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Stability of Slopes for Dam Excavation by Slope Mass Rating in the Pare Hydroelectric Project

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***Abstract*—Dam is an important element in all river valley projects, and excavation of both banks of the river, where the dam is abutted, is a very important consideration for the total cost of the project. Thus, the stability analysis of the side slopes of the rock mass is a very important exercise, for a feasible hydro-electric power project. The study area lies in the Papunpare district of Arunachal Pradesh, India which is represented by Upper Siwalik sub-group of the Sub-Himalayan range. In this paper the stability of rock slopes for a stable excavation for dam construction, is analyzed with the help of Slope Mass Rating (SMR) by using Basic Rock Mass Rating. Support measures, where ever required has also been recommended based on SMR. The satisfactory performance of the excavated slopes at the dam site of Pare H.E. P. project establishes that SMR method can be used with confidence for rock slope stability analysis.**

***Keywords*—SMR; RMRbasic; adjustment factors; stability**

I. INTRODUCTION

Concrete gravity dam of a Hydro Electric Power project is abutted to the fresh rocks on both banks of the river. A stable, yet the most economical slope, needs to be designed for the purpose. In this paper, Slope Mass Rating system (Romana, 1985) as in [1] is used to study the stability of the rock slopes for abutting the dam of the Pare H.E.P. project at Papunpare district of Arunachal Pradesh. The study area lies within the upper Siwalik sub-group of the Sub-Himalayan range and are characterized by soft tertiary sedimentary sandstone/ siltstone. Four drill holes, namely, DAH 2, 3,4 & 5, drilled by NEEPCO Ltd. along the dam axis, exhibits repetitive sequence of coarse to fine grained, greyish coloured, soft, friable, moderately fresh sandstone, pebble impregnated sandstone, sand rock and pebble beds, on either banks. Geology of the dam site, as mapped by geologists of NEEPCO Ltd. are presented in the following sub-section.

II. GEOLOGY OF DAM SITE

The left and right rocky abutment was indentified with three sets of joint oriented in different directions. The dip/strike of the joint sets are given in the table I.

TABLE I. DIP/STRIKE OF JOINT SETS

Joints	Left Abutment		Right Abutment	
	Dip	*Strike*	*Dip*	*Strike*
J1	60°-75°	N235°-250°	52°-70°	N230°-240°
J2	45°-75°	N150°-180°	28°-46°	N140°-170°
J3	32°	N195°	32°	N195°

III. ROCK MASS CLASSIFICATION

In a river valley project, excavation of a dam requires the modified rock slopes to be stable. The improper excavation methods on natural slope conditions and modification of cut slopes can develop new cracks which may lead to instability of the rock slope. Therefore the preliminary approach of a dam excavation should include the understanding of the geological and geomechanical parameters to prevent slope failure during and after excavation.

For various engineering designs and stability analysis, Rock Mass Classification systems form the cornerstone of empirical design approach and are extensively implemented in rock engineering. Rock Mass Classifications have been recently employed in underground constructions, tunneling and in mining projects (Barton 1974, 1988; Bieniawski 1989; Laubscher 1990) as in [2][3][4]. A rock mass is characterized by comparing the values obtained from visual inspection or by simple tests with some standard sets of descriptions and values for some specific parameters. Thus with the help of standard qualitative data and guidelines, rock masses described by different geologists and engineers at different locations can be compared and analyzed.

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A. Rock Mass Rating System

This classification system (developed by Bieniawski in 1973, [5]) can be applied to a given rock mass that is divided into a number of geological structural regions where each region represents separate geological structural unit. Generally the boundary of the units coincides with a change in the rock type or with structural feature such as fault. The following are the six representing parameters (given by Bieniawski in 1989) which are determined for each unit:

1) Uniaxial Compressive Strength (UCS) of intact rock material
2) Rock Quality Designation (RQD)
3) Joint or Discontinuity spacing
4) Joint condition
5) Groundwater condition
6) Joint orientation

All the above mentioned parameters can be obtained from field and can also be measured from borehole data. The ratings of these six parameters are summarized and the RMR value is obtained. As the dam block is divided into nine blocks, the basic RMR is derived for each of the blocks.

*a) Uniaxial Compressive Strength of Intact Rock Material:*Table II shows the rating of the parameter Uniaxial Compressive Strength which is calculated using the relation of principal stresses.

TABLE II. UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK MATERIAL

Friction angle (φ)	C in KN/m^2	UCS in KN/m^2	UCS in Mpa		Rating
48°	16.1	838.84	0.838	Extremely Weak	0

*b) Rock Quality Designation:*Table III presents the rating corresponding to the average RQD value.

TABLE III. ROCK QUALITY DESIGNATION (RQD) FROM BOREHOLES

Borehole	RQD (%)	Average RQD (%)	Rating
DAH2	20	18.75	3
DAH3	16		
DAH4	21		
DAH5	18		

c) Discontinuity Spacing: There are many set of discontinuities present in different dam blocks, some ranging from very closely spaced to moderately spaced while some are randomly spaced. Ratings are given accordingly for each discontinuity set occurring on the rock mass (Table IV).

d) Discontinuity Condition: This parameter includes continuity, aperture, weathering of the planes of weakness or the wall rock, roughness of discontinuity surfaces and infilling materials present in the discontinuities. From the geology obtained from dam sites, the ratings for each of the conditions have been calculated for each dam blocks and are found to fall under the range of 19-25. This implies that the rock mass is of mixed quality conditions as both good and poor quality prevails.

e) Groundwater Condition: The general hydraulic condition derived from this site varies from moist to dripping.

Table IV shows the computation of the corresponding values of basic RMR of the three joint sets from the ratings of the parameters. The basic RMR values are computed for dam block 1 and 9 as it falls in left and right abutment of the dam site respectively.

TABLE IV. BASIC RMR OBTAINED FROM THE RATINGS OF THE PARAMETERS

Dam Block Nos.	Joint sets/ Bedding	RQD	UCS	Discontinuity spacing	Discontinuity condition	Ground water condition	RMR basic
Dam Block No. 1	J1	3	0	5	21	7	36
	J2	3	0	5	22	7	37
	J3	3	0	5	25	7	40
Dam Block No. 9	J1	3	0	10	19	7	39
	J2	3	0	15	23	7	48
	J3	3	0	5	23	7	38

The above RMR_{basic} values obtained can be used to calculate the Slope Mass Rating values which will help to predict the stablility of the rock slope.

B. Slope Mass Rating (SMR) System

Slope Mass Rating system has become the most extensively used classification system for rock slopes. The SMR system is the extension of the basic Rock Mass Rating along with four adjustment factors that take into account the geometrical relationship between the rock slope face and discontinuity affecting rock mass (factors F_1 to F_3) as well as the excavation method used (F_4).Romana (1985) derived SMR system for the purpose of assessment of rock slope stability, from the studies of natural and cut slopes along the roads. It is obtained using the following expression:

$$\mathbf{SMR = RMR_b + (F_1 . F_2 . F_3) + F_4} \quad (1)$$

Where RMR_b is the basic RMR obtained from Bieniawski's Rock Mass Classification system without any correction.

F_1 depends upon the parallelism between discontinuity, α_j (and the plunge direction of line of intersection, α_i in case of wedge failure) and slope dip direction. It ranges from 0.15 to 1.0. Initially the value of F_1 was established and was found approximately equal to $(1\text{-sinA})^2$, where A represents the angle between slope strike and joint strike.

F_2 depends on the discontinuity dip (βj) in the case of planar failure and βi (or plunge) of the intersection line in wedge failure. Its value also varies from 0.15 to 1.0. For toppling failure, F_2 is 1.0. Empirically, $F_2 = \tan\beta_j$

F_3 depends on the relationship between slope dip (βs) and discontinuity dip (βj) (for toppling or planar failure cases) or the plunge of line of intersection (βi) (wedge failure case).

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F_4 is a correction factor that depends on the excavation method used.

For the evaluation of the adjustment factors, some dip angles of the slope face are considered and with the help of dip/strike of the discontinuities all the factors are calculated for the rock masses. The strike of the dam axis on left bank is N74°E so the slope strike for the left abutment is found to be N164° and strike of the dam axis on right bank is S74°W and thus the slope strike for right abutment is found to be N344°**.** According to the formula proposed by Romana (1985), all the adjustment factors have been calculated.

1) Adjustment Factor F_1: Using the formula $\mathbf{F_1 = |\alpha_j - \alpha_s|}$, where α_j is the joint strike and α_s is the slope strike, it has been observed that for slope strike N164° on the left bank and N344° on the right bank of Pare river orientation is very favorable with respect to the strikes of the joint sets in most of the considered cases except for joint strike ranging from N150° to N180° present on the left rocky abutment with slope strike N164° which refers to fair condition. This represents that overall both the slopes are stable with respect to adjustment factor F_1.

2) Adjustment Factor F_2: As F_2 depends on the joint dip angle, it has been observed that only for joint dip 28° and 32° the factor F_2 comes out to be favorable and fair respectively. For other joint dips greater than 45°, F_2 represents very unfavorable condition. This refers that the slope may undergo planar failure.

3) Adjustment Factor F_3: As the adjustment factor F_3 refers to the relationship between joint dip and slope dip, the values of F_3 are obtained for various slope dip with respect to the three joint sets present on both the abutments.

For the left abutment a number of slope dip (βs) are considered ranging from 45° upto 75° and F_3 is calculated for each joint sets as shown in Table V.

Similarly in the right abutment certain slope dips are considered ranging for 45°-75°, and F_3 is calculated for each of the joint sets as shown in Table VI.

4) Ajustment Factor F_4: This adjustment factor is related to the method of excavation which includes natural slope, or the cut slope excavated by pre-splitting, smooth blasting, normal blasting, poor blasting and mechanical excavation.

As per the information gathered from the agency it has been known that mainly pre-splitting is used while excavating the slopes. Value of the adjustment factor F_4 for pre-splitting is +10 as proposed by Romana (1985).

5) Calculation of Slope Mass Rating:

The Slope Mass Ratings are calculated for the rocky abutments situated on the either banks of the river Pare where joint sets and bedding planes are present using the formula as in (1).

For the ease of the calculation, only the extreme values of the range of dip and strike of a joint set has been considered for which SMR values are obtained and rest of the angles under that range are considered to fall under that particular range of SMR.

a) SMR for left abutment: Here, all the SMR values for the rock mass present on the left bank of river Pare have been calculated and the failure modes have been determined for each of the joint sets with respect to the considered slope dip angles as shown in Table V.

b) SMR for right abutment: Similarly, all the SMR values for the rock mass present on the right bank of river Pare have been calculated and the failure modes have been determined for each of the joint sets as in Table VI.

TABLE V: CALCULATION OF SMR VALUE USING DIFFERENT SLOPE DIPS FOR LEFT ABUTMENT

CALCULATION OF SMR VALUE USING SLOPE DIP 45°												
Joint sets	***Slope dip (β_s)***	***Slope Strike (α_s)***	***Joint dip (β_j)***	***Joint strike (α_j)***	***F_1***	***F_2***	***F_3***		***F_4***	***RMR_{basic}***	***SMR***	***Failure mode***
							β_j-β_s	*Rating*				
J1	45°	N164°	Min 60°	N235°-250°	0.15	1	60-45 = 15°	0	10	36	46	Planar along some joints and many wedges
			Max 75°		0.15	1	75-45 = 30°	0	10		46	
J2		N164°	Min 45°	N150° - 180°	0.7	0.85	45-45 = 0°	-25	10	37	32.125	Planar or big wedges
			Max 75°		0.7	1	75-45 = 30°	0	10		47	Planar along some joints and many wedges
J3		N164°	32°	N195°	0.15	0.7	32-45 = -13°	-60	10	40	43.7	
CALCULATION OF SMR VALUE USING SLOPE DIP 50°												
J1	50°	N164°	Min 60°	N235°-250°	0.15	1	60-50 = 10°	-6	10	36	45.1	Planar along some joints and many wedges
			Max 75°		0.15	1	75-50 = 25°	0	10		46	
J2		N164°	Min 45°	N150° - 180°	0.7	0.85	45-50 = -5°	-50	10	37	17.25	Big planar or soil-like or circular
			Max 75°		0.7	1	75-50 = 25°	0	10		47	Planar along some joints and many wedges
J3		N164°	32°	N195°	0.15	0.7	32-50 = -18°	-60	10	40	43.7	

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TABLE V: Contd.

Joint sets	Slope dip (β_s)	Slope Strike (α_s)	Joint dip (β_j)	Joint strike (α_j)	F_1	F_2	F_3		F_4	RMR_{basic}	SMR	Failure mode
							β_j-β_s	Rating				
CALCULATION OF SMR VALUE USING SLOPE DIP 55°												
J1	55°	N164°	Min 60°	N235°-250°	0.15	1	60-55 = 5°	-6	10	36	45.1	Planar along some joints and many wedges
			Max 75°		0.15	1	75-55 = 15°	0	10		46	
J2		N164°	Min 45°	N150° - 180°	0.7	0.85	45-55 = -10°	-50	10	37	17.25	Big planar or soil-like or circular
			Max 75°		0.7	1	75-55 = 20°	0	10		47	Planar along some joints and many wedges
J3		N164°	32°	N195°	0.15	0.7	32-55 = -23°	-60	10	40	43.7	
CALCULATION OF SMR VALUE USING SLOPE DIP 60°												
J1	60°	N164°	Min 60°	N235°-250°	0.15	1	60-60 = 0°	-25	10	36	42.25	Planar along some joints and many wedges
			Max 75°		0.15	1	75-60 = 15°	0	10		46	
J2		N164°	Min 45°	N150° - 180°	0.7	0.85	45-60 = -15	-60	10	37	11.3	Big planar or soil-like or circular
			Max 75°		0.7	1	75-60 = 15°	0	10		47	Planar along some joints and many wedges
J3		N164°	32°	N195°	0.15	0.7	32-60 = -28°	-60	10	40	43.7	
CALCULATION OF SMR VALUE USING SLOPE DIP 65°												
J1	65°	N164°	Min 60°	N235°-250°	0.15	1	60-65 = -5°	-50	10	36	38.5	Planar or big wedges
			Max 75°		0.15	1	75-65 = 10°	-6	10		45.1	Planar along some joints and many wedges
J2		N164°	Min 45°	N150° - 180°	0.7	0.85	45-65 = -20°	-60	10	37	11.3	Big planar or soil-like or circular
			Max 75°		0.7	1	75-65 = 10°	-6	10		42.8	Planar along some joints and many wedges
J3		N164°	32°	N195°	0.15	0.7	32-65 = -33	-60	10	40	43.7	
CALCULATION OF SMR VALUE USING SLOPE DIP 70°												
J1	70°	N164°	Min 60°	N235°-250°	0.15	1	60-70 = -10°	-50	10	36	38.5	Planar or big wedges
			Max 75°		0.15	1	75-70 = 5°	-6	10		45.1	Planar along some joints and many wedges
J2		N164°	Min 45°	N150° - 180°	0.7	0.85	45-70 = -25°	-60	10	37	11.3	Big planar or soil-like or circular
			Max 75°		0.7	1	75-70 = 5°	-6	10		42.8	Planar along some joints and many wedges
J3		N164°	32°	N195°	0.15	0.7	32-70 = -38	-60	10	40	43.7	
CALCULATION OF SMR VALUE USING SLOPE DIP 75°												
J1	75°	N164°	Min 60°	N235°-250°	0.15	1	60-75 = -15°	-60	10	36	37	Planar or big wedges
			Max 75°		0.15	1	75-75 = 0°	-25	10		42.25	Planar along some joints and many wedges
J2		N164°	Min 45°	N150° - 180°	0.7	0.85	45-75 = -30°	-60	10	37	11.3	Big planar or soil-like or circular
			Max 75°		0.7	1	75-75 = 0°	-25	10		29.5	Planar or big wedges
J3		N164°	32°	N195°	0.15	0.7	32-75 = -43	-60	10	40	43.7	Planar along some joints and many wedges

Thus, from the above table it has been observed that the rock mass is partially stable with respect to plane failure except for joint dip 45° with joint strike ranging from N150° to N180° which indicates that the left rocky abutment is completely unstable due to the presence of this joint. Factor F_3 comes out to be very unfavorable for joint dip 45° and also for 32° having joint strike N195° for all the considered slope dip angles. While, as the slope dip increases, the rating of F_3 decreases and thus in turn increases the instability of the rock slope. When we consider toppling mode of failure the rock mass comes out to be favorable. In Table VII the stability criteria of the left rocky abutment along with the failure probability is given with respect to the dip/strike of the discontinuity sets present in the rock mass.

TABLE VI: CALCULATION OF SMR VALUE USING DIFFERENT SLOPE DIPS FOR RIGHT ABUTMENT

Joint sets	**Slope dips (β_s)**	**Slope Strike (α_s)**	**Joint dip (β_j)**	**Joint strike (α_j)**	**F_1**	**F_2**	**F_3** β_j-β_s	**F_3** Rating	**F_4**	**RMR_{basic}**	**SMR**	**Failure mode**
CALCULATION OF SMR VALUE USING SLOPE DIP 45°												
J1	45°	N344°	Min 52°	N230°-240°	0.15	1	52-45 = 7°	-6	10	39	48.1	Planar along some joints and many wedges
			Max 70°		0.15	1	70-45= 25°	0	10		49	
J2		N344°	Min 28°	N140° - 170°	0.15	0.4	28-45 = -17°	-60	10	48	54.4	
			Max 46°		0.15	1	46-45 = 1°	-6	10		57.1	
J3		N344°	32°	N195°	0.15	0.7	32-45 = -13°	-60	10	38	41.7	
CALCULATION OF SMR VALUE USING SLOPE DIP 50°												
J1	50°	N344°	Min 52°	N230°-240°	0.15	1	52-50 = 2°	-6	10	39	48.1	Planar along some joints and many wedges
			Max 70°		0.15	1	70-50 = 20°	0	10		49	
J2		N344°	Min 28°	N140° - 170°	0.15	0.4	28-50 = -22°	-60	10	48	54.4	
			Max 46°		0.15	1	46-50 = -4°	-50	10		50.5	
J3		N344°	32°	N195°	0.15	0.7	32-50 = -18°	-60	10	38	41.7	
CALCULATION OF SMR VALUE USING SLOPE DIP 55°												
J1	55°	N344°	Min 52°	N230°-240°	0.15	1	52-55 = -3°	-50	10	39	41.5	Planar along some joints and many wedges
			Max 70°		0.15	1	70-55 = 15°	0	10		49	
J2		N344°	Min 28°	N140° - 170°	0.15	0.4	28-55 = -27°	-60	10	48	54.4	
			Max 46°		0.15	1	46-55 = -9°	-50	10		50.5	
J3		N344°	32°	N195°	0.15	0.7	32-55 = -23°	-60	10	38	41.7	
CALCULATION OF SMR VALUE USING SLOPE DIP 60°												
J1	60°	N344°	Min 52°	N230°-240°	0.15	1	52-60 = -8°	-50	10	39	41.5	Planar along some joints and many wedges
			Max 70°		0.15	1	70-60 = 10°	-6	10		48.1	
J2		N344°	Min 28°	N140° - 170°	0.15	0.4	28-60 = -32°	-60	10	48	54.4	
			Max 46°		0.15	1	46-60 = -14°	-60	10		49	
J3		N344°	32°	N195°	0.15	0.7	32-60 = -28°	-60	10	38	41.7	
CALCULATION OF SMR VALUE USING SLOPE DIP 65°												
J1	65°	N344°	Min 52°	N230°-240°	0.15	1	52-65 = -13°	-60	10	39	40	Planar or big wedges
			Max 70°		0.15	1	70-65 = 5°	-6	10		48.1	Planar along some joints and many wedges
J2		N344°	Min 28°	N140° - 170°	0.15	0.4	28-65 = -37°	-60	10	48	54.4	
			Max 46°		0.15	1	46-65 = -19°	-60	10		49	
J3		N344°	32°	N195°	0.15	0.7	32-65 = -33°	-60	10	38	41.7	
CALCULATION OF SMR VALUE USING SLOPE DIP 75°												
J1	75°	N344°	Min 52°	N230°-240°	0.15	1	52-75 = -23°	-60	10	39	40	Planar or big wedges
			Max 70°		0.15	1	70-75 = -5°	-50	10		41.5	Planar along some joints and many wedges
J2		N344°	Min 28°	N140° - 170°	0.15	0.4	28-75 = -47°	-60	10	48	54.4	
			Max 46°		0.15	1	46-75 = -29°	-60	10		49	
J3		N344°	32°	N195°	0.15	0.7	32-75 = -43°	-60	10	38	41.7	

SMR for the right rocky abutment shows that the rock mass is comparatively better than the left rock mass because of the orientation of the discontinuities for which the ratings of adjustment factors F_1 and F_2 came out to be good while for factor F_3, ratings are decreased as the slope dip has been increased. As a whole, the right abutment mostly lies in the partially stable category and for each of the three joint sets present in the rock mass in relation to the considered slope dip of 55° and has been observed to be fair. In Table VIII the stability criteria of the right rocky abutment along with the failure probability is given with respect to the dip/strike of the discontinuity sets present in the rock mass.

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TABLE VII. STABILITY OF THE LEFT ABUTMENT

Slope dip angles (β_s)	Joint set 1 SMR				Joint set 2 SMR				Joint set 3 SMR		Failure Proba-bility of the rock mass (%)
	For β_j=60° and α_j=N235° - 250°	*Stability*	*For β_j=75° and α_j=N235° - 250°*	*Stability*	*For β_j=45° and α_j=N150° - 180°*	*Stability*	*For β_j=75° and α_j=N150° - 180°*	*Stability*	*For β_j=32° and α_j=N195°*	*Stability*	
45°	46	Partially stable	46	Partially stable	32.125	Unstable	47	Partially stable	43.7	Partially stable	40
50°	45.1	Partially stable	46	Partially stable	17.25	Completely unstable	47	Partially stable	43.7	Partially stable	40
55°	45.1	Partially stable	46	Partially stable	17.25	Completely unstable	47	Partially stable	43.7	Partially stable	40
60°	42.25	Partially stable	46	Partially stable	11.3	Completely unstable	47	Partially stable	43.7	Partially stable	60
65°	38.5	Unstable	45.1	Partially stable	11.3	Completely unstable	42.8	Partially stable	43.7	Partially stable	60
70°	38.5	Unstable	45.1	Partially stable	11.3	Completely unstable	42.8	Partially stable	43.7	Partially stable	60
75°	37	Unstable	42.25	Partially stable	11.3	Completely unstable	29.5	Unstable	43.7	Partially stable	90

TABLE VIII. STABILITY OF THE RIGHT ABUTMENT

Slope dip angles (β_s)	Joint set 1 SMR				Joint set 2 SMR				Joint set 3 SMR		Failure Proba-bility of the rock mass (%)
	For β_j=52° and α_j=230° - 240°	*Stability*	*For β_j=70° and α_j=230° - 240°*	*Stability*	*For β_j=28° and α_j=140° - 170°*	*Stability*	*For β_j=46° and α_j=140° - 170°*	*Stability*	*For β_j=32° and α_j=N195°*	*Stability*	
45°	48.1	Partially stable	49	Partially stable	54.4	Partially stable	57.1	Partially stable	41.7	Partially stable	40
50°	48.1	Partially stable	49	Partially stable	54.4	Partially stable	50.5	Partially stable	41.7	Partially stable	40
55°	41.5	Partially stable	49	Partially stable	54.4	Partially stable	50.5	Partially stable	41.7	Partially stable	40
60°	41.5	Partially stable	48.1	Partially stable	54.4	Partially stable	49	Partially stable	41.7	Partially stable	40
65°	40	Unstable	48.1	Partially stable	54.4	Partially stable	49	Partially stable	41.7	Partially stable	40
75°	40	Unstable	41.5	Partially stable	54.4	Partially stable	49	Partially stable	41.7	Partially stable	40

IV. OBSERVATION

The rocky abutment present in the left bank of river Pare consists of three set of joints which are oriented in both favorable and unfavorable orientations. Joint set 2 is found to be the most critical joint sets having dip angle ranging from 45° to 75°. Joints with dip of 45° produce completely unstable slopes, which require re-excavation (even for slopes with slope dip 45°). However, joints with dip 75° have SMR value above 40 for slope dip up to 70° and is partially stable which can be made stable with corrective support measures in the form of systematic bolting/ anchors or systematic shotcrete etc. In the field, it is found that with these measures rock slopes are stable for slope dip up to about 69°. Thus, it may be concluded that for Joint set 2 in the left abutment, predominant joint dip is 70° to 75°. Rock in the right bank of river Pare is better compared to the right bank and falls under partially stable category with 40% failure probability.

V. CONCLUSION

The Pare Rock mass is found to be characterized by three joint sets both at the right and the left bank at the proposed dam site of Pare Hydro Electric Power project. In the left bank, during geological mapping, it was observed that Joint set 2 has joint dip ranging from 45° to 75°. Joints having 45° joint dip renders the rock slopes with 45° slope dip and steeper completely unstable. However, at the site it has been found that rock slopes up to about 70° stand albeit with certain support measures, but are not completely unstable. This may be because the predominant joint dips of joint set 2 are close to 75°.

Present study shows that the right rocky abutment is partially stable having 40% failure probability, thus can be regarded as normal rock slopes. Left rocky abutment is found to be completely unstable with 90% failure probability.

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