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An Analysis of Causes of Urban Landslides in Residual Lateritic Soil

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AN ANALYSIS OF CAUSES OF URBAN LANDSLIDES IN RESIDUAL LATERITIC SOIL

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ABSTRACT

Landslides in natural slopes of residual soil are a common problem encountered in tropical regions. Guwahati city, located in Assam in the north-eastern part of India, is an urban watershed covered by a number of hills and hillocks that are capped with lateritic soil. Although the slopes originally consisted of hard and strong rocks, their stability have been impaired by weathering, heavy rainfall and seepage flows. Encroachments and cuttings on the hill slopes due to unplanned urbanisation and earthquake tremors have aggravated the problem. A study of landslides was undertaken focussing on degree of weathering of the rock units, their mineralogy and petrography, physical and mechanical properties as well as various structural features to identify the role of geology in initiating the slides. Soil samples obtained from the sites were tested. Data obtained from the field and laboratory were analysed to determine the causes of the landslides.

INTRODUCTION

Guwahati is the capital city of Assam state in the north-eastern region of India. There has been a fast growth of population and commercial activities. The city comprises of a number of hills and hillocks covering a substantial amount of its total area. Being situated in a geo-dynamically sensitive belt, the city experiences frequent earthquakes of varying magnitude and other geotectonic activities. The average rainfall is in excess of 150 cm per year. There is widespread deforestation, and population pressure is forcing people to move up the steeper slopes. This has created instability of many hill slopes of the city. As a result, in the last two decades, particularly during rainy seasons, several landslides have occurred claiming many lives.

Landslides are common in residual soils, particularly during periods of intense rainfall. The stability of slopes in such soils is difficult to predict on the basis of field or laboratory tests. The soil properties can vary considerably laterally and with depth due to differential weathering patterns. The rainfall-induced landslides are generally shallow in nature.

A landslide or slope failure can be best understood with reference to associated geological information, which in most cases conveys the mode of failure. In this study, an attempt was made to understand the landslides problem of Guwahati city focussing mainly on the possible influence of geological characteristics such as mineralogy, petrography and structures of the rock units of the area.

PURPOSE OF THE STUDY

This study was a “C” type of evaluation, rather post-mortem investigation, of seven landslides scattered all over Guwahati city (Figure 1). The study was a part of a main investigation work that involved study of slope morphology and land-use patterns, geotechnical properties, geological characteristics, rock weathering and soil formations, and geo-hydrological properties.

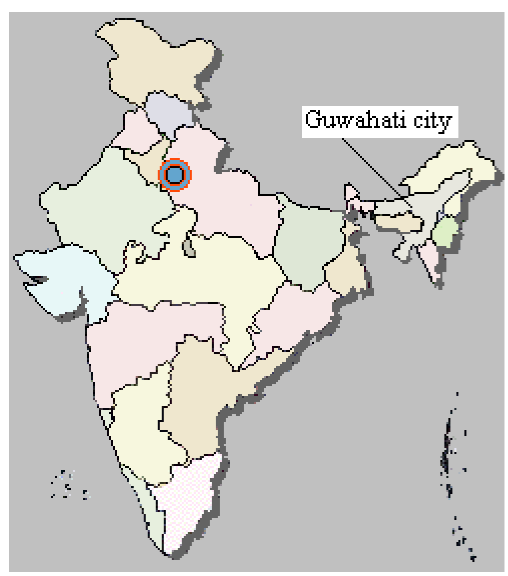


Fig. 1. Location of Guwahati city in Indian mainland

The study reported herein was limited to the fourth aspect and accordingly the objectives were confined to the following:

- To study the mineralogical and petrological characteristics of the different rock units of the landslide areas.
- To determine the mechanical properties of different rock units.
- To study the various structural features of the rock units and work out probable sequences of deformation and to find out their influence on the possible causes of the landslides.
- To study the nature and extent of the problem and interpret results of both field and laboratory studies.

ENVIRONMENTAL SETTING OF THE AREA

The study area is a extension of the "Shillong Plateau" and is bounded by the Brahmaputra River in its northern side. The entire area is characterized by hill ridges and flat lands. The hills are scattered over the entire central portion and generally show NE-SW trend with some local variations. Pockets of low lying areas are seen in between the hills. The soils of the study area have developed mainly from the weathering of granitic rocks from pre-Cambrian age.

The climate of the area is mainly of tropical monsoonal type, with south-east monsoon from the Bay of Bengal passing over the area during summer. The area receives rainfall of various intensity and duration from the beginning of May to the end of October. The variation of average monthly temperature and rainfall throughout the year is shown in Figure 2. The average annual rainfall in the area varies from 180 cm to 195 cm. Notable basins in the study area are Bharalu Basin, Silsako Basin, Deepor Basin, Kalmoni Basin and Foreshore Basin.

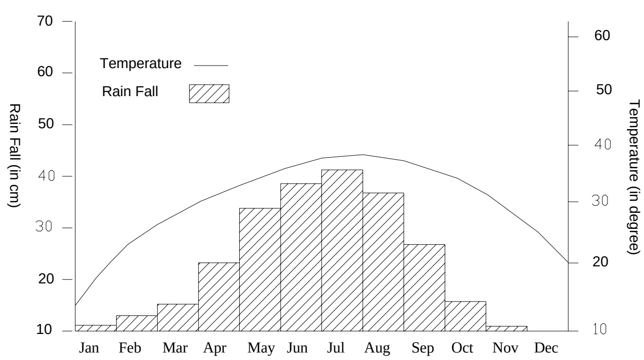


Fig. 2. Variation of average monthly temperature and rainfall in the study area

METHODOLOGY

Understanding the geology of a region is of vital importance in tackling problems associated with slopes and slope development. Local geological details, such as the geometry of the subsurface, rock types and groundwater, have an influence on the performance of individual slopes.

Reconnaissance and Preliminary Survey

An extensive reconnaissance survey was carried out to locate the landslide areas scattered along the hill slopes of the city. Based on the data and information collected from the reconnaissance survey, seven sites were selected for detailed field investigation on the basis of recurrence of landslides, damage to property, casualties and vulnerability.

Field Investigation

Field visits to the selected sites were made and information on individual rock types, their physical properties, mode of occurrence, various structural features, weathering as well as samples of individual rock units were collected by adopting different hand tools. Brunton compass and clinometer were used for accurate measurement of dip, strike, foliation, lineation, joints etc.

Laboratory Investigation

The collected individual rock units were made into thin sections which were studied with the help of petrological microscope to interpret texture, microstructure and constituent minerals. The percentages of the constituent minerals of all types of rocks were determined by model analyses using Swift automatic point counter. In addition to the above, impact tests, specific gravity and water absorption tests were carried out to interpret the physical and mechanical properties of the rock units.

LANDSLIDES SELECTED FOR DETAIL STUDY

The seven areas selected for detail investigation were Dispur Kacharibasti, Madgharia, Rupnagar, Birubari, Kalapahar, Dhirenpara, and Nabagraha.

Dispur Kacharibasti Landslide. This was located in the eastern part of the Narakasur hill. In this locality, the landslide of 14^{th} October 1991 was a devastating one. The landslide occurred with a sudden spreading of soil and rock mass after three days continuous spell of about 250 mm rainfall. Altogether, sixteen persons lost their lives in an event of few minutes that devastated the entire area burying a number of houses. The distance between the crown and the toe was about 160 m and the average distance between the right and left flanks was about 70 m. The height of the crown from the toe was about 80 m. The naturally existing slope varied from 15° to 30° near the toe and from 60° to 70° close to the crown area of the failure surface. After failure the slope angle was less than 10° at the foot hill and almost vertical near the crown area of the slope.

Madgharia Landslide. The area was located at the foothill area of Madgharia. The landslide of 29^{th} July 1989 was characterized by toe failure with sudden spreading of soil. The distance between the crown and the toe was 18 m, with a height difference of 15 m. The distance between the left flank and the right flank was 14 m approximately. The naturally existing slope was 30° and after it became 60° near the crown area. Sporadic incidences of toe cutting and removal of vegetation cover from the entire Madgharia was noticed.

Rupnagar Landslide. This was on the northern face of Narakasur hill near Rupnagar. The failure consisted of slumping of soil and rock mass encompassing an area of 7000 m^2 accompanied by intermittent rolling, sliding and toppling of massive boulders which continued for five days from 10th to 14th July 1988. The biggest boulder was of the size of about 8 m × 6 m × 5 m. Large crescentic cracks were noticed at the crown area of the slope on the night before the failure. Severe mud flow was reported two to three days before the landslide.

Birubari Landslide. The affected area was located at Birubari where a massive landslide occurred on 14th August 1982 by sudden spreading of soil. The area was underlain by a massive bed rock dipping along the slope. The existing slope angle at the failure surface was about 15° compared to the natural slope angle of 33°.

Kalapahar Landslide. This was a case of rock fall that occurred during a light shower on 27th August 1988. A massive porphyritic granite rock got separated from its in situ position and then toppled. The hill slope in this area was very steep.

Dhirenpara Landslide. This happened on 5th September 1987 and was located on the eastern face of Fatasil hill. The landslide was characterized by sudden spreading of quasi-viscous soil and rock mass from the slope following land subsidence at the toe region of the slope. A downward movement of soil and rock masses, accompanied by intermittent rock fall, continued for 3 to 4 hours. Altogether eighteen houses were swept away surrounding an area of about 6000 m^2. The distance between the crown and toe and between left to right flanks were 120 m and 50 m respectively.

Nabagraha Landslide. The slides mainly took place on the southern down-hill area of Karnachal hill. In this area, numerous landslides occurred and among them, the landslide of 15th July 1989 was the largest one. The slope angle after the failure varied from 40° to 75°.

WEATHERING OF ROCKS IN THE LANDSLIDE AREAS

Under favourable conditions of temperature, rainfall and drainage, intense weathering of rocks of granitic origin leads to formation of thick horizons of residual soil profiles. Figure 3 illustrates a typical residual soil profile which consists of three distinctly divided zones (Little, 1969). Laterites and saprolites are two types of residual soils. Laterites are typically bright red to reddish brown soils. Saprolites are zones consisting of completely or highly weathered bedrock that contains soil-like materials having the original relic rock structure.

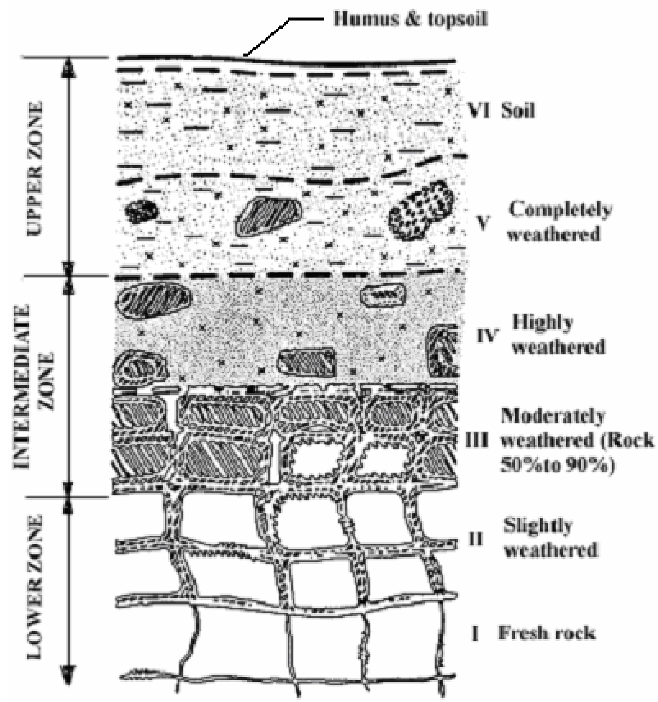


Fig. 3. Typical horizon of tropical residual soil developed from igneous rock (Little, 1969)

The rock type should always be determined in assembling data for the appraisal of a residual deposit. Rocks have no formal classification equivalent to that for soils. They are made up of small crystalline units known as minerals. Bedding, faulting, jointing and weathering in rock have pronounced effects on its behaviour.

Granite gneiss, which was a major country rock of the area, showed varying degrees of weathering at different landslide areas. At Dispur Kacharibasti and Nabagraha landslide areas, it was observed to be at a highly weathered stage. At Madgharia and Birubari landslide areas, they were moderately weathered and they were slightly weathered at Rupnagar, Kalapahar and Dhirenpara landslide areas.

Porphyritic granite, which occurred in association with granite gneiss also showed varying degrees of weathering at various landslide areas. At Dispur Kacharibasti, it was highly weathered, whereas it was at slightly weathered state at Kalapahar and Rupnagar landslide areas.

Residual soils found in the landslide areas were mostly the weathered products of granite gneiss and porphyritic granite. Decomposition and successive products of an average granite that contains microcline, quartz, plagioclase and biotite (mica) as chief minerals are shown in Figure 4.

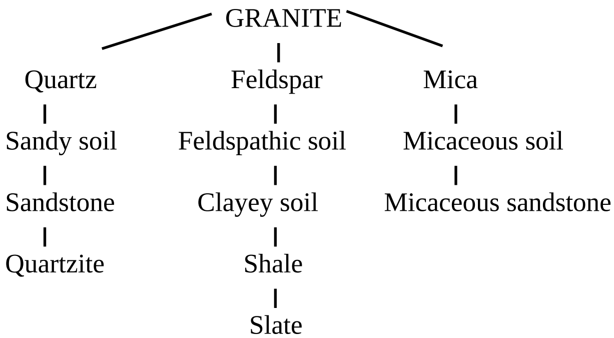


Fig. 4. Weathering of average granite and its products

The further decomposition of feldspar can be shown as

$$K_2OAl_2O_36SiO_2 + 6H_2O + CO_2 \longrightarrow Al_2Si_2O_5(OH)_4 + 4SiO_2.4H_2O + K_2CO_3$$

In the study areas, formation of soils alone was noticed, and other products were not encountered. With heavy rains, high temperature and good drainage, some materials from the residual soils were leached out and high iron content was left behind. This led to the formation of reddish lateritic soil, encountered in all the landslide areas of Guwahati.

In the landslide areas, removal of vegetation cover and poor surface drainage systems resulted in washing of finer portion of this soil from the slopes of the hills by rain and percolating water. It resulted in the formation of coarse-grained soils at the top of the slope and mud flows at the downhill areas.

MINERALOGY AND PETROGRAPHY OF THE ROCK UNITS

Igneous rocks such as granite, dolerite and gabbro, when unweathered, exhibit high shear strength for any engineering construction purpose. Igneous rocks, if hydrothermally altered along shear zones, would pose sliding problems for slopes even though it is unweathered. Joints, faults and shear zones permit the entry of water and air into the rock mass, and facilitate weathering within the rock mass. When weathering becomes advanced, sliding along the weathered zones would take place.

Metamorphic rocks, such as gneiss, schist, quartzite, slate, phyillite and marble, vary considerably in terms of slope stability. Foliation in gneiss or schist renders the rock weaker and more susceptible to weathering and decay. Quartzite and gneiss are strong if they are not deformed by faulting and folding. Mica schists are weak physically and upon weathering, they become slippery and fail under light loads.

The various rock units found at different landslide areas are presented in Table 1.

Table 1. Rock units identified at different landslide areas

Area of Landslide	Rock Units Identified
Dispur Kachribasti	Granite gneiss, Prophyritic granite, Biotite schist, Hornblende-biotite-schist, Pegmatite
Madgharia	Granite gneiss
Rupnagar	Granite gneiss, Prophyritic granite, Hornblende-biotite-schist, Pegmatite
Birubari	Granite gneiss
Kalapahar	Granite gneiss, Prophyritic granite
Dhirenpara	Granite gneiss, Prophyritic granite, Hornblende-biotite-schist, Pegmatite
Nabagraha	Granite gneiss

<u>Granite Gneiss</u>

This rock was found in all the landslide areas investigated. In general, the rock showed two colours viz. grey and pink. The grain size of the rock varied from fine to medium and they showed gneissose structure. The mineral grains occurred as subhedral to anhedral grains. The rock was well- foliated. The lineation was marked by a preferred orientation of biotite flakes. The rock was highly jointed and showed three types of joints. The following minerals of the rock units were identified under microscope.

Chief Minerals: Quartz, microcline, plagioclase and biotite

Secondary Minerals: Sericite and chlorite

Accessory Minerals: Zircon, hornblende, sphene, apatite and magnetite

The common mineral assemblages of the rock were:

Microcline--plagioclase--quartz--biotite--hornblende--apatite--chlorite.

Microcline--plagioclase--quartz--biotite--zircon--magnetite--sericite.

Microcline--plagioclase--quartz--biotite--sphene--sericite.

Microcline--plagioclase--quartz-- biotite--zircon--sericite.

Microcline--plagioclase--quartz--biotite--zircon--chlorite.

The results of model analysis of the rock are presented in Table 2.

Table 2. Model Analysis of Granite Gneiss (vol %)

Mineral Constituents	Name of Landslide Area				
	Dispur Kacharibasti	Madgharia	Birubari	Rupnagar	Dhirenpara
Microcline	33.62	20.11	34.71	41.91	16.11
Plagioclase	25.16	25.36	24.05	24.71	24.46
Quartz	32.48	46.89	31.68	29.96	54.79
Biotite	4.24	4.06	5.16	0.29	0.36
Accessories	4.50	3.55	4.40	3.10	4.26
Total	100.00	99.97	100.00	99.97	99.98

<u>Microcline</u>. It accounted for 16.11% to 41.91% of the rock. Microcline occurred as subhedral grains with irregular boundaries. Characteristic cross-hatch twinning was common. Perthitic intergrowths with plagioclase were common.

<u>Plagioclase</u>. The amount of plagioclase varied from 24.05% to 25.36% of the rock. Mineral grains were subidioblastic to xenoblastic. It showed polysynthetic twinning. Myrmekitic intergrowth was common. The extinction angle was 14° to 20°.

<u>Quartz</u>. It accounted for 29.96% to 54.79% of the rock. Quartz occurred in xenoblastic form. Two types of quartz were observed.

Quartz I - It occurred as bigger grains with irregular outlines showing wavy extinction.

Quartz II - It occurred as small grains and showed uniform extinction.

<u>Biotite</u>. It accounted for 0.29% to 5.16% of the rock. It occurred as prismatic and pleochloric grains with both smooth and sharp boundaries. It showed straight extinction. It sometimes altered to chlorite.

<u>Hornblende</u>. It occurred as prismatic grains with two sets of cleavage intersecting almost at 87° and 93°. The extinction angle was 14°.

<u>Zircon</u>. It occurred as subhedral grains showing high relief. It was colourless but the grain boundaries were very sharp.

<u>Sphene</u>. It occurred as subhedral grains with brown colour.

<u>Aptite</u>. It occurred as subidioblastic grains.

<u>Sericite and Chlorite</u>. They were found as the altered products of plagioclase and biotite respectively.

Similarly, the results of model analysis of porphyritic granite and hornblende-biotite-schist are presented in Tables 3 & 4 respectively.

Table 3. Model Analysis of Porphyritic Granite (vol %)

Mineral Constituents	Name of Landslide Area		
	Dispur Kacharibasti	Rupnagar	Dhirenpara
Microcline	42.86	47.10	40.66
Plagioclase	26.25	23.55	28.20
Quartz	19.82	18.32	20.12
Biotite	5.58	6.15	5.78
Accessories	5.36	4.88	5.24
Total	99.87	100.00	100.00

Table 4. Model Analysis of Hornblende-Biotite-Schist (vol %)

Mineral Constituents	Name of landslide		
	Dispur Kacharibasti	Kalapahar	Nabagraha
Hornblende	64.29	43.50	55.64
Biotite	10.71	23.52	11.95
Quartz	10.40	13.80	11.57
Plegioclase	9.72	15.64	16.44
Accessories	4.88	3.34	4.38
Total	100.00	99.80	99.98

STRUCTURAL FEATURES OF THE ROCK UNITS

The stability of a hill slope, to a great extent, is controlled by structural features of the rock units which include features of inhomogeneity, and by discontinuities involving mostly bedding planes, joints, faults, shear zones, folds and unconformities.

Degree of jointing and fracturing relative to the adjacent slope and nearness to a tectonically active zone is an important criterion in determining stability of hill slopes. Joints in the hillslope may allow the overlying, unsupported rock to slide down causing a landslide. They also help in erosion and weathering of rocks.

The orientation of a bedding plane relative to a hillslope also plays a significant role in initiating failures. A bedding plane dipping along the hillslope may possibly lead to a server slope failure. Further, sliding depends on the angle of dip; higher the angle of dip greater is the sliding possibility.

Faults generally represent zones of weakness within the earth in which movements are likely to occur through long period of time. A fault plane with percolating water may suitably result in sliding giving rise to a landslide.

Stability of a hill slope in relation to these structural features decreases even further due to the presence of water. If the rocks are sheared and shattered, they will naturally become saturated with water. Their shear strength will consequently be less.

Planner Structure

Foliation. The trend of dominant foliation in the present area was generally NE-SW with some local variations. Two types of foliations were recognized in the field.

Differentiated layering or Compositional layering: In the field, compositional layering or differentiated layering was observed in the granite gneiss, hornblende-biotite-schist and biotite-schist. The original nature of the foliations could not be determined, although these might have been the relics of the original bedded structures in the sedimentary and flow layers of varying thickness and differing mineral composition. In case of granite gneiss and hornblende-biotite-schist, the dark bands were rich in mafic (ferromagnesian) minerals such as biotite, hornblende etc. and the light coloured bands were rich in light coloured felsic (quartz and feldspar) minerals. In case of biotite-schist, the compositional layering consisted of alternating layers of biotite and quartzo-feldspathic minerals.

Axial plane foliation: Granite gneiss and hornblende-biotite-schist encountered in various landslide areas showed foliation and it was marked by strong preferred orientation of the minerals. The foliation on granite gneiss showed both conformable and unconformable relationship with other associated rocks.

Flow Layer. Platy flow structure was observed in the porphyritic granite at many landslide areas such as Dispur Kacharibasti, Rupnagar, Kalapahar, Dhirenpara etc. During the formation of porphyritic granite, the feldspar phenocrysts and biotite minerals became oriented with their largest face parallel to the moving magma layers because of the laminar flow at the flow stage; the force full injection of magma giving rise to well-developed planar structure also termed as a flow layer.

Joints. Joints with varied attitude were readily observed in all the rock types of the landslide areas. Various types of joints observed in the rock units could be classified as dip joint, strike joint, diagonal or oblique joint, tension joint and shear joint.

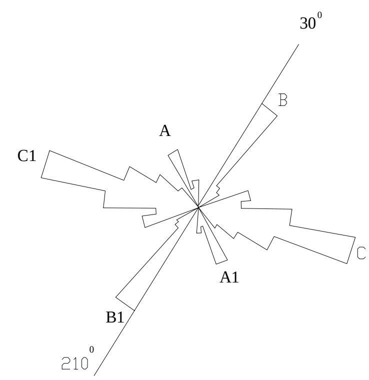
At Dispur Kacharibasti, the rock granite gneiss was found to be highly jointed with large dimensional cracks. At the root area of the slide, which consisted of a massive granite gneiss rock, concentration of the joints was very high. In this portion of the failure surface, numerous oblique joints with length ranging from 9 inches to 10 feet were observed. On the right side of this root area, sets of strike, dip and oblique joints with length varying from few centimeters to several feet were observed. Seepage of water through the joints was noticed.

At Rupnagar landslide area, porphyritic granite was highly jointed. Here geometrically all the three sets of joints were recognized viz. dip joint, strike joint and oblique joint. At the cliff of the hill slope in an outcrop, porphyritic granite showed three prominent sets of joints.

Sixty five readings of joints in granite gneiss from Dispur Kacharibasti landslide area, sixty five readings of joints in porphyritic granite from Kalapahar landslide area and fifty readings each in porphyritic granite and granite gneiss from Rupnagar and Dhirenpara landslide area respectively were taken and the rose diagrams are plotted as Figures 5 to 8.

Figure 5 shows the orientation of joints in granite gneiss at Dispur Kacharibasti landslide area. The joints showed preferred orientation in the following different directions: (i) N30°W-S30°E, (ii) N30°E-S30°W, and (iii) N80°W- S80°E. Thus the existence of three major sets of joints in granite gneiss was very clear.

The first set of joints trending N80°W-S80°E was the dominant set of joints. This set of joints was more or less perpendicular to the foliation and may be termed as dip joints. The second set of joints trending N30°E-S30°W was almost parallel to the strike of foliation; hence they could be termed as strike joints. All the sets of joints did not show the same frequency of occurrence. The first set of dip joints was the most frequent one.



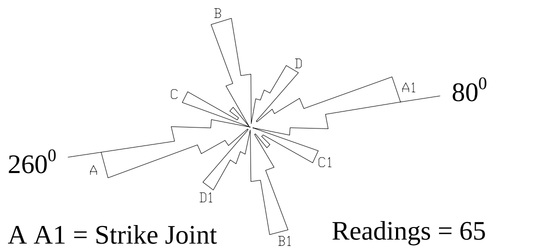
A A1 = Oblique Joint
B B1 = Strike Joint
C C1 = Dip Joint

Readings = 65
Interval:
2 units = 1 reading

Fig. 5. Rose diagram of joints in granite gneiss at Dispur Kacharibasti Landslide

Figure 6 shows the orientation of joints in porphyritic granite at Kalapahar landslide area. The joints showed preferred orientation in the following different directions: (i) N80°E-S80°W, (ii) N20°W-S20°E, (iii) N40°E-S40°W and (iv) N70°W-S70°E.

The first set, i.e. the set trending N80°E-S70°W, was the dominant set of joints. This set of joints could be termed as strike joints, as it was parallel to the foliations. The second set of joints in N20°W-S20°E direction was a dip joint as it was perpendicular to the foliations. The joints in N70°W- S70°E direction were oblique joints. Of all the joints, occurrence of the first set of joints was more frequent.



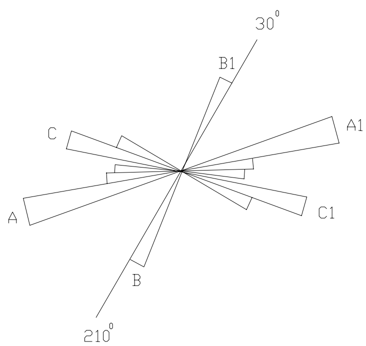
A A1 = Strike Joint
B B1 = Dip Joint
C C1 = Oblique Joint

Readings = 65
Interval:
2 units = 1 reading

Fig.6. Rose diagram of joints in porphyritic granite at Kalapahar Landslide

Figure 7 shows the orientation of joints in porphyritic granite at Rupnagar landslide area. The joints showed preferred orientation in three directions: (i) N80°E-S80°W, (ii) N30°E-S30°W, (iii) N70°W-S70°E and as such there were three prominent sets of joints.

The frequency of occurrence of the first set of joints trending oblique to the strike of foliation i.e. N80°E-S80°W was more than the other two sets of joints. The third set of joints, trending perpendicular to the strike of foliation, could be termed as dip joints.



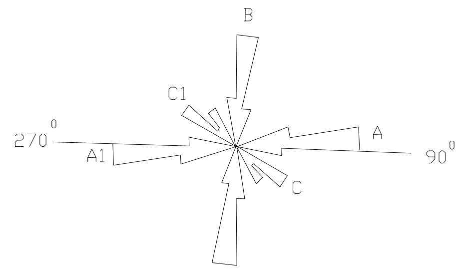
A A1 = Oblique Joint
B B1 = Strike Joint
C C1 = Dip Joint

Readings = 50
Interval:
2 units = 1 reading

Fig. 7. Rose diagram of joints in porphyritic granite at Rupnagar Landslide

Figure 8 shows the orientation of joints in granite gneiss at Dhirenpara landslide area. The joints showed three distinct sets of joints which were oriented in the following directions: (i) N90°E-S90°W, (ii) N10°E-S10°W and (iii) N60°W-S60°E.

The first set, i.e. trending N90°E-S90°W, was the dominant set and it was more or less parallel to the strike of the foliations. The second set of joints trending N10°E-S10°W was almost perpendicular to the foliations, hence they could be termed as dip joints. The third set of joints being slanting to the foliation direction were oblique joints.



A A1 = Strike Joint
B B1 = Dip Joint
C C1 = Oblique Joint

Readings = 50
Interval:
2 units = 1 reading

Fig. 8. Rose diagram of joints in granite gneiss at Dhirenpara Landslide

Linear Structures**.** Mineral lineations were mostly seen in granite gneiss, biotite schist and hornblende-biotite-schist. In granite gneiss, lineation was mainly by elongated clots of biotite mineral which were parallel to the gneissic banding. In biotite schist, mineral lineation was exhibited by elongated mineral flakes of biotite with their long axis parallel to the schistosity. In hornblende-biotite-schist, mineral lineation was defined by elongated crystals of hornblende, the long axis of which was parallel to the foliation.

Other Structures. Two types of folds were found in various landslide areas. Isoclinical fold was encountered in granite gneiss at the Nabagraha, Madgharia and Dhirenpara landslide areas and asymmetrical fold was encountered in granite gneiss at Dispur Kacharibasti landslide area.

Sills of pegmatite were encountered at Dispur Kacharibasti, Rupnagar and Dhirenpara landslide areas mostly in granite gneiss. A dyke of pegmatite in granite gneiss was encountered at Dispur Kacharibasti landslide area. Quartz veins showing both conformable and unconformable relationship with the associated rock were observed in almost all the landslide areas.

MECHANICAL PROPERTIES OF THE ROCK UNITS

The rock samples collected from the landslide areas were tested for aggregate impact value, specific gravity and water absorption values. These tests were conducted as per the relevant Indian Standard of code of Practice. The results of these tests are presented in Table 5.

From the table, it can be noted that the specific gravity of granite gneiss varied from 2.48 to 2.62. Porphyritic granite showed high specific gravity ranging from 2.67 to 2.70 at various landslide areas. Among the various rock units, hornblende-biotite-schist encountered at Rupnagar landslide area had the highest specific gravity of 2.85.

Table 5. Mechanical and physical properties of the rocks

Landslide Affected Area	Rock Units	Aggregate Impact Value (%)	Specific Gravity (g/cc)	Water Absorption Ratio (%)
Kacharibasti	Porphyritic granite	24.82	2.70	0.50
Kacharibasti	Granite gneiss	31.99	2.48	2.34
Kacharibasti	Biotite schist	82.26	2.57	6.15
Nabagraha	Granite gneiss	29.67	2.62	1.24
Birubari	Granite gneiss	26.78	2.57	0.90
Rupnagar	Horn-biotite-schist	10.02	2.85	0.50
Rupnagar	Porphyritic granite	28.44	2.70	0.84
Kalapahar	Porphyritic granite	28.26	2.67	1.24
Kalapahar	Granite gneiss	14.15	2.60	0.95
Dhirenpara	Horn-biotite-schist	13.60	2.78	0.15
Dhirenpara	Granite gneiss	12.33	2.61	0.85
Dhirenpara	Porphyritic granite	22.58	2.67	0.35

The value of water absorption of the rocks of various landslide areas varied from 0.15% to 6.15%. The aggregate impact values of rock units of landslide areas varied from 10.02% to 82.36%. In general, porphyritic granite had impact values ranging from 22.58% to 28.44% and the major country rock granite gneiss had impact values ranging from 12.33% to 31.99%. The biotite-schist of Dispur Kacharibasti showed the highest value of water absorption and impact value.

The performance of rock under the action of overburden load, water, temperature, and tectonics of the earth crust depends upon the physical and mechanical (strength) properties of the material. Low value of specific gravity and high values of water absorption and impact are an indication of low physical strength of rocks. On the other hand, higher value of specific gravity of rocks as slope building material increases the driving force thus reducing the stability of the slope.

Some of the geotechnical properties of the soils encountered in landslide areas are discussed below. The soils were either sandy or fine grained soils. The soils mostly had the group symbol CI. The degree of expansion of the soils was low or medium. The coefficient of permeability ranged from 6.0×10^{-5} cm/sec to 8.1×10^{-4} cm/sec.

DISCUSSION

Details such as mineral orientation, stratification, fracture, faulting, shear zones and joints must be gathered and assembled for a meaningful landslide analysis. Discontinuities divide the rock mass into variously shaped blocks and in most cases control the failure surface location (Hunt, 1986). All major types of joints such as dip, strike and oblique were observed in the study area. Orientation of these joints had a serious implication on the stability of the slope as they served as potential slip surfaces.

The rock units of landslide areas chiefly composed of minerals like hornblende, biotite, plagioclase, quartz and microcline. The average hardness of these minerals in Mohs scale was Quartz: 7.0; Microcline: 6.0; Plagioclase: 6.0; Hornblende: 5.5; and Biotite: 2.5 to 3.0. Quartz had the highest compressive strength. The amount of quartz in granite gneiss and porphyritic granite ranged from 18.32% to 54.79% and in hornblende-biotite-schist, it ranged from 10.4% to 13.8%.

Granite gneiss and hornblende-biotite-schist showed good interlocking of mineral grains. Their grains sizes were also fine to medium. So, these rocks should not have been conducive to slope failure. But the gneissose and schistose structure present in the rocks reduced their stability. Although porphyritic granite had good interlocking texture, coarseness of grains and presence of flow layer reduced its mechanical and physical strength. Further, the flow layer present in porphyritic granite formed weak planes. The abundant rock types of the landslide areas were jointed. Among all factors, the most significant in these rocks, particularly in granite gneiss, was the deep zone of decomposition that developed due to the warm and moist climate of the city. This had severely reduced stability of the hill slopes.

At Kalapahar site of rock fall, the highly jointed rock outcrop dipped almost vertical. At Dhirenpara landslide area, the rock outcrops at the failure surface were also found dipping into the slope at an angle of 60°. At Dispur Kacharibasti, failure surface was located on a joint system in granite gneiss parallel to the slope surface. The Kalapahar rockfall was also chiefly because of joint orientation. Here three sets of joints practically formed an overhang and the massive porphyritic granite separated by such joints gave away when rain water percolating through these joints reduced the shear strength of the rocks along the discontinuities.

The complexity and extreme variation of slope failure of Guwahati was because of the varying degree of decomposition of rocks and homogeneity of rock mass. The common rock types available in this locality were of igneous and metamorphic origin. Decomposition of these rocks gave rise to a gradual transition from a natural residual soil to saprolite. Further, weathering of fresh rock resulted in increase of pore spaces within the rock mass that facilitated more water absorption. During and after a continuous spell of rainfall, these highly weathered rocks became easily saturated with water and they almost behaved like a temporary water table. This caused an increase in driving force and a decrease in shear strength of the slope resulting in failure. Landslides such as those in Dispur Kacharibasti, Rupnagar and Nabagraha occurred due to such reasons.

During rainy season, percolating water through the joints and cracks helped in erosion of rocks and thus tremendously influenced the weathering of rocks. The courses of small streams often followed joints system. Besides, it altered the feldspar mineral of the rock to clay which ultimately helped in slope failure. During rainstorm, the rate of surface water infiltration in the unsaturated zone of soil or colluvium exceeded the rate of deep percolation in the rock below colluvium. A temporary water table was created and some water moved as seepage parallel to the slope. This seepage water along with surface runoff carried finer soil portion resulting in mud flows at the downhill areas. This continuous process ultimately caused accumulation of cohesionless, coarse soil particles at the upstream of the slope resulting in considerable decrease in shear strength of the slope. At Dispur Kacharibasti, Madgharia, Birubari, and Rupnagar landslides, this phenomenon was observed.

CONCLUSIONS

Evaluation of landslides is an interdisciplinary endeavour requiring knowledge and concepts from engineering geology, soil mechanics and rock mechanics. Awareness of geology is necessary for appropriate idealization of ground conditions and the subsequent development of realistic geotechnical models. All the principal causative factors like heavy and prolonged rainfall, cutting and excavations on slopes for dwellings, excessive weathering, and earthquake tremors operate in this region.

Although the hill slopes of the landslide areas of Guwahati consisted of hard and strong rock, their stability had been impaired by weathering and structural conditions of rocks, slope morphology and the amount of water that found access underground. Among all these factors, water played a crucial role in initiating and controlling landslides. Due to the presence of foliations, weak planes were formed facilitating weathering and percolation of water. The most abundant structural features observed were the joints. Their distribution and orientation was found to be the chief cause of of the landslides.

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