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Rock Slope Stability Analysis along NH-44 in Sonapur Area, Jaintia Hills District, Meghalaya

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Abstract: Occurrences of landslide are most common and critical issue in North-East India. The various types of slope failures have been affected most part of slopes and road section between Malidor to Sonapur area (approx 30 Km) along NH-44 within Jaintia hills district, Meghalaya, India. These slope failures causes considerable loss of life and property along with many inconveniences such as disruption of traffic along highways. The unscientific excavations of rock slopes for road widening or construction purposes may weaken the stability of the slopes. The rocks exposed in the area are highly jointed sandstone and shale of Barail Group of Oligocene age. The Sonapur landslide is most dangerous and destructive rock fall-cum debris flow. The present study includes the kinematic analysis of the slope to assess the potential failure directions as the rocks are highly jointed in some parts of road cut sections. The continuous slope mass rating (CSMR) technique has been applied for slope stability analysis at five vulnerable locations. Kinematic analysis indicates mainly wedge type of failure along with few toppling and planar failures. These failure required immediate treatment to prevent the slide and long term stability of the slope.

Keywords: SMR, Kinematic Analysis, Slope Stability, Sonapur, Meghalaya

INTRODUCTION

Slope failure is one of the serious problems in the hilly terrains of North-East India specially along the road and highways which can lead to disruption in traffic, loss of properties and lives or injuries as well as environmental degradation. North-eastern region is geodynamically more active in nature where the landslide hazards are inherent, especially during monsoon time as the rainfall is more intense. The unplanned excavations of rock slopes for construction or widening of roads may damage the stability of slopes. The NH-44 Silchar- Sonapur- Shillong route is the single route for communication and transportation of the people of Barak valley, Mizoram and Tripura with rest of the country. The road is blocked for many days in almost every monsoon season due to landslide. The slide is more destructive and dangerous mostly on the left bank of Lubha river in Jaintia hills district, Meghalaya which carries water, mud, vegetation and debris along with large boulders (Bhandari et al. 2008).

A number of methods are adopted for slope stability analysis like limit equilibrium, physical, kinematic and numerical models (Vishal et al. 2010; Trivedi et al. 2012; Gupte et al. 2013; Pradhan et al. 2014). Among these one of the most widely used methods is Slope Mass Rating (SMR) technique (Romana, 1985,1993) which is based on the rock mass rating (RMR) technique given by Bieniawski (1979, 1989). RMR technique based on both field and laboratory study, which includes strength of the rocks, discontinuity spacing, discontinuity condition and also groundwater condition. SMR is calculated with the use of RMR along with some adjustment factors which are discrete and are more decision based as proposed by Romana (1985). The continuous slope mass rating (CSMR) proposed by Tomas et al. (2004, 2006, 2007) gives continuous determination and very less decision based. The CSMR result into more precise value of SMR by providing unique value to each adjustment factor of slope.

In the present study, landslide vulnerable zones would first be delineated along the road cut sections between Malidor to Sonapur area in Meghalaya considering various parameters. The distance of about 30 km along NH-44 between Malidor and Sonapur has been investigated to collect the field data for laboratory analysis. The rocks are highly jointed and folded, so kinematic analysis has been done in order to find out the type and the probable direction of failure.

GEOLOGY OF THE AREA

The proposed study area is located in Sonapur region of Jaintia hill district of Meghalaya along the NH-44 about 141.74 km, from Shillong. The area under investigation falls in the Survey of India toposheet no. 83C/8 between latitudes 25°09'19"N- 25°11'03"N and longitudes 92°26'20"E-92°27'09"E. It is located in the north-eastern India on left bank of the Lubha river which is represented by Mesozoic-Tertiary rocks overlying the Archaean gneisses (Barman, G., 1967-68). The Assam-Arakan basin is a typical polyhistoric basin having more than one phase of sedimentation and tectonism and consequence to that, a lot of complexities are encountered while dealing with the geology of the area. Thus, there is enough geological diversity in this region which beckons observation (GSI, 1985; Naqvi and Rogers, 1987; Sarma and Dey, 1996). The rocks found in this area are mainly sandstone, shale and siltstone belonging to Barail Group of Oligocene age. The representative rock specimens have been collected to determine physico-mechanical properties under laboratory condition. These are highly weathered and erosion continues on the exposed rock sections (Fig.1).

METHODOLOGY

Detailed field investigations were carried out to collect the representative samples, to measure the attitude of the excavated slopes and to measure the discontinuities present in the rock mass. Laboratory analysis was also done to evaluate the strength parameters as per ISRM, 1981 suggested methods. Kumud Raj Kafle (2010) recommended a relationship to obtain SMR from RMR and introduced some adjustment factors depending on the joint and slope relationship (usually of negative value) and a factor depending on the method of excavation (usually positive value). The slope mass rating (SMR) proposed by Romana (1985) , is calculated by adding four correction factors to the basic RMR. These factors depend on the geometrical relationship between discontinuities present within the rock mass and the slope, and the method of excavation of the slope which have a discrete character. *SMR* is calculated as follows:

$$SMR = RMR_{basic} + (F_1.F_2.F_3) + F_4$$

The RMR basic is determined by adding the ratings of five parameters which are uniaxial compressive strength (UCS), Rock Quality Designation (RQD), Joint or discontinuity spacing, Joint condition and groundwater condition (Table 1). The Rock Mass Classes are determined from the total ratings (Table 2).

The CSMR is also determined using an equation which is similar to discrete SMR, but the difference lies in computing the adjustment factors ($F1$, $F2$ and $F3$) which are depending on the joint-slope relationship. The factor F4, depending on the method of excavation is same for discrete SMR as well as CSMR. Romana (1985) proposed the adjustment ratings for discrete SMR which is as follows:

F_1 depends upon the parallelism between joints and slope face that strikes. The value of F_1 ranges from 0.15 to 1.0. The value is 0.15 when the angle between the critical joint plane and the slope face is more than 30° and the probability of failure is very low, whereas the value is 1 when both are near parallel.

The value of F_1 was established empirically earlier, but subsequently it was found to match approximately the following relationship.

$$F_1 = (1 - \text{SinA})^2$$

where, A denotes the angle between the

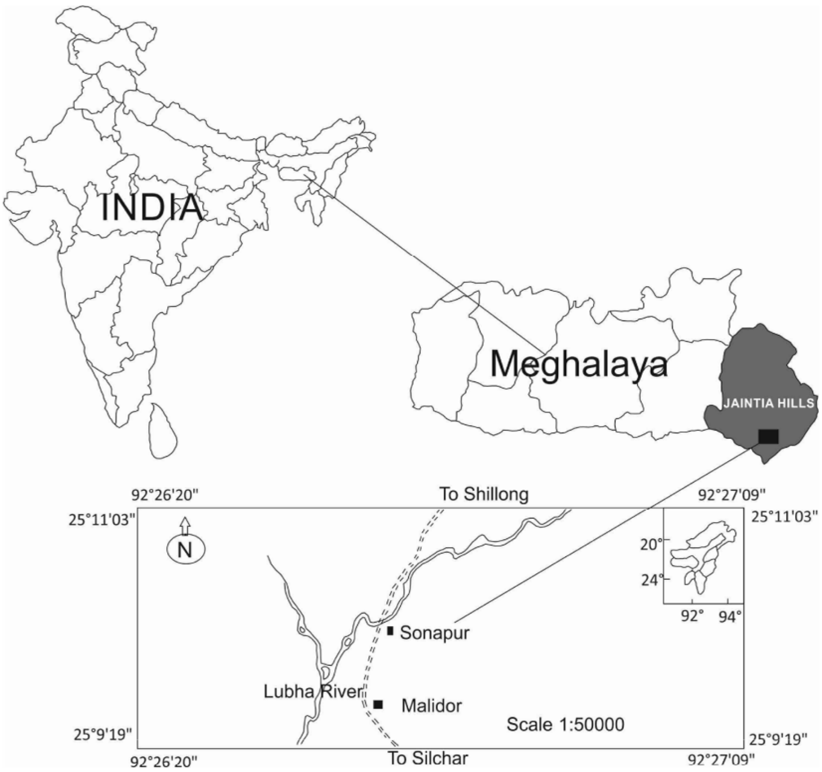

Fig.1. Location map of study area (modified from GSI,1985)

Table 1. Rock mass classification (Bieniawski, 1989)

Parameters				Ranges of values				
UCS	Values	>250 MPa	100-200MPa	50-100MPa	25-50MPa	5-25	1-5	<1Mpa
	Rating	15	12	7	4	2	1	0
RQD	Values	90-100%	75-90%	50-75%	25-50%		25%	
	Rating	20	17	13	8		3	
Joint spacing	Values	>2 m	0.6-2.0 m	200-600 m	60-200 m		<60 m	
	Rating	20	15	10	8		5	
Joint condition	Values	Very rough surfaces No continuous No separation	Slightly rough surfaces Separation<1mm Slightly	Slightly rough surfaces Separation <1mm Highly	Slickensided surfaces Separation 1-5mm		Soft gauge >5mm Separartion >5mm	
	Rating	30	25	25	25		0	
Groundwater	Rating	Completely dry 15	Damp 10	Wet 7	Dripping 4		Flowing 0	

Table 2. Estimation of RMR (Bieniawski,1989)

Rock Mass Classes determined from the total ratings					
Ratings	100-81	80-61	60-41	40-21	<21
Class No	I	II	III	IV	V
Description	Very Good Rock	Good Rock	Average Rock	Poor Rock	Very Poor Rock
Average stand-up time	20 yr for 15 m span	1 yr for 10 m span	1 wk for 5 m span	10 hr for 2.5 m span	30 min for 1 m span
Cohesion of Rock mass (KPa)	>400	400-300	300-200	200-100	<100
Friction Angle of rock mass (deg)	>45	45-35	35-25	25-15	<15
Probability of failure	None (0.9)	Some block failure (0.6)	Planar along some joints or may wedge failure (0.4)	Planar or big wedge failure (0.2)	Big planar or soil-like or circular (0)

strikes of the slope face (α_s) and that of the joints (α_j), that is (α_s - α_j) (Singh and Goel,1999).

F_2 refers to joint dip angle (β_j) in the planar failure mode. The value of F_2 ranges from 0.15 to 1.0, it is 0.15 when the dip of the critical joint is less than 20° and 1.0 for the joints with dip greater than 45°. F_2 remains 1.0 for the toppling mode of failure (Singh and Goel,1999).

$$F_2 = \tan \beta_j$$

F_3 shows the relationship between the slope face and joint dip. In the planar failure, F_3 refers to the probability of joints day-lighted in the slope face. But,in case of wedge failure, F_3 indicates the relationship between the slope face and dip of plunge of intersection of two joints (Singh and Goel,1999). Conditions are favorable when slope face and joints are parallel and very unfavorable when the slope dips 10° more than joints. For the toppling failure unfavourable conditions depend upon the sum of dips of joints and the slope β_j+β_s.

For CSMR, the adjustment factors F_1, F_2 and F_3 depends on joint-slope relationship and are calculated by using following equation proposed by Tomas et al. (2007)

$$F_1 = \frac{16}{25} - \frac{3}{500} \text{ Arctan } \left[\frac{1}{10} \left(A - 17 \right) \right]$$

Where F_1= adjustment factor

$|A| = |\alpha_j - \alpha_s|$ for planar failure

$|\alpha_j - \alpha_s|$ for wedge failure

$|\alpha_j - \alpha_s - 180|$ for toppling failure

α_j, α_s and α_i are dip direction of joint, slope and plunge direction intersection of two joint planes.

$$F_2 = \frac{9}{16} + \frac{1}{195} \text{ Arctan } \left(\frac{17}{100} B - 5 \right)$$

Where B is equals to dip (β_j) of joint for planar failure and toppling, to dip on plunge of line of intersection for wedge failure.

$$F_3 = -30 + \frac{1}{3} \text{ Arctan (C)}$$

$$F_3 = -13 - \frac{1}{7} \text{ Arctan (C-120)}$$

Where, C is an angular difference of dips of joint and slope (β_j-β_s) for planar failure. C is different of dip of plunge of line and dip of slope (β_i-β_s) for wedge. For toppling, C is defined as sum of dip of joint and slope (β_j+β_s)

F_4 refers to the adjustment factor for method of excavation, which has been fixed empirically. The value of F_4 varies are as follows: natural slope +15, pre-splitting +10, smooth blasting +8, normal blasting or mechanical excavation 0, deficient blasting - 8.

RESULTS AND DISCUSSION

Detailed geological and geotechnical investigations were carried out in the study area along NH-44. The most causative factors of slope failure in study area are multiple joint sets, weathering of the rock mass and high intensity of rainfall. Kinematic is the most simplified failure analysis in terms of joint sets, bedding plane, cut slope and angle of internal friction but it is only suitable for preliminary design (Hoek and Bray, 1981; Coggan et al., 1998). The analysis has been carried out in the study area to locate the vulnerable zone and potential mode of failure

The investigation consists of five rock slopes along the road which have provided detailed information. The rocks of the cut slopes are highly folded and jointed. Kinematic analysis shows mainly wedge type of failure along with few toppling and planar based on the joint patterns (Table 3).

Table 3. Joints data on different locations

Location	Orientation of slopes	Orientation of joints		
		J1	*J2*	*J3*
L_1	30°/330°	28°/305°	90°/290°	32°/185°
L_2	30°/200°	55°/230°	28°/145°	-
L_3	25°/220°	25°/220°	40°/160°	-
L_4	47°/173°	60°/295°	58°/25°	-
L_5	40°/60°	60°/50°	90°/325°	-

Rock Mass Rating (RMR) has been calculated by using the earlier mentioned parameters. UCS has been calculated by laboratory experiments in universal testing machine (UTM). RQD has been calculated by using the formula RQD= 115-33Jv (Jv -joint volume count). The result of all the required parameters has been given in the Tables 4 and 5. RMR has been calculated for all five locations.

In the First zone (L1), bedding plane (S_0) dipping 57° due N5°; slope (S_L) 30° due 330°; angle of internal friction (ϕ) is 12°; joint planes J_1 , J_2 and J_3 are 28° due 305° , 90° due 290° and 32° due 185° respectively. According to structural orientation, there will be chances of planar failure (Fig.2).

In the Second zone (L2), bedding plane (S_0) dipping 67° due 215°; slope (S_L) 30° due 200°; angle of internal friction (ϕ) is 12°; joint planes J_1 , and J_2 are 55° due 230°

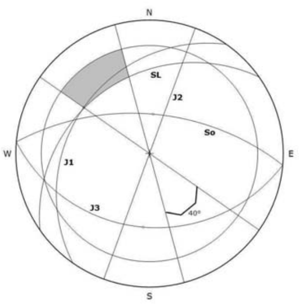

Fig.2. Planar failure (L1)

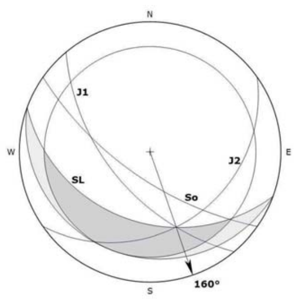

Fig.3. Wedge failure (L2)

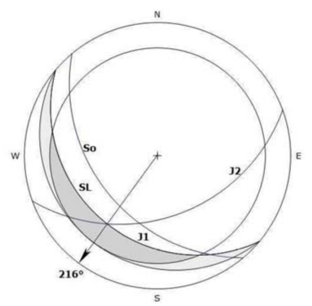

Fig.4. Wedge failure (L3)

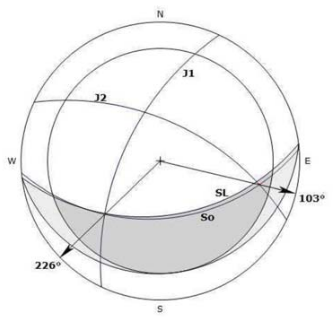

Fig.5. Wedge failure (L4)

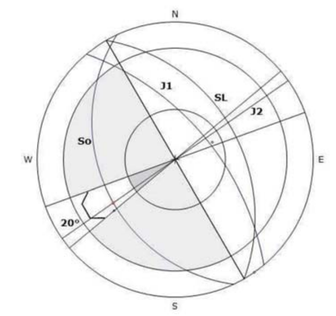

Fig.6. Toppling failure (L5)

Table 4. Rock Mass Rating (RMR) for various rock types of Malidor-Sonapur area

Location No	Rock type	Uniaxial compressive strength	RQD from Jv	Joint spacing	Joint condition	Groundwater condition	RMR basic
L1	Sandstone	1	8	5	20	7	41
L2	Sandstone	1	8	5	25	10	49
L3	Sandstone	1	8	5	25	10	49
L4	Sandstone	1	13	5	10	10	39
L5	Sandstone	1	8	5	25	4	43

Table 5. Results of continuous slope mass rating (CSMR)

	RMR	Slope orientation	Feature	Dip	Dip direction	F1	F2	F3	F4	CSMR	Class/Stability
L_1	41	30°/330°	P	28	230	0.41	0.49	51.14	15	45.71	III/Partially stable
L_2	49	30°/200º	W	27	160	0.24	0.45	53.86	15	58.19	III/Partially stable
L_3	49	25°/220º	W	26	214	0.93	0.41	15	15	58.28	III/Partially stable
L_4	39	47º/173°	W	31	226	0.16	0.64	1.19	15	52.76	III/Partially stable
L_5	43	40º/60º	T	20	334	0.85	0.97	0.19	15	57.84	III/Partially stable

and 28° due 145° respectively. There is a chance of wedge failure between J_1 and J_2 with potential failure direction SE (Fig.3).

In the Third zone (L3), bedding plane (S_0) dipping 40° due 230°; slope (S_L) 25° due 220°; angle of internal friction (ϕ) is 12°; joint planes J_1 , and J_2 are 25° due 210° , and 40° due 160° respectively .The J_1 and J_2 shows the wedge failure with potential failure direction SW (Fig.4).

In the Fourth zone (L4), bedding plane (S_0) dipping 45° due 175°; slope (S_L) 47° due 173°; angle of internal friction (ϕ) is 12°; joint planes J_1 and J_2 are 60° due 295° and 58° due 25° respectively. The J_1 and bed shows the wedge failure with potential failure direction SW, Whereas there is also a chances of wedge failure between J_2 and bed towards SE direction (Fig.5).

In the Fifth zone (L5), bedding plane (S_0) dipping 33° due 245°; slope (S_L) 40° due 60°; angle of internal friction (ϕ) is 12°; joint planes J_1 , and J_2 are 6o° due 50° and 90° due 325° respectively. According to structural orientation, there is a chance of toppling failure, as the structure separated by steeply dipping discontinuities (Fig.6).

By using RMR values for all five locations, CSMR has been calculated (Tables 4-5). The adjustment factors F_1, F_2 and F_3, have been calculated from the formulae proposed by Tomas et al. (2007). The orientation of discontinuities with respect to slope forming wedge, toppling and planar type of failure in critical zone of influence as in kinematic analysis plots. By plotting the data it was observed that in the study area, there are mainly wedge type of failure occurs along with few toppling and planar failures which are match with field observations (Figs. 7 a-c).

The continuous slope mass rating (CSMR) has been calculated for planar, wedge and toppling failures for all five locations (Table 5). All the locations fall under the stability class no III which have normal rock mass description. The slopes of these locations are partially stable. In location no. 1 planar failure occurs, while in location no.2, 3, 4 wedge failures occur and the location no. 5 is affected by toppling failure. The lithology of those locations is sandstone. Huge landslide occurs in these areas due to various reasons. It may be due to its lithology or may be due to groundwater flow. The rocks of these areas are highly jointed and joints are the weak planes. The water percolates through these joints and weakens the rocks.

Fig.7. (a) Wedge failure. **(b)** Toppling failure and **(c)** Planar failure

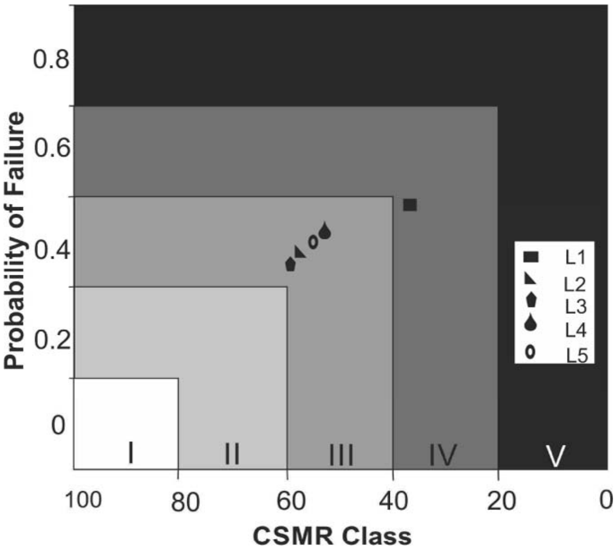

Fig.8. Plot of CSMR values of five different locations.

The supports of that will be suitable for those locations are spot or systematic bolting, spot shotcrete, toe wall and or dental concrete. The CSMR value measured for all five locations have been plotted in CSMR class-probability of failure chart based on Romana Standard classification of SMR (Fig. 8).

CONCLUSIONS

Five vulnerable slopes have been investigated in Sonapur area along NH-44 cut slopes and the values of CSMR indicate that the sandstone slopes are partially stable. These CSMR results are match with the field observation. These slopes required proper treatment to make this crucial road safe and long term stability for the public transport.

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