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Slope Stability Analysis Using RMR & SMR Techniques in Cut Slopes, Dum Dum Parai, Kodaikanal, India

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***Abstract* - Landslides are among the major natural disasters in the world. In hilly terrains of India, including Himalayan mountains landslides have been a major and widely spread natural disasters that strike life and property almost perennially and occupy a position of major concern. The present study of slope stability analysis by using Rock Mass Rating (RMR) techniques with Slope Mass Rating (SMR) in and around Dum Dum Parai area of Kodaikanal, Dindigul District, Tamil Nadu involves in collecting the data from different sources. Pre-field data are collected such as selection of location, Base map, climatic condition, etc., On-field data are acquired by collecting the samples from different places where failures obtained. Post-Field data are done by testing the samples which are collected and obtaining the compressive strength for the rock and rock quality rating. Slope stability analysis is done by using the methods of Rock Mass Rating techniques with SMR. Based on the rock quality parameters and predicted slope stability conditions. Finally, Remedial measures are to be taken in the necessary places where required and remedial measures such as decreasing the degree of slope and designed retaining walls.**

Keywords: RMR with SMR, Rock quality and Slope stability.

I. INTRODUCTION

In the last few decades, there had been remarkable enlarge in the occasion of natural disasters such as earthquake, landslides, floods, hurricanes, cyclones, etc. are plaguing the world from time to time. Ecological deprivation is due to the farming and settlements extension by means of deforestation. The repeated problems in Kodaikanal area are mainly road blockades due to slope failure along the pavement during rains leading to smaller and medium slide due to unplanned construction, drainage and agricultural activities. The construction activities in the form of resorts, hotels, houses, cottages and other structures have resulted in a large-scale deforestation. The tourist's inflow has increased alarmingly in the past few years, evidenced by large number of new resorts in and around Kodaikanal municipality.

The stability problems can be classified as "internal" or "external." "Internal" embankment stability problems generally result from the selection of poor quality embankment materials and/or improper placement of the embankment fills and/or improper placement requirements. The infinite slope failure mode is an example of an "internal" stability problem; often such a failure is manifested as sloughing of the surface of the slope. Internal stability can be assured through project specifications by requiring granular materials with minimum gradation and compaction requirements. Slope failure processes are the complex among sites in the hilly terrain. These are one major natural hazard which not only results in the loss of life and property but also can economic burden on the society. Hence, there is a necessity for better methods of landslide evaluation and its zonation. A natural hazard means the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon. Though hazard is a process and it is very difficult to map a process which has not yet occurred. However, hazard mapping may be defined as "the identification of those sites where there is a likelihood of hazardous events rather than hazard affected sites". The conventional limit equilibrium method determines the stability of slope by evaluating of FOS. These methods are based on analysis of slopes, incorporating several engineering parameters of the slope material. This involves collection of samples, evaluation of shear strength properties under field condition and subsequent slope stability analysis. Obviously, this is a detailed investigation process and hence requires significant amount of time and resources. However, this is always needed for a method which can be carried out rapidly for preliminary assessment of slope stability. One such method is RMR and SMR techniques developed by Romana (1985). This method is preliminary based on field data and it is comparatively fast. Hence, the RMR technique is used here for stability assessment of individual rock slopes.

Generally, rock mass rating are inhomogeneous, discontinuous media composed of rock material and naturally occurring discontinuities such as joint, fractures and bedding planes. These features make any analysis very difficult using simple theoretical solutions, like limit equilibrium method. Moreover, without including special interface or joint

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elements, the displacement finite element method is not suitable for analyzing rock masses with fractures and discontinuities. The stability of rock slopes has attracted the attention of researchers for decades. In order to deal with the complications of the slope failure mechanisms, Good and Kiefter and Jaegar outlined several simple methods and their limitations for estimating strength and stability of rock slopes. Due to advancement of various computational techniques, our ability to more accurately evaluate rock slope stability and interpret the likely failure mechanism has improved.

Many kinds of researchers have contributed to protecting us from the disaster. In this research concentrate about a landslide which is one of the natural disasters. Landslides have caused more damage in the Western Ghats. In this research carry out the research at Dum Dum Parai which is 20km away from Batlagundu and 39 km away from Kodaikanal (Figure 1.1). Over the last twenty years, the road leading to Kodaikanal has been hit by rocks several times, affecting traffic. In particular, the impact was significant in 2010 and 2014 (Figure 1.2). The main reason for this is that the route, which was laid during the British period, has not been maintained since. Furthermore, as a result of population growth and traffic density, appropriate maintenance and safety citations are required.

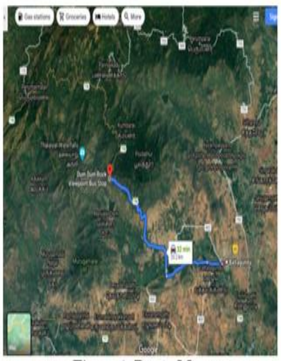

Figure 1. Route Map

Figure 2 Rock fall

II. STUDY AREA AND METHODS

2.1 Study Area

Kodaikanal is situated in the southern tip of the upper Palani hills in the Western Ghats and long history of hill resorts in Dindigul district, Tamil Nadu (Figure 3). Its name in the Tamil language means "The Gift of the Forest". Kodaikanal is referred to as the "Princess of Hill stations" and has a long history as a retreat and popular tourist destination. Dum Dum Parai is located towards the Batlagundu to Kodaikanal town is situated. It is situated at 21km from Batlagundu and 40km from Kodaikanal, Tamil Nadu, India. It has an extent from 10°12’48”N to 10°19’12”N latitude and between 77°27’46”E to 77°33’16”E longitude. The study area is partly covered by 58F/7, 8, 11 and 12 Survey of India toposheets. The base map incorporating main details and reference information was prepared from above said Survey of India toposheets by using Geographic Information System software. Dum Dum Paraiis a dense forest region with a moderate climate throughout the year.

2.1.1 Climate: The climate of the Dum Dum Parai, Kodaikanal is an average annual temperature is about 20.8°C/69.4°F. The precipitation is about 2630mm/103.5 inch per year. Driest month is January is about 51mm or 2.0inch. The greatest amount of precipitation occurs in October with an average of 374mm/14.7inch. With an average of 22.9°C/73.2°F in April is the warmest month. The lowest average temperature in the year occur in December, when it around 18.9°C/65.9°F. The precipitation varies 323mm/13inch between the driest month and the wettest month. The variation in temperature throughout the year is 4.0°C or 39.3°F.

2.1.2 Rainfall: The annual average rainfall in Dum Dum Parai, Kodaikanal is about 219.17mm. From January to February is about around 53mm. In the month of March is about 88mm. With an average rainfall is 286.38mm from the month of April to November and the rainfall is about 11mm in the month of December. The annual average rainy days is about 13.58 days. In the month of January to March, the average rainy days around 6. The 12 rainy days in month of April and December. With an average of rainy days is about 17.57 days from the month of May to November.

2.1.3 Elevation: The elevation of kodaikanal is about 2133m from the above mean sea level (MSL). The study area Dum Dum Parai situated on Batalakundu-Kodaighat road, Near Kodaikanal. The elevation of study area is about 820m from the above mean sea level.

2.1.4 Geology: The study area is made up of hard crystalline rock masses of archean age, charnockite and gneisses are being the major formation. Major portion of Kodaikanal taluk is covered by charnockite rock and it is covered by about 90% of the taluk area. The remaining area comes under hornblende biotite gneiss.

2.1.5 Hydrological conditions: After monsoonal season, hydrogeological conditions gathered from the field, for the reason that rainfall is an important triggering factor of the vulnerable slides in hilly region. The hydro-geological conditions of the sub-watershed show that eastern, central and southwestern parts of the facets are generally damp in conditions. Most of these areas are coming under agricultural activities.

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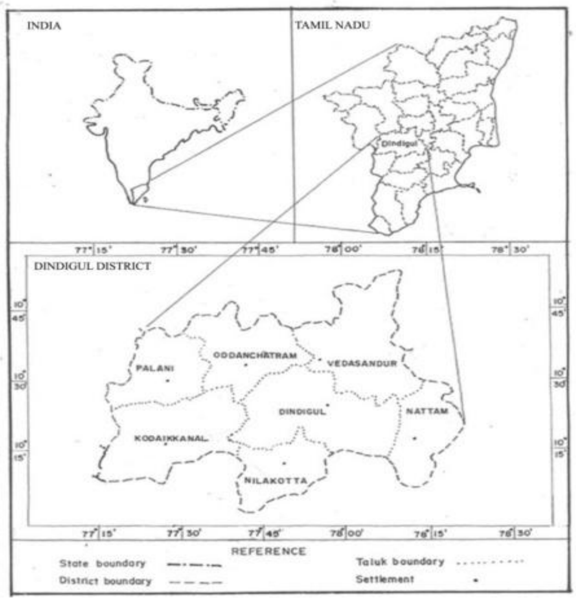

Figure 3: Location Map

2.2 Pre field work

The pre field work contains

i. Literature Review – Various literatures collected.
ii. Data collection and Map collection – Source map collected from Survey of India, data collected from field work.
iii. Past history of landslide locations – Identified the past landslides from newspaper and field visit.

2.3 On field work

The On field work contains

i. GPS location of a section
ii. Rock Mass Rating Parameters collection
iii. Field Photographs

2.3.1 GPS location of a section: Global positioning system (GPS) is a land based technology that work to improve the accuracy of GPS navigation. In this study, GARMIN – Etrex 10 was used to find out exact locations with accuracy of 7m in horizontal and 8m in vertical position. In the field investigation, locations of the selection (rock and soil) with landmark and landslide inventory points collected using Global Positioning System. The coordinates are collected from site for easy mapping and result analysis. The Northing, Easting and Elevation values of the location are collected by using GPS and are plotted in the location data table and used while mapping the locations.

2.3.2 Rock mass rating$_{basic}$: Rock mass rating (RMR) is an important input parameter of slope mass rating (SMR). The Rock Mass Rating (RMR_{basic}) system also known as the Geomechanical classification is a rock mass classification developed by Beiniawski (1973) of South African Council for Scientific and Industrial Research (CSIR). The following six parameters are used to classify rock mass in the RMR_{basic} system IS 13365 (Part 1): 1998:

a) Compressive Strength of rock material
b) Rock Quality Designation
c) Spacing of discontinuity
d) Condition of discontinuity
e) Groundwater condition
f) Orientation of discontinuities

a) Compressive Strength of rock material: The strength is an important criterion for sustaining stresses created due to external forces. The basic reason for any stress analysis is the prediction of failure at the point where the applied stress equates strength. This is the basis of laboratory strength tests. An estimation of the minimum load at which the rock fails is important in all geotechnical investigations. The strength of a material is a measure of its ability to resist the stresses without failure.

b) Rock Quality Designation: The RQD was developed by Deere (Deere et al. 1989) to provide a quantitative estimate of rock mass quality from drill core logs. RQD is the ratio between sum of the cores having length more than or equal to 10 cm, to the total drill run (Beiniawski, 1973). It is expressed in percentage and takes into account the natural fracturing of rocks. Palmstorm (1982) suggested that, when no core is present and if the discontinuity traces are noticeable on surface exposures, the RQD may be estimated from the number of discontinuities per unit volume (IS 11315 (Part 11):1987). The relationship of rock masses are follows:

$$RQD = 115 - 3.3\,Jv \text{-------} (1)$$

Where Jv is the sum of the number of joints per unit length for all joint sets (volumetric joint count).

c) Spacing of discontinuity (IS 11315 (Part 2):1987): Spacing means the distance between two adjacent joints of a given joint set. The distance between various joints has been measured with small graduated tape. The average spacing was taken for each formation.

d) Condition of discontinuity (IS 11315 (Part 4):1987): This parameter includes roughness of discontinuity surfaces, continuity, opening or separation, the infilling of material and weathering of the wall rock. All observations have been done visually.

e) Groundwater condition (IS 11315 (Part 8):1987): The groundwater condition of the slope was observed during field

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investigation. The groundwater condition may be described as completely dry, damp, wet, dripping and flowing.

2.4 Post field work

The Post field work contains

i. Experimental analysis for rock samples
ii. RMR parameters calculation
iii. Identify the slope conditions
iv. SMR parameters
v. Measuring dip and strike

2.4.1 Experimental Analysis for Rock Samples: The strength is an important criterion for sustaining stresses created due to external forces. The basic reason for any stress analysis is the prediction of failure at the point where the applied stress equates strength. This is the basis of laboratory strength tests. An estimation of the minimum load at which the rock fails is important in all geotechnical investigations. The strength of a material is a measure of its ability to resist the stresses without failure. The following strength tests are available for RMR_{basic} stability studies.

i. Uniaxial Compressive Strength
ii. Point Load lump Strength Index

The UCS is determined using regular sized samples in the laboratory, whereas point load lump strength index test can be done using irregular lump samples obtained from the field. The test can be done even in the field as the equipment is portable in nature and the lump samples can be obtained from the field. The equipment is used in this context is AIM – 206-1 model machine of AIMIL make. The standard thickness of the lumps was about 5cm. The sizes of the lumps were generally selected following the criteria as indicated below (IS 8764: 1998).

$$0.3\ W < D < W$$

Where, W = Minimum width of the specimen in cm. If the size is not parallel, then ‘W’ is obtained from W1, W2 and W3 as follows:

$$W = (W1+W2+W3)/\ 3 \text{ ------- } (1)$$

D = Minimum cross sectional thickness of specimen in cm.

The procedure used for testing compressive strength is explained below.

Hydraulically, by pumping through the handles of the machine on initial load of about 2 KN was applied. The dial reading was assigned zero at that load. The load was applied continuously till failure and penetration of point into the lump was noted.

The point load lump strength index was calculated by using the formula:

$$I_{L\ (50)} = P/\ (WD)^{0.75}\sqrt{5.0} \text{ ------- } (2)$$

Where,
$I_{L\ (50)}$ = Point load lump strength index
P = Load at failure in kg
W = Minimum width of specimen in cm
D = Minimum cross sectional thickness of specimen in cm.

The compressive strength of rocks can be determined from the point load test. The cohesion and angle of internal friction can also be obtained from the rock mass rating (RMR) after assigning ratings for other parameters also have been determined from the rock mass rating values of each rock sample. The point load index tests are shown in Figure 3.4.

2.4.2 RMR parameters calculation: Rock mass quality is evaluated by RMR index. Based on the results, the slopes are classified into different instability classes with risks. The Geomechanical classification parameters and their ratings are shown in Table 1.

2.4.3 Identify the rock quality conditions: Rock mass rating (RMR) is an important input parameter of slope mass rating (SMR). The Rock Mass Rating (RMR_{basic}) system also known as the Geomechanical classification is a rock mass classification developed by Beiniawski (1973) of South African Council for Scientific and Industrial Research (CSIR). The following ratings (Table 3.2) are useful for predetermination of the slope based on the six parameters of rock mass in the RMR_{basic} system IS 13365 (Part 1): 1998:

Table 1: RMR Parameters and ratings

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

<table>
<tr><th colspan="3">Parameter</th><th colspan="7">Ranges of values</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Strength of intact rock material</td><td>Point-load strength index (MPa)</td><td>>10</td><td>4 - 10</td><td>2 - 4</td><td>1 - 2</td><td colspan="3">For this low range, uniaxial compressive test is preferred</td></tr>
<tr><td>Uniaxial compressive strength (MPa)</td><td>>250</td><td>100 - 250</td><td>50 - 100</td><td>25 - 50</td><td>5 - 25</td><td>1 - 5</td><td><1</td></tr>
<tr><td>Rating</td><td>15</td><td>12</td><td>7</td><td>4</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Drill core quality RQD (%)</td><td></td><td>90 - 100</td><td>75 - 90</td><td>50 - 75</td><td>25 - 50</td><td colspan="3"><25</td></tr>
<tr><td>Rating</td><td>20</td><td>17</td><td>13</td><td>8</td><td colspan="3">3</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Spacing of discontinuities</td><td></td><td>>2m</td><td>0.6 - 2m</td><td>200 - 600mm</td><td>60 - 200mm</td><td colspan="3"><60mm</td></tr>
<tr><td>Rating</td><td>20</td><td>15</td><td>10</td><td>8</td><td colspan="3">5</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Condition of discontinuities</td><td></td><td>Very rough surfaces Not continuous No separation Unweathered wall rock</td><td>Slightly rough surfaces Separation <1mm Slightly weathered wall rock</td><td>Slightly rough surfaces Separation <1mm Highly weathered wall rock</td><td>Slickensided surfaces or Gouge <5mm thick or Separation 1 - 5mm Continuous</td><td colspan="3">Soft gouge >5mm thick or Separation >5mm Continuous</td></tr>
<tr><td>Rating</td><td>30</td><td>25</td><td>20</td><td>10</td><td colspan="3">0</td></tr>
<tr><td rowspan="4">5</td><td rowspan="4">Groundwater</td><td>Inflow per 10m tunnel length (l/min)</td><td>None</td><td><10</td><td>10 - 25</td><td>25 - 125</td><td colspan="3">>125</td></tr>
<tr><td>ratio (joint water pressure)/(major principal stress)</td><td>0</td><td><0.1</td><td>0.1 - 0.2</td><td>0.2 - 0.5</td><td colspan="3">>0.5</td></tr>
<tr><td>General conditions</td><td>Completely dry</td><td>Damp</td><td>Wet</td><td>Dripping</td><td colspan="3">Flowing</td></tr>
<tr><td>Rating</td><td>15</td><td>10</td><td>7</td><td>4</td><td colspan="3">0</td></tr>
</table>

2.4.4 SMR Parameters: Slope Mass Rating (SMR) system was developed by Romans (1985) as an application of Bieniawski (1989) Rock Mass $Rating_{basic.}$ In order to assess slope instability, risks parameters are introduced to cover

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altitude of discontinuities and slope, failure mode (Planar, Wedge, and Toppling) and slope excavation methods. Rock mass quality is evaluated by RMR index. Based on the results, the slopes are classified into different instability classes with risks. Slope mass Rating is obtained from RMR by adding a factorial adjustment factor depending on the method of excavation.

$$\mathbf{SMR = RMR_{basic} + (F1 \times F2 \times F3) + F4} \text{ ------- } (3)$$

Adjustment rating for joints in rock slopes is a product of three factors.

F1 depends on parallelism between joints and slope face strikes. F2 refers to joint dip angle in the planar mode of failure, in a sense, is a measure of the probability of joint shear strength. F3 reflects the relationship between slope face and joint dip. Conditions are fair when slope face and joint are parallel. When the slope dips 10° more than joints, very unfavorable condition. The adjustment factor for the method of excavation is F4 on whether one deals with a natural slope or one excavation, or poor blasting. The potential rock slope sections were selected based on general condition and were subjected to slope stability analysis.

2.4.5 Measuring dip and strike: The following procedure is being adopted during the measurement of dip and strike angles.

a) Measuring Strike: In order to measure the strike, place the side or edge of the compass against the plane of the outcrop. Sometimes it is easier to put your field book against the outcrop and then the compass against the book to get a smoother and/or a large surface. Now, rotate the compass keeping the lower side edge of the compass fixed, until the bulls-eye level bubble is centered (the round tube; not the long narrow one). When the bubble is centered, the compass is horizontal against the plane and parallel to the line of strike. Now, with the bulls-eye bubble centered, record the number that either end of the compass needle is showing. Place the bottom edge of the compass flat against the plane of interest. Adjust the compass orientation, making sure the bottom edge is always flat against the plane, until the air bubble in the "Bull's eye level" is centered. Read either end of the compass needle to obtain the value of strike.

b) Measuring Dip: To measure the dip of the bedding plane, take your compass and put its side against the rock so that it points in the same direction as the line of dip (The dip line is perpendicular to the strike line). Move the clinometers until the clinometers level bubble is centre. As we did when we found the strike, record where the white tipped end of the clinometers needle is pointing. Note the degrees and the direction. Recall that the dip direction must always be perpendicular to the strike direction (e.g., a strike of 40° could only dip to the SE or NW, never NE or SW). After you determine strike, rotate the compass 90°. Place the side of the compass flat against the plane. Adjust the lever on the back of the compass until the air bubble in the "Clinometers level" is centered. Read the dip directly from the scale in the compass.

III. SLOPE STABILITY AND ANALYSIS

Rock slopes are generally characterized by presence of rocks with thin overburden at places, traversed by geological discontinuities namely bedding, joint, foliation, thrust and other such features Many methods are available to predict stability of the vulnerable rock slope sections. In order to evaluate the rock slopes, RMR has been used to evaluate landslide potential of rock slopes.

3.1 Slope Stability Analysis for Potential Rock Sections

In order to past landslides and present weathering conditions, the rock slopes are identified and selected for further analysis. In this research, 15 lump rock samples were collected in five critical sections for determining the point load index. These samples were obtained from 5 rock slopes which are being considered for stability analysis. The point load index values vary from 2MPa to 10MPa. Based on these parameters, rock mass rating (RMR) values have been obtained**.** A perusal of the RMR values indicates that these values range from 50 to 65. The rock mass rating classification parameters and their ratings are shown in **Table 2.** The rock mass ratings and their conditions are shown in **Table 3**. Slope mass Rating is obtained from RMR by adding a factorial adjustment factor depending on the method of excavation. Evaluation of slope mass rating is obtained from RMR by adding a factorial adjustment factor depending on the method of excavation (**Table 4**) and conditions of slope is shown in **Table 5.** The condition of slope and slope stability section map of study area is shown in **Figure 4 & 5.**

Table 2: RMR Ratings – From Field Data

Parameters			Rock sections				
			R1	**R2**	**R3**	**R4**	**R5**
1	Strength of inact rock materials	Point load Index	8	7	3.5	1.2	1.0
		Uniaxial Comp. strength	---	---	---	---	---
		Rating	12	12	07	04	04
2	Rock Quality Designation (%)	Ranges	80	85	70	40	30
		Rating	17	17	13	8	8
3	Spacing of discontinuities	Ranges	1.5m	1.2m	500mm	180mm	130mm
		Rating	15	15	10	08	08
4	Condition of discontinuities	Surfaces	Slightly rough surfaces	Slightly rough surfaces	Slightly rough surfaces	Slicken - sided surfaces	Slicken - sided surfaces
		Separation	<1mm	<1mm	<1mm	1-5mm	1-5mm
		Weathered	Slightly	Slightly	Highly	Continuous	Continuous
		Rating	25	25	20	10	10
5	Groundwater Conditions	Ranges	Damp	Damp	Wet	Dripping	Dripping
		Rating	10	10	07	04	04

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Table 3: RMR Rating and Conditions

Rock Section	Rating	Conditions
R1	79	Good
R2	79	Good
R3	57	Fair
R4	34	Poor
R5	34	Poor

Table 4: SMR Rating

Rock Section	RMR Rating	(F1 x F2 x F3)	F4	SMR Rating
R1	79	0	0	79.0
R2	79	0	0	79.0
R3	57	-7.5	0	49.5
R4	34	0	0	34.0
R5	34	0	0	34.0

Table 5: SMR Ratings and Conditions

Rock Section	SMR Rating	Class	Description	Stability	Failure	Support
R1	79.0	II	Good	Stable	Some blocks	Spot
R2	79.0	II	Good	Stable	Some blocks	Spot
R3	49.5	III	Fair	Partially stable	Some joints or many wedges	Systematic
R4	34.0	IV	Poor	Unstable	Planar or large wedges	Important / Corrective
R5	34.0	IV	Poor	Unstable	Planar or large wedges	Important / Corrective

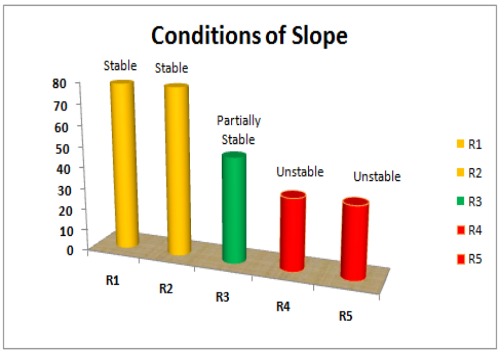

Figure 4: Conditions of Slope

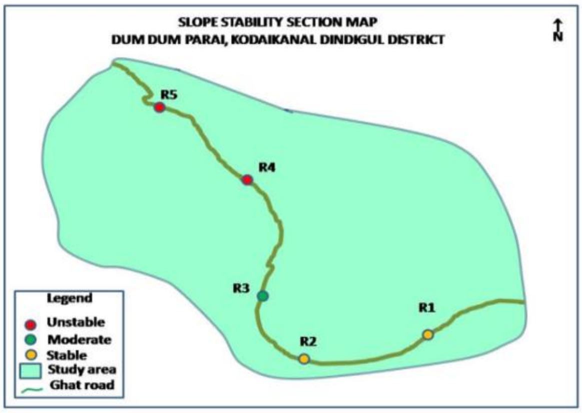

Figure 4: Slope Stability Section Map

IV. CONCLUSION AND RECOMMENDATIONS

The present study of slope stability analysis by using RMR & SMR method in and around Dum Dum Parai, Kodaikanal area of Dindigul District, Tamil Nadu involves in collecting the data from different sources. Slope stability analysis is done by using rock slopes for the methods of Rock Mass Rating (RMR) and Slope Mass Rating (SMR). Based on the field parameters and experimental test, rating is calculated and predicted slope stability condition. As per RMR calculation, the values indicate two sections (R1 and R2) are comes under good quality, one section (R3) is under fair quality and last two sections (R4 and R5) are comes under poor quality. Along with conditions of discontinuities the SMR values also indicates the same class category of two sections (Rock section 1 and R2 section) are comes under Class II, one section (R3 section) is under Class III and rest of two sections (R4 section and R5 section) are comes under class IV. It concluded R1 and R2 are good in stable conditions, R3 are fair in stable conditions and R4 and R5 are poor in stable conditions. Finally, Remedial measures are to be taken in the necessary places where required. Remedial measures such as decreasing the degree of slope and suitable designed retaining walls.

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