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Research Article

UTILIZING A GEOMECHANICAL CLASSIFICATION TO PRELIMINARY ANALYSIS OF ROCK SLOPE STABILITY ALONG ROADWAY D340- 41.42, SOUTHWEST OF TURKEY: A CASE STUDY

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ABSTRACT

Road construction is mostly passed through mountainous regions or hilly terrains in Turkey like in all world. In hence, roadway construction and widening are being constructed through blasting and excavation, leading to rock slope instabilities and failures then poses threats to life and property. The reasons for failure sometime after construction are likely due to the deterioration of rock masses in cut slopes. However, slope instability and failures mainly occur due to adverse slope geomorphological complexities, joint discontinuities, weathering, man-made activities, unloading; and several induced factors such as seasonal heavy rainfall events, snow coverage, etc. The objectives of this paper are therefore to identify the most significant parameters influencing the behavior of cut slope rock masses with employing SMR ,and to perform a preliminary slope instability assessment along roadway D340- 41.42, southwest of Turkey, where slopes located in a region of Taurus’s rugged terrains with known complex geometry, then propose a suitable control measures to mitigate potential failures of rock slope stability. In this study, 19 rock cuts are selected based on the observed failure mechanisms, slope geometry and materials. A systematic site investigation incorporating relevant engineering geological and geotechnical parameters were carried out in detail. Based on slope instability observations and SMR results rating, concluded that these slopes were widely controlled by discontinuities (structurally controlled failures). As well, SMR classification scheme was successfully used for failure classification in Taurus’s terrains. Finally, slope flattening with various angles method, wire mesh, toe support by detached rock blocks and drainage ditches re-design are proposed as a remedial measurement to protect road slope stability from failure.

Keywords: *Slope Stability Failures, Rock Mass Classification, SMR Classification System, Roadway D340- 41.42, Turkey*

1. INTRODUCTION

Stability assessment is of essential importance for planning and construction of infrastructure, including roads in hilly terrain (Basahel and Mitri, 2017; Lenka, *et al.*, 2018). Slope stability in hilly regions is easily affected and frequent failures are present all over the world. In Turkey, most road networks and some railway tracks are passed through hilly terrains, such as Taurus's rugged terrains in the present study. So, these roadways construction and widening are being constructed through blasting and excavation, this blasting creates new fractures in the rock slopes poses threats to life and property.

In Taurus precarious, slopes are well known for their instability due to the dynamic nature of slopes, geomorphological complexities, joint discontinuities, weathering, long period snowfall which sometimes cause the roads to be completely closed, in addition to heavy and sustained rainfall, and ongoing activity. This constraint sometimes causing disruption of traffic along this important hill route and creating recurrent economic loss to the state exchequer.

To avoid these troubles, it is then very important to assess engineering geological properties of the lithological units with elaborated investigations for stability of slopes, in hence, this paper highlights utilizing SMR classification after (Romana, 1985) developed for rock slope stability assessment, then classify the rock mass of the investigated slopes into different slope classes of Turkey, according their vulnerability to failure along roadway D340- 41.42, southwest of Turkey, where slopes located in a region of Taurus's rugged terrains known with complex geometry.

In order to examine cut slope and assess their stabilities, a systematic site investigations incorporating relevant engineering geological and geotechnical parameters have been carried out in detail, this work was accomplished with scan-line technique suggested by (ISRM, 2007), during investigation all field observations / measurements, characterization of rock mass for all slope instability analysis were recorded, Also, slope instability modes were identified too. Finally, and to mitigate the endangered cut slopes from failure, the strengthening measurements and many remedial solutions were proposed.

2. GEOLOGICAL DESCRIPTION

The studied roadway cut is located within the Central Taurus Belt, it is a part of D-340 along a major highway connecting between Konya and Alanya cities, lying southwest of Turkey with coordinates (36°58'52" N;32°27'32"E) and (36°44'54" N;32°27'55"E) (Fig. 1).

Geologically, roadway D340-42.41 region was covered by shallow marine sedimentary rocks that resulted from deposition of limestone, clayey limestone and recrystallized limestones during the Early-Middle Cambrian. Exposed lithological units along studied roadway were belong to "Gevne group "varied from Kusakdagi formation (Pk) to Dedebeleni formation (Jd) with some Quaternary deposits and recent slope debris (Q) (Fig. 2), ranged in age from Jurassic - Upper Jurassic (Dedebeleni formation) to Upper Permian (Kusakdagi formation) (Turan, 1990).

The studied roadway was a problematic due to the existence of lithological units with variable characters which mainly comprised of micritic limestone, reefal limestone, clayey limestone, mudstone, sandstone, conglomerate; and Quaternary clastic deposits comprised of gravel-sand-silt and clay (Fig. 1)

However, during field studies the observed cut slopes are located within four formations are: 1) Kusakdagi formation (Pk) (Upper Permian) comprised of bituminous - fossiliferous and reefal limestone beds described in field with grey-black color, moderate - thickly bedded, moderately to highly weathered, hard, and moderately jointed, and thin abundant algal limestone with interbedded of shale and quartzite. 2) Beyreli formation (Tb) (Middle -Upper Triassic) was a sequence layers varied from light gray, hard, slightly-moderately weathered, well bedded sandy recrystallized limestone, sandstoe, shale to light brownish colors of mudstones and micro-conglomerates beds characterized with moderately-highly weathered, highly jointed 3) Camici formation (Jc) (Jurassic?) recognized by colored with red clayey, thick and conglomerate - dominated sandstones, mudstones. This conglomerate was reddish, coarse grained with poor rounded shape, slightly-moderately weathered and medium strong; and Dedebeleni formation (Jd) (Upper Jurassic) dominantly comprised of limestone and micritic limestone with soft morphological clay and silt, claystone- clayey limestone alternated with re-crystalized and little dolomitic limestone, these units characterized with light gray to white colored, limestone hard to extremely hard, highly jointed.

Structurally, the study area is repeatedly affected by folded, uplifted - thrusting and erosion activities through Early Cimmerian Orogeny (Turan, 1990), thus, this led to a rugged terrain like Taurus ranged in elevation between (1052-1403 m) above sea level and form a dendritic drainage pattern which was observed during field studies too.

The researched roadway stretch was an extensively deformed, this observed obviously by making up major thrust fault namely "Gevne thrust fault" accompanied by transional faults, then led to form deeply valley namely "Gevne stream" as a weakness planes induced most of slope instabilities exposed along this road.

Therefore, most of the observed failure modes (planer, wedge, toppling) in the field were controlled by discontinuities. In addition to several climatic factors directly and indirectly widely induce road slope instability such as seasonal heavy included rainfall events and snow coverage on open spaces and site-specific roadway traffic (Trenouth and Gharabaghi, 2016).

These factors combined with the erosion and man-made activity, water run-off and groundwater mainly cause to slope instabilities. Briefly, the factors impact on roadway lifetime are consecutive and myriad, could be argued.

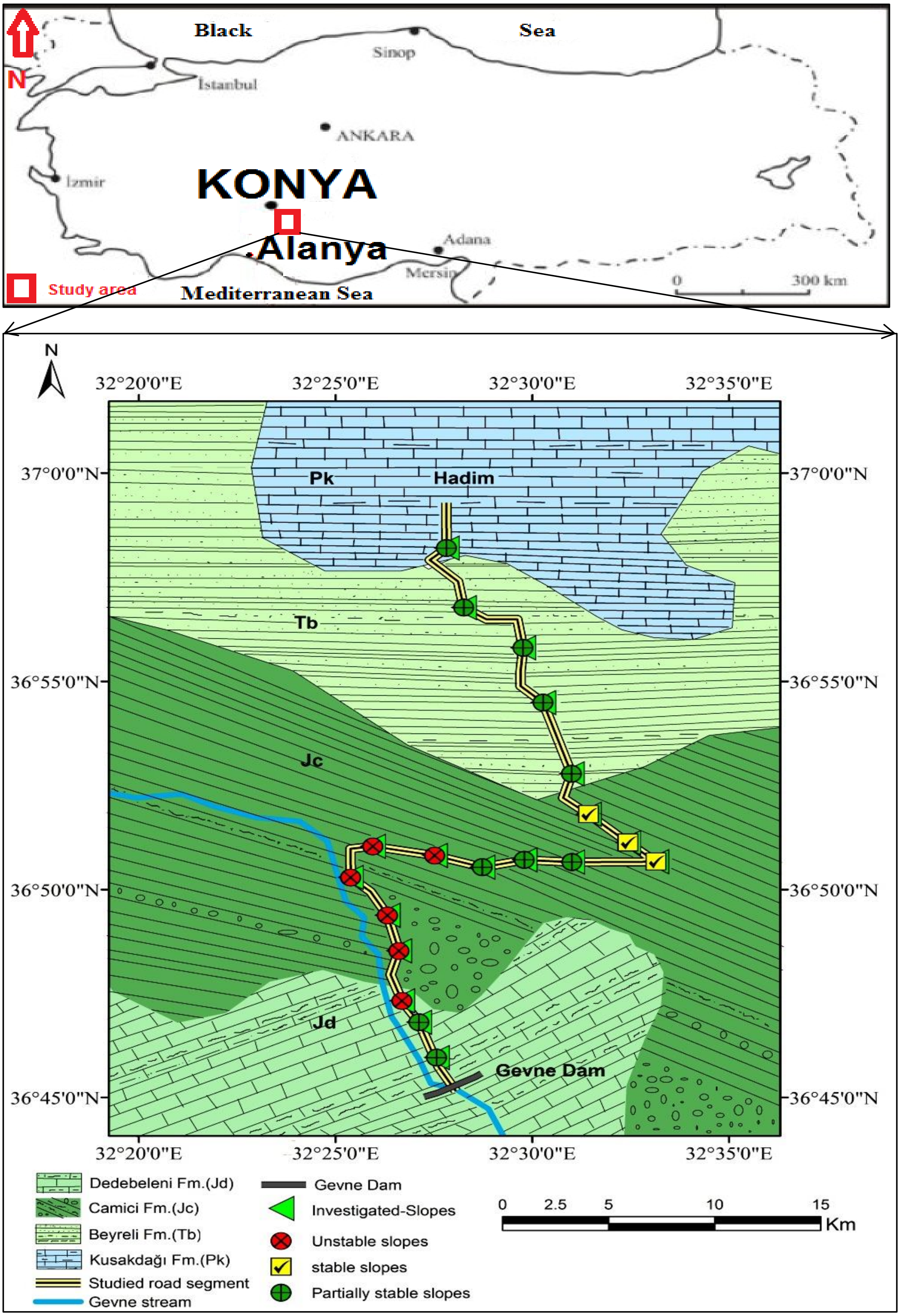

Fig. 1. Location and Geological map of study area, *modified from* Directorate of Mineral and Explorations (MTA, 1985).

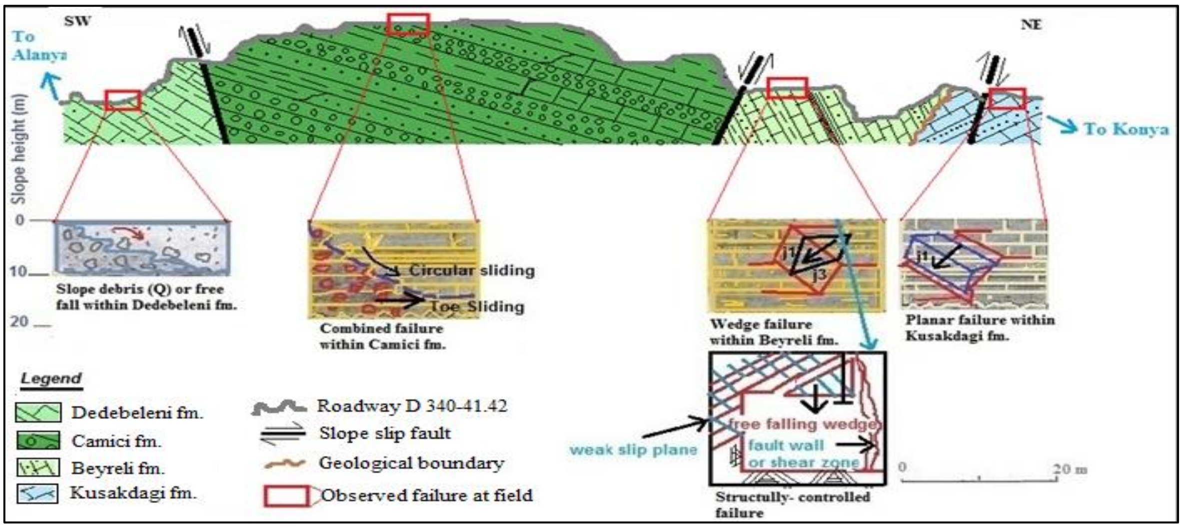

Fig. 2. Geological sketch showing discontinuity impact on failures modes observed along roadway D340-41.42.

3. APPLICABILITY OF ROCK MASS CLASSIFICATION TO SLOPE STABILITY

In rock mass classification system, most of the methodology is proposed to identify the quantitative condition of road slopes (Saranaathan, 2015). In general, the slope stability determination methods depending on the material involved (Sonmez *et al.*, 1998) . However, many authors have applied geostatistics to investigate slope stability assessment in a rock mass (Aksoy, 2008; Harrison and Hudson, 2000; Liu and Chen, 2007; Morales *et al.*, 2019; Pastor *et al.*, 2019; Tomas *et al.*, 2012) qualitative and quantitative methods have been used to detect and predict rock slope stabilities, As is well known, Rock Mass Classification calculated based of RMR, is probably one of the most widely used classifications (Pantelidis, 2009; Romana, 1997) is mainly used and developed to perform slope stability and examine failure of rock cut slopes, but largely accepted, endorsed and used in current paper classification system is slope mass rating (SMR) (Romana, 1985; Romana *et al.*, 2003) specifically designed for calibration of slopes, which basically modified from basic Rock Mass Rating (RMR_{basic}).

3.1. APPLICATION OF SLOPE MASS RATING (SMR)

For evaluating the stability of rock slopes, (Romana,1985) proposed a classification system called the “slope mass rating” (SMR) system (Table 1). SMR is basically obtained from Bieniawski’s rock mass rating (RMR) by subtracting adjustment factors of the joint–slope relationship and adding a factor depending on method of excavation.

Romana (1985) established a relationship to find ‘Slope Mass Rating ‘depending on the RMR_{basic} index (Bieniawski, 1989) and a factorial adjustment factors that depict the geometrical relationship between discontinuities affecting the rock mass and the slope (F1, F2, F3) (Table 2), slope excavation method (F4) (Table 3). It is completely depend on the geometrical relationship slope and discontinuities orientation with observed failure modes in field (Table 4). The final calculation is of the form:

$$SMR = RMR_{basic} + (F1.F2.F3) + F4 \quad (1)$$

Where: (RMR_{basic}) is evaluated according to (Bieniawski, 1979) by adding the ratings of five parameters (see Table 5). F1, F2, and F3 are adjustment factors related to joint orientation with respect to slope orientation, and F4 is the correction factor for method of excavation:

i) F1 – depends on parallelism between joints and slope face strikes. It is in range from 1.00 (when both are near parallel) to 0.15 (when the angle between them is more than 30°).

ii) 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. This value varies from 1.00 (for joint dipping more than 45°) to 0.15 (for joints dipping less than 20°).

iii) 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 occur. The adjustment factor for the method of excavation F4 depends on whether one deals with a natural slope or one excavated by pre-splitting, smooth blasting, mechanical excavation, or poor blasting. Based on the SMR results, the studied slopes are classified into different instability classes with risks descriptions according to the following Table:

Table 1. Description of SMR classes (Romana, 1985).

Class	SMR	Descript-ion	Stability	Failure probability
V	0- 20	Very bad	*C. unstable	0
IV	21-40	Bad	unstable	0.2
III	41-60	Fair	*P.stable	0.4
II	61-80	Good	stable	0.6
I	81-100	*V.good	*C.stable	0.9

*V: very; *C: completely; *P: Partially.

Table 2. Adjustment ratings for F1, F2, and F3 (Romana, 1985, modified by (Anbalagan,*et al.*, 1992))

Case of slope failure	Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
P $\|\alpha j-\alpha s\|$	> 30º				
T $\|\alpha j-\alpha s-180\|$		30-20º	20-10º	10-5º	< 5º
W $\|\alpha j-\alpha s\|$					
P/T/W F1	0.15	0.40	0.70	0.85	1.00
P $\|\beta j\|$	< 20º	20-30º	30-35º	35- 45º	> 45º
W $\|\beta j\|$					
P/W F2	0.15	0.40	0.70	0.85	1.00
T F2	1.00	1.00	1.00	1.00	1.00
P βj- βs	> 10º	10- 0º	0º	0- (-10º)	< (-10º)
W βj- βs					
T βj+βs	<110º	110-120º	>120º	-	-
P/T/W F3	0	- 6	-25	-50	-60

FAILURE: P planar; W wedge; T toppling. DIP DIRECTION: α j discontinuity; α s slope. DIP: βj discontinuity; βs: slope .

Table 3. Adjustment factor F4 for the method of excavation (Romana, 1985).

Excavation method	F4 value		
Presplitting	+10	Normal blasting or mechanical excavation	0
Smooth blasting	+8	Deficient blasting	- 8
Natural slope	+15		

4. CASE STUDY

In this study, Slope Mass Rating (SMR) after (Romana, 1985) was used to determine the slope stability and examine their stability conditions, in order to do this,19 road cuts have been chosen in the study area along roadway D340- 41.42. A detailed field investigation with seven scanlines, 10 m each has been carried out in the different selected localities of the study area.

This investigation involved record of both quantitative and qualitative recording of various rock masses parameters with an emphasis on collect the required geological and geotechnical data/measurements for finding both RMR and SMR. The methodology of current study can be summarized by the following main steps:

1- Determination of the six parameters related to RMR_{basic} for each investigated slope, to find SMR values.

2- Collection of field data related to discontinuities in term of spacing, orientation (dip/strike) with respect to slope, conditions of joints, ground water, Rock Quality Designation (RQD %); and Rock strength of rock material. Here, it is worth to mention that RQD % rating was calculated by field survey using mean discontinuities spacing (Palmstrom, 2005; Singh and Goel, 1999) from this relationship; RQD % = (115 -3.3 jv), where jv is the volumetric joint count.

3- Based on the field investigations, investigate and record, then finding Romana's rating adjustments (F1, F2, F3) and assess excavation method (F4) parameters, to determine the respective Slope Mass Rating (SMR values).

4- According to SMR values classify of the rock slope stability into different instability classes with risks consequently.

5. RESULTS AND DISCUSSION

As well as, this study was meant to assess then classify the rock mass of the investigated slopes along roadway D340- 41.42 into different slope classes according their vulnerability to landslide employing SMR classification. The carried - out investigation involved 19 rock slopes (S1-S19) along this roadway (Fig. 1).

Most of the investigated slopes comprise three sets of discontinuities (J1, J2, J3) along dip with some randomly oriented sets forming blocks of different sizes, these joints, slope conditions; and related adjustment factors (F1, F2, F3) were studied in detail, then evaluated according to Tables 2,3. Joints - slope measurements parameters at different locations were given in Table 4 too. Most of the encountered failure modes regarding to the geometrical relationship between joints and slope were controlled by fracturing.

In this study, RMR_{basic} rating values and SMR rating values were calculated too. RMR_{basic} rating values ranges from 61 to 72 (Table 5), SMR rating values ranges from 30.30 to 68.10 (Table 6). These ratings were assigned to each parameter. From these results it was found that, some slopes despite have a moderate to high RMR_{basic} values with good quality of rock mass, but it was remained unstable and prone to failure.

For example, in the Table 5, S3-S6, S7- S8 rock slopes although, have medium to high values of RMR_{basic} (both are 66), but have the lower SMR values in Table 6. (30.30, 36.25 respectively).

Obviously, this may be due to effect of joints orientation and excavation method (blasting) on the slope instability which denoted in the previous equation with (F4).

Accordingly, slope stability condition for all nineteen (19) rock slopes were assessed and classified in (Table 7) into five potential failure classes based on their

Table 4. Slope – discontinuities orientation relationship with observed failure modes in field. (DD = Dip direction, DA = Dip amount)

Rock slope No.	Slope orientation DD / DA	Bedding plane DD / DA	Joints orientation J1 (DD / DA)	J2 (DD / DA)	J3 (DD / DA)	Observed failure in field
S1 - S2	089/41-68	210/34-35	222/70	355/80	098/90	Wedge J1&J3
S3 - S6	087/30-37	180/30-35	280/82	030/83	140/87	Planar J1,Toppling J1,2,3
S7 - S8	105/34	255/37	225/80	349/72	115/ 70	Planar j2
S9 - S11	115/44	270/40	235/87	045/56	135/85	Planar J1; Wedge J1&J3
S12 - S14	112/40	220/31-40	225/82	025/85	100/64	block failure, Rockfall
S15 - S17	095/55	310/20-40	188/83	030/90	125/75	Toppling J1,J2,J3
S18 - S19	110/87	230/40	230/65	045/65	-	wedge J1&J2

Table 5. RMR classification based on estimated (RMR_{basic}) values parameters for the studied rock slopes

Rock slope No. →		S1-S2	S3-S6	S7-S8	S9-S11	S12-S14	S15-S17	S18-S19
USC rating (R1)		12	8	11	13	12	10	12
RQD rating % (R2)		13	12	13	17	12	14	13
Discontinuities spacing Rating (R3)		8	10	9	8	10	8	10
Discontinuities condition rating (R4)	Persistence	6	6	5	4	5	4	4
	Aperture	1	1	2	4	1	3	1
	Roughness	6	5	5	6	5	5	4
	Infilling	6	4	5	4	3	6	5
	Weathering	3	3	2	3	4	4	4
	Total	**22**	**21**	**19**	**21**	**18**	**22**	**18**
Ground water rating (R5)		14	15	14	13	14	13	15
Discontinuities orientation (R6)		0	0	0	0	- 5	0	0
RMRbasic		69	66	66	72	66	67	68
RMR*		69	66	66	72	61	67	68
Rock mass class		Good	Good	Good	Good	Good	Good	Good
RMR description		II	II	II	II	II	II	II

RMR* = ∑classification parameters (R1+R..+R5) + Discontinuity orientation adjustment (R6)

Table 6. Results of SMR Rating values for studied rock cut slopes.

Rock slope No.	RMR basic	Observed failure	The factorial adjustment factors F1	F2	F3	F4	SMR** rating
S1 - S2	69	Wedge J1&J3	0.85	0.85	-25	+8	58.93
S3 - S6	66	Planar J1, Toppling J1,2,3	0.85	0.70*	-60	0	30.30
S7 - S8	66	Planar j2	0.70	0.85	-50	0	36.25
S9 - S11	72	Planar J1; Wedge J1&J3	0.85	0.85	-25	0	53.93
S12 -S14	61	Free rock falling	0.15	1.00	-6	+8	68.10
S15 - S17	67	Toppling J1,J2,J3	0.85	0.70	-25	0	52.12
S18 - S19	68	Wedge J1&J2	0.70	0.70	-50	0	43.50

0.70* is an average value for planar and Toppling, SMR** = RMR_{basic}+ (F1.F2.F3) + F4

Table 7. Slope stability assessment of roadway D340 - 41.42 slopes according to classes and SMR values in Table 6.

Rock slope No.	SMR** value	Class No.	Slope description	Stability	Inferred failure from SMR	Failure Probability %
S1 - S2	58.93	III	Fair	Partially stable	Planar along some joints or many wedge failure	40
S3 - S6	30.30	IV	Bad	unstable	Planar or Big Wedge	60
S7 - S8	36.25	IV	Bad	unstable	Planar or Big Wedge	60
S9 - S11	53.93	III	Fair	Partially stable	Planar along some joints or many wedge failure	40
S12 -S14	68.10	II	Good	stable	Some block failure	20
S15 - S17	52.12	III	Fair	Partially stable	Planar along some joints or many wedge failure	40
S18 - S19	43.50	III	Fair	Partially stable	Planar along some joints or many wedge failure	40

SMR values in Table 6, and according to all obtained results, the probability of failure for all studied slopes have been computed as inserted in Table 7. and compared to the observed values, then represented in Fig. 3 too.

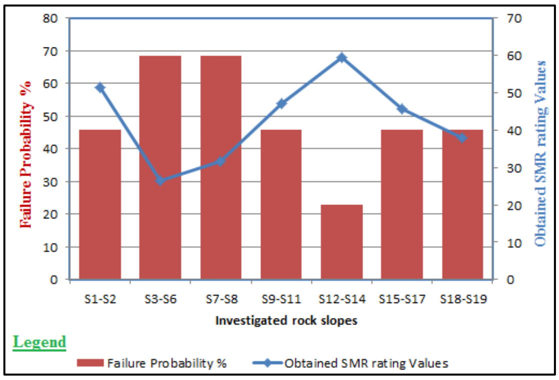

Fig. 3 Failure Probability according to their SRM rating values for the investigated slopes in the current study.

From this figure it was found there is a reverse relationship between SMR rating values and probability of failure (failure probability increases with decreasing of SMR values). Furthermore, slope stability analysis for nineteen investigated rock slopes have been explained in Table 7 and Fig. 4, then categorized into partially stable, unstable, and completely stable. slope stability analysis was classified with taking into account multiple considerations of anticipated conditions during field study.

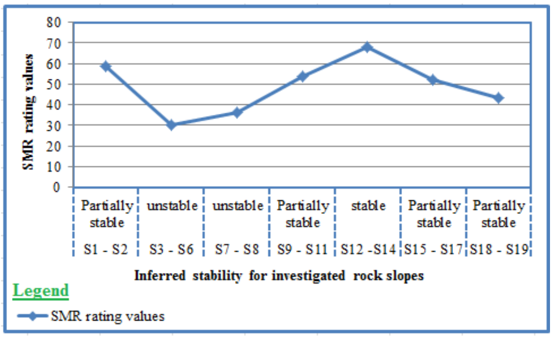

Fig. 4 Slope stability analysis for the investigated slopes in the current study.

Consequently, we can classify these failures modes as a "structurally - controlled failures". This can reasonably be expected because the study area was repeatedly affected by folded, uplifted – thrusting through Early Cimmerian Orogeny. In addition to impact of severe weather conditions such as climates heavy rains, snow, etc..; and man-made activities, therefore, field studies and obtained results have shown that there is a positive correlation between joints - slope parameters and failure modes (planer, wedge, toppling).

Also, in this study, we propose that slope flattening with various angles method, wire mesh; and toe support by detached rock blocks are suitable remedial solutions to ensure slope stability of the studied roadway from failure. On the other hand, it is inferred that rock bolting is not suitable for the cut slope of this study due to the highly fractured nature of the rock mass. If any, as shown in Fig. 5, re-design of roadside drainage ditch to protect sensitive rock slopes from failure can be optimized, where drainage is generally used to mitigate larger rockslides and failures.

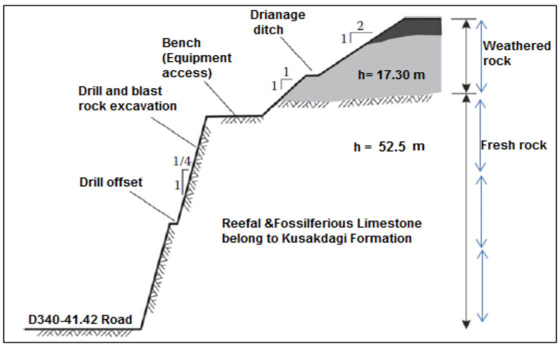

Fig. 5 suitable proposed solution by Slope flattening with various angles for investigated rock slope No.17

6. CONCLUSION

Utilizing SMR classification (Romana, 1985) which we sought to test in this paper, an adjustment factors (F1, F2, F3) and excavation method (F4) were considered in this study. From this study, it was found that SMR can be applicable to thickly-massive and extremely rocks like massive limestone of this study, because this rock will need to a heavy blasting, this blasting creates new fractures in the rock slopes, So, the effects of the new fractures on rock slopes with SMR classification as (F4) factor can be estimated. Probably some correction should be added for the block size (relative to slope height).

Also, in this study, SMR was successfully used for failure modes classification assessment in rocky and hilly areas (like Taurus in present study). In hence, from the current study we inferred that a detailed study should be carried out where SMR is less than 40 (S3-S8 in Table 5), and further studies need to be done to determine the cause of the differences that occur.

Moreover, it was found that the preliminary analysis with limited data RMR and SMR is more suitable. The detailed analysis requires more data and a comprehensive study of each layer.

Consequently, the geologist and geotechnical engineers works at General Directorate of Highways in Turkey are encouraged to use this classification in the initial evaluation of rocky slopes instabilities conditions, it is a practical, easy tool and it does not require much time.

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