Remedial measures for damaged slopes due to landslides in Chittagong Hill Tracts

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ABSTRACT

At two locations of Rangamati district in Chittagong Hill Tracts of Bangladesh extensive landslides occurred. The soil samples on the slopes are, in general, silty sand, which are susceptible to downslope migration. The incidence of slope failures has been attributed to heavy rainfall during monsoon. For restoration of the damaged slopes, the existing slopes were flattened, reinforced with anchors and a system of surface horizontal drains and sub-surface counterfort drains were designed and constructed. Six horizontal surface drains were provided, one placed at the top, one placed at the bottom and four at intermediate levels of the slope. Strips of counterfort drains, consisting of graded coarse aggregates wrapped all around with geotextiles, were laid along the hill slope. The geotextiles serve as filter to minimize clogging of aggregates and also allow free flow of water. A cantilever retaining wall with weep-holes was constructed at the bottom of the slope to increase the stability of the slope. The whole slope system was reinforced with anchored steel bars into the compacted fill material. Surface protection consisting of close turf was applied to slopes to prevent slope materials from surface erosion. The whole remedial system worked effectively and no signs of distress have been observed since the completion of the works.

1 INTRODUCTION

During monsoon heavy rainfall induced landslides frequently occurred in the Chittagong Hill Tracts of Bangladesh. Landslides and slope stability problem is considered here one of the stumbling blocks of infrastructure development where various ethnic peoples are residing over the years. Landslides have been one of the major and widespread natural disasters that strike life and property repeatedly. This paper reports a case study where an integrated remedial system designed and implemented to correct damaged slopes at Radio Centre and Television Relay Centre located on top of a hill in Rangamati District of Bangladesh.

2 NATURE OF DAMAGE AT THE PROJECT SITES

Figure 1 shows a typical section of existing land sliding slopes. The slopes of the sites became very steep due to considerable erosion of slope materials caused by heavy rainfall in this region. During the field visit, nature and extent of damage that had occurred at the two sites were assessed. Figure 2 shows a photograph of a section of one of the damaged slopes. The sections show considerable erosion of the existing slopes and some measures to protect the slopes using timber piling by the PWD (Public Works Department) Rangamati Division. It is noted that most of the damage occurred above RL 82 m (from PWD datum) in the three locations. No evidence of deep sliding was observed during site visit.

3 GENERAL CONDITIONS OF THE PROJECT AREA

3.1 Geology of the project area

Chittagong Hill Tracts lies in the folded belt of the Bengal Foredeep within Bengal Basin. High north-south striking hill ranges occupy wholly the districts of Chittagong and Hill Tracts. The anticlines form the hills and the synclines, the valleys. The hill districts include Khagrachari, Bandarban, Rangamati, Cox'sbazar and the eastern part of Chittagong in the southeast. These hills form part of Arakan range of Myanmar. The hills are mainly formed of folded sedimentary deposits of Dihing, Dupitila, Tipam and Boka Bill formations. Towards the east, the ranges get higher and the slopes steeper until they reach the highest hill range in the east that marks the boundary between Bangladesh, Myanmar and India. The Hill Tract area around Rangamati consists of Tipam Sandstone formation of middle Miocene epoch. Fine to coarse grained, massive gray, weathered to yellow, and brown sandstone constitute the major portion of the sediments of the Tipam group of Rangamati section. Thick and thin interbeds of laminated gray shale, siltstone, and silty shale commonly occur. Conglomerate and pebbly sandstone although uncommon, is associated with the sandstone. Some sandstone beds commonly display crossbedding.

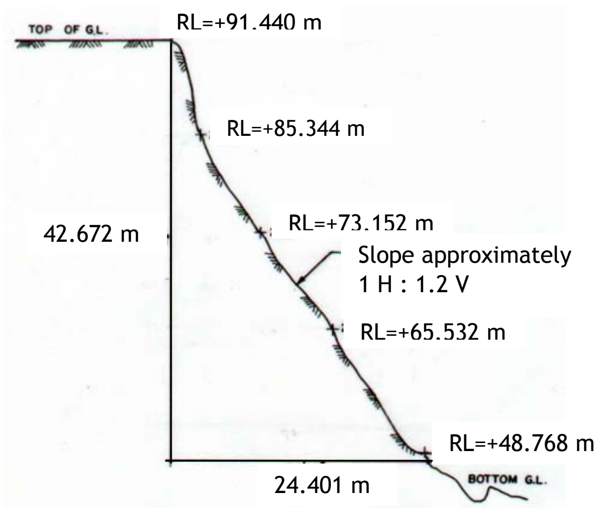

Figure 1: Typical section of slope after landslide

Figure 2: A photograph of damaged slope and temporary slope protection works by wooden piles

3.2 General soil condition of the project sites

The soil samples collected from slopes are generally silty sand. Laboratory investigations on two samples from Radio Centre and one sample from Television Relay Centre slopes of Rangamati were conducted at BUET Geotechnical Engineering Laboratory to evaluate the soil properties at the two sites. Laboratory tests included index tests, grain size analysis and Standard Proctor test. All the samples are non-plastic silty sand. Proportions of sand, silt and clay in slope soils and their compaction properties are shown in Table 1.

An investigation in to the susceptibility of the slope materials to downslope migration was carried out. The following procedure suggested by Permanent International Association of Navigation Congress (PIANC 1987) gives a general method of identifying soils susceptible to downslope migration. Soils susceptible to downslope migration will satisfy the following condition:

- A proportion of particles must be smaller than 0.06 mm.
- Additionally the soil will satisfy at least one of the following:
  1. The uniformity coefficient, $C_u < 15$
  2. 50% or more of the particles will lie in the range 0.02 mm < d < 0.1 mm.
  3. The plasticity index (I_p) will be less than 15. If I_p is unknown at the preliminary design stage then the following criterion may be substituted: Ratio of clay (d < 0.002 mm) to silt (0.002 < d < 0.06) < 0.5

If the soil is considered susceptible to downslope migration the design should take care of appropriate steps to control it. The numerical values of different parameters used to identify susceptibility to downslope migration of the soils from the slopes of the two sites are shown in Table 3. It has been found that all the samples are susceptible to downslope migration. Therefore it appeared that measure should be taken to prevent downslope migration of soil particles at both slopes. This could be achieved by adopting appropriate techniques for stabilising the slopes.

Table 1: Proportions of sand, silt and clay in slope soil and compaction properties

Sample Location	Sand (%)	Silt (%)	Clay (%)	D_{60} (mm)	D_{10} (mm)	Optimum moisture content (%)	Maximum dry density (kN/m^3)
Radio Main Gate	63	33	4	0.21	0.0055	11.7	17.4
Radio Main Building	62	34	4	0.21	0.0058	13.5	17.2
Television Station	73	26	1	0.20	0.0140	10.5	17.6

Table 2: Values of various parameters used to assess susceptibility to downslope migration of soils of Rangamati Radio and TV Relay Centres

Sample Location	% of particles ≤ 0.06 mm	Uniformity coefficient $C_u = D_{60}/D_{10}$	% of particles in the range of 0.02 mm to 0.1 mm	Ratio of clay fraction to silt fraction	Plasticity index	Remark
Radio Main Gate	35	38	19.0	0.12	Non-plastic	S
Radio Main Building	34	36	20.5	0.12	Non-plastic	S
Television Station	24	14	21.5	0.04	Non-plastic	S

S = Susceptible to downslope migration

4 CAUSES OF LANDSLIDES AT THE PROJECT SITE

The most common failures in soils, fills and colluvium of project site are very shallow, being controlled by depths of weathering and infiltration of water during rainstorms. According to the Bangladesh Bureau of Statistics, for the past thirty years the annual rainfall in the Hill Tracts ranges between 2000 mm to 4200 mm. The incidence of slope failures in Rangamati Radio and TV Relay Centres is due to heavy rainfall during the rainy season. Because of heavy rainfall during monsoon, sufficient water percolated into the slopes, which had the following effects on the slopes:

- total loss of suction within the soil mass of the slopes
- significant increase of pore-water pressure within the soil mass of the slopes

- reduction of the frictional resistance of slope materials
- weakening inter-granular bonds (chemical weathering) of slope materials

An increase in the pore-water pressures along the potential slip surfaces reduced the effective normal pressure and thus the shear strength of the slope material. Consequently, landslides were initiated.

5 METHODS OF CORRECTING LANDSLIDES

Various methods have been used to correct landslides such as regrading of slopes and the use of retaining walls, surface and subsurface drainage, ground anchors, soil nails, tied-back walls, contiguous bored-pile walls and other types of restraining structures. For minor slips, small timber piles driven at close spacing have been used for stabilizing slopes. The commonly used correction methods can be divided into the following four main groups (Tan et al. 1987, Brand 1984):

(i) Geometrical methods, which involve the change of the geometrical conditions of a slope.
(ii) Hydrological methods, such as lowering of the groundwater table or a reduction of the water content of the soil or rock.
(iii) Mechanical methods.
(iv) Chemical methods.

Increase in stability of slope by geometrical methods include the follows:
- Flattening of the slopes
- Removal of soil or other loads at the top of the slope
- Placing pressure berms at the toe of the slopes

For routine design of cut slopes, empirical approach based on past experience, and limit equilibrium analysis using Bishop's Simplified Method for circular failure surfaces are commonly used. Janbu's Simplified Method for non-circular slip analysis is occasionally used. The acceptable long-term factor of safety adopted is in the range of 1.3 to 1.5.

In hydrological methods, increase in the stability of slopes can be achieved by lowering of ground water table, reduction of water content and immediate reduction of pore water pressure from soil using various types of drainage systems. Some commonly used drainage systems are as follows:
- surface drains
- counterfort drains
- horizontal penetrating drains
- drainage galleries
- drain holes

Mechanical stabilization of slopes includes the following measures:
- ground anchors
- soil nails
- reinforced earth
- contiguous bored-piles wall
- conventional retaining walls.

In case of reinforced earth slope, geosynthetic or metal reinforcement with or without anchors are used. Geogrids and geotextiles are commonly used as geosynthetic reinforcement.

Grouting can increase the slope stability of primarily coarse-grained soils. Both chemicals and cement can be used to stabilise such soils.

6 PROPOSED REMEDIAL MEASURES FOR DAMAGED SLOPE SITES

From the review of the available techniques of correcting landslides, it was decided to use geometrical, hydrological and mechanical methods together. Remedial measures included flattening of the existing slopes reinforced with anchors and construction of surface drains. The solution appeared to be the most suitable from the viewpoint of cost effectiveness, ease of construction and time for construction. Figure 3 shows the designed and implemented slopes at sites. A system of surface horizontal drains and sub-surface counterfort drains has been designed and implemented in Rangamati Radio and Television Centre sites. This system is to facilitate and improve the drainage of the slope and to lower the ground water level, thereby, increase the stability of the slope. Although surface drains are not sufficient for the stabilization of the slope in motion, they can contribute substantially to controlling landslide.

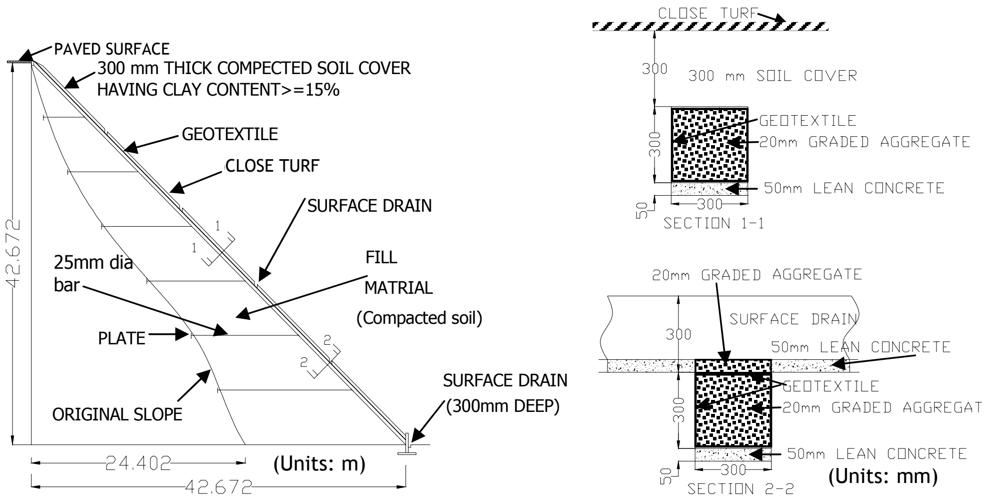

Figure 3: Layout and cross-sections of proposed remedial measures for slope stabilization.

The main purpose of surface drainage and surface protection is to improve slope stability by reducing infiltration and erosion caused by heavy rainstorms. The slope drainage system should collect runoff from both slope and the catchment area up-slope and lead it to convenient points of discharge beyond the limits of the slope. Surface protection should be applied to slopes formed in materials susceptible to rapid surface erosion or to weakening by infiltration. The two methods are often used together as part of a preventive or remedial works design. The top surface behind the building and up to the surface drain was either paved or covered by bitumen to prevent percolation of rainwater into the sub-soil. Figure 3 shows the detailed layout and cross-sections of the surface horizontal drains and sub-surface counterfort drains.

The original slope of the sites (shown in Figure 1) has to be modified into milder slope of 45 degree or less. This should be achieved by placing fill materials on top of the existing slopes. The fill material shall be compacted to at least 90% of its maximum Proctor dry density. Strips of counterfort drains spaced at 3 m centre-to-centre have to be laid along the hill slope. Each of these drains are 300 mm wide and 300 mm high, the drains consist of graded 20 mm coarse aggregates wrapped all around with a geotextile. The geotextile was to minimise clogging of the coarse aggregates and will also allow free flow of water without inducing large pore water pressure. The geotextiles were 3.0 mm thick and of 350 gm/m^2 weight having minimum vertical permeability 1.0 mm/s and minimum horizontal in-plane permeability 2.0 mm/s. The base of the drains was sealed with 50 mm thick lean concrete. The drains were covered with a 300 mm thick layer of soil to enable turfing over them.

Six horizontal surface drains were provided, one placed at the top, one placed at the bottom and four at intermediate levels of the slope. A cantilever retaining wall was constructed at the bottom of the slope to increase the stability of the slope. Weep-holes were provided within the retaining wall in order to reduce water pressure exerted to the wall. The whole slope system was reinforced with 25 mm round steel bars which was anchored by a 300 mm x 300 mm x 12 mm steel plates placed at the end of the fill. Location of bars and anchor plates are shown in Figure 3. The principal purpose of providing slope protection was to prevent the hydraulic load created by rainwater from inducing failure in the slope soil. The possible modes of failure of the slope can be categorised broadly into two types:

(a) Local stability – condition including, local sliding, local bearing failure, soil migration, liquefaction, settlement and heave.
(b) Overall stability – the stability of the slope as a whole.

The local sliding condition may develop in the interface between present slope and the bottom of the reconstructed fill of the slope. Analysis of such condition would require knowledge of available shear strength at the soil interface. As the soil at this interface is above water table and dry, it is unlikely to develop sliding condition. Also use of 90% Proctor Compaction should provide adequate resistance against local sliding. The position of retaining wall also would provide additional resistance against local sliding. From the geotechnical properties of the slope soils it is expected that the soil within the project area should have very low expansion potential. Hence, little deformation and volume change is expected on wetting and drying.

The overall stability failure mechanism develops from slip circles resulting in a deep sliding surface. This is a conventional soil mechanics stability problem. Pre-existing slip planes within the soil, or lenses and bends of cracked material can have a significant effect on slope stability. From slope stability analysis and past experience in the project site area, it was concluded that there is no possibility of deep slip failure. The proposed remedial measures were implemented in 2000 and observed and assessed since then. During this period, the slope suffered no damage and distress.

7 CONCLUSIONS

Extensive landslides at two locations of Rangamati district in Chittagong Hill Tracts of Bangladesh occurred. The incidence of slope failures has been attributed to heavy rainfall during monsoon. For remediation of the damaged slopes, the existing slopes were flattened, reinforced with anchors and a system of surface horizontal drains and sub-surface counterfort drains were designed and constructed. The remedial measures were implemented in 2000 and have been observed and assessed since then. The performance of the protective measures has been found to be satisfactory suffering no damage and distress. From this case study it appeared that integrated solution of flattening of the existing slopes, reinforcing with anchors and the construction of surface drains and internal counterfort drains is the most suitable from the viewpoint of cost effectiveness, ease of construction and time for construction.

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