Leakage in Head Race Tunnel and Surge Shaft and its Remedial Measures - Case Study From Ranganadi Hydroelectric Project, Lower Subansiri District, Arunachal Pradesh

Ranendra Sarma and Anjani Bora

Abstract

Ranganadi Hydroelectric Project (405 MW) was commissioned in 2001. It has been developed with the creation of a pondage by constructing a 67 m high concrete gravity dam across Ranganadi River near Yazali. The storage so created is diverted to a surface powerhouse through a 10.27 km long and 6.80 m dia head race tunnel and the tail waters are let into Dikrong River. The tunnel passes through Precambrian schist and gneiss, Gondwana Group of rocks namely, sand stone, carbonaceous shale with coal seams, volcanics and meta-basics and soft friable sandstone of Upper Siwaliks with clay bands, shale and coal streaks. Main Boundary Fault (MBF) is the tectonic contact between Gondwana Group of rocks and Tertiary Sandstone.

During October/November 2006, leakage of water to the extent of 2500 lps from Adit-III was observed. Considering the magnitude and trend of the leakage, the powerhouse was shutdown for taking up detailed remedial measures which included extensive drilling and cement grouting of weak and fragmented sandstone surrounding the surge shaft and part of head race tunnel. The problem of leakage and its rectification with necessary geological backdrop has been briefly discussed in the paper.

Introduction

The Project is situated approximately 600 km away from Guwahati, the Gateway of North East India. It has been developed with the creation of a pondage by constructing a concrete gravity dam along Ranganadi River near Yazali and the pondage so created is diverted to a surface powerhouse and the tailwaters flow into Dikrong River. The project comprises of a 67 m high concrete gravity dam having an effective storage capacity of 5.70 Mcum, 10.27 km long and 6.80 m dia head race tunnel (HRT) and a surface power house with 3 units of 135 MW each operating under a design head of 300 m (Fig.1). Design annual generation of energy is 1,509 MU in 90% dependable year. Both Ranganadi and Dikrong Rivers are tributaries of Brahmaputra.

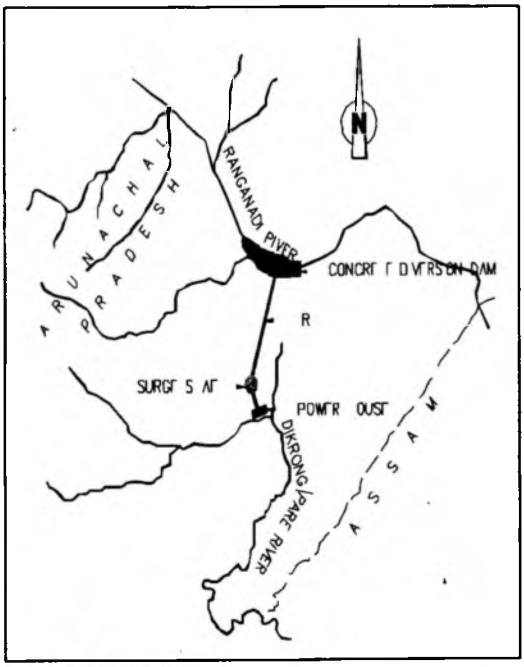

Fig. 1. Project Layout

*Geological Seuvey of India

Geology of the project area

The project area is occupied by mica schist and granite gneiss of Precambrian age, sandstone, carbonaceous shale and meta-volcanics of Gondwana Group and soft friable sandstone with bands of clay, shale and streaks of coal belonging to Upper Siwaliks. Thrusted over is the Bomdila Group (Gondowana) of rocks represented by carbonaceous shale, sandstone and slaty shales with coal bands. Siwalik Group is separated from Bichom Group by Main Boundary Fault. All the contacts viz., Bomdila-Bichom, Bichom-Siwalik are tectonic in nature and they trend NE-SW in general with steep to sub-vertical dips. Faults in the area in general are parallel to general trend of the foliation/bedding of rocks. Faults are manifested by slickensides, gougy material, brecciation, slip planes and minor displacements along joints. Geological section along head race tunnel is shown in Fig.2.

Problem of leakage

Water leakage around Adit-II and Adit-III of Water Conductor System (Fig.3) of the Project had been a constant source of problem for the project since its commissioning in 2001. Earlier, the leakage was observed in Adit-II with maximum quantity of 800 lps. Treatment was carried out twice; once in the year 2001-02 and again in 2003-04. It was successfully tackled with cement/ epoxy grouting of the contact between steel liner and concrete lining, cracks in rock and around the plug.

In January 2002, minor leakage was noticed in Adit – III which subsequently increased to 160 lps in January 2004. Treatment to plug the leakage was carried out in 2003-04 with limited success. It got reduced to 87 lps. This leakage gradually increased to 500 lps in August 2006. After a quantum jump, the leakage reached 2500 lps in October 20 06 with silt content. It was apprehended that the leakage may increase further, as seen from

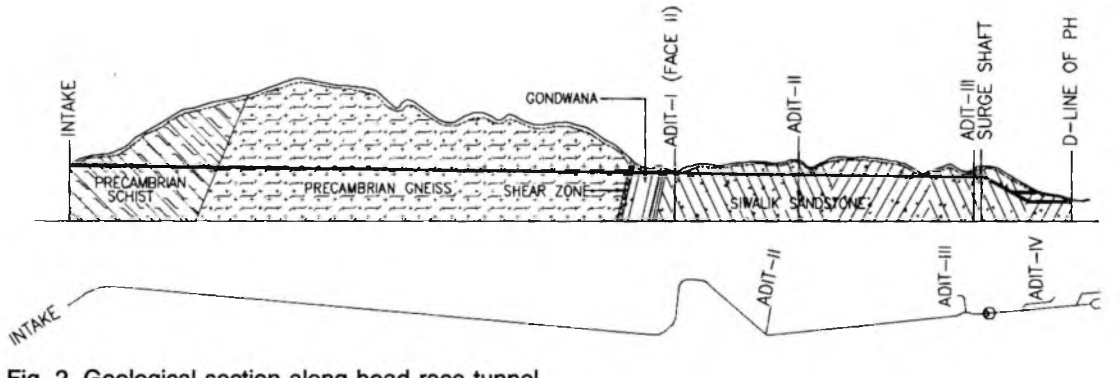

Fig. 2. Geological section along head race tunnel

Surge shaft and HRT were excavated through fresh, grey, medium grained soft and friable sandstone. The rock is mostly under the cover of 1 to 2 m thick overburden. Due to the Himalayan building activity, the Siwalik sediments are overridden by the Gondwana rocks along the Main Boundary Fault and got intensely folded and faulted. Series of plunging anticlines and synclines are, therefore, commonly seen in the area.

the trend and cause serious damage to head race tunnel and thus, a shutdown of generating units was taken and depletion of tunnel started on 8th November 2006.

Assessment of problem

Head race tunnel and surge shaft were inspected from inside by Dr. B. K. Mittal, Former Chairman, CWC and Shri B. M. Hukku, Former Senior Dy. Director General, GSI on 17th November 2006 and again from 22nd to 26th December 2006.

During inspection, a cavity was noticed downstream of surge shaft base slab just before the kink in penstock/pressure shaft. The circumferential joint in steel liner was found to be opened up. Some voids were detected behind concrete lining. Presence of a network of seepage paths in soft sandstone around the periphery of surge shaft was apprehended. Major source of leakage was identified as the deep cavity formed downstream of surge shaft base slab. The cavity was suspected to be connected to the left wall of Adit-III through permeable bedding plane or joints which transmitted the water from Water Conductor System.

Another source could be the lift joints in lining of surge shaft. Concrete lining to surge shaft was provided from top to bottom. This could have caused formation of lift joints all along the lining which gradually opened up over the time and became a major entry point for leakage water. The Siwalik sandstone is loosely compacted and friable and gets disintegrated with water. So, seepage paths can be easily formed due to carrying away of sand grains by water.

Permeability of the lining and surrounding rock mass strongly influence the stress on concrete linings of pressure tunnels and shafts. Concrete lining is always somewhat permeable due to the presence of voids and shrinkage cracks in the concrete and construction joints, etc. In this context, the relative permeability between the lining and the rock requires to be duly considered. Moreover, if the rock around the tunnel is disturbed and loosened by the excavation process, the full external water pressure effectively acts on the lining and to prevent this consolidation grouting of rock mass is essential. It was understood that the rock mass surrounding the surge shaft and HRT became highly permeable with time causing more external water pressure on the PCC lining resulting in the formation of cavity and other cracks in it.

Remedial measures undertaken

Based on recommendations of the experts and drawings/sketches furnished by Design & Engineering Wing, the Project Authorities carried out remedial measures in HRT and surge shaft as discussed below.

Curtain grouting around surge shaft

Three rings grout curtains with depths varying from 60 m to 105 m were placed around periphery of surge shaft at a pressure of 2 kg/cm^2 (Fig.3). The spacing of holes was 4.5 m to 6.0 m and grouting was done in 5 m stages by ascending order. There was a wide range of grout intake as shown in Table 1. Total number of holes drilled for grouting purpose was 63 and the cumulative depth drilled was 6,045 m and the total quantity of cement injected was 19,250 bags. The inner ring was initially placed followed by the outer ring. The middle ring was placed at the end and average grout intake per running meter was comparatively less in this ring.

Table 1: Data on grouting of surge shaft

Grout Row	No. of Holes	Drilled depth in m	Grout Intake
1st Row (Inner)	16	1505	11500 bags
2nd Row (Middle)	21	2060	2250 bags
3rd Row (Outer)	26	2480	5500 bags

Table 2: Data on grouting at HRT-Adit III junction

Grout Ring	Location	Drilled depth in m	Grout Intake
U/S Ring No.1	1.5 m u/s from Adit-III steel liner	60.0 m	15 bags
U/S Ring No.2	3.5 m u/s from Adit-III steel liner	60.0 m	11 bags
D/S Ring No.1	1.5 m d/s from Adit-III steel liner	79.0 m	157 bags
D/S Ring No.2	3.5 m d/s from Adit-III steel liner	67.5 m	2350 bags
Total		266.5 m	2533 bags

Curtain grouting at HRT -Adit-III junction

Adit-III and surge shaft meet the head race tunnel at RD 9145 m and RD 9207 m respectively. Between RD 9025.00 m and RD 9193.13 m, i.e. on both upstream and downstream sides of Adit-III junction, steel liner has been provided to HRT due to low vertical cover. From RD 9193.13 m to RD 9200.63 m, it is a 7.50 m long concrete lined upstream transition zone. Between RD 9200.63 m and RD 9216.13 m, surge shaft base slab is located. Between RD 9216.63 m and RD 9224.13 m, a 7.50 m long concrete lined downstream transition (downstream of surge shaft) is present and steel lined pressure shaft (penstock) starts immediately after this transition. Four rings of grout curtains with 6 holes of 10.0 m depth each per ring, upstream and downstream of Adit-III steel liner to seal off probable seepage paths were placed. Table 2 presents the data on grouting.

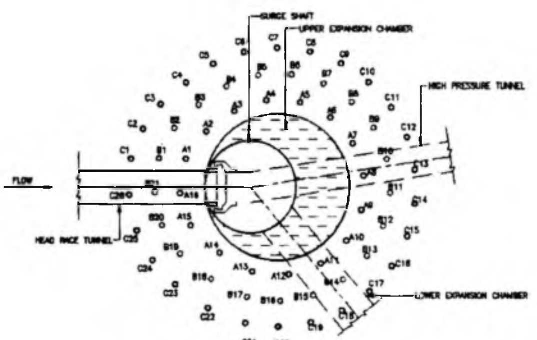

Fig. 3. Grout hole pattern for surge shaft

Grout intake per hole was not significant except in hole no.. 3 & 4 in downstream Ring no. 2 which consumed 478 bags & 1858 bags respectively.

Curtain grouting downstream of surge shaft

Two rings of grout curtains with 6 holes of 15.0 m average depth per ring were placed between surge shaft and kink of pressure shaft . Table 3 presents the grouting data.

Table 3 : Data on grouting downstream of surge shaft

Ring No.	Location	Depth drilled in m	Grout intake
Ring No. 1	1.5 m u/s from Penstock kink	93.5 m	176 bags
Ring No. 2	3.5 m u/s from Penstock kink	80.0 m	51 bags
Total		173.5 m	227 bags

Grouting at base slab of surge shaft

The suspected voids beneath the base slab of surge shaft were filled up with cement grout. Total number of holes drilled for grouting under the slab was 17 to a total depth of about 110 meters and 750 bags of cement was injected. Out of these holes, Hole-B1 of 9.5 m (inclined) located at left d/s side of surge shaft alone consumed 661 bags of cement.

Grouting above Orifice slab level

During grouting of Hole No.4, at Ring No. 2 located d/s of Adit-III steel liner, grout flow was observed from wall of surge shaft at 40 cm (approx.) above orifice base slab level upstream of gate groove. Orifice base slab was inspected immediately and a circumferential crack of 6 m (approx.) length with opening of 5.0 to 7.0 cm was observed on downstream wall of surge shaft at 1st lift joint from bottom of orifice slab. It was decided to drill and grout as much as possible from orifice level. Accordingly, 19 short holes were drilled on surge shaft wall from El. 504.0 m (orifice level) to El. 510.0 m and about 600 bags of cement was consumed by these holes.

Work could not be advanced beyond El. 510.0 m due to difficulty in erecting the stage. Moreover, grout intake was negligible.

Concreting of surge shaft base slab

While breaking & clearing the damaged portion of concrete of the base slab, a cavity filled up with water was found just upstream of Penstock on right hand side. It was found to be clean and well developed and found to be extending obliquely by 30° to 55° to tunnel alignment towards upstream side/adit-III side. Height of cavity was 2.85 m at base and it gradually decreased to 0.30 m at a distance of 5.0 m. The seepage water from different directions accumulated in the cavity. Eight no. of 25 mm dia and 4 m - 5 m long TS anchors were placed in the cavity and filled up with M25 grade concrete. Needle vibrators were used to maximize the flow of concrete into the recesses inside the cavity. Seepage water was channelised by using flexible pipes to a makeshift sump of plastic bucket which was emptied from time to time by pumping. With the progress of concreting, the bucket was progressively raised and finally the outlets of the flexible pipes were kept outside the concreted area.

Concreting at surge shaft base slab had to be planned for execution in two phases to avoid interruption with overall restoration work as part of the slab beneath the orifice was the only platform for transportation of construction material from surge shaft to the tunnel. During the first phase, base slab downstream of orifice was taken up by putting up temporary barrier. Another 7 no.. of 25 mm dia and 4 m long TS anchors were placed in the slab upstream of cavity before placing M25 A20 silica fume concrete. Fabricated steel shutters were used on both the sides of the transition. The top level of the newly laid concrete was fixed in such a way so that the minimum thickness is 100 mm.

In the second phase, concreting of the remaining area of the base slab was taken up and completed.

Water Permeability Test (WPT)

After carrying out drilling & grouting in curtain rings and base of surge shaft slab, Water Permeability Tests were carried out. Table 4 presents the details of the tests and corresponding results.

Due to higher value of Lugeon obtained at Hole No. 3 of Ring-1 located downstream of Adit-III steel liner, grouting with 53 bags of cement was done in the hole. A new hole for 10 m depth was drilled adjacent to Hole No.3 and WPT was done again and Lugeon value obtained was less than 1 which indicated excellent grout efficacy.

Pre-grouting and post-grouting Water Permeability Tests were carried out extensively around the periphery of surge shaft. Pre-grouting tests were carried out in all the holes and result varied from 3 Lugeon to full water loss which indicated very high permeability of the rock mass in most of the cases. About 70 no. of post-grouting permeability tests was carried out around surge shaft and the maximum Lugeon value obtained was 2.50. It shows drastic reduction in permeability of the rock mass after grouting.

Table 4: Statistics on Water Permeability Test carried out at site

Hole No.	Location	Permeability in Lugeon
4	Curtain Ring-1 u/s of Penstock	5.41
5	Curtain Ring-2 u/s of Penstock	0.50
3	Curtain Ring-1 d/s of Adit-III steel liner	13.89
1	Curtain Ring-1 u/s of Penstock	1.57
3	Curtain Ring-1 u/s of Penstock	0.71
6	Curtain Ring-2 u/s of Penstock	0.06
6	Curtain Ring-1 d/s of Adit-III steel liner	0.44
-	Surge shaft base slab , 2.5 m u/s of Penstock (near E4 hole)	0.01
-	Surge shaft base slab at RHS, 2.5m u/s of Penstock	0.01

Conclusions

There is always a possibility of formation of seepage lines in Siwalik Sandstone in proximity of Main Boundary Fault similar to one discussed here. Conducting water permeability tests before and after the grouting operations, adequate consolidation grouting of rock mass, close co-ordination between geologists, design engineers and site engineers, adoption of proper construction methodology, optimisation of rock blasting with proper pattern, adoption of additional safety measures in contact zones are some of the precautionary measures suggested to avoid the post-construction complications like the one discussed in the paper. Repairing of hydro-structures during operation is very difficult because of resource constraint, lack of infrastructure at site, inaccessibility to underground structures, loss of generation, grid restriction etc. Therefore, adequate precautionary measures should be taken in planning and executing the underground hydraulic structures like tunnels, surge shafts etc. in unfavourable geological conditions.