Characterization of Pare Rock Mass and Support System Design for Head Race Tunnel

Pragati Goswami, Diganta Goswami, Ranjeet Bahadur Singh, Pawan Kumar Singh, Sylvia Kashyap

Abstract: The Head Race Tunnel (HRT) of Pare Hydro-Electric Power Project in Arunachal Pradesh, India, traverses through the Upper-Siwalik Sub-Group of the Sub-Himalayan Range, exhibiting spatial heterogeneity with respect to geotechnical and geological properties. In such complex geological set up, consisting of bedding planes, joints, fractures, varied hydrological conditions etc., prediction of rock mass quality or the characterization of the rock mass is a difficult task. Although challenging, it is important to predict the general response of the rock mass to tunnel excavation. This paper attempts to characterize Pare Rock Mass around the HRT, based on Rock Mass Quality Designation (RQD), Terzaghi’s Rock Load Theory, Rock Structure Rating (RSR), Rock Mass Rating (RMR), and, Rock Mass Quality (Q) system. An attempt is also made to design the support system for HRT through Pare Rock Mass, based on these parameters. A critical examination of various support systems derived from the above mentioned methods and the support system actually provided at the HRT at Pare Hydroelectric Power Project is also presented in the paper. The study presented in this paper will provide insight about the suitability of a particular method in the design of support system in a rock mass similar to Pare rock mass.

Keywords: Pare Rock, Rock Mass Classification, Support design, Tunneling.

I. INTRODUCTION

Pare Hydroelectric Power Project, which is being executed by NEEPCO Ltd, at Pare, Arunachal Pradesh, India, is a run-of-the river scheme with a 78.0m high concrete gravity dam and a 7.5m diameter concrete lined modified Horse shoe shaped Headrace Tunnel (HRT), 2.83km long, along with other salient components. Geotechnical investigation prior to the construction of the HRT, and also during its excavation has given enough exposure for characterization of the rock mass. Various available and extensively used methods for assessing important parameters like stand-up time, and, designing support system for the HRT, such as, Deere’s RQD, Terzaghi’s Rock Load Theory, Rock Structure Rating (RSR), Bieniawski’s Rock Mass Rating (RMR), Barton’s Rock Mass Quality (Q) etc. [1],[2] are employed to arrive at a final design for the support system of HRT. The actual support system used for the HRT at Pare, which has been performing well, is compared with the ones obtained from the various other methods. The first part of the paper deals with characterization of the Pare rock mass by various available methods and the second part is devoted to the design of the support system of the HRT.

II. GEOLOGICAL FEATURE OF THE PROJECT SITE

Drill holes at the HRT site and the rock exposed during tunneling reveals that the rock mass is predominantly medium grained, salt pepper textured, soft, friable grayish sandstone. Because of presence of mega folds, faults and the thrust it has been experiencing, the landform shows presence of tectonic lineaments and heterogeneity in lithology.

Pare lies within the Upper-Siwalik Sub-Group of the Sub-Himalayan Range. Alternate lenses of pebbly sandstone and carbonaceous shale are observed within the weak to very weak, moderately to highly jointed sandstone with seepage face.

III. ROCK MASS CHARACTERIZATION OF PARE HRT ROCK

From the drill hole at the HRT site and also from the geological mapping for about 100m running distance during actual excavation of the HRT, characterization of the Pare HRT rock mass is done. Geological mapping was done at fifty sections during HRT excavation, and Table I shows one such sample description at anchajine of 1198.7m in the HRT. Following sub-sections from A to E describe various approaches adopted for characterization and the sub section F shows the results of the rock mass characterization at HRT, Pare, Arunachal Pradesh.

Accepted Manuscript Received on March 30, 2020.

Pragati Goswami, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: pragatigoswami900@gmail.com
Diganta Goswami, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: digantagoswami2@gmail.com
Ranjeet Bahadur Singh, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: rsbingsntpc@gmail.com
Pawan Kumar Singh, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: singhpawan123@gmail.com
Sylvia Kashyap, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: sylvia.kashyap@gmail.com

Revised Manuscript Received on March 30, 2020.

Pragati Goswami, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: pragatigoswami900@gmail.com
Diganta Goswami, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: digantagoswami2@gmail.com
Ranjeet Bahadur Singh, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: rsbingsntpc@gmail.com
Pawan Kumar Singh, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: singhpawan123@gmail.com
Sylvia Kashyap, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: sylvia.kashyap@gmail.com

Retrieved Number: F9575038620/2020/BEIESP
DOI: 10.35940/jrte.F9575.038630

Published By: Blue Eyes Intelligence Engineering & Sciences Publication

©BEIESP
A. Rock Quality Designation

Deere et al. [3] defined the Rock Quality Designation (RQD) as a modified core recovery percentage in which the sound rock core pieces over 100mm are summed and divided by the length of core run. The core logging at the site gives an average RQD of 20. Rock Quality Designation (RQD) is the simplest method for assigning quality to rock. Since in many cases RQD is the only information available for describing rock discontinuities, determination of RQD is very important as it provides useful information for effective evaluation of the deformation modulus and unconfined compressive strength of rock masses based on RQD [5]. RQD is one of the important parameter in many of the rock mass classification systems such as Rock Structure Rating (RSR), Rock mass Rating (RMR), Rock Tunnel Quality Q-System, etc.

The RQD values can be obtained either from drill core or from empirical correlation between volumetric discontinuity frequency as proposed by Palmstrom (2005) and shown in (1) [4].

\[
RQD = 110 - 2.5 \text{ } J_v \quad \text{for } 4 \leq J_v \leq 44
\]

Where, \( J_v \) = Volumetric Joint frequency

\[
J_v = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \cdots
\]

Where \( S_1 \), \( S_2 \) and \( S_3 \) are the mean discontinuity set spacing.

While using (1), RQD is found to be close to 100, which is very high compared to the values obtained from core logging as per Deere, 1989 [5]. It may be concluded that, while using \( J_v \), the aperture condition of having clay filling plays a major role while getting a correct RQD value. In further calculations RQD is taken to be 20 as obtained from core logging. The Pare rock has two to three joint sets with few random joints. Characterization of Pare Rock Mass is done as per Deere, 1968 [6], which defines rock classes based on RQD, and is presented in Table II.

B. Terzaghi’s Rock Load Theory

Terzaghi in 1946 [7] classified a rock mass successfully for the design of tunnel support in his paper which was the earliest reference to the use of rock mass classification in which descriptive classification are estimated on the basis of the rock loads, carried by steel sets. Table III, exhibits calculation of Rock Load Factor (Hp) as per Terzaghi (1946) and derivation of the Rock Condition.

C. Rock Structure Rating (RSR) System

Rock Structure Rating (RSR) classification was first described by Wickham et al in 1972 [8]. It is a quantitative based method which is basically used for describing the quality of a rock mass and for selecting appropriate supports on the basis of their Rock Structure Rating. It is based on three parameters, for which ratings are given and added together to obtain the final value of RSR. Rock Structure Rating (RSR) of the Pare Rock Mass is derived and presented in Table IV.

D. Rock Mass Rating (RMR) System

Bieniawski (1979) [9] and Bieniawski (1993) [10] characterizes rock mass based on Rock Mass Rating (RMR) on the basis of six parameters such as Unconfined Compressive Strength (UCS), RQD, Spacing and Condition of discontinuities, Ground water condition and Orientation of the joints in the rock mass. Table V shows RMR and characterization of the Pare rock mass at chainage 1198.7m of the HRT.

E. Rock Mass Quality (Q) System

The Q-system of rock mass classification was originally proposed by Barton et. al. (1974) [11] and Barton (2002) [12] at the Norwegian Geotechnical Institute (NGI) and it is based on the number of case histories of tunnels and caverns. They defined the rock mass quality (Q) by the following influential factors:

\[
Q = \frac{[RQD/J_v][J_1/J_2][J_3/SRF]}{[J_4/J_5][J_6/J_7][J_8/SRF]}
\]

Classification of Pare rock based on Q-System is presented in Table VI.

F. Results of Pare Rock Mass Characterization

The following tables present the characterization of Pare Rock Mass based on the above mentioned classification systems.
Table- II: Characterization of Pare Rock based on RQD

<table>
<thead>
<tr>
<th>Rock Quality Designation (RQD)</th>
<th>Rock Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Very Poor</td>
</tr>
</tbody>
</table>

Table- III: Characterization of Pare Rock based on Terzaghi’s Rock Load Theory

<table>
<thead>
<tr>
<th>RQD (%)</th>
<th>Rock class</th>
<th>Rock Condition</th>
<th>Rock load (Hp)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>VI</td>
<td>Crushed</td>
<td>(0.6–1.10) (B + Ht) = 1(7.5 + 6.47) = 13.97</td>
<td>Considerable side pressure. Softening effects of seepage towards bottom of tunnel</td>
</tr>
</tbody>
</table>

B=tunnel span in meters; Ht = height of the opening in meters; and Hp= height of the loosened rock mass above tunnel crown developing load.

Table- IV: Characterization of Pare Rock based on RSR System

<table>
<thead>
<tr>
<th>Parameter A</th>
<th>Parameter B</th>
<th>Parameter C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock type origin</td>
<td>Rock Hardness</td>
<td>Geological Structure</td>
</tr>
<tr>
<td></td>
<td>Joint spacing (inch)</td>
<td>Joint orientation (Dip Direction)</td>
</tr>
<tr>
<td></td>
<td>Direction of Tunnel drive</td>
<td>Overall Rock mass quality due to Parameter A and B</td>
</tr>
<tr>
<td></td>
<td>Joint Condition</td>
<td>Amount of water flow (gallons/min/m)</td>
</tr>
<tr>
<td></td>
<td>Total RSR (A+B+C)</td>
<td></td>
</tr>
<tr>
<td>Sedimentary</td>
<td>Soft</td>
<td>Moderately to highly faulted</td>
</tr>
<tr>
<td>Basic Rock Type</td>
<td>Rating</td>
<td>Rating</td>
</tr>
<tr>
<td>IV</td>
<td>8</td>
<td>32</td>
</tr>
</tbody>
</table>

Table- V: Characterization of Pare Rock based on RMR System

<table>
<thead>
<tr>
<th>Tunnel Chainage (m)</th>
<th>UCS</th>
<th>RQD</th>
<th>Spacing</th>
<th>Condition of discontinuity</th>
<th>Groundwater</th>
<th>RMR basic</th>
<th>Orientation</th>
<th>RMR</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1198.7</td>
<td>1</td>
<td>3</td>
<td>15</td>
<td>10</td>
<td>4</td>
<td>33</td>
<td>-2</td>
<td>31</td>
<td>Poor</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3</td>
<td>10</td>
<td>10</td>
<td>4</td>
<td>29</td>
<td>-2</td>
<td>27</td>
<td></td>
</tr>
</tbody>
</table>

Table- VI: Characterization of Pare Rock based on Q System

<table>
<thead>
<tr>
<th>Tunnel Chainage (m)</th>
<th>RQD&lt;sub&gt;min&lt;/sub&gt;</th>
<th>J&lt;sub&gt;n&lt;/sub&gt;</th>
<th>J&lt;sub&gt;r&lt;/sub&gt;</th>
<th>J&lt;sub&gt;a&lt;/sub&gt;</th>
<th>J&lt;sub&gt;w&lt;/sub&gt;</th>
<th>SRF</th>
<th>Q</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1198.7</td>
<td>20</td>
<td>6</td>
<td>1</td>
<td>1.5</td>
<td>1</td>
<td>2.5</td>
<td>0.8889</td>
<td>Very Poor</td>
</tr>
</tbody>
</table>

In = joint set number, Jr = joint roughness number for critically oriented joint set, Ja = joint alteration number for critically oriented joint set, Jw = joint water reduction factor, SRF = stress reduction factor.

Likewise, starting from chainage 1165.00m to 1265.10m of the Pare headrace tunnel, characterization was done, based on the geological mapping during actual tunnel excavation. It is found that from chainage 1165.00m to 1198.70m, the rock falls under “poor” category with RMR ranging from 25 – 40 and from chainage 1198.7m to 1265.10m, the rock falls under “very poor” category with RMR ranging from 18 – 22.

Whereas in Q-system, the rock falls under “poor” category throughout the length with Q value ranging from 0.2 – 1.33.
A detailed design of the support system for the Pare HRT is carried out, based on Q value and is presented in sub-section A and B, and the support systems recommended by various classification system is discussed in sub-section C together with the design analysis performed in this paper and the supports system actually provided at the site.

A. Methodology

As mentioned earlier, the rock comes under poor quality throughout the length with Q ranging from 0.2 – 1.33, and hence the design will be same throughout the considered length of the HRT. So, an average rock mass quality of \((\text{Q}_{\text{max}} \times \text{Q}_{\text{min}})^{1/2}\) is assumed in the design calculations. As ultimate support pressure is related to rock mass quality, an empirical correlation was proposed by Singh et al. (1992) [2] for a time period of 100 years after the installation of supports:

\[
p_{\text{ult}} = 0.2 \frac{Q_{\text{ult}}}{F} \cdot f' \cdot f''
\]  

Where,  

- \(p_{\text{ult}}\) = ultimate support pressure in MPa;  
- \(Q\) = rock mass quality;  
- \(f'\) = correction factor for overburden = \(1+ (H-320)/800\);  
- \(f''\) = correction factor for tunnel closure = \(2 as J/J_{a} = 0.16<0.5\) (for squeezing condition);  
- \(H\) = overburden above crown or tunnel depth below ground level in meters = 200m.

Support Pressure is obtained using (4), which is taken into consideration while designing its support system taking the help of NATM. Also wall support pressure is calculated using (4) putting \(Q = 12.5\) Q, as this support pressure is very important in case of squeezing rock condition.

For design of supports, bolt length, bolt diameter, shotcrete thickness, shear strength of shotcrete are the most vital component, from which we can check its support capacity.

Bolt Length, \(l_{b} = 2+((0.15 \text{ B or } H/\text{ESR}) \text{ m}) (5)\)

Anchor Length, \(l_{a} = 0.40 \text{ B/ ESR m (for Roof)} (6a)\)

\(l_{l} = 0.35 \text{ H/ESR m (for Walls)} (6b)\)

Where, \(B = \text{width of excavation in meter = 7.5m, } H = \text{height of excavation in meter = 6.5m, } \text{ESR = excavation support ratio = 1.6 for water tunnel as in Barton, 2008.}\)

Thickness of Steel Fibre Reinforced Shotcrete lining,

\[
t_{\text{fsc}} = \frac{P_{\text{roof}} \cdot B \cdot F_{\text{fsc}}}{2q_{\text{fsc}}} \]  

Where, \(P_{\text{roof}}\) = ultimate roof/wall support pressure, \(B\) = size of opening, \(F_{\text{fsc}}\) = mobilization factor of shotcrete = 0.6±0.05, \(q_{\text{fsc}}\) = shear strength of shotcrete = 600t/m²
Table VII: Calculated results of Components of Support System

<table>
<thead>
<tr>
<th>Q&lt;sub&gt;avg&lt;/sub&gt;</th>
<th>φ</th>
<th>Ultimate Support Pressure, p&lt;sub&gt;ult&lt;/sub&gt; (t/m²)</th>
<th>Wall Support Pressure, (t/m²)</th>
<th>Bolt Length, l (m)</th>
<th>Anchor Length, l&lt;sub&gt;a&lt;/sub&gt; (Roof)</th>
<th>Anchor Length, l&lt;sub&gt;a&lt;/sub&gt; (Wall)</th>
<th>Thickness of Shotcrete Lining, t&lt;sub&gt;sc&lt;/sub&gt; (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.52</td>
<td></td>
<td>50.98</td>
<td>37.42</td>
<td>2.73</td>
<td>1.95</td>
<td>1.42</td>
<td>191.2</td>
</tr>
</tbody>
</table>

But the value of length of bolt and thickness that New Austrian Tunneling Method (NATM) [13] proposed is 5-7m and 150-200mm respectively. Hence a set of trials are done selecting different values of bolt length and thickness of concrete lining within the range. The final dimensions which give a safe design with respect to ultimate tunnel support pressure are presented in Table VIII with the help of (8), (9), (10) and (11).

Table VIII: Analysis of Support Capacities

<table>
<thead>
<tr>
<th>U&lt;sub&gt;r&lt;/sub&gt; (t/m²)</th>
<th>p&lt;sub&gt;ult&lt;/sub&gt; (t/m²)</th>
<th>U&lt;sub&gt;ult&lt;/sub&gt; (t/m²)</th>
<th>B (m)</th>
<th>q&lt;sub&gt;ult&lt;/sub&gt; (t/m²)</th>
<th>t&lt;sub&gt;sc&lt;/sub&gt; (mm)</th>
<th>F&lt;sub&gt;sc&lt;/sub&gt;</th>
<th>S&lt;sub&gt;ult&lt;/sub&gt; (m)</th>
<th>S&lt;sub&gt;rock&lt;/sub&gt; (m)</th>
<th>P&lt;sub&gt;ult&lt;/sub&gt; (t/m²)</th>
<th>q&lt;sub&gt;ult&lt;/sub&gt; (t/m²)</th>
<th>l&lt;sub&gt;a&lt;/sub&gt; (m)</th>
<th>F&lt;sub&gt;r&lt;/sub&gt;</th>
<th>Sinθ</th>
<th>p&lt;sub&gt;ult&lt;/sub&gt; (t/m²)</th>
<th>p&lt;sub&gt;ult&lt;/sub&gt; (t/m²)</th>
<th>p&lt;sub&gt;ult&lt;/sub&gt; (t/m²)</th>
<th>p&lt;sub&gt;ult&lt;/sub&gt; (t/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>50.98</td>
<td>55.98</td>
<td>7.5</td>
<td>600</td>
<td>160</td>
<td>0.64</td>
<td>0.08</td>
<td>0.11</td>
<td>37.0</td>
<td>95</td>
<td>4.66</td>
<td>3.2</td>
<td>0.94</td>
<td>42.67</td>
<td>13.6</td>
<td>0</td>
<td>56.27</td>
</tr>
</tbody>
</table>

C. Support Systems Suggested by Various Methods

There is various support category recommendation for tunnel in many of the Rock Mass Classification System as mentioned earlier. In this paper, a study is being done for support measures using Terzaghi’s Rock Load Theory, Classification System of Stini and Lauffer, Deere’s Rock Quality Designation (RQD) Classification System, Rock Structure Rating (RSR) Classification System, Rock Mass Rating (RMR) system of Bieniawski and Rock mass quality (Q) system of Barton et al. as shown in Table IX.

Table IX: Support Systems based on Various Classification Systems for Pare HRT rock

<table>
<thead>
<tr>
<th>Rock Mass Classification System</th>
<th>Value of Rock Load Factor</th>
<th>Support Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terzaghi’s Rock Load Theory</td>
<td>13.97 (from Table III)</td>
<td>Medium to heavy circular steel sets with spacing of 0.6 to 1.2m, rock bolts with a spacing of 1.2 to 1.8 m and considerable mesh and straps required together with 15cm shotcrete layer for the Drilling and blasting construction method as given in Terzaghi, 1946 [7]</td>
</tr>
<tr>
<td>Classification system of Stini and Lauffer</td>
<td>Value of Active Span</td>
<td>7.5 m</td>
</tr>
<tr>
<td>Stand-up time</td>
<td>1 day as per the chart given by Lauffer, 1988 [17]</td>
<td></td>
</tr>
<tr>
<td>Rock Quality Designation (RQD)</td>
<td>Value of RQD</td>
<td>20, Very poor as mentioned in Table II</td>
</tr>
<tr>
<td>Support Measure</td>
<td>Heavy circular steel sets with 0.6 m centre to centre having a Rock load of 2.0 to 2.8B , rock bolts pattern of 0.9 m centre to centre and shotcrete layer of thickness 150mm or more, combined with medium to heavy sets as per Deere, 1969 [18]</td>
<td></td>
</tr>
<tr>
<td>Total RMR value</td>
<td>31 and 27 (from Table V)</td>
<td></td>
</tr>
<tr>
<td>Rock Mass Rating (RMR) system</td>
<td>Support Measure</td>
<td>Excavated recommended to be multiple drifts of 0.5-1.5 m advancement in top heading with installation of support concurrently with excavation and shotcreting is to be done as soon as possible after blasting. Recommended support should be Systematic bolts of 20mm diameter and 5-6 m long, spaced 1-1.5 m in crown and walls; Shotcrete layer of thickness 150-200 mm in crown and 150 mm in sides; and steel sets containing medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required as per Bieniawski 1989[20]</td>
</tr>
<tr>
<td>Rock Mass Quality (Q) system</td>
<td>Value of Q</td>
<td>0.889 (from Table VI)</td>
</tr>
<tr>
<td>Support Measure based on the design performed</td>
<td>Steel fibre reinforced Shotcrete of thickness 160 mm, having shear strength of 6000/m², bolt length of 5m having diameter 25mm with a spacing of 0.8m should be provided.</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Actually provided on Site Support Measures</td>
<td>Initial layer of concrete on face and crown, single layer of wiremesh (100mmX100mmX5mm) with shotcrete of 100mm thickness, Bolting with 16mm diameter tie rods, ISMB200 steel Rib with 1000mm c/c, Backfill Rib spacing with shotcrete. 32mm dia. 4000mm long forepoles @ 250mm C/C in the crown wherever required.</td>
<td></td>
</tr>
<tr>
<td>Rock Structure Rating (RSR) system</td>
<td>Total RSR value 49 (from Table IV) Support Measure 3 inches of shotcrete, 1 inch diameter rock bolts spaced at 3 ft centre to centre and the support could be provided by 6 H 20 steel sets (6 inch deep wide flange H section weighing 20 lb per foot) spaced 4 feet apart [19] as per Wickham et al, 1974.</td>
<td></td>
</tr>
</tbody>
</table>

**V. CONCLUSION**

Various parameters to characterize Pare Rock Mass of the Upper-Siwalik Sub-Group of the Sub-Himalayan Range have been determined and presented in this paper. These parameters have also been used to design the support system for the HRT for Pare Rock Mass. Based on the study, following conclusions are drawn:

- Excavation of the HRT reveals that the Pare Rock mass is predominantly medium grained, salt pepper textured, soft, friable, grayish, weak to very weak, moderately to highly jointed sandstone with seepage face with occasional alternate lenses of pebbly sandstone and carbonaceous shale.
- RQD obtained from volumetric joint count (Palmstrom, 2005) gives a very high value, above 90%, whereas, that obtained by core logging as per Deere, 1988 gives an average RQD of 20.
- Based on the average RQD value, Pare Rock Mass Quality falls under “very poor” category. As per Terzaghi’s rock load factor of 13.97, rock class is VI. Following Rock Structure Rating of 49, basic rock type is IV. As per the RMR value, Pare rock mass may be termed as “Poor” to “Very Poor” and as per the Q value, the same falls under “Very Poor” category.
- For an active span of 7.5m of the opening, the stand-up time of the rock mass is 1 day.
- Terzaghi’s Rock Load Factor suggests the thickness of the shotcrete lining for the HRT as 150mm. Deere (1969) based on RQD, Bieniawski (1989) Rock Mass Rating and Barton’s Q value indicates the thickness of the shotcrete lining of the HRT to be above 150mm. The thickness of the shotcrete lining is arrived at a value of 160mm, following provisions of IS 15026 (2002). However, in practice a thickness of 100mm of the shotcrete lining is found to behave satisfactorily for most of the length of the HRT except attaining squeezing condition in a few locations. However, the same calculated as per Rock Structure Rating (RSR) is only 75mm and may be termed as inadequate.
- RSR is slightly on the higher side so far rock bolt diameters is concerned, but on the lower side when it comes to steel rib size.

**ACKNOWLEDGMENT**

This work is the result of a research project sponsored by NEEPCO Ltd. We sincerely acknowledge NEEPCO Ltd. For providing us the various geological as well as geotechnical data of Pare rock mass, which was necessary for carrying out the present work.

**REFERENCES**

Pragati Goswami has completed B.Tech in Civil Engineering from Assam Science and Technology University (ASTU), Guwahati. She is currently pursuing M.Tech. in Geotechnical Engineering under ASTU from Assam Engineering College, Guwahati. Her areas of interest are Geotechnical Engineering, Rock Mechanics. Her recent publication is on “Stability of Slopes for Dam Excavation by Slope Mass Rating in the Pare Hydroelectric Project” in the journal named International Journal of Engineering Research & Technology (IJERT).

Dr. Diganta Goswami is currently working as Associate Professor in Department of Civil Engineering in Assam Engineering College, Guwahati. He obtained his Ph. D. degree in Civil Engineering from IIT, Roorkee. His areas of research include Geotechnical Engineering, Finite Element Analysis, Tunnels and other river valley project, Foundation Analysis and Design. He has published more than 30 articles in reputed journals and handled many government and private funded projects in India. His recent publication is on “Stability of Slopes for Dam Excavation by Slope Mass Rating in the Pare Hydroelectric Project” in the journal named International Journal of Engineering Research & Technology (IJERT).

Ranjeet Bahadur Singh is working with NTPC Limited as a Deputy General Manager (Civil). He has completed his M.Sc. Engineering in Water Resources from National Institute of Technology (Patna). He has had the privilege of contributing in the construction work of Tala Hydroelectric Project Authority (THPA), an autonomous entity set up by the Government of India in collaboration with the Royal Government of Bhutan. He was also involved and has overseen the construction of the Lohari Nagpala Hydro Electric Power Project (LPHPP), a flagship project of NTPC Limited which is one of the most challenging terrains of the Upper Ganga Basin. His recent publication is on “Stability of Slopes for Dam Excavation by Slope Mass Rating in the Pare Hydroelectric Project” in the journal named International Journal of Engineering Research & Technology (IJERT).

Pawan Kumar Singh has completed B.E in Civil Engineering from Jorhat Engineering College, Jorhat and M.E. in Geotechnical Engineering from Assam Engineering College, Guwahati. He is currently pursuing Ph.D. under Guwahati University, Guwahati. His areas of interest are Geotechnical Engineering, Slope Stability, Rock Mechanics. His recent publication is on “Stability of Slopes for Dam Excavation by Slope Mass Rating in the Pare Hydroelectric Project” in the journal named International Journal of Engineering Research & Technology (IJERT).

Sylvia Kashyap has completed B.Tech in Civil Engineering from Assam Science and Technology University (ASTU), Guwahati. She is currently pursuing M.Tech. in Geotechnical Engineering under ASTU from Assam Engineering College, Guwahati. Her areas of interest are Geotechnical Engineering, Rock Mechanics. Her recent publication is on “Stability of Slopes for Dam Excavation by Slope Mass Rating in the Pare Hydroelectric Project” in the journal named International Journal of Engineering Research & Technology (IJERT).