Journal of Civil Engineering and Environmental Technology
Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 2, Number 4; April-June, 2015 pp. 329-334

http://www.krishisanskriti.org/jceet.html

Stability Analyses on the Effect of Rainfall on landslides in Sikkim

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Abstract—*Landslides constitute the major natural hazard which accounts for considerable loss of life, property and damage to communication networks, human settlements, agricultural and forest land in Sikkim. Therefore, analysis of stability of slopes is of utmost importance. This paper focuses on the reduction of shear strength of soil due to saturation and effect of seismic loading on slopes. In this study, software Geo5 is used to determine factor of safety against different soil properties with the change in the water content under different seismic loadings. Different values of shear strength parameters such as cohesion (c), angle of internal friction (φ) and unit weight of soil (ϒ) are found using laboratory experiments on three soil samples collected from three locations(5th mile, 8th mile & 13th mile) in Gangtok, Sikkim. The calculation of factor of safety is based on slope stability analysis using Bishop's method. From the results, it is observed that factor of safety of the slope stability increases with the increase in the cohesion(C) and angle of friction (φ).In addition, factor of safety is also found to have decreased with the increase in the slope angle (ß) and height of the slope (H).*

1. INTRODUCTION

Landslide is a general term for a wide variety of downslope movements of earth materials that result in the perceptible downward and outward movement of soil, rock, and vegetation under the influence of gravity. The materials may move by falling, toppling, sliding, spreading, or flowing. Some landslides are rapid, occurring in seconds, whereas others may take hours, weeks, or even longer to develop. Slope failures may develop due to human induced factors such as the loading of the slope or the cutting away of the toe for construction purposes, many failures occur simply due to rainfall infiltrating an otherwise stable slope.

2. CAUSES OF LANDSLIDES

Many factors contribute to slides including geology, gravity, weather, groundwater, wave action, and human actions. Landslide occurs when several of these following factors converge

1. Natural factors
   (i) Gravity: Gravity works more effectively on steeper slopes, but more gradual slopes may also be vulnerable.

   (ii) Geological factors: Many slides occur in a geologic setting that places permeable sands and gravels above impermeable layers of silt and clay, or bedrock. Water seeps downward through the upper materials and accumulates on the top of the underlying units, forming a zone of weakness.

   (iii) Heavy and prolonged rainfall: Water is commonly the primary factor triggering a landslide. Slides often occur following intense rainfall, when storm water runoff saturates soils on steep slopes or when infiltration causes a rapid rise in groundwater levels. Groundwater may rise as a result of heavy rains or a prolonged wet spell. As water tables rise, some slopes become unstable.

   (iv)Earthquakes: Seismic activities have always been the main cause of landslides throughout the world. Any time plate tectonics move the soil that covers moves with it. When earthquakes occur on areas with steep slopes, many times the soil slips causing landslides.

   (v) Forest fire: fires cause soil erosion and induce floods and landslides due to the destruction of the natural vegetation. (eg. ridges of Manipur-Nagaland border).

3. ANTHROPOGENIC FACTORS

Human actions most notably those that affect drainage or groundwater, can trigger landslides eg. are Inappropriate drainage system, change in slope/land use pattern, deforestation, agricultural practices on steep slopes, cutting & deep excavations on slope for buildings, roads, canals & mining ,inappropriate disposal of debris after excavations are examples.

(i) Inappropriate drainage system

Natural drainage lines on slopes are blocked by terracing/ contour bounding adopted to prevent soil erosion and to enhance percolation during dry season for cultivation, without adequate provision for surface drainage of excess storm water during high intensity rains increase the landslide vulnerability.

(ii) Cutting & deep excavations on slopes for buildings, roads, canals & mining:

Developmental activities like construction of buildings, road cutting, embankments, cut and fill structures causes modification of natural slopes, blocking of surface drainage, loading of critical slopes and withdrawal to toe support promoting vulnerability of critical slopes.

iii) Change in slope/land use pattern, deforestation, agricultural practices on steep slopes:

Deforestation and cultivation of seasonal crops and increase in settlements. Improper land use practices such as heavy tilling, agricultural practices and settlement.

4. STUDY AREA: GANGTOK SIKKIM

Map 1

Map 2

5. HISTORY

Gangtok is a municipality, the capital and the largest town of the Indian state of Sikkim. It also is the headquarters of the East Sikkim district. Gangtok is located in the eastern Himalayan range, at an elevation of 1,650 m (5,410 ft). The town's population of 100,000 belongs to different ethnicities such as Nepali, Lepchas and Bhutia. Nestled within higher peaks of the Himalaya and enjoying a year-round mild temperate climate, Gangtok is at the centre of Sikkim's tourism industry.

6. GEOGRAPHY

Gangtok is located at 27.3325°N 88.6140°E (coordinates of Gangtok head post office). It is situated in the lower Himalayas at an elevation of 1,650 m (5,410 ft). The town lies on one side of a hill, with "The Ridge", a promenade housing the Raj Bhawan, the governor's residence, at one end and the palace, situated at an altitude of about 1,800 m (5,900 ft), at the other. The city is flanked on east and west by two streams, namely Roro Chu and Ranikhola, respectively. These two rivers divide the natural drainage into two parts, the eastern and western parts. Both the streams meet the Ranipul and flow south as the main Ranikhola before it joins the Teesta at Singtam. Most of the roads are steep, with the buildings built on compacted ground alongside them.

Climate

Gangtok features a monsoon-influenced subtropical highland climate. Because of its elevation and sheltered environment, Gangtok enjoys a mild, temperate climate all year round. Like most Himalayan towns, Gangtok has five seasons: summer, monsoons, autumn, winter and spring. Temperatures range from an average maximum of 22 °C (72 °F) in summer to an average minimum of 4 °C (39 °F) in winter. Summers (lasting from late April to June) are mild, with maximum temperatures rarely crossing 25 °C (77 °F). The monsoon season from June to September is characterized by intense torrential rains often causing landslides that block Gangtok's land access to the rest of the country. Rainfall starts to rise from pre-monsoon in May, and peaks during the monsoon, with July recording the highest monthly average of 649.6 mm (25.6 in). In winter temperature averages between 4 °C (39 °F) and 7 °C (45 °F). Snowfall is rare, and in recent times Gangtok has received snow only in 1990, 2004, 2005 and January 2011.

Fig. 1: Various landslides in Sikkim

Temperatures below freezing are also rare. During this season the weather can be unstable, and change abruptly from bright sunshine and clear skies to heavy rain within a couple of hours. During spring and autumn the weather is generally sunny and mild. Owing to its elevation, Gangtok is often enveloped in fog during the monsoon and winter months.

7. METHODS USED

Fellenius Method (The Ordinary Method of Slices):

The Ordinary Method of Slices (OMS) was developed by Fellenius (1936) and is sometimes referred to as "Fellenius Method." This method is applicable to soil slopes with both friction and cohesion. In this method, the forces on the sides of the slice are neglected. The normal force on the base of the slice is calculated by summing forces in a direction perpendicular to the bottom of the slice. Once the normal force is calculated, moments are summed about the center of the circle to compute the factor of safety.

Factor of safety = Σ [c′ $\Delta\ell$ + (W$\cos\alpha$ - ul) $\tan\varphi$']/ΣW $\sin\alpha$

Where

c' and φ'= shear strength parameters for the center of the base of the slice

W = weight of the slice

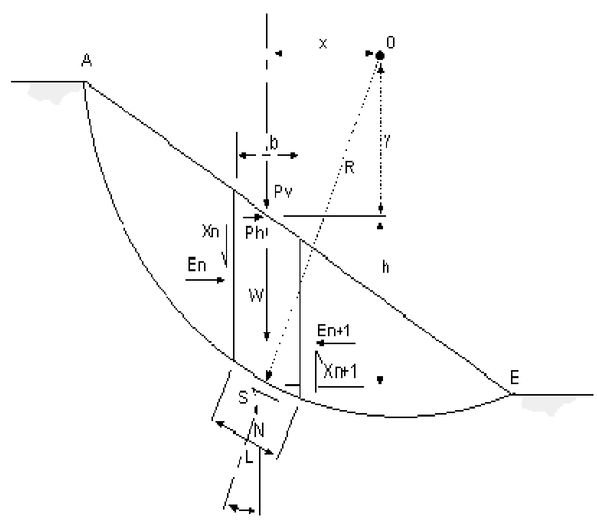
α = inclination of the bottom of the slice

u = pore water pressure at the center of the base of the slice

$\Delta\ell$ = length of the bottom of the slice

8. BISHOP'S METHOD OF SLICES

A slices method of slope stability analysis which involves a different procedure and gives different answers compared with the Ordinary Method of Slices has been proposed by Bishop (1955). With this method, the analysis is carried out in terms of stresses instead of forces which were used with the Ordinary Method of Slices. The stresses and forces which act on a typical slice and which are taken into account in the analysis are shown in Fig. below. The major difference between the Bishop Method and the Ordinary Method of Slices is that resolution of forces takes place



F - Factor of Safety

Ph - Horizontal component of external load

Pv - Vertical component of external loads

E - Horizontal Interslice Force

X - Vertical Interslice Force

W - Total weight of soil = γbh

N - Total normal force acting along slice base

R - Distance from slice base to moment centre

S - Shear force acting along slice base

h - Mean height of slice

b - Width of slice

L - Slice base length = b/cosα

u - Pore pressure at slice base

α - Slice base angle to horizontal

x - Horizontal distance of slice from moment centre

y - Vertical distance of slice surface from centre

γ - Unit weight of soil

c - Cohesion at base

ϕ - Angle of friction at base

General expression to calculate the overall factor of safety for a circular slip circle is:

$$F = (\Sigma S.R) / \Sigma [(W + Pv) x + Ph.y]$$

= (Restoring moment)/ (Disturbing moment).

Where,

$$S = cL + (N - uL) \tan \phi,$$

$$N = (W + Pv + Xn - Xn+1) \cos \alpha - (En - En-1 + Ph) \sin \alpha$$

As the factor of safety (F) is directly related to c and tan ϕ, it is a factor of safety on material shear strength.

9. SCOPE

- To obtain shear strength parameters of the soils in the laboratory.
- To obtain variation of shear strength parameters with change in the water content.
- To use GEO5 software for the determination of FOS.

Obtained soil strength parameters using lab experiments on three soil samples collected from Gangtok Sikkim (5th mile, 8th mile and 13th mile)

Table 1

Soil sample	5th mile		8th mile		13th mile	
Water content (%)	C (kg/cm^2)	φ	C (kg/cm^2)	φ	C (kg/cm^2)	φ
0	0.16	28.02	0.26	23.51	0.18	22.42
5	0.15	27.95	0.25	23.14	0.17	22.05
10	0.14	27.55	0.25	23.04	0.17	22
15	0.13	27.33	0.23	22.70	0.16	21.70

Table 2

Soil sample	5th mile	8th mile	13th mile
ϒmax(g/cc)	1.539	1.513	1.493
ϒmin(g/cc)	1.229	1.222	1.119
emax	1.118	1.169	1.359
emin	0.748	0.7515	0.768

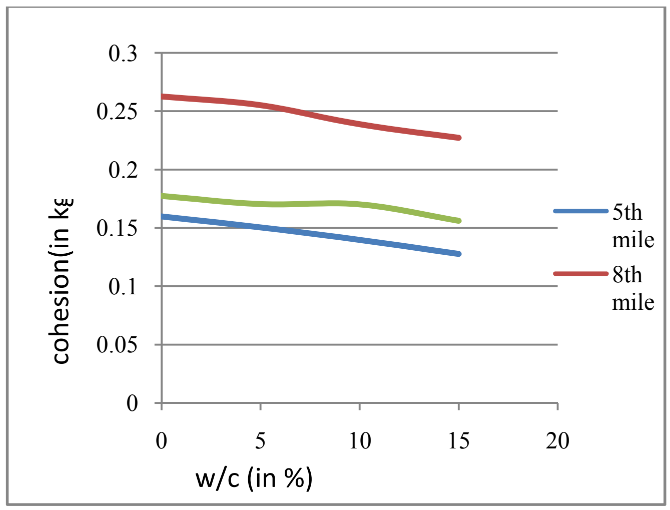


Fig. 2: Variation of cohesion against water content

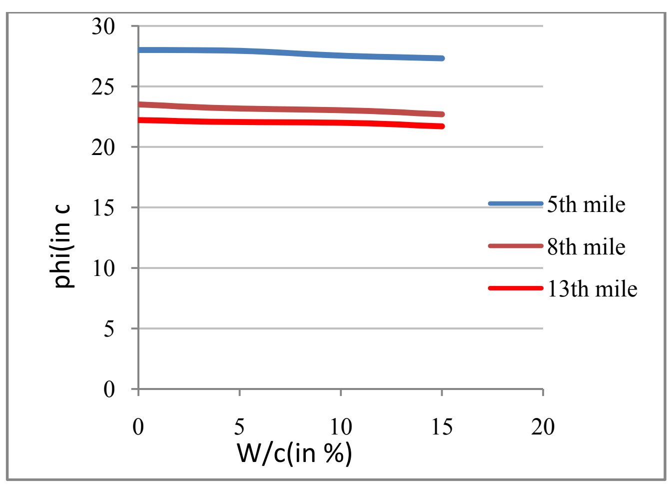


Fig. 3: Variation of angle of internal friction against water content

Table 3: Soil sample- 5th mile

Kh			0g	0.05g	0.1g	0.15g	0.2g
ß	**H (m)**	**W/c (%)**	**Factor of safety**				
30	13.9	0	1.92	1.74	1.57	1.43	1.34
		5	1.83	1.66	1.50	1.37	1.28
		10	1.74	1.57	1.43	1.31	1.21
		15	1.66	1.50	1.37	1.25	1.15
45	24	0	1.14	1.06	0.99	0.92	0.85
		5	1.09	1.01	0.93	0.87	0.81
		10	1.03	0.97	0.89	0.83	0.78
		15	0.99	0.91	0.85	0.79	0.74
60	41.6	0	0.70	0.66	0.62	0.58	0.54
		5	0.67	0.63	0.59	0.55	0.51
		10	0.64	0.60	0.56	0.52	0.48
		15	0.61	0.57	0.53	0.49	0.45

Table 4: Soil sample-8th mile

Kh			0g	0.05g	0.1g	0.15g	0.2g
ß	**H (m)**	**W/c (%)**	**Factor of safety**				
30	13.9	0	2.15	1.95	1.75	1.53	1.32
		5	2.04	1.85	1.64	1.43	1.21
		10	1.95	1.75	1.54	1.32	1.12
		15	1.85	1.65	1.44	1.22	1.02
45	24	0	1.26	1.18	0.99	1	0.96
		5	1.2	1.12	0.96	0.98	0.91
		10	1.15	1.07	0.93	0.93	0.86
		15	1.09	1.02	0.88	0.88	0.81
60	41.6	0	0.77	0.73	0.70	0.67	0.63
		5	0.73	0.70	0.67	0.63	0.59
		10	0.70	0.67	0.53	0.59	0.55
		15	0.67	0.63	0.59	0.55	0.51

Table 5: Soil sample-13th mile

Kh			0g	0.05g	0.1g	0.15g	0.2g
ß	**H (m)**	**W/c (%)**	**Factor of safety**				
30	13.9	0	1.78	1.61	1.46	1.33	1.21
		5	1.69	1.53	1.38	1.26	1.14
		10	1.61	1.46	1.33	1.21	1.07
		15	1.52	1.38	1.26	1.14	1
45	24	0	0.99	0.98	0.92	0.86	0.81
		5	0.95	0.93	0.87	0.81	0.76
		10	0.90	0.88	0.83	0.76	0.71
		15	0.85	0.83	0.78	0.71	0.66
60	41.6	0	0.63	0.61	0.59	0.56	0.53
		5	0.61	0.59	0.56	0.52	0.51
		10	0.59	0.56	0.53	0.50	0.48
		15	0.56	0.53	0.51	0.48	0.45

Fig.4. Obtained Factors of safety under seismic loadings with different slope angles and water content.

(a) ß=slope angle; (b) W/c=water content (%);
(c) H=height of the slope (in m);
And (d) Kh=horizontal earthquake coefficient

10. CONCLUSIONS

1. From the above results, it is found that factors of safety for slope angle 30° and height of slope 13.9m under seismic loadings (as shown in the tables above) for soil sample-5th mile are found to be >1, which is stable against slope failure and are found to be >1 for slope angle 45° up to seismic loading 0.05g and till 5% of water content and is found to be unsafe on further increase in the water content and for seismic loadings for slope angle 45° and for slope height 24m.
2. In the case of soil sample 8th mile, it is found that obtained factors of safety for slope angle 30° and slope height 13.9m are found to be >1, which is stable against slope failure under different seismic loadings and for slope angle 45° and slope height 24m, FOS are found to be > 1 up to seismic loading 0.05g and found to be unstable against slope failure on seismic loadings> 0.05g. And for slope angle 60° and slope height 41.6m, it is found that soil is unstable against slope failure.
3. In the case of soil sample 13th mile, obtained factors of safety for slope for slope angles 30° and 45° and for slope height 13.9m and 24m, factors of safety are found to be >1, which is stable against slope failure and found to be unsafe against slope failure for slope 60° and slope height 41.6m.
4. From the results, factors of safety are also found to have decreased with the increase in the slope angle (ß) and height of the slope (H) and found to have increased with the increase in the cohesion (C) and with the increase in the angle of internal friction (φ).

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