Journal of Rock Mechanics and Tunnelling Technology (JRMTT)
27 (1) 2021 pp 17-36

Available online at www.isrmtt.com

Seri Nalla Fault Zone, Atal Tunnel, Rohtang- Overcoming the Challenges

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ABSTRACT

Tunnel projects in complex geological setting like the Himalaya are very unique due to the geological uncertainties and tunneling in such areas are always a challenge. The Seri Nallafault zone was encountered unexpectedly prior to its expected location. DRESS methodology has proved very effective in countering the Seri Nalla zone.

This paper presents the geological challenges faced during tunnelling through the Seri Nallafault zone and the subsequent efforts undertaken to overcome those challenges.

Keywords:Atal tunnel; Fault zone; Himalaya; DRESS; Drainage

1. INTRODUCTION

The 9020m long, single tube, bi-directional, two lane, Atal tunnel, Rohtang (Fig. 1), the longest road tunnel in the world above 3000m altitude was inaugurated and dedicated to the nation on 3rd October, 2020 by Hon'ble Prime Minister of India, Shri Narendra Modi.

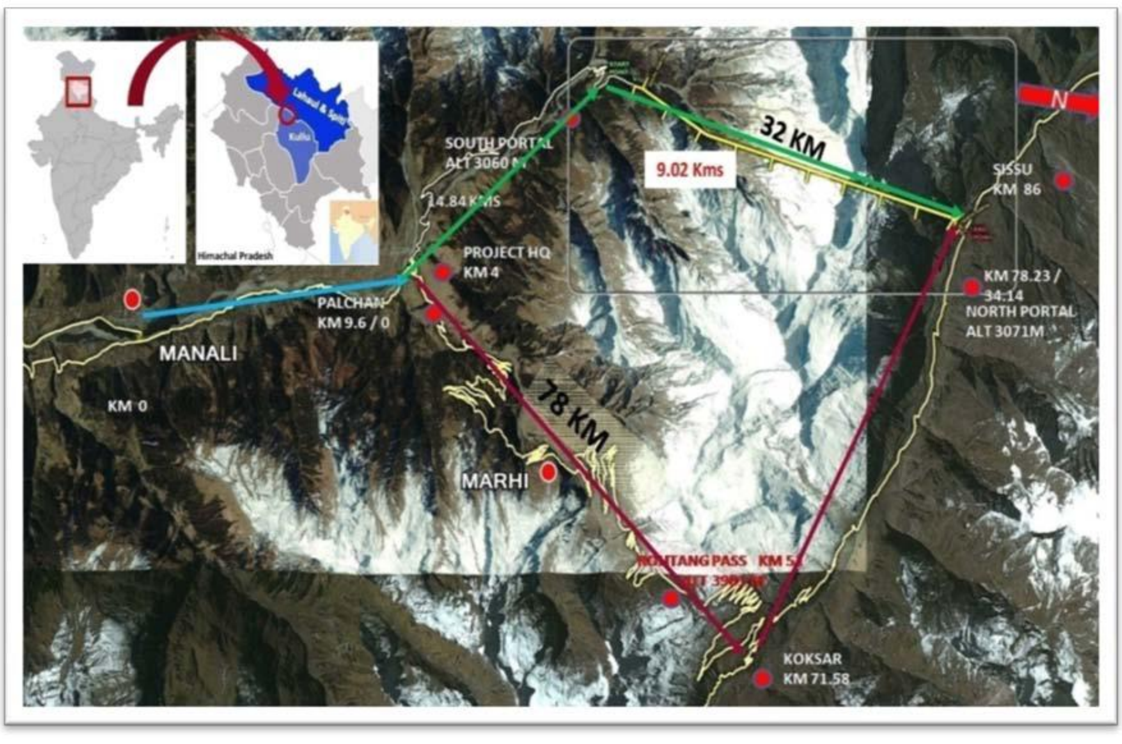

Figure 1- Location of Atal tunnel, Rohtang (Rites, 1996)

Atal tunnel, Rohtang, an engineering marvel in the high Himalaya will ensure all-weather connectivity to landlocked Lahaul valley from Manali and will be a key driver of socio-economic development in the area.The tunnel has reduced the distance of the highway from Manali to Leh by 46km.

The shape of the tunnel is modified horse-shoe (Figs. 2 & 3). Drilling and blasting along with New Austrian Tunneling Method (NATM) was used for the construction of thetunnel. The design of the tunnel is very unique because the emergency egress tunnel is not parallel but is a part of the main tunnel, below the carriageway adding to the overall cross-sectional area (136 m^2) of the tunnel. The tunnel consists of 8 m wide carriageway and 1 m wide footpath on both sides. The thickness of final concrete lining is 500 ± 50 mm and with 0.5% gradient from both portals for effective drainage.

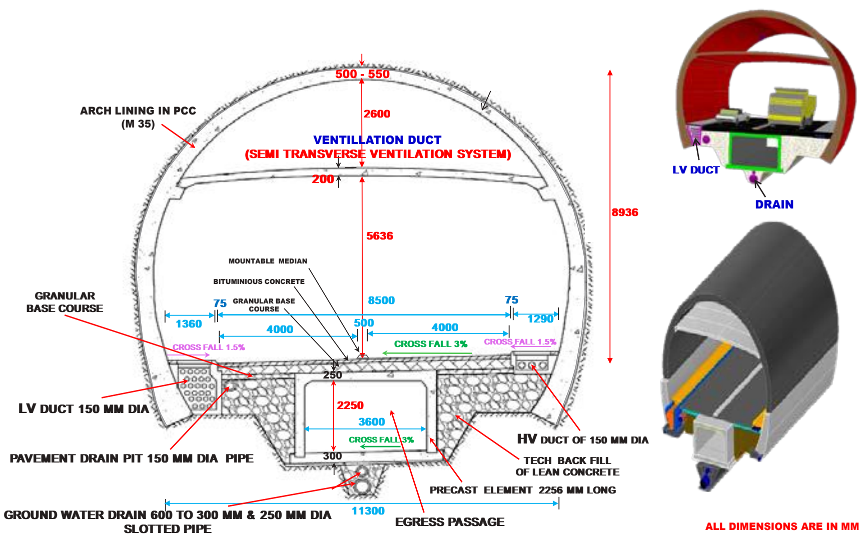

Figure 2 - Cross-section of Atal tunnel, Rohtang

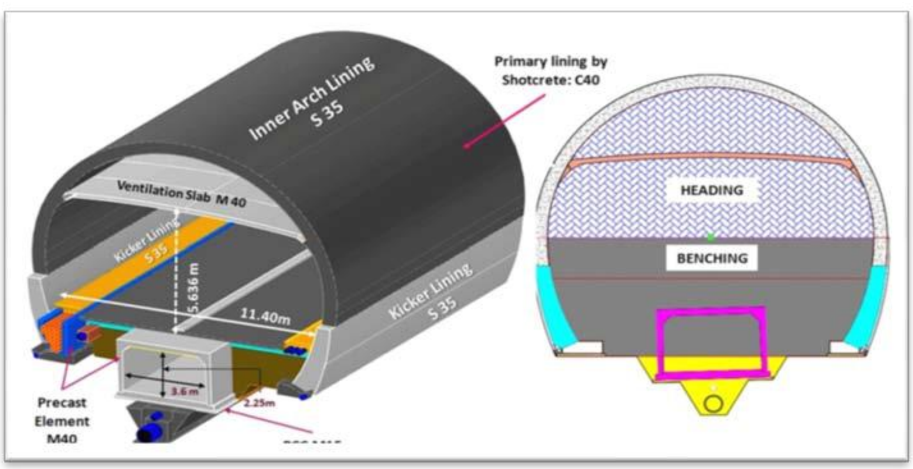

Figure 3 - 3D View andcross-section of Atal tunnel, Rohtang

The Seri Nalla fault zone was the biggest challenge encountered during the construction of Atal tunnel, Rohtang. With a length of 587 m, this section of the tunnel was the most critical and time consuming and posed a variety of challenges.

The "Seri Nalla fault" was expected to be encountered between tunnel Ch.2+200 and Ch. 2+800 as per tender documents. The Seri Nalla fault zone was anticipated to cross the tunnel from the South Portal side based on both surface and subsurface data. Based on limited subsurface data, this zone was considered to have consisted of sheared and fractured rock where potential squeezing of the tunnel was also anticipated. This was the main contact between the Quartzitic Schist and Migmatites on the South Portal side.

During the excavation of the tunnel, the Seri Nalla fault zone encountered between tunnel Ch. 1+887 and Ch. 2+474 m (Seri Nala transition Ch. 1+887 to Ch. 1+905 and main Seri Nallaaaultzone from Ch. 1+900 to Ch. 2+462 and again transition from Ch. 2+460 to Ch. 2+474) where the actual encountered contact was quartzitics chist and phyllitic quartzite.

The Seri Nalla along the tunnel alignment at surface starts at Ch. 2+350m and ends at Ch. 2+523m. The most important lineament affecting the tunnel alignment is the Seri Nalla fault (Figs. 4, 5 & 6). This fault is trending N50°E-S50°W, with an almost vertical to sub-vertical dip. In addition to the Seri Nalla fault, there are a number of parallel or sub-parallel minor lineaments across the Seri Nalla that are also crossing the tunnel alignment. The width of fault zone at surface is around 173 meter and consists of sheared phyllite with clay gouge. Along the slopes of left bank (Western Bank) of Seri Nalla the rocks are highly jointed and fractured quartz phyllites. Along the slopes of the right bank (Eastern Bank) of Seri Nalla moderately jointed phyllites and quartz phyllites are observed.

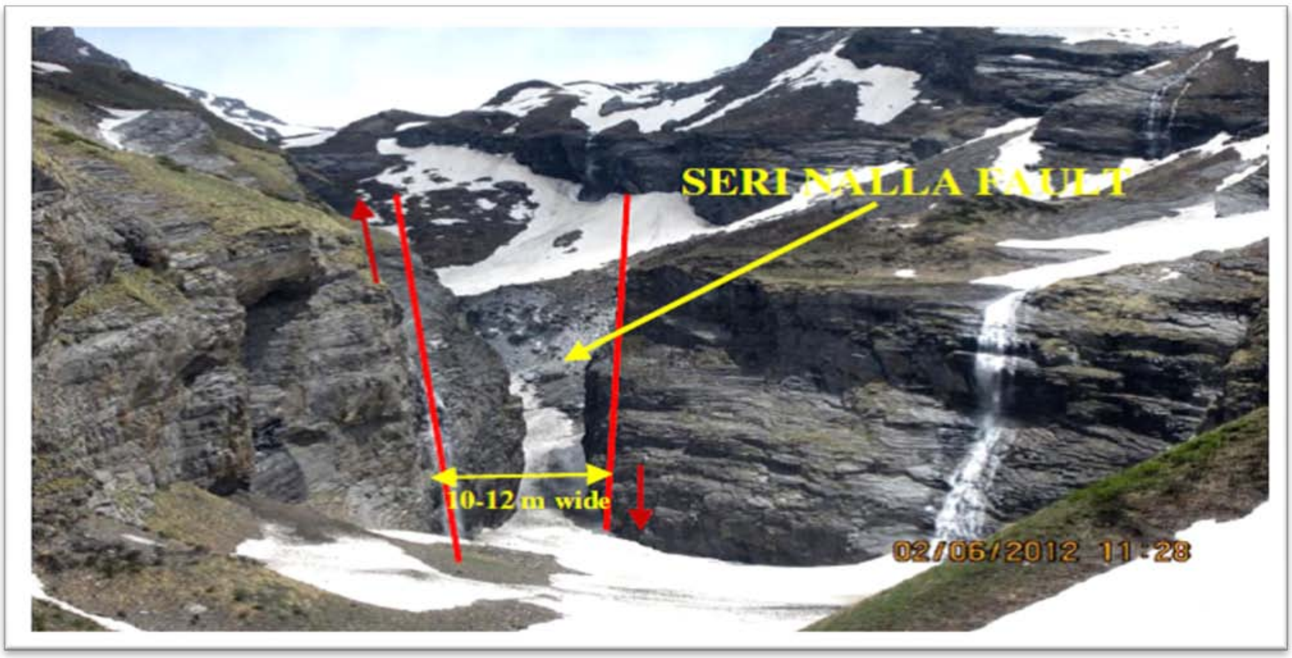

Figure 4 - Seri Nallafault at surface

2. GEOLOGICAL ANALYSIS OF THE SERI NALLA FAULT ZONE

During excavation of the tunnel, at around Ch. 1+900 m a trace of shear zone (consisting of clay with minor rectangular fragments of rock charged with water) 10° oblique to the tunnel axis was encountered on the western side (left corner) of the excavated face. The sheared mass kept extending from the left side towards the centre. At Ch. 1+913m, half of the face was covered with sheared material. At Ch 1+927 m the full face of tunnel heading was covered by sheared and shattered rock mass along with clay bands/seams and boulders in soil matrix. Minor to medium inflow of water increasing to large inflow with increasing Ch. was also encountered (Bhandari et al. 2013).

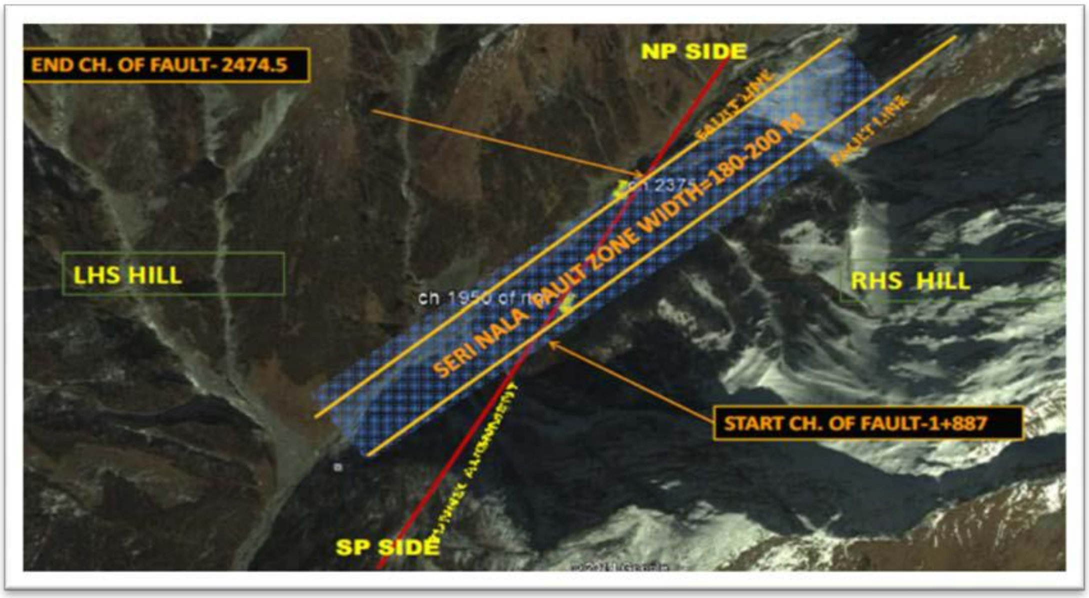

Figure 5 -Seri Nalla fault zone satellite imagery

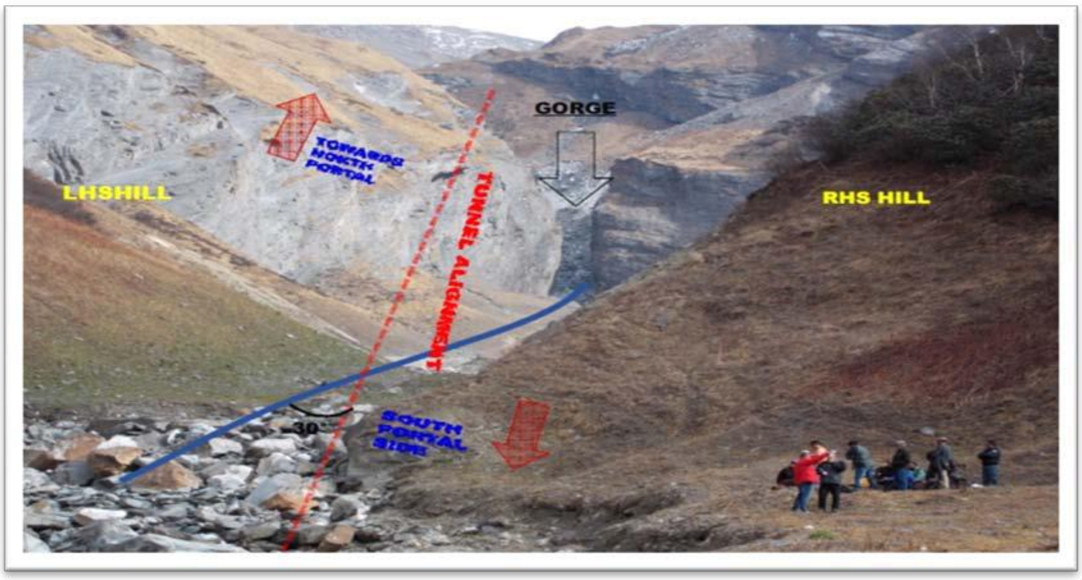

Figure 6 - Seri Nalla fault zone on surface crossing the tunnel alignment

The rock type occurring in this zone was basically quartzitic schist, quartzitic phyllite and phyllite along with sheared and shattered rock mass and clay gauge. The presence of sheared rock mass and clay gauge materials indicates the presence of fault zone. The rocks were intersected by a number of shear seams and minor fault planes. The rock type was classified as rock class III at the start of this zone and gradually with the occurrence of continuous poorer strata; the rock type was gradually changed to Class IV, Class V and Class VI. "Q" value in this area ranged from 1.36 to 0.06 (Poor to Extremely Poor). Minor to medium inflow of water (1-3 l/sec) was seen in this zone (Fig.7).

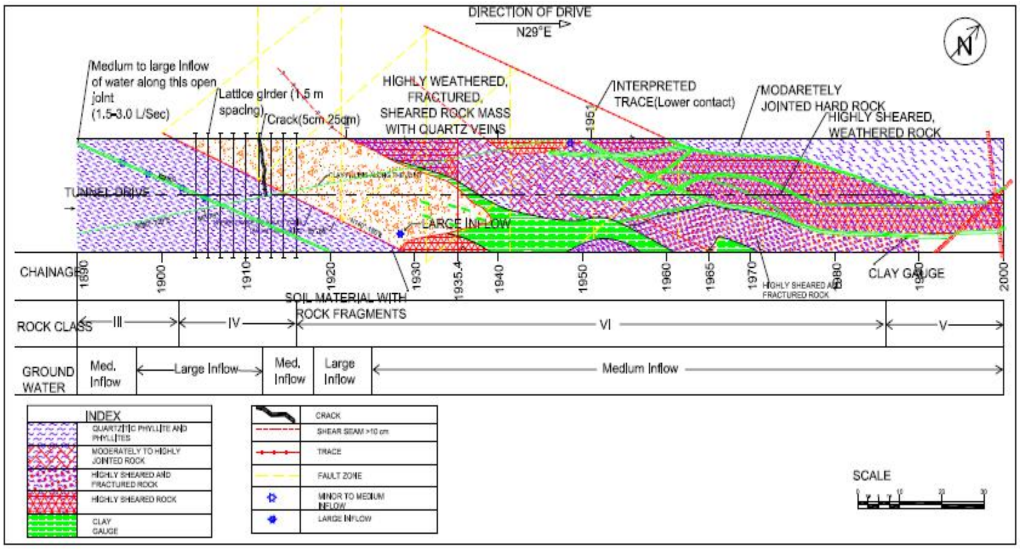

Figure7- Geological plan at tunnel grade between Ch. 1+890m and Ch. 2+000m

When the face reached Ch. 2+046 m, minor inflow of water was recorded from face along the foliation plane. The rate of seepage increased when face reached Ch. 2+049 m; initial rate of inflow of water at face was around 5 l/s and then increased upto 30 l/sCh 2+049 to 2+050 m, the first cavity was formed with about 400 m^3 of muck flowing out. Figure 8 shows the geological cross section.

Another cavity much larger than the previous one was formed at Ch. 2+077 m where about 1000 m^3muck flowed out. One more cavity was formed at Ch 2+158 to 2+159 m where 20-25 m^3 muck came out.

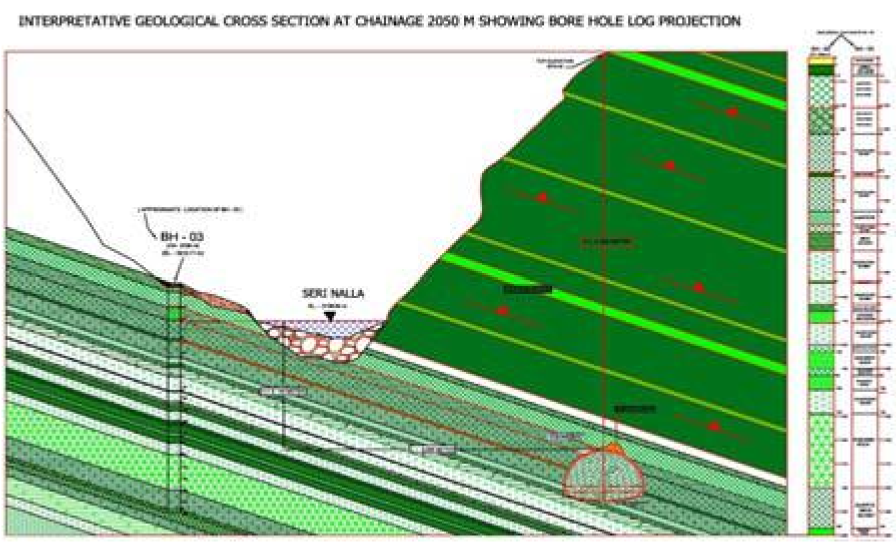

Figure 8 - Geological cross section of Seri Nalla at Ch. 2+050m (Pathak et al., 2020)

The rock type occurring in this zone was basically quartzitic schist, quartzitic phyllite, phyllitic quartzite and phyllite along with shattered rock mass, multiple shear seams, multiple clay seams/bands and clay gauge. The rock type was classified as rock class VI and VII. “Q” value in this area ranged from 0.02 to 0.8 (very poor to extremely poor). Medium to large inflow of water was observed in this zone.

At Ch. 2+360 m, river borne material (RBM) was first encountered along with highly sheared and shattered phyllitic rock. RBM comprising of boulders, cobbles, pebbles, gravels in clayey, silty and sandy matrix, was encountered almost throughout this zone. A major cavity was formed at Ch. 2+390 m where 100 to 150 m^3 muck flowed out. Throughout this zone the strata was classified as rock class VII with "Q" value ranging from 0.01 to 0.36 (very poor to extremely poor). Medium to very large inflow of water was observed at this zone with the highest inflow occurring at Ch. 2+400 to 2+402 m where 100-110 l/sec inflow of water was observed.

The first rock contact was observed at Ch. 2+442 m on the western side (left corner) in the same way when it started. With the advancement in excavation of the face, the phyllitic quartzite rock exposure which had started from the left corner gradually started to increase in the face and at Ch. 2+459 m the whole face was covered with rock which was just below the 40^{th} round of Pipe Roofing.

With the increase in rock exposure in the face, "Q" value increased to 0.73 to 0.95 at Ch 2+459 and 2+460 m (Figs. 9 & 10).

Figure 9 - Start of Seri Nalla fault zone

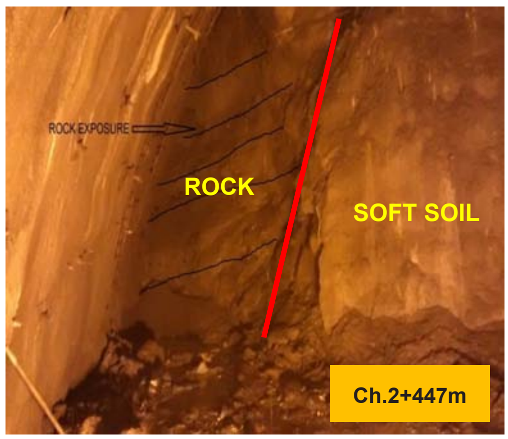

Figure 10 - End of Seri Nalla fault zone

3. CHALLENGES ENCOUNTERED IN THE SERI NALLA FAULT ZONE

3.1 Muck Flow Leading to Cavity Formation

When the excavation face reached Ch. 2+046 m, minor inflow of water was recorded from face along the foliation plane (Fig. 11). The rate of seepage increased when the face reached Ch. 2+049 m; initial rate of inflow of water at face was around 5 l/sec and then increased up to 30 l/sec. At Ch 2+049 m to 2+050 m, the first cavity was formed with about 400 m^3 of muck flowing out. Effort was made to control and divert the water from the face by using PU grout and also by stabilizing the face with shotcrete and additional rock bolts. The second cavity, much larger than the previous one was formed at Ch. 2+077 m where about 1000 m^3muck flowed out (Fig. 12). The third major cavity was formed at Ch. 2+390 m where 100 to 150 m^3 muck flowed out. Table I shows the muck flow in the Seri Nalla zone.

Figure 11 - Cavity at Ch. 2+045m

Figure 12 - Cavity at Ch. 2+077m

Table 1 -Geological condition and failure on south portal

Date	Ch. (m)	Geological Condition	Problem
22.04.2012	2+049 to 2+050	Rock mass extremely poor	400 m^3 muck flow
08.09.2012	2+077	Rock mass extremely poor	1000 m^3 muck flow
05.07.2013	2+158 to 2+159	Gougyand clay material with sheared rock mass	20-25m^3
28.05.2014	2+374	River borne material found from 2+360m onwards with fluvioglacigal	50-60 m^3 in 4-5 Times
21.06.2014	2+381	River borne material found from 2+360m onwards with fluvioglacial	
05.07.2014	2+384	LHS: River borne material and RHS: earthy crushed rock mass plus some rocky material exposed	
24.07.2014	2+385	LHS: River borne material and RHS: earthy crushed rock mass plus some rocky material exposed	
29.08.2014	2+390.05	Brecciated material	100-150 m^3
24.08.2014	2+394 (Pilot tunnel)	Boulders and cobble mixed clayey material	
29.08.2014	2+394 (Pilot tunnel)	Boulders and cobble mixed clayey material	
30.10.2014	2+394	Boulders and cobble mixed clayey material	20 m^3
22.12.2014	2+402	Excavated material consisting of boulder and cobbles of phyllitic and quartzitic rock	70 m^3
27.12.2014	2+407	Excavated material consisting of boulder and cobbles of phyllitic and quartzitic rock	45 m^3
11.02.2015	2+413	Excavated material consisting of boulder and cobbles of phyllitic and quartzitic rock	08 m^3
04.03.2015	2+413-17	Crushed rock, gravels and clayey matter mixed with water	40-50 m^3

3.2 High Ingress of Water

High ingress of water was first encountered at Ch. 2+045m where the flow on the first day was 5l/sec which after 2-3 days increased to 30 l/sec. The maximum ingress of water was encountered between Ch. 2+390m to Ch. 2+410m where the inflow of water was 100-110 l\sec.

3.3 Encounter of River Borne Material (RBM)

River borne materials (RBM) was encountered from Ch. 2+370m till Ch. 2+460m from the south portal side. The RBM material comprised of rounded to sub-rounded boulders, cobbles, pebbles, gravels in clayey, silty, sandy matrix along with sand pockets and clay bands.

Figure 13- Heavy ingress of water

Figure 14 - Flow of river borne material

4. GEOLOGICAL INVESTIGATIONS CONDUCTED IN SERI NALLA FAULT ZONE

Geological investigations were carried out in Seri Nalla zone to acquire information about the geology of the area. Three types of investigations were carried out namely core drilling, water pressure test and tunnel seismic profiling.

4.1 Core Drilling

Core drilling was first carried out during October 2012 at Ch. 2+053, 2+066, 2+070 and 2+072 m. Drill holes at Ch.2+072 and 2+070m were carried out in the face at an angle 10° upwards with the horizontal. The holes were drilled till depth of 15 to 30 m. In all the holes highly fractured and sheared rock with some clay seams were encountered (Figs. 15 & 16).

Figure 15 - Core drilling

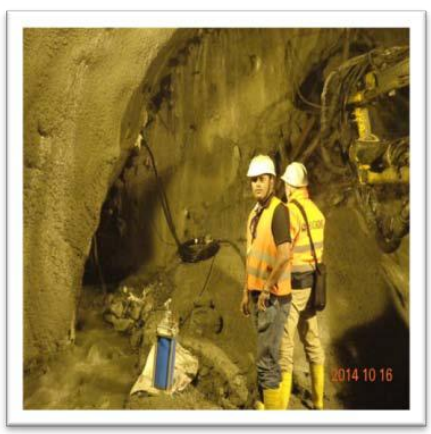

Figure 16 -Water pressure test

Core drilling was again carried out at the face between 28th Apr, 2015 and 18th May, 2015 at Ch. 2+410.50 to a depth of 60.50 m. The drill hole data indicated presence of RBM upto a depth of 44m i.e., Ch. 2+454.50 m. Lithological contact between RBM and rock was encountered around Ch.

2+454 ± 1 m and from 45.0 m to 60.5 m (i.e. from Ch. 2+454.50 to 2+471 m), fresh to slightly weathered quartziticphyllite was encountered.

4.2 Water Pressure Test

Water pressure test were done at different Ch.s in Seri Nalla before grouting to find out the Lugeon value. The Maximum Lugeon value recoded was 98.0 (turbulent flow) at Ch 2+410 and minimum value recoded was 0.42 (turbulent flow) at Ch. 2+389.5m. Between Ch 2+406 to 2+411, the average value of Lugeon was recorded 81.15, which was very high and indicate that large grouting was required in this reach (Table 2).

Table 2- Permeability of Seri Nalla zone

Ch. (m)	Permeability (Lugeon)	Ch. (m)	Permeability (Lugeon)
2+020	16.8	2+395	40.0
2+040	19.0	2+395	7.0
2+060	8.0	2+395	5.0
2+073	40.4	2+406	78.0
2+080	25.0	2+410	98.0
2+388	1.92	2+410	6.11
2+388	2.92	2+410.5	54.0
2+389.5	0.42	2+411	94.6
2+389.8	7.47	2+423	20.4
2+393	75.0	2+435	21.0
2+395	94.0	2+435	69.0

From Ch.2+423 to 2+435m, Lugeon value was recorded 20.4,21.0 & 69.0. The average value in this reach was 36.8, which indicated medium grouting requirement.From Ch. 2+388 to 2+395m, Lugeon value was recorded from 0.42 to 94.0. The average value in this reach was 26.0, which also indicated medium grouting requirement. From Ch. 2+020 to 2+080m, Lugeon value was recorded from 8.0 to 40.4 with an average value of 21.84, which also indicated medium grouting requirement.

Based on the water pressure tests, consolidation grouting in single stage and multi stage was done before the advancement of the tunnel.

4.3 Tunnel Seismic Profiling (TSP)

Tunnel seismic profiling (TSP) can detect lithological heterogeneities within hundreds of meters ahead of the face. It is the most effective prediction method because of its large prediction range, high resolution and ease of application on a tunnel construction site. TSP identifying weak zones and fault zones ahead of tunnel face are crucial for preventative measures to be carried out in advance for safer tunnel excavation.

Total 8 numbers of TSPs were carried out in this project out of which 6 nos. were done in the South portal side and all in the Seri Nalla zone. The first was carried out at Ch. 1+943m and the sixth was carried out at Ch. 2+391m (Fig. 17).

This test is useful for computation of mechanical properties of the rock like P (primary) and S (secondary) velocity, V_P/V_S ratio, Poisson's ratio, Rock density, dynamic Young's modulus, shear modulus.

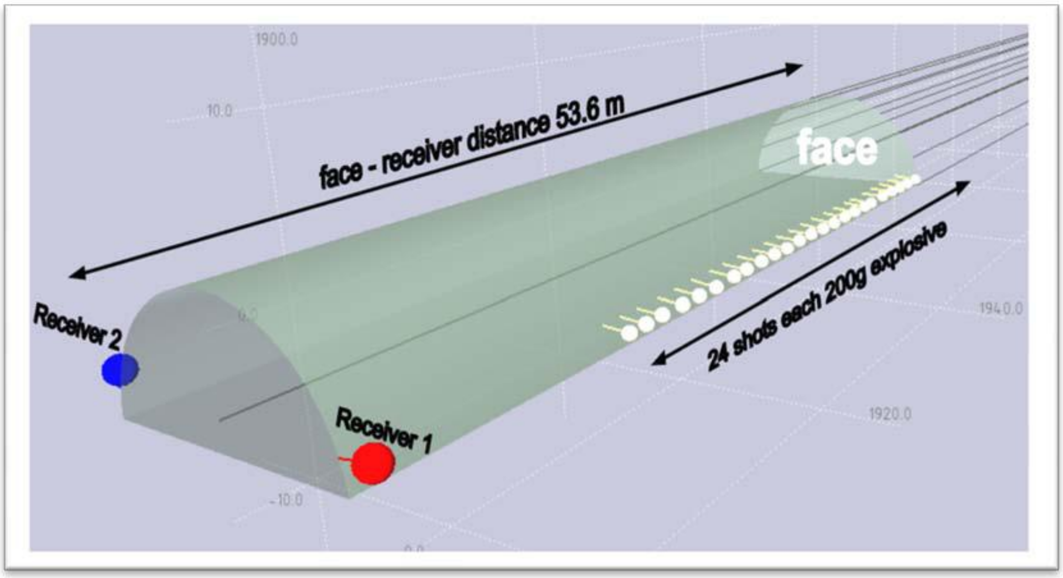

Figure 17 - Layout of TSP survey at Atal tunnel, Rohtang

5. REMEDIAL MEASURES UNDERTAKEN IN SERI NALLA FAULT ZONE

When the Seri Nallafault zone was first encountered, regular systematic support was installed which consisted of lattice girders, wire mesh, shotcrete and rock bolts. But after the occurrence of the first major cavity at Ch. 2+046m, DRESS method of tunnelling was adopted. DRESS method implies to Drainage, Reinforcement, Excavation and Systematic Supports. This method consisted of systematic pre-drainage ahead of face (installation of long perforated MS pipes of dia. 76mm) to drain out the water inside the rock mass. Reinforcement of the rock mass was done by usingpipe-roofs and forepoles to form an umbrella and subsequent grouting. Pipe-roofing was done by using MS pipes of 89mm, 76mm and 114mm diameter and later on 40mm TMT bars were also inserted inside the 114mm diameter pipes for additional reinforcement. Forepolingwas carried out by using 32mm SDRs. Excavation was done in small steps by mechanical means and finally the systematic supports were installed. The DRESS method was very useful to excavate through the soft, weak and water charged strata of Seri Nalla. In total 40 rounds of Pipe-roofs were done in this area which consisted of both single and double layers of pipe-roofs.

In addition to pipe-roofing, there were several other additional measures and methods applied to successfully tackle the Seri Nalla which are enumerated below:

5.1 Grouting

Different types of grouting were carried out in this area like multi-stage grouting with micro fine cement and sodium silicate admixture, consolidation grouting, grouting in roof pipes and grouting in SDRs with both micro fine cement and ordinary cement.

5.1.1 Consolidation grouting

Consolidation grouting was carried out between Ch 2+048 to 2+071 m at a pressure of 0-5 bars where total grout intake was 130200 kg and the intake per linear metre was around 258.33 kg.

Consolidation grouting was again carried out at Ch 2+431.5 m with micro fine Cement and Sodium Silicate admixture at a pressure of 0-9 bars where total grout intake was 4250 kg and the intake per linear metre was around 25.75 kg.

5.1.2 Multi stage grouting

Multi stage grouting was carried out with MS pipes of 76.1 mm diameter and 6 m length using micro fine cement and admixture. Table 3 details gives details of multi stage grouting.

Table 3 - Multi stage grouting details

Ch. (m)		Intake quantity (tonne)	Admixture quantity (litre)
From	To		
2398	2402.5	13.87	693.5
2402.5	2407	8.5	425
2408.5	2410	2.85	142.5
2401	2410	10.48	505.6
2413	2417	9.425	573.1

5.1.3 Grouting in pipe roofs

Between Ch 2+045.6 and 2+458.2m total 40 rounds of pipe roofs were installed which were in both single row and double row. Total cement intake during pipe roof grouting was 833785 kg and the average intake per linear metre was around 30.81 kg/m. Table 4 gives details the grout intake in each pipe roof round.

Table 4 - Pipe roof grouting details

Pipe Roof Round	Ch. (m)	Total Cement Intake (kg)	Intake (kg/m)	Pipe Roof Round	Ch. (m)	Total Cement Intake (kg)	Intake (kg/m)
1	2045.60	36900	45.78	21	2258.50	17600	28.25
2	2053.00	8800	16.12	22	2271.90	13300	26.65
3	2058.48	14550	20.38	23	2283.43	6200	17.51
4	2064.00	26650	41.51	24	2304.30	13200	20.89
5	2070.10	35560	25.33	25	2310.75	11650	30.66
6	2076.00	42750	41.07	26	2317.10	2450	8.70
7	2084.25	52450	38.15	27	2371.40	14300	24.83
8	2095.00	56100	40.30	28	2380.00	18700	35.93
9	2105.60	16400	22.91	29	2386.05	23700	55.76
10	2117.50	18450	25.93	30	2391.05	12800	35.56
11	2129.60	17600	28.07	31	2395.00	19200	66.55
12	2140.65	23700	38.35	32	2403.00	34150	46.34
13	2150.69	32600	51.06	33	2403.00	17400	22.61
14	2159.70	36800	44.10	34	2413.00	13750	20.48
15	2170.82	30150	48.39	35	2417.00	23950	16.78
16	2182.70	12300	58.85	36	2424.00	18025	7.40
17	2194.50	0	0.00	37	2431.00	32300	13.63
18	2200.50	0	0.00	38	2439.50	32375	13.95
19	2236.50	12400	33.60	39	2447.70	16675	14.04
20	2246.50	15650	29.87	40	2458.20	2250	14.52

5.2 Piling

Piling was carried out to provide additional support to the tunnel walls before benching. Pilling was carried out from Ch.2+000 to 2+080m using MS pipes of 76 mm diameter, 6 m in length and inserted at a spacing of 1 m on both sides at an angle of about 45° in downward inclined direction (Fig. 18).

5.3 Micro Piling

These were same as soil dowels. These were reinforcing hollow bars and were grouted. Micro piling was carried out between Ch. 2+345 to 2+370m to counter the high vertical deformations. These micro piles were 114 mm in diameter and 6 m in length, fully reinforced. These micro piles were inserted near the base plate of Lattice Girders in vertical direction downwards. Eleven numbers of micro piles were again inserted between Ch. 2+403.50 and 2+407.50m. These were inserted 50° downwards near the base plate of lattice girders and reinforced with 20 mm steel bars. These micro piles were 76 mm in diameter and were of 6 m length with 3 m length being perforated (Fig. 19).

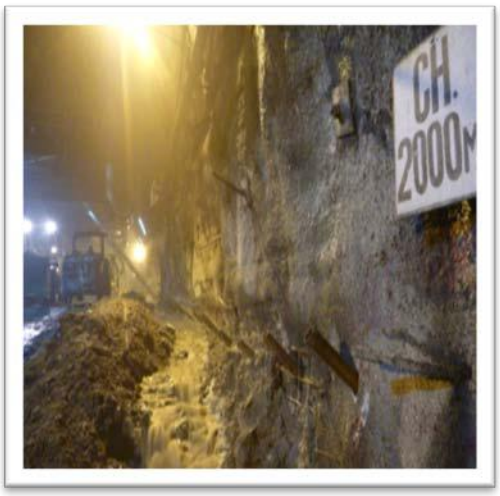

Figure 18 - Piling

Figure- 19Micro pilingat LG base

5.4 Installation of Pipe-Roof

Fortyrounds ofpipe-roofing were installed in the Seri Nallazone with different length and diameter between Ch. 2+045 and 2+458m (Figs. 21 & 21) with following specifications:

- Single & double layer pipe roof,
- Pipe roofing using dia 76.0, 88.9, 114.3 mm,
- Length of pipe-roof used 9, 12& 15m,
- 40mm rod inserted within 114 mm pipe-roof to act as additional reinforcement,
- Fore-poling also done with SDR in between pipe roofs, and

Drainage pipes of 9m to 24m drilled with 76mm diameterwere installed to drain the water effectively.

Figure 20 - Single row pipe roof

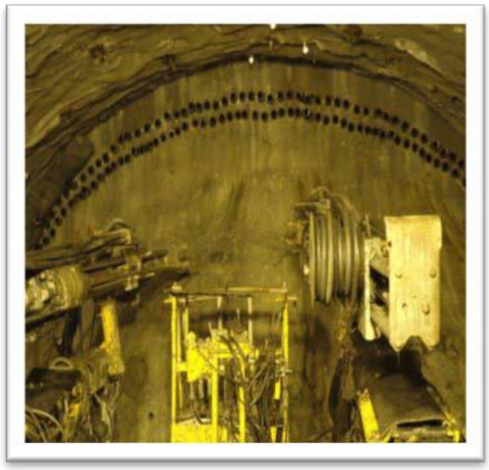

Figure 21 -Double row pipe roof

5.5 Pilot Tunnel

This method was applied in a small stretch from Ch. 2+385.45m to Ch. 2+394.50m where a secondary tunnel smaller in diameter (4 m) to the main tunnel was first excavated through the weak strata (Fig. 22).

Figure 22 - Pilot tunnel

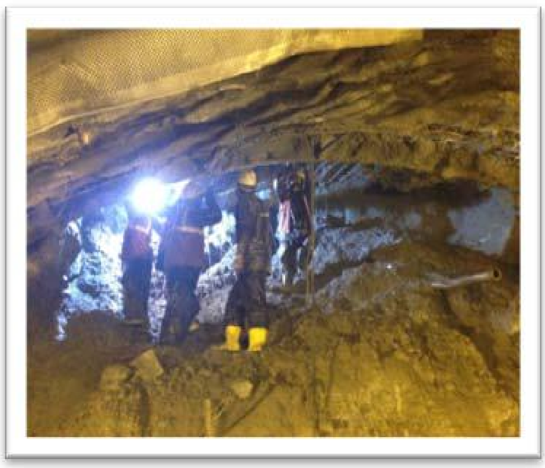

Figure 23 -Multiple drift excavation

5.6 Multiple Drift with Panel Excavation

Multiple drifting with panel excavation was done in the RBM (river borne material) encountered area where the heading was divided into small panels and excavated accordingly (Fig. 23). A continuous shell was created by excavating sections in panels. Each panel was individually supported with wiremesh and shotcrete. Once peripheral arch was completed, the lattice girder was erected. This also ensures that the deformation of the rock mass/tunneling media is kept to a minimum. A face stabilization core was left at the centre of the face to act as additional support against the flowing ground condition, which had been previously supported with wire mesh, shotcrete and rock bolts.

5.7 Temporary Invert

Temporary invert was excavated in very poor to extremely poor ground conditions (Excavation Class 6 &7) to act as a counter measure against upheaving of soft ground (Fig. 24).

5.8 Saw Tooth Filling

As the pipes used in pipe roofing cannot be inserted horizontally along the tunnel, so they had to be drilled at an inclination of about 8° to 10° from horizontal. Due to the inclination, it created gap between excavation and actual required level, so to fill this gap saw tooth filling was used. Saw tooth filling was carried out between Ch. 2072.00 to 2462.00 m. The Saw tooth was filled with shotcrete from one pipe roof round to another (Fig. 25).

Figure 24 - Excavation for temporary invert

Figure 25 - Saw tooth filling

5.9 3D Deformation Monitoring

The maximum vertical deformation recorded was 861.0 mm at Ch. 2+403m between 11'O clock and 12' O clock position after excavation. The maximum horizontal deformation recoded was 275.0 mm at Ch. 2+030m between 9and 10'O clock position. The rate of movement was very high in this zone.

The larger and continuing long-term deformation normally occurs in rock of low strength. The entire reach of Seri Nalla were in sheared, shattered rock mass and river borne material (RBM) with medium to high inflow of water, which has low strength as indicated by its character(Fig. 26).

5.10 Re-Profiling

As seen from the 3D monitoring results, the deformation in the Seri Nalla heading had deformations up to 891mm. Re-profiling had to be carried out at several places due to undercuts in those sections. These undercuts were due to the higher deformations in those areas. Scaling of these areas had to be carried out together with cutting of the previously installed pipe roofs, lattice girder, rock bolts and new lattice girders had to be installed followed by wire mesh and shotcrete (Fig. 27).

Figure 26 - 3D deformation monitoring

Figure 27 - Re-profiling and lattice girder support

5.11 Extension for Benching and Invert

Though the nature of the strata to be encountered was known, but how it would behave was not exactly known as the water was moving within the strata. So, the section was divided into heading 2, benching and invert section as shown in Fig. 28. Heading 2 was excavated on both sides leaving central portion for movement of traffic.

Deep invert was constructed across the entire Seri Nalla stretch. This was done mainly to close the tunnel ring so that there is even distribution of stresses across the soft and weak Seri Nalla zone.The deep invert excavation was carried out to the required levels as per the design, half side for facilitating traffic movements.

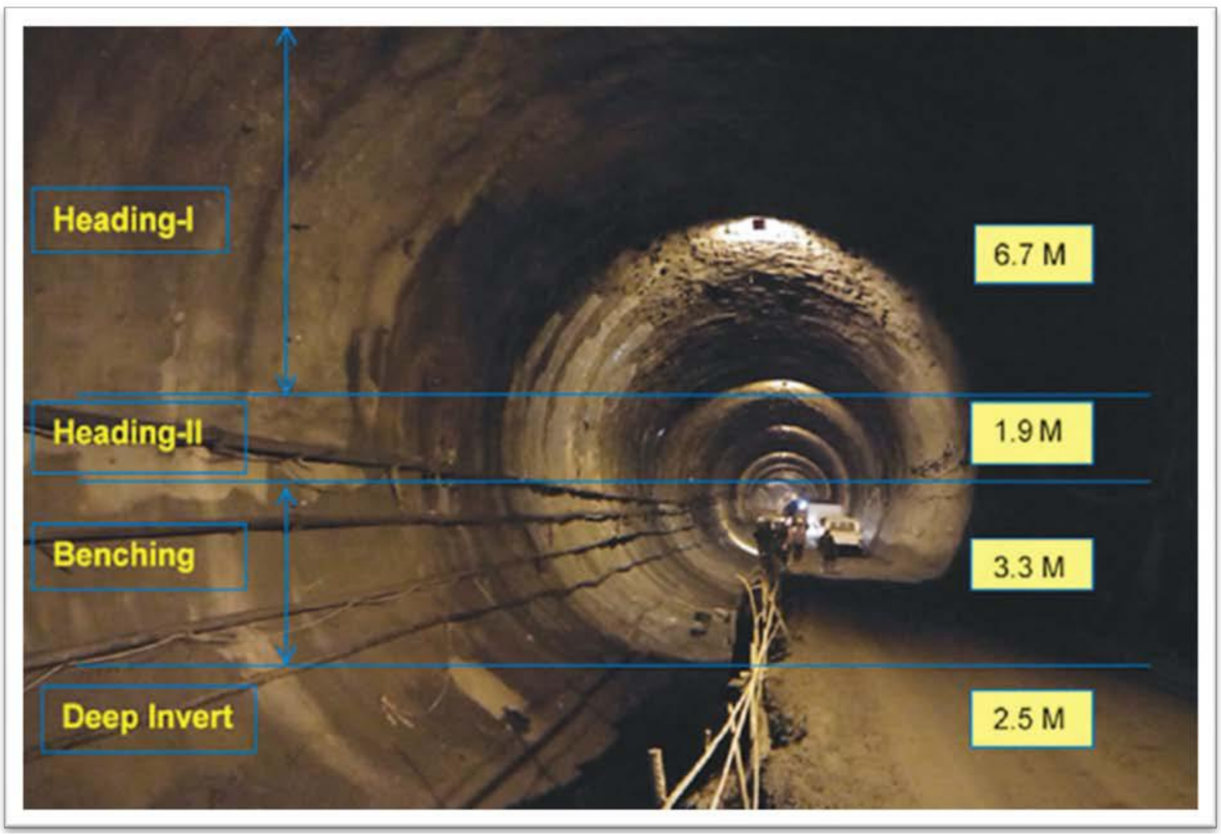

Figure 28 - Sequence of extension of heading 2, benching and invert

Due to logistical problems during the excavation of benching and invert,for movement of men & machinery and supply of concrete to other work fronts, two bailey bridges were installed (Fig. 29).As the time was of paramount importance and shifting of bridge wastaking too much time so the arrangement was made in such a way that both end of the bridges were fixed onroller so that time of shifting of bridge can be reduced, earlier it was taking two days (48 h)which was reduced to 12 to 15 h so that the cycle time of the activity could be reduced (Fig. 29).

Figure 29 -Bailey bridge used for logistics in Seri Nalla zone

5.12 Water-Proofing and Concrete Lining of Deep Invert in the Seri Nalla Zone

After the excavation of the deep invert, a 350 mm shotcrete layer was applied. A 50 mm diameter drainage pipe was drilled from the shotcrete layer 50 cm into the ground at 2 m radial spacing. On top of this shotcrete layer, a 30 mm smoothening layer of shotcrete was applied. On top of the smoothening shotcrete layer, dimpled membrane of 25 mm was installed both radially and longitudinally.

A 50 mm protection layer of wire mesh and shotcrete was applied on top of the dimpled membrane. Above this, a 20 mm water proofing membrane of geo-textile and geo-membrane was installed. 150mm diameter PVC pipes were welded to the water proofing membrane so that water coming in to drainage pipe drilled in to the ground below the initial 350 mm shotcrete layer comes in these PVC pipes and then can be collected in the catch pit and later discharged in the main drain as shown in Fig. 30.

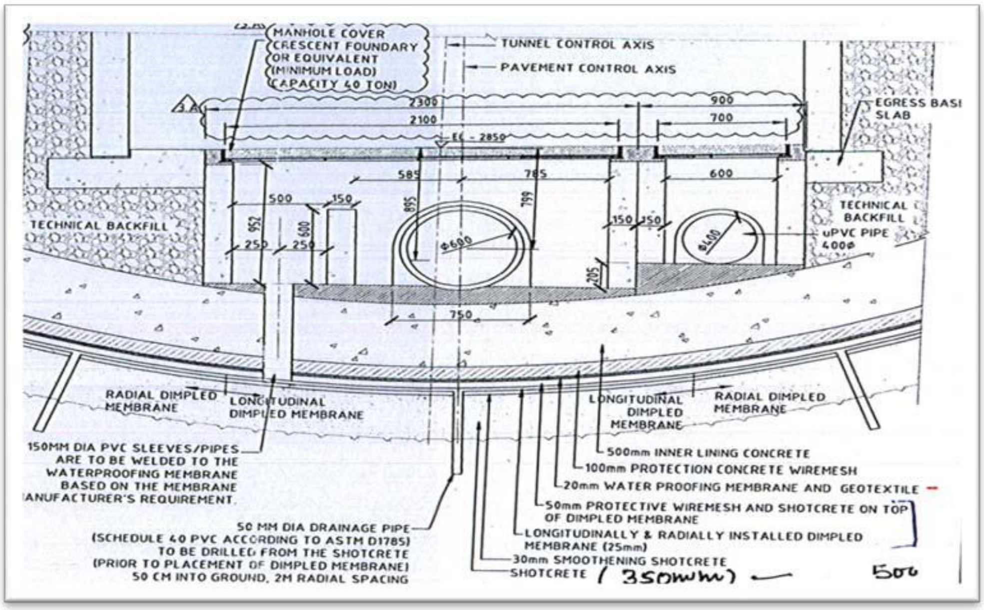

Figure 30 - Sequence of activities for execution of deep invert

Figures 31 & 32 - Water proofing in deep invert section of Seri Nalla zone

A 100 mm protection concrete layer with wiremesh was applied on top of the water proofing membrane.On top of this protective concrete layer, 500 mm RCC (Main bar 25 mm and Distribution bar 20 mm) lining was done with the grade of concrete being S35as shown in Figs. 33 & 34.

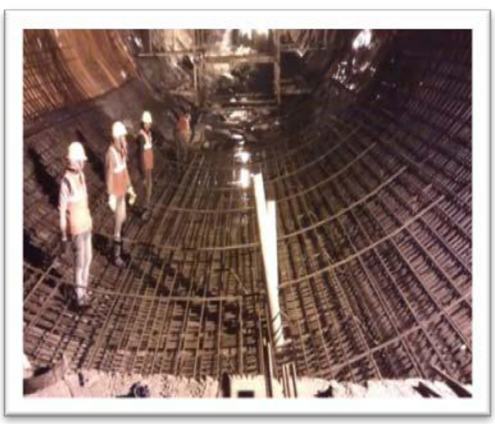

Figure 33 - Reinforcement for deep invert

Figure 34 - Lining of deep invert

After the lining of the deep invert, other activities like the reinforcement and concreting of the kicker lining and reinforcement and concreting of the base slab followed by installation of the pre-cast EET (emergency egress tunnel) is carried out as shown in Figs. 35, 36, 37 and 38.

Figure 35 - Reinforced kicker lining

Figure 36 - Reinforcement of base slab

Figure 37 - Concreting of base slab

Figure 38 - Lining of deep invert

5.13 Water-Proofing and Concrete Lining of Overt Section

In case of Overt Section, re-profilinghad to be carried out at several places due to undercuts in those sectionsas a result of higher deformations in those areas. As a result scaling of these areas had to be carried out together with cutting of the previously installed pipe roofs and new lattice girders had to be installed followed by wire mesh and shotcrete (Figs. 39, 40 and 41).

After re-profiling,geo-textile and geo-membrane were installed before the reinforced lining. In this zone 500 mm RCC (Main bar 25 mm and distribution bar 20 mm) final lining was carried out with the grade of concrete being S35.

Figure 39 - Water-proofing of overt section

Figure 40 - Reinforcement of overt

Figure 41 - Completed final lining of overt

6. CONCLUSIONS

The Seri Nallafault zone was encountered unexpectedly prior to its expected location. For such cases when the strata to be tunneled are under high squeezing conditions and also presence of river borne material with high inflow of water is encountered, which was not expected >250m below the surface, tunnelling is always very difficult task because no one can foresee accurately in advance.

DRESS methodology proved very effective in countering the Seri Nalla fault zone. This method proved very effective in countering weak, soft and flowing ground conditions encountered in the Seri Nallafault zone. TSPs can be used for advance probing in order to access the geological conditions in advance and subsequent planning to counter them.

At places of major ingress, water seepage could not be totally sealed, and it had to be channelized into the pavement drain through a network of pipes and bund drains along the tunnel lining. Systematic grouting was used to divert water to specific areas and subsequently drained. Through the drainage systems, it is being tried to ensure that the road surface is kept devoid of hindrance due to waterseeping into the tunnel from the Seri Nallazone and it does not create any threat to the traffic movement.

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