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Rockfall Assessment along Saptashrungi Gad Temple (SGT) Road, Nashik, Maharashtra, India

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Abstract: Rockfall is a type of landslide, wherein, a single block or groups of independent blocks move down the hilly slopes/regions under the influence of gravity. The movement is the combination of free-fall, bounce, slide or roll. Rockfall will be the scientific interest only if they occur in remote area, however they are more than the spectacular natural process if occur along the busy roadways. Heavy rainfall is the major cause for rockfall; however, there are other causes too. Rockfall Hazard Rating System for India (RHRSI) is scheme for rating rockfall prone zones and use to define overall stability of slopes along mountainous and steep slopes. Once rating system identifies critical zones, proper protection measures can be applied through various methods to prevent rockfalls. In this article, RHRSI is adopted to identify slopes, prone to rockfalls and afterward proper preventive measure can be proposed. Saptashrungi Gad Temple (SGT) is a pilgrim's site, situated 60 km from Nashik. A 9.73 km curve road with several hair pin turns has been taken by pilgrims as well as tourist to reach to the temple. This zigzag nature of the road, starting from the toe of the hill to the top of the temple, causes risk to the life of the pilgrims, tourists and could cause damage to the vehicles from the rockfalls. SGT curve road is chosen for rockfall hazard rating. Also, an attempt has been made to focus on the consequence of failure along with risk of failure. To this aim, the RHRSI is applied to SGT curve road on several locations prone to rockfall hazard and to propose remedial measures that can control the risk from the rockfall and will reduce the loss of life and damage to the properties.

***Keywords:** RHRSI, Rockfall, Risk..*

1. Introduction

Roads through hilly regions often encounter rockfalls, cause injuries and death to roadway users, traffic delays, diversions and damage of road surface. Typical examples are discussed by several researchers [1-4]. The term risk and hazard have different sense related to affected zone. One can define hazard as a source of potential damage, or a situation with a potential for causing damage, in terms of human injury; damage to health, property, environment and other things of value whereas risk is the chance of injury or loss defined as a measure of the probability and severity of an adverse effect to health, property, environment, or other things of value [5]. The responses of the government agencies after any casualties are to release the emergency funds and to remediate the individual slope. However, the consequences of rock failure are very large, costlier than the remediation. So, the transportation agencies need to adopt a proactive approach based on a systematic identification and prevention of the rockfall problem.
For the systematic identification of rockfall prone slopes, a rating system should be used to speed up the analysis of potentially dangerous rockfall slope. Considering the relevance of the topic, this paper identifies rockfall prone zone with the help of Rockfall Rating System for India [6] and focusing on the consequence of failure [7].

2. Location and Accessibility of SGT Curve Road.

The Saptashrungi Gad Temple (SGT) is a holy place for the pilgrims and lots of pilgrims are visiting the temple every year. The study area is located near Nashik and NH-3 highway provides an arterial link to Nashik. From Nashik, a State Highway (SH)-17 is connected to the NH-3 highway that reaches the Gad site located near the village of Vani. The site has been experiencing rockfalls during last couple of years that have caused much damage to road and inflicted injuries to pilgrims. The study area belongs to the Sahyadri ranges of the Deccan Trap and comprises hard and amygdaloidal basalts, bole beds (red bole) and lateritic soils. The age of the basaltic rocks ranges from Upper Cretaceous to Lower Eocene. Weathered, jointed, fractured and columnar joints in basaltic rocks have been observed.

The SGT curve road can be divided into several zones on the basis of altitude, rockmass characterization, traffic history and frequent rockfall occurrence. Therefore, RHRSI investigation has been performed on five locations along SGT curve road and named as Zone-1 to Zone-5 (Fig.1).

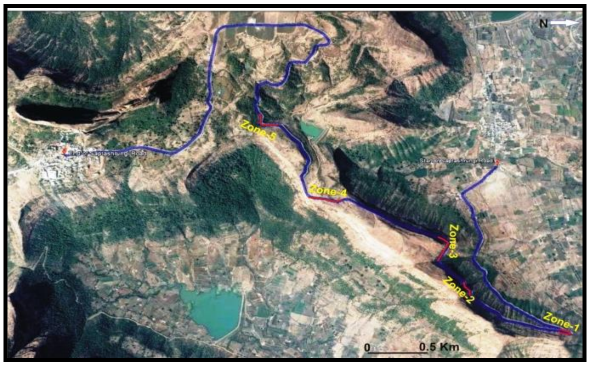

Figure 1 *SGT curve road shown by blue line and location of rockfall prone zone marked by red line.*

3. Rockfall Hazard Rating System for India (RHRSI).

RHRSI is a qualitative method for the prioritization of the most rockfall prone zones along roadways, highways and railways that need urgent remedial works. The method is proposed by Ansari et al., [6] and includes five major classes (28 parameters) by which slopes are evaluated and scored (Table-1). Then, the scores pertaining to different parameters are totaled. For each parameter, the rating criteria scores increase exponentially from 3 to 81 points. In this regard, it is worth noting that the set scores are merely representatives of continuum of points from 1 to 100.

The parameters contain several sub-parameters based on characterization of vulnerability (slope height, geologic character, volume of rockfall/block size), rockfall triggering causes (climate and presence of water on slope) and rockfall frequency. Factors affecting the temporal spatial probability as well as vulnerability of the elements at risk [ditch effectiveness, average vehicle risk (AVR), percent of decision sight distance (PDSD), roadway width (RW)] are also contemplated. As a consequence, the resulting total score can be considered as a rough estimation of rockfall risk in relative terms to which persons within vehicles travelling along a given road are exposed [8]. Obviously, slopes having the highest total scores present the greatest risk.

Once rated, the sites can be prioritized on the basis of their total scores. The lists so obtained can be used in the decisional process aimed to ascertain where safety projects should be initiated. In this way, the Rockfall Hazard Rating System (RHRS) method contemplates the so-called ‘‘preliminary design and cost estimate’’ that essentially is a cost-benefit analysis. Finally, the last step consists in annually reviewing and updating of the scores as well as in maintaining the rockfall database.

Also, a relation between risk of failure and consequence of failure has been plotted using the same RHRSI by dividing these 28 parameters into risk and consequence factors. For this average slope angle score, ditch catchment and traffic class is considered in consequence of failure and rest of the parameters considered in risk of failure. For example, a vertical slope present the highest risk of failure but a lower consequence with adequate catchment area and a 30° slope present highest consequence for large rolling blocks and an 85° slope would have the highest consequence from small bouncing blocks. The risk and consequence analysis will help in finding out the zone of high risk and high consequence rather than low risk and low consequence.

4. Results and Discussions

On the basis of field survey, five rockfall zones (Zone-1 to Zone-5) have been identified (Fig.1) in order to determine which slope section poses the highest risk to life. To achieve this aim, parameters mentioned in Table-1 used rating. The points system mentioned in Table-1 is an exponential one and brief explanations of the parameters are as follows.

4.1. Slope Geometry

Slope is the essential parameter to access the availability of rockfall. Slope height, angle, launching features and ditch effectiveness are the main parameters considered for the rating. These parameters are explained below.

(a) Slope Height: It is an important measure of risk because rocks present on the higher slopes have higher potential energy and possess greater hazard thus assign higher rating. After knowing the slope height, its corresponding point/score can be weighted from the table-1. Also, exact score can be calculated using equation (1)

$$\text{Excat score for slope height (SH)} = 3^{\left(\frac{\text{SH (m)}}{7.5}\right)} \qquad (1)$$

(b) Average Slope Angle: It provides useful information about the run-out distance and indicates that the scoring of slope angle at critical slope angle may change the scenario of rockfall trajectory, consequently damage level from the rockfall too.

(c) Launching Features: This parameter is the measure of the smoothness of the slope and gives an idea about the position of rockfall occurrence [7, 9].

(d) Ditch Effectiveness: Ditch is the area in between the slope and roadway. The effectiveness of a ditch is measured by its ability to restrict falling rock from reaching the roadway or public place.
Ditch effectiveness is a subjective parameters and its weight is given in table-1. Also, ratings for all slope

geometry parameters for different zones are tabulated in table-2.

4.2. Climatic Conditions

Studying climate and presence of water in the slope is essential as water and freeze cycles contribute an important role in rock movement. Annual precipitation, annual freeze/thaw cycles, seepage/water and slope aspect are the important parameters considered under the climatic condition for rating. These parameters are explained below;

(a) Annual Precipitation (AP): It provides actual amount of rainfall in a year. AP score can be calculated using equation (2).

$$\text{Excat score for annual precipitation (AP)} = 3^{\left(\frac{AP(mm)}{254}\right)} \quad (2)$$

The data for annual rainfall can be retrieved from Indian Meteorological Department (IMD).

Table 1: *Rockfall Hazard Rating System for India (RHRSI) [6]*

Category			3 Points	9 Points	27 Points	81 Points
Slope		Slope Height	7.5 m	15 m	23 m	30 m
		Average Slope Angle Score	A	B	C	D
		Vegetation	Fully Vegeted	Patchy Vegetation	Isolated Plants	None
		Launching Features	None (Smooth Slope)	Minor (< 0.6m Surface Variation	Many (0.6 To 1.8m Surf. Variation	Major (> 1.8m Surf. Variation
		Ditch Catchment	Good Catchment	Moderate Catchment	Limited Catchment	No Catchment
Climate		Annual Precipitation	254mm	508mm	762mm	1016mm
		Annual Freeze Thaw Cycles	1-5	6-10	11-15	>16
		Seepage/Water	Dry	Damp/Wet	Dripping	Running Water
		Slope Aspect	W	N, S, NW, SW	SE, NE	S
Geology	Sed. Rock	Degree of Undercutting	0 To 0.3m	0.3 To 0.6m	0.6 To 1.2m	> 1.2m
		SDI	95-100%	60-95%	30-60%	< 30%
		Degree of Inter-bedding	1 To 2 Weak Interbeds, < 15cm	1 To 2 Weak Interbeds, > 15cm	> 2 Weak Interbeds, < 15cm	> 2 Weak Interbeds, > 15cm
	Crystalline Rock	Rock Character	Homogeneous/ Massive	Small Faults/ Strong Veins	Schist Shear Zones < 15cm	Weak Pegmatite's/ Micas/Shear Zones > 15cm
		Degree of Overhang	0.0m to 0.3m	0.3m to 0.6m	0.6m to 1.2m	> 1.2m
		Weathering Grade	Fresh	Surface Staining	Slightly Altered/ Softened	Core Stones
	Discontinuities	Block Size/Volume	$0.3m/2.3m^3$	$0.6m/4.6m^3$	$0.9m/6.9m^3$	$1.2m/9.2m^3$
		Block Shape	Tabular	Blocky	Blocky To Angular	Rounded And Smooth
		Number of Sets	1	1 Plus Random	2	> 2
		Persistence, Orientation	< 3m And Dips Into Slope	> 3m And Dips Into Slope	< 3m And Daylight Out of The Slope	> 3m And Daylight Out of The Slope
		Aperture	Closed	0.1 to 1mm	1 to 5mm	> 5mm
		Weathering Condition	Grade I & II	Grade III	Grade IV	Grade V &VI
		Friction	Rough	Undulating	Planar	Slicken sided
		Infilling Material	Heal Infilling	Coarse grain fault gouge	Fine grain fault gouge	Clay Infilling
Traffic		Percentage Decision Sight Distance (DSD)	100%	80%	60%	40%
		Average Vehicle Risk (AVR)	25%	50%	75%	100%
		Roadway Width Including Paved Shoulder (m)	13.2 m	10.8 m	8.4 m	6 m
		No. of Accident	0 To 2	3 To 5	6 To 8	9 and Over
Rockfall History/Frequency			0 to 3 per year	4 to 7 per year	8 to 12 per year	> 12 per year

(b) Annual Freeze/Thaw Cycles: Annual freeze/thaw cycles generate discontinuities which in turn cause rockfall. However, in Indian climatic condition freezing/thawing cycles occur only in Himalayan region, whereas in other parts of the country where rockfalls occur more frequently, such cycles are not encountered. The area is not experiencing any free/thaw cycles hence this parameter do not consider for the present study.

(c) Seepage/Water: Seepage/water parameter takes into accounts the presence of water on slope and takes a minimum point for dry condition and a maximum point for running water condition. This parameter is strongly conditional by the amount of annual rainfall and identified by field survey.

(d) Slope Aspect: Last parameter that is to be considered in climatic condition is slope aspect. It has been identified by different authors that the slope aspect will dramatically affect the climatic conditions [10]. The slope face, that experiences more sunlight during the day have greater temperature variation that causes ice to melt deeper into the rockmass/discontinuities and results in the instability of the slope, thus weighted with the highest. However, if the slope face has lesser temperature variation then a relative less rating should be assigned.

Points for each parameter of the climatic conditions are given in table-1 and corresponding values for climatic conditions for all five zones have been given in table-2.

4.3. Geological Conditions

These parameters take into account the geology of the site and discontinuities individually. Sedimentary and crystalline rocks are the geological materials which are considered for the classification of RHRSI. In each of the materials, the cause of rockfall is important i.e. in sedimentary rocks; undercutting and differential erosion makes the rockfall to happen, whereas in crystalline rocks, inhomogeneity in rockmass and discontinuities play the same role. Parameters that affect the stability of geological materials are discussed in brief as follows:

4.3.1. Sedimentary Rocks

(a) Degree of Undercutting: In sedimentary rock undercutting is caused by differential erosion and weathering. Also large lithological variations provides large amount of undercutting within a rock slope.

(b) Slake Durability Index (SDI): SDI test is used for sedimentary rocks like shale, sandstone and limestone due to their variable hardness, durability and water sensitivity. Rock types like shale and mudstone are particularly susceptible to degradation due to high clay content. When these rock types are exposed in the slope alternating with sandstone, degradation can take place in the form of swelling in weaker layers and the time over which weakening and disintegration can occur. Ultimately the effect of disintegration will produce the loss of strength of rocks with time and it will favor the slope failure. This will produce the rock fall hazard [11].

(c) Degree of Inter-Bedding: It tells about the degree of lithological variation and their corresponding layer thickness within the rock slope that leads to the differential erosion and causes rockfall hazard.

4.3.2. Crystalline Rocks

(a) Rock Character: It includes the homogeneity of the rockmass that varies from homogenous to weak pegmatites/micas/shear zones in rating as given in table-1.

(b) Degree of Overhang: In sedimentary rocks, differential erosion causes undercutting of the layer, while in crystalline rocks, differential erosion generates overhang features that may ways for rockfall. Rating for degree of overhang is mentioned in table-1.

(c) Weathering Grade: Weathering causes rocks to break and ultimately causes rockfall as the case in sedimentary rock. Hence, rating should be given to the weathered intact rock and not to the surface of discontinuities that are rated separately in discontinuity parameters.

4.3.3. Discontinuities

Discontinuities play a vital role in rockfall hazards. Discontinuity parameters like number of joint sets, their orientations, persistence and aperture give an idea about the shape and size of the falling rock mass [11]. Also details explanation for discontinuities parameters are as follows;

(a) Block Size/Volume: This rating determines what type of rockfalls may most commonly occur. For example, if rocks fall individually, considering the sizes of the rocks is required. If a number of small and large sizes rockfall, use the mass of the fallen rocks in the first event to determine the rating. The corresponding score for this parameter is mentioned in Table-1. The particular value for block size or volume can also be calculated using the following formulae:

$$\text{Exact score for block size (BZ)} = 3^{\left(\frac{\text{BZ (m)}}{0.3}\right)} \tag{3a}$$

$$\text{Exact score for block volume (BV)} = 3^{\left(\frac{\text{BV (m}^3\text{)}}{2.3}\right)} \tag{3b}$$

Block size/volume is an important parameters dealing with the degree of damage to rockfall. However, more importance should be given to the large block as its hold more kinetic energy during its fall.

(b) Block Shape: Shape of the falling block gives an idea about the mechanism of the movement i.e. the block will slide or roll down the slope. It will also tell the amount of hazard associated with the shape as tabular block have lesser threat compare to rounded boulders.

(c) Number of Discontinuity Sets: Discontinuities on slope increases the amount of infiltration, action of frost wedging and chemical weathering. If a rock slope has more number of discontinuities set then it facilitate more for chemical and physical weathering on the slope. So, it plays a crucial role for characterization of rockfall hazard and so the corresponding rating is given in table-1 for the same.

(d) Persistence, Orientation and Aperture: This is the property of discontinuity that further increases the rating if it favor the hazard conditions. Persistence gives an idea about the perseverance's of discontinuity and comes in the category of continuous and discontinuous whereas orientation of the discontinuity provide detail about the slope instability i.e. adverse if daylight out of the slope and favorable if daylight into the slope face. Aperture is the perpendicular distance that separates the adjacent rock walls of an open discontinuity and hence increased the infiltration rates, frost wedge action and chemical weathering just like number of discontinuities discussed above [11]. The aperture is very critical in conditions where a release joint is present. The corresponding rating for persistence, orientation and aperture is given in Table-1.

(e) Weathering Conditions: Weathering at the surface of discontinuities reduces the mechanical strength by reducing cohesion and friction along the discontinuity surfaces. Weathering condition has been proposed by Hoek and Bray, 1981 their corresponding rating is mentioned in Table-1.

(f) Friction: Friction directly affects the potential for a block to move relative to another block. Friction along discontinuity is evaluated either by observations or by feeling the discontinuity surface. Rough surfaces have the least rating due to its sharp asperities, reducing the movement of block. However, slickensides have the highest value and considered that the movement occurred on the discontinuity surfaces in the past causing reduction in the strength.

(g) Infilling Material: Infilling materials can decrease or increase the shear strength of the slope material. Discontinuity filled with calcite is an example of increase in shear strength and known as healed infilled material [11]. Infilling along the discontinuity surfaces can have an important effect on the stability of the slope and play crucial role in rockfall hazard.

The geological conditions is mainly composed of crystalline rock (basaltic composition), No sedimentary rocks are present as identified by the field survey. Other geological conditions such as discontinuities and its sub categories are identify with rigorous filed work and there corresponding rating is mentioned in table-2.

4.4. Traffic Conditions

Parameters related to traffic conditions are PDSD, AVR and RW with pavement including paved shoulder and number of accidents. These parameters are discussed below;

(a) Percent decision sight distance (PDSD): It compares the actual amount of sight distance available through rockfall section to the low design amount provided [12]. It is calculated by using following formula;

$$PDSD = 100 * \left(\frac{\text{actual sight distance)}}{\text{decision sight distance}} \right) \tag{4}$$

Actual decision sight distance is a distance in which a 15cm object, placed on the corner of the road disappears from the sight of the driver [12]. It is an important parameter because curves of the roadways along the mountainous region can limit the ability of a driver to notice rocks present on the road.

Decision sight distance (DSD) is measured by using posted speed limit (PSL). Also below is the exponent formula for exact score of DSD.

$$\text{Exact score for PDSD} = 3^{\left(\frac{120\text{-\%PDSD)}}{20} \right)} \tag{5}$$

Assuming posted speed limit of 20 km/h, a corresponding DSD is equal to 0.183 km and its RHRSI values for each zones are mentioned in table-2.

(b) Average Vehicle Risk (AVR): It gives rating that relates the percentage of time a vehicle is present in the rockfall prone zone. This percentage is obtained by using the below formula based on slope length (SL), average daily traffic (ADT), and PSL at the site

$$AVR = \left(\frac{ADT\left(\frac{veh.}{day} \right) * \frac{SL(km)}{24\left(\frac{hrs}{day} \right)}}{PSL\left(\frac{km}{hr} \right)} \right) * 100 \tag{6}$$

AVR indicates that how many vehicles are in the rockfall section at a particular time. A rating of 100% means that on an average a vehicle will be within the defined rockfall section 100% of the time. The result approximates the likelihood of vehicles being present and thus considered to be involved in a rockfall incident. Exact score for AVR can be calculated using equation (7)

$$\text{Exact score for AVR} = 3^{\left(\frac{\%AVR)}{25}\right)} \quad (7)$$

AVR is the parameter which changes as the ADT changes. The average daily traffic (ADT) is the traffic count by the roadway based on Ministry of Road Transport and Highway or by Center Road Research Institute. These values are updated by these agencies on a regular basis. The SL value for two locations was assumed as coincident with its medium longitudinal length; ADT was calculated in the middle of the section. The PSL is assumed to be 20 km/h. The corresponding rating is shown in Table-2.

(c) Roadway Width (RW): It is defines as maneuvering room for a driver to avoid rockfall and is measured perpendicular to the highway centerline. If the roadway width is not constant throughout the rockfall section then the minimum width is used for rating. The unpaved shoulder adjacent to the roadway is not included in the measurement. Also on divided roadways, only the portion available to the drivers is measured. Similar to AVR and DSD roadway width can be calculated using the formula,

$$\text{Exact score for roadway width (RD)} = 3^{\left(\frac{15.6\text{-RD (m)}}{2.4}\right)} \quad (8)$$

Roadway width is calculated by the field survey and their corresponding value along with rating is given in Table-5.

(d) Number of Accident: Information related to the number of accidents was required for the rating of the last parameters of traffic conditions and have least score for accident number 0 to 2 and highest for accident numbers 9 and more.

4.5. Rockfall History/Frequency

Historical rockfall activity helps to predict future rockfall events. Due to this rockfall history has been included in RHRSI. It varies from 0-3 falls per year to greater than 12 falls per year. Also exact weight can be calculated using the equation mentioned below;

$$\text{Exact score for Rockfall History/Frequency(f)} = 3^{(1+0.25*f)} \quad (9)$$

The historical information is best obtained from the maintenance personnel, who are responsible for the slope monitoring and their direct involvement of the rock fall activity at the site. In the present study, the rockfall frequency was computed on the basis of the available historical data (Personal communication with local person, research articles and newspapers).

4.6. Risk-Consequences Analysis

A risk-consequence analysis has been performed using values of table-5. A graph has been prepared as shown in Fig. 2. With this analysis sometime a location is vulnerable for rockfall but not required immediate attention. The analysis will divide the rockfall hazard in four zone i.e. LL= low risk-low consequence; LH=low risk-high consequence; HL=High risk-low consequence and HH= High risk-High consequence.

Majority of the SGT curve road comes under low risk-low consequence; however, zone-1 and zone-3 show high risk-high consequence results. Therefore, these two zones need attention for remedial measures from the rockfall hazard due to its risk-consequence analysis.

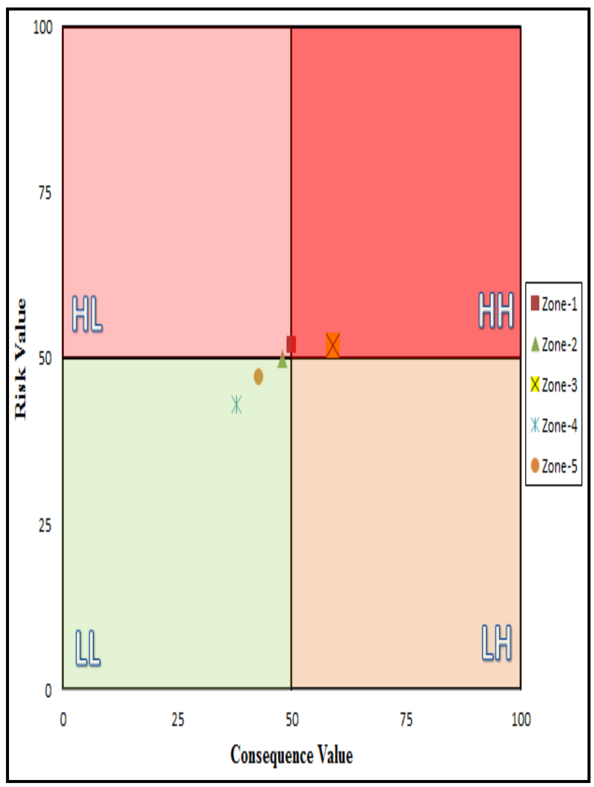

Figure 2 *Risk-consequence graph for five zones (LL= low risk-low consequence; LH= low risk-high consequence; HL = high risk-low consequence and HH= high risk-high consequence).*

***Table 2:** Rockfall Hazard Rating System for India (RHRSI) [6]*

		Parameters	Value	Rating	Value	Rating	Value	Rating	Value	Rating	Value	Rating
Slope		Slope Height	12 m	5.8	26 m	45.1	40 m	100.0	10 m	4.0	6.0 m	3.0
Slope		Av. Slope Angle Score	D	81	D	81	D	81	D	81	D	81
Slope		Vegetation	Isolated Pt.	27	Isolated Pt.	27	Isolated Pt.	27	Isolated Pt.	27	Isolated Pt.	27
Slope		Launching Features	Many	27	Many	27	Many	27	Many	27	Many	27
Slope		Ditch Catchment	No	81	No	81	No	81	No	81	No	81
Climate		Annual Ppt.	1121mm	100	1121 mm	100	1121mm	100	1121mm	100	1121mm	100
Climate		Annual Freeze/Thaw Cycles	-	-	-	-	-	-	-	-	-	-
Climate		Seepage/Water	Dripping	27	Dripping	27	Dripping	27	Dripping	27	Dripping	27
Climate		Slope Aspect	N	9	N	9	N	9	N	9	NE	27
Geology	Sedimentary	Deg. of Undercutting	-	-	-	-	-	-	-	-	-	-
Geology	Sedimentary	SDI	-	-	-	-	-	-	-	-	-	-
Geology	Sedimentary	Deg. of Inter-bedding	-	-	-	-	-	-	-	-	-	-
Geology	Crystalline	Rock Character	Small Fault	27	Small Fault	27	Small Fault	27	Small Fault	27	Small Fault	27
Geology	Crystalline	Deg. of Overhang	10 cm	3	30-60 cm	9	30-60 cm	9	10 cm	3	10 cm	3
Geology	Crystalline	Weathering Grade	Altered	27	Altered	27	Altered	27	Altered	27	Altered	27
Geology	Discontinuities	Block Volume	$1.4\ m^3$	2	$1.7\ m^3$	2.3	$1.7\ m^3$	2.3	$1.4\ m^3$	2	$1.4\ m^3$	2
Geology	Discontinuities	Block Shape	Blocky	9	Blocky	9	Angular	27	Blocky	9	Blocky	9
Geology	Discontinuities	No. of Sets	2 Plus	81	2 Plus	81	2 Plus	81	2 Plus	81	2 Plus	81
Geology	Discontinuities	Persistence, Orientation	< 3m, Daylight Out Of Slope	27	< 3m, Daylight Out Of Slope	27	< 3m, Daylight Out Of Slope	27	< 3m, Daylight Out Of Slope	27	< 3m, Daylight Out Of Slope	27
Geology	Discontinuities	Aperture	1-5mm	27	1-5mm	27	> 5mm	81	1-5mm	27	1-5mm	27
Geology	Discontinuities	Weathering Condition	Grade-IV	27	Grade III	9	Grade III	9	Grade I&II	3	Grade I&II	3
Geology	Discontinuities	Friction	Undulate	9	Undulate	9	Undulate	9	Undulate	9	Undulate	9
Geology	Discontinuities	Infilling Material	Clay	81	Clay	81	Clay	81	Clay	81	Clay	81
Traffic		Percentage Decision Sight Distance (DSD)	40%	81	60%	27	40%	81	80%	9	60%	27
Traffic		Average Vehicle Risk (AVR)	100%	81	100%	81	100%	81	50%	9	75%	27
Traffic		Roadway Width Including Paved Shoulder (m)	7 m	51	7m	51	7 m	51	10.0 m	51	7 m	51
Traffic		No. of Accidents	3 to 5	9	3 to 5	9	3 to 5	9	3 to 5	9	3 to 5	9
Rockfall History			>12/yr	81	>12/yr	81	>12/yr	81	>12/yr	81	>12/yr	81
			Total	980.8	Total	954.3	Total	1135.3	Total	773	Total	864

5. Conclusion

On the basis of the available data (rockfall history), five zones which is very prone to rockfall hazard were identified along Saptashrungi Gat Temple Road. In the present study, these five zones have been rated using RHRSI owing to the presence of factors predisposing rockfalls (i.e. presence of hazardous cliffs). Also a risk-consequence analysis has been performed to get an idea about the consequence of the rockfall once happened. Using the different parameters of RHRSI as mentioned in table-1 for the slopes of these five zones and comparing the results of each other. It has been found that zone-1 and zone-3 has higher value of hazard rating as compare to zone-2, zone-4 and zone5.

Risk-Consequence analyses on the same zones indicate similar relation as in relative RHRSI values and found zone-1 and zone-3 poses high risk and high consequence.

Some basis protection measures should be adopted to stop the rockfall reaching to the road. These might be a combination of drape mesh and effective ditches along the slope.

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