STABILITY ANALYSIS OF ROCK SLOPE AT ADOSHI AND KHANDALA

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ABSTRACT -The Mumbai-Pune Expressway (Maharashtra), officially known as the 'Yashwantrao Chavan Mumbai Pune Expressway' is India's first six-lane concrete, high-speed, access controlled tolled expressway. It spans a distance of 94.5 km. The expressway starts at Kalamboli (near Panvel), and ends at Dehu Rd. (near Pune). It cleaves through the scenic Sahyadri mountain ranges through passes and tunnels. The expressway handles about 43,000 (passenger carrying units) PCUs daily and is designed to handle up to 1,000,000 PCUs. The expressway experienced problems with rock fall. The present study aims to carry out Stability analysis of rock slope at Adoshi and Khandala including suggesting the remedial measures required if any. A reconnaissance inventory carried out by the Central Road Research Institute, New Delhi, India revealed that about 90% of the slope failures. The Rock fall and debris flow are the predominant problems at Adoshi and Khandala location. The size of the rock blocks varies from a few centimeters to a meter and some time even larger in diameter. The hill slope geometry at this location is such that rock blocks fall directly onto the expressway. This direct fall makes the impact more dangerous and more potentially fatal when rock blocks impact a running vehicle. Such incidences are particularly frequent during the rainy season. Theses landslides have caused tremendous loss of human life and several time blocked the vehicular traffic on expressway. The purpose of this study is to map the entire area and analyse the reason for such rock falls & landslides and propose remedial measures. The design of these remedial measures would not be the scope of this study and could be taken up as future scope of work. The comprehensive study is presented in this paper.

***Keywords* - Bore log, rock quality designation (RQD), weighted jointing density (WJD), Rock Mass Index (RMi).**

INTRODUCTION

The need for the Mumbai-Pune expressway was established by a study conducted by the ministry of surface transport (MOST) during the seventh five-year plan (1985-90) which identified this corridor as amongst the three most congested national highway corridors and proposed it to be developed, as a part of the "National Expressway System". Accordingly, it was decided to explore the possibility of providing a new expressway between Pune and Mumbai. The need for constructing the Mumbai Pune express highway was borne by the fact that Mumbai was commercial capital of India and Pune was developing into a major industrial and commercial centre. The vehicular traffic in the Mumbai Thane Pune belt was 60755 PCU in the year 1996 and was expected to reach 100000 PCU by the year 2004 requiring a ten-lane corridor between Mumbai and Pune. This belt also contains 72 per cent of factories, provides 77 per cent of industrial employment, control 88 per cent of working capital, and yielded 86 per cent of total state industrial output.

More recently this link between Pune and Mumbai has become crucial for the development of the computer and information sector that is perceived to be a key element in facilitating globalization and international business linkages. The distance between the two cities is some 180 km and it takes about four and a half to five hours to cover it under good traffic conditions. However due to flooding and landslides in the Western Ghats the roads get frequently and unpredictably paralyzed by accidents, which block the narrow and winding curves of the two-lane highway. These increase the traveling time to somewhere around 10 to 15 hours. At present 400 persons are killed due to accidents on the existing Mumbai-Pune National Highway each year.

The slopes on left side of Adoshi and Khandala before entering into it are vertical rock. The first case of rock and debris fall at this location reportedly occurred in the year 2003-2004, during monsoon. Since the rock blocks are intermittently falling from the face, as well as from top of the slope. The size of the block varies from a few centimeters to a meter and sometimes even more in diameter. The incidences of the rock fall are frequent during rainy season. The impact of the falling as noticed is very high. There are reported instances of boulders not only damaging the side drains but also middle of the expressway. The hill slope condition at this location is such that the rock block falls directly on expressway because there is no space between the expressway and the cut slope, and therefore resulting in no reduction in the momentum of the detached rock before actually hitting the expressway. The sliding material itself blocks a part of the expressway, thereby causing inconvenience to the traffic. The direct fall makes the impact more dangerous and is most of the times fatal when rock block hit running vehicle resulting to the loss of life which cannot be valued.

REVIEW OF LITERATURE

Palmstrom (1996) proposed a rock mass index (RMi) to characterize rock mass strength as a construction material. The presence of various defects (discontinuities) in a rock mass that tend to reduce its inherent strength are taken care of in rock mass index (RMi),which is expressed as

$$RMi = q_c\, Jp$$

(q_C the uniaxial compressive strength of the intact rock material in MPa and Jp the jointing parameter) Jp composed of mainly four jointing characteristics, namely, block volume or density of joints, joint roughness, joint alteration, and joint size. It is a reduction coefficient representing the effect of the joints in a rock mass. The value of Jp varies from almost 0 for crushed rock masses to 1 for intact rocks as claimed by Palmstrom (1996), some of the benefits of the RMi system in rock mechanics and rock engineering that it enhances the accuracy of the input data required in rock engineering by its systematic approach of rock mass characterizations. It can be easily used for rough estimates when limited information about the ground condition is available, for example, in early stages of a feasibility design of a project where rough estimates are sufficient.

Based on the literature pertaining to the classification of rock mass and stability of slope reviewed Palmstrom A. *et al.*, (1982, 1996, 2000, 2001, 2002, 2003, 2005, 2009, 2010), it is seen that adopting proper precautionary measures to tackle the hazard problems needs thorough investigation. A list of all rock parameters and an understanding of all rock properties and rock mechanics are necessary for any rock engineering project. Then an objective-based method of planning should be undertaken. A procedure for identifying causes of failure is most relevant to the project within the scope of the objective, and finally the ability to select relevant engineering techniques rounds out the process. Taking these steps, we can utilize existing knowledge in an optimal way to develop stable design, construction, and monitoring procedures for any project. One needs to map the entire area and understand the jointing pattern and rock mass classification

The expressway experienced problems with rock fall. A reconnaissance inventory carried out by the Central Road Research Institute, New Delhi, India revealed that about 90% of the slope failures The Rock fall and debris flow are the predominant problems at Adoshi and Khandala location. This direct fall makes the impact more dangerous and more potentially fatal when rock blocks impact a running vehicle. Such incidences are particularly frequent during the rainy season. Theses landslides have caused tremendous loss of human life and several time blocked the vehicular traffic on expressway. The purpose of this study is to map the entire area and analyse the reason for such rock falls & landslides and propose remedial measures. The design of these remedial measures would not be the scope of this dissertation and could be taken up as future scope of work.

GEOLOGICAL CONDITIONS

The geological conditions in the study area are dominated by basalt, an extrusive rock created by the out pouring of volcanic magma which cools quickly to from small crystals. Basaltic lava flows for great distances before solidifying. Successive eruptions of basalt have formed the Deccan plateau region of South West India.

The composition of the volcanic flow differs in each episode, the rock mass possesses layered structures with horizontal continuity but vertical heterogeneity .In a vertical column of 686m, at least 20 basalt flows varying in thickness from 15m to 70m have been recognized along the some sections. The flows are of simple to compound pahoehoe type and exhibit variations in color, grain size and frequency of distribution of phenocrysts. The natural hill slopes produced from this type of rock have a stepped shape, with the steeper portion corresponding to harder layers and flatter areas to the softer layers. Predominant vertical jointing favors the formation of steep slopes. In both cases, the structure of rock mass is usually of layers of different constitutions, altering weak and strong rocks, with preferential seepage along horizontal discontinuities or weak layers.

The condition of the rock can be defined as amygdaloidal basalt with vesicules and coarse grains. The strength of the intact rock does not contribute significantly in the case of fractured or jointed rocks. In these rocks, the discontinuities play a major role in forming favorable conditions for failure along mostly its day lighted surfaces. There is a sub-horizontal altered basaltic layer separating two basaltic layers that run across the slope. The weathered mass in this layer is highly susceptible to erosion in the presence of water, which leads to scouring at the base of the upper layer and, ultimately, failure of the overhanging rocks. There is also another oblique joint intersecting the sub-parallel one, which creates a favorable condition for rock fall. Similarly, other intersecting fractures play an important role in dislodging rock blocks of varying sizes.

(a) View of Adoshi Hill after the distress

(b) View of Khandala Hill after the distress

(c) Rock fall at Adoshi Tunnel (d) Khandala Tunnel

Fig 1. Adoshi and Khandala tunnel

PARAMETRIC STUDY

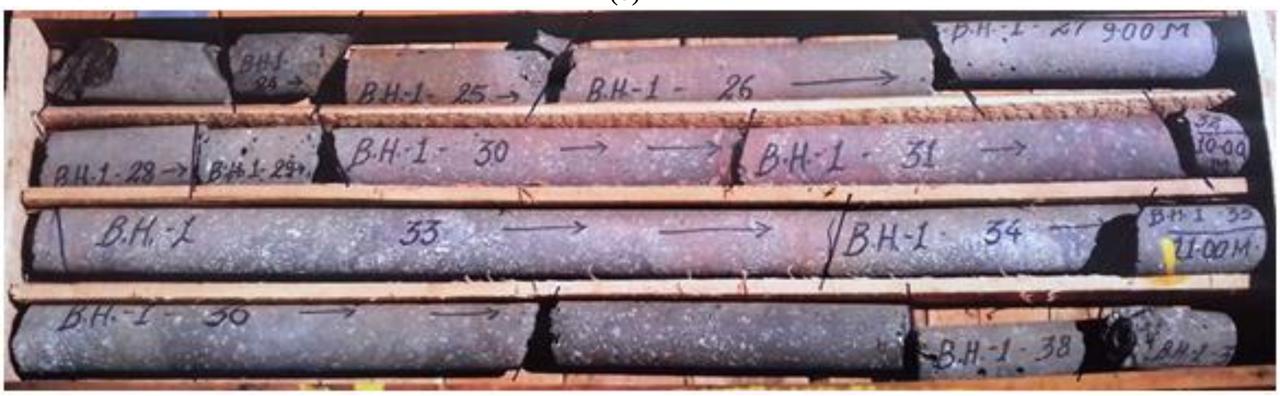
Rock quality designation (RQD) is by its original definition (Deere, 1966) the length in percent of measured length of the un-weathered drill core bits longer than 10 cm. The RQD is easy and quick to measure, and it is therefore frequently applied in core logging. Often it is the only method used for measuring the jointing density along the core drill hole. Field data collected in form of bore logs photographs visual observation and field tests were analyzed.

Bore log

Four numbers of bore holes were driven 15m deep from existing ground level to collect NX size core. Selection of location for bore hole was planned with objective to get comprehensive impression of physical and chemical properties of rock subject to mapping.

No. of bore holes	:	4
Depth of termination	:	15m to 20m (at least 5m in good quality hard rock)

(a) Sample Bore Log for depth 0.0 to 8.0 m
(b)



(b) Sample Bore Log for depth 8.0 to 12.0 m

(C) Sample Bore Log for depth 12.0 to 15.15 m

Fig 2. Sample Bore logs BH1

Bore log data revealed that the topmost layer constituted of Murrum followed with highly weathered and highly fractured amygdaloidal basalt with recovery in form of rock fragments and nil RQD (core pieces length > 10cm). This layer ranged between ground and 4m to 7m depth. Middle layer showed moderate recovery in form of core pieces with moderate RQD of 35 % to 70 % .This layer ranged between 5m to 11m depth and constituted fairly jointed amygdaloidal basalt. Bottom layer post 10m to 11m depth was found to be the strongest with above 90 % recovery and similar percentage of RQD.

Table 1. Laboratory test result for rock recovered from bore log

Sr. No.	Bore Hole no.	Depth (m)	Diameter (cm)	Area	Loading KN	UCS in kg/cm^2	UCS in MPa	Dry Density	Porosity	Water Absorption	Specific Gravity
1	BH -1	8.00	5.39	22.82	18.02	80.51	7.89	2.26	14.18	6.26	2.57
2	BH -1	13.00	5.45	23.33	39.80	173.97	17.05	2.53	6.84	2.70	2.60
3	BH -2	8.00	5.45	23.33	19.66	85.92	8.42	2.35	13.45	5.73	2.61
4	BH -2	13.00	5.40	22.93	41.84	186.05	18.23	2.59	6.65	2.57	2.64
5	BH -3	8.00	5.45	23.33	22.86	90.90	8.91	2.29	14.56	6.36	2.58
6	BH -3	13.00	5.48	23.58	40.92	176.95	17.34	2.60	5.60	2.15	2.66
7	BH -4	8.00	5.39	22.82	19.42	86.72	8.50	2.25	15.30	6.80	2.36
8	BH -4	13.00	5.40	22.89	47.74	210.44	20.62	2.38	6.24	2.63	2.59

RQD calculation from Bore log (Weighted Joint Density Method)

Length of core piece L = 1m (9m depth- Middle layer)

Table 2. wjd sample calculation

Interval	f1	n	Nw = f1 X n	
> 60^o	1	0	0	wjd = $\frac{\sum Nw}{L} = \frac{22}{1}$ =22
31^o - 60^o	1.5	2	3	
16^o - 30^o	3.5	2	7	
< 16^o	6	2	12	
			$\sum$Nw = 22	

$$\text{RQD} = 115 - 3.3\,\text{Jv}$$
$$= 115 - 3.3 \times 22 = 42.4$$

Length of core piece L = 1m (11m depth - Bottom Layer)

Table 3. wjd sample calculation

Interval	f1	n	Nw = f1 × n	
> 60°	1	1	1	$wjd = \frac{\sum Nw}{L} = \frac{5.5}{1} = 5.5$
31° - 60°	1.5	3	4.5	
16° - 30°	3.5	0	0	
< 16°	6	0	0	
			∑Nw = 5.5.	

RQD = 115 − 3.3 Jv
= 115 − 3.3 × 5.5 = 96.85

Rock cut

Photographs for Khandala and Adoshi section of vertical rock cut with previous history of rock slide were clicked for mapping & analysis. The length and height of rock cut was physically measured. The photos were mapped with 5m × 5m grid

Khandala Section of Rock cut:

Length : 405m
Height : 15m to 22m
Number of Mapping sections (5m × 5m grid) : 243

Adoshi Section of Rock cut:

Length : 760m
Height : 12m to 23m
Number of Mapping sections (5m × 5m grid) : 456

For statistical analysis purpose 5m × 5m grid sections were further segregated in three layers top, middle and bottom.

RQD calculation from photograph Mapping

Top Layer 1/section 1: lose soil RQD nil
Middle Layer 1/section 1by Weighted Joint Density (wjd) Method
Area for mapping A = 5 × 5 = 25 m^2

Table 4. Weighted Joint Density sample calculation

Interval	f1	n	Nw =f1 X n	
> 60°	1	12	12	$wjd = \frac{\sum Nw}{\sqrt{A}} = \frac{108.5}{\sqrt{25}} = 21.7$
31° - 60°	1.5	13	19.5	
16° - 30°	3.5	10	35	
< 16°	6	7	42	
			∑Nw = 93.5	

RQD = 115 − 3.3 Jv
= 115 − 3.3 × 21.7 = 43.39

Bottom Layer 1/section 2 by Weighted Joint Density (wjd) Method
Area for mapping A = 5 × 5 = 25 m^2

Fig 3. Khandala rock cut for mapping and for joint measurement

Table 5. wjd sample calculation

Interval	f1	n	Nw =f1 X n	
> 60^o	1	5	5	wjd = $\frac{\sum Nw}{\sqrt{A}} = \frac{31}{\sqrt{25}}$ =6.2
31^o - 60^o	1.5	4	6	
16^o - 30^o	3.5	4	14	
< 16^o	6	1	6	
			$\sum$Nw = 31	

$$RQD = 115 - 3.3\ Jv$$
$$= 115 - 3.3 \times 6.2 = 94.54$$

The Rock Mass Index System (RMi) Sample calculations

$$RMi = \sigma c \times JP$$
$$JP = 0.2\sqrt{Jc} \times Vb^D$$
$$D = 0.37Jc^{-0.2}$$
$$Jc = JR \times JL/JA$$

Table 6. Input parameters

Input Parameter	Middle Section 2	Bottom Section 2	Remark
σc	80.51	173.97	From Laboratory report
JR	1.25	2	From Table
JA	2	1	From Table
JL	1	0.75	From Table
S1	0.035	0.65	From Bore log

Table 7. Calculations of RMi

Formula	Middle Section 2	Bottom Section 2	Remark
Jc = JR X JL/JA	0.625	2	
D = $0.37Jc^{-0.2}$	0.406	0.322	
Vb ≈ S1X 5S1 X10S1 = 50 $S1^3$	0.002	13.73	
JP = $0.2\sqrt{Jc}$ X Vb^D	0.012	0.657	
RMi = σc X JP	0.96	114.25	

Table 8. Calculations of RMi

Section	JC	RQD from mapping	JP from graph	σc	RMi
Middle Section 2	0.625	43.39	0.011	80.51	0.885
Bottom Section 2	2	94.54	0.5	173.97	86.98

Table 9. Characterization of RQD and RMi

Section	RQD from core	RQD from mapping	Characterization term for RQD	RMi calculated from Vb	RMi from graph	Characterization term for RMi
Middle Section 2	42.4	43.39	Fair	0.96	0.96	Moderately Strong
Bottom Section 2	96.85	94.54	Excellent	144.25	86.98	Extremely Strong

CONCLUSION

A parametric study is carried out to study the classification of the rock for Khandala and Adoshi. Some of the broad conclusions deduced from the study are summarized below with the remedial measures

- The study of rock classification for Khandala and Adoshi rock cut section illustrate peculiar behaviour of rock mass.
- The RQD and RMi values (243 for Khandala Section and 456 for Adoshi section) show significant correlation between layers when statistically analyzed.

- Upper layer consisting of soil and rock fragments is highly susceptible to slide.
- Middle layer with Fair RQD and moderately strong RMI show the signs of sliding and toppling with upper layer.
- Bottom layer having extremely strong RMi and excellent RQD is found to be most stable.

From the above observations, the rock anchors should be driven in middle layer and anchored in bottom stable layer to arrest sliding and toppling of middle layer. Steel mesh can be rock bolted with grouting and shotcrete to arrest falling of lose fragments of rock and soil on all three layers.

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