# Rock Mass Characterization using Rock Mass Rating and Tunnel Seismic Prediction (TSP) Technique in Head Race Tunnel of Sewa Power Station, Stage-II, J&K, India

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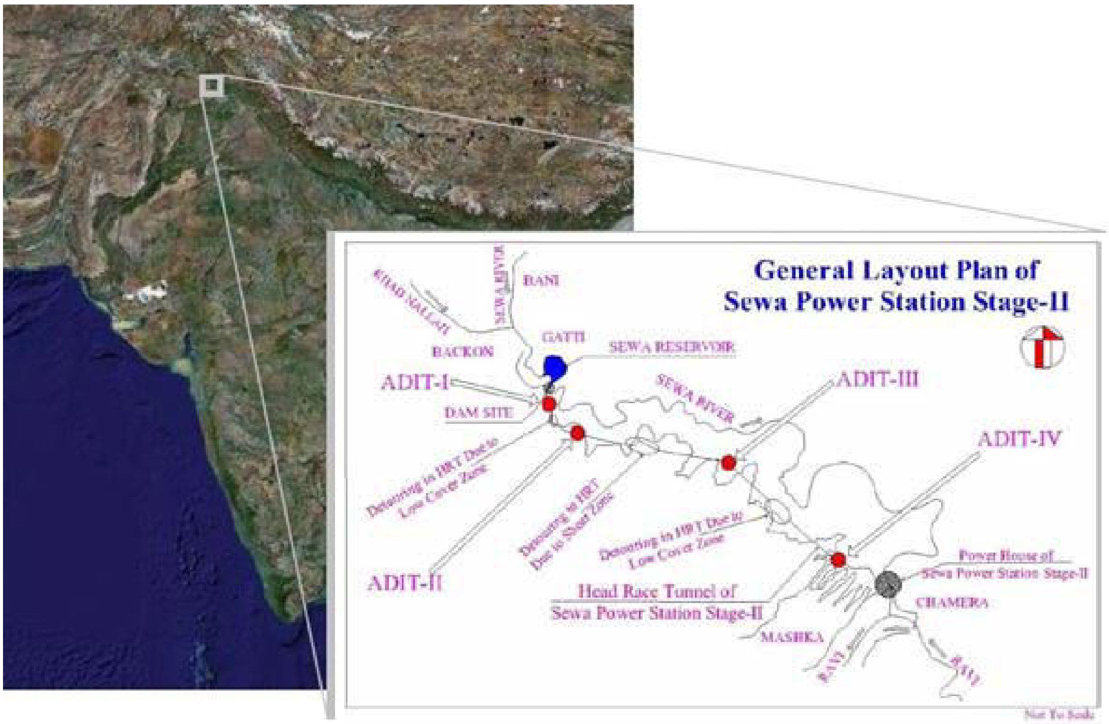
**Abstract**

During underground excavation one of the important aspects for a speedy and safe excavation is to characterize rock mass for its stand up time. In HRT of Sewa Project, RMR classification was used during excavation and based on RMR values, rock mass was supported. It has been observed that RMR classification has limitation especially in terrain having wide geological diversity, as one cannot predict the nature of rock mass beyond the excavated face. Therefore, apart from RMR classification, a non destructive geophysical technique i.e. Tunnel seismic prediction (TSP) was used to predict rock mass ahead of excavation, plan drainage measures, assess weakness within the media and thereby employ support measures. The TSP results indicated that the method provides a good picture in terms of rock strength and presence of groundwater. Consequently, such zones were known in advance and accordingly necessary arrangements were made for fast and safe excavation. This is additional advantage of TSP apart from giving prediction of weak discontinuities. The paper deals with rock mass characterization of underground structures specially HRT using RMR classification and TSP technique.

## 1. Introduction:

Sewa Power Station-II is a run of the river scheme, harnessing the potential of river Sewa, a tributary of Ravi River. A gross head of approx. 599 m in lower one third course of river Sewa between Gatti (Dam) & Mashka (Powerhouse) is being utilized to generate 120 MW (40MW x 3) of power. A small pondage of adequate capacity has been provided as an operating pool to meet diurnal peaking load demand.

A 10.084 km long Head race tunnel was constructed to carry 24.25 cusec of water from dam to powerhouse. In order to facilitate the excavation of HRT four Adits (with eight Faces) were provided at chainage 364m, 2729m, 5609m and 10028m respectively. RMR classification was used for identifying the rock class and based on rock mass rating, support was provided in all underground structures. The general lay out of Sewa Power Station is given in Figure 1.




(After Dabral & Tripathi, 2013)

Figure 1 General Layout plan of Sewa Power Station, Stage-II.

## 2. Geology of the Study Area:

Wide geological diversity and structural complexity characterizes the area. Rocks of Bhadarwa group, Tanawal group, Panjal volcanics and Murree formations cover the project area separated by major thrusts (Figure 2). HRT is crossing from high grade metamorphic to medium and low grade metamorphic rock. The upstream part of HRT for about 5115 m chainage is traversed by augen/granite gneisses. The contact of Dalhousie granite and Tanawal group is thrusted but contact is sharp (encountered at RD 493m U/S of Adit-III, Face-V). The remaining part of HRT lies in the tectonised sequence of Tanawal Formation. In view of the obliquity of the tunnel alignment with the general disposition of rocks, a considerable portion of tunneling is through folded and faulted sequence of Tanawal group of rock. Further, the strike of the formations is generally EW, dipping steeply towards N or S giving negative rating to RMR value. At places, number of sheared rock mass was encountered during tunneling, particularly along the vicinity of fault zones. Main part of sequence comprises of calcareous slates, phyllitic slates, limestone and quartzites representing competent rock. The subordinate part comprises of carbonaceous phyllites, sericitic/ choritic phyllites and sheared limestones, representing incompetent rock, which is highly foliated, partly soft and at places sheared. Mainly the poor tunneling medium includes carbonaceous phyllites & crushed limestones. At places due to karstic nature of limestones water bearing zones were encountered. Heavy seepage in slate was also observed especially in Face-VI & VII.

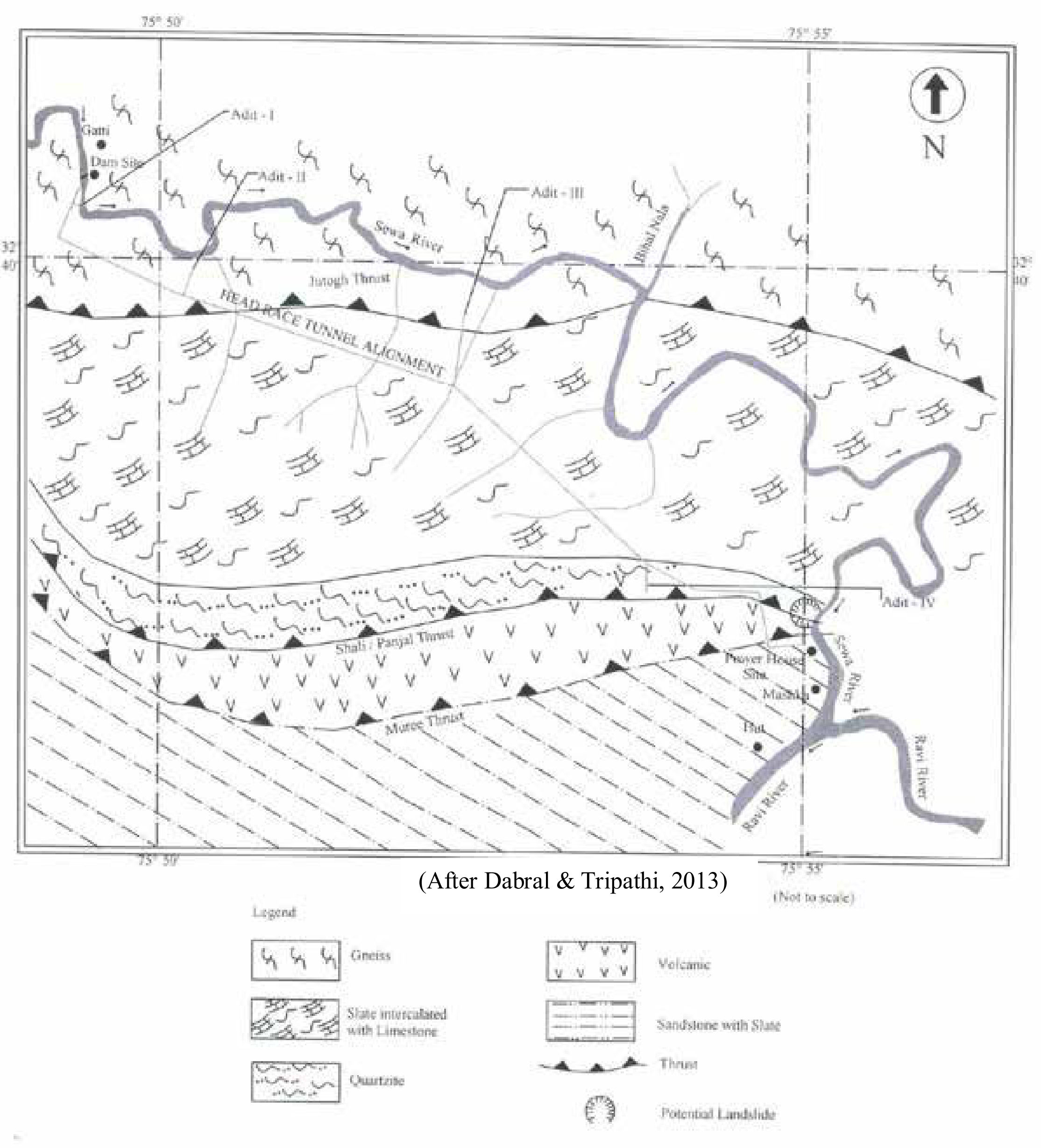



Figure 2 Geology in and around the Project area.

The following sequence of rocks comprises the geological setup encompassing the project components (Table 1).

Table 1
General Geology of the Project Area

| Formation / Lithology | Age |
|---|---|
| Bhadarwa group of rocks comprising phyllites and Slates. | Pre-cambrian |
| Dalhousie granite comprising augen / granite gneiss (Jutogh formation) | |
| -------------------------------Jutogh Thrust------------------------------- | |
| Tanawal group (Agglomeratic) of rocks comprising phyllites, limestones, carbonaceous slates & quartzites. | |
| -------------------------Panjal / Shali Thrust----------------------------- | |
| Panjal Volcanics - green, amygdaloidal and vesicular basalts | Permo-carboniferrous Upper Triassic |
| ----------------------------Murree Thrust-------------------------------- | |
| Murree formation comprising sand stone, siltstone and shale | Lower Miocene |

## 3. Rock Mass Characterization in Head Race Tunnel:

A total of ~10km of Head race tunnel was excavated to carry water from dam to power house. The excavation traversed through diverse geological conditions and it was found that the rock mass was discontinuous mainly due to joints, shear planes, bedding planes, foliations, gneissocity, slaty cleavages and at places due to presence of shearing/faults. As stability and deformation are governed by these geological features hence analysis of joint sets, joint orientation, their spacing, roughness, thickness, open or closed and joint material was made to arrive RMR values so that the stability of rock mass can be increased either by providing active or passive support. Details of various lithologies as follows:

The gneisses are generally off white to gray coloured, medium to coarse grained, massive to closely jointed. Foliation is well developed in this rock mass due to presence of flaky mica bands, the augens are aligned conspicuously along the foliation planes, which at places display warping.

The slate, phyllite, carbonaceous phyllite has been grouped together as there is apparently no clear distinction between the different phyllitic assemblages and during excavation transition zones between the phyllites have been observed, particularly between carbonaceous slates and phyllites with limestone and massive phyllite. Due to the wide variation in the jointing, the phyllites vary from being moderately jointed as in the case of carbonaceous slates to intensively jointed as in carbonaceous phyllites. The carbonaceous phyllites are, in general, closely to intensively jointed, weak and fragile. The carbonaceous slates are moderately jointed, dark grey to black in colour and exhibit staining along exposed joint surfaces. Foliation surfaces are prominent and splintering along foliation is occasionally observed.

Lime stones are generally light to dark grey in colour with chert bands or patches of amorphous silica which shows crystalline encrustations on the surface. Limestone horizons contain 20-30% phyllites and slaty intercalations and transitional zones grading into massive phyllites has also been observed between Face-VI and Face VII. Due to the brittle nature of the rock mass, crushing of the litho-logical unit into small chalky fragments and pulverized material has been observed at places.

In Face-VII upto RD 223m and the entire Face-VIII i.e. 56m was in quartzite rock which were intensely jointed, fractured and at times fragmented. The intense nature of the jointing is possibly a repercussion of faulting, as the lithological contact between the quartzite and the underlying volcanic is apparently a faulted / thrusted one.

Details of rock mass characteristic are summarized in Table 2.

Table 2
Characteristic of Rock Mass Encountered in HRT

| Rock Type | Gneiss | Slate | Carbonaceous Phyllite | Phyllite | Limestone | Quartzite |
|---|---|---|---|---|---|---|
| Strength | R3-R6 | R1-R2 | R0-R1 | R1-R2 | R3-R4 | R3-R4 |
| Jv / RQD | 8-10 | 16-18 | 20-22 | 16-18 | 8-10 | 10-12 |
| Weathering | Fresh to SW | Fresh to SW | Fresh to SW | Fresh to SW | SW to MW | Fresh to SW |
| Groundwater | Dry to dripping | Dry to wet | Dry to Damp | Dry to Damp | Flowing to damp | Dry to Damp |
| Dip direction /Amount | 165-195/30-55 | 150-175/25-40 | 145-170/15-30 | 150-175/25-40 | 170-210/32-45 | 185-220/25-45 |
| Spacing (mm) | 20-60 | <6,6-20 | <6 | <6,6-20 | 20-60 | 20-60 |
| Aperture | Tight to partly open | Tight to partly open | Tight | Tight to partly open | Tight to partly open | Tight to partly open |
| Filling | CR/CF | CF | CF | CF | CR | CF/CR |
| Roughness | R/U | S/U | S/P | S/P | R/U | Rough / Undulatory |

R/U – Rough/Undulatory, S/P – Smooth Planar; CR- Crushed rock, CF - Clay Filling.

As per RMR classification, out of the total length of 10084m, 0.2% (20m length) is in Class-I category, 54.3% (5453) is in Class-II category, 38% (3835m length) is in Class-III category and 7.7% (776m length) is in Class-IV category (Figure 3).

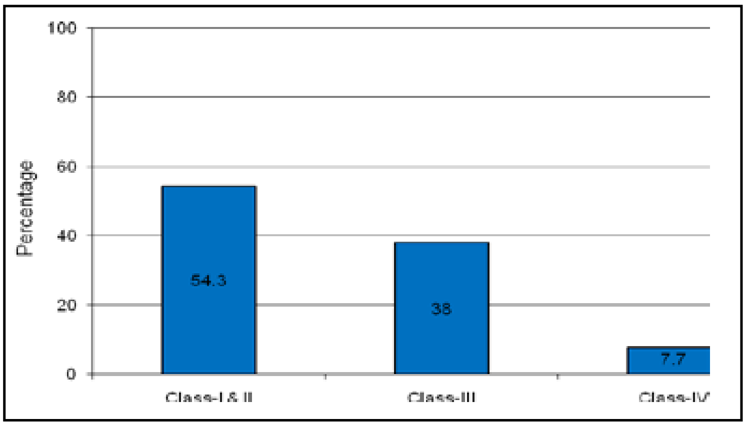



Figure 3 Percentage of Rock Class Encountered During Excavation in HRT.

## 4. Rock Mass Characterization using Tunnel Seismic Prediction Method (TSP):

TSP is a rapid investigable system solution developed for underground construction and evaluates geological conditions normally associated with discontinuities in rock masses by seismic echo signals reflected from changes in elastic rock characteristics. Application of TSP as a geophysical tool for assessment of rock mass condition ahead of tunneling face is still in developing stage. Even then compared with geological projection by surface investigation and probing by predrilling, TSP has important advantages over conventional methods. With an investigation range of ±200m it is a rapid tool for providing accurate information concerning the geology and engineering properties of rock mass. TSP survey was carried out at four different faces of HRT.

After blasting the reflected seismic compression and shear waves are processed to determine rock mechanical properties such as Poisson's ratio and Young's Modulus. The lower Young's Modulus value indicates reduced rock strength whereas the higher value indicates enhanced rock strength. Similarly, the higher Poisson's ratio value indicates water bearing zones. Details of rock mass properties obtained from TSP survey in provided in Table 3 wherein the RMR values are also given in last column for comparison.

### 4.1 Comparison of TSP Results with Actual Excavation Conditions

In Adit-II, Face-IV, out of 247m of prediction 145m length (i.e. 58% of total length) was in stable to improved rock strength zone, 51m (i.e. 21% of total length) was in decreasing rock strength zone and 51m (i.e. 21% of total length) in decrease rock strength zone with water bearing possibilities. After excavation such decreasing rock strength were identified wherein shearing and crushed/clay filling has reduced the strength of tunneling media. Moreover, water potential zones were also more or less met, as predicted by TSP.

In Adit-III, Face-V prediction length was 227m and out of it 118m (i.e. 32% of total length) falls in changeable rock strength with minor improving to improved and good rock strength zone. Slightly to minor decreasing zone length was 94m (i.e. 41% of total length). A total of 12m (i.e. 5% of total length) fall in decreasing rock strength with water bearing zone and finally 3m (i.e. 2% of total length) was predicted to be in fractured zone. The fractured zones as predicted by TSP were not met during excavation. The results do matches for decreasing and increasing rock strength zone.

At Face-VI of Adit-III out of 213m of predicted length 98m (i.e. 46% of total length) falls in changeable rock strength with minor decrease to decrease rock strength. A total of 5m (i.e. 2% of total length) in fractured zone with water bearing possibilities. 29m (i.e. 14% of total length) in stable to improving rock strength with water bearing possibilities, 38m (i.e. 18% of total length) in improving to good rock strength and finally 22m (i.e. 10% of total length) in stable rock mass condition. In Face-V, after test decreasing rock strength were identified and that was due to crossing of carbonaceous phyllite rock band along foliation direction. But fractured zones were not met as predicted by TSP. However, water bearing zones were met.

In Adit-IV, Face-VII prediction range came for 49m and out of it 27m (i.e. 55% of total length) fall in improving to good rock strength, 13m (i.e. 27% of total length) in weak zone with water ingress and 9m (i.e. 18% of total length) in fractured zone. Conditions were met more or less as predicted by TSP.

Table 3
Rock Mass properties obtained from reflected seismic wave by TSP survey.

| Face | Rock Type | RD | Density (g/cm$^3$) | Poisson's Ratio | Shear Modulus (GPa) | Dynamic Young's Modulus (GPa) | Rock Class as per RMR |
|---|---|---|---|---|---|---|---|
| Face IV | Gneiss | 979 - 1226 | 2.53-2.65 | 0.13-0.37 | 18-22 | 46-57 | II & III |
| Face-V | Gneiss | 1335-1562 | 2.71-2.93 | 0.16-0.31 | 25-37 | 64-92 | II |
| Face-VI | Slate | 1270-1347 | 2.70-2.91 | 0.09-0.38 | 19-37 | 54-91 | II |
| Face-VII | Slate intercalated with carbonaceous phyllite | *1540-1589 | 2.15-2.33 | 0.09-0.33 | 7-12 | 18-31 | IV/III |

*Rock mass from RD 1587 to 1589m is in Class-III category.

## 5. Conclusions:

In HRT of Sewa Project, RMR classification was used to characterize the rock mass and accordingly support was provided to increase the stand up time. The characterization was based on the physical and mechanical properties and it has been observed that the RMR classification was appropriate as after break phenomena or collapsing after excavation had not been reported in the project.

The TSP results indicated that the method give a good picture in terms of rock strength and presence of groundwater. Moreover, presence of shear seams and filling does reduces the overall strength of rock mass. Therefore, such zones were known in advance and necessary arrangements were made for fast and safe excavation. This is additional advantage of TSP apart from giving prediction of weak discontinuities. In two faces i.e. in Face-IV and Face-VII the predictive range was for 247m and 59m respectively. During excavation more or less similar conditions were met especially identification of water bearing zones and poor strength rock mass condition. It was useful as necessary precautionary measures were taken for dewatering the groundwater and placing of pressure relief holes for easing of hydrostatic pressure. Further, after TSP test the low strength zones were also known, therefore, it was possible to reduce the powder factor and optimize the excavation process. In Face-V & VI decrease and increase rock strength zone as predicted were also met.

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