Tunnelling Through Weak Zones using Dress Methodology in Himalaya

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Abstract

Tunnelling through major weak zones, especially charged with ground water, has always been a great problem particularly in the Himalayan geoenvironment. There are number of cases where tunnelling activity had to be suspended for several days or even months. For such conditions, DRESS (drainage, reinforcement, excavation and support solution) Methodology appears to be an appropriate solution. In India, this methodology was first adopted at a mega power project, the Nathpa-Jhakri Project, in western Himalaya to tunnel through a very thick sheared rock zone, Daj Shear, interpreted in a 27.4 km long 10.15m finished diameter head race tunnel (HRT). Tunnelling for a length of about 360m has been done using this method though the main shear zone was expected to be 120m thick excluding the fracturing effect to the surrounding rock mass and small sympathetic shears. The paper deals with the tunnelling conditions predicted and encountered. The excavation and support procedure adopted in negotiating the Daj shear has also been discussed in detail.

This method of tunnel construction has also been used successfully to cross extremely poor and water charged tunnelling media along HRT of Tala Hydroelectric Project, Bhutan, and currently it is being used at Katra-Srinagar-Baramula Railway Project in Jammu and Kashmir.

Introduction

Encountering weak features is common in any long tunnel, particularly in Himalayan rocks. These weak zones may be faults, shears, soft rocks, shattered and fractured zones, etc. Tunnelling through such zones is normally difficult that poses major construction problem especially if these zones are significantly thick and associated with ground water flow and intersect the tunnel for long length.

The 1500MW Nathpa Jhakri Hydroelectric Project (NJHP), in brief, consists of 62.5m high concrete gravity dam, four underground desilting chambers (each 525m x 16.31m x 27.5m), 27.4 km long head race tunnel (HRT), 301m deep surge shaft and an underground power house of size 222m x 20m x 49m. The surge shaft and desilting chambers are the deepest and largest, respectively, of its kind in the world. The HRT of the Project has predominantly encountered gneiss/augen gneiss and quartz-mica schist with some percentage of amphibolite and quartzite. The rock cover varied from a negligible 8m to about 1500m over the HRT while it was of the order of 80m (at Daj khad crossing) to about 300m in the Daj Shear zone reach.

The 27.4 km long and 10.15m in diameter HRT of the Project in Western Himalaya, Himachal Pradesh, intersected a major sheared rock zone, the Daj Shear, as anticipated at the investigation stage. The Daj Shear zone was crossed by using DRESS Methodology for the first time in India. Later, the method was applied to negotiate Kalikhola Shear Zone in the HRT of Tala Hydroelectric Project, Bhutan (Jeur et al., 2003) and to tunnel through a wide overburden zone at the Katra-Srinagar-Baramula Railway Link Project in Jammu and

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Kashmir state, India. The present paper deals with the nature of the Daj Shear and how it was successfully negotiated by applying the aforesaid method.

'DRESS' has been used for the first time at Nathpa Jhakri Project in India (Sirkek et al., 1999). Before going into the details of tunnelling using 'DRESS', a brief description of the method is felt necessary.

DRESS Methodology

The word DRESS stands for Drainage, Reinforcement, Excavation, and Support Solution. The method consists of drainage beyond the heading by drilling holes with simultaneous insertion of partly perforated steel pipes, improving the heading by grouting and shotcreting, forming forepoling arch by providing cement grouted casing forepoles followed by excavation and concurrent installation of supports. The number of forepoles may vary depending on the rock mass conditions. Worse the rock, more the forepoles and relatively better the rock less the forepoles.

Generally, forepoling is done for a certain length that varies depending on site conditions and roughly 65-75% of forepole length is excavated and supported before installing next set of forepoles known as forepole block. In order to facilitate the installation of next set of forepoles, diameter of the tunnel vary increasingly towards the heading creating a step at the junction of two consecutive blocks of forepoles between the maximum excavation line of previous block and the minimum excavation line of the next block. The process is repeated for advancement of the tunnel (Fig 1).

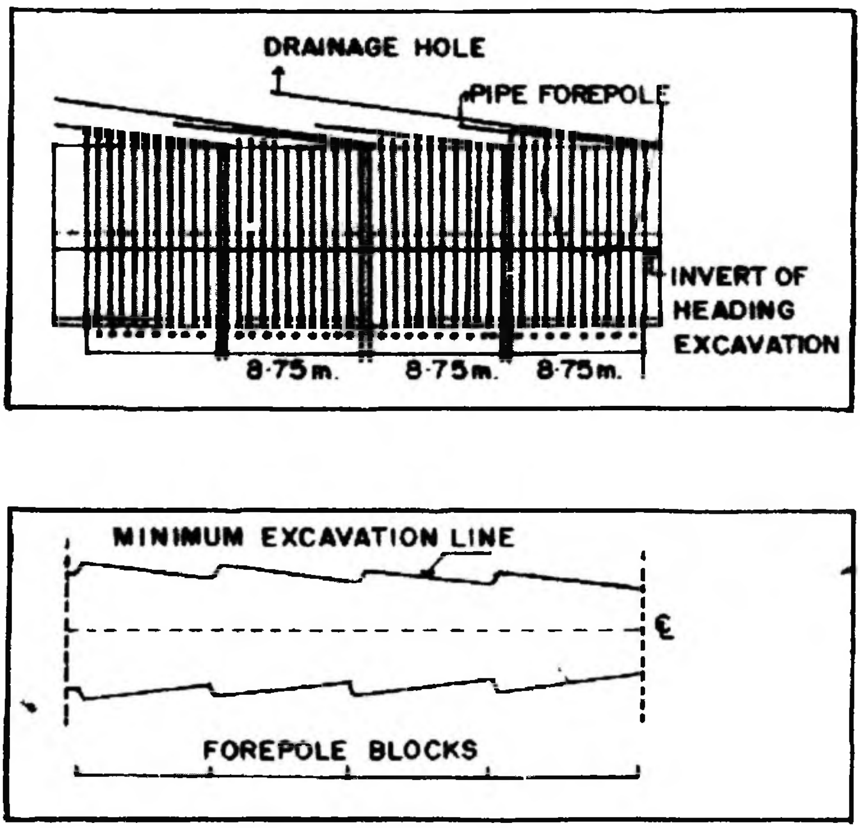

Fig. 1: General section and plan of the tunnel for 'DRESS' method.

ODEX tube drilling system is used for carrying out the main function of forepoling through a special hydraulic crawler drill (PACCHIOSI type P 1500 TAF or Casagrande PG 175 with diesel engine) with down the hole (DTH) hammer (Atlas Cop 32). This system allows simultaneous drilling and casing of the horizontal and sub-horizontal holes in all kinds of weak rocks. The details of equipment and the mechanism of driving the casing forepoles into the rock mass without rotation are not described being out of scope of the present paper.

Daj Shear Zone

On the basis of surface and subsurface geological investigations carried out by Geological Survey of India for the HRT (Singh and Kumar, 1976; Ashraf and Chowdhary, 1988; Jalote et al., 1991) , the Daj Shear Zone was expected to consist of 40-60m thick gougy and crushed rock materail along the HRT between Ch. 26000m and Ch. 26500m (Fig. 2). It was expected to be associated with over 100m shattered quartz-mica schist and amphibolite charged with ground water. The Shear was expected to "pose tunnelling problems including large overbreaks with tunnel collapses, heavy ground water seepage and squeezing conditions" (Jalote et al., Op. cit.).

During the pre-construction and construction stage investigations, the HRT in this area was further explored by two drill holes (Fig. 3). The data of these holes revealed the presence of sympathetic shears and the thickness of the shear zone was revised to 120m excluding the shattering effect to the surrounding rock mass (GSI, 1997).

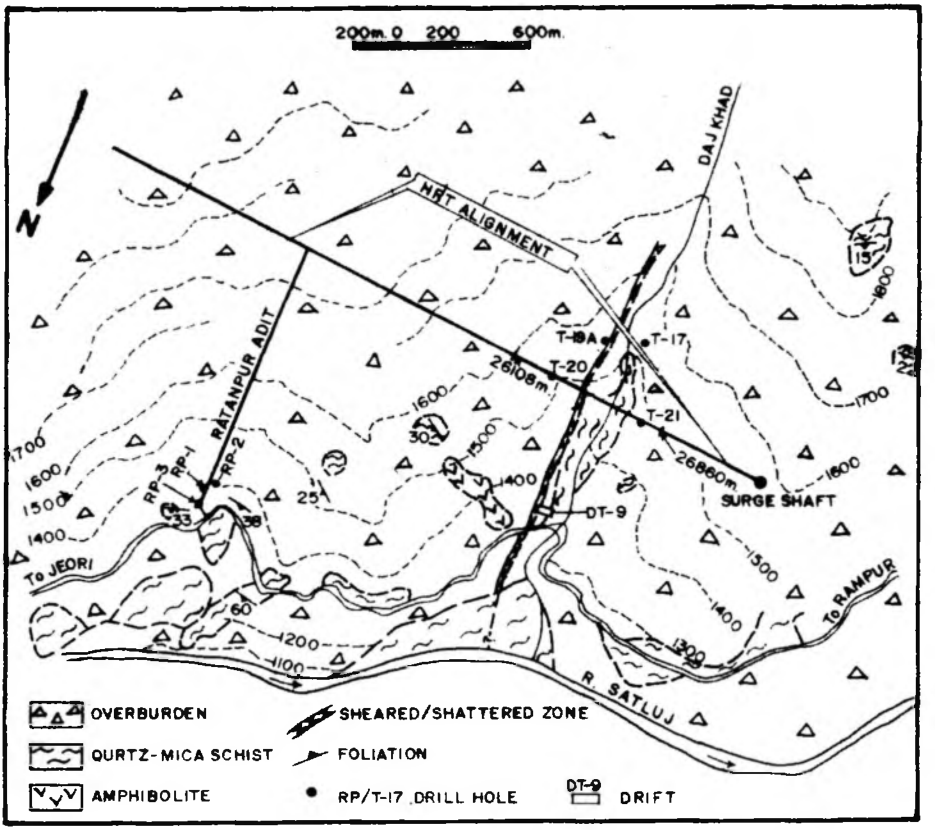

Fig. 2: Geological plan of the Daj Shear zone area showing subsurface explorations.

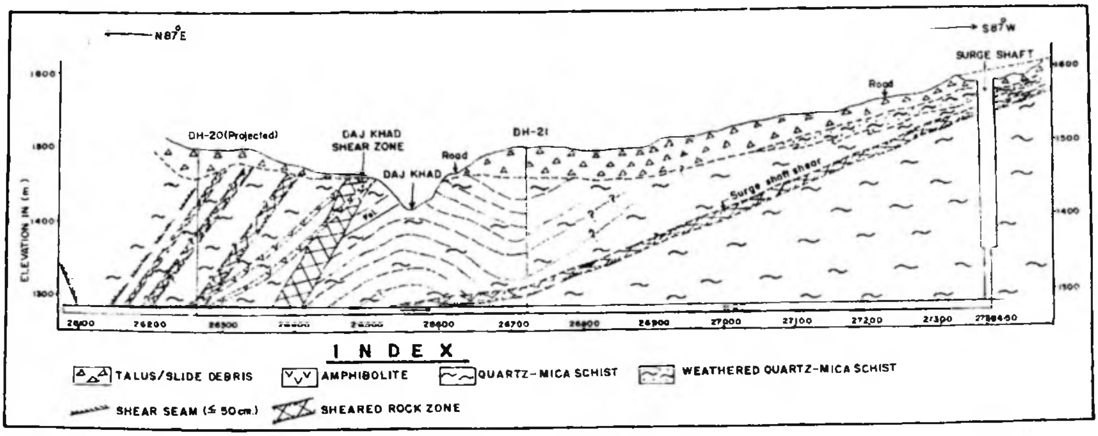

Fig. 3: Geological section along HRT in the Daj Shear zone and the Surge Shaft area.

The HRT intersected the Shear zone at Ch. 26139m (Ratanpur downstream heading) where extremely poor rock mass consisting of gouge, rock flour and crushed rock with heavy ground water inflow was observed. At this location, a 30-40m thick very soft rock zone (altered mica schist) affected by the shear zone was encountered. On the downstream side, it was followed by a thick amphibolite band. Under such poor conditions, tunnel progressed to Ch. 26162.5m by supporting the rock with steel ribs from Ch. 26135m (Kumar, 2007). Deformation in the steel rib supports was observed, which was probably due to rock load and therefore, further excavation had to be stopped. Later, steel rib in this reach pierced into the invert due to very soft nature of rock and the crown subsided. The 27m length of the tunnel had to be filled by muck to check further subsidence of ribs.

On the other hand, poor rock conditions were also encountered from Ch. 26633m to 26522m (Face-6 upstream heading) due to the presence of another shear named Surge Shaft Shear. The tunnelling in this reach was done by supporting the rock mass with steel ribs, which showed signs of deformation.

The nature of rock mass conditions encountered during tunnelling and the predictions made for the Daj Shear were considered and discussed at length in order to find some viable and safe method of tunnelling. Various possible solutions were studied and it was decided by the project organisation that the remaining length of the HRT between Rattanpur downstream and Face-6 upstream heading to be excavated using the 'DRESS' method.

Crossing the Daj Shear Zone by 'DRESS'

Tunnelling through the shear zone by DRESS was started from the Face-6 upstream heading from Ch. 26522m because the excavation of this reach was required early for the installation of steel liner in Daj khad reach as fabricated pieces of steel liner had been planned to be brought to the tunnel grade from the surge shaft. For the tunnel advancement, the procedure adopted is described below.

First of all, with the forepoling machine (ODEX tube drilling system) advance drainage beyond the heading was done by drilling six to eight drainage holes of 77 mm diameter up to 24 m length at an angle of 15° upward. These holes were cased with 50 mm diameter pipes having 12m perforated section in the 24m length and were covered with geotextile. Geotextile was used to avoid the choking of drainage holes. Advance drainage was followed by improvement of the face ahead by cement grouting (W.C. Ratio 1:1) and where the grout intake was very low or negligible due to the presence of clay gouge, the face was strenghtened by shotcreting and

8 m long grouted anchor bars of 25 mm diameter.

After the drainage and strengthening of the face, main function (i.e. forepoling) of the DRESS Methodology is carried out. Umbrella forepoling arch in the roof (above spring level) had been provided by installation of 12 m long and 114.3mm outer diameter casing forepoles of steel pipes driven ahead of the heading by forepoling machine along with DTH hammer. These forepoles had an inclination of 6° upward at a spacing of about 400 mm c/c and varied in number from 25-37 depending on the rock conditions. Forepoles were grouted to make them solid with cement grout (W.C. Ratio 0.75 to 0.45) at a maximum pressure of 5 kg/cm^2 (Sirkek et. al., 1999). Thereafter, the tunnel had been excavated by shovel, and partial blasting, if required, to a maximum length of 8.75 m. Simultaneously with progressive tunnel advance of 0.75m to 1.50 m depending upon the stand-up time, the tunnel had been supported by steel ribs of ISM 300 x 140 at 0.75 m c/c. A total of 12 steel ribs (R1 to R12) were installed in the excavated length of 8.75m in one block of 12m. The first steel rib (R1) had been installed at the minimum excavation line and subsequent ribs (R2 to R12) were provided in a variable minimum excavation line radius in order to facilitate installation of forepoles in the next block. A step of 900 mm in the tunnel section had been created between R1 (of the next block) and R12 (of the previous block) minimum excavation line radius for this purpose by continuously increasing the tunnel section from R1 to R12. Ribs were anchored at spring level by 6 m long (25 mm dia) cement grouted bolts in addition to ISMC 150 x 75 mm runners joining 3-4 ribs.

In a forepole block of 12m, an over 3m length was left unexcavated and had been used as overlap between the two consecutive forepole blocks. The tunnelling continued in the same way in each forepole block from Ch. 26522m to Ch. 26317m from Face-6 upstream heading with the exception that the advance drainage holes had been provided in alternate blocks of forepoles. Where there was no significant shearing, particularly between Daj and Surge Shaft shears, the rock mass (schist) was poor due to the effect of shearing. Therefore, 'DRESS' methodology was continued in this reach as well because it was not feasible to change the tunnelling method in short reaches. The average progress of tunnelling was of the order of 17m/month (Mahajan and Verma, 1999). The forepoling machine was then shifted to Ratanpur downstream heading to continue tunnelling in the same manner from Ch. 26162m to Ch. 26317m.

Since the nature of strata in the Daj Shear was very poor, the rock mass was further strengthened with self drilling (threaded with a steel bit attached at the drilling end) cement grouted 32 mm dia 6 m long rock bolts at 1 m x 0.75 m or 1 m x 1.5 m c/c. The invert was supported by providing 350 mm thick shotcrete as temporary support instead of the designed 400 mm thick concrete during heading to prevent possible invert heaving and converging/piercing of steel ribs at the invert.

After the heading advancement, benching excavation had been carried out with a minimum lag of 50m from the heading. The benching excavation was done using hydraulic hammer and side walls were supported by extending the ribs and other support elements at every 3m benching advance. The space between ribs and excavated rock profile had been filled with shotcrete. The final tunnel invert had been provided with steel arch embedded in 400mm concrete.

'Dress' at Tala Hydroelectric Project

The HRT of the Tala Hydroelectric Project, Bhutan, intersected a major shear zone, Kalikhola Shear Zone, in the Kalikhola upstream face. Geologically, the rock mass comprised alternate bands of quartzite, amphibolite and biotite schist with 10cm to 50cm thick shear seams and completely sheared and gougy mass of 12m in the excavated portion. Rocks were folded and charged with groundwater rendering the rock mass very poor to exceptionally poor leading to flowing and squeezing conditions. The tunnelling was carried out in the very poor to exceptionally poor rock mass for a length of about 49m from RD 660m to 709 by applying various techniques and support elements to stabilise the tunnel and even late attempt of DRESS method by installing 12m long forepoles of 110mm diameter from RD 699m. Steel ribs backfilled with concrete was the main tunnel support with rock mass strengthening by self drilling hollow anchors (MAI Anchors), jet grouting, injecting polyurethane grout, etc. (Goel and Khazanchi, 2002). Where flowing conditions were encountered, the face was plugged with bulkhead and grouted the crown portion before further advance. However, the tunnel collapsed when the face was at RD 709m from the Kalikhola Adit junction. The failed material (about 3500m^3) flowed back to about 70m. Tunnelling remained suspended for about an year and in the mean time, decision to divert the alignment was taken (Jeur et al., 2003).

The tunnel was diverted from RD 607m of original alignment at 45^o (horizontal bend) towards hill to attain an additional lateral rock cover of over 100m. It was expected that the new alignment would encounter better geological conditions with increased vertical and lateral cover though the shear zone was expected to intersect the realigned tunnel. Tunnelling for a length of about 400m was carried out very cautiously but without any significant problem. The rock mass conditions deteriorated at RD 1005m but the excavation continued for another 8m with steel supports. However, the supports could not sustain the rock load of the sheared rock mass and resulted in the collapse of the crown. After stabilising the tunnel with MAI anchors and grouting through them, further excavation was carried out using DRESS method by deploying Casagrande PG 175 hydraulic crawler drill for ODEX tube drilling. Forepoling for 9m to 15m was done in different blocks for the construction of tunnel through the Kalikhola Shear Zone for about 300m, which has been completed successfully and the project has been commissioned.

Concluding Remarks

The aforesaid discussion clearly indicates that the DRESS Methodology is quite successful in negotiating very poor to exceptionally poor tunnelling media comprising crushed and pulverised rock mass highly charged with groundwater. Similar method called 'Roof Piping' has been successfully applied to tunnel through thick overburden reach by IRCON at Katra-Srinagar-Baramula Rail Link Project in J & K. It may be pointed out here that at both the Nathpa-Jhakri and Tala projects, the decision to apply DRESS method was taken when the geological conditions made it nearly impossible to advance the tunnel. Therefore, it may be called a last minute arrangement during construction, which had been adopted after other possible solutions were tried or considered ineffective.

Based on the tunnelling experience of major river valley projects, particularly in the Himalaya, it may be stated that any long tunnel has a strong chance of encountering thick fault, shear, or other weak zone. There are many such examples where such geological conditions occurred, e.g. Pandow-Baggi tunnel at Beas Satluj Link Project (Agarwal and Srivastava, 2007) HRT of Sanjay Vidyut Pariyojana-Bhaba, railway tunnel T1 and T2 of Katra-Srinagar-Baramula rail line, etc.

Therefore, in view of hydro boom in the Indian subcontinent, it appears to be a good proposition to suggest that large tunnelling projects in Himalaya should make provisions of DRESS Methodology in design at the planning and bidding stage for extraordinary poor zones expected or any such unforeseen zones (surprises) in order to avoid contractual problems resulting in delayed decisions on the part of management. On encountering these weak zones, the method should be adopted without loosing any construction time so as to avoid delays in the completion of tunnelling projects. Further, this method appears to be more relevant in the present scenario of short duration of geotechnical investigation and fast track construction of river valley projects.

Cost of this methodology may be a deterrent in its application but compared with the expected amount of revenue loss on account of delays and escalations, which may run in several crores of rupees, it may not be a costly affair at the end.

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