

Stabilization of a collapsed rock mass and installation of 100 tons permanent strand anchors at the Punatsangchhu-II Hydroelectric Project, Bhutan

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Abstract

The Punatsangchhu-II Hydroelectric project (1,020 MW), on the Punatsangchhu river is spread along the Wangdue –Tsirang National Highway in Bhutan in the central Himalayan region, about 80 km east of Bhutan's capital Thimphu. The project includes a complex system of rock tunnels and caverns. The powerhouse complex has been excavated within rocks of the Thimphu Gneissic complex comprising mainly quartz-feldspathic gneiss, biotite micaceous quartzite with leucogranite and pegmatite patches and veins. In March 2016, a huge rock mass collapse occurred in the already excavated downstream surge chamber (DSC) because of an active shear zone. The total volume of muck generated in the collapse was estimated to be approximately 100,000cum. The designer required the muck fallen into the cavern to be improved to low grade concrete of M10 strength to install 100 T capacity Cable Anchors supporting slender RCC walls. BAUER was entrusted the job as a specialist sub-contractor. The job involves nearly 19,960m of drilling and systematic grouting followed by 19,900m of permanent tieback strands anchors with working load up to 1,000KN each. Along with various equipment for the injection works, up to five new drilling rigs have been mobilized from Europe for this work. The engineering challenges of this project was further compounded due to the cramped working environment and the difficulties related to drilling. With a width of approximately 18m and a height of 8m, the work area is extremely small, creating a challenging environment for equipment and personnel, while overcoming the technical challenges. The paper describes the drilling, grouting and anchors solutions adopted and the unique and unprecedented geotechnical challenges of this project.

Keywords: Cable Anchors, Grouting, Drilling, cavern, stabilization.

1. Introduction

The Punatsangchhu Hydroelectric Project Authority (PHPA) of Bhutan is implementing two mega power plants with an installed capacity of 1,200MW and 1,020MW respectively (Fig.1). Both the projects spread over a distance between 20Km and 35Km downstream of Wang- due Bridge along Wangdue-Tsirang National Highway in Wangdue Phodrang Dzongkhag of Bhutan and it is approximately 115Km east of Thimphu, the capital of the Royal Kingdom of Bhutan. Both projects are undertaken by the Royal Government of Bhutan (RGoB) and Government of India (GoI) for the mutual benefit of both the countries. Punatsangchhu-II Hydroelectric Project (PHEP-II) envisages the construction of one concrete gravity dam (CGD) across the Punatsangchhu river, and an underground power- house complex (PHC) and a complex of three major caverns. One major roof rock fall incidence took place on 3rd March 2016 in the downstream surge chamber (DSC). The total quantity of collapsed muck who entered the partially excavated cavern was assessed to be around 65,000m³, approx. 35,000m³ of collapsed muck lay above the cavern. An empty cavity, with a volume of approx. 45,000m³ is laying above the collapsed rock mass. The bouldery muck fill completely covered the complete 50m high cavern. It was necessary to determine the cavity's extent, dimension, volume and orientation to design suitable remedial measures. Hence, the project management explored different options to decipher the cavity dimensions by application of surveying, geophysical techniques, cavity monitoring system, exploratory drill holes and other feasible methods.

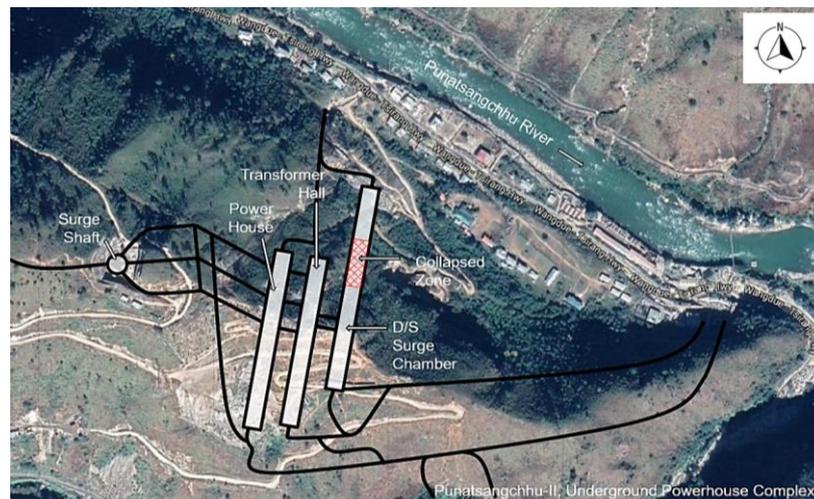


Fig. 1. General layout of Punatsangchhu-II Hydroelectric Project, Bhutan

Geology

Regionally, PHEP-II area is located within a part of the Tethyan belt of Bhutan Himalayas, which lies north of main central thrust. The rocks of Sure and Chekha Formations of the Thimphu Group of Precambrian age are exposed in this region. Different rock variants were encountered in the DSC including quartzo-feldspathic-biotite gneiss, biotite gneiss, biotite schist, micaceous quartzite, leucogranite and pegmatite. Generally, the foliation has gentle dip, ranging between 5° and 25° directed between N190° and E240°, Figure 2 shows a 3D projection of the shear zone crossing the DSC cavern.

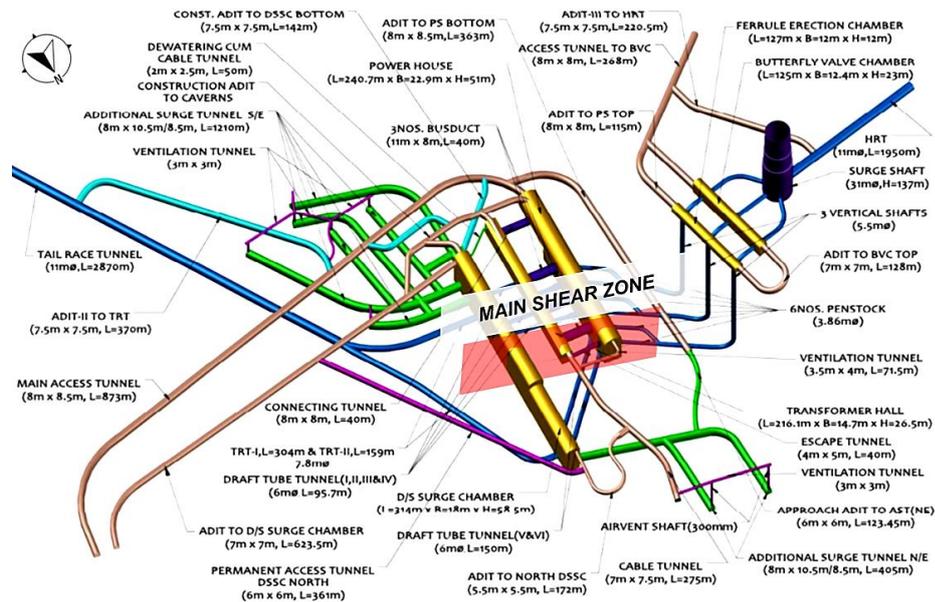


Fig. 2. Power House complex and approximate location of shear zone

2. Geotechnical Assessment of the downstream surge chamber, DSC

The excavated surface of the downstream as well up- stream wall indicated a highly deformed rock mass. During excavation of the DSC cavern, several geotechnical problems were faced, like the occurrence of a major shear zone, the presence of low dipping foliation joints posing slabbing conditions in the crown portion, erratic occurrence of intrusive bodies of variable dimensions, minor shearing along foliation joints and other joints at few locations. Besides presence of water seepage, dripping along the shear zone and ingress of water on the down- stream wall at EL 599m.

3. Rock Mass Failure Mechanism and cavity Formation

Excavation in DSC started in the month of March 2013. As published in the Journal of Geotechnical Research (Vol. 01, Issue 01, 2019), on 3rd March, 2016, a first major rock fall occurred in DSC with intermittent loose falls, followed by two major falls on 11th and 22nd March, 2016. The condition of the cavern with muck flown from the crown blocking the approach towards northern end after different major falls are shown in Figures 3 and 4. The

Figure 5 shows a picture of the collapsed material taken inside the DSC in 2016 March 22. The failure of the rock mass initiated from the crown of DSC between along the major shear zone extending on either wall dipping towards face. The rock mass gave up within a very short span at an odd hour, around 1 AM on 3rd March, 2016.

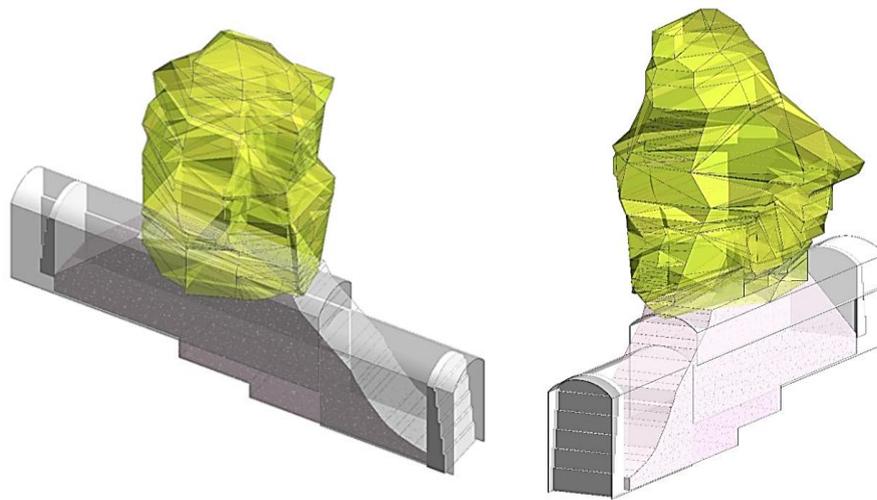


Fig. 3. Approx. shape of the cavity above the DSC and fallen muck inside the cavern

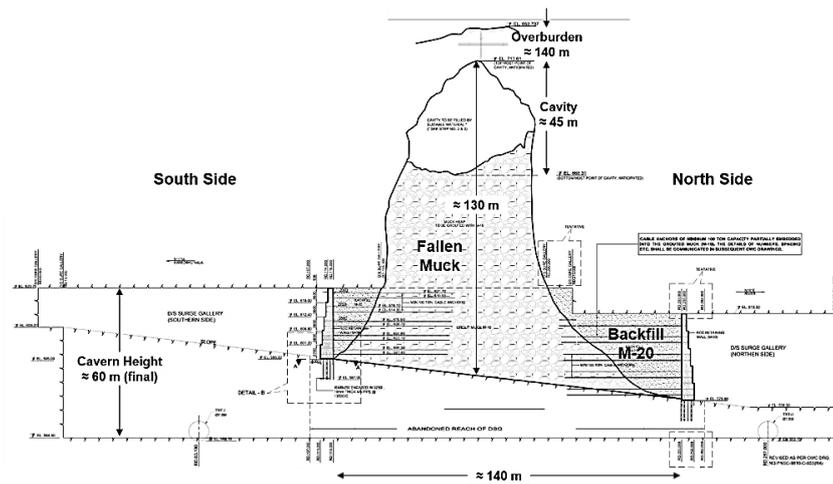


Fig. 4. Longitudinal section (tender stage drawing) of the surge chamber with the cavity

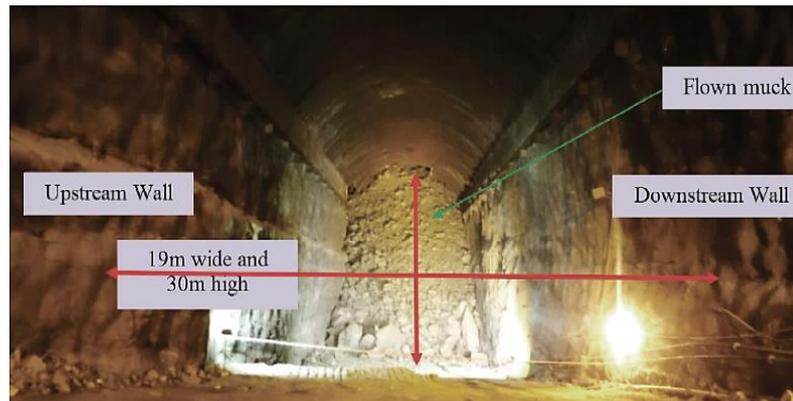


Fig. 5. Flow of muck inside the DSC on 11/03/2016 north side

4.1 Characterization of the fallen rock

The failed rock mass comprised of fragmented rock pieces of varied sizes, sandy clay and dry clay fractions with big rock blocks (max. size ~9.0m x 1.5m x 3.0m). The shapes and size of the fallen boulders clearly indicated that failure of rock mass was not limited to shear zone alone but extended much beyond. The disintegrated blocks expanded its volume after disintegration and filled the cavern. These blocks which were flown into the cavern led to the development of cavity above the muck. Since then, there was sufficient time lag in treatment of the cavity which further gave rise to the lateral and longitudinal expansion of the cavity due to the presence of sub-horizontal strata traversed by different joint sets forming potential structural wedges.

4.2 Cavity Delineation and its extents

Initially, cavity size and its direction or extension were unknown. Attempts have been made to assess the extension and dimension of the cavity above crown and it seemed that the extension of the cavity towards down- stream wall is greater than towards upstream wall and receding backward due to inclination of shear zone. In order to treat the cavity and proceed with further excavation works in major caverns, it was crucial to determine the dimensions of the cavity. This was not a simple job. There were inherent complexities in determining the actual extents and dimensions of the cavity, viz. steep and unfavorable topography, inaccessibility to the northern end of DSC, 240m – 280m of overburden, risk to person and equipment involved in exploration. However, several options to deal with the cavity were explored and the following methods were taken up. The final option was chosen by the owner, together with his designers and consultants.

4.3 Cavity exploratory Drilling

Attempts were made to drill NX sized boreholes from the surface at apt locations intending to daylight into the cavity so that at least point data information can be obtained which could provide the coordinates of the apex of the cavity above DSC crown. Three holes punctured into the cavity indicating the cavity apex at an elevation of 694.5 m, 153m above the roof of the DSC. This provided some insight into the height of the cavity, but this approach too could not help in determining the complete extents of the cavity. The Figures 3 and 4 show the shape and dimensions of the cavity.

5 Design of the intervention for the treatment and stabilization of the fallen rock muck

Reinforced concrete wall were constructed after the collapse, simultaneously with the backfill of the caverns. The partial backfill of the tunnels outside the collapse area was required to stabilize the two separate cavern sections and to facilitate the drilling and grouting works (Fig. 6) . The designer required the fallen rock debris between the walls to be improved by means of a cement-based injection, to create a monolithic block in between the containment walls. Finally, the boundary sidewalls were tied back with permanent anchors. Anchor scope comprises 359 permanent cable anchors of 100T capacity each. The central part of the cavern will be abandoned, and two smaller compensation chambers connect by a bypass tunnel will be created. The abandoned volume will be partly compensated via additional tunnel adits.

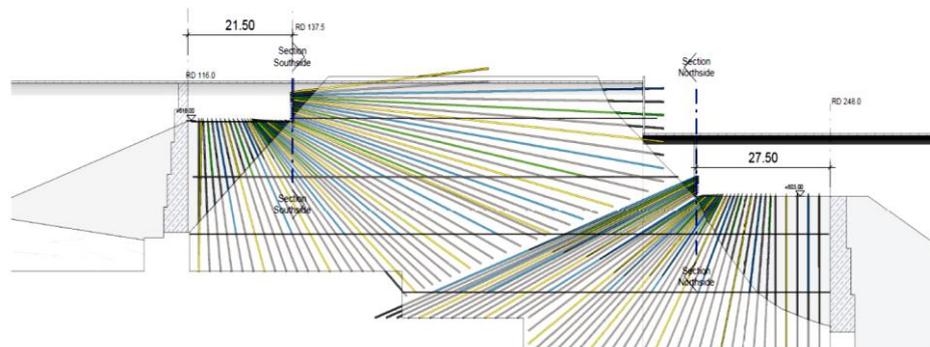


Fig. 6. Longitudinal section with fallen muck borders, containing walls and injection holes

5.1 Phase I of the works, injection of the rock mass

To allow drilling and injection works to be performed safely from both sides of the fallen muck zone, two reinforced concrete walls were constructed and both sides of the chamber backfilled. The scope was to contain the fallen mass and to create a stable and safe work platform for the consolidation grouting. The injection scope includes 524 holes with approx. 19,960 drill meters and single hole length up to 80m. The injection was conceived in two separate phases. Low pressure backfill grouting through small diameter PE hoses, staggered along the hole. The phase of the injection under pressure started only after the completion of the low pressure backfill phase. The drill and injection sequence of each phase was subdivided into primary secondary and tertiary holes, to distribute the grout homogenously inside the heterogeneous / fallen rock mass.

5.2 Hole drilling

Drilling works started in January 2020, approximately four years after the collapse of the rock mass in the DSC cavern occurred. The fallen rock mass was quite unstable, it included large blocks of hard rock, massive steel beams of the collapsed cavern roof and buried equipment and abandoned strings of drilling rods and tools. Klemm double head drilling rigs type KR 806 and KR 909 (Fig. 7) have been mobilized for this project. Drilling immediately appeared as the

major and most difficult challenge of this project.



Fig. 7. Two Klemm KR 909 rigs working in narrow space inside the cavern

5.3 Grouting Phase 1 Low pressure backfill

This injection phase was conceived as low pressure backfill of the cavities within the fallen rock mass, through a bundle of small diameter PE hoses, staggered along the hole. Injection was done using screw Mohno pumps with a closed loop circuit (Fig. 8). Grouting started from the deepest hose and proceeded upwards once grout communication with the upper hose or with the surface was detected. The backfill injection was subdivided into primary, secondary and tertiary holes (P,S,T sequence). One sequence was only started after completion of the previous one.

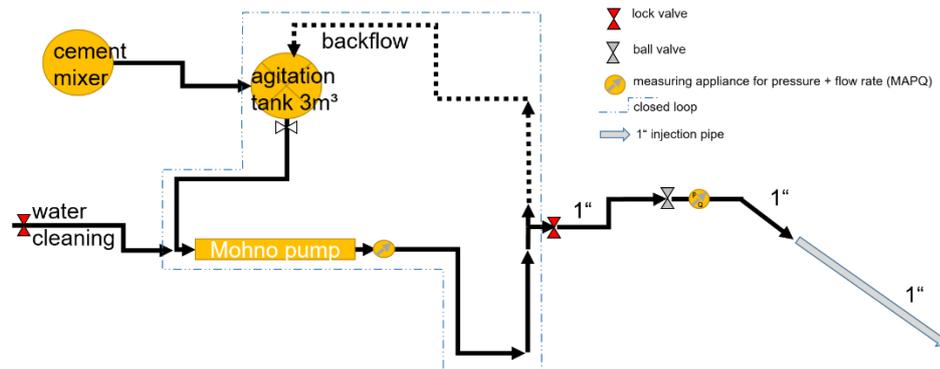


Fig. 8. Scheme of cavities backfill injection with Mohno pumps and closed loop circuit.

Fill Grouting was conceived for the backfill of large empty cavities between the fallen rock blocks and for stabilizing the rock muck, creating an initial cohesion in the collapsed mass. Against the initial expectations, the volume of grout that could be injected under low pressure reached only the amount of 4,200 m³ which represents the 6.5 % of the total rock mass fallen in the cavern, approx. 65,000 m³. The low grout take could be due to soil and mud that with time partially filled the open cavities and previous gravity grout feed campaigns by others that were abandoned.

5.4 Grouting Phase 2 Consolidation grouting under pressure through MPSP TAM pipes with fabric bags (MPSP)

Upstage grouting with double packer, through MPSP TAM pipes started after the completion of the backfill grouting campaign. Scope of this second injection phase was to reach smaller voids under higher pressure and to squeeze and thus compact the soft soil mass between the blocks of rock. Hole drilling and injection was also divided into three phases, with primary, secondary, and tertiary holes (P,S,T) with holes always drilled in between the previous ones. Also in this case, one phase only started after completion of the previous one. The TAM pipe is inserted inside the temporary casing. The casing is retrieved and a double packer is introduced inside the TAM pipe and placed in correspondence of each bag to expand it with a small volume of cement grout. Grouting with double packer can be done placing the packer in correspondence of the rubber sleeves between the bags.

5.5 Grout types

The client required a minimum UCS strength of 10 MPa after 28 days for the samples recovered from the injected rock mass. Several laboratory tests were conducted on various cement grouts, in order to establish the final mix design for the injection works. Cement mixes with a w/c ratio ranging between 0.6 and 0.8 and bentonite and retarder as admixtures, were tested. For the injection a mix with w/c ratio of 0.8, a bentonite/cement ratio of 0.014 and retarder/cement ratio of 0.007. The grout showed an apparent Marsh Viscosity of 42-43 sec over three hours and a bleeding comprised between 0.5% and 1.5%.

5.6 Quality controls during drilling and grouting

The grouting pumps were equipped with automatic recording devices from Obermann MAT GmbH (MAPQ units, PC LOG SG 4 and associated software) to record flow and pressure vs time. (P/Q recording). Grouting data were saved in a data base and thus available for different numeric and graphic elaborations.

5.7 Final quality controls on the injected rock mass, coring and WPT

The quality of the injected rock mass was checked by means of a series of inclined cored boreholes. Twelve cored holes were drilled from the north side and 20 holes from the south side. Thirty-three samples were UCS tested and the The average UCS strength was 28 MPa. Thirty-two Lugeon tests were performed in the last 10 m of the cored boreholes, the average value was 10 UL. Both UCS and Lugeon values were considered satisfactory for the client and the site was prepared for the installation of the cable anchors.

6 Permanent cable anchors

Drilling and installation of the permanent cable anchors through the two lateral containment walls has started after completion and final verification of the injection campaign. The design includes a total of 359 holes and approx.19,900 drill meters, with single hole length ranging between 35 and 70m.

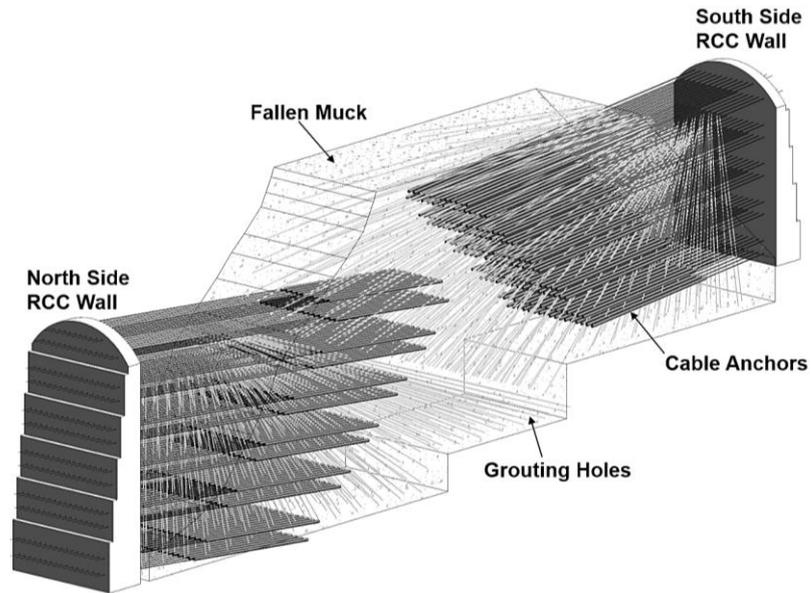


Fig. 9. 3d view showing grouting holes and permanent cable anchors



Fig. 10. Overview of cable anchor works at lower level

In parallel with the cable anchor installation, BAUER has been requested to execute the drilling of rock bolts in the cavern upstream and downstream walls (Fig. 9 & 10). In general, this rock bolts are being drilled in parallel with the cable anchor installation as benching down. Rock bolts are executed with 5° positive inclinations and 15m length.

6.1 Anchor Hole drilling

Drilling works for the anchors started in October 2020. The same drilling system as for grouting was also used for the anchors. All anchors had to be drilled passing through the two lateral containment RC walls, with a thickness ranging between 2.6 and 6.0 m. This required the execution of a series of 230mm preliminary corings with diamond barrels. Temporary cased drilling for overburden materials was adopted, using a water driven DTH hammer installed on the inner rods, using an OD 152 and ID 132 mm casing. This installation sequence as requested by the Technical Specifications of the project resulted as very onerous and time-consuming operation due to the numerous steps and phases.



Fig. 11. Anchor tensioning and hole drilling



Fig. 12. General view and details of anchor heads

6.2 Strand anchor assembly

Prefabricated strand anchors were manufactured in Germany by Spantec GmbH, shipped to Bhutan and finally assembled on site (Fig. 11 & 12).

7 Conclusions

The results of the backfill and consolidation grouting campaign were considered as satisfactory by the client. A working group committee constituted by PHPA-II, designer and BAUER was assigned to analyze all quality control results and data from the grouting campaign and confirm the effectiveness of the grouting works. From the detailed analyses based on drilling penetration rates, volumetric grout takes, estimation of void reduction, WPT and UCS tests, it was concluded that the engineering challenge to strengthen the muck by consolidation grouting to achieve the strength of M10 grade was completed successfully. Despite major restrictions caused by the COVID 19 pandemic, including a long lockdown period from August to September 2021 and associated huge difficulties to import drilling tools, shortages of cement etc., the drilling and grouting works have been completed within the contractual period. The installation and tensioning works for the permanent cable anchors were completed in April 2022.

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