Impact of Geothermal Zones in the Head Race Tunnel of a Mega Power Project in the Himalayas – investigation and Tunnelling Through Hot Conditions

Ashok Kumar*

Abstract

The paper deals with the investigation of and tunnelling through high geothermal zones along the 27.4 km long head race tunnel (HRT), one of the longest in the world, at 1500 MW Nathpa Jhakri Hydel Project, constructed in metamorphic Precambrian rocks in the Himalayan geoenvironment. Out of the two geothermal zones (Nathpa-Sholding and Wadhal-Manglad) predicted along the HRT, Wadhal-Manglad zone posed most difficult tunnelling conditions as expected. High temperature tunnelling problems and measures adopted to tackle these conditions for tunnel advancement have been discussed besides concrete lining including its performance. Suggestions have been made for assessing hot conditons during construction on the basis of experience at this mega Himalayan power project.

Introduction

One of the longest hydel tunnel in the world (27.4 km long, 10.15 m diameter) has been constructed at a major river valley project, the 1500 MW Nathpa Jhakri Hydroelectric Project, on Satluj river in the Himalaya. Besides usual tunnelling problems like weak and soft tunnelling medium, excess ground water discharge, ground stresses/rock pressures, etc., the head race tunnel (HRT) passed through predicted geothermal zones– one between Nathpa and Sholding adits (NSTZ) and the other between Wadhal and Manglad adits (WMTZ; Fig. 1 & 2). The present paper deals with the investigation of these zones and tunnelling problems encountered in the high temperature zones along HRT during construction.

Fig. 1: Geothermal manifestations in the head race tunnel

Besides HRT, the Project, in brief, comprises 62.5 m high concrete gravity dam, four balloon -shaped underground desilting chambers (each 525 m x 16.31 m x 27.5 m), a 301 m deep surge shaft and an underground power house complex with the machine hall being 222m long, 20m wide and 49m high. The rock cover over the tunnel grade varies from a meager 8m to about 1500m. But the tunnel lies at a depth of about 500m to 900m below the surface in the two geothermal reaches.

The project is housed within Jeori Granitoid Complex of Precambrian age (Bhargava et al., 1980; Bhargava and Ameta, 1987, GSI, 1999). Gneiss and schist are the two main rocks in the project area, which are folded, faulted, and moderately jointed. The initial length of 14.5 km of the tunnel is in gneissic rocks comprising augen gneiss, gneiss, granite gneiss, etc. while the remaining downstream portion is within the quartz-mica schist (QMS) and some quartzite. Quartzite was neither exposed nor intersected in any exploratory drill hole (Kumar, 2007). Amphibolite is present in both gneisses and schist generally along foliation and occasionally across it. The Wadhal-Manglad geothermal zone in the HRT has been encountered largely in quartzite and amphibolite (Fig. 2).

*Geological Survey of India, Lucknow, email: akumar259@yahoo.com

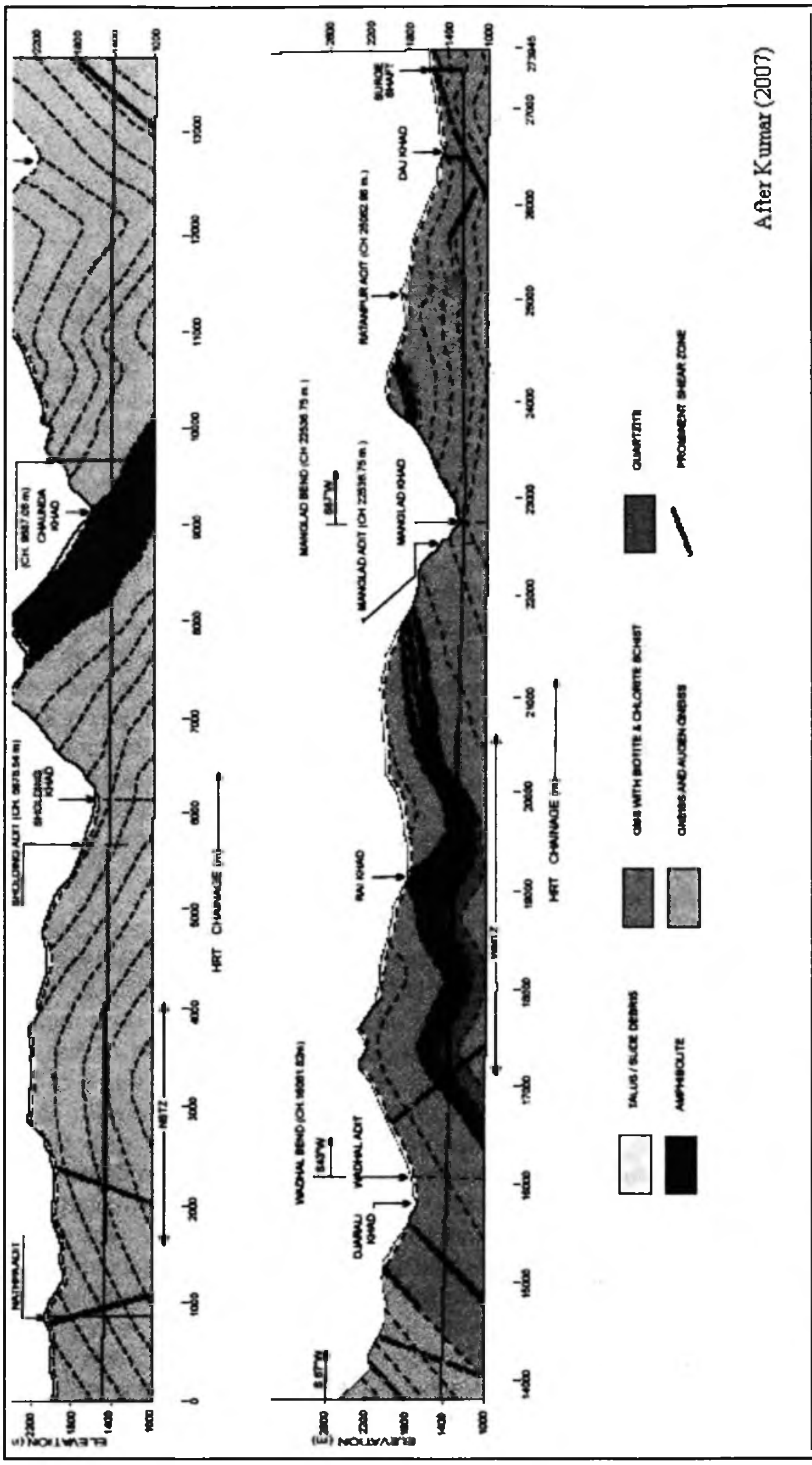

Fig. 2: Geological section depicting geothermal zones in the tunnel of the Project (NSTZ – Nathpa Sholding zone, WMTZ – Wadhal Manglad zone)

Fig. 2: Geological section depicting geothermal zones in the tunnel of the Project (NSTZ-Nathpa Sholding zone, WMTZ-Wadhal Manglad zone)

Geothermal Activity

Geothermal activity, manifested in the form of thermal springs, is known to occur at number of localities in the Indian part of Satluj basin (Aggrawal and Gupta, 1999; GSI, 1991;). Most of the geothermal springs are depicted in Fig. 3. However, there are three localities in the project area, Nathpa, Jeori and Jhakri, where thermal springs with surface temperatures 60°C, 46°C and 34°C (Shankar and Prakash, 1977; Gupta et al., 1996) are known to occur. In addition to these geothermal springs, thermal water has been encountered in two drill holes at Jeori. Also temperature of the order of 40°C was observed in the excavations of the underground power house complex of Sanjay Vidyut Pariyojna-Bhaba (Ashraf and Chowdhary, 1988) which is located 1 km upstream of the dam.

Investigation

Initial study of the geothermal activity in and around the project area was carried out by Shankar and Prakash (op.cit.) who gave an account of Jeori, Nathpa, Tapri and Karcham hot springs and calculated the base temperatures in the range of 144°C-207°C by Na-K-Ca geothermometery and 185°C-258°C using silica geothermometery. However, Gupta et al. (op.cit.) worked out the base temperatures as 38°C, 95±10°C and 123°C for Jhakri, Jeori and Nathpa areas respectively. Later Prakash and Thussu (1979) also carried out studies in connection with the geothermal investigation of the project and suggested cooling arrangements like refrigeration/extra ventilation in the tunnel.

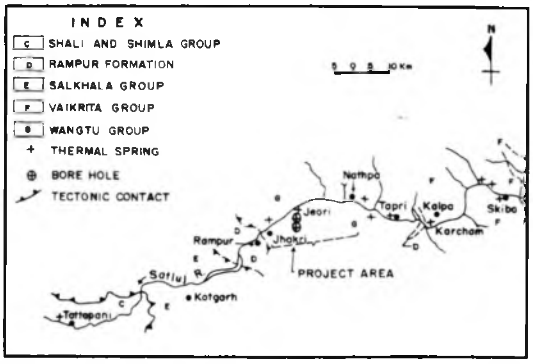

Fig. 3: Geothermal springs in the Indian part of Satluj Valley

Temperature measurements in some drill holes were carried out to work out the geothermal gradient which range from 0.05°C/m to 0.12°C/m (Singh and Kumar, 1976; Table 1, Fig. 4). The geothermal gradient in some geothermal belt of Himalaya has been calculated as 50°C/km (0.05°C/m) by Giggenback et al. (1983) against the world average of 30°C/km. In Nathpa-Sholding area the thermal gradient in hole T-2 is close to the Himalayan value whereas the average gradient is 0.08°C/m (Kumar, 2004) in Wadhal-Manglad section which is highly abnormal.

Table 1: Geothermal gradient in HRT drill holes located in Nathpa-Sholding and Wadhal-Manglad.

HRT Area	Hole No.	Rock Type	Geothermal Gradient (°C/m)
Nathpa-Sholding	T-1	Gneiss with pegmatite and amphibolite	0.016
	T-2		0.06
Wadhal-Manglad	T-7	Quartz-mica schist & amphibolite	0.09
	T-8	Quartz-mica schist	0.1
	T-10	Amphibolite	0.12
	T-14	Quartz-mica schist	0.05
	T-15	Amphibolite with schist	0.06

On the basis of detail studies, two significant geothermal zones, as mentioned above, were expected to be encountered at the tunnel grade. However, out of these, the Wadhal-Manglad zone was expected to pose most severe hot conditions during tunnelling with temperatures above 40°C, as this zone was characterised by low resistivity values besides high geothermal gradient.

Geochemistry

The thermal water encountered in the HRT is neutral to alkaline (pH 7.4-8.5) and mainly bicarbonate type in the Wadhal area. However, a sample from high temperature (60°C±) reach of this section is of chloride type. The sulphate concentration is generally low (60-78 mg/l) except in the very hot reach (460 mg/l). The sodium (3400 mg/l) and Cl (4980 mg/l) concentrations are very high in the hot reach. In the Nathpa-Sholding area, the HRT thermal water changes from bicarbonate to bicarbonate-sulphate water from upstream to downstream and HCO_3^{--} content decreases (175 to 58 mg/l) with increase in sulphate (0.5 to 38 mg/l; Aggarwal and Gupta, op.cit.).

Tunnelling through Geothermal Zones

Excavation of the HRT has been carried out in two stages, top heading and benching, using drill and blast method. In the first stage, about 70% top section was excavated leaving a wide bench to facilitate the movement of vehicles and machinery engaged in construction.

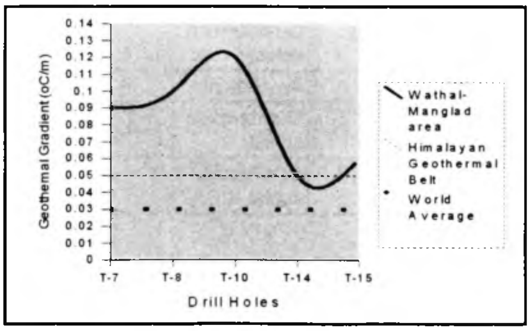

Fig. 4: Geothermal gradient in the Wadhal-Manglad area of the Project in relataion to Himalayan Geothemal belt and the world average

The thermal water having temperature 34 – 51°C has been intersected intermittently in a length of 2.5 km from Ch. 1600m to 4100m in the Nathpa-Sholding section while in the Wadhal-Manglad reach hot water of 36 – 65°C has been encountered between Ch.17050 m and 20450m (Kumar and Jalote, 2001; Kumar, 2004). The geothermal zones are as per prediction. Aggrawal and Gupta (op. cit.) concluded that the thermal water of the tunnel is of meteoric origin and it has undergone only shallow down depth circulation. Using silica geothermometry, they calculated the base temperature of HRT thermal waters in the range of 85±10°C in Nathpa-Sholding and 100±10°C in Wadhal-Manglad zone. The hot water ingress in the HRT in Nathpa-Sholding area did not pose any severe problem for tunnelling as the air temperature did not rise beyond 38°C whereas most difficult tunnelling conditions were experienced in the Wadhal-Manglad section, particularly at the first intersection of locked-up hot water. Problems experienced in construction of HRT through the Wadhal-Manglad geothermal zone are discussed here.

Hot Water Blow-out

First significant intersection of geothermal activity in the HRT was experienced at about 1 km downstream of Wadhal adit junction where the tunnel has a steeper gradient of 1(V): 60.85(H) than in the upstream of this adit. When the top heading of the tunnel reached Ch. 17067m on 15th January 1995, large quantity of hot water having 55°C temperature gushed into the tunnel from the right side. The discharge was estimated to be of the order of 90-100 l/s (Chadha et al., 1999) which flooded the tunnel up to 300m back from the heading. Consequently, working conditions became miserable due to heat and humidity and all construction work had to be totally stopped. To cope up with the situation, the ventilation system and the de-watering capacity was augmented by installing additional fan of 200 kW, pumps, and pipeline. The complete de-watering process took a total of 25 days.

After de-watering, examination of the blow-out site revealed the presence of a 7-8 m deep cavity in the well jointed amphibolite and biotite-chlorite schist along a shear zone. The shear zone along with schist possibly formed the barrier for the thermal water to get accumulated at this location. The cavity was tackled by concrete backfill after supporting the tunnel with steel ribs. In due course of time (about 5-6 months), the hot water discharge decreased gradually to < 5 l/s indicating that it was locked up water.

High Temperature Conditions

In the remaining high temperature reach of WMTZ, hot water has been encountered almost continuously with face advancement at the time of excavation. However, after some months the hot water seepage transformed into cold water in long reaches leaving some limited hot water flow/seepage points in the tunnel. The hottest reach in this geothermal zone has been observed for a length of about 550 m between Ch. 18,250 m and 18,800 m where thermal manifestations of 60°C and above occurred (Fig. 4).

High temperature thermal water flow into the HRT created miserably unbearable and dismal working conditions as the air temperature rose to 45-46°C accompanied by very high humidity. Such conditions were countered substantially by adopting certain measures like installation of 180,000 Cu m/h capacity additional fan, injecting air at the working face, dumping of 15-20 m^3 ice at the at the heading, pumping out the hot water from near the heading to the portal through pipes to restrict heat emission from hot water into the air, etc. It may be mentioned here that the ice producing plant was available near the Wadhal adit portal before encountering the geothermal zone in HRT. The remedial measures proved quite effective as the air temperature decreased to 38-39°C besides reduction in humidity.

Concrete Lining

The headrace tunnel has been totally concrete lined. In view of high temperature conditions and chemical nature of hot water in Wadhal-Manglad area, the question of durability of concrete lining was weighed. Therefore, the concrete mix was designed carefully based on available literature and practice. In the hot zone, reinforced concrete has been used for the tunnel lining with the concrete mix having cement content of 380 kg/m^3 of PPC cement having 25% fly ash. Just upstream of the hot zone, 420 kg/m^3 OPC cement with 30% fly ash has been used in the concrete mix. Incidence of cracks in lining in the hot zone was found to be remarkably low (about 3%) in contrast to the immediately upstream cold zone tunnel lining where cracks concentrated in middle third portion of almost every gantry pour of 18 m length (NJHP, 2000).

Concluding Remarks

The geothermal zones likely to be intersected in the tunnel were broadly identified on the basis of site and laboratory investigations. But it has been almost impossible to accurately pinpoint the chainage of problematic reaches that may be attributed to limitations in investigation on account of difficult terrain conditions, high rock cover over tunnel grade, non-availability of advance technology at the time of investigation, etc. Therefore, prediction of local anomalies is very difficult.

It may be worthwhile to mention here that a finite element numerical model (based on pure conduction) used by Goy et al. (1996) to calculate temperatures at depth for the 55 km long rail tunnel of Maurienne-Ambin project (between France and Italy), was useful for deep tunnels where the difference between the calculated and encountered temperatures was found to be generally 1°C while differences were higher at shallow depths. The higher difference at shallow depths was explained by circulation of water connected to the surface. It indicates that the prediction of local temperature anomalies, particularly at shallow depths, is quite difficult.

It may, therefore, be concluded that local temperature and hydrological anomalies need to be identified and tackled during construction. It is suggested that systematic monitoring of air, water and rock temperatures must be regularly carried out and advance probe holes be drilled from the face when approaching such zones at the time of construction in order to assess the intersection of possible nature of hot conditions and other anomalies in advance.

References

Aggarwal, R.K. and Gupta, G.K. (1999): Report on the study of geothermal phenomena in subsurface excavation in the Nathpa Jhakri Hydel Project, District Kinnaur, HP. *Unpubl. Rep. Geol. Sur. Ind.*, FS-1996-97.

Ashraf, Z. and Chowdhary, A.K. (1988): A comprehensive geotechnical report on the studies carried out for Nathpa Jhakri Hydel Project, Shimla and Kinnaur district, HP. *Geol. Surv. Ind. Unpubl. Rep.*(May 1988).

Bhargava, O.N. (1980): The tectonic windows of the Lesser Himalaya. *Himalayan Geology*, Vol.10, pp 135-155.

Bhargava, O.N. and Ameta, S.S. (1987): The Rampur Window revisited. *Proc. Nat. Sem. on Tertiary Orogeny*, pp.-24.

Chadha, A.K., Chaubey, J., Chauhan, K.S., Pande, A.K., Kaushal, V., Acharya, A.K., Chauhan, R.K., and Pundhir, G.S. (1999): Geology of Nathpa Jhakri Hydroelecric Project. *Sem. Rock Mechanics and Tunnelling Technology*, ISRMTT, New Delhi, pp 13-34.

Geological Survey of India (1991): Geothermal Atlas of India. *Geol. Sur. Ind.* Spl. Publ. No. 19.

Geological Survey of India (1999): Geological Map, Shimla Quadrangle (53E), Himachal Pradesh and Uttar Pradesh.

Giggenbach, W.F., Gonfiantini, R., Jangi, B.L. and Truesdell, A.H. (1983): Isotopic and chemical composition of Parbati valley geothermal discharges, NW Himalaya, India. Geothermics, Vol. 12, pp. 199-222. In Aggrawal, RK and Gupta, GK (1999): Report on the study of geothermal phenomena in subsurface excavation in the Nathpa Jhakri Hydel Project, District Kinnaur, HP. *Unpubl. Rep. Geol. Sur. Ind.*, FS-1996-97.

Goy, L., Fabre, D., and Menard, G. (1996): Modelling of rock temperatures for deep alpine tunnel projects. *Jour. Rock Mech. and Rock Engg.*, Vol. 29, No. 1 (Jan 1996), pp 1-18.

Gupta, G.K., Aggarwal, R.K., Sharma, S.K., Mathur, V.K., Bindal, C.M., Rai, R.P., Chittranshi, A. and Rai, A.P. (1996): Hydrochemistry of the geothermal fluid in Nathpa Jhakri Project area, Kinnaur and Shimla districts, HP. Proc. ISEG Symp. Modern practices in geotechniques. Jour. Engg. Geol., Vol. XXV (1-4), pp 237-242.

Kumar, Ashok (2004): Tunnelling problems through high geothermal gradient zones in Nathpa Jhakri Hydel Tunnel in Northwest Himalaya (Abst). *32nd Int. Geol. Congr.*, Italy. Vol., Abst. 101.

Kumar, Ashok (2007): Nathpa Jhakri Hydroelectric Project, A geotechnical study. *Geol. Sur. Ind. Bull.*, Series B, No. 60, pp 142.

Kumar, Ashok and Jalote, PM (2001): Construction stage geotechnical report on Nathpa Jhakri Hydroelectric Project, Kinnaur and Shimla districts, HP. *Geol. Sur. Ind. Unpubl. Rep.* (1993-2001), GSI, Lucknow.

Nathpa Jhakri Hydroelectric Project (2000): Report of the 25th meeting of the Penal of Experts. *Unpubl. Rep.*, NJPC, Shimla (June, 2000).

Prakash, Gyan and Thussu, J.L. (1979): Geological and hydrogeological surveys in connection with the geothermal investigation in Nathpa Jhakri Hydel Project area, Satluj valley, district Shimla. HP. *Geol. Sur. Ind. Unpubl. Rep.* (FS-1977-78).

Shankar, Ravi & Prakash, Gyan (1977): Report on the visit to geothermal areas in Nathpa Jhakri Hydel Project in Satluj valley, Shimla and Kinnaur districts, HP. *Geol. Sur. Ind. Unpubl. Rep.* (FS-1976-77).

Singh, Pratap and Kumar, S. (1976): Report on the detailed geological investigation on the proposed Nathpa Jhakri Project, Shimla and Kinnaur districts, HP. *Geol. Sur. Ind. Unpubl. Rep.* FS: 1974-75-76, GSI, Lucknow.