Rockfall Risk Assessment along Mumbai-Pune Expressway, Maharashtra, India

M. K. Ansari[1], M. Ahmad[2], T. N. Singh[3]

[1]Indian Institute of Technology Bombay, Department of Earth Sciences, Powai, Mumbai, India

[2]Indian Institute of Technology Bombay, Department of Earth Sciences, Powai, Mumbai, India

[3]Institute of Technology Bombay, Department of Earth Sciences, Powai, Mumbai, India

Abstract: ***Mumbai-Pune Expressway is the India's first six-lane concrete, high speed highway. The expressway is 93.0 km in length and has been utilized by 43000 vehicles in a day. In year 2004, the expressway suffered from rockfall problem and 17 locations hit by the rockfall. The rockfall may cause damage, injury and death to the users of these passageways. So a quantitative risk assessment (QRA) has been needed to identify the risk present along this expressway. 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 6.84*10-2.***

Keywords: Expressway, Risk, Rockfall, QRA.

1. Introduction

Transportation passageways are often susceptible to rockfall hazard. A rockfall 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. Rockfall events have been reported on Mumbai-Pune Expressway (MPE) 0. Mumbai Pune Expressway is the India's first six-lane concrete, high-speed, access controlled tolled expressway [2]. It spans a distance of 93 km and connecting Mumbai (administrative capital of Maharashtra) to Pune (financial capital of India). The expressway starts at Kalamboli (near Panvel), and ends at Dehu Rd. (near Pune). It cuts through the scenic Sahyadri mountain ranges thru passes and tunnels. It has five interchanges: Kon (Shedung), Chowk, Khalapur, Kusgaon and Talegaon. The expressway handles about 43,000 PCUs daily [3]. In this article an attempt has been made to identify the vulnerability and risk of rockfall along the MPE. A systematic risk analysis has been performed based on highly used approaches proposed by various researchers ([4], [5], [6] and [7]).

2. Background of Quantitative Risk Assessment (QRA) Method

Quantitative risk assessment (QRA) is a very powerful tool for the characterization of hazard zones and their risk mitigation ([8], [9] and [10]). There are three main components i.e. risk analysis, risk assessment and risk management for landslides and engineering slopes for QRA procedure [5]. 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 [5];

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

Where;

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

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

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

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

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

As soon as the risk hazard area has been demarcated, 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].

3. Results and Discussions

The quantitative risk assessment for the life loss of persons travelling along the MPE has been estimated based on three conditions as mentioned below;

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

For the present study the time span is considered since 2002-2012 (10 years). Also the total rockfall events along the Mumbai-Pune Expressway has been considered as 115 events {in year 2005, 17 locations have suffered rockfalls events)} 0 (Fig.1). So, knowing the length of the MPE as 93 km, the normalized frequency, $P_{(R)}$, of the rockfalls is equal to **1.24*** ***10^{-1}***. Also considering maximum probability of rockfall blocks reaching the lane at risk, therefore $P_{(T:R)}$ is equal to **1**. Now for three different cases, three different values of $P_{(S:T)}$ need to find out for the risk assessment.

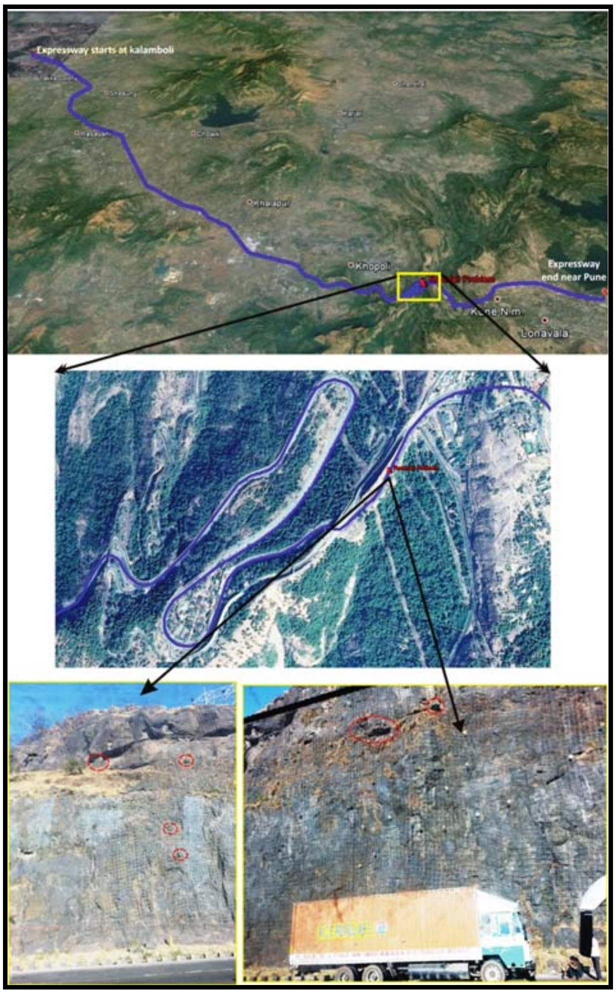

Figure 1: Mumbai-Pune expressway shown by blue line. Location of expected rockfalls is shown by red circles.

3.1 Case-1

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

$$P(S{:}T) = (N_V/24) * (L_V/1000) * (1/V_V) \quad (2)$$

In equation-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 **Error! Reference source not found.**, average number of vehicles per day travelling along the MPE is 43,000. Assuming average length of the vehicle is equal to 4.0 m and velocity is 80 km/h. On the basis of available data and using equation 2, the value of $P_{(S:T)}$ equal to ***8.96*10^{-2}***. The vulnerability $V_{(D:T)}$ value is taken as ***1*** for the maximum damage. Finally, the total probability of one or more persons at risk losing their life by driving along MPE is given by equation-1 and it has been estimated as ***1.15*10^{-2}***.

3.2 Case-2

The case of impact of moving vehicle on a fallen rockmass 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 on the road. Furthermore, poor visibility during rainy season may result in reduction of the sight distance [7]. In case-2, the temporal spatial probability P(S:T) can be computed using below equation;

$$P(S{:}T) = (N_V/24) * (L_{DSD}/2*1000) * (1/V_V) \quad (3)$$

Where; LDSD 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 the considered posted speed limit of 8 km/h, Ref. [12] suggests a low design value for DSD equal to 229.0 m. Therefore using equation 3, the probability of a vehicle crushing onto a rockmass blocks on the road is 2.56. 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 **5.69*10^{-2}**.

3.3 Case-3

This case consider the impact of falling rockmass 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 rockfall happened and $P_{(S:P)}$ is the spatial probability that a vehicle be on the rockfall trajectory. For the calculation of $P_{(T:P)}$, it was 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 rockmass 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 **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 0.67.

Now, with the help of equation 4, the temporal spatial probability is estimated as 1.90*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 ***2.35*10^{-6}***. For each case, the annual probability of one or more deaths per kilometer is mentioned in **Table-1**. Also the total annual probability considering all cases is **6.84*10^{-2}** /annum/km. Moreover, after analyzing all the results obtained from three cases of risk condition, it can be inferred that the case-2 is the worst.

Table 1: Risk of life loss (per year and km) for one or more person travelling along Mumbai-Pune Expressway

	P(R)	P(T:R)	P(S:T)	V(D:T)	P(LOL),tot
Case-1	115	1	8.96E-02	1	1.15E-02
Case-2	115	1	2.56E+00	1	5.69E-02
Case-3	115	1	1.95E-06	1	2.35E-06
				Total Risk	6.84E-02

4. Conclusions

The investigation provides the assessment for the risk of life loss to the persons travelling along the Mumbai-Pine Expressway. The quantitative risk assessment (QRA) is estimated using three different conditions and the annual probability of one or more deaths has been evaluated along the expressway. This study clearly demonstrated that the expressway under the risk of rockfalls. The results obtained provide an indication that the case-2 is worst as compare to other two cases. However, in all three cases, expressway required protection from the rockfall according to risk involved.

References

[1] K. Kumar, P. S. Prasad, S. Mathur, N. K. Goyal, "Study of Rockfall and Subsidence at km 41 on Mumbai–Pune Expressway–A Case Study," The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG), 1-6 October, Goa, India, 2008.

[2] Mumbai-Pune Expressway, India. Road Traffic Technology. Retrieved 2010-08-21. [Online]. Available :www.roadtraffic-technology.com/projects/mumbai/

[3] The Economic Times, "Mumbai-Pune expressway may soon have eight lanes" Feb. 23, 2013. [Online]. Available: http://economictimes.indiatimes.com/articleshow/18642402.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppsthttp://economictimes.indiatimes.com/news/economy/infrastructure/mumbai-pune-expressway-may-soon-have-eight-lanes/articleshow/18642402.cms.

[4] C.M. Bunce, D.M. Cruden, N.R. Morgenstern, "Assessment of the hazard from a rockfall on a highway," Can Geotech J., 34, 344–356, 1997.

[5] R. Fell, K.K.S. Ho, S. Lacasse, E. Leroi, "A framework for landslide risk assessment and management. In: Hungr O, Fell R, Couture R, Eberhardt E, editors," Landslide risk management. London: Taylor and Francis, 3–26, 2005.

[6] W. Roberds, "Estimating temporal and spatial variability and vulnerability. In: Hungr O, Fell R, Couture R, Eberhardt E, editors." Landslide risk management. London: Taylor and Francis, 129–157, 2005.

[7] M.K. Ansari, M. Ahmad, T. N. Singh, "Rockfall risk assessment for pilgrims along the circumambulatory pathway, Saptashrungi Gad Temple, Vani, Nashik Maharashtra, India," Geomatics, Natural Hazards and Risk, 5(1),81-92, 2014. DOI:10.1080/19475705.2013.787657.

[8] J. Corominas, R. Copons, J. Moya, J. M. Vilaplana, J. Altimir, J. Amigo, "Quantitative assessment of the residual risk in a rockfall protected area," Landslides, 2, 343–357, 2005.

[9] R. Fell, J. Corominas, C. H. Bonnard, L. Cascini, E. Leroi, W.Z Savage, "Guidelines for landslide susceptibility, hazard and risk zoning for land use planning," Eng Geology, 102, 85–98, 2008.

[10] M. Ahmad, R.K. Umrao, M. K. Ansari and T. N. Singh, "Assessment of rockfall hazard along the road cut slopes of state highway-72, Maharashtra, India" Geomaterials, 3(1), 15–23, 2013.

[11] F.C. Dai, C.F. Lee, Y.Y. Ngai, "Landslide risk assessment and management: An overview," Eng Geology, 64, 65–87, 2002.

[12] A.A.S.H.T.O, "A Policy on Geometric Design of Highway street, American Association of State Highway and Transportation Officials, Washington, D.C., 1984.

Author Profile

Mohammad Khalid Ansari received M.Sc. and M.Tech degrees in Applied Geology from University of Allahabad and Indian Institute of Technology Kanpur in 2005 and 2008 respectively. A Ph. D student of Indian Institute of Technology Bombay. Mumbai. He now with DAR AL HANDASAH, a consultant company as a geologist.