Quantitative risk assessment (QRA) for Saptashrungi Gad Temple (SGT road), Vani, Nashik, Maharashtra, India

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Abstract

Rock fall 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. Rock fall 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. Also, depending upon the location of occurrence, they have potential serious effects. Heavy rainfall is the major cause for the rock fall; however, there are other causes too. 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 rock falls. About 375 vehicles in a day are passing through toll that has been official established after a private bus fell into the valley in 2008. In year 2008, the road as well as the temple areas suffered from rock fall problems and many locations hit by the rock falls. The rock falls may cause damage, injury and death to the users of this passageway. So, a quantitative risk assessment (QRA) has been performed to identify the risk exist along this zigzag roadway. Three cases have been studied for the risk assessment and it has been identified that the most prone case is case-2 where the risk to the loss of life is equal to $2.81*10^{-2.}$ Also, total risk associated with all three cases is equal to $3.28*10^{-2}$ and when plotted in the bi-algorithmic F-N plane gives an indication for the societal risk as not acceptable. In light of this study, a remedial measures should be adopted which can control the risk from the rock fall and will reduce the loss of life and damage to the properties.

Key words: Risk, Rock fall, QRA.

1. Introduction:

Rock fall is the movement of individual blocks or group of blocks from the hilly terrains or slopes under the influence of gravity. The movement involved free fall, bouncing, sliding or rolling. Rock fall problems threat to the users of the transportation passageways i.e. railways, highways and roadways [1-4]. A rock fall on steep slopes can cause damage, injury and death to the users of these passageways. So, systematic risk analysis is required to ascertain the probability of failure in area of high public intervention.

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 the temple (Fig. 1). 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 as well as cause damage to the vehicles from rock falls. About 375 PCUs daily are passing through toll that has been official established after a private bus fell into the valley in 2008 [5-6]. In year 2008, the road as well as the temple areas suffered from rock fall problems and many locations hit by rock falls [1, 6].

This paper deals with the vulnerability and risk of rock fall along the Saptashrungi Gad Temple (SGT) Road. A systematic risk analysis has been performed based on highly used approaches proposed by various researchers [6-10].

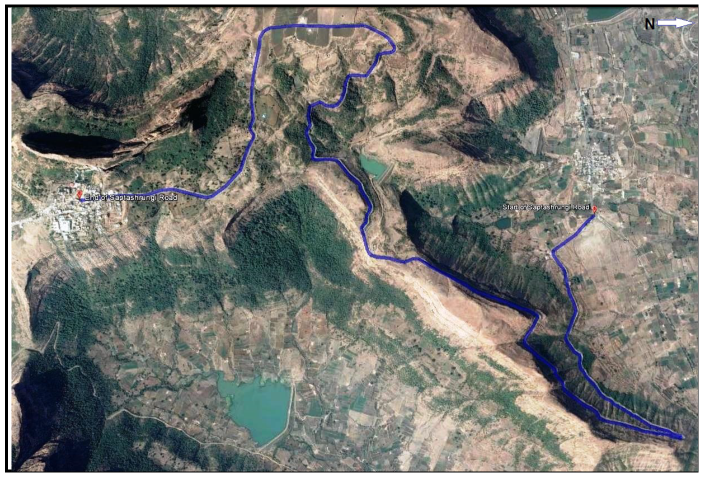

Figure 1 Zigzag nature of the road shown by solid blue line. (Source: map.google.com)

1. Background of quantitative risk assessment (QRA) method:

Hazard characterization and risk mitigation has been done very effectively by quantitative risk assessment (QRA). There are three main components i.e. risk analysis, risk assessment and risk management for landslides and engineering slopes for QRA procedure [8-9]. Risk analysis includes hazard and consequence analyses. Also hazard analyses generally contain three important steps (i) Definition of scope, (ii) Danger identification and (iii) Estimation of probability of occurrence to estimate hazard.

The final step for the risk analysis and require for the risk calculation is risk estimation through the probabilistic equation. For example, the annual probability that a person may lose his/her life can be estimated using the following equation [9];

$$P_{(LOL)} = \Sigma\{[1-(1-P_{(S:T)})]^{P_R * P_{(T:R)}} \times V_{(D:ST)}\} \qquad \ldots(1)$$

Where;

$P_{(LOL)}$ = Annual probability that a person may lose his/her life

$P_{(R)}$ = frequency of the rockfall events of a given magnitude

$P_{(T:R)}$ = probability of the rockfall reaching the element at risk

$P_{(S:T)}$ = temporal spatial probability of the element at risk

$V_{(D:T)}$ = vulnerability of the element at risk to the rockfall event

As soon as the risk hazard area has been demarcating, risk management act to identify the measures required for the mitigation that may be as follows (i) planning control, (ii) engineering solution, (iii) acceptance and, (iv) monitoring and warning systems [11].

2. Results & discussions:

The QRA for the life loss of pilgrims and tourists passing along the SGT Road has been estimated based on three conditions as mentioned below;

(a) Case-1: direct impact of rock mass blocks against travelling vehicles;
(b) Case-2: impact of travelling vehicles on fallen rock mass blocks, and
(c) Case-3: impact of falling rock mass block on standing vehicles.

For the present study the time span is considered since 2002-2014 (12 years). Also the total rockfall events along the road have been considered as 120 events (personal communication with local persons, newspapers). So, knowing the length of the SGT Road as 9.73 km, the normalized frequency, $P_{(R)}$, of the rock falls is equal to **1.03/year/km**. Also for worst cases i.e. for the maximum probability of rock fall blocks reaching the lane at risk has the value of $P_{(T:R)}$ equal to **1**. Three risk situations have been discussed above as case-1 to case-3, therefore three different values of $P_{(S:T)}$ needs to identified for risk assessment.

A. Case-1:

Case-1 considered falling rock mass blocks hitting the travelling vehicles. The spatial temporal probability in this case can be calculated using the below equation;

$$P_{(S:T)} = \frac{N_v}{24} * \frac{L_v}{1000} * \frac{1}{V_v} \quad ...(2)$$

In eq. 2, N_V is the average number of vehicles/day; L_V is the average length of the vehicles (m) and V_V is the velocity of the vehicles (km/hr). From available data on traffic [6], average number of vehicles per day travelling along the SGT-Road is 375. Assuming average length of the vehicle is equal to 5.8 m and velocity is 20 km/h. On the basis of available data and using eq. 2, the value of $P_{(S:T)}$ equal to ***$4.53*10^{-3}$*.**

The vulnerability $V_{(D:T)}$ value is assumed ***1*** for the maximum damage. Finally, the total probability of one or more persons at risk losing their life by driving along SGT-Road is given by equation-1 and it has been estimated as ***$4.66*10^{-3}$***.

B. Case-2:

The case of impact of moving vehicle on a fallen rock mass blocks have been estimated in view of that the hazard to the vehicle posed by a rock falling on the road in front of the vehicle increases as the distance between vehicle and the point of impact of the rock on the road decreases. Moreover, along a road section, the sight distance can change significantly; indeed, road curves along with obstructions, such as rock outcrops and roadside vegetation, can severely limit a driver's ability to spot and react to a rock in the road. Furthermore, poor visibility during rainy season may result in reduction of the sight distance (Ansari et al., 2014a). In case-2, the temporal spatial probability $P_{(S:T)}$ can be computed using below equation;

$$P_{(S:T)} = \frac{N_v}{24} * \frac{L_{DSD}}{2000} * \frac{1}{V_v} \quad ....(3)$$

Where; L_{DSD} is decision sight distance and other parameters have been explained above. The decision sight distance is the length of roadway required by a driver to see a problem and then bring a vehicle to stop. In this regard, for considered posted speed limit of 8 km/h [12] suggests a low design value for DSD equal to 70.0 m. Therefore using eq. 3, probability of a vehicle crushing onto a rock mass blocks on the road is ***2.73*10⁻²***. Also considering the value of vulnerability $V_{(D:T)}$ is ***1*** for the maximum damage, total probability of one or more persons at risk losing their life by driving along MPE is given for case-2 by equation-1 and it has been estimated as ***2.81*10⁻².***

C. Case-3:

This case consider the impact of falling rock mass blocks on the standing and/or stationary vehicles. In this case, the temporal spatial probability $P_{(S:T)}$ can be calculated as;

$$P_{(S:T)} = P_{(T:P)} * P_{(S:P)} \quad ....(4)$$

Where, $P_{(T:P)}$ is the temporal probability that a vehicle be on the road when rock fall happened and $P_{(S:P)}$ is the spatial probability that a vehicle be on the rock fall trajectory.

For the calculation of $P_{(T:P)}$, it has been considered that the duration of the delay of standing vehicles on an average is equal to 15 min. So the temporal probability is equal to the fraction of year for which a vehicles occupies the space strike by the rock mass blocks and can be computed using the below equation;

$$P(T:P) = \frac{t}{8760} \quad ...(5)$$

Where, t is the time that the vehicles are at risk and equal to 0.25 h, hence the temporal probability is found to be $\boldsymbol{2.85 * 10^{-5}}$.

Also, spatial probability, $P_{(S:P)}$ of impact was achieved by the following equation;

$$P(S:T) = \frac{L_v}{L_v + S_v} \quad ....(6)$$

Where, S_v is the average spacing between the vehicles equal to 2 m and the spatial probability is equal to 0.74.

Now, with the help of equation 4, the temporal spatial probability is estimated as $\boldsymbol{2.12*10^{-5}}$ and considering the value of vulnerability $V_{(D:T)}$ is 1 for the maximum damage, total probability of one or more persons at risk losing their life by driving along MPE is given for case-3 by equation-1 is equal to $\boldsymbol{2.18*10^{-5}}$.

For each case, the annual probability of one or more deaths per kilometer is mentioned in table1. Also, total annual probability considering all cases is $3.28*10^{-2}$ /annum/km. Moreover, after analyzing all the results obtained from three cases of risk condition, it can be inferred that case-2 is the worst case. When the data plotted in the bi-logarithmic F-N plane (figure 2), it falls above the limit of the tolerability curve and notify that the societal risk cannot be acceptable in such situation.

Table 1
Risk of life loss (per year & per km) for one or more person travelling along MPE

Cases	P(R)	P(T:R)	P(S:T)	V(D:T)	P(LOL),tot
Case-1	1.03	1.00	4.53E-03	1.00	4.66E-03
Case-2	1.03	1.00	2.73E-02	1.00	2.81E-02
Case-3	1.03	1.00	2.12E-05	1.00	2.18E-05
				Total Risk	3.28E-02

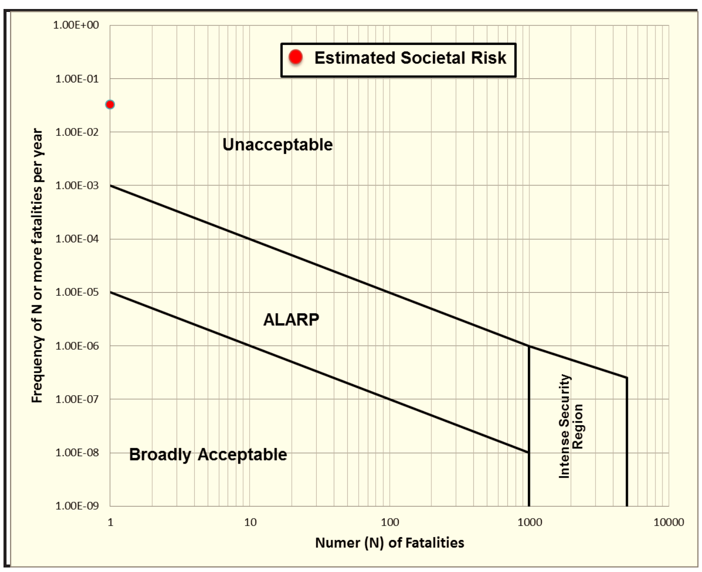

Figure 2 Estimated societal risk for SGT road.

3. Conclusion:

The investigation provides the assessment for the risk of life loss to the persons travelling along the SGT Road. The quantitative risk assessment (QRA) is estimated using three different conditions and the annual probability of one or more deaths has been evaluated. This study clearly demonstrated that the SGT Road is under the risk of rockfall. The result obtained provides an indication that the case-2 is worst as compare to other two cases. Also, total risk associated with all three cases is equal to $3.28*10^{-2}$ and when plotted in the bi-algorithmic F-N plane gives an indication for the societal risk as not acceptable. In light of this study, a remedial measures should be adopted which can control the risk from the rock fall and will reduce the loss of life and damage to the properties.

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