ROCKFALL ANALYSIS AND APPLICATION OF AVAILABLE METHODS OF MITIGATION TO SAPTSHRUNGI GHAT ROADS

R. Satavalekar M.Tech Student, AMD, SVNIT, Surat, Gujarat, India, satavalekarrs@gmail.com
A.J. Shah Associate Professor, AMD, SVNIT, Surat, Gujarat, India, ajs@amd.svnit.ac.in

ABSTRACT: A landslide or a landslip is a geological phenomenon which includes wide range of ground movement, including rock falls. These affect the environment and mankind and their growing threat makes us responsible to come to some mitigation programs. In this paper, the rockfalls at Saptshrungi ghat roads near Nasik have been analysed. Different areas where rockfall can actually occur and applying the various methods of analysis and stabilization to the site will also be discussed. The calculation of factor of safety is 0.97 of the site using the geological information and by using Rocfall 4.0 we get the actual rock fall. Mitigation methods like rock reinforcement, wire mesh, catch ditches and barriers have been designed, modelled & compared for the Saptshrungi ghat road. It is observed that provision of rock anchors along with wire mesh is a good solution for this particular site.

Keywords: Rock anchors, Wire Mesh, Barriers, Catch ditches, & Rocfall.

INTRODUCTION
Nasik is a pilgrimage city. Pilgrims visit there the whole year. The city is an important one in the state of Maharashtra and surrounded by Sahyadri ranges. The temple is situated 60km from Nasik in the Sahyadri ranges and it is amongst the 51 Shakti peeths located in the Indian subcontinent. Since February 2008, this area is observing rock fall and the ghat road as well as the temple faced a lot of damage and injuries to devotees.

So, in this paper we have analysed the slope and designed different stabilization methods for the same.

LITERATURE REVIEW
Topal et al [5] in Turkey has used Rocfall 4.0 software for assessment of fall out distances, bounce height, kinetic energy and velocity of rocks. This analysis helped in zoning the rockfall danger zone and by its help the correct stabilization method has been designed for that particular area. On similar idea, Chris et al [1] published a paper with a novel methodology to investigate and evaluate the risk posed by rockfalls. The author has proposed that Rocfall 4.0 can be extended as a design tool for sand traps and selection of safety fences. Kulkarni et al [3] in their paper designed the rock fall barrier using the Rocfall 4.0 and also designed the foundation and anchors for the same. The construction of barrier is quite recent and there have been no rockfall event after it was installed. Muhunthan et al [2] in their research report have discussed various field problems and solutions to the same. Along with that they have discussed the testing of wire mesh and its design and provided a formula which can be used to check the global stability of wire mesh which has been used in the later part of the paper for designing the wire mesh.

OBSERVATIONS

Figure 1 Saptshrungi temple ghat road
A survey was carried out on the ghat road shown in the figure above and it revealed compact basalts and amygdaloidal basalts. The ghat road has a hair pin bend and steep slopes made of massive rock and at some places jointed compact basalts also occur. The road leading to the temple has gone through continuous collapsing of weathered material. Large sized pieces were detached from the cliff portion and fell on the shrine area. Entire cliff is made up of pile of greenish blue hydrothermally altered amygdaloidal basalt flows resulting into formation of grooves.
REMEDIAL MEASURES
Looking to the above scenario stabilization programme is justified. The three main types of stabilization methods are rock reinforcement, rock removal and protection.

Rock reinforcement further consists of rock bolting, dowels, tied back walls, buttresses, drainage and shot in place buttresses Rock removal consists of Resloping, Trimming and Scaling and lastly we have Protection which consists of Ditches, Mesh, Catch fences, Warning fences, rock sheds and tunnels.

ANALYSIS AND DESIGN
Planar failure occurs on this particular slope.
Height of slope \( H = 23\) m
Cohesion \( c = 45\) kN/m\(^2\)
Dip of sliding plane \( \Psi_p = 40^\circ \)
Slope of face angle \( \Psi_f = 60^\circ \)
Angle of internal friction \( \phi = 45^\circ \)
Unit weight of rock \( \gamma_r = 26\) kN/m\(^3\)
Unit weight of water \( \gamma_w = 9.81\) kN/m\(^3\)
Tension crack depth is \( Z = 6\) m
Distance of tension crack \( b = 15\) m.

The factor of safety formula for planar failure is [7]

\[
FOS = \frac{cA + (W \cos \Psi_p - U - V \sin \Psi_p) \tan \phi}{W \sin \Psi_p + V \cos \Psi_p}
\]

Where \( A = \text{area of sliding plane and is given by the formula} [7] \)

\[
A = (H + b \tan \Psi_s - Z) \cot \Psi_p
\]

\( W = \text{weight of sliding block and is given by} [7] \)

\[
W = \gamma_r (1 - \cos \Psi_f \tan \Psi_p) \left( H + \frac{1}{2} b \cos \Psi_f \right) + \frac{1}{2} b \left( \tan \Psi_s - \tan \Psi_p \right)
\]

\( U \) and \( V \) are the water forces acting on the sliding plane and is given by

\[
U = \frac{1}{2} \gamma_w Z w (H + b \tan \Psi_s - Z) \cot \Psi_p
\]

\[
V = \frac{1}{2} \gamma_w Z w^2
\]

By substituting the various values in above formulae, we get FOS as 0.97 which means the slope is not safe. By using the Rocfall 4.0 software, we get the exact location of falling rock which will be useful for designing the stabilization methods.

STABILIZATION METHODS

Rock Reinforcement
Rock reinforcement is the placement of rock bolts, untensioned rock dowels, prestressed rock anchors or wire tendons in a rock mass to reinforce and mobilize the rock’s natural competency to support itself. [6]

The use of rock bolts was initiated by the mining industry [6]. The most commonly used technique for the stabilization of slope is rock reinforcement

Formula for rock reinforcement is given by [8]

\[
FS = \frac{cA + (W \cos \Psi_p - U - V \sin \Psi_p + T \sin (\Psi_f - \Psi_p)) \tan \phi}{W \sin \Psi_p + V \cos \Psi_p + T \cos (\Psi_f - \Psi_p)}
\]

Where only values of \( T \) and \( \Psi_f \) change and others remain the same as before

\( T \) (total force) = 240kN
\( S_b \) (shear strength) = 750kN/m\(^2\)
\( F.S \) (factor of safety) = 1.5
\( D_h \) (diameter of hole in metres) = 0.06m
Table 1. Calculation of factor of safety for rock reinforcement.

<table>
<thead>
<tr>
<th>ΨT</th>
<th>T</th>
<th>N</th>
<th>No</th>
<th>L</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>-5625.7</td>
<td>-23.44</td>
<td>65</td>
<td>-39.79</td>
<td>-2.77</td>
</tr>
<tr>
<td>85</td>
<td>-27047</td>
<td>-112.7</td>
<td>50</td>
<td>-191.3</td>
<td>-0.44</td>
</tr>
<tr>
<td>80</td>
<td>4902.28</td>
<td>17.051</td>
<td>45</td>
<td>67.956</td>
<td>1.124</td>
</tr>
<tr>
<td>75</td>
<td>2612.5</td>
<td>10.885</td>
<td>20</td>
<td>28.947</td>
<td>1.173</td>
</tr>
<tr>
<td>70</td>
<td>1292.48</td>
<td>8.0395</td>
<td>10</td>
<td>13.648</td>
<td>1.378</td>
</tr>
<tr>
<td>65</td>
<td>9607.01</td>
<td>40.029</td>
<td>45</td>
<td>67.956</td>
<td>1.124</td>
</tr>
<tr>
<td>60</td>
<td>4092.28</td>
<td>17.051</td>
<td>20</td>
<td>28.947</td>
<td>1.173</td>
</tr>
<tr>
<td>55</td>
<td>2612.5</td>
<td>10.885</td>
<td>10</td>
<td>13.648</td>
<td>1.378</td>
</tr>
<tr>
<td>50</td>
<td>1929.48</td>
<td>8.0395</td>
<td>10</td>
<td>13.648</td>
<td>1.378</td>
</tr>
<tr>
<td>45</td>
<td>1538.87</td>
<td>6.412</td>
<td>5</td>
<td>7.8846</td>
<td>1.077</td>
</tr>
<tr>
<td>40</td>
<td>1114.66</td>
<td>4.6444</td>
<td>5</td>
<td>7.8846</td>
<td>1.077</td>
</tr>
<tr>
<td>35</td>
<td>895.106</td>
<td>3.7296</td>
<td>5</td>
<td>6.3316</td>
<td>1.341</td>
</tr>
<tr>
<td>30</td>
<td>767.289</td>
<td>3.197</td>
<td>5</td>
<td>5.4275</td>
<td>1.564</td>
</tr>
<tr>
<td>25</td>
<td>723.693</td>
<td>3.0154</td>
<td>5</td>
<td>5.1191</td>
<td>1.658</td>
</tr>
<tr>
<td>20</td>
<td>698.753</td>
<td>2.874</td>
<td>5</td>
<td>4.879</td>
<td>1.74</td>
</tr>
<tr>
<td>15</td>
<td>663.678</td>
<td>2.7653</td>
<td>5</td>
<td>4.6946</td>
<td>1.808</td>
</tr>
<tr>
<td>10</td>
<td>644.227</td>
<td>2.6843</td>
<td>5</td>
<td>4.557</td>
<td>1.863</td>
</tr>
<tr>
<td>5</td>
<td>630.546</td>
<td>2.6273</td>
<td>5</td>
<td>4.4602</td>
<td>1.903</td>
</tr>
<tr>
<td>3</td>
<td>626.554</td>
<td>2.6106</td>
<td>5</td>
<td>4.432</td>
<td>1.915</td>
</tr>
<tr>
<td>2</td>
<td>624.861</td>
<td>2.6036</td>
<td>5</td>
<td>4.42</td>
<td>1.92</td>
</tr>
<tr>
<td>1</td>
<td>623.367</td>
<td>2.5974</td>
<td>5</td>
<td>4.4094</td>
<td>1.925</td>
</tr>
<tr>
<td></td>
<td>623.367</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From the above calculations we get optimized angle as 5º, but practically it is feasible to insert the anchor at 10º-15º. Therefore to get 1.5 FOS at 15º, the total force required will be 664kN, number of bolts per metre will be 5 with a bonded length of 4.6m and unbounded length of 10m therefore a total length of 14m at spacing of 2m.

**Barriers**

A variety of barriers can be constructed either to enhance the performance of excavated ditches, or to form catchment zones at the toe of slopes. The required type of barrier and its dimensions depend on the energy of the falling blocks, the slope dimensions and the availability of construction material [3]. Barriers absorb impact energy by deforming, and systems with high impact energy capacity are both flexible and are constructed with materials that can withstand the impact of sharp rocks [3].

**Wire Mesh**

During 1980’s various fences and nets suitable for installation on steep rock faces, in ditches and on talus run-out zones were developed and thoroughly tested. A common feature of all these designs is their ability to withstand impact energy from rock falls due to their construction without any rigid components. When a rock impacts a net, there is deformation of the mesh which then engages energy absorbing components over an extended time of collision. This deformation significantly increases the capacity of these components to stop rolling rock and allows the use of light, low cost elements in construction [7]. The formula used for calculating the factor of safety of wire mesh is as follows [2].

\[
F.S = \frac{f_a + f_{dm} + f_w}{f_{wm} + f_{wm}}
\]

Where
- \( f_a \) = anchor capacity
- \( f_{dm} \) = force due to accumulated debris
- \( f_w \) = interface friction
- \( f_d \) = debris load
- \( f_{wm} \) = mesh weight
Table 2. Calculation of factor of safety of wire mesh

<table>
<thead>
<tr>
<th>P</th>
<th>J</th>
<th>$f_w$</th>
<th>$f_d$</th>
<th>$f_{dm}$</th>
<th>$f_{wm}$</th>
<th>$f_a$</th>
<th>F.S</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>8</td>
<td>67.9</td>
<td>784.8</td>
<td>1620</td>
<td>140.3</td>
<td>1920</td>
<td>1.5</td>
</tr>
<tr>
<td>240</td>
<td>6</td>
<td>67.9</td>
<td>784.8</td>
<td>1620</td>
<td>140.3</td>
<td>1200</td>
<td>1.1</td>
</tr>
<tr>
<td>240</td>
<td>10</td>
<td>67.9</td>
<td>784.8</td>
<td>1620</td>
<td>140.3</td>
<td>2400</td>
<td>1.8</td>
</tr>
<tr>
<td>240</td>
<td>5</td>
<td>67.9</td>
<td>784.8</td>
<td>1620</td>
<td>140.3</td>
<td>1440</td>
<td>1.3</td>
</tr>
<tr>
<td>240</td>
<td>6</td>
<td>67.9</td>
<td>784.8</td>
<td>1620</td>
<td>140.3</td>
<td>1200</td>
<td>1.1</td>
</tr>
<tr>
<td>240</td>
<td>10</td>
<td>67.9</td>
<td>784.8</td>
<td>1620</td>
<td>140.3</td>
<td>2400</td>
<td>1.8</td>
</tr>
<tr>
<td>240</td>
<td>4</td>
<td>67.9</td>
<td>784.8</td>
<td>1620</td>
<td>140.3</td>
<td>960</td>
<td>1.0</td>
</tr>
<tr>
<td>240</td>
<td>6</td>
<td>67.9</td>
<td>784.8</td>
<td>1620</td>
<td>140.3</td>
<td>1440</td>
<td>1.3</td>
</tr>
<tr>
<td>240</td>
<td>8</td>
<td>67.9</td>
<td>784.8</td>
<td>1620</td>
<td>140.3</td>
<td>1200</td>
<td>1.1</td>
</tr>
<tr>
<td>240</td>
<td>4</td>
<td>67.9</td>
<td>784.8</td>
<td>1620</td>
<td>140.3</td>
<td>960</td>
<td>1.0</td>
</tr>
</tbody>
</table>

\[ f_w = \gamma_w \cdot s_w \cdot \cos \beta \cdot \tan \delta \]
\[ f_d = 0.5H_d^2 \cdot \gamma_d \cdot w_d \cdot \cos \beta \cdot (\cot \phi_{cs} - \cot \beta) \cdot \tan \delta \]
\[ f_{wm} = \gamma_w \cdot s_w \cdot \sin \beta \]
\[ f_{dm} = 0.5H_d^2 \cdot \gamma_d \cdot w_d \cdot \sin \beta \cdot (\cot \phi_{cs} - \cot \beta), \]

where $\phi_{cs}$ = estimated slope angle of accumulated debris

Therefore the design for wiremesh is as follows:

Where

\[ \gamma_w = 18 \text{kN/m}^2 \]
\[ \beta = 60^\circ \]
\[ S_w = 9 \text{m} \]
\[ H_d = 6 \text{m} \]
\[ \delta = 40^\circ \]
\[ \gamma_d = 30 \text{kN/m}^2 \]

$\varphi_{cs} = 30^\circ$

P = 240kN

By observing this design we can provide wire mesh along with rock reinforcement as it gives a factor of safety of 1.5 for 8 number of reinforcement per metre length.

**CONCLUSIONS**

The rock fall occurs due to the continuous weathering of the deccan trap basalt that has happened over the years.

In this paper we have discussed rock reinforcement, wire mesh design and rock fall barrier design.

Barriers are definitely a cost effective type of stabilization method and in my design the rock fall is also stopped by the barrier system but there is a chance of rockfall that might take place from a different path and trajectory is out of the barrier path, hence provision of only barriers is not a recommended design.

Hence, the best suited stabilization for this site is associated with wire mesh, as it definitely assures a safer design.

**REFERENCES**