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Research Article

Assessment of Slope Instability and Risk Analysis of Road Cut Slopes in Lashotor Pass, Iran

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Assessment of the stability of natural and artificial rock slopes is an important topic in the rock mechanics sciences. One of the most widely used methods for this purpose is the classification of the slope rock mass. In the recent decades, several rock slope classification systems are presented by many researchers. Each one of these rock mass classification systems uses different parameters and rating systems. These differences are due to the diversity of affecting parameters and the degree of influence on the rock slope stability. Another important point in rock slope stability is appraisal hazard and risk analysis. In the risk analysis, the degree of danger of rock slope instability is determined. The Lashotor pass is located in the Shiraz-Isfahan highway in Iran. Field surveys indicate that there are high potentialities of instability in the road cut slopes of the Lashotor pass. In the current paper, the stability of the rock slopes in the Lashotor pass is studied comprehensively with different classification methods. For risk analyses, we estimated dangerous area by use of the RocFall software. Furthermore, the dangers of falling rocks for the vehicles passing the Lashotor pass are estimated according to rockfall hazard rating system.

1. Introduction

Appraisal hazard and risk analysis is one of the most important issues in the rock slopes instability study. Risk is a measure of the probability and severity of adverse effects [1]. Risk is the combination of probability of an event and its consequences [2]. Therefore, for risk analysis of slope instability, the first step is assessment of the slope instability potential and probability of occurrence of the slope failure, and the next step is determination of the consequence and degree of danger of the slope instability.

Rock mass classification is a useful means for the assessment of the instability potentialof rock cut slopes based on the most important inherent and structural parameters [3]. The geomechanics classification or the rock mass rating (RMR) introduced by Bieniawski [4] was the first attempt to assess rock slope instability based on rock mass classification. Romana [5], by developing RMR, proposed slope mass rating (SMR) classification system, especially for rock slopes classification and judgment about slopes stability. Slope stability rating (SSR) system is proposed by Taheri and Tani [6, 7] for the characterization of slope stability of heavily jointed rock masses. This system is based on the geological strength index (GSI) system and the nonlinear Hoek-Brown failure criterion. To provide a more quantitative numerical basis for evaluating the GSI, this classification system was modified by Sonmez and Ulusay [8] and Sonmez and Ulusay [9] in which latest version of the quantitative GSI chart is used in the SSR system. Since some of the major slope stability parameters are not included in GSI, in SSR systems, besides the geological strength index (GSI), five additional parameters have been taken into account. These additional parameters included the uniaxial compressive strength, rock type, slope excavation method, groundwater, and earthquake force.

The RQD parameter is not used in the SSR calcification systems. This is the most advantage of the SSR comparing to the SMR and other calcification systems (SRMR, CSMR, GSI, VRFSR, and FRHI). The RQD is a basic component of many rock mass classification systems. There are several major disadvantages related to RQD definition and the drilling procedure [3]. Furthermore, in the RMR and SMR classification systems are simultaneously used the RQD index and "discontinuity spacing" parameter. In fact, the spacing of discontinuities has double influence on the final rating [10]. The other advantage of SSR classification is taken into account: the effect of earthquake force on the slope instability. This is very important and essential for slopes stability analyses in seismic active zones. Iran is located in the Alpine-Himalayan orogenic system and shows high seismic activity.

In many cases, spatially in vertical slopes or very steep slopes such as cut slope, other types of rock slope failure (wedge failure, planer failure, and toppling) may eventually lead to the rockfall event. If sliding distance of rock block or rock mass that detached by sliding, toppling, or falling was negligible to descending distance through air, it is defined as a rockfall [11]. Rockfalls constitute a major hazard in rock cuts alongside roads in mountainous regions that causes loss of life and property because of its very rapid movement [12].

In the past, the rockfall simulation was based on experience and extensive in situ rockfall tests [13]. Ritchie [14] by carrying out full scale tests on rockfall event proposed simple chart for determining required width and depth of rock catch ditches in relation to height and slope angle. Over the last decades, many computer programs are developed for simulation of rockfall [15–18]. One of the most practical programs of these computer programs is the RocFall software that can be used to simulate almost all types of rockfall events [19]. This software provides valuable information about kinetic energy, velocity, bounce height, and fall-out distance of falling rock fragment that are essential to determine the consequence and degree of danger of slope instability. The RocFall software also can be used to design remedial measures and test their effectiveness [19].

At the last two decades, a number of slope instability risk assessment systems have been developed and rockfall hazard rating system [20] is one of the most well-known of these systems [21]. This method used a simple approach for assessing and quantifying the risk of rockfalls in the transportation routes [22]. The rockfall hazard rating system (RHRS) contains nine deferent parameters which can be divided into two groups: the parameters that define rockfall hazard (slope height, geologic character, volume of rockfall/block size, climate, and presence of water on slope and rockfall history) and the parameters that indicate the vehicle vulnerability (ditch effectiveness, average vehicle risk, percent of decision sight distance, and roadway width) [12].

In this research, at the first step, the instability potential of the Lashotor trenches was assessed by use of SMR and SSR classification systems. Rock mass classifications indicate high instability potential and likely rockfalls in the Lashotor cut slopes. Therefore, direction, speed, and energy of the falling rock fragments are simulated for risk analyses using the RocFall software. Finally, the risk of falling rocks for the vehicles passing the Lashotor pass is estimated by using the rockfall hazard rating system.

2. General Characteristics of the Study Area

The Lashotor pass was constructed at 1991 in distance of 22 km of the Isfahan-Shiraz highway in Iran to eliminate the inappropriate and dangerous curvatures in the Lashotor pass and shorten the path. As shown in Figure 1, the length of the previous way is 6.88 km, while the current path in the Lashotor pass is 3.62 km. Also the new road is straighter than the previous one. Generally, this pass has 250 meters length and 24 meters width. The maximum height of the walls is 34 meters and the dips of the cut slopes are about 80 degrees.

Geologically, the Lashotor pass is located in the Kolah-Ghazi region in the central part of the Sanandaj-Sirjan zone. In this region, 30 to 50 meters of the upper Cretaceous limestone is lying on the lower Cretaceous shale and marl layers. In the central part of the Sanandaj-Sirjan zone, the fault pattern consists of major NW-trending longitudinal faults, NE-SW-trending transverse faults, and N-S-trending oblique faults [23]. Fault pattern in the study area is shown in Figure 2.

The nearest fault to the Lashotor pass is the Kolah-Ghazi fault. This fault has several branch minor faults. Approximately 61 m offset occurs along the Kolah-Ghazi fault, where the Quaternary gravel plains and the Holocene alluvial deposits are dissected and dextrally displaced by the fault and its branching minor faults. The maximum value of the slip rate calculated along the Kolah-Ghazi fault is about 9.2 mm/year [23]. Figures 3 and 4 show general view of the eastern and western Lashotor cut slopes. The movement caused by fault in the eastern cut slope face is indicated in Figure 3. Figure 4 shows a branch fault of the Kolah-Ghazi fault in the southern part of the Lashotor pass.

The presence of tectonic structures, such as faults and folds, can play significant role in the slope instability [24]. According to Pourghasemi et al. [25] there is high instability probability of slopes in distance less than 100 m of faults. KhaloKakaie and Naghadehi [26] studied slope stability with use of interaction matrix and estimated proportional share of sixteen parameters in slope failure. According to these studies, presence of faults and folds played significant role in the slope failure and its proportional share in slope failure is about 7.75%.

Figure 4 shows an unstable rock wedge in the western slope that is formed by intersection of the joint sets. These are just a few of evidences which address the instability of cut slopes in the Lashotor pass. The most notable failure in this pass occurred during a construction which caused temporary cessation of excavation [27]. The failed part of the western slope is shown in Figure 5.

3. Assessment of Instability Potential and Failure Types of the Slopes

For assessing of instability potential and failure types, at the first step, discontinuity and their spatial orientations in the Lashotor slopes were studied. According to the strike and dip of the discontinuity in respect to slope face orientation, we

Figure 1: The pervious and current roads are shown in the Google Earth image.

can determine the probability and type of failure. Properties and orientation of joints sets and bedding plane in the two walls of the Lashotor pass are determined in a field survey. A total of 253 discontinuities were surveyed.

Most of the joints have rough surfaces and calcite filling. Deduced information from the field joints study has been analyzed by using Dips and Swedge software, whose results are presented in Figures 6 and 7.

As shown in Figures 6 and 7, there are five discontinuities sets (four joint sets and bedding surface) in both walls of the Lashotor pass, in which intersection of the joint sets formed different unstable wedges in eastern and western walls.

Table 1: Value of RMR_B in the two slopes of the Lashotor pass.

Parameters	Western cut slope		Eastern cut slope	
	Value	Rating	Value	Rating
UCS	4.2 MPa	12	4.2 MPa	12
RQD	88%	17	89%	17
Joint spacing	1.3 m	15	0.6 m	10
Joint condition	Slicken sided and 1–5 mm wide	10	Slicken sided and 1–5 mm wide	10
Ground water condition	Damp	10	Damp	10
Summation (RMR_B)		64		59

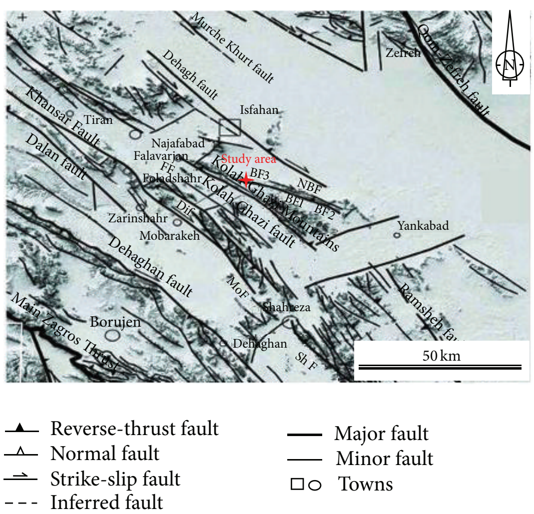


Figure 2: Fault pattern in the Kolah-Ghazi region [23].

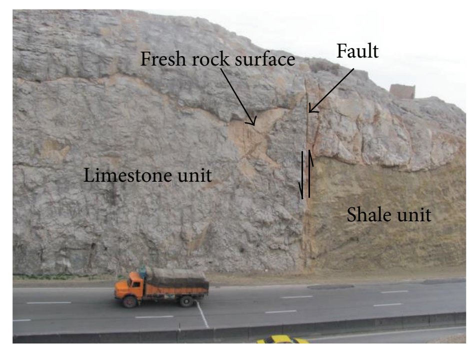


Figure 3: A general view of the eastern slope: rock unit, fresh rock surface, and displacement of fault are shown.

3.1. Slope Mass Rating (SMR) Classification. One of the most common classification systems for evaluation of rock slope stability is the SMR classification. The slope mass rating (SMR) is obtained from basic rock mass rating (RMR_B) by adding adjustment factors depending on the relative orientation of joints and slope and adding another factor depending on the method of excavation based on (1) as follows [28]:

$$SMR = RMR_B - (F1 \cdot F2 \cdot F3) + F4, \quad (1)$$

where the RMR_B is computed according to Bieniawski's [4] proposal, $F1$, $F2$, and $F3$ are adjustment factors that are related to joints orientation with respect to slope orientation, and $F4$ is the correction factor depending on the excavation method of slope.

Table 1 shows the required parameters for determination of RMR_B and their rating for two walls of the Lashotor pass.

Adjustment factors of $F1$, $F2$, and $F3$ for each probability slide plane or slide line are evaluated separately and their results are presented in Tables 2 and 3.

Finally, after determination of RMR_B and adjustment factors for most critical state, values of modified SMR for the two walls are calculated and presented in Table 4.

The slope excavation method is a normal blasting. Therefore, factor of $F4$ is zero.

Table 2: Adjustment factors ($F1$, $F2$, and $F3$) of the western cut slope.

	$F1$	$F2$	$F3$	$F1 \cdot F2 \cdot F3$
J1	0.15	1	−25	−3.8
J2	0.15	1	−25	−3.8
J3	0.33	1	−25	−8.25
J4	0.52	1	−25	−13
Sliding line resulting intersection of J1 and J2	0.55	1	−60	−33
Bedding plane	0.6	0.15	−60	−5.4

The sum adjustment factors for the wedge failure are more than other types of failure. Therefore, it is concluded that wedge failure type is more critical than others in both walls of the Lashotor pass and should be considered as a worst state with lowest SMR rate.

Based on the SMR classification system, the rock mass in the two slopes of the Lashotor pass is in the bad class (IV) and they are unstable and a big wedge failure is feasible (Probability of Failure 60%).

3.2. Slope Stability Rating (SSR) Classification. A lot of excavated slopes in Iran and Australia were studied by Taheri and Tani [6]. Based on this investigation, they presented the slope stability rating (SSR) classification system as follows:

$$SSR = GSI_{(2002)} + (F1 + F2 + F3 + F4 + F5), \quad (2)$$

(a)

(b)

FIGURE 4: Two views of the western slope: rock unit, Kolah-Ghazi fault branch, unstable rock blocks, and traces of previous slope failure are shown.

TABLE 3: Adjustment factors ($F1$, $F2$, and $F3$) of the eastern cut slope.

	$F1$	$F2$	$F3$	$F1 \cdot F2 \cdot F3$
J1	0.15	1	−25	−3.8
J2	0.15	1	−25	−3.8
J3	0.30	1	−25	−7.5
J4	0.58	1	−25	−14.5
Sliding line resulting intersection of J2 and J3	0.68	1	−50	−34
Bedding plane	0.6	0.15	−60	−5.4

TABLE 4: SMR values.

	$\mathrm{RMR_B}$	$F1 \cdot F2 \cdot F3 + F4$	SMR
Western cut slope	64	−33	31
Eastern cut slope	59	−34	25

where $\mathrm{GSI}_{(2002)}$ is modified GSI by Sonmez and Ulusay (2002) and $F1$, $F2$, $F3$, $F4$, and $F5$ are adjustment factors whose explanation and rating are presented in Table 5.

3.2.1. Determination of $GSI_{(2002)}$. To determine the GSI using modified chart of Sönmez and Ulusay [9], quantitative GSI chart, two parameters of surface conditions rating (SCR) and structural rating (SR) must be determined as follows:

$$\mathrm{SCR} = R_r + R_w + R_F, \tag{3}$$

$$\mathrm{SR} = -17.5 \ln\left(J_V\right) + 79.8, \tag{4}$$

where R_r, R_w, and R_f are roughness rating, weathering rating, and infilling rating, respectively, and J_V is the number of joints per unit volume of rock mass. Rating of these parameters and the SCR value are presented in Table 6.

The number of joints within unit volume of rock mass (J_V) is calculated using the following equation:

$$J_V = \sum_{i=1}^{j} \frac{1}{S_i}, \tag{5}$$

FIGURE 5: The rock wedge prone to sliding in the west cut slope of the Lashotor pass.

where S_i is the average joint spacing in meters for the ith joint set and j is the total number of joint sets except the random joint set.

In the studied slopes $J_V = 8$ and SR value with use of (4) was equal to 43.

Using two parameters SCR and SR, GSI value of the slopes rock mass was determined to be about 55.

3.2.2. Determination of Adjustment Factors $F1$, $F2$, $F3$, $F4$, and $F5$. $F1$: the intact rock strength, UCS, is one of the effective parameters on the stability of rock slopes. Point load test was done on approximately cubic shape samples. The point load index was determined to be about 4.2 and the uniaxial comparative strength of the samples were estimated using the point load index in the range of 50 to 100 Mpa. Therefore, the rate of $F1$ according to Table 5 is equal to 28.

$F2$: slope stability analyses showed that the variation of m_i in the Hoek-Brown failure criterion and the dry unit weight of intact rock have considerable effects on the stability of rock slopes. Since these two parameters are related to rock type (lithology) of slope, Taheri and Tani [6], with the use of the reference tables of rock material specifications proposed by Hoek et al. [36], classified rocks into six groups with different lithological characteristics (Table 6). As mentioned above lithology of the rock mass of the slopes is carbonate and shale, which, according to Table 5, are in Group 3 and their rates are equal to 9.

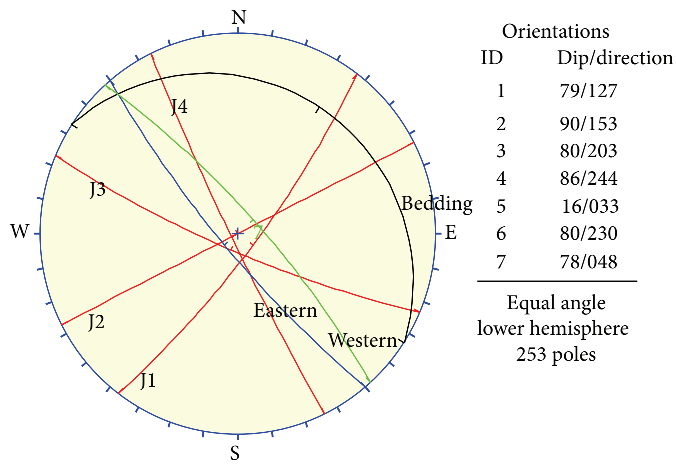
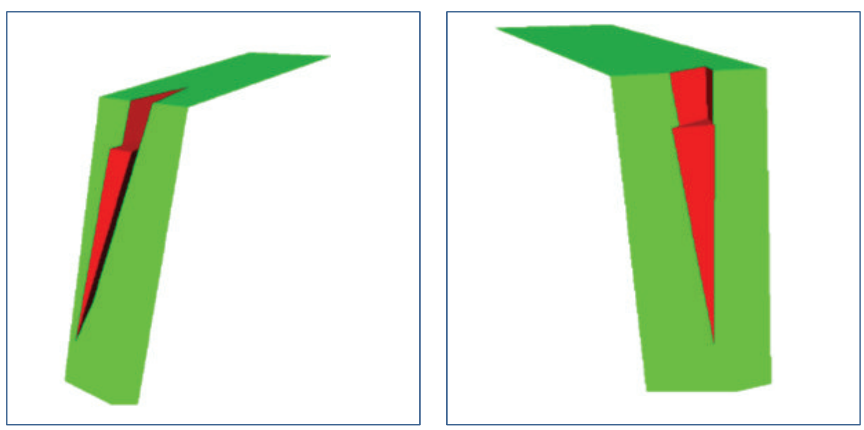


FIGURE 6: The stereographic projection of joints sets and bedding in the western and eastern slope of the Lashotor pass.



(a) (b)

FIGURE 7: (a) Three-dimensional view of the sliding wedge which forms the intersection of the joints J1 and J2 and the western slope face. (b) Three-dimensional view of the sliding wedge which forms the intersection of the joints J2 and J3 and the eastern slope face.

TABLE 5: Adjustment factors $F1$, $F2$, $F3$, $F4$, and $F5$ and range of value in the SSR classification system (Taheri and Tani 2010) [6].

	Parameter		Range of values					
$F1$	Uniaxial compressive strength (MPa)		0–10	10–25	25–50	50–100	100–150	150–200
	Rating		0	7	18	28	37	43
$F2$	Rock type		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
	Rating		0	4	9	17	20	25
$F3$	Slope excavation method		Waste damp	Poor blasting	Normal blasting	Smooth blasting	Presplitting	Natural slope
	Rating		−11	−4	0	6	10	24
$F4$	Groundwater	(Groundwater level from bottom of the slope/slope height) × 100	Dry	0–20%	20–40%	40–60%	60–80%	80–100%
	Rating		0	−1	−3	−6	−14	−18
$F5$	Earthquake force	Horizontal acceleration	0	0.15 g	0.20 g	0.25 g	0.30 g	0.35 g
	Rating		0	−11	−15	−19	−22	−26

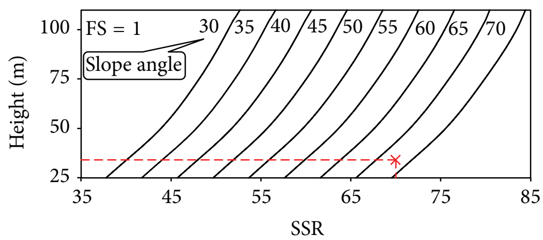


Figure 8: Determination of stable dip of rock slope based on SSR value and slope's height.

Table 6: Joints surface condition rating (SCR) and its rating in the studied slopes according to modified GSI classification [9].

	Roughness	Weathering	Infilling	SCR (mean)
Description	Rough-very rough	None_slightly	Hard	—
Rating	5-6	5-6	2–4	14

*F*3: the slope excavation method has considerable effects on the stability of rock slopes. The conventional excavation methods and their rates are presented in Table 5. As previously mentioned, excavation method of the Lashotor pass is normal blasting and, according to Table 5, $F3 = 0$.

*F*4: since the groundwater level is below the bottom of the pass, rate of this parameter ($F4$) according to Table 5 is equal to zero.

*F*5: the dynamic loading of earthquake has great effects on instability of slopes and should account for slope stability analysis especially in active seismic zones. Based on the seismic hazard zonation map of Iran for the return period of 75 years [37], the Lashotor pass is located in the low risk zone with the horizontal ground acceleration of about 0.2 g.

In detailed study, the amount of horizontal earthquake acceleration for studied area can be calculated using the relationship between the distance of the site to the hypocenter of earthquakes and earthquakes magnitude.

Also various relations are proposed by many researchers for any regions to determine the magnitude of earthquakes in terms of the length of causative fault. The most widely used of these relations for Iran are presented by Mohajer-Ashjai and Nowroozi [31], Nowroozi [29], and Ambraseys and Melville [30]. Major faults at the study area and other required parameters to calculate the maximum earthquake magnitude and horizontal peak ground acceleration (PGA) are presented in Table 7. The results of calculations of the maximum earthquake magnitude and PGA for the major faults around the Lashotor pass are presented in Table 8.

Based on the results of the calculations, the predicted maximum ground horizontal acceleration for the study area is equal to 0.3 g, which is generated by the Dehagh fault (DeF). Therefore, rate of $F5$ according to Table 5 is determined to be equal to −22.

3.2.3. Calculation of SSR and the Slope Stability Assessment. The value of slope stability rating (SSR) of two walls of the Lashotor pass was determined to be about 70. Due to the lack of orientation effect of discontinuities with respect to slope orientation in SSR value, the value of SSR is the same for both sides of the Lashotor pass.

Taheri and Tani [6] presented several graphs with the different safety factor for judgments about slope stability based on height and dip of the slope and its SSR value. By plotting of the SSR value versus the slopes height in these graphs (Figure 8), it was found that the dip of the studied slopes (approximately 80°) was higher than the maximum stable dips (nearly 65°). Therefore, to achieve stable slopes, with the minimum acceptable safety factors (FS = 1), the dips angle of slopes should be reduced to less than 67°.

4. Rockfall Simulation Analysis

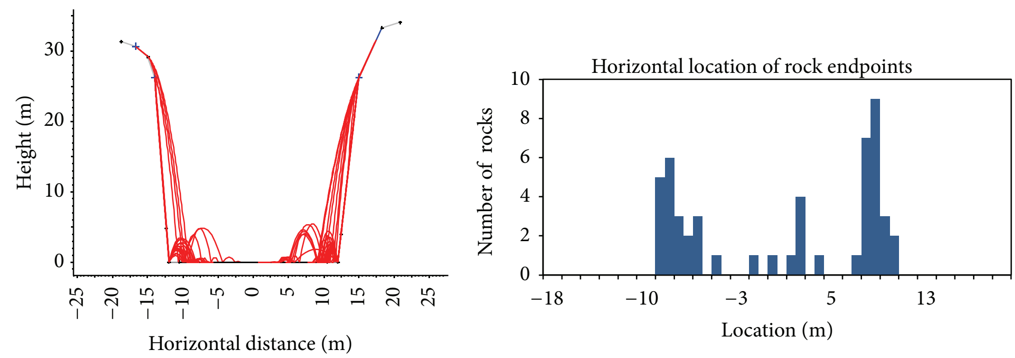
An essential component in the evaluation of potential hazard of rock slope instability is simulation of rockfalls to estimate the rock falling trajectories, translational velocity, total kinetic energy, and endpoints location of the falling rocks. RocFall software is a 2D statistical analysis program for rockfall simulation. In this paper, RocFall© V4 software [38] was used for modeling of rockfalls in the Lashotor pass. Rockfall simulation in the Lashotor pass in Figure 9 indicated that most of the falling rocks will reach the highway.

As it is shown in Figure 10, falling rock have high velocity which exceeded 20 m/s in the moment of impact with the surface of highway.

5. Falling Rock Hazard

One of the most accepted methods for rockfall hazard assessment in highway is the rockfall hazard rating system (RHRS) developed by Pierson et al. [35]. Table 9 gives included parameters and typical scores in this classification system. Also, the scores of each parameter (y) can be determined by $y = 3^x$, where x for different parameter is calculated by

$$
\begin{aligned}
&\text{Slope height}\\
&\qquad x = \frac{\text{slope height (feet)}}{25},\\
&\text{Average vehicle risk}\\
&\qquad x = \frac{\%\text{time}}{25},\\
&\text{Decision Sight distance (\%)}\\
&\qquad x = \frac{(120 - \%\text{Decision sight distance})}{20},\\
&\text{Roadway width}\\
&\qquad x = \frac{(52 - \text{Roadway width (feet)})}{8},\\
&\text{Block size}\\
&\qquad x = \text{Block size (feet)},\\
&\text{Volume}\\
&\qquad x = \frac{\text{Volume (cu.ft.)}}{3}.
\end{aligned}
\tag{6}
$$



(a) (b)

FIGURE 9: (a) Slopes geometry and trajectories. (b) Endpoints graph of falling rock fragments.

TABLE 7: Major faults at around of the Lashotor pass.

Name of fault	Strike/dip and dip direction of fault	Length (km)	Mechanism	Horizontal distance (km)
North Baharestan (NBF)	095–115/60e75 SW	45	D + R	6.7
Baharestan (BF)	280–300/45 NE	33	R + D	2.4
Dalan (DaF)	290–320/60 NE	180	R + D	51
Mobarakeh (MoF)	310–325/70 NE	60	R + D	21
Dizicheh (DiF)	310–335/75e80 NE	37	R + D	19
Dehaghan (DF)	120–145/60 SW	250	R + D	56
Dehagh (DeF)	290–320/60e70 NE	200	R + D	16
Kolah-Ghazi (KGF)	300–310/55 NE	50	R + D	0
Foladshahr (FF)	120–145/70 SW	70	R + D	11

N: normal, R: reverse, D: dextral, and S: sinistral strike-slip component of movements.

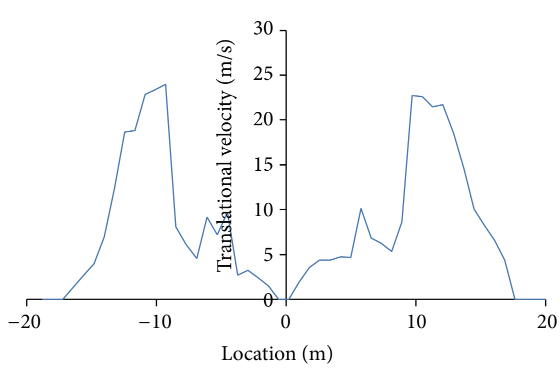


FIGURE 10: Translational velocity envelope of rockfalls.

(1) Slope height (m): vertical height of the slope has great effect on the energy and velocity of filling rocks. Height of the Lashotor slopes is about 34 meters. One of the factors which can be very hazardous rockfall event in the Lashotor pass is the height of the slopes.

(2) Ditch effectiveness: the effectiveness of a ditch is measured by its ability to prevent falling rock from reaching the roadway [39].

As is shown in Figures 3 and 4, the highway has no ditch. Therefore, the rating of this category was assumed to be equal to 81.

(3) Average vehicle risk (AVR): this parameter defined percentage of time that a vehicle will be at risk and calculated as [20]

$$\text{AVR\%} = \frac{(\text{ADT}/24) \times \text{Slope length}}{\text{Posted speed limit}} \times 100, \quad (7)$$

where ADT is the average traffic per day (vehicle/day).

Posted speed limit in this section of highway equals 120 km/h and the slope length is about 250 m. With respect to importance of the Shiraz-Isfahan highway, this highway has heavy traffic. Therefore, at most of the time more than one vehicle is presented within the Lashotor pass (AVR > 100%).

(4) Percent of decision sight distance: this parameter is dependent on two items: (1) the length of roadway that drivers need to make instantaneous decision which is function of posted speed limit through the rockfall section and (2) actual sight distance that is defined as shortest distance along a roadway that a six-inch object is continuously visible to a driver.

Percent of decision sight distance can be calculated as follows [20]:

$$\text{DSD\%} = \frac{\text{Actual sight distance}}{\text{decision sight distance}} \times 100. \quad (8)$$

Table 8: Maximum potentiality earthquakes magnitude of faults and maximum horizontal acceleration in the study area.

Fault	Nowroozi [29]	Ambraseys and Melville [30]	Mohajer-Ashjai and Nowroozi [31]	Mean	Dams and Moore [32]	Niazi and Bozorgnia [33]	Zare et al. [34]	PGA
NBF	6.7	6.6	6.8	6.7	0.39	0.16	0.16	0.24
BF	6.5	6.4	6.6	6.5	0.37	0.14	0.15	0.22
DaF	7.3	7.3	7.3	7.3	0.24	0.13	0.08	0.15
MoF	6.8	6.7	6.9	6.8	0.32	0.13	0.11	0.19
DiF	6.6	6.4	6.7	6.57	0.29	0.11	0.1	0.17
DF	7.3	7.3	7.3	7.3	0.26	0.15	0.07	0.14
DeF	7.3	7.3	7.3	7.3	0.51	0.24	0.21	0.3
KGF	6.7	6.6	6.8	6.7	0.41	0.16	0.18	0.25
FF	6.9	6.8	6.9	6.87	0.41	0.17	0.17	0.25

Table 9: Rockfall hazard rating system parameters and their scores [35].

Category	Rating criteria and score			
	Points 3	Points 9	Points 27	Points 81
Slope height	7.5 m	15 m	22.5 m	30 m
Ditch effectiveness	Good catchment	Moderate catchment	Limited catchment	No catchment
Average vehicle risk (% of time)	25%	50%	75%	100%
Percent of decision sight distance	Adequate sight distance, 100% of low design value	Moderate sight distance, 80% of low design value	Limited sight distance, 60% of low design value	Very limited sight distance, 40% of low design value
Roadway width included paved shoulders	13.20 m	10.80 m	8.40 m	6.00 m
Geologic character				
Case 1				
Structural condition	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
Rock friction	Rough, irregular	Undulating	Planar	Clay infilling or slickenside
Case 2				
Structural condition	Few differential erosion features	Occasional differential erosion features	Many differential erosion features	Major differential erosion features
Difference in erosion rates	Small	Moderate	Large	Extreme
Block size	30.48 cm	60.96 cm	91.44 cm	121.92 cm
Volume of rockfall per event	2.3 m^3	4.6 m^3	6.9 m^3	9.2 m^3
Climate and presence of water on slope	Low to moderate precipitation, no freezing periods, no water on slope	Moderate precipitation or short freezing periods intermittent water on slope	High precipitation or long freezing periods or continual water on slope	High precipitation and long freezing periods or continual water on slope and long freezing periods
Rockfall history	Few falls	Occasional falls	Many falls	Constant falls

According to ODT [40] suggestion, the lower value of the decision sight distance in speed of 120 km/h is about 340 m. The route in the Lashotor pass is straight and no horizontal and vertical curves or obstacles exist on the road that limit sight of derivers. Therefore, actual sight distance is approximately equal to needed distance for deriver decision.

(5) Roadway width: this item defines the available maneuver room for a driver to avoid falling/fallen rock blocks. The roadway width of the Lashotor pass with respect to the highway is divided by centerline bocks, considering half whole of its width (measured from one edge of the shoulders to the centerline bocks).

(6) Geologic character: the RHRS method discussed two categories of the geological conditions which control rockfalls. Case 1 includes slopes or cuts where joints, bedding planes, or other discontinuities are

Table 10: RHRS ratings for the Lashotor slopes.

Parameter	Value	Rating
Slope height	34	100
Ditch effectiveness	No catchment	81
Average vehicle risk	450	100
Sight distance	Adequate sit distance 100%	3
Roadway width	12 m	6
Structural condition	Continuous joints, adverse orientation	81
Rock friction	Planar	27
Block size	0.5–1 m	37
Climate water	Moderate precip.	9
Rockfall history	Occasional falls	9
Total score		461

the dominant structural feature that control rockfalls occurrence. In this case consider continuity and orientation of joints and rock friction. Case 2 is for slopes where differential erosion and/or oversteepened slopes are the main factors that control rockfalls occurrence. Field survey and study of rockfall event that occurred in the Lashotor slopes show that the slopes are classified as case 1. Orientation, continuity, and surface condition of 253 discontinuities in the Lashotor slopes were defined.

(7) Block size or volume of rockfall per event: use of block size or volume depends on type of rockfall event that is most likely to occur. Block size should be used for individual block fall and volume should be used for rock mass fall. Based on field survey, individual blocks are typical of the rockfall in the Lashotor pass, although rock mass fall is not unexpected.

(8) Climate and presence of water on slope: presence of water and freeze/thaw cycles in addition to reducing the rock mass stability also played important role in the weathering [39]. According to the meteorological records, average of annual rainfalls in the studied area is about 122 mm and average of minimum temperature in December, January, and February is below zero.

(9) Rockfall history: historical information about frequency and magnitude of previous rockfall events is an excellent indicator for future expected events [20]. Except for the huge failure that occurred during the construction period, there is not any official report about rockfall occurrence in the Lashotor cut slopes. But the evidences of various rockfall events were indicated in the felid survey.

Summary explanation of RHRS parameters and ratings in the Lashotor pass is presented in Table 10.

According to this classification, slopes with a total score less than 300 are assigned a very low priority while slopes with a rating in excess of 500 are identified for urgent remedial action. As shown in Table 10, total score or RHRS value of the Lashotor pass slopes is about 461 that is near to limit of 500 and therefore remedial action is urgent.

6. Conclusion

Field evidence and primary survey of the Lashotor pass indicate high potentiality of slope failure in two of its rock cut slopes. Joint study and analysis of results with use of Dips and Swedge software indicate high likelihood of wedge failure, especially in the eastern slope, and toppling in the two slopes. The most significant influenced parameter in the Lashotor slopes instabilities is presence of the fault in the walls of the pass.

Based on the SMR values of slopes, the slopes rock mass is in bad class and unstable and prone to big failure. Based on SSR values and with respect to dip and high of the slopes, safety factors of both slopes are less than 1 and therefore unstable.

Also, based on this interaction matrix and the weighting coefficient of the parameters presented by KhaloKakaie and Naghadehi [26], instability indexes (IIj) of the Lashotor slopes are about 57 and classified as the unstable slopes.

Rockfall simulation in the Lashotor pass by RocFall software indicated that most of the falling rocks will reach the highway. Rockfall hazard rating system value of the Lashotor pass slopes is about 461 that emphasizes the risk of instability and the danger threatening vehicle moving there.

Based on two rock mass classification systems, SMR and SSR, probability of slope instability occurrence in the Lashotor pass is high, and based on rockfall simulation and rockfall hazard rating system occurrence of rockfall in the Lashotor pass can have very dangerous results. Therefore, the Lashotor should be classified as high-risk area.

One of the considerable problems in the Lashotor pass is exposure of shale layers in south section. Since the shale rock is weak and prone to weathering, deterioration and softening of the shale layer along the time increase the instability potential of the slopes. In addition to that long periods of exposure of carbonate rock mass to the slope face allow for the increase of weathering effects and weaken the rock mass, which result in increased possibility of dislodging of rock pieces.

Studying various methods of stabilization of the slope (advantage, limitation, and applied requirement), and with respect to the slopes conditions, reinforced shotcrete is suggested for the slopes stabilization. Shotcrete protects the rock from progressive weathering and erosions that could eventually produce unstable overhangs and increased instability potential. The reinforced shotcrete will also control the fall of small blocks of rock and increase structural support. Also simulation of rockfalls with RocFall V4 software indicated that dig of shallow ditches in two sides of the highway can trap a large number of fallen rock fragments and prevents them from arriving to the highway.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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