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Incident of Ground Collapse up to Daylight and Recovery Actions Taken in Shallow Ranwediyawa Tunnel in Sri Lanka

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Abstract

The Ranwediyawa tunnel was constructed under the Mahaweli Water Security Program (MWSIP) to minimize the social impacts on the villages, where the irrigation canal runs through the village. The tunnel was slightly redirected from the original canal path which was planned to run through the village road having a deep excavation over a length of 620m with a mixed ground condition. The area has a high ground water table and seasonally varies slightly due to the area's weather pattern with varying topography and which has a deep open excavation from 12m to 18m for the construction of cut & cover conduit.

Having a shorter period of design the Ranwediyawa tunnel was designed with a ground cover varying from 9m to 20m, including 5 support classes according to the RMR classification. Both tunnel portals start with completely to slightly weathered rock and move into moderately weathered to fresh rock. Both tunnel drives were driven by mechanical excavation with NATM concept with few small chimney collapses, however, a major collapse occurred once the upstream drive reached the rock-type boundary and it was developed to daylight.

This paper describes the details of the initial excavation procedures, the major geological conditions and the recovery procedures which were taken to complete the tunnel excavation. Also, this paper covers special arrangements made by the Contractor in the shortage of resources available in the project as the incident occurred during the spreading of the COVID-19 period. The tunnel drive successfully passed this weak geological area with long pipe roofing support before the tunnel excavation after two months with a few days of site closure due to the identified worker getting COVID-19 in the tunnel team.

Keywords: weathering; recovery; collapse; pipe roofing; daylight

1. Introduction

The Mahaweli Water Security Investment Program, financed by the Asian Development Bank and the Government of Sri Lanka, aims to complete the Mahaweli Development Program, started in the 1970s to improve farmer incomes, food security, equity between different areas of the country, public health, and domestic, municipal, and industrial water supplies. Up to 900 million m^3 of water will be transferred annually through canals, reservoirs, and tunnels from the Mahaweli River to the water-scarce north and north-west, where smallholder farmers have traditionally practiced single-season rice cultivation. The transfer will facilitate the cultivation of a second, diversified, crop and must be shared with competing consumptive demands, as well as meeting daily peak energy demands through releases for hydropower [1].

The North-Western Province Canal Project (NWPCP) under the Mahawelli Water Security Investment Program (MWSIP) comprises one of the three components. This NWPCP component is divided into five major projects and the Ranwediyawa tunnel belongs to the

NWPCP ICB2 package which has a 17 km length canal. This package was awarded in September 2018 after completing the detailed design and the tendering procedure to China State Engineering Corporation Limited as an ICB contract.

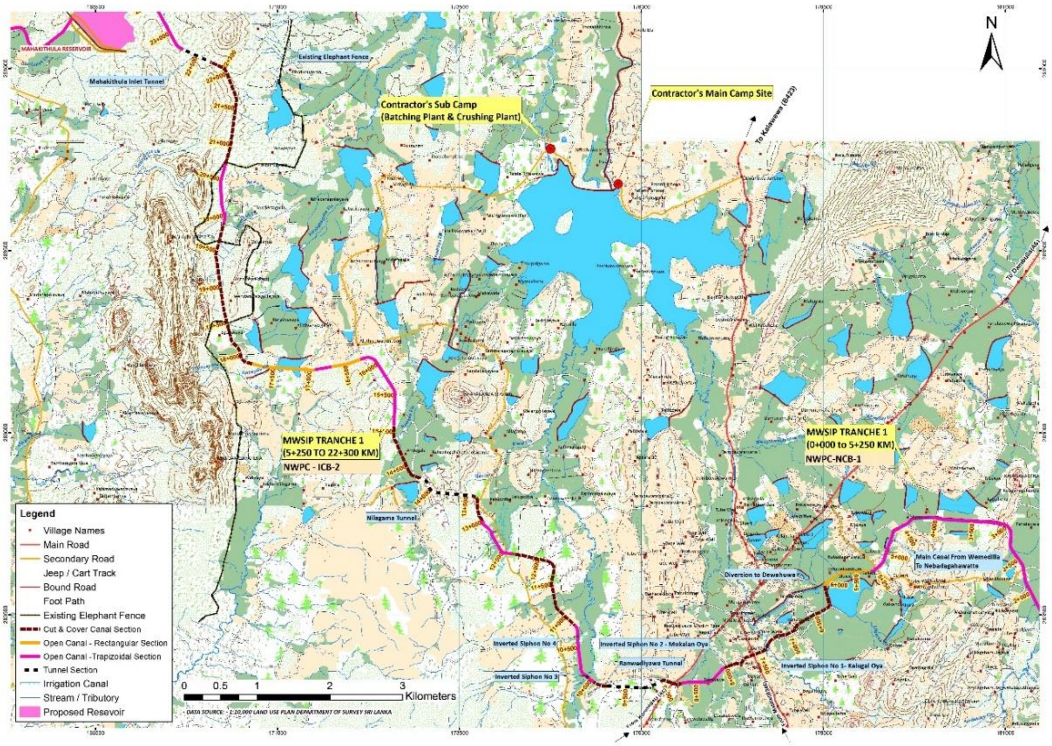

Figure 1 Project location

Construction of the Rawediyawa tunnel started with outlet portal excavation at the beginning of February 2020, followed by starting of tunnel excavation in September 2020. However, the construction of the inlet portal was delayed and started at the beginning of February 2021 various other issues, followed by the tunnel excavation starting at the end of April 2021. During the excavation of this tunnel, it was faced a few small chimneys collapsed in both drives and a daylighted chimney collapsed in June 2021, 145m inside in the outlet drive from the portal. After this, the collapsed area was passed through with an accepted tunnel recovery methodology and normal tunnel excavation resumed from this drive at the mid of September 2021. Finally, this tunnel was broken through without any chimneys in this drive on 4 March 2022.

This paper covers the details of design and predicted geology, the details of the incident of daylighted collapse, recovery methodology with altered recovery procedure based on the actual site ground reaction, and details of the geological conditions of the actual ground face during the tunnel excavation.

2. Design Details of the Ranwediyawa Tunnel

The tunnel was designed following the RMR [2] with five support classes including a portal support class that extended 10-15 m from the portal of both tunnel drives. The support classes were designed with RMR 0-30 as support class 4w, RMR 31-60 as support class 3w, RMR 61-80 as support class 2w and RMR 81-100 as support class 1w are shown in Figure 2.

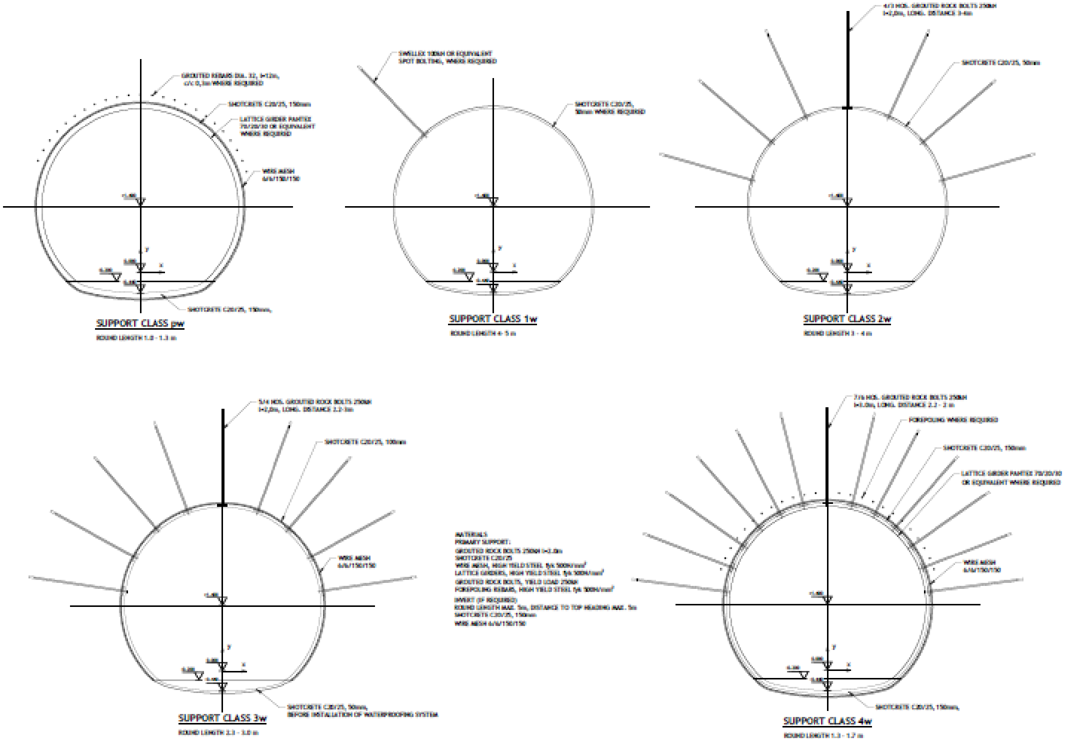

Figure 2 Design support classes

The design predicted a total length of 30 m tunnel as portal support class (each 15 m length on either side drive), a total length of tunnel 355 as the support class 4w and a balance tunnel length of 235 m as the support class 3w.

3. The Design Predicted Geology Condition of the Ranwediyawa Tunnel

The Ranwediyawa tunnel runs through a ground contained with completely and highly to moderately weathered rock at the portal for a couple of hundred meters and enters into moderately to fresh rock at the middle of the tunnel length which includes the rock types of biotite gneiss at the inlet side and Charnockite gneiss at the outlet side as shown Table 1.

Table 1 Anticipated Geology of the Ranwediyawa Tunnel in Design Stage

Chainage	Rock Type
09+060 - 09+133	*CW-HW Biotite gneiss*
09+133 - 09+513	Biotite Gneiss
09+513 - 09+543	Charnokitic Gneiss
09+543 - 09+680	*Highly to completely weathered rock*

The tunnel was designed to run an initial 10m as the portal support class (pw) and follow with support class 4w over 155 m, support class 3w for a 240m length then run into a support class 4 and portal support class (pw) with 155 m & 10 m lengths respectively. This variation in the ground is shown in Figure 3.

4. Actual Faced Geological Condition of the Ranwediyawa Tunnel

The actual geological condition faced while driving the tunnel is detailed in Table 2 and shown in Figure 4.

Table 2: Actual Geological details along the tunnel

Chainage	Rock Type
09+060 - 09+105	Highly to completely weathered rock
09+105 - 09+145	Biotite Gneiss
09+145 - 09+185	Highly to completely weathered biotite gneiss
09+185 - 09+205	Garnet Quartzo feldspathic gneiss
09+205 - 09+260	Garnet biotite gneiss
09+260 - 09+285	Highly to completely weathered rock
09+285 - 09+435	Garnet biotite gneiss
09+435 - 09+460	Garnet Quartzo feldspathic gneiss
09+460 - 09+473	Biotite Gneiss
09+473 - 09+523	Garnet biotite gneiss
09+523 - 09+531	Completely weathered sandy Pegmatite formation
09+531 - 09+678	Highly to completely weathered rock

5. Details of the Work Procedure of the Tunnel Drive and Meeting the Situation

This tunnel was driven in both directions following the design support classes as per the agreements between both the Engineer and Contractor’s geologists after a joint inspection and mapping of each tunnel face. Also, involved both parties tunnel staffs to finalize supports of each face as per actual ground condition and available resources in a timely with the Contractor.

The outlet portal upstream drive was started on 26th September 2020, with support class pw with a modification of 9 m long 50 mm dia. heavy-duty (HD) steel pipes instead of the original design of 12 m long 32 mm dia. grouted rebar, due to the hole collapsing while drilling. Then the tunnel was driven continues each round of mechanical excavation by using the excavator either top heading and benching of stage or full-face excavation and support works with a minimum of 1-1.5 m overlap of fore polling either by installation of 3 m long 25 mm rebar or 50 mm HD steel pipes. This drive was continued with a few small collapses up to 1-1.5 m depth and those were treated timely and followed support class 4w after the first 12m of portal support system. However, the fore polling pipes or rebar were not filled with enough grout in a few locations as high-water seepage through holes due to the non-availability of required equipment as was not predicted at the start of the project work. Also, it was impossible to rearrange the required equipment due to the restriction on importation in the country due to the spreading of COVID-19 around the world.

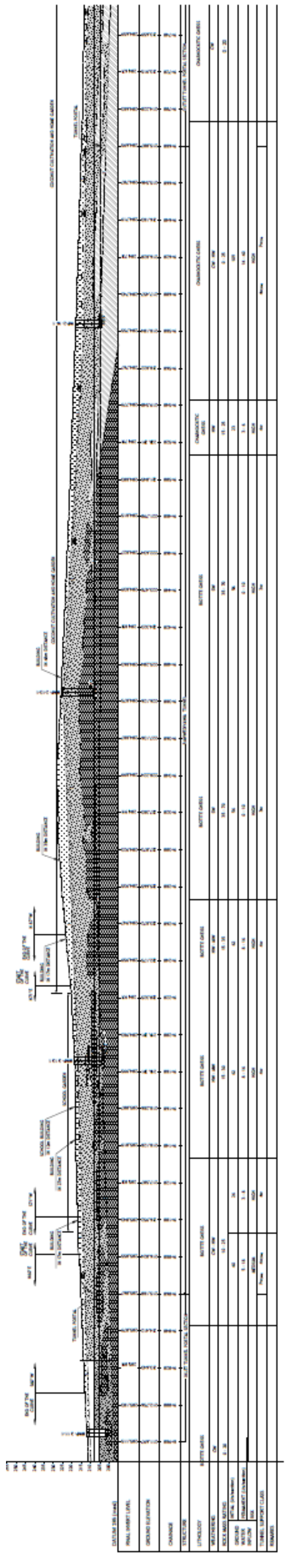

Figure 3 Predicted Geological long section of the Ranwediyawa tunnel at the design stage.

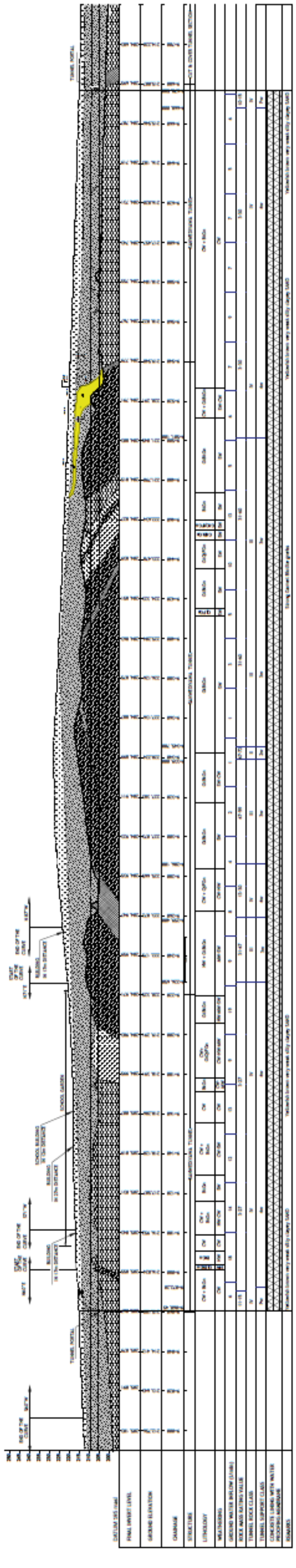

Figure 4 Actual geological as built long section of the Ranwediyawa tunnel after excavation

The tunnel drive was reached on 7th June 2021the chainage of 9+535.9 after excavation of 142.6 m length as the tunnel started at 9+678 after the portal excavation which was varied due to the initial survey error at the start of portal excavation and the weak ground at the portal too. After the completion of the previous round of support works, a set of 3.5 m pipes was installed into the ground as the fore-polling pre-excavation umbrella support for the next set of rounds of tunnel excavation. Then the second round was completed after an excavation of 1.2 m on 9th June 2021 at the end of the day shift followed by the first round of 0.7 m excavation. The tunnel started a small collapse from the tunnel face of 9+534 and an unsupported roof of about 0.4 m from the last supported lattice girder, which requires the drilling space for the fore-polling while marking the positions and cleaning. This collapse continued for some extended time and it created a huge cavity in front of the tunnel face, the fallen material was somewhat dry condition while falling however it was fully wetted after mixing with water that was coming from the last tunnel face as shown in Figure 5. At the time of this occurrence the absence of an experienced tunnel team with the Contractor at the tunnel face, it was left the tunnel to continue the collapse.

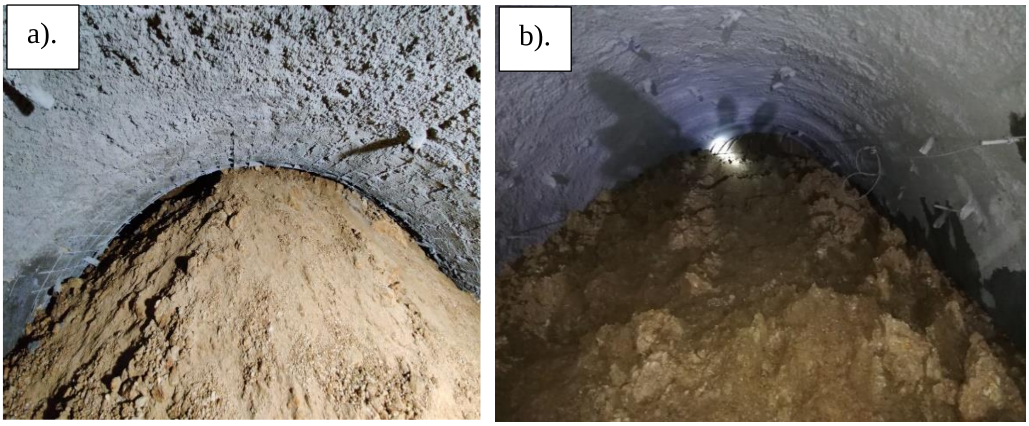

Figure 5 Ranwediyawa tunnel face collapse at 9+534, photos on a) 10 June 2021 and b)12 June 2021

After this event, the tunnel drive was slowed and the agreed working procedure was followed to continue the tunnel construction as described below subheadings.

6. Identification of the Root Cause of the Collapse Area and Size of the Cavity Formed

After the incident, the Contractor failed to propose a mitigation procedure the Engineer issued an instruction which includes the below-mentioned items to follow at the tunnel site after 12 June 2021.

1. Make a sandbag or any other suitable barrier to stop the flow of the collapsed material along the tunnel, as it was observed the collapsed material flowed along the already excavated tunnel due to increasing water.
2. Drill a few hand-arguer holes above the collapsed location to identify the size of the created cavity.
3. Fixing monitoring points at the surface above the cavity and nearby areas to identify any active movement of the area.
4. Identify the laboratory testing to identify the properties of the collapsed and arguer hole material.

As per the initial arguer hole investigation on 13th June 2024, it was identified a cavity of over 150m^3 in size, which is shown below in Figure 6. At the same time an agreed procedure the cavity was started to be filled with 165 m^3 of C15 concrete on 14th and 15th June 2024, while monitoring the movement of collapsed material inside the tunnel. Also drilled a second arguer hole from the surface.

The concrete filling continued for two days and two steel pipes were fixed in the concrete body through the arguer holes to monitor any movement of the filled concrete block due to its weight. Also, another 52m^3 cement mortar was filled on 17th June 2024 and the sinking of this concrete was monitored after the initial setting of the mortar continuously and those were stable for 12 hours until the sandbag removal for the next agreed procedure on 19th June 2024

The actual geology of the collapse area is shown in Figure 7 which was the root cause of the collapse which was developed after a few further agreed investigations in the area a few days later. The collapse area has been identified as the sandy formation from the completely weathered pegmatite. The field and laboratory tests confirmed the formation is non-plastic sandy clay with 4.4×10^{-8} ms^{-1} permeability.

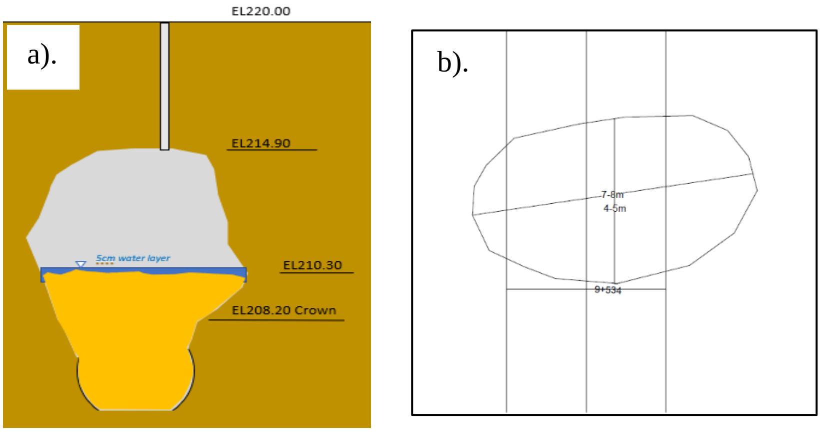

Figure 6 Identified the size of the cavity after initial investigation. a) section view of the cavity at 9+531 and b) plan view of the cavity

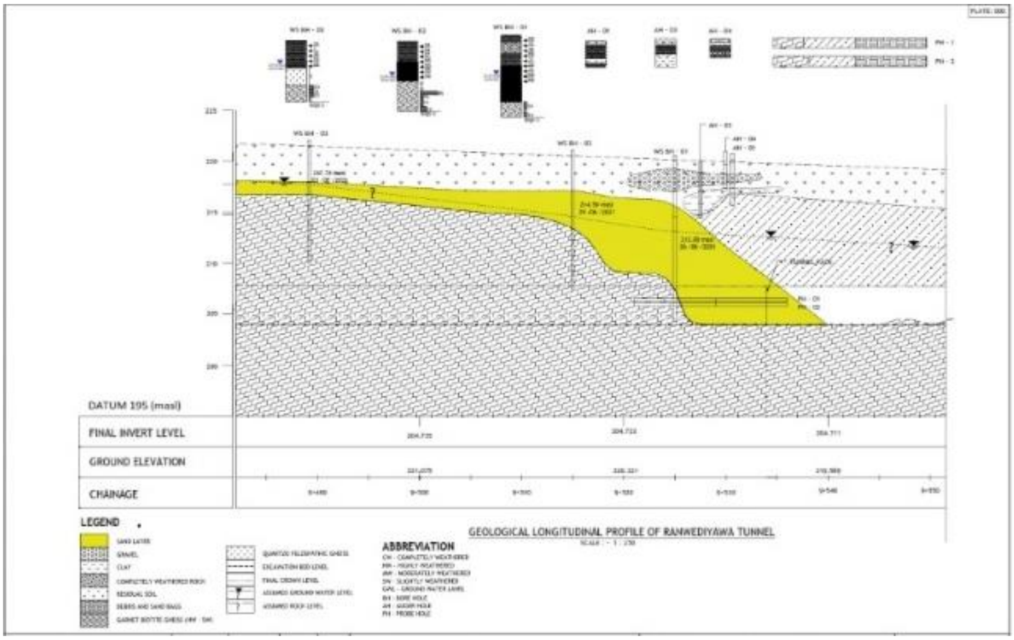

Figure 7 Actual Geology of the Collapse Area

7. Initial Procedures Cavity Treatment

The following initial procedures were followed to reach the tunnel face to start the treatment at the collapsed area to stabilize the tunnel.

1. Removal of floated material and moving the sandbag barrier at chainage of 9+540, 6 m behind the collapse start location chainage 9+534.
2. Completed the balance invert support works to complete the full ring support as per both parties' agreement and according to the original design support class 4.
3. Same time it was observed continuously sinking the concrete block and stable after touching the hard formation front of the tunnel face and the already completed lattice girder support at 9+534.4.
4. Cavity was daylighted on 23rd June 2024 as a sink hole of 1.2 m diameter and increased by 3-4 m in a few days as shown in Figure 8.

Figure 8 Daylighted cavity and surface drilled holes for investigation and treatment

5. After careful observation it was known some cavities between the concrete block and the natural ground on either side of the concrete block. To treat this, sandbags were filled up to the tunnel crown shown in Figure 9, some concrete was filled through the newly drilled holes from the surface, balance void was filled with grout and this process was completed on 29th June 2024.

Figure 9 Tunnel face covered with sandbags before filling the gaps with concrete and grout

6. Based on the observation of both surface movement and tunnel inside again continued the debris removal and completed the unsupported tunnel wall and tunnel invert to form the full rings up to 9+536.

8. Procedure Followed on Tunnel Construction Through the Collapse Area

Sametime, after both parties' few discussions and the analysis of the collected data over 20 days, developed a geological section based on the detail shown in Figure 7. The Contractor's tunnel team developed and Engineer approved the working procedure as the method statement of rectification and implemented the following procedure as the collapsed treatment.

1. It was drilled one probe hole at the face to identify the ground condition then another two drain holes at the possible lowest (1 m from the invert) location in the tunnel face were drilled to avoid or minimize the developing porewater pressure in the face. This stage of work continued until 3^{rd} July 2021, also some sandbags were removed to make visible any movements of the casted concrete block while starting the next stage of the agreed procedure.
2. After arranging the drill machine ZBE 100B and the stage preparation as shown in Figure 10 on 7^{th} July 2024, drilling and installation of 24 numbers of long pipe roofing with 87 mm diameter and 12 m length to reach into the hard ground was completed on 17^{th} July 2024 with 32 mm diameter rebar and grouting which is shown in Figure 11.

Figure 10 Tunnel face a) on 6^{th} July 2024 and b) on 17^{th} July 2024

3. Start the temporary steel arch with modification to hold the crown already installed pipe supports were completed on 18^{th} July 2024 shown in Figure 12.

Figure 12 Initial steel arch support and starting of manual cleaning of the drive

4. Manually concrete block was chipped out after drilling a few holes and the top heading was excavated manually by hand-held machines and supported with steel arch sets as agreed for the next 3 rounds with an average of 1m intervals.
5. Completed the previous balance lattice girder supports after carefully excavating and supporting separately each side wall then completed the invert support to form the full ring support up to 9+536.
6. After that, stagewise the top heading, benching and invert excavation and support work with the steel arch of the full ring as shown in Figure 12 was done to complete the collapse zone up to chainage 9+528. Then only the top heading and benching up to 9+525 were completed with steel arch support and continued the tunnel excavation as per the design support classes as per the face mapping after each round of excavation.

Figure 12 Stagewise excavation and supports at the collapse area

7. Also followed 5 m length of fore polling pipe supports of each 5 m excavation and support work completion to stabilize the tunnel as the long pipes support were installed at an angle of 10° to the tunnel alignment.
8. After passing the collapsed zone excavation and support work, the opened shink hole pit was filled with soil as the agreed working procedure for the treatment of the collapsed zone shown in Figure 13.
9. After reaching the tunnel drive to the hard strata, the first steel rib was rearranged after cutting the steel pipes inside the required tunnel section as designed. Also, the actual supports of the tunnel chainage between 9+540 to 9+515 are shown in Figure 14 which gives the variation of the supports with design in this tunnel section.

Figure 13 While backfilling the shink hole open-pit

9. Results and Discussion

The initial collapse happened by bending the 50 mm diameter pipes in the previous fore-polling support set due to the force of the loosed sandy material's weight. This happened due to the failure of the pre-excavation investigation in the correct location of the face continually as decided by the tunnel team geologists due to the absence of the correct probe drilling equipment. This tunnel construction was started with the minimum resources available to the Contractor due to the spreading of COVID-19 around the world and it was not possible to get any special equipment promptly. This has resulted in delays in arranging the equipment and delays in the rectification too.

The corrective measures taken after the initial collapse were to save the tunnel and the tunnel team with the available resources and possible procedures to avoid further collapse. The delay in making a sandbag barrier or any other barrier near the face creates a large volume of material flowing and creates a large cavity. Also, because of the inexperience of the tunnel team the Contractor has a fear of working in such a situation, hence it is required to employ a well-experienced tunnel team for this kind of mixed ground tunneling.

The tunnel convergence monitoring shows minor changes within 3-8mm in its initial readings in each section of the tunnel after the support works, hence the post-collapse treatment successfully completes the tunnel construction. However, arranging equipment such as long drilling for pipe roofing support is a must in this type of tunnel construction as this was not with the Contractor at the time of tunnel drive started and it was delayed in following the agreed working procedure and mobilization of a sub-contractor for this work.

Also, it requires separate accommodation facilities for this kind of work during periods like the spreading of COVID-19 pandemic. Two tunnel workers were affected by COVID-19 and the tunnel was closed for over 15 days in the collapsed area during treatment time in August 2021. However, this incident did not affect the tunnel face as the tunnel face was supported with sandbags before closing the tunnel.

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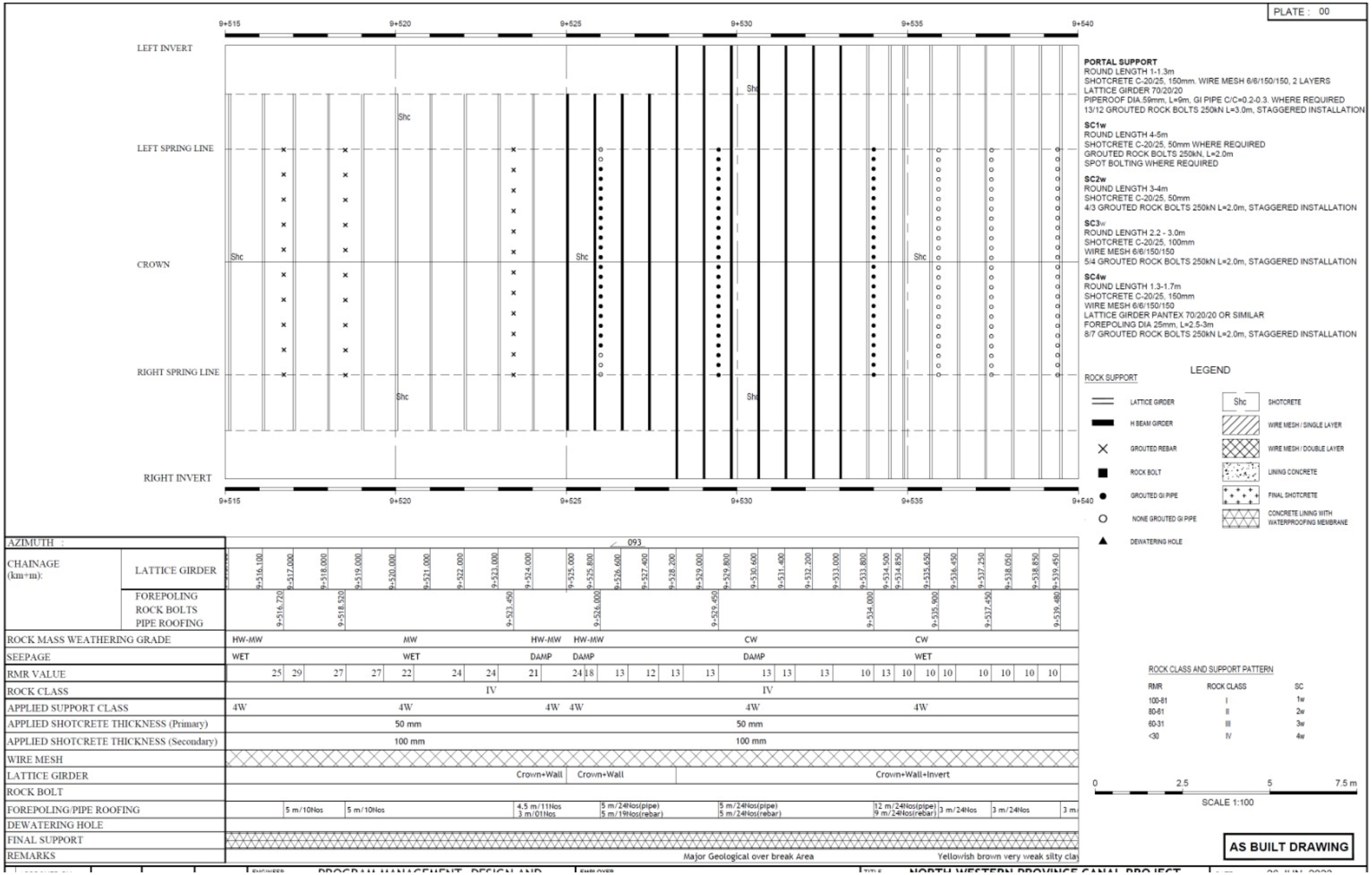

Figure 14 Actual support followed between chainage 9+540 to 9+515 to show the variation of the support system due to the collapse