Providing Solutions and Experiences when Facing Difficult Rock Conditions during Excavation in Middle American Tunnel Projects

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Two Middle America projects stand out for the difficult working conditions faced and the innovative solutions presented to overcome obstacles. Set in picturesque rural Panama near the Costa Rica border, the hydroelectric Bajo de Mina tunnel project faced poor, loose rock conditions making it difficult to progress through two mountain outcroppings where water was to be diverted from a natural river, through the terrain and into power generators. The second project, the Naica mine in Mexico presented difficult working conditions in the form of severe water intrusion and extremely high temperatures, also making working conditions extremely difficult and tunneling progress extremely slow. These projects both employ similar technology, but use different approaches for two unique solutions.

1.1 Baja De Mina, Panama

1.2 Project/Scope

The Republic of Panama is constructing two adjacent hydroelectric projects with 14 kms of tunnels (6 m diameter) in northwestern Panama. Tunnel depth varied from 25 meters to over 60 meters below surface. The project is located in an underdeveloped area of the country where access is limited and the impact of construction on the environment is of high priority. State-of-the-art tunneling practices were determined to be impractical, requiring that more traditional methods be employed, including the use of ordinary excavation equipment such as back-hoes and diggers. It was quickly discovered that much of the rock within the tunneling path was loose, and contained a large amount of sediment that was severely impacting the integrity of the tunnel, which hindered the speed of the excavation and posed risks. The contractor employed many safety measures to protect its personnel, but the loose rock and potential for slides still made the tunneling process slow and very difficult.

The rock conditions in several fronts were poor and the contractor had experienced numerous slides and rock falls inside the tunnels. A slide in the main tunnel in Bajo de Mina had reduced the advance to almost a complete halt for three months while the contractor removed the slide and installed support in the form of steel arches covered by wire mesh and shotcrete. Advance had been slow and geological study showed the rock integrity was poor over several long stretches of the tunnel path. Some of the tunnel areas deemed to be in poor shape were as long as 700 linear meters. The contractor was looking for ways to increase the advance through these difficult stretches while ensuring proper support and safety of the work area. Overall geology was rocky with high concentrations of loose sediment mixed in with volcanic layers that were filled with fissures and unconsolidated organic matter.

Rock support was accomplished with traditional 6" steel beams on 2 meter centers. Wooden rigging was placed between the beams and little additional fill was needed due to the close tolerance of the supports. Where applicable, shotcrete was used over the steel supports in layers of up to 40 – 60 mm.
1.3 Drawing of the tunnel section under construction where poor rock and soil conditions were found to contribute to rock slides and collapse. Service entrances and access tunnels were utilized to aid in transporting workers, equipment and materials in and out of the longest stretches of the tunnel. This tunnel section will eventually be used to divert water flow from a river to a hydroelectric power station to provide electricity to rural portions of Western Panama.

1.4 Applications

Attempts at supporting the roof of the tunnel and providing stability to the excavation using cement grout injections were attempted. These attempts were found to be time consuming, expensive and impractical. There were additional logistical difficulties of transporting, handling and storing powdered material in a high-humidity, tropical climate during the rainy season and in a tunnel with high water ingress conditions.

The proposed solution was to use self-drilling anchors and injection resins to create a protective umbrella of consolidated rock under which the extraction of material could be completed safely, and the support arches could be placed quickly. This practice was the first of its kind in Panama.

The plan called for drilling the tunnel section known as Ventana 1 Aguas Arriba with self drilling anchors along the contour of the tunnel at precisely located positions 0.5 m apart and 7 m deep. Then the contractor's personnel and technical experts reviewed the site, tunnel conditions, material pump and injection criteria. The injection was made with a combination of expanding and non-expanding silicate injection grout specially designed for the immediate stabilization of unconsolidated geological formations during tunneling. First, an expanding grout was injected into the rock face, expanding at the end of the 7 m SDA, until pump pressures or relief of material escaping from adjacent fractures had indicated that the major, large voids had been filled. Immediately after, a non-expanding silicate grout was injected to further fill smaller fissures and consolidate the rock to be extracted. This material was injected into the rock with the intention of bonding and stabilizing weak or unconsolidated ground while maintaining it's integrity during the tunneling process. The combination of the depth of the injections and spacing between the self-drilling anchors allowed the maximum stabilization by providing overlap and securing the geological formations.

An additional benefit to this was the simplicity of getting the materials into the tunnel and within meters of the tunnel face for application. The equipment used - a pump, hoses and variety of accessories - could easily be carried by hand or transported on the back of a pick-up truck, bucket of a loader or any golf-cart sized vehicle. All materials used were available in 20 liter canisters able to be carried by hand or easily transported in the back of a SUV, pick-up truck, or similar vehicle. The durable containers also allowed for storage in rugged conditions or conditions exposed to poor weather prior to their use. The largest
equipment in the tunnel was the Jumbo drilling machine, a back-ho excavator and eventually a loader capable of removing material from the tunnel.

Further tunneling and removal of rock was then able to be completed immediately. Additional steel support and removal of material could now be done quickly and efficiently without fear of slides and without collapse of the face or sides of the wall as had been experienced before. The steel self-drilling anchors were cut via torch in some instances and removed to provide additional rock removal from the ceiling of the tunnel. This was done with no consequences of rock fall or degradation of the integrity of the stabilized rock. The contractor was now able to tunnel 9 meter sections in 3 days where the same section may have taken 3 weeks prior.

1.5 Summary

The conditions of the hydroelectric tunnel project provided challenges in the areas of logistics, excavation and safety. When materials commonly used proved to be ineffective, more advanced ideas needed to be employed to keep the project moving forward in a safe and efficient manner. Self-drilling anchors and injection resins provided a strong, fast and effective stabilization to the weak, shifting rock of the tunnel section. Commonly used in TBM applications, the resin injection techniques were a first in this unique project, and a first in Panama, helping the contractor speed up the schedule and provide an efficient working situation for employees. By using a state-of-the-art resin technology paired with simple transportation and application techniques, the tunneling world was able to bring world-class solutions to remote Central American projects.

2.0 Naica Mine, Mexico

Minera Maple or Unidad Minera Naica, “Naica”, is the main producer of lead in Mexico. Its monthly output is estimated at 65,000 tons/month. The operation, exploration, and development activities, as well as the mining output, are negatively affected by the presence of hot-sulfated water in the deposit in which it is currently working.

2.1 Project/Scope

For two years the mine has been developing a twin access tunnel to a very high grade deposit of lead. This twin tunnel is key to development as it will be a “permanent tunnel” for the extraction of ore, movement of equipment, personnel, and ventilation.

2.2 Conditions

The presence of hot, sulfated water creates an extreme working environment with the following characteristics:

1. Water temperatures 55-60 °C (130 - 140°F)
2. Ambient temperatures between 40-55 °C (105 – 130°F)
3. 100% humidity
4. Heavy water ingress in many areas in the mine
5. Strong water pressures: 500 - 600 psi
6. Pumping requirements: 22,000 – 25,000 gal/min in 5 pumping stations to permit operation and avoid mine flooding.
7. Mines major cost item – Electricity for 24/7 pump operation.
8. Extreme work conditions for personnel and low productivity due mainly to the heat created by the hot water ingress.

The standard process for controlling the hot water ingress has been using cement injections. The cement injections have had a very limited effectiveness against the strong water flow, the water temperature and high water pressures involved. The cement grout was effectively washed out before it could stabilize and set up in the tunnel wall. Attempts to seal the water ingress with many other different type of products
and applications have also been unsuccessful. Additional stress on the project was amplified by the fact that the contractor was facing an upcoming national holiday calling for a stoppage of work for a period of time and the water ingress had to be stopped prior to the holiday.

Specific details:
Naica Mine, Chihuahua, Mexico – 10.5m dia with traditional steel ribbing support
Location: Frente 1, Nivel 640 (640 m beneath the surface)
Water Temperature: 55-60 ºC
Water Flow: 1200-1500 gals/min
Water Pressure: 500-600 psi
Other: Water with Sulfates and other minerals of volcanic origin.
Extreme Working Environment: 40-55 ºC

The extreme water infusion into the tunnel is best illustrated with photos of the actual jobsite.

2.2.1 Heavy hot water ingress 2.2.2 Drilling with Jumbo near water ingress

Additional complications to the conditions were compounded by inserting the human factor into such an environment. Contractors and mining personnel were all trained and practiced safe working procedures throughout the project. Safety precautions included limiting the amount of time a person was allowed in the tunnel working in such hazardous conditions. Personnel were limited to 20 minute intervals to work in the mine.

2.3 Applications

Many different products were used and different techniques were attempted in efforts to stop the water from infiltrating the tunnel, including trials of injection resins. The rock was mostly volcanic, with some large visible fissures and geological surveys had indicated rock separation in lengths of up to 25 meters were ahead of the excavation, indicating the infiltration of water was not a spot concern, but one that existed ahead of the tunnelling and would reoccur in future excavations as well.
The team faced two major problems:

- The strength of the flow did not give the injection resins enough time to react inside the fault cavity to seal the flow. This meant the resin was expelled un-reacted, and often reacted and set up outside of the fissures. There was also concern that the sulphates and heat of the water affected the unmixed components and degraded the chemical composition of the material, rendering it ineffective.

- The strength of the flow and the heat of the water combined to create an atmosphere like a sauna with ambient temperatures above 40 °C which meant it was only possible to work for short stretches of time inside the mine. At regular intervals (every 15 to 30 minutes) all personnel had to move to a cool room to recover from the heat. Personnel were continually showered with cold water to enable work at the front. Safety was of great concern to the contractor and work crews, and all possible precautions were taken to prevent harm or injury to those in the tunnel.

The work shifts were limited to six hours due to the heat and extreme working conditions. Of these six hours, there were only an estimated two to three hours of effective work due to the rest and recovery time required in the cool room.

2.4 New Ideas and Solutions

To achieve the full benefit of the silicate resins, new techniques would have to be employed to deal with the extreme conditions. A technical team was organized in conjunction with the contractor, owner and material supplier. The group worked together to formulate a series of unusual steps to deal with the situation

First, the water flow was reduced by drilling four to six relief holes. These holes were drilled with tubes, valves, and packers. Then, several 1 7/8" holes were drilled near the opening where the water flowed with the intention of injecting the holes with resin near the opening and eventually plugging the opening. The injection was made with an SK-90 high pressure pump with lances and packers.

Initial injections reduced the water flow but did not stop it completely. The resin typically reacts about 30 seconds after mixing and stops foaming about 60 seconds after mixing. This reaction rate is faster as the temperature increases. With the high water temperature, we estimated that the reaction time was about 15 to 20 seconds with foaming ending at about 30 to 45 seconds. Even with this fast reaction rate, the resin was being expelled by the strong water flow before it had time to react inside the cavity-fault.

Brainstorming at the site on the last day prior to the holiday produced a solution. It was agreed that there was a need to speed the reaction of the resin so that it was "already foaming" by the time it came out of the lance inside the cavity. This meant that time within the hose and injection lances needed to be increased so that the reaction started in the injection system, as opposed to, post placement in the wall.

This was achieved by forcing the resin through back-to-back static mixers - and back-to-back lances and increasing the length of the hose. The back-to-back static mixers ensured a better mix of the two components. Coupled with the lances and increased length of hose, it was possible to get the resin to foam immediately as it was coming out of the lances while not giving the material any time to wait for the reaction to take place within the rock.

The idea worked. The water ingress was completely stopped. The relief holes were also injected with resin and completely sealed.

2.5 Summary

The use of the silicate injection resins is not a new concept, although this is the first project in Mexico to use such technology. The application is unique for two major reasons. First, the extreme conditions faced in the mine were unprecedented and very hazardous. The trials of different materials such as cementitious grouts had been proven ineffective and were not able to contain the water, nor react in the...
heat and pressure fast enough to contain the infusion. Secondly, the application itself had been rethought, and utilizing tools and techniques available, the injection of the resin was changed to accommodate the need for an immediate set to the resin. This provided an ultra-fast cure to stop the water immediately. The final step, more forward-thinking, was to provide relief holes and a way of controlling the release of water from the tunnel wall out of the work area and give the work crews additional time to work and proceed with mining efforts.

3.0

Middle America is a new frontier for silicate resin technology. These two projects demonstrate not only perfect applications for such technology, but are examples of unique circumstances, creative thinking and collaborative efforts to provide solutions. The use of silicate resins in Middle America will continue to provide solutions to the tunneling community. The two projects above are examples of how we can use unique applications of readily available materials to address problems that we all may face.