

Strengthening of Old Excavated and Concrete lined Head Race Tunnel of Tehri Pumped Storage Plant (1000 MW)

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Abstract—The excavation of Head Race Tunnels (HRT-3 and HRT-4), along with concrete lining and intake-side plugs, was initially carried out by THDCIL during Phase-1 of the Tehri Hydro Power Project (1000 MW). The Tehri Hydropower Plant has been in commercial operation since 2006. After five years of successful generation, construction activities for the Tehri Pumped Storage Plant were initiated by the GE–HCC consortium.

Civil works were executed by Hindustan Construction Company (HCC), while GE Vernova implemented the electro-mechanical (EM) and hydro-mechanical (HM) works. To complete the water conductor system of the Pumped Storage Plant, it was essential to strengthen the previously excavated tunnels and remove the intake-side concrete plugs. These measures ensured the smooth functioning of the system and reliable integration of the pumped storage facility with the existing hydropower infrastructure.

This paper provides a brief description of strengthening works undertaken to achieve operational readiness of the Tehri Pumped Storage Plant.

Index Terms—Tehri, Pumped Storage Plant, Head Race Tunnel, Concrete Lining, Epoxy, Hydropower, First Filling, Surge Shaft.

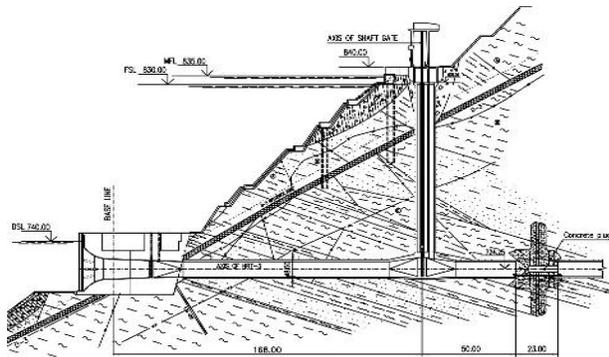
I. INTRODUCTION

The Tehri Dam Project is a prestigious hydropower cum pump storage plant project is located in the left bank of river Bhagirathi in the Bhagirathi valley in Uttarakhand in Northern India falling between 78°30' and 79°00' e longitudes and corresponding 30°30' and 33°30' n latitudes. It will be a peaking power plant located between the tehri and koteshwar dam, which is also part of tehri hydro power complex. The gross installed capacity of Tehri Dam Project including Tehri Hydro Power Project, Koteshwar and Tehri PSP is 2400MW. An underground 1000 MW (4x250 MW)

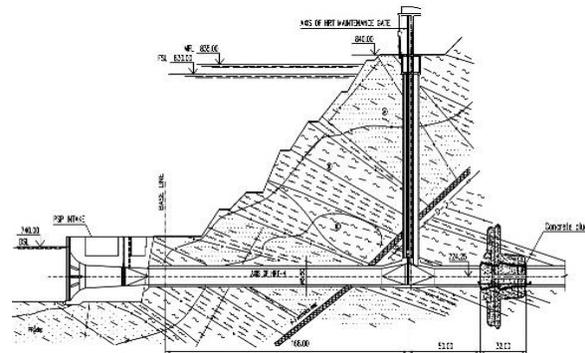
Pumped Storage Plant (PSP) is under construction parallel and close to the existing plant Hydro Power Project. During the construction of Tehri HPP, 04 Nos. HRTs were constructed as a part of the water conductor system of Tehri Hydro Complex. HRT-1&2 were dedicated for Tehri HPP, whereas HRT-3&4 were made to cater Tehri PSP. Since the construction of Tehri PSP was to be done at alter stage. i.e after the construction of Koteshwar HEP in the downstream side, therefore, HRT-3 & 4 were plugged using concrete of M30 grade. The plug remained in contact with water for a period of more than 30 years, and gained strength to the tune of 200% i.e. the concrete plug was now having strength of around M60 grade concrete. As construction of the balance portion of the water conductor system pertaining to Tehri PSP i.e penstocks, TRTs was complete, the mechanical closure of BFV valves in Unit-5,6,7&8 along with commissioning of MIV were pre-requisites for commissioning of the water conductor system, therefore, the only activity left for making the system operational was the removal of this concrete plug and repairing works in HRT 3&4. Perhaps it was the first time in history of hydro projects that a concrete plug of this magnitude was to be dismantled. This activity could be done only when an effective dewatering system is in place in the u/s side of the plug so that the plug can be removed safely. In order to ensure effective dewatering, pumps of total capacity around 15000 Ipm were deployed and so that the work can be taken up even when the reservoir level is above EL. 755 m. It was in the first week of May 24 that the reservoir level was nearing MDDL i.e. EL 740, and this was high time to carry out the dismantling of balance plug, simultaneous strengthening of PSP intakes at EL 745 m, followed by repair of lining in the plug reach as these were directly linked with the

scheduled commissioning of the project and the time slot available for this activity was only 40 days. Moreover, a permanent shutdown of Tehri HPP &

KHEP was taken from the grid to facilitate the activity. Therefore, the activity had to be completed in a stringent time frame about 40 days at any cost



L-section along HRT-3



L-section along HRT-4

OBSERVATIONS IN HRT'S: - Major findings observed during the site visit from 16th to 17th August 2021 by a team of engineers from THDCIL, HCC and SMEC.

joint locations were observed. Such heaving however does not appear to have been caused due to uplift and might have been caused due to workmanship.

a. The concrete lining of HRT 3&4 was found to be generally in good condition without any sign of structural failures. The HRT-3&4 has been subject to building up of external pressure over the last 10+ years and it has withstood vagaries of time under severe loading conditions i.e. tunnel empty with external pressures without any noticeable distress suggesting that no structural remedy is required to be carried out.

e. The pipes installed at some locations in the invert / at springing/crown indicated build-up of pressure, and on opening of the valve installed near the plug allowed release of water at substantial rate.

b. Minor Seepage was observed in localized zones with signs of calcite deposits. Such calcination is considered normal for Tunnel lining of this age. Seepage was seen to be mainly at transverse ring concrete lining joints, at horizontal construction / possible cold joints at the spring-line and at the crown. The highest seepage was observed near the plug location which is adjacent to the existing HRT-2 and is in close proximity to the built-up reservoir.

II. PROPOSED REMEDIAL MEASURES IN HRT

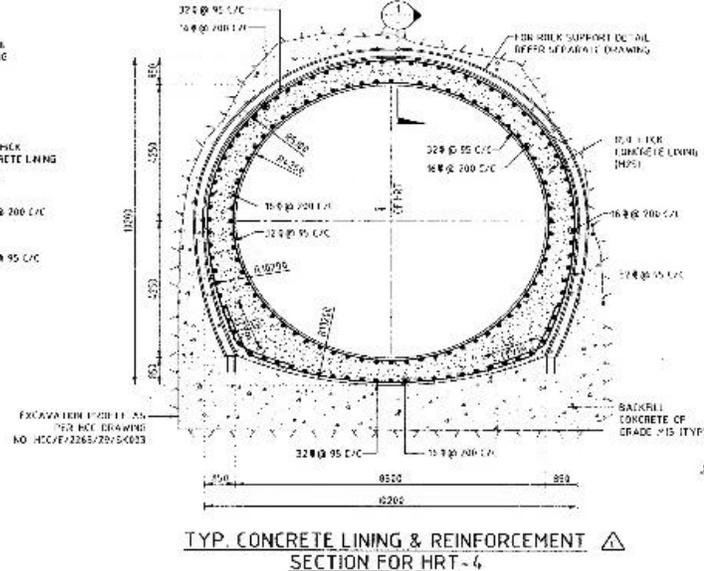
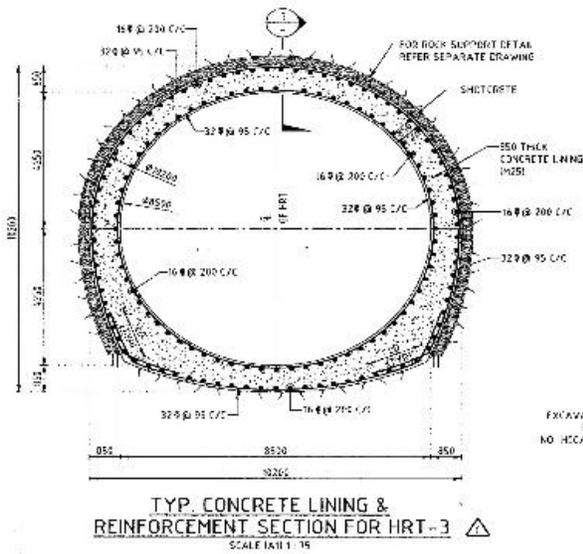
Based on the visual inspections, our assessment / recommendations for rectification works in HRT 3 as well as for HRT 4 are as proposed below: -

c. The concrete lining thickness, as informed, was around 700-900mm and there was reportedly no reinforcement provided. The tunnel concrete lining opened up at the junction of pilot shaft for U/s surge shaft.

1. HRT Concrete lining: - Concrete Lining of water conductor system is required to provide a smooth filling and a reduced friction factor to control head losses and to reduce the seepage losses. Design of HRT 3 & 4 lining at Upstream surge shaft for the Tehri PSP with the basic principles of structural modelling and results using STAAD.Pro. Thickness of concrete has been checked for compressive stresses due to external loads with normal / extreme internal loads and the tensile stresses due to maximum internal pressure in the lining has been checked. The circumferential reinforcement has been designed for maximum tensile and compressive stresses. After analysis the results are as follows, thickness of concrete lining is 850 mm, concrete grade is M25 and reinforcement is circular main bar 32mmØ @ 95mm c/c and distribution bar 16mmØ @ 200mm c/c. Contact (38mmØ @ 6000mm c/c) and consolidation

d. Some undulations in concrete, some damages / exposed aggregates / localized honeycombing and slight heaving in lining at circumferential concrete

(38mmØ @ 6500mm c/c) grouting have been executed at a proposed lining for controlling of seepage losses.



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e. The pipes installed at some locations in the invert / at springing/crown indicated build-up of pressure, and on opening of the valve installed near the plug allowed release of water at substantial rate. PROPOSED REMEDIAL MEASURES IN HRT: - Based on the visual inspections, our assessment / recommendations for rectification works in HRT 3 as well as for HRT 4 are as proposed below: -

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concrete lining is 850 mm, concrete grade is M25 and reinforcement is circular main bar 32mmØ @ 95mm c/c and distribution bar 16mmØ @ 200mm c/c. Contact (38mmØ @ 6000mm c/c) and consolidation (38mmØ @ 6500mm c/c) grouting have been executed at a proposed lining for controlling of seepage losses.

2. Consolidation grouting: - Grouting work has been carried out with help of following materials & equipment such as Rotary Hammer Drilling RIG, Heavy Duty Electric Compressor, Drill Bits & Spare Parts, Grouting Pump, Jack Hammers, Trolleys or any suitable equipment's etc. Firstly, drilling has been

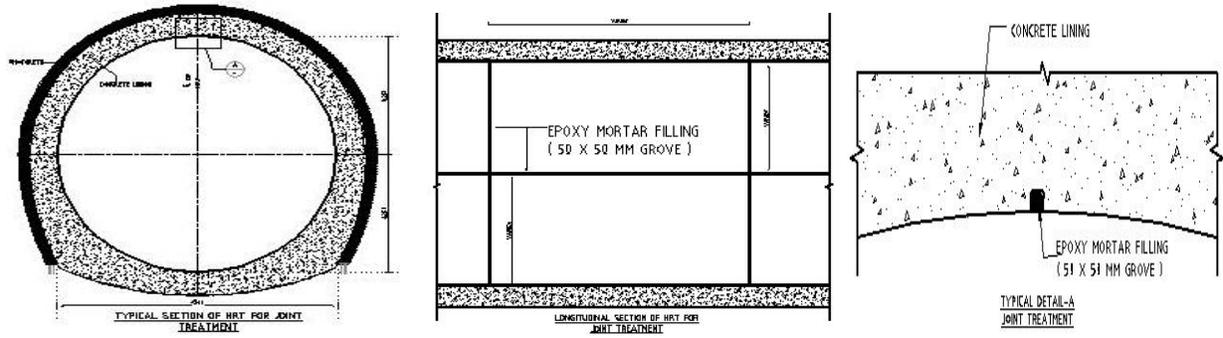
carried out to make a 750mm hole in the lining. Drilling operations have been carried out to drill hole of min. 38mm Ø and length min. 7.5m. Upward drilling has been done by using jack hammers. Before grouting work, firstly clean the hole if any drilling deposits are present and fix mechanical packers at the lining surface. The grout mix was prepared based on w/c ratio of 0.40-0.50 with required water and 50kg of ordinary Portland cement and grout additives (200gm/100kg of Cement). Grout is injected through a pipe that is installed on the top notch of mechanical packer the grouting to be continued till the grout overflows from the top of the hole consistently.



II. JOINT TREATMENT

Repair work has been carried out with help of following materials such as low-viscosity, crystallization-resistant epoxy resin based on bisphenol-A and modified with a reactive diluent-Araldite GY 257 or Equivalent, Polyamidoimidazoline adduct hardener - Aradur 140 or Equivalent Aradur 140 make it possible to formulate heat-resistant epoxy resin mortars, Low-viscosity, accelerated, aliphatic polyamine hardener which is used for construction adhesive for repair mortars and injection system-Aradur 2958 or Equivalent, Quartz Sand. & equipment such as mixing containers with stirrer, bucket, wire brushes, paint brushes/ rollers, emery paper, trowels, hammers, plumb line, tools & Tackles, pickup, trolley, hand drilling machine, hand chiselling machine, handy epoxy grouting injection pump, packers & nozzles, drill bits & chiselling tools etc. Firstly, Wire brush cleaning of surface & chip cracks & make U shape grooving of size 50 mm x 50 mm by chiselling Machine. The typical details are shown below. Apply primer coat made by combination of Araldite GY257,

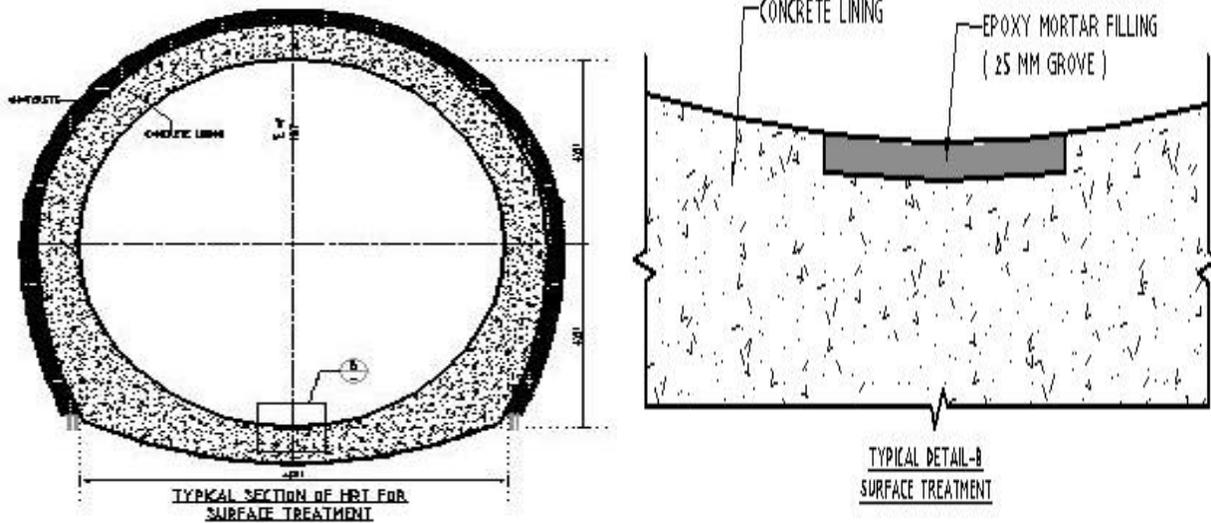
Aradur 140 & Aradur 2958, or their Equivalents, to the surface by brush/ roller. The ratio used has been such as GY 257 -> 100 PBW (Resin), Aradur 140 -> 50 PBW (Hardener), Aradur 2958 -> 10 to 15 PBW (Accelerator), Add Thinner (if required), 10-20% based on site weather conditions (PBW stands for "parts by weight"). If required to do epoxy grouting the procedure will be to make drills by drilling machine for the hole size of 14mm & depth of minimum 250mm at every 300 mm distance. Holes to drill inside the groove cut areas on the cracks. Fix packers / nozzles on the drilled holes fixed with epoxy mortar. Application of Epoxy Mortar with hand trowel & filling of total cavity or groove. Pressure Injection fill the Epoxy Mortar made of mixing in proper ration of Araldite GY257, Aradur 140 & Aradur 2958 or their Equivalents, in the nozzles/ packers by handy epoxy grouting injection pump. If mortar spilled out from the adjacent drill hole, then the grouting was stopped. Upon confirmation of prepared surface i.e epoxy mortar is in tacky conditions, apply 2 coats of seal coat prepared by mixing of Araldite GY257, Aradur 140 & Aradur 2958 or their equivalents.



IV. SURFACE TREATMENT

All the cracked surface or damaged surface were treated as per following method statement. The typical details are shown below. Repair work has been carried out with help of following materials & equipment such as mixing containers with stirrer, bucket, wire brushes, paint brushes/ rollers, emery paper, trowels, hammers, plumb line, tools & Tackles, pickup, trolley, hand drilling machine, hand chiselling machine, handy

epoxy grouting injection pump, packers & nozzles, drill bits & chiselling tools etc. Firstly, chip off the loose concrete particles, defective concrete surfaces have been removed to a depth of 25 mm where the sound concrete appears, the surface were cleaned by means of chipping, chiselling, hammering by hand tools. Surface was cleaned with a wire brush. Epoxy mortar was applied in a defined ratio to level the surface and match the alignment of existing tunnel lining.



V. PLUG PORTION REMOVAL AND REPAIR WORKS

In accordance with the contract, HRT-03 and HRT-04 were plugged with concrete during the construction of the HPP and these plug length's at site in a HRT-3 is 23m and HRT-04 is 32m. Section IV.3 CW of the Employer's requirements states that the contractor must remove the concrete plugs from the HRTs and repair the affected sections after plug removal, but only after completing the civil works related to the

HRT, surge shafts, powerhouse cavern TRT, and associated structures. Removal of these plugs is necessary for the finalisation of the water conductor system of the PSP project. Subsequent to the above and during the project review meeting held on 19-07.2022 at THDCIL's Rishikesh office, chaired by the CMD Sir of THDCIL, HCC was advised to initiate seepage control measures at the MGS gates. This is necessary because commencing HRT plug breaking works is not feasible until seepage is managed, as uncontrolled water ingress from upstream due to the high-water

pressure of Tehri Dam could impact all downstream activities. Following the Employer's instructions, pumps of various capacities were installed for the work. Owing to greater than anticipated water ingress, both the capacity and quantity of pumps were augmented accordingly. By July 2023, seepage was within permissible limits, allowing commencement of HRT plug breaking work. Following steps was used for removal and repair of concrete plug: -

I. As per the THDCIL's confirmation, HCC was permitted to begin partial dismantling of HRT plugs under specified terms and conditions due to concerns about water ingress. Firstly, plug breaking can be performed from the D/s side for a length of 8m in HRT 03 and for 10m in HRT 04. The plug should be dismantled carefully to avoid causing any damage to the U/s portion of the plug, specifically beyond 8m in HRT 03 and beyond 10m in HRT 04. If, seepage occurring near the dismantled section of the plug should be closely monitored, and any increase in seepage must be addressed through grouting.

II. Due to the challenges associated with dismantling plugs in HRT-3 and HRT-4 using Conventional methods such as rock breakers, drilling & blasting, along with project time Constraints and potential impacts on the stability of the surrounding lining, adjacent HRT gates, and intake structures, a meeting was convened at THDCIL's office on 11.07.2023. The meeting was chaired by the Director Technical and attended by representatives from THDCIL and other stakeholders. During this meeting, HCC delivered a short presentation via video conferencing, detailing the proposed process for plug dismantling in HRTs using BROKK machinery. Given its perceived advantages, the proposal was accepted by all parties and THDCIL Instructed the consortium to proceed with the work and it was informed by HCC vide its letter no. HCC/TPSP/CONT/2023/6539, dated 1st Sep 2023. However, during execution, site Conditions deviated from those outlined in the previously submitted methodology. The primary contributing factors included the actual strength of the concrete plug surpassing initial projections and persistently high dust levels at the work front, despite the presence of the ventilation system. These conditions led to inadequate ventilation, necessitating extended cooling periods for specialized equipment and personnel. Consequently, productivity declined, and the timely completion of the remaining HRT plug dismantling

operations was placed at risk. In light of the above, an extensive discussion took place during the meeting held on 9th and 10th October 2023 between HCC and THDCIL. Subsequently, CIMFR was consulted on 21st October 2023 regarding the application of drilling and blasting methods, along with specialized equipment, for the remaining HRTs plug dismantling. In accordance with CIMFR's recommendations, a revised blasting pattern was designed and communicated to THDCIL via HCC letter no. HCC/TPSP/CONT/2023/ 6630, dated 2nd November 2023. Following this, a detailed methodology for further execution of the plug dismantling works was submitted through HCC letter no. HCC/TPSP/CONT/2023/ 6675, dated 15th December 2023.

I. Drilling and Blasting methods for dismantling of plug are as follows: - In a HRT plug details such as HRT-3 consisting of 16 m gallery portion and 7 m solid plug and HRT-4 consisting of 24 m gallery portion and 8 m solid plug as per the attached drawings.

a. Plug dismantling for gallery portion

- The plug breaking shall be carried out using Drill and Blast method as per the attached blasting pattern.
- The necessary pre-requisites such as water supply, electric supply, and installation of ventilation system, electric compressor, jack hammers, lighting and illumination shall be arranged before start of plug dismantling in HRT-3/4.
- Drilling and blasting will be started from the gallery from d/s towards u/s side.
- Initially holes of depth 1.20m and 32mm dia. will be drilled from u/s side. Controlled blasting will be done.
- Dummy holes will be drilled in 1 row at 150 mm c/c spacing, 76mm dia. and hole depth for 3m length.
- Holes will not be drilled 30 cm peripheral area of plug. Dummy holes will be drilled keeping 30 cm length adjacent to periphery of plug.
- Initially excavation of heading will be done then afterwards Benching will be carried out.
- Blasted muck will be removed using bobcat loader.
- The bigger size concrete pieces will be broken using BROKK 500 D equipment.

- Second round of holes of depth 1.20m and 32mm dia. will be drilled at same location towards periphery and controlled blast will be done.
- Drilling pattern for dismantling of plug above invert of plug as discussed with CIMFR.
- After completion of dismantling of plug above invert of gallery, bench area dismantling will be carried out.
- Drilling pattern for dismantling of plug below invert of plug as discussed with CIMFR is given in attached drawings.
- The 30 cm peripheral area plug dismantling will be carried out using grinding.
- The blasted muck will be transported using small tractor from plug location and will be dumped to Us SS 3/4 bottom. Using JCB machine dumped muck will be loaded to bucket and will be lifted from upstream surge shaft bottom up to top. Bucket will be lifted using gantry and bucket will be unloaded at surge shaft top chamber and then after bucket will be lowered down to bottom. Blast muck will be taken to Koti dumping yard by hyva / tipper.

b. Plug dismantling for solid plug portion for HRT 3 / 4P:-

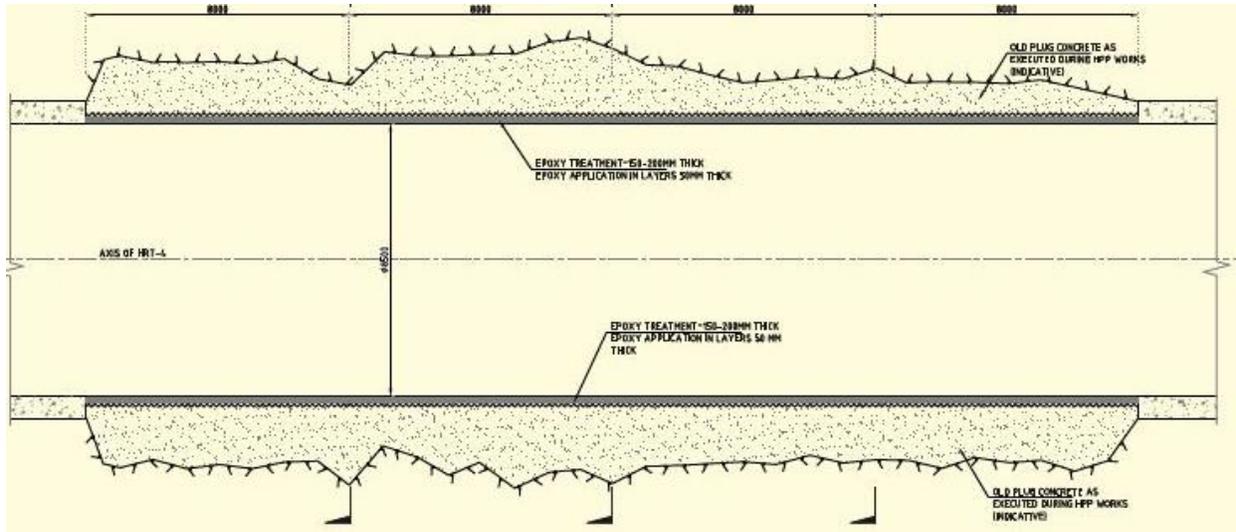
- This portion of plug dismantling shall be taken up after the mechanical locking BFV's for units and commissioning of the MIV's.
- The water level at upstream end of plug (towards MGS) shall go down up to HRT invert.
- Staging will be erected for drilling and light charged blasts will be taken. Blast pattern will be same as gallery portion except set of five reamer holes of 76mm dia. Spacing – 200 mm c/c and Hole depth of 3.0m.
- Initially heading excavation will be done and then afterwards benching will be carried out.

- Bigger size concrete segments shall be broken using BROKK 500 D equipment.
- Mucking will be done in same fashion as done for gallery portion.

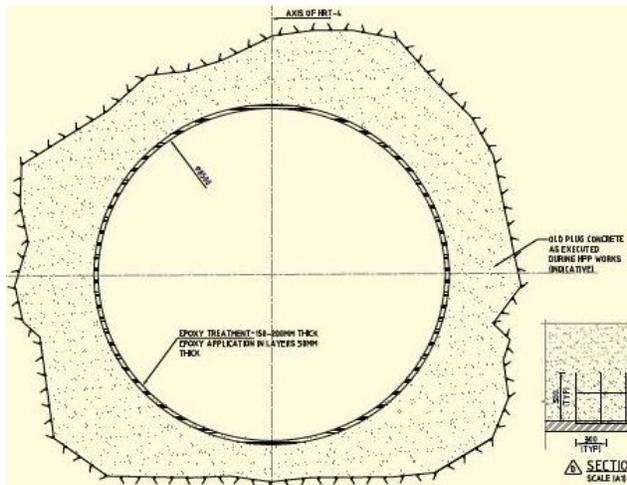
II. After successful completion of plug removal work in HRT, the HRT surface was to be repaired with epoxy mortar as per approved drawings (refer attached drawings). The Epoxy mortar is a solvent free low viscosity. Is has high compressive and tensile strengths. It does not require a bonding layer under normal substrate condition and is directly poured / plastered onto the prepared substrate or rust-free steel surface.

Before applying the epoxy mortar, the HRT surface was prepared with a suitable Hilti or equivalent grinder. Grinding of 30 cm plug concrete in the peripheral area and clean & drying the concrete surface. The Epoxy Mortar may be applied as plaster directly on the substrate of the concrete layers. If, the desired thickness is more than the 50 mm, then it may be applied in layers after 8-10 hours of curing of every layer. In case of desired thickness more than 50 mm, Epoxy mortar should be applied with smooth & adhesion free shuttering. After cleaning the surface, firstly applied the primer (Aradaur 450 / Aradur 140) and thereafter application of epoxy mortar (Araldite 257, Aradaur 140 & Quartz sand). After applying epoxy lining to the HRT, all the equipment and accessories were removed from the site and proper cleaning was done of the HRT before starting the water conductor system. The mixing ratio of Epoxy shall be as per manufacturer recommendation and site conditions. As per site conditions, the mixing ratio of chemical shall be as followed:

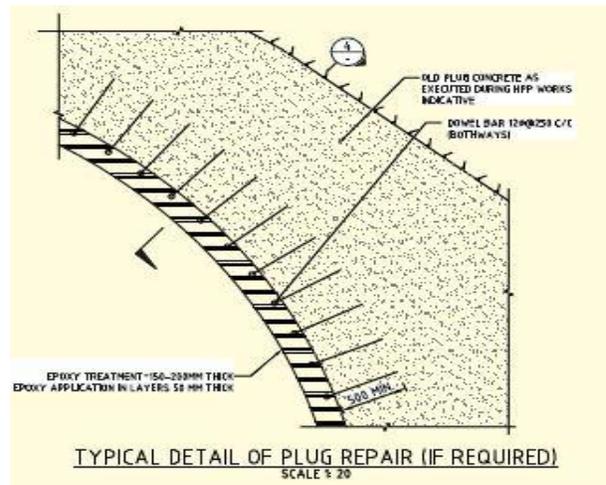
Sr. no.	Details of Product	Mixing ratio for HRT	
1.	Araldite GY 257	100 parts by weight	2 Kg
2.	Aradur 140	50 parts by weight	1 Kg
3.	Aradur 2958	3% of Araldite GY 257	0.060 Kg
4.	Quartz Sand	350 part by weight	7 Kg



Plan of HRT plug portion



Section of HRT plug portion



Repair details of HRT plug portion

VI. CONCLUSION

The work involved various constraints and hazards, like, the safety of adjoining structures was of paramount importance, the accessibility of the site was difficult, the application of material emitted heat and gases which were hazardous, the safety of manpower was also a challenge. In spite of all the odds the work was completed within the specified time limit without hampering the commissioning schedule. Therefore, this work is an example of engineering grit, determination of mankind and dedication of Engineers towards nation building.

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- [2] Completion report of HRT repairing works tehri PSP project, Unpublished report.