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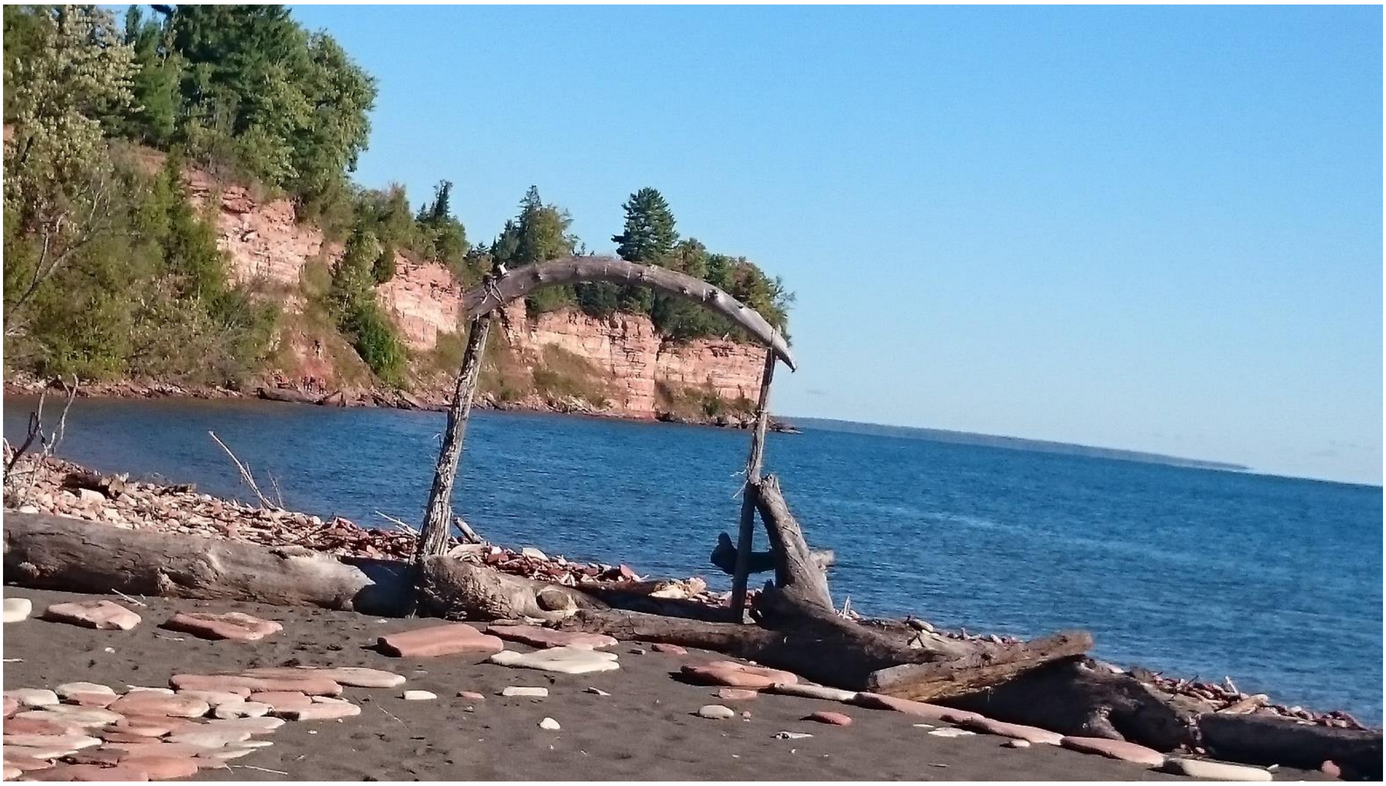

HAZARD ANALYSIS OF BARAGA CLIFFS

GE 3860: Engineering Geology & Geoinformatics

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1 ABSTRACT

Once, processing area for copper ore, The Baraga Cliffs are located in the Keweenaw Bay area. Seven miles north of Baraga, MI, US-41, highway running along these cliffs, is threatened due to recession rate of the cliffs as a consequence of erosion or undercutting by wave action. This report focuses on the hazard analysis of the Baraga Cliffs that might result in the devastation of life and property by collapsing or settling down at the periphery of Lake Superior.

A rough estimate by the geologists for the hazard to occur within ten to twelve years has been made. In this report we will analyze the ongoing problem by using various field and laboratory techniques such as Uniaxial Compressive Strength Test, Coring of the intact rock sample, etc. Observations and calculations from laboratory tests will facilitate the characterization of the rocks with the use of Rock Mass Rating (RMR) by Bieniawski (1973) and Geologic Strength Index (GSI) from Hoek and Marinos, 2000, that in turn, will produce a hazard analysis report for further amendments by Michigan's Department of Transportation (MDOT).

2 INTRODUCTION

Baraga County is the part of Michigan state in the U.S. Baraga Cliffs are 100 feet sandstone cliffs situated on the shoreline of Lake Superior in Keweenaw Bay. Belong to Palaeoproterozoic Era, Baraga Group (ca. 1850 ± 1 Ma) of northern Michigan is around 1200 m thick sedimentary succession of marine clastic, iron formation, chert, and phosphatic sedimentary rocks that accumulated at the peak of the world's first major phosphogenic episode. The cliffs are composed of Jacobsville Sandstone Formation, which is associated with the Lake Superior segment of the Mid-continental Rift System as it began to subside relative to the edges of the rift zone during the Pre-Cambrian age (Kalliokoski, 1982). The Jacobsville Sandstone was overlain by the Paleozoic sediments of the Michigan Basin. These are attractive reddish-brown stones exhibiting leaching with alternating oxidized (red) and reduced layers (white) in nature.

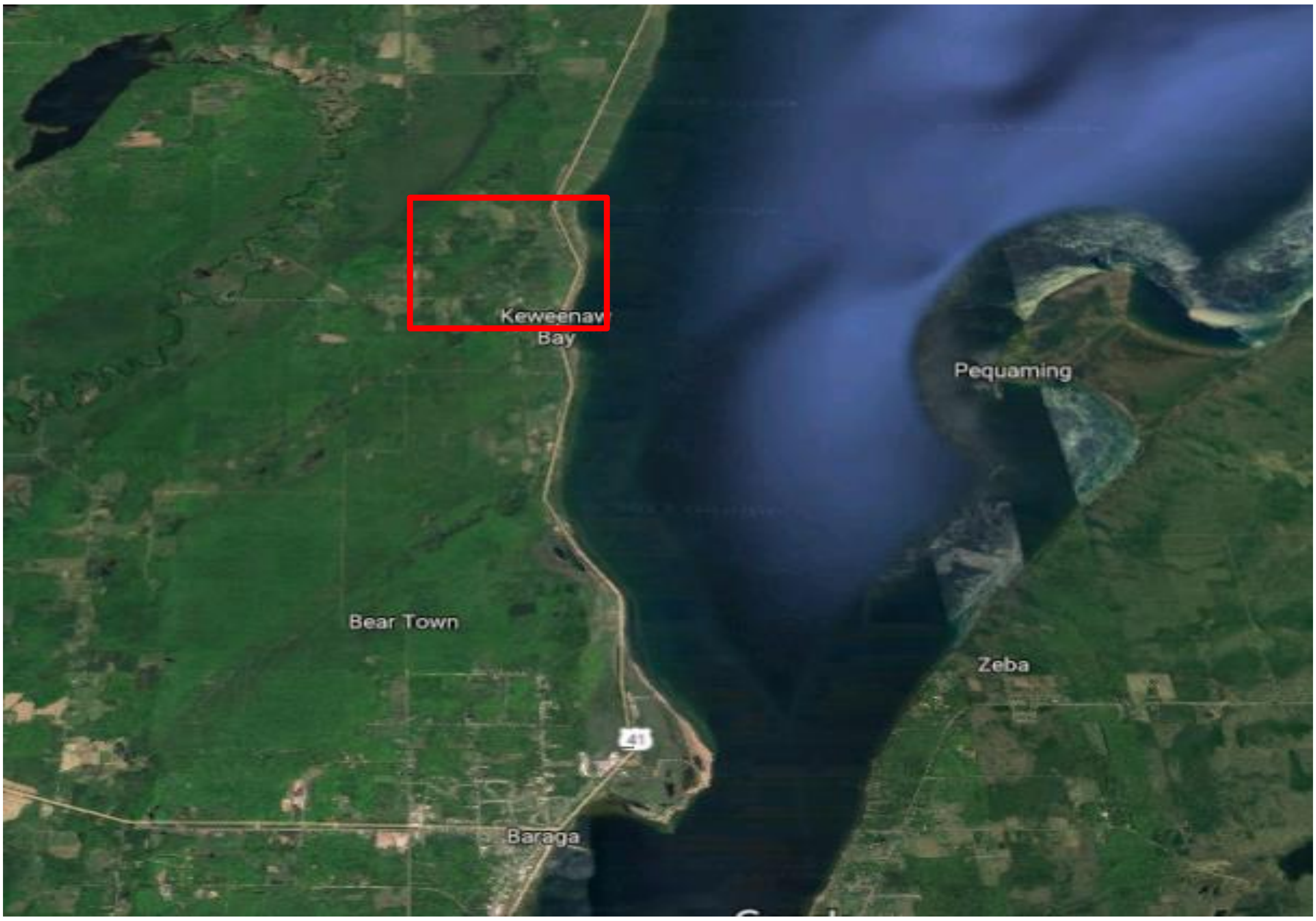


FIGURE 1 LOCATION OF SECTION OF HIGHWAY US-41

The highlighted area in red polygon is our area of interest that marks the region deteriorating due to natural phenomena as well as human activities.

A section of US highway-41 north of Baraga has been rerouted by Michigan Department of Transportation along a cliff. This portion of highway is located at around 7 miles north of Baraga, MI. This area is undergoing recession due to various erosional as well as environmental factors. Found in a research study, the average cliff recession rate was between 0.15 and 1.5 inches per year, but various sections of the cliff were regressing at a faster rate due to factors like weathering of rocks and seepage of water from surface, water flowing above the sandstone with low permeability within the cliff face and degradation of talus slope material at the cliff base. An important factor for ocean cliff recession is that, cliff erosion is primarily a function of the cliff's rock strength followed by wave action and longshore current processes (Lahousse and Pierre, 2003; Stephenson and Kirk, 2000). There are factors that are very important when we talk about cliff stability to be kept in mind. Some of them are illustrated by a chart below:

Erosion Factor	Contribution
Intact rock strength	20%
Discontinuity characteristics	
Spacing	30%
Orientation	20%
Width	7%
Continuity & infill	7%
Water Erosion	6%
Weathering	10%

Table 1: Erosion factors affecting cliff stability (after Shelby, 1993)

As any successful design requires consistency in the design process and lot of measurements and monitoring is taken into consideration, various geotechnical engineers play significant role in not only shaping the engineering structures, but also provides with an alarm of impending danger to the society. Based on the research conducted by Stanley J. Vitton and Alexander Williams, it was suggested that various methods such as LIDAR mapping, Inclinometer measurements should be implemented to continuously monitor the area to ensure the stability of the highway.

3 OBJECTIVE

The main purpose of this study visit is the preparation of a hazard analysis report on Baraga Cliffs, MI by careful visual as well as experimental analysis of an outcrop from these Cliffs by using various field and laboratory techniques that, in turn, can lead to the proposal of advanced engineering solutions to stabilize or reroute the highway, US-41 running along these cliffs.

4 BACKGROUND

To gauge the criticality of the situation a field visit was conducted by the Department of Geological Sciences under the supervision of Dr. Thomas Oommen for all the students to do various visual and experimental analysis of the cliff. In this regard the analysis will be based on the established charts that are used worldwide by geotechnical engineers prior planning to construct any structure. Rock Mass Rating (After Bieniawski 1989) for evaluation of rock quality, Uniaxial Compressive strength of intact rock according to Brown (1981) for calculating UCS will be used.

Currently the highway is lying on the cliffs but, methods are employed for monitoring the area. The site is physically under the danger of collapsing but, there is enough time to stabilize the situation. Further in this report there will be detailed discussion on the methodology and results that will be taken under consideration for suggesting or proposing significant engineering solutions.

5 METHODOLOGY

The strata of the cliff was studied insitu by using visual techniques that resulted in a schematic cross section which is seen in the figure on the right.

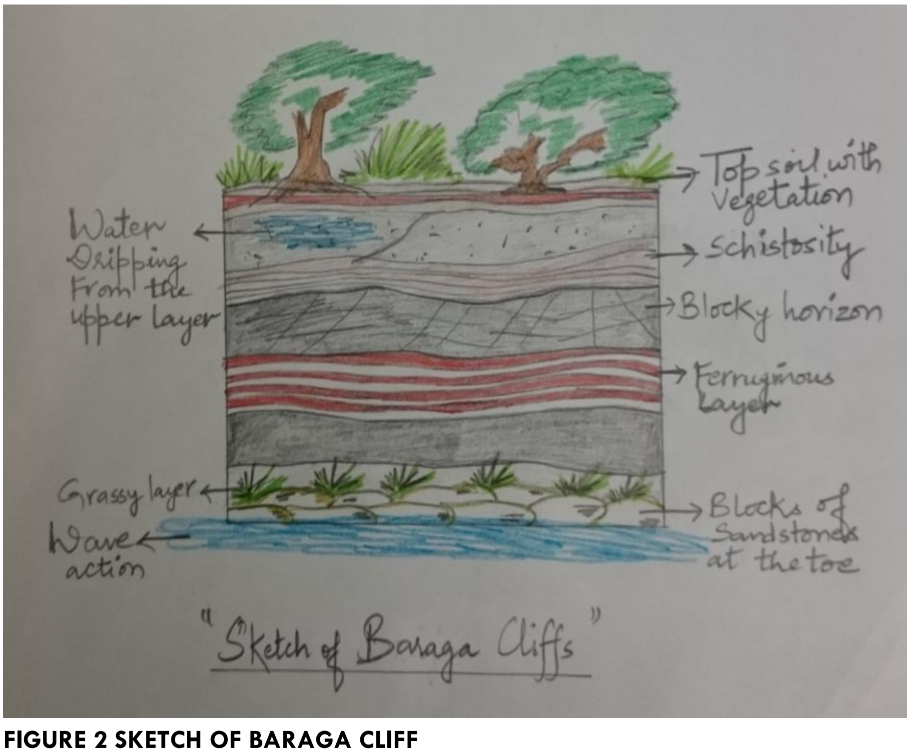


FIGURE 2 SKETCH OF BARAGA CLIFF

After the rough estimate of physical factors like size of the outcrop, thickness & extent of different layers, weathering, structures, geologic features & vegetation etc., Uniaxial Compressive Strength with Schmidt Hammer was performed on the accessible rock layers that gave us different rebound number that can be seen in the table below:

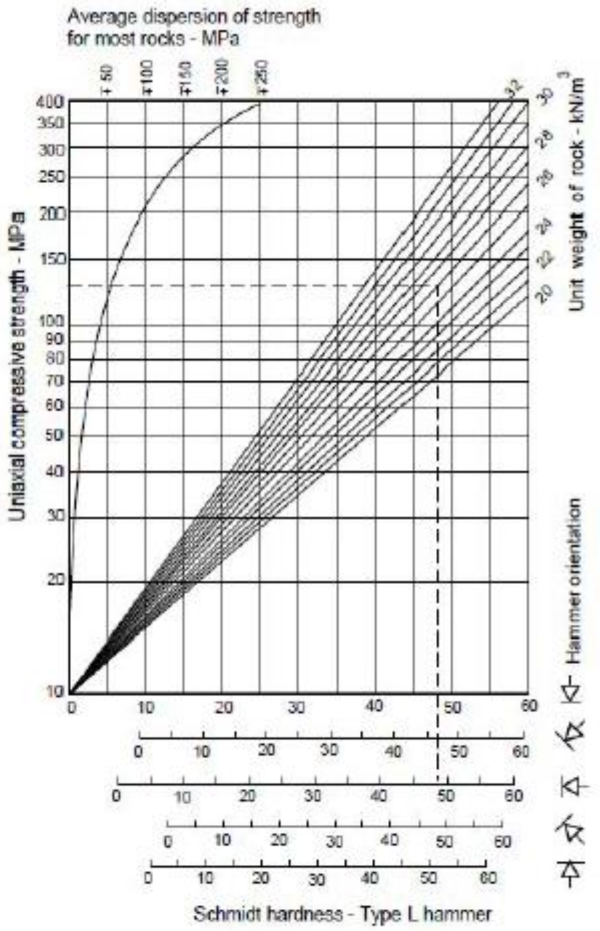
Reading	Rebound Number			
	Layer1	Layer2	Layer3	Layer4
1	48	0	10	24
2	56	0	20	28
3	64	0	0	18
4	22	13	20	24
5	64	0	21	0
6	52	0	14	0
7	57	12	16	10
8	34	10	10	40
9	38	6	24	23
10	53	0	0	14
	Avg. =48.8	Avg. =4.1	Avg. =13.5	Avg. =18.1

Table 2: UCS values from different layers estimated by Schmidt Hammer

Schmidt Hammer:

FIGURE 3 SCHMIDT HAMMER

By using figure 4, the average of rebound values of all the layers was converted to UCS (MPa) that gave the estimated value between 20-25 MPa. This value led to the interpretation of the strata as weak with Grade R2 according to the chart developed by Brown (1981).



Source: Hoek, Evert. "Practical rock engineering." (2000).

FIGURE 4 SCHMIDT HAMMER CONVERSION CHART

Grade*	Term	Uniaxial Comp. Strength (MPa)	Point Load Index (MPa)	Field estimate of strength	Examples
R6	Extremely Strong	> 250	>10	Specimen can only be chipped with a geological hammer	Fresh basalt, chert, diabase, gneiss, granite, quartzite
R5	Very strong	100 - 250	4 - 10	Specimen requires many blows of a geological hammer to fracture it	Amphibolite, sandstone, basalt, gabbro, gneiss, granodiorite, peridotite , rhyolite, tuff
R4	Strong	50 - 100	2 - 4	Specimen requires more than one blow of a geological hammer to fracture it	Limestone, marble, sandstone, schist
R3	Medium strong	25 - 50	1 - 2	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with a single blow from a geological hammer	Concete, phyllite, schist, siltstone
R2	Weak	5 - 25	**	Can be peeled with a pocket knife with difficulty, shallow indentation made by firm blow with point of a geological hammer	Chalk, claystone, potash, marl, siltstone, shale, rocksalt,
R1	Very weak	1 - 5	**	Crumbles under firm blows with point of a geological hammer, can be peeled by a pocket knife	Highly weathered or altered rock, shale
R0	Extremely weak	0.25 - 1	**	Indented by thumbnail	Stiff fault gouge

* Grade according to Brown (1981).
** Point load tests on rocks with a uniaxial compressive strength below 25 MPa are likely to yield highly ambiguous results.

FIGURE 5 FIELD ESTIMATE OF UNIAXIAL COMPRESSIVE STRENGTH OF INTACT ROCK ACCORDING TO BROWN

Laboratory Tests:

The samples from the field were taken to the Laboratory for further analysis and following steps were performed for the UCS (Uniaxial Compressive strength) on a UCS machine:

1- Coring was done on Drill Press. (fig6)
2- Core cutting was done on Tile cutter. (fig7)
3- Cut cores were dried in oven.
4- Uniaxial compressive strength test performed on an UCS machine. (fig8)

FIGURE 6 CORING ON DRILL PRESS

FIGURE 7 CORE CUTTING ON TILE CUTTER

FIGURE 8 UCS MACHINE

45° fracture plane observed under the machine o the sample failure that can be illustrated by the figures below:

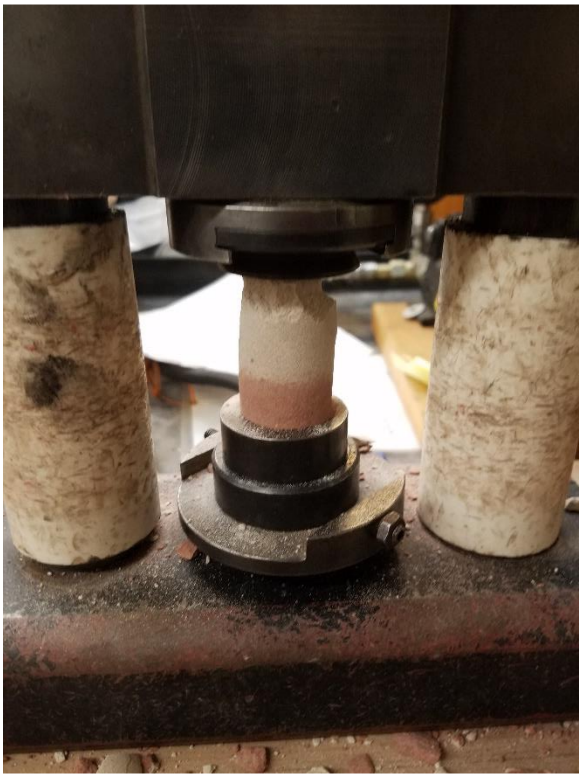


FIGURE 9 CORE SAMPLE UNDER UCS TEST MACHINE

FIGURE 10 PERFECT 45 DEG FRACTURE PLANE

FIGURE 11 FRACTURED SAMPLE

FIGURE 12 FRACTURED SAMPLE

6 RESULTS

The laboratory test is displayed in the table below as numerical values:

Core ID	Diameter (inches)	Length (inches)	Condition	Pressure (psi)	Load (psi)	Area (inches^2)	UCS (psi)
1	1.246	2.02	Dry	5293.88	6564.41	1.21	5425.13
2	1.248	2.04	Dry	4020.5	4985.36	1.21	4086.37
3	1.246	2.04	Dry	2451.14	3039.41	1.22	2491.32
4	1.255	2.02	Wet	4342	5384.08	1.23	4377.3
5	1.255	2.03	Wet	3960	4910.4	1.23	3992.2
6	1.24	2.03	Wet	3078	3816.72	1.21	3154.3

Table 3: Data from UCS test in laboratory

Avg. UCS for Dry Sample = 4000.94 psi

Avg. UCS for Wet Sample = 3841.27 psi

Based on the laboratory tests calculations the UCS value range show that the rock quality is weak and using the classification given below the class for the sandstones at Baraga Cliffs is D with the low level of strength as UCS ranges between 27.5-55 MPa.

Engineering Classification of Intact Rock (West, 1995 adapted from Deere and Miller, 1966)

Class	Level of Strength	UCS, MPa
A	Very high	220
B	High	110-222
C	Medium	55-110
D	Low	27.5-55
E	Very low	27.5

FIGURE 13 ENGINEERING CLASSIFICATION OF INTACT ROCK BY DEERE AND MILLER

The use of RMR by Bieniawski (1973) and GSI from Hoc and Marines, 2000 gave the indication of the strata being blocky, highly weathered, disintegrated, poor quality with dripping ground water and unfavorable strike & dip orientations.

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values						
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core Quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Groundwater	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125		
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.

** Modified after Wickham et al (1972).

FIGURE 14 ROCK MASS RATING (RMR) BY BIENIAWSKI (1973)

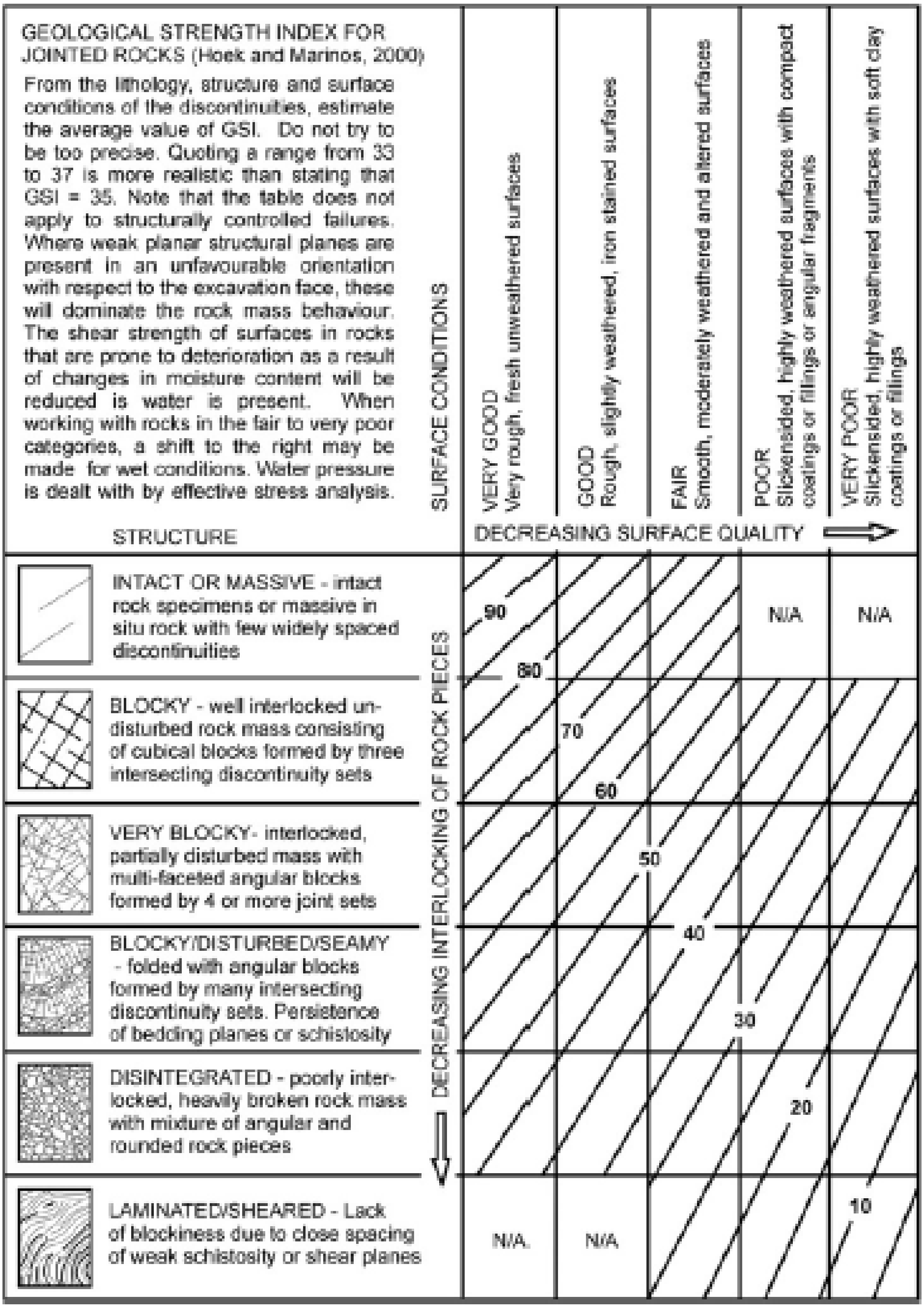


FIGURE 15 GEOLOGIC STRENGTH INDEX (GSI) FROM HOEK AND MARINOS, 2000.

7 DISCUSSION

By using various charts for classification as well as field and laboratory analysis, it is very evident that the lithology of Baraga Cliffs is very blocky, disturbed and poor in quality. The strata observed was slightly folded with angular blocks formed by various intersecting discontinuity sets. Schistosity was prominent with alternating white (reduction) and red (oxidation) bands. The red coloration was indicative of ferruginous material. In the upper layers of the cliff water dripping could be observed. The uppermost layer was totally weathered constituting soil horizon. Six bedding planes were prominently seen having 0.2 to 6mm of spacing in joints. Third layer showed cross bedding.

Comparison between the present data and the research done by Stanley J. Vitton and Alexander Williams, Michigan Technological University, Department of Civil & Environmental Engineering, showed huge variations. RMR values presented by Vitton and Williams was 70 and the rock quality was good. But, present scenario depicts that the quality of the rock is poor with RMR value around 29. Their work stated that there is no indication of large scale collapse, but, present situation is very much indicative of the cliff collapsing within next ten years due to cutting action by wave at the toe.

According to any geotechnical engineer Slope stabilization techniques are very much significant that needs to be taken under consideration now. Vegetation on the hill, cementation with meshing, barriers to protect the toe of the cliff, tie back anchors are some of the measures that could be taken to protect the strata and stabilize the slope.

8 CONCLUSION

The cliff section is very unstable with the poor rock quality that is undergoing erosion due to wave action. Therefore, there’s a high possibility of the strata to collapse within next ten to fifteen years. So, it is highly recommended to shift the road away from the cliff to avoid any kind of human life casualties.

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