IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 14, Issue 4 Ver. IV (Jul. - Aug. 2017), PP 43-48
www.iosrjournals.org

Factors affecting slope stability for triggering rainfall induced landslide at Chittagong City: a case study on 2007 and 2008 landslides

*Abu Jafor Mia, Atikul Haque Farazi, Md. Ilias Mahmud
Department of Geology and Mining, University of Barisal, Barisal-8200, Bangladesh
Corresponding Author: Abu Jafor Mia

Abstract: *Rainfall induced landslide has become a common phenomenon in Bangladesh causing huge loss of life and properties almost every year. As landslide phenomenon in Chittagong City commonly takes place in the rainy season, it is worthy to find out other factors that affect slope stability rather focusing solely on rainfall. We investigated some engineering parameters like grain size, cohesion, and angle of internal friction of slope materials where the devastating landslides in 2007 and 2008 took place. Grain size analysis revealed that the slope material is composed of 83-98% sand, 2-17% silt and little or no clay particle. Results from direct shear test showed that cohesion of slope materials is very low ranging from 0.0459 to 0.0801 kg/cm^2, whereas internal friction angle varies from 26.83^o to 34.30^o. But, original slope angle of that particular sites are much higher extending up to 84^o. Hence, higher percentage of sandy materials, low cohesion value and greater original slope angle than internal friction angle were the main attributes that severely affected slope stability that, in turn, triggered landslides in the study area. Moreover, different human activities like hill cutting that make the slopes more vulnerable were also responsible for landslide hazard in Chittagong City in 2007 and 2008.*

Keywords: *Landslide, Grain size, Cohesion, Angle of internal friction, Chittagong City*

Date of Submission: 30-06-2017 Date of acceptance: 28-07-2017

I. Introduction

Chittagong, the second largest city of Bangladesh, is situated in the south-eastern part of the country. It is also the second largest economic center, after the capital city Dhaka rendering rapid growth of the city. Due to fast development of the city, numerous unplanned and informal settlements are also growing in the hilly areas. Chittagong City lies in the western fringe of the eastern portion of the Tertiary Chittagong Tripura Fold Belt (CTFB). The geographic and complex terrain conditions of Chittagong City have made it one of the most vulnerable areas for landslide, where devastating landslides result in casualties, property damage, and economic loss almost every year [1]. Table 1 represents some of the fatal landslides within the area for the last 50 years. A phenomenal landslide hazard in Chittagong City and its surroundings occurred on June 11, 2007 caused casualties of 135 people and injured hundreds more, and left many people homeless [2]. Notably, the landslides were triggered by a heavy rainfall for a period of around 12 hours, which was estimated to 348 mm. Subsequently, hazardous landslides took place at Chittagong City as well as Cox's Bazar and Teknaf in 2008 affected many people's life and properties [2]. All of the landslides throughout this period occurred in the rainy season due to heavy downpour for a prolonged time [3]. Moreover, without having strict hill management policy in the Chittagong City, many people built up informal settlements along the hill slopes in Chittagong [4]. And collectively, evident illegal hill cutting for housing and transportation, indiscriminate deforestation, and agricultural practices made the area more vulnerable to landslide [3].

A landslide can be defined as the downward movement of a mass of rock, earth or debris under the effects of gravity [5] [6]. It is well known that the rainfall is one of the important triggering factors producing landslides in the mountainous areas of different countries [3] [7] [8]. Some recent studies on landslides in Chittagong City analyzed the role of rainfall [3], established landslide susceptibility map [1][4], and prepared the inventory of landslides [9], but studies evaluating the other factors like geotechnical properties that affect slope stability are still lacking. However, to minimize the hazard risk, we should have proper knowledge of the soil parameters that render slope instability for these rainfall induced landslides, so that proper mitigation techniques can be hit out. This article investigates different geotechnical parameters to find out the causative factors, in association with rainfall and human interventions, responsible for landslide hazard at Chittagong City.

Table 1: Historical landslides in Bangladesh.

Date	Location	Casualties	Wounded	Cause of landslide
16 Jul 1968	Kaptai-Chondroghon road section	--	02	Removal of protective vegetation and heavy rainfall.
26 Jun 1970	Ghagra-Rangamati Road Section	01	--	Removal of protective vegetation and heavy rainfall.
30 May 1990	Chittagong University	11	25	Extremely heavy rainfall
11 Jul 1997	Rangamati, Bandarban, Cox's Bazar, and Chittagong	30	10	Heavy rainfall
15 Aug 1999	Chittagong	12	09	Heavy, incessant rainfall
13 Aug 1999	Bandarban	07	14	Heavy, incessant rainfall
11 Aug 1999	Chittagong	10	13	Heavy, incessant rainfall
24 Jun 2000	Chittagong University and City area	13	20	Torrential rainfall
11 Jun 2007	Chittagong	135	213	Extremely heavy rainfall
18 Aug 2008	Cox's Bazar	03	09	Heavy rainfall
18 Aug 2008	Chittagong	11	20	Heavy rainfall
31 Jul 2009	Lama, Bandarban	10	--	Incessant rainfall
15 Jun 2010	Cox's Bazar	50	100	A series of rainfall
2 Jun 2017	Chittagong	146	20	Heavy rainfall

(Sources: Banglapedia [10], The Daily star, The Daily ProthomAlo, The Daily Azad, and The Daily Ittefaq)

II. Description Of The Study Area

The Chittagong City is located in the folded belt of Bengal Foredeep. The city area is comprises of small hills and narrow valleys. It is surrounded by the coastal plain and the Bay of Bengal to the west, Karnafuli River to the south-east, and the floodplain of the Halda River to the north-east. It is situated between latitudes $22^{o}14'$ and $22^{o}24'\ 30''$ N and longitudes between $91^{o}46'$ E and $91^{o}53'$ E (Fig. 1). The city has a population of about 2,068,082 within the area of 160.99 sq.km [11].

II.1 Stratigraphy

Chittagong Hill was formed during the Tertiary period of the geological scale. Dihing Formation, Dupi Tila Formation, Tipam Sandstone Formation, and Bokabil Formation are exposed from east to west in Chittagong City. So far, all the landslides have occurred in sandstones of Dupi Tila Formation[4].The hills are primarily composed of unconsolidated or semi-consolidated layers of sandstones, siltstones and shales, along with minor beds of conglomerates with local unconformities. Shale leads to heavy silt loam or silty clay loam subsoil in the area. The geological structures and soils in the study area are weak and also have steep slopes that enhance the risk of susceptibility to landslide. The exposed stratigraphy of Chittagong City along with their geotechnical characteristics are summarized in Table 2.

II.2 Geomorphology and Topography

Chittagong City has different geomorphology and topography from the other cities of Bangladesh as it is situated in the hilly region of Bangladesh. The study area can be divided into three broad morphometric units: i) the hills and adjacent valleys in the north, where the elevation varies from 12 to 80 m, ii) the fluvio-tidal plain consisting of tidal plain of the Bay of Bengal in the west and south, where elevation ranges from 5 to 10m, and iii) the floodplain of the Karnafuli River with elevation from 5 to 10m.

The hills are dome-shaped with flat top, having average elevation of 30m. The length of the hill slopes is very short, 15 to 50 m, and gradient varies from 10 to 40^{o}. The profile of the slopes is concave to convex and finally fairly regular. Moreover, from east to west, slopes elevations and gradients become higher. Valleys along the hill strike are elongated, asymmetrical, relatively deeper, and V-shaped, having higher gradient in the eastern side than west. Valleys across the strike are asymmetrical, shallow, U-shaped, open and smooth. The hills are rolling type with subdendritic medium dense drainage system [12].

The coastal plain and floodplain areas are considerably flat, where there are regional slope towards east, west, and southeast. Channel shifting processes have created undulations of about 2 to 4^{o} slope. Here, elevation varies from 1.5 to 6m from west to east [13].

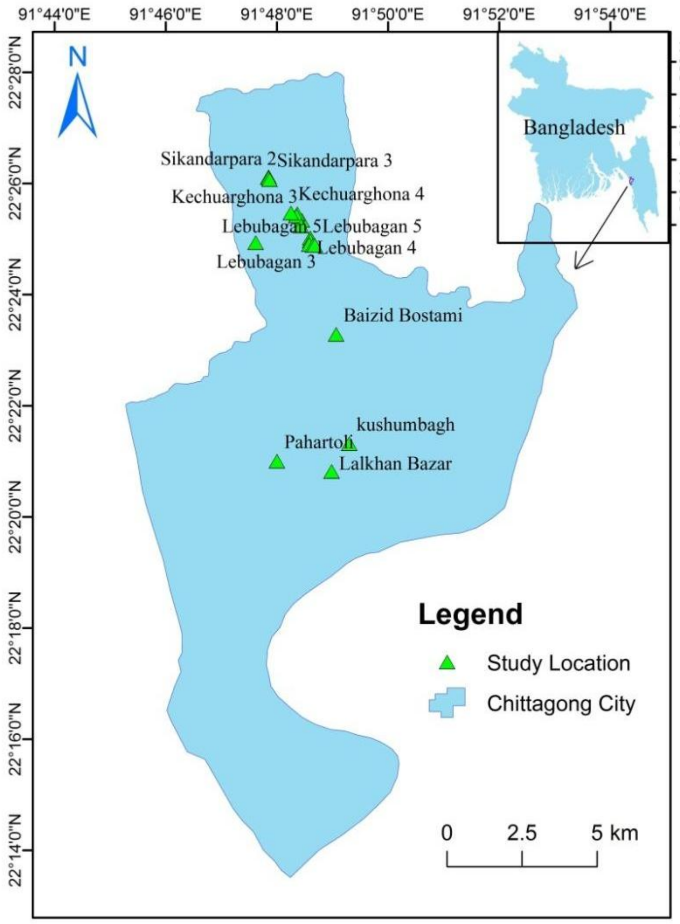

Figure 1: Location map of the study area. This map also indicates locations of field study and data collection.

II.3 Climate and rainfall

Chittagong City lies in the tropical monsoon climatic zone and characterized by high temperature, heavy rainfall, and frequent excessive humidity. The monsoon season begins in June and continues usually to September. The cold and dry weather prevails from the month of November to February. Annual average rainfall in the study area is 3172 mm. Monthly average rainfall is negligible during cold and dry season, which range from 8 to 76 mm, [personal communication with Bangladesh Water Development Board].

Table 2: Stratigraphic succession of Chittagong City and its surrounding area alongside their geotechnical characteristics (Modified from Karim et al., 1990 [4]).

Name of the formation/ geologic age		Rock type	Geotechnical characteristics
Dihing Formation/Pliocene		Reddish brown to brick red, massive, highly ferruginous, weathered sandy to clayey silt, clay and pebbly sandstone, and at places oxidized iron incrustation. On top, there are weathered residual soils. Unconformity	Slightly weathered residual soils, very soft (30-100 kg/cm^2) to soft (30-10 kg/cm^2) in hardness, low to medium relative strength (uniaxial compressive strength 1-2 kg/cm^2)
Dupi Tila Formation/Mio-Plioene		Predominantly sandstone with alteration of silty sand and silty shale. Sandstones are massive, medium to fine grained, silty sand beds are greyish to yellowish brown, thickly laminated to bedded. Silty shale is light grey to grey grey, very thinly laminated and fissile. Iron incurstation is also present. Unconformity	Slightly to moderately weathered, massive, at places longitudinal joints are present as dipping almost parallel to the bedding, spacing varies from closed to 1.5cm, filled with ferruginous band with coarse sand. They ares soft (30-10kg/cm^2) in hardness. Has low to medium relative strength.
Tipam Sandstone Formation/Mid-Miocene	Upper Tipam	Sandstone, siltstone, and occasional shale. Sandstones are cross bedded. Local unconformity is present at the base.	Soft in hardness, moderately weathered, faulted, conjugate (planar) joints are present with vertical dipping orientation, spacing < 1cm, has medium relative strength, uniaxial compressive strength > 550kg/cm^2.

	Middle Tipam	Silty shale and shale, bedded, shale relatively hard, at places calcareous.	Moderate (100-250kg/cm^2) to hard (250-700kg/cm^2) in hardness, faulted, laminated, has medium to high relative strength, uniaxial strength varies from 500-1100kg/cm^2.
	Lower Tipam	Massive sandstone, yellowish brown to brown, medium to coarse grained, loose to dense, cross bedded.	Dominantly moderate (100-250kg/cm^2) in hardness, at places hard (250-700kg/cm^2), slightly weathered, faulted, planar and conjugate joints are seen with vertical dipping orientation, spacing < 1cm, ferruginous and argillaceous cement is present, has medium to relative strength, uniaxial compressive strength varies from 250-700kg/cm2).
BokaBil Formation		Silty shale, siltstone, sandstone and alteration of sand and siltstone. Cross bedding, ripple marks and load casts are present.	Moderate (100-250 kg/cm^2) to hard (250-700 Kg/cm^2) in hardness; fresh; faulted; planar, diagonal to conjugate joints are present, wchih have closed spacing; has medium to high relative strength, uniaxial compressive strength varies from 250-700 kg/cm^2.

III. Materials And Methods

Both field investigation and laboratory analysis have been performed to carry out this study. In the field, original slope angle is measured at 18 different sites where landslides in 2007 and 2008 took place. Original slope angles have been recorded to compare with internal friction angle of the slope materials. Besides, 10 and 8 sediment samples were collected from different sites of the field for grain size analysis and direct sheer test respectively. Grain size analysis is performed to determine the percentage of different grain sizes contained within a sediment sample. It was carried out at the Engineering Geology Laboratory of Department of Geology at University of Dhaka considering ASTM D 422 - Standard Test Method for Particle-Size Analysis of Soils. Whereas, direct sheer test was carried at Engineering Geology Laboratory of Geological Survey of Bangladesh (GSB) to determine cohesion and internal friction angle of the slope materials. Direct sheer test is covered in ASTM D 3080 - standard test method for direct shear test of soils under consolidated drained conditions.

Table 3: Measurements of original slope anglefrom different locations in the study area.

Location Name	Location ID	Latitude	Longitude	Original slope angle
BaizidBostami	Ctg-01	$22^0 23'$ $17''$	$91^0 49'$ $04''$	84^o
Kushumbagh	Ctg-02	$22^0 21'$ $19''$	$91^0 49'$ $18''$	64^o
Lalkhanbazar	Ctg-03	$22^0 20'$ $49''$	$91^0 48'$ $59''$	84^o
Pahartoli	Ctg-04	$22^0 21'$ $00''$	$91^0 48'$ $00''$	35^o
Sikandarpara 1	Ctg-05	$22^0 26'$ $07''$	$91^0 47'$ $51''$	24^o
Sikandarpara 2	Ctg-06	$22^0 26'$ $06''$	$91^0 47'$ $51''$	42^o
SIkandarpara 3	Ctg-07	$22^0 26'$ $04''$	$91^0 47'$ $52''$	48^o
Lebubagan 1	Ctg-08	$22^0 25'$ $01''$	$91^0 48'$ $36''$	42^o
Lebubagan 2	Ctg-09	$22^0 24'$ $58''$	$91^0 48'$ $36''$	54^o
Lebubagan 3	Ctg-10	$22^0 24'$ $56''$	$91^0 47'$ $37''$	43^o
Lebubagan 4	Ctg-11	$22^0 24'$ $54''$	$91^0 48'$ $35''$	37^o
Lebubagan 5	Ctg-12	$22^0 24'$ $53''$	$91^0 48'$ $39''$	36^o
Lebubagan 6	Ctg-13	$22^0 24'$ $53''$	$91^0 48'$ $41''$	35^o
Kechuarghona 1	Ctg-14	$22^0 25'$ $20''$	$91^0 48'$ $27''$	42^o
Kechuarghona 2	Ctg-15	$22^0 25'$ $27''$	$91^0 48'$ $22''$	40^o
Kechuarghona 3	Ctg-16	$22^0 25'$ $25''$	$91^0 48'$ $21''$	45^o
Kechuarghona 4	Ctg-17	$22^0 25'$ $48''$	$91^0 48'$ $15''$	43^o
Workshopghona 5	Ctg-18	$22^0 25'$ $14''$	$91^0 48'$ $26''$	45^o

IV. Results And Discussion

According to the field observation, original slope angle of the landslide sites is comparatively high and it varies from 24^o to 84^o (Table 3).Around 40% of sites have slope angle more than 45^o. Only one sites show original slope angle less than 35^o.Grain size analysis reveals that slope material of landslide sites, which is analogous to Dupi Tila sandstone formation, is composed of medium to fine grained sand with little or no clay particle (Table 4). All sites show sand percentage more than 80. Silt percentage ranges from 3 to 17. Results from direct shear test show that cohesion of sediment samples taken from landslide sites is very low (Table 5). It varies from 0.0459 to 0.0801 kg/cm^2.This is due to high percentage of sand size particle and absence of prominent silt and clay proportions. Moreover, internal friction angle measured at eight different landslide sites varies from 26.83^o to 34.30^o (Table 5).Internal friction angle greatly depends upon the composition of the slope materials and grain size. Coarse grained sands usually have higher internal frictional angle than the fine grained sand while shale has low value of that. Because of comparatively fine grained sand particles, internal frictional angle of slope materials of Chittagong City is relatively low.

The slopes of any area would be stable if the slope angle of that area remains close to the internal friction angle of the material that made that surface. But it is observed from the study that, in most of the cases, angle of slope surface highly deviates from internal friction angle. Landslides take place in the areas where the angle of the slopes is greater than the internal friction angle of slope materials [14]. Moreover, there is a good relation between

Table 4: Grain size analysis data of samples taken from the study area.

Sample ID	Sand%	Silt%	Sample ID	Sand%	Silt%
GsCtg-01	97	3	GsCtg-11	86	14
GsCtg-02	97	3	GsCtg-12	95	5
GsCtg-03	98	2	GsCtg-13	83	17
GsCtg-04	88	12	GsCtg-14	88	12
GsCtg-05	89	11	GsCtg-15	96	4
GsCtg-06	88	12	GsCtg-16	94	6
GsCtg-07	91	9	GsCtg-17	92	8
GsCtg-08	93	7	GsCtg-18	86	14
GsCtg-09	93	7	GsCtg-19	91	9
GsCtg-10	88	12	-	-	-

cohesion and landslide occurrence. If cohesion is less, the probability of landslide occurrence is more and vice versa. So the low cohesion value of sandstones of Dupi Tila Formation made Chittagong city area more susceptible to landslide hazard. In addition, any modifications of the hill slope like hill cutting, destabilization of hill slope by engineering construction, etc. that increase hill slope angle are also responsible for landslide hazard in Chittagong hill tracts as well Chittagong City. So, it could be said that higher slope angle than internal friction angle, low cohesion value, and presence of medium grained sandy soil, and human interference to hill slope are the main attributes for triggering rainfall induced landslide hazard at Chittagong City.

Table 5: Direct shear test results showing angle of internal friction and cohesion of samples obtained from the study area.

Sample ID	Angle of internal friction (^{o})	Cohesion (kg/cm^2)
DsCtg-01	33.30	0.0460
DsCtg-02	33.50	0.0562
DsCtg-03	32.30	0.0460
DsCtg-04	33.50	0.0330
DsCtg-05	32.10	0.0443
DsCtg-07	34.30	0.0360
DsCtg-11	26.83	0.0607
DsCtg-17	33.10	0.0662

V. Conclusion

This research has been carried out to evaluate the engineering parameters of slope materials of Chittagong City, for which slope stability is interrupted during heavy rainfall. With a view to assessing the geotechnical parameters like soil cohesion, internal friction angle, and slope angle, field investigation was conducted at the 2007 and 2008 landslide areas along with collecting soil samples for laboratory analysis. Laboratory analysis for the aforesaid engineering parameters and field investigation revealed that low cohesion value, low internal friction angle, and outweighing of slope angle from that of internal friction are main causes of rainfall triggered landslides at the hills of the study area. Moreover, hill-cutting, indiscriminate deforestation, informal agricultural activities cause the area far more vulnerable to such landslides due to significantly increasing slope angle. This paper is a simplistic observation to find out geotechnical factors, in addition to rainfall and human interference, which affect slope stability in the study area. Detailed study incorporating various additional geotechnical parameters would provide a comprehensive picture of the causative factors that trigger slope instability.

Acknowledgements

Authors like to thank Md. Zillur Rahman, Associate Professor, University of Dhaka, for kind guidance and consultancy during this research work. They would also like to express their gratitude to Department of Geology, University of Dhaka, and Geological Survey of Bangladesh for letting using their laboratory.

References

[1] M.A. Islam, S. Murshed, M.M. Kabir, A.H. Farazi, M.Y. Gazi, I. Jahan, and S.H. Akhter, Utilization of open source spatial data forlandslide susceptibility mapping at Chittagong district of Bangladesh—an appraisal for disaster risk reduction and mitigation approach, International Journal of Geosciences, 8, 2017, 577-598. doi: https://doi.org/10.4236/ijg.2017.84031
[2] Comprehensive Disaster Management Program-II (CDMP) II, Report on landslide inventory, land-use mapping, DEM preparation, precipitation threshold value, and establishment of overlay warning devices, Disaster Management and Relief Division (DMRD), Ministry of Food and Disaster Management (MoFDM), Dhaka, Bangladesh, 2012
[3] Y.A. Khan, H. Lateh, M.A. Baten, A.A. Kamil, Critical Antecedent Rainfall Conditions for Shallow Landslides in Chittagong City of Bangladesh, Environmental Earth Sciences, 67, 2012, 97-106. doi:https://doi.org/10.1007/s12665-011-1483-0
[4] B. Ahmed, Landslide susceptibility mapping using multi-criteria evaluation techniques in Chittagong Metropolitan Area, Bangladesh, Landslides 12, 2015, 1077–1095. doi: 10.1007/s10346-014-0521-x
[5] D.M.Cruden, (1991) A simple definition of a landslide. Bull Int Assoc Eng Geol, 43, 1991, 27–29
[6] L. Highland, P.T. Bobrowsky, and others, The landslide handbook: a guide to understanding landslides (US Geological Survey Reston, VA, USA), 2008.
[7] B. Pradhan, S. Lee, Delineation of landslide hazard areas on Penang Island, Malaysia, by using frequency ratio, logistic regression, and artificial neural network models, Environmental Earth Sciences, 60(5), 2010, 1037–1054
[8] K.T. Chang, S.H. Chiang, F. Lei, Analysing the relationship between Typhoon-triggered landslides and critical rainfall conditions. Earth Surface Process Landforms, 33, 2008, 1261–1271.
[9] M.S. Rahman, B. Ahmed, F.F. Huq, S. Rahman, T.M. Al-Hussaini, Landslide inventory in an urban setting in the context of Chittagong Metropolitan Area, Bangladesh.Proc. of 3rd Inter. Conf. on Advances in Civil Eng., 21-23 Dec, 2016, CUET, Chittagong, Bangladesh, 170-178.
[10] Banglapedia, Landslide, http://en.banglapedia.org/index.php?title=Landslide
[11] Bangladesh Population Census 2001, Bangladesh Bureau of Statistics
[12] Karim, M.F. Ahmed, S. and Olsen, H.W., Engineering geology of Chittagong City, Bangladesh, Geological Survey of Bangladesh (GSB) Report, Unpublished, 1990.
[13] M. Muminullah, Geology of the northern part of Chittagong district, Bangladesh, Records of Geological Survey of Bangladesh, 1(11), Part-3, 1974, Dhaka, Bangladesh.
[14] Banglapedia, Chittagong City, http://en.banglapedia.org/index.php?title=Chittagong_City
[15] G.V. Middleton, R.W. Peter, Mechanics in the Earth and Environmental Sciences, Cambridge University Press, UK, 1994

Abu Jafor Mia. "Factors affecting slope stability for triggering rainfall induced landslide at Chittagong City: a case study on 2007 and 2008 landslides." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) 14.4 (2017): 43-48.