Construction of Head Race Tunnel for Sewa H.E.Project (Stage-II), Lot SW-1: Innovative Approach of Gammon - A Case Study.

R.K.Khali,
Gammon India Limited, Gammon House, Veer Savarkar Marg, Prabhadevi, Mumbai-25, INDIA.

1.0 Introduction:
Sewa-II Hydroelectric Project is located in the Lesser Himalayas in Kathua district of J&K situated in a lush green valley of Sewa river, a tributary to mighty Ravi River. This Project is a run-of-the-river scheme proposed to harness hydroelectric potential of river Sewa. The Sewa hydroelectric project has the following main structures:

i. The 53m high concrete gravity dam near village Gatti to divert the water into powerhouse through a water carrier system

ii. A 10.02km long horse shoe shaped Head Race Tunnel of 3.30m dia inclusive of 380m long 3 underground pressure tunnels of 2.4m diametre, and a 622m long vertical pressure shaft with surface penstock length of 175m.

iii. A 298m long diversion tunnel of 6m dia already stands constructed on the right bank of the river to facilitate construction of the Diversion Dam. The diversion tunnel was designed to take the flood discharges too.

iv. A Surface Power House aiming at generating 120MW power through three turbines of 40MW each measuring 100.5mx22mx49m.

v. A typical orifice type spillway with 4 bays of 7mx10 and having a width of 46m.

vi. Two D shaped, Intake Tunnels of 3m dia with the respective lengths of 153 and 130ms supplemented by 2 Du-four type, 95m long Desilting Chambers covering the width of 8m and depth varying from 10.7m to 11.2m.

2.0 Layout of Head Race Tunnel and Adits:
Layout of the Project is shown in figure-1
The most striking feature of this project is its Head Race Tunnel, which has been awarded to Gammon India Limited in Lot SW-1 works by the legal owner of the project, National Hydroelectric Power Corporation, Faridabad.

The 10.02 km long with 3.3 m dia horse shaped Head Race Tunnel(HRT) was planned on the right bank of the river Sewa. To facilitate the construction of HRT, four adits were proposed. A 122 m long adit-1 downstream of the nallah(dry riverine), 226m long adit-II on the left bank of the nallah, 418m long adit-3 on left bank of nallah and the 255 m long adit-4 on the road of surge shaft will meet the Head Race Tunnel respectively at RD 347m, RD 2717m, RD 5678m, and RD 9960m.
3.0 Geology alongside the alignment of the Head Race Tunnel:
In order to facilitate the excavation of HRT, four Adits have been provided with eight Faces of varying lengths. The following are the main geological features along the alignment.
HRT from its junction crosses from high grade metamorphic rock to medium and low grade metamorphic rock. The upstream part of HRT of about ±5115 m chainage is traversed by augen/granite gneisses. The contact of Dalhousie granite and Tanawal group is thrusted but the same is sharp (encountered at RD 493m U/S of Adit-III, Face-V). The remaining part of HRT lies in the highly tectonised sequence of Tanawal Formation comprising Carbonaceous Phyllite, Slate, Phyllitic assemblage, Limestone and Quartzite.
4.0 Tunnel Excavation and Rock Support:

4.1 Tunnel Construction

The scope covers the boring, overt and invert lining, and construction of the intake structure for carrying the water of Sewa River to the Power House. This was a fast track structure; nevertheless we completed the job within the time schedule despite all operational difficulties. The Head Race Tunnel with an inner diameter of 3.3m and a revised length of 10.84Km was constructed by using the drill- and- blast method. The local progressive loosening was limited by employing careful excavation methods and timely installation of support elements. The support elements were shotcrete, welded wire- mesh, rock bolts, steel ribs, fore poling, and precast lagging. The adequacy of the support elements was assessed by 3-D logging. A permanent rock supporting system adopted for the purpose was tensioned with the help of rock bolt/rock anchors (2m long) and shotcreting of varying thickness, from 50mm to 100mm. Overt and invert concreting provided the thickness of 225mm. Tunnel -boring was done through 4 Adits, named as Adit-1, Adit-2, Adit-3 & Adit-4. Since the strata of the tunnel in most part was Class-II&III, self supported rock, emphasis was given on drilling and blasting pattern for smooth profile.

A pull of 2.5 – 3.5 m was largely achieved during heading excavations. As excavation of considerable length had to be done from each face, a number of refuges were provided at intervals by Gammon for maneuvering and loading of the dumper and other equipments in the tunnel. Here, a shear zone consisting of altered clayey gouge and crushed rock material prone to occasional rock mass failure, was to be encountered. Hence, steel ribs- support was provided. The rock support during excavation comprised the following five types:

Class-I –The excavated section remains basically unsupported and spot rock -anchors are installed.

Class-II- The support system consists of 50mm thick shotcrete along with spot rock-anchoring.

Class-III- The rock support system consisted of 100mm shotcrete in two or more layers with welded wire- mesh and rock anchors of 2m length 25mm dia@1.5m c/c.

Class-IV- Steel ribs of ISMB measuring 125x75mm at a spacing of 0.75m c/c along with rock anchoring, wire mesh, with a shotcreting of 100mm and backfill concreting were provided.

Class-V- For class-V rock, in addition to Class-IV rock supports, the steel ribs were extended in invert shape also.

---

Class III

Class IV
Typical cycle times for full face excavation in various classes of rock support are as follows:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Class-I</th>
<th>Class-II</th>
<th>Class-III</th>
<th>Class-IV</th>
<th>Class-V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey</td>
<td>0:40hr</td>
<td>0:40hr</td>
<td>0:40hr</td>
<td>0:40hr</td>
<td>0:40hr</td>
</tr>
<tr>
<td>Drilling</td>
<td>3:00hrs</td>
<td>3:00hrs</td>
<td>3:00hrs</td>
<td>3:30hrs</td>
<td>3:30hrs</td>
</tr>
<tr>
<td>Charging Explosives &amp; Blasting</td>
<td>2:30hrs</td>
<td>2:30hrs</td>
<td>2:30hrs</td>
<td>2:30hrs</td>
<td>2:30hrs</td>
</tr>
<tr>
<td>Defuming</td>
<td>2:30hrs</td>
<td>2:30hrs</td>
<td>2:30hrs</td>
<td>2:30hrs</td>
<td>2:30hrs</td>
</tr>
<tr>
<td>Scaling</td>
<td>1:00hrs</td>
<td>1:00hrs</td>
<td>1:00hrs</td>
<td>1:30hrs</td>
<td>1:30hrs</td>
</tr>
<tr>
<td>Mucking</td>
<td>5:00hrs</td>
<td>5:00hrs</td>
<td>5:30hrs</td>
<td>5:30hrs</td>
<td>5:30hrs</td>
</tr>
<tr>
<td>Rock-Anchoring/ shotcreting/wire-mesh</td>
<td>2:00hrs</td>
<td>6:30hrs</td>
<td>5:00hrs</td>
<td>6:00hrs</td>
<td></td>
</tr>
<tr>
<td>Steel Supports (with lagging)</td>
<td></td>
<td></td>
<td>8:00hrs</td>
<td>12:00hrs</td>
<td></td>
</tr>
<tr>
<td>Shuttering</td>
<td></td>
<td></td>
<td>2:00hrs</td>
<td>2:00hrs</td>
<td></td>
</tr>
<tr>
<td>Concrete Backfill</td>
<td></td>
<td></td>
<td>4:30hrs</td>
<td>3:00hrs</td>
<td></td>
</tr>
<tr>
<td>Fore-poling/pre grouting</td>
<td></td>
<td></td>
<td></td>
<td>8:00hrs</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10:30hrs</td>
<td>16:40hrs</td>
<td>21:40hrs</td>
<td>35:40hrs</td>
<td>47:10hrs</td>
</tr>
<tr>
<td>Advance in meters</td>
<td>2.75</td>
<td>2.50</td>
<td>2.25</td>
<td>2.00</td>
<td>0.5 to 1</td>
</tr>
</tbody>
</table>

4.2 Construction, Planning and Equipment:
To achieve the higher rate of excavation, modern construction equipments such as Scheff Loader ITC-312, Low Bed Tippers and Scoop Trams were used for the small sized tunnel as shown below.

The conventional drill and blast method using 5 Atlas Copco single boom Rocket boomer was adopted at all 4 adits and was eventually found more suitable for excavation.
4.3 Concrete Lining

In order to minimize hydraulic losses and to protect the surrounding rock, 30 to 55 cm thick concrete lining was designed and provided. Concrete lining of the tunnel was carried out in three phases - Kerb beam, Invert and Overt. After laying the Kerb-Beam, the Overt was laid first, to be followed by the Invert. A total of 9 telescoping concreting Gantry, each of 9m length, and 3.3m diameter, and horse shoe in shapes, were used for Overt concreting of the tunnel and 24 two cum transit mixers for transporting concrete directly into the hopper of the concrete pump were used.

The gantries were telescopic collapsible folding type, suitable for continuous concrete lining. Compatible concrete pump and the batching plant transit miller combination ensured continuous feeding of the concrete. The shutters were electrically controlled with the help of hydraulic power packs and hydraulic jacks for movement on rails. Construction of kerbs helped in easy fixing of the shutters. Before starting the concreting, dummy trial of shutters was taken, so as to rule out undercuts. Invert concreting was poured directly using invert templates.

An arrangement was made with equipment manufacturers for providing service base at each Adit itself, so that breakdown of any equipment could be attended to immediately by experienced service personnel. This ensured 75% availability of most of the equipments.

4.4 Major Problems Encountered and Remedial Measures Taken During Excavation:

4.4.1 Cavities encountered in HRT with large over-breaks and solution thereof adopted

At certain locations formation of chimney or cavity or large over-breaks occurred at heights ranging from 6-18m. At such locations the faces were sealed with the help of muck filled bags, followed by shotcreting and bulkhead-fixing. Small space, such as manholes, was created through these bulkheads and reinforcement steel was provided both in longitudinal & transverse directions. The backfilling of concrete was accomplished by using concrete pumps. The rock strata on either side was grouted and allowed to stabilize. Later on, the muck was removed gradually in multi-drifting fashion, followed by the erection of segmental ribs. After erection of the complete rib section, 5m long anchors were provided. Adit wise details of cavities and solution adopted are given below:

4.4.2 Adit-II and HRT (Face-III &IV)

Adit-II portal is situated near one seasonal rill known as Kembli. The exposed rock mass, i.e., gneiss is highly sheared and shattered near the Adit portal. The initial ±60m of Adit was
excavated through poor rock mass categorized as Class-IV condition. It was observed that due to sheared and shattered nature of the rock mass and clayey filling material along joints, the rock strata was very unstable and a huge cavity formed during the excavation. Rock fall during excavation was a regular phenomena; therefore instant support was used for safe excavation. Excavation proceeded mainly by using the steel- ribs erection and back- filling technique. Excavation of HRT through Face-III proceeded on a weak and weathered rock mass. As a result the superincumbent cover over HRT was less. The, rock mass here was found to be weathered, filled with clayey/crushed rock material resulting from the impact of physical agencies. The weak tunneling media rock mass was supported with Class-IV treatment. At some portions, chimney formation took place which, in turn, created huge void and excess muck. Moreover, on 16.06.06 at RD ±506m, the tunnel got almost day lighted due to low cover zone along a seasonal rill. The stretch between Face-II & III was resurveyed, and it was decided to detour the tunnel as further stretch to avoid the low cover zone.

In the area between Face-II and III, especially before Gulesta rill (from Face-III), poor tunneling media was encountered during tunneling owing to sheared and weathered nature of rock mass. Excavation through the detoured tunnel also experienced hostile conditions, and huge cavities were negotiated mainly from RD 481-501& 602-608m. Heavy water inflow conditions were experienced in this reach. Cavity treatment consumed a lot of time, as difficulty was faced in backfilling in the area dogged by heavy water inflow. Detouring of HRT between Face-II & III increased the tunnel -length by ±43m. Moreover, ±60m of length from Face-III was abandoned for purpose of design. In the same way, from Face-II, 27m of length was abandoned. The additional total excavated length from Face-III was 689m and tunneling media for this face remained mainly through weathered gneiss rock; whereas some intrusive rock bands were also negotiated. Excavation from Face-IV was negotiated through the Gneiss rock which offered good rock mass conditions up to RD ±775m. On 15.04.2006, at RD ±775m, one shear zone was encountered in this reach, and a huge amount of slush entered from the shear zone and plugged the tunnel many times with pulverized material and water. Various methodologies like rib erection, fore poling, grouting, core drilling & DRESS methodology, were adopted to treat the shear zone, but nothing succeeded. On 25.07.06, 02.08.06 and 08.08.06 huge amounts of slush flowed from the shear zone. Once again, on 06.11.06, tremendous amount of slush entered from the shear zone and plugged the tunnel over a length of 400-500m with pulverized material and water. Removal of slush consumed a lot of time as it was very difficult to haul the slush in the flowing condition. Almost a long period of eight months was consumed in treating the cavity with different methods, and removing the slush from the tunnel. Eventually, it was decided to detour the tunnel, and the first blast was taken on 04.01.07. In the detoured part also, extension of shear zone was encountered at RD ±775m on 26.01.08 which continued up to RD ±770m. In this patch, the shear zone was successfully treated by providing proper supports like fore poling, grouting and rib erection with back filling. Detouring in Face-II, III, & IV increased the length of HRT. Moreover, 40m length in U/S and 55m in D/S face was abandoned for proper detouring. After rerouting Face-IV, the rock mass negotiated for the tunneling media was gneiss which stretched up to RD 1293m (Breakthrough RD of Face-IV)

4.4.3 Adit-III and HRT Face-V &VI
The rock here was very low in strength and could not provide enough standup time, As a result the excavated portion collapsed at the junction of HRT.
The restoration work consumed time, as heavy rib -support was provided to open up the junction portion. Carbonaceous phyllite rock continued through Face-V up to RD 50m, which ended in Face-VI at RD 71m. As a result of poor tunneling media, both the faces fell in Class-IV rock mass condition and were supported with steel ribs at 0.5m c/c spacing.
At RD 493m Jutogh thrust was encountered at Face-V. Huge cavity formation took place in this reach which was supported with steel ribs. Tunneling media after RD 493m onward remained in the gneiss rock and this face was excavated up to RD 1586m. (Breakthrough RD of face-V)

At Adit–III Face-VI heavy seepage condition was encountered (with ±7800 lit/min max discharge measured on 16.08.08). To tackle the seepage problem a number of dewatering pumps (3 nos. 60HP (one in spare), 1no. 25 HP, 2 nos. 16 HP and 1no 10HP) were deployed. In the initial stage, around the junction area of Adit-3 carbonaceous rock mass was negotiated and this rock mass crossed the HRT face-5 and face-6 at RD 54m and RD 71m respectively. This paved the way for poor rock mass tunneling media, and for the safe tunneling media ribs of 50cm c/c spacing were provided. At face-VI, the rock media remained mainly in carbonaceous phyllite, siliceous limestone, limestone and the very considerable stretch remained in the slate rock mass. Slate was observed till the breakthrough RD i.e., 2139m (From face-6)

4.4.4 Adit- IV and HRT Face-VII &VIII
The excavated length from face-VIII was 56m and the tunneling media for face-8 mainly remained in quartzite rock mass. This rock mass was observed up till the RD 223m of face-7. Thereafter, tunneling media for this face remained mainly in carbonaceous phyllite, phyllitic limestone, and weathered slate rock types. In intermediate reaches, carbonaceous rock mass led to the poor tunneling media and ribs were provided at regular intervals from this face in order to move ahead for the better and safe tunneling. Heavy ingress of water from RD 430 to 580m was a cause of concern for the tunnelers. Proper drainage -holes of 15m each, were provided at the crown portion to relieve the excess hydrostatic pressure. Very poor tunneling media was also negotiated from RD 1535m onward where sheared carbonaceous phyllite rock- mass along with heavy ingress of seepage water, was observed from the face. To proceed further, this reach was treated with fore-poling and injection of grouting, and dry mix was fixed behind the rib portions. The segmented support system was adopted throughout this reach. The last stretch of this face was excavated through the weathered slate rock- mass. The breakthrough from face-VII was made at RD 2278m RD.

Additional curves were provided from face-VI and face-VII to avoid the low cover zone, and the tunnel was relocated to the adequate rock cover zone. For this reason the tunnel from face-VI, after providing a curve, was detoured at RD 1562m. Another curve was provided at RD 1989m. The face-VII was also detoured at RD 1723m. The total increased length between face-VI and face-VII was 84m.

5.0 Ventilation System:
Ventilation also became a critical activity owing to a longer lead and low diameter of tunnel. To tackle the ventilation problem, Two 75 KVA ventilation fans at portal and two 20KVA fans inside the tunnel were installed for face-VI and face-VII. The activities of dewatering and ventilation, being a critical activities in excavation cycle hamper the progress frequently and consequently increase the cycle time of any tunneling process.

6.0 Size of tunnel, steep slope, and storage of seepage and rain water at the face
Owing to the small size and deep gradient of the tunnel, it was difficult to plant the proper equipment meant to be used inside tunnel. After going through the plant directories 7Ton dumpers and scheff loader ITC-312/Scoop tram & Ajax fiori/thwaites combination/JCB & 7Ton tipper combination were selected for working inside the tunnel for removing the muck. Even these equipments could not perform well on down gradient on the expected scales.
7.0 Dewatering:
Since the tunnel was bored in down gradient from four faces, serious problems for dewatering were faced. Seepage also increased at different RD’s due to heavy rainfall. Dewatering was done by using higher capacity pumps in different stages, deploying specialized agencies. In the down gradient, deep *sumps* were made at 250m intervals and dewatering pumps were installed as shown below.

8.0 Conclusion-the Success story
The construction of Head Race Tunnel at Sewa H.E. Project is unique where meticulous planning for boring and concrete lining was done well in advance. As a result concrete lining was started immediately after day lighting each face of the tunnel by installing telescoping gantries and successfully handed over the tunnel to NHPC.
Proper construction planning of each activity of Head Race Tunnel paved way for faster construction.
Team work, proper co-ordination/co-operation and dedication of Gammon and NHPC engineers have been the keys to this success.