(\gamma_{sat}-\gamma_w)+\cos\alpha)\tan\varphi^{/}}{z\gamma_{sat}\cos\alpha\sin\alpha+w_t\sin\alpha} \qquad (1)$$

Where, $c^{/}$ and $\varphi^{/}$ are the effective soil strength parameters, Δc is the increased cohesion due to tree roots, α is the slope angle, $t\ w$ is the vegetation surcharge (weight / unit area), γ_{sat} is the saturated unit weight of soil and γ_w is the unit weight of water.

In order to predict the landslide threshold conditions, the soil strength parameters are estimated from the Mohr-Coulomb failure envelope derived from the peak values of a series of shear stress-displacement curves (Ekanayake et al. 1997). The most destructive deep landslides may be hardly influenced by vegetation, but a combination of deep rooted trees for anchoring and shallow rooted grass (for stabilizing topsoil) is still generally perceived to stabilize slopes prone to mass movement. A living tree roots can contribute up to 20 kPa to the soil shear strength (O'Loughlin and Watson 1979).

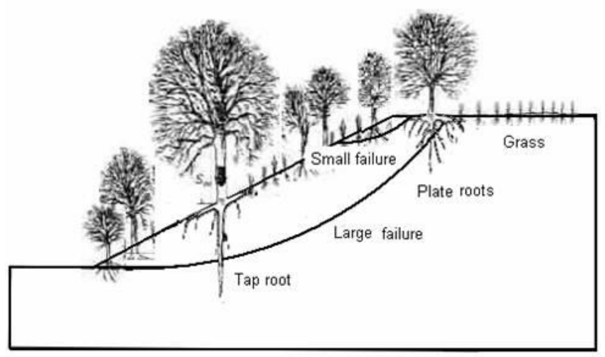


Figure 2 Mechanisms of root reinforcement of grass, plants and tree (downloaded from http://slideplayer.com/slide/4558026/)

2. STUDY AREA AND GEOLOGICAL SETTING

Cox's Bazar is a located to the southeastern district of Bangladesh (Figure 3). It lies between 21º26' 22.07 N to 24º35' N latitude and 92º0'27.83E longitude. It is 2491.85 km² in the area, and has a population of 2.28 million. Our study area includes six different locations (Figure 3 and 4). The location 1 is situated at Adharrsho gram (Latitude: N 21° 27'13.01'' and Longitude: E 92° 09'23.76''), location 2 is at Hitupi (Latitude: N 21° 26.198' and Longitude: E 92° 09.023'), and location 3 is at Hitupi Jadipahar (Latitude: N 21° 27'13.01'' and Longitude: E 92° 09'23.76'') at Ramu Upazila in Cox' bazar district. The location 4 is situated at Boidhoghona (Latitude: N 21° 26'22.08'' and Longitude: E 91° 58'46.92''), location 5 is on Light House (Near the radar station Latitude: N 21° 26' 6.36'' and Longitude: E 91° 58'28.92''), and location 6 is at Himchori (Near the Army Camp) (Latitude: N 21° 21'17.56'' and Longitude: E 92° 1' 30.23'') in Cox's Bazar district.

Geologically the Cox's Bazar area area is the part of the folded belt of Bengal Basin and was developed due to oblique subduction of the Indian Plate some ten kilometers to the West (Steckler et al., 2016).

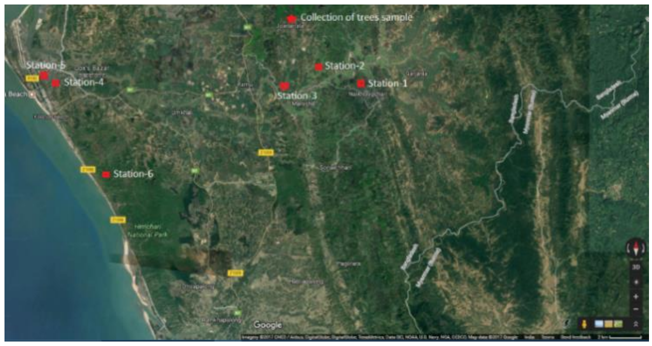
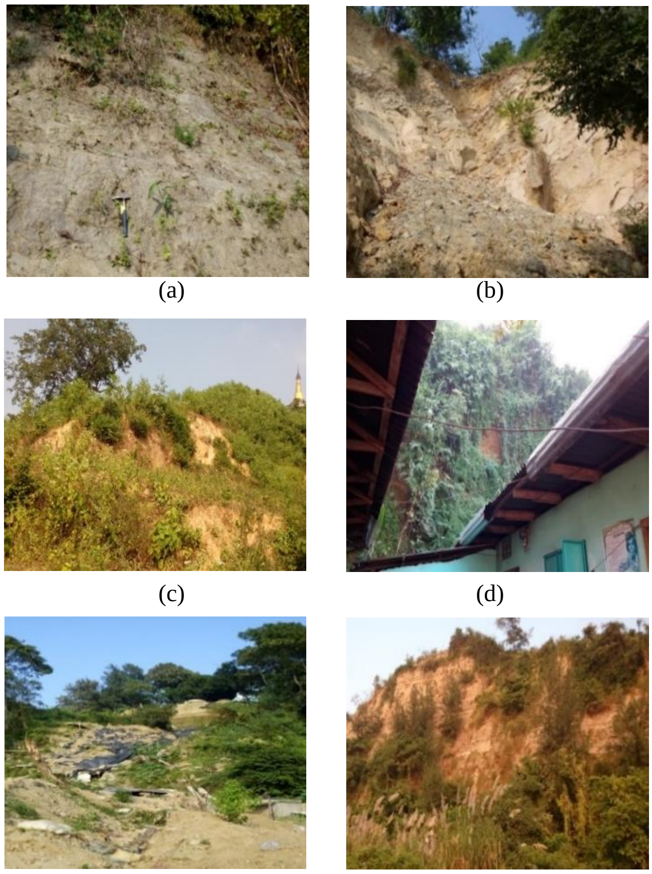


Figure 3 Locations of the study area (downloaded from Google earth)



(a) (b)

(c) (d)

(e) (f)

Figure 4 Photographs of the sample locations
a) Adorsho gram, b) Hitupi c) Hitupi Jadipahar d) Boidhoghona e) Light House, f) Himchori

It is the western extension of accretionary prism due to collision of the Indian Plate with Burmese Plate. Exposure of Cox's Bazar area are mainly of the Neogene sedimentary succession which are well developed and due to the predominance of sandstone (Hossain 1978). Sediments throughout the cliff sections are more or less similar in lithology, consisting mostly of loosely consolidated massive sandstones (Rahman and Khan 1995).

The slope in Cox's Bazar area such as location 1 is very steep with the slope angle of about 71°. In location 2, location 3, location 4, location 5, and location 6, the slope of the hills are comprised of sandstone and the slope angle is 52, 60, 84, 72, 41 and 65. In six areas, people are living near the foothills. They are at a greater risk as landslides are frequent in these areas. These phenomena are observed during field visits.

However, we have collected the sample of tree's root to measure its strength from Joarianala of Ramu Upazila of Cox's Bazar district for designing the root support.

3. METHODOLOGY

Total forty eight (48) soil samples were collected from eight (08) points in six (06) different locations in the Cox's bazar area. At each point, three (03) samples were taken for the direct shear test and one (01) sample was taken for Unconfined Compressive Strength (UCS) test. The in situ samples were taken by cylindrical core sampler (made of steel) of 2 inch diameter after removing the soil/rock of weather zone. 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 by ASTM standards. These tests are conducted at the laboratory of Shahjalal University of Science & Technology. Two types of samples (dry samples with little moisture content; wet sample of 60-70% water content) were prepared for the tests. The detail method is already described in (Islam et al. 2014) and (Islam and Hoque 2014). However, we also describe little here for better understanding to the readers.

3.1 Laboratory Tests of insitu samples

The tests include 1) Direct Shear Test, 2) Unit Weight analysis, 3) Unconfined compressive strength test are described here.

3.1.1 Measurement of unit weight of rock

Weight (W) of the each sample was measured by electronic weight machine using ASTM standard. Unit weight of a soil mass is the ratio of the total weight of the soil to the total volume of the soil. Unit weight is measured using the equation

$$\gamma = \frac{\mathrm{W}}{\mathrm{V}} \tag{2}$$

Where, γ = Unit weight of the soil sample, KN/m^3
W = Weight of the soil sample, KN
V = volume of the cylindrical sampler, m^3

The unit weight values are used to determine factor of safety using **Slide 6.0**.

3.1.2 Direct Shear Measurement

The direct shear test is a laboratory testing method which is used to determine the shear strength parameters of soil. The test was carried out 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 Apparatus**) using the ASTM D3080 method.

3.1.3 Unconfined Compressive Strength test

The test was performed at the Soil Mechanics Laboratory of Civil and Environmental Engineering Department of Shahjalal University of Science and Technology is using unconfined compressive strength tester (**ELE International, Model 25-3605**) using the ASTM D2166 method.

3.2 Root Tensile Strength Testing

Almost twenty samples of different ages of tree roots (1 year, 2 years, 3 years) were collected from the Joarianala Range Forest of Ramu Upazila in Cox's Bazar district. The tensile strength of roots was determined using **the Universal Testing Machine (Tensile strength tester DERICK WDTW)** at the department of Chemical Engineering and Polymer Science of Shahjalal University of Science and Technology equipped with a 8.5 mm maximum diameter and 15 cm length (Figure 5). The root ends were clamped and a strain rate of 20 mm/min was applied until rupture occurred. The applied force required to break the roots were taken as the measure of root strength. The location and form of the break were denoted and the unstressed mean under-bark diameter of the roots at the rupture point was measured using digital callipers. Tensile strength was calculated by dividing the applied force required to break the root of the cross-sectional area of the root at its rupture point.

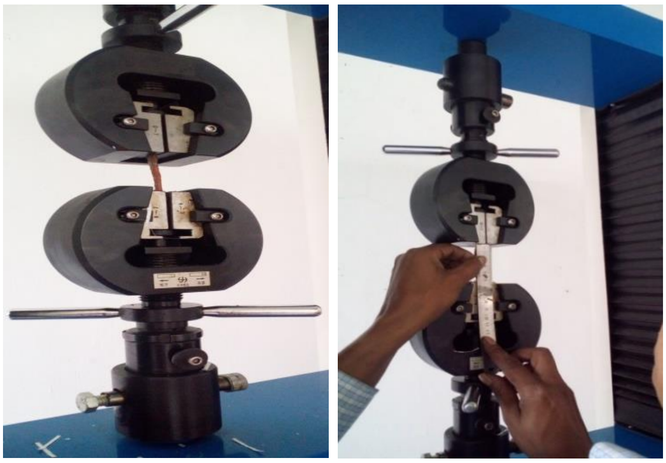


Figure 5 Photographs showing the tensile strength measurements at the laboratory of CEP, SUST

Tests subject to slippage, or those roots that broke because of crushing at the jaw faces, were Disregarded. The tensile strength is expressed following equation (Watson and Marden 2005)

$$TS = \frac{F}{A} \tag{3}$$

Where, TS=Tensile Strength (MPa), F=Force (N), A= Area (mm$^{2)}$

3.3 Model Setup

Based on the engineering properties of soil obtained from the laboratory analysis (Table 1), different basic models (for different locations) are proposed for numerical analysis (Figure 6a-f).

The model 1 (Figure 6a) is proposed for location 1 (Adharso Gram area) with clay formation. The slope angle, length of slope are given as measured in the field (Table 1). Similarly other five models represent the slopes of Hitupi, Hitupi jadipahar at Ramu, Boidhoghona, Light House, and Himchori (Figure 6b-f), respectively. These model consist of massive sandstone formation. Model for locations 4 and 6 consists of loose weathered sands.

4. RESULTS AND DISCUSSIONS

Results from laboratory measurements show that friction angle, cohesion, and Young's modulus decreases significantly in wet condition than dry condition (Table 1). On the other hand, the value of unit weight is higher in wet condition than dry condition (Table 1).

Table 1 Engineering properties of the soil sample in the cox's bazar

Condition of Soil	Location / Sample	Slope angle (ϕ°)	Slope Height ft	Unit Weight (kN/m^3)	Angle of Friction (ϕ°)	Cohesion (kPa)	Young modulus (kPa)	Poison Ratio	FS (Bishop[1])	FS (Bishop[2])	Soil/rock strength (kPa)
	1/2	71	55	15.21	24.12	12.62	48.00	0.44	0.44	0.86	0.81
	2/4	52	47	19.50	28.68	45.44	16.00	0.36	0.36	1.03	5.87
	3/4	60	49	32.91	28.67	50.35	8.59	0.36	0.36	1.18	1.09
Wet Condition	4/8	84	60	18.85	16.07	75.00	7.60	0.48	0.48	0.34	0.23
				28.73	36.04	81.75					
	5/10	72+41	34+40	26.75	23.00	55.25	80.56	0.39	0.39	1.15	0.98
	6/11	65	70	23.47	28.49	01.25	56.99	0.49	0.49	1.15	0.63
				30.23	6.93	65.98					
	1/2	71	55	13.99	30.32	18.55	90.46	0.44	0.44	1.25	2.45
	2/4	52	47	15.68	28.63	45.44	29.84	0.36	0.36	4.07	5.549
Dry Condition	3/4	60	49	29.65	30.50	100.1	17.70	0.36	0.36	6.10	5.45
	4/8	84	60	14.34	32.46	0.200	13.74	0.48	0.48	2.49	2.06
				25.45	14.24	125.0					
	5/10	72+41	34+40	23.29	04.53	30.76	142.02	0.39	0.39	2.54	2.08
	6/11	65	70	18.17	32.76	01.87	110.23	0.49	0.49	1.43	1.31
				18.47	07.75	201.78					

[1]for circular failure plane [2]for non- circular failure plane

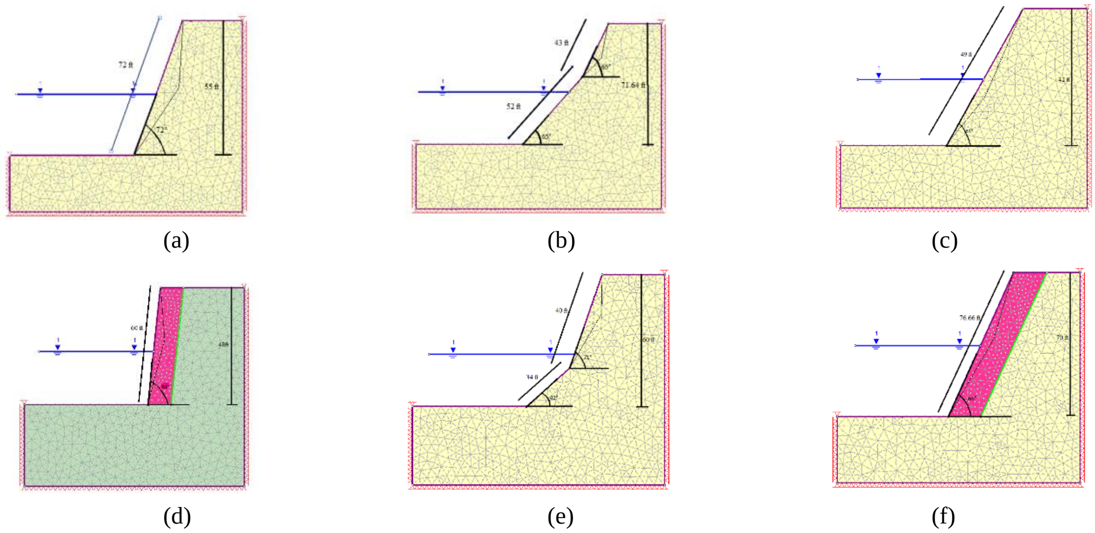


Figure 6 Model setup for numerical modeling of a) Adharsho gram, b) Hitupi, c) Hitupi jadipahar at Ramu, d) Boidhoghona, e) Light House, and f) Himchori

The main reason of these phenomena is the infiltration of rainwater. Rainwater seeps through the surface and flows along the slope. Addition of water from rainfall adds weight to the slope. Such water also fills the pore spaces between the grains and increases the pore water pressure (Zhang et al. 2015). Thus, it is obvious that rainfall is one of the main factors that can affect slope failure of the study area.

Root-wood tensile strength appears to increase at very similar rates with age, length and diameter of the root (Table 2). We have analyzed root strength including other parameters such as diameter, length of the root of different available tap rooted tress of the study area such as Chapalish, Dhakijam, Gorjon, Koroi, Sal & Telsur. All samples are collected from Joarianala, Ramu Cox's Bazar. The tensile strength of different roots compared to age is given in the Table 2 and Figure 7.

4.1 Results from Numerical Modeling

In this study, the most commonly used Limit equilibrium (LE) method were used to carry out the slope stability analysis.

Results from the numerical modeling show that the safety factor values are greater than 1 at both dry and wet condition indicating that the slopes of the study area are stable at both conditions except location 4 and 6, where weathered loose sands are considered in the models. The modeling results for slope location 6 are given in the Figure 8 for different condition and different slope failure plane. The field observations show that the soil/rock in the slopes are very hard and compact except the weathered or altered portion. These altered portions are really loose sands. It is well known that the natural alteration of slopes is particularly slow and there are many factors and processes including climate, geology, hydrology, vegetation,

Table 2 Tensile strength measurement using UTM

Serial Number	Common Name	Scientific Name	Year	Diameter mm	Length m	Tensile Strength, MPa
1	Chapalish	*Artocarpus Chapalisha*	1	7.5	0.46	14
			2	7.2	1	30
			3	7.1*7	1.8	48
			4	7.5	3.3	83
2	Dhakijam	*Syzygium Grande*	1	7	0.49	16
			2	8	1.2	29
			3	7.5	2.1	45
			4	7.5	3.8	77
3	Gorjon	*Dipterocarpus spp*	1	7.7	0.38	18
			2	6.5	0.95	40
			3	7.5	1.8	62
			4	7.5*7	3.45	91
4	Koroi	*Albzi Procera*	1	7*7	0.45	17
			2	7*6.5	1.1	36
			3	7.5	2.3	58
			4	7.5	4.1	74
			5	7.5	6.3	96
5	Sal	*Shorea Robusta*	1	6.5	0.31	10.6
			2	7.5*7	0.57	26
			3	6.5*6	1.4	47
			4	7.5	2.2	73
6	Telsur	*Hopea Odorata*	1	6	0.51	21
			2	7.5	1.6	51
			3	7.5	2.4	78
			4	7.5	3.85	104.5

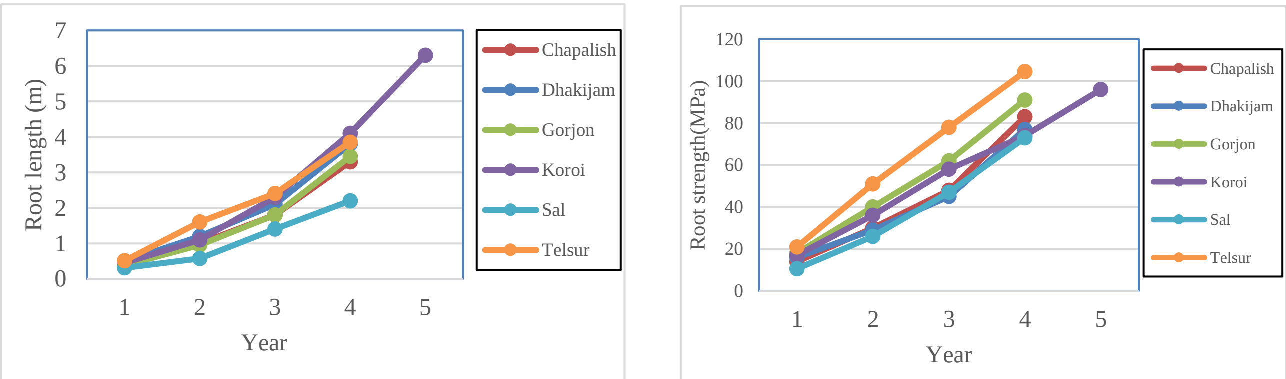


Figure 7 Graphs showing the relationship between a) root length and b) root strength against age of the trees

weathering, and transport influence this process. However, the human activities can change the natural slope system in a variety of ways such as diggings, agricultural activities or building construction that can stimulate instability by loading the slope, removing vital support, and increasing pore-water pressures. Moreover, grading, cutting, and filling also modify the natural angle of repose. From the analysis, it is found that the slopes for locations 4 and 6 are susceptible to fail during the rainy season. This is why, remedial measure should be taken to avoid the slope failures of these two locations. A support system may be end anchored rock bolts, geo-textile, masonry reinforcement, vegetation and so on. To avoid slope failure for location 4, vegetation support (VH type root) with tensile strength of 70-80 MPa and with a length of 3-6 m is recommended.

The numerical modeling results show that after using the support such as Chapalish, Dhakijam, Gorjon, Koroi, Sal and Telsur, the factors of safety is increased at a satisfactory level. Laboratory measurement shows that after 4 years of grew, the root of the Chapalish tree had reached a length of 3.3 m with the tensile strength of 83 MPa (Table 2 and Figure 7). Similarly, the root of Dhakijam, Gorjon, Koroi and Shal had reached a length of 3.8 m, 3.45 m, 4.1 m, 6.3 m and 3.85 m and the tensile strength of 77 MPa, 91 MPa, 74 MPa, 73 MPa and 104.5 MPa after 4 years except the Shal tree. Shal tree reached above parameters at 5 years. Modeling result also shows that vegetation support is not feasible for location 4 that of slope angle more than 70°. Mechanical support was proposed for the location to avoid landslide (Figure 9c).

In case of the treatment with the Chapalish tree among the others to prevent the slope failure, the numerical analyses are shown in the Figure 9a-b. Factor of Safety values after proposed support are given in the Table 3. In this case, spacing between the trees of 2 m was proposed.

Table 3 Factors of Safety after Support

Station	Chapalish	Dhakijam	Gorjon	Koroi	Shal	Telsur
4	0.171	0.167	0.164	0.165	0.182	0.161
6	1.125	1.149	1.293	1.279	1.039	1.293

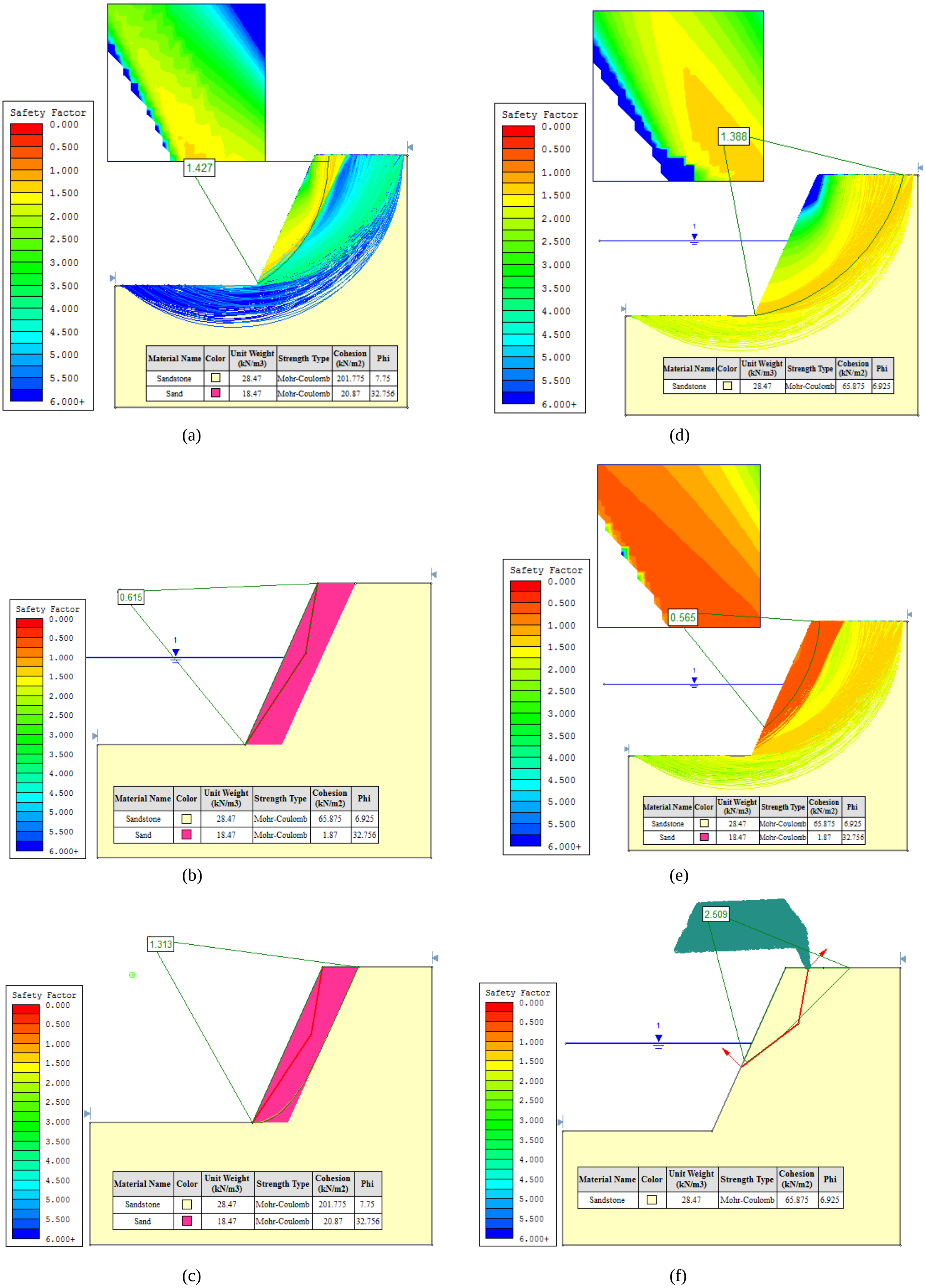
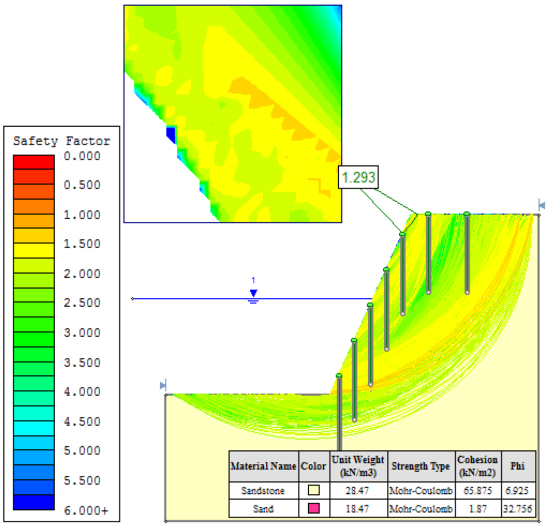
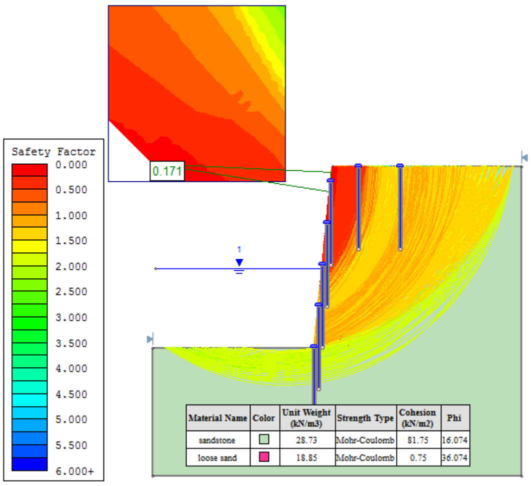


Figure 8 FS Value using the Bishop's simplified method for circular and noncircular failure for a-b) dry condition and c-d)wet condition at location 6 in the Cox's bazar; e-f) showing the FS value for wet condition assuming massive rock formation using Bishop's simplified method



(a)



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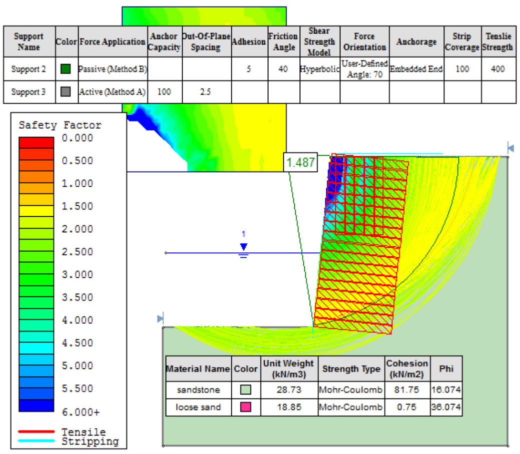

(c)

Figure 9 a-b) FS value at wet condition with the support of roots (Chapalish) of location 4 and 6 for circular failure using Bishop simplified method, c) FS value for mechanical support with geotextile and anchor

5. CONCLUSION

Slope failure in the Adorsho gram, Kocchopia union, Hitupi, jadi pahar, at Ramu Upozila and Boidhoghona, Light House (near the radar station), Himchori (near the army camp) in Cox's bazar district was analyzed. Steep slope angle and the rainwater infiltration are the main causes of the slope failure of these areas. The value of cohesion, friction angle and Young's modulus decreases significantly in the wet condition than the dry conditions. On the other hand, the unit weight value is higher in the wet condition than dry the conditions. The slope stability analysis using the limit equilibrium method (Slide 6.0) shows that the factor of safety are greater than 1 at both the dry condition and at the wet condition which indicates that the slopes are stable during both the dry season and wet season. However, the susceptible weathered soils due to human activity could fail during the rainy season. However, to avoid the slope failure, vegetation (tap-root trees) support with tensile strength (70-80 MPa) with length (3-7 m) is proposed for the vulnerable locations.

6. ACKNOWLEDGEMENT

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