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Geotechnical Evaluation of Kalijhora Landslide on Sevok – Teesta Bazaar Road, Along NH 10, Kalimpong District, West Bengal.

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Abstract: Kalimpong District in the Eastern Himalaya in West Bengal, India has been intensely destabilized by many landslides. Recently the incidence of landslide occurrence has increased rapidly with the gradual anthropogenic abuse of slopes specially the development of transport arteries and consequent jerk and vibration by vehicles. Due to landslides, the Darjeeling Himalayan region faces major problems of geoenvironmental imbalance and poses threats to life and property. In 2015, a major landslide occurred near Kalijhora area on right bank of Teesta river along NH 10, between Sevok – Teesta bazaar road, Kalimpong District, West Bengal. This landslide is reactivated last few years causing disruption of traffic along this important hill route and creating recurrent economic loss to the state exchequer. In view of the importance of the Kalihora landslide, detailed investigations incorporating relevant engineering geological and geotechnical parameters were carried out in order to find out the factor of safety.

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I. INTRODUCTION

The Darjeeling Himalaya is a fragile terrestrial system, which is too often disturbed by various environmental catastrophes. Slope instability along transport and arterial sectors is perhaps the most hazardous among the environmental catastrophe threatening the Darjeeling Himalaya. Nowadays landslides especially along the transport and arterial sectors of Darjeeling Himalaya are creating serious problems leading to total disruption of vehicular traffic between the hills and the plains with the consequent disastrous effect on the transport of goods and tourist operation. Therefore, at present landslides along the main thoroughfares are common problem to the hill people.

The Darjeeling Himalaya, a part of Eastern Himalaya lies between the Nepal Himalaya in the west and Bhutan Himalaya in the east. It is bounded towards north by the Sikkim Himalaya and towards south by Duar Plains of Ganga-Brahamputra Alluvium. The river Tista flowing north to south across Darjeeling Himalaya exposes a full cross section of the eastern Himalaya. Darjeeling Himalayan ranges have suffered mass destruction due to its typical environment, characterized by well-foliated granite-gneissic and phyllitic rocks, huge amount of rainfall and temperature, higher degree of physical and chemical weathering and frequent neo-tectonic movements as well.

Detailed engineering geological investigations incorporating relevant geotechnical parameters were carried out in order to assess the status of stability of the slope and to design suitable control measures. Kalijhora landslide has been identified as a circular type of failure. The slide occurred last few year as a slope failure above the road and during monsoon time the entire slope above and below the road up to Tista river is affected by landslide activity.

II. LOCATION OF STUDY AREA

The present researcher has selected the Kalijhora landslide (Latitude 26° 56' 14.0" N and Longitude 88° 26' 31.5" E), along main transport and arterial routes of Darjeeling Himalaya (Kalimpong District) running through West Bengal (Fig.1) for searching the reasons behind such slope instability along transport and arterial sectors, their effects and for building a model to mitigate such hazard. The Kalijhora landslide falls in the Survey of India (SOI) toposheet no. 78 B/5 and is situated 28 km away from Siliguri along the Teesta valley road or the National Highway 31A (now NH 10) from Sevok to Teesta-bazar which is the main route connecting the North Bengal plains with hills of West Bengal and Sikkim. The population of Kalimpong and Sikkim fully depends on this road for their sustenance and transportation. This slide has frequently damaged and destroyed parts of the road.

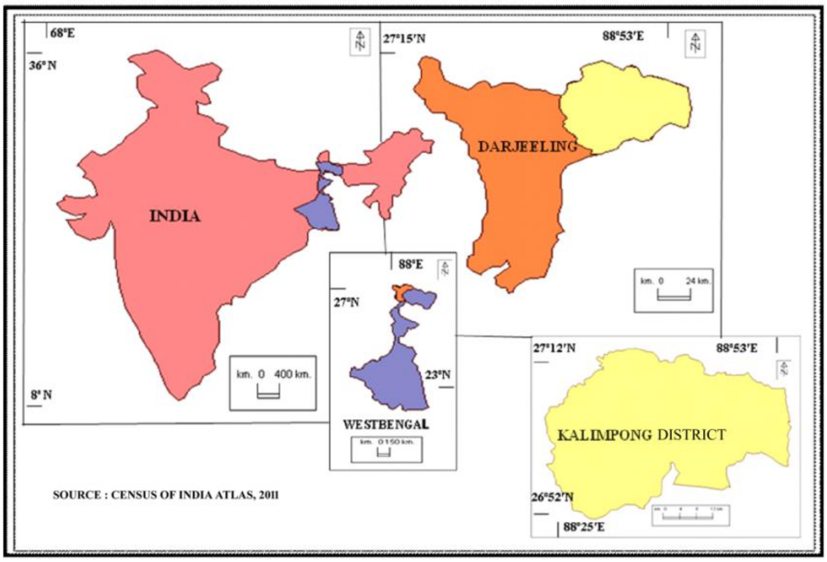

Fig.1. Location map of the study area

III. GEOLOGICAL SETTING OF THE AREA

The study area is a part of extra peninsula, made up of rocks of ages ranging from pre-Cambrian to Quaternary. Three distinct geological formations are found in the region, which are as follows: 1. The Siwalik, 2. The Damudas and 3. The Daling - Darjeeling Gneiss. The outcrops of these form a series of bands, running parallel to the general trend of the Himalayas and dipping one beneath the other into the hills. The most curious feature of these subdivisions is that the younger formations always appear to underlie the older thus the Tertiary beds disappear under the Gondwanas, the Gondwanas under the Daling series, and the latter under the gneiss, the original order of superposition having been completely reversed by folding and faulting.

The Daling comprise mica-schist, greenish fissile slate and Phyllite with bands of quartzite. The most impressive feature is the progressively higher grade of metamorphism of the Daling upwards. The surface exposure is bounded by the Darjeeling Gneiss to the north and by the rocks of the Damuda series to the south. Along river basins deposits of recent alluvium is found. The dip of the rock beds ranges from 30° to 80° towards mainly north and northeast. The rocks of the Daling series and Darjeeling gneiss are overlain by the rocks of Permian age along a thrust.

IV. PHYSIOGRAPHIC OF STUDY AREA

Physiographically the Kalimpong district in Darjeeling Himalaya is highly complex with innumerable variety of micro and macro relief forms. The Kalimpong hills are rather rugged with radials descending gullies and streams contributing to the Teesta and Jaldhaka Basins. The landform of the study area represents mega folded, faulted, trusted and later dissected by system of consequent and subsequent river courses. Due to the presence of tectonic lineaments and lithological heterogeneity, with approaching maturity of dissection, the region has attained a very high degree of relief. Simultaneous rejuvenation along with the operating erosion cycle has rendered the river vigorously aggrading in nature. In the process, a micro relief of parallel ridges and valleys has been etched out over the whole region. North-eastern portion of the study area is rugged where elevation is greater than 2000 metres. The elevation of southern and western portion is less than 400 metres and the elevation of the remaining part ranges between 400 to 2000 metres.

The kalijhora landslide located on a fairly steep slope adjoining Teesta river on its left bank and falls under physiographic division of the valley regions (below 400 m.), which is found in the south-eastern portion of the study area.

V. OBSERVATIONS OF KALIJHORA LANDSLIDE

On way to Kalimpong, Kalijhora landslide near the vicinity of Teesta Low Dam Hydel Project perched at an altitude of 156 meters. It lies on the banks of the Teesta River. It is 28 km away from Siliguri on NH31A (Latitude 26° 56' 14.0" N and Longitude 88° 26' 22.8" E). This slide was severely active during 2006-2007. This particular landslide got initiated during the monsoon of 2007. This slide was also active during 2009 and recent after earthquake in 2015.

Morphology of the landslide:

The Kalijhora landslide (figure 2 and plate 1, 2) is a rotational debris slide. Mostly pebble with sand and silt are involved as slide materials. The length of the scar is 65 m and the wide of the landslide reaches 30 m in the middle part. The slope angle is 40° NE to SW and average depth of the landslide scar is 2.1 m. Total area affected by this slide is 1950 m^2 and total volume of materials displaced is 4095 m^3. The soil color of the slide area is grey sandy soil. The kalijhora area is vegetated by herbs, shrubs and scattered bushes. Improper land use practices like construction of road and widening of existing road, deforestation due to creation of hydel project etc are the characteristic of the slide area.

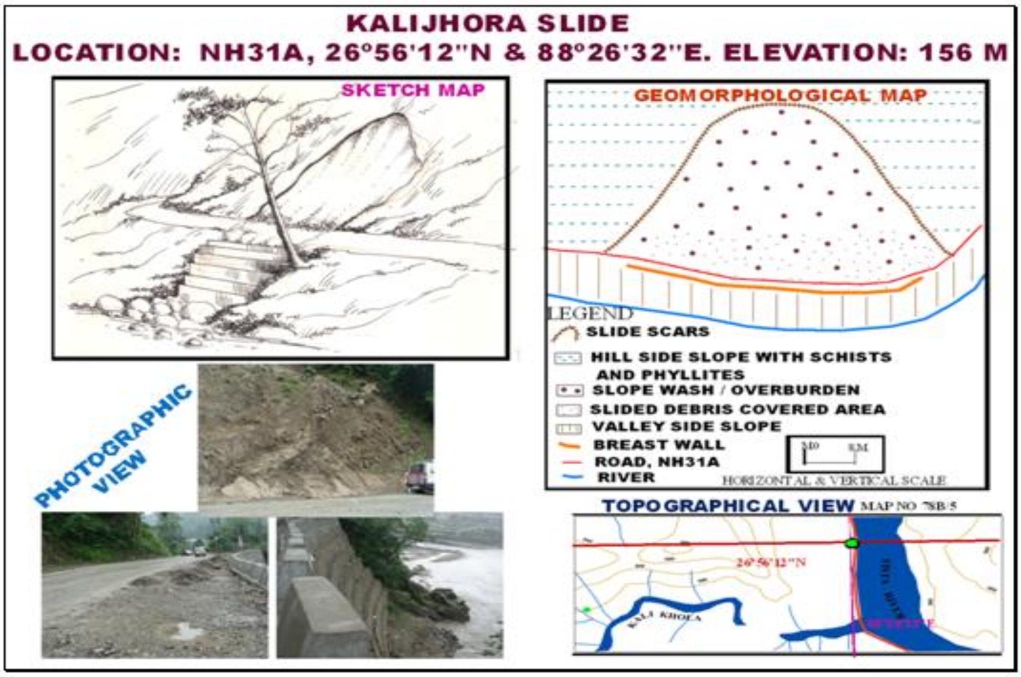

Fig.2. Morphological map, Topographical, Photographic and Sketch view of Kalijhora slide.

Therefore, arresting the toe erosion by Teesta River in the right bank a few heavy cross-beam structures and fixing of heavy precast concrete tripods are required to be constructed, which might be effective in arresting the toe erosion.

Plate 1.Upper view of Kalijhora slide, slide face are situated along NH 10.

Plate 2. Road damaged due to Kalijhora slide and toe erosion of Teesta River.

VI. STABILITY ANALYSIS OF KALIJHORA LANDSLIDE

Landslide occurs when the driving forces (FD) which is chiefly resulted from the self weight of the slope material, tending to pull soil and rock downhill, equal or excess of the resisting force(FR) given by the shear strength of the material. Therefore, the factor of safety analysis divides stable force by the force of instability,

i.e., F = resisting forces/ driving forces = FR/FD

Factors causing landslide to occur fall in two categories:

1. Factors increasing driving force and 2. Factors reducing resisting forces

Factors increasing driving forces may occur due to:

1. Steeping the slope.
2. Adding weight (loading) to the slope especially in the upper parts.
3. Increase in the height of a slope (either by human or down cutting)
4. Seismic shacking.

Factors reducing resisting force can be categorized -

1. Heavy rainfall adding water to the slope which increases the pore water pressure and reduced angle of friction as well as soil strength.
2. Different types of physical and chemical weathering.
3. Slope undercut by river.

If the factor of safety is less than or equal to 1 (I.e., F<1), the slope will fail because driving forces will equal or excess of the resisting forces. If F is significantly grater than 1, the slope will be quite stable, But F is slightly greater than 1, small disturbances, such as slide undercutting, or steeping or very heavy rain or seismic shacking, may cause the slope easily to fall.

In case of debris slopes, a structural pattern does not exit. Hence, the failure surface is free to find the line of least resistance through the slope. This failure generally tends to follow a rotational pattern, resembling circular surface and is termed as ' rotational' or ' circular' failure. This pattern of failure has been adopted for stability analysis at the site.

The stability analysis was carried out using circular failure charts (CFCs) as proposed by Hoek and Bray. It is a simplified and rapid analytical technique for stability analysis of circular failure in loose debris materials. The possible groundwater conditions i.e. 25% can also be incorporated in this analysis. The input parameters considered for analysis are

Average slope angle

It is average angle between horizontal surface and slope face where sliding occurs. It can be obtained from field observation.

Height of the slope (H)

It is the vertical height of the slope face measured from the toe of the slope upto highest point of phreatic surface. Generally, H. represents it.

Unit weight (γ)

Soil unit weight is calculated from the soil bulk density. Measurement of soil bulk density involved the determination of the mass and the volume of a given amount of soil material. It is defined as the weight per Unit volume of soil. The value is calculated from the laboratory. Hence, it will be represented in terms of kN/m^3

Thus, γ = (weight of the soil / volume of the soil) kN/m^3

= Bulk Density (ρ) * 9.81 kN/m^3

Table 1: Unit weight (γ) of the soil samples from the landslides in the study area.

Slides No.	Location	Bulk density (P) = Mass/Valume		Unit weight N/m3
		gm/cm	kg/m	
1	Kalijhora	1.672	1672	16400

Moisture content (W)

The difference in weight between wet soil and dry soil gives the moisture content of the soil sample. The moisture content detect by the formula

W = (W2 - W1) / W1*100%

Where W2 is the wet weight and W1 is the dry weight of the soil.

Table .2: Calculation table for determination of moisture content

Slides No.	Location	W2	W1	W2 - W1	W2 - W1 / W1 * 100 (in %)
		(in gm.)			
1	Kalijhora	270.56	218.65	48.09	17.77%

Shear strength parameter:

The strength of materials is made up of 1.Cohesion and 2.Internal friction. We can write this as an equation: Strength = cohesion + internal friction.

Cohesion and angle of friction take important role in slope stabilization. Therefore, we consider a visual field inspection of the slide mass in the selected spot as well as consider the typical values of cohesion and soil friction angle for different soils according to USCS. For this purpose grain size distribution and textural diagram (Figure 3 and 4) are use to determine the nature of debris material of the particular site.

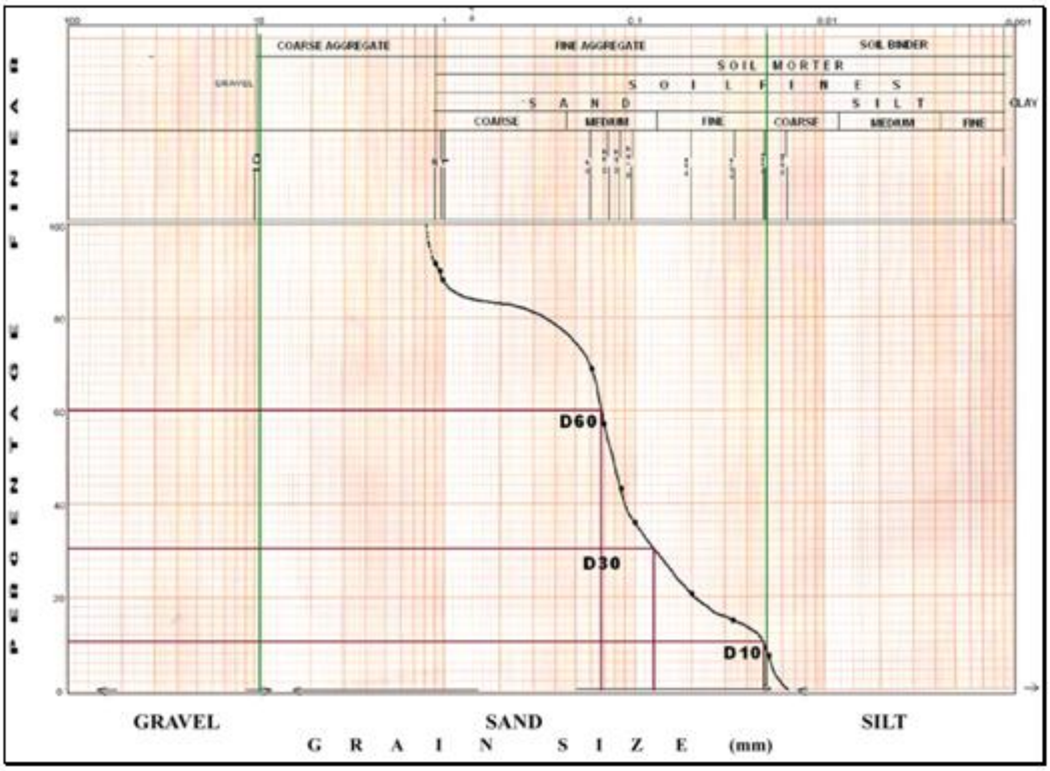

Figure.3: Grain-size distribution Curve of Kalijhora slide.

From this analysis, we get the total percentage of gravel, sand and silt is 8.3, 85.6 and 14.4 respectively. These are plotted in the triangular diagram to find out the types and nature of soil at Kalijhora. According to Unified Soil Classification System (USCS) this is loamy sand soil with 8.3% gravel.

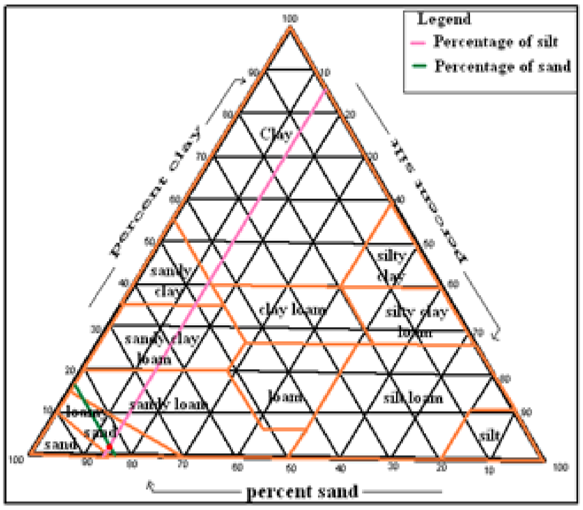

Figure. 4 – Determination of soil types by soil triangular diagram of Kalijhora.

Cohesion:

Cohesion is the innate " stickiness" of a material. The attraction of its molecules is for each other. For example clay and granite are both cohesive. On the other hand the dry sand is cohesion less. The cohesion is a term used in describing the shear strength of soil

Angle of friction (Φ)

Internal friction is due to the grains of the material rubbing against each other. Internal friction is measured by angle of friction (Φ).The friction depends on

(i) how slick the grains are (the co-efficient of friction or angle of internal friction), which depend on the particular material, and

(ii) How hard the grains are being forced against each other by gravity (the normal stress). If there is water in pore space between the grains, the water pressure forces the grains apart and reduces the frictional strength.

Note that this is not lubricant. Rather than making things slippery, the increased pore pressure reduces the normal stress (reduces how had the grains forces together, thus reducing the frictional strength. As an equation

Internal friction = coefficient of friction * (normal stress - pore pressure)

All the strength of dry sand comes from internal friction.

Typical values of COHESION and soil friction angle for different soils according to USCS:

Some typical values of Soil cohesion and angle of friction are given in the table.3, for loamy sands soil types. These values should be used as guide for computing soil strength parameters.

From the grain size distribution curve and soil triangular diagram of the slide mass we find that the soils of the slides area are loamy sand (SM). According to Unified Soil Classification system the range of the soil strength parameters for loamy sand soil (SM) are given below.

Table 3: Soil strength parameters for loamy sand soil

Description	USCS	Cohesion (kPa)			Soil friction angle (in degrees)		
		min	max	value taken	min	max	value taken
Loamy sands	SM	10	20	15	31	34	32

After choosing the required circular failure chart of 25% ground water condition, determination of factor of safety has been carried out with some parameters and using following steps.

VII. DETAILED INPUT PARAMETERS CONSIDERED IN ANALYSIS

Average Slope angle (ϴ)
Height of the slope (H)
Unit weight of soil (γ)
Cohesion (C)
Angle of internal friction (φ)
Moisture content (W)

VIII. CALCULATION OF FACTOR OF SAFETY FOR KALIJHORA LANDSLIDE

Step 1:

The value of dimensionless ratio ($C/\gamma.H.\tan\varphi$) from the data obtained from field observations and tests conducted is calculated. (Fig.5)

Step 2:

This value is marked on the peripheral arc (outer circular scale) of the failure chart for the corresponding groundwater condition. The radial line from the outer circular scale is then followed to the particular curve for slope angle (in degree).

Step 3:

The corresponding value of $\tan\varphi/F$ (Y-intercept) and $C/\gamma.H.$ (X-intercept) is found out by projecting horizontally and vertically on two axes of the chart. Hence the F value is calculated as average of the above two F values (obtained from X & Y intercepts

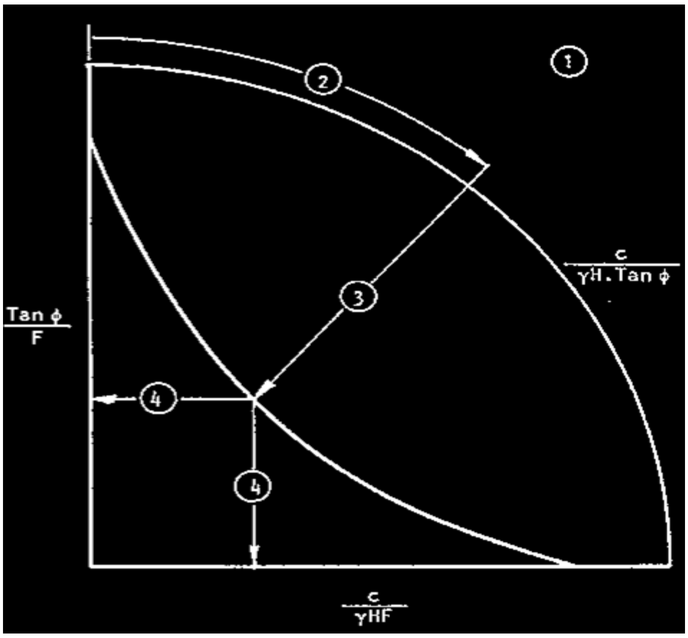

Figure 5. Calculation of Factor of safety from Circular Failure Chart (Hoek & Bray,)

Detailed of input parameters considered in analysis:

Average slope angle (ϴ) – 40º [Measured]
Height of the slope (H) – 65m [Measured]
Unit weight of soil (γ) – 16400 N/m³.
Cohesion (C) - 15,000 KN/m².
Angle of internal friction (Φ) – 32º.
Moisture content (W) – 17.77%.

W % of 17.77 indicates 25% groundwater condition therefore CFC under 25% groundwater has been selected for calculation purpose.

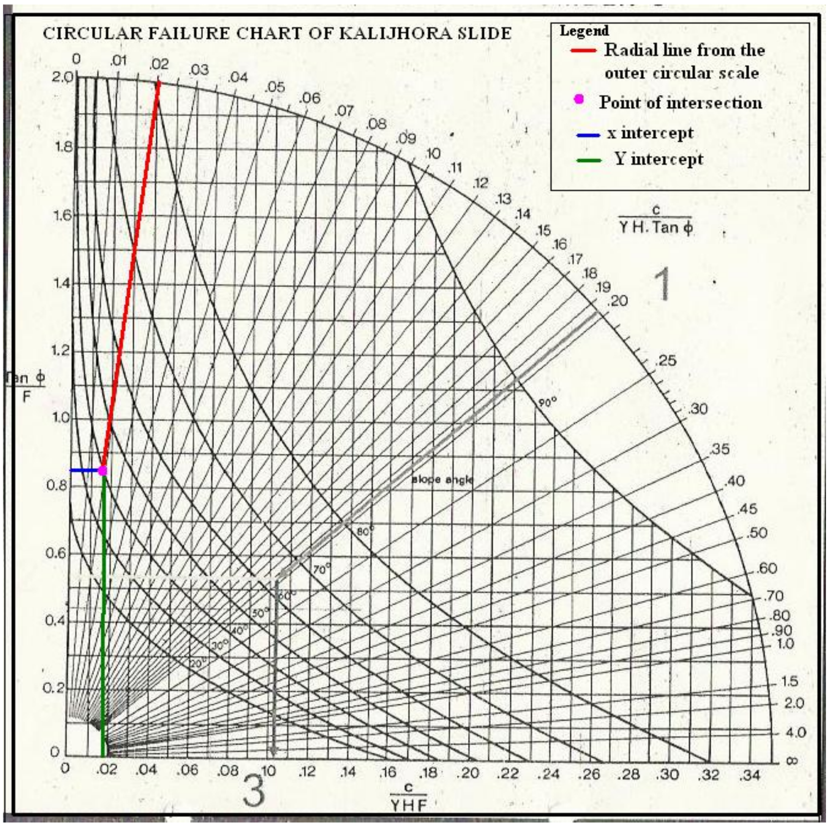

Figure 6. – CFC of Kalijhora.

Step 1
Dimensionless ratio
= C/γ.H. tanΦ
= 15000/ (16400*65 *tan 32°)
= 0.02
This value is marked on the peripheral arc (outer circular scale) of CFC. (Fig.6)

Step 2
The radial line from the outer circular scale is then followed to the particular curve for ϴ = 40º
From this we get x intercept=0.018 and y intercept=0.84

Step 3

Value of Y axis = TanΦ / F	Value of X axis = C/ γ.H.F
TanΦ / F = 0.84	C / γ.H.F = 0.018
F = tan32º / 0.84	F = 15000 / 0.018 *16400 *65
= 0.74	= 0.78

- ***Factor of Safety***

= (F value along Y intercept + F value along X intercept) / 2
= (0.74 + 0.78) /2
= 0.76

IX. DISCUSSION

Stability analysis of the kalijhora slide has been carried out using CFC (Figure 6.). The Fs value obtained 0.76, which is less than one. The analysis indicates that the slope is critically unstable fewer than 25% ground water condition. However when rainfall occurs, the saturation of slope may be more than 25%. The observation has done in pre monsoon period; therefore, during rainy season the slope will became more unstable and fails every year.

X. CONCLUSION

The kalijhora landslide is important, as it often blocks significant NH 10. The slide was initiated on the thick slope debris due to toe cutting by the Teesta river. It gradually attained huge dimension over the year since 2005. The slide is a rotational failure, which progress further up with every passing year. The stability analysis of the slope has been carried out using CFC of Hoek and Bray after obtaining shear strength parameters of the slope materials. The analysis indicates that the slope is critically unstable under 25% ground water condition.

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