Water Cutoff in Raise Bore Pilot Hole

Location: **Red Lake, Ontario**

Sector: **Mining**

Project site with pilot hole situated beneath diamond drill (shown on left)

Case Description

A large diameter ventilation raise was under construction using raise bore construction methods at an underground gold mine located in Northern Ontario. Following pilot hole breakthrough into the underground workings, a significant water inflow was observed that jeopardized raise reaming operations.

Solution

The mine owner retained Peter White to supervise drilling and grouting operations to intercept and cutoff the water inflow prior to resuming ventilation raise construction.

With video camera inspection, it was observed that a significant fracture had been encountered at a depth of 122 m that was the major source of groundwater infiltration. The combined pilot hole inflow from all sources was in excess of 100 cubic meters per day.

To prepare for drilling and grouting operations, a 280 mm diameter inflatable packer was installed at a depth of 133 m to stop water from flowing down the 380 mm diameter pilot hole. This packer enabled drilling and grouting work to proceed under static water conditions with no residual flow.

Significant engineering challenges were identified and resolved to facilitate safe installation, operation and recovery of the large inflatable packer within the pilot hole.

Relevant weight parameters within the 380 m diameter pilot hole were established as follows:

- 400 kg inflatable packer
- 1,600 kg HQ drill rods
- 15,000 kg water column

To support the estimated 17,000 kg load, a combination of HQ drill rods and 3/4 inch diameter non-rotating steel safety cable was selected to provide an adequate factor of safety.

280 mm diameter inflatable packer assembly installation at collar of pilot hole

Diamond drill holding HQ drill rods

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As delivered, the conventional 280 mm diameter inflatable packer required significant custom adaptation and modification to accommodate the technical requirements for this project.

Brackets were welded to the upper steel section of the inflatable packer for attachment of three slings that were in turn attached to the 3/4 inch safety cable. Centralizers were welded at top and bottom of the 280 mm diameter packer to maintain packer alignment within the pilot hole.

The large packer incorporated a nominal 8-inch steel pipe that was open on both ends. A nominal 3-inch steel drain pipe was concentrically mounted within the 8-inch packer pipe and welded into position with centralizers.

A 57 mm diameter inflatable packer was mounted within the internal 3-inch steel drain pipe to act as an integral water release valve within the large packer pipe.

A top sub assembly was specially fabricated to adapt between the 8-inch NPT thread on the packer pipe and the HQ drill rods used to lower the inflatable packer into the pilot hole.

The top sub-assembly also provided three flush ports connected with the HQ drill rods that enabled clean water to be pumped from the surface through the HQ drill rods to continuously flush the top of the inflatable packer to prevent accumulation of cement on top of the packer within the 380 mm pilot hole.

Open ports were installed through the 8-inch packer pipe to allow groundwater to pass through the inside of the 280 mm diameter packer after the packer had been inflated within the 380 mm pilot hole.

A bottom sub assembly was fabricated to close the annular space between the 3-inch internal drain pipe and the 8-inch packer pipe so that groundwater entering at the top of the 280 mm diameter packer would have to flow out through the 3-inch internal drain pipe.

The 57 mm diameter packer was mounted within the 3-inch internal drain pipe. A separate packer inflation port was provided through the wall of the 8-inch packer pipe and connected to the 57 mm diameter packer using a short inflation hose.

Separate inflation hoses for each packer utilized 100R2AT-04 hydraulic hoses with female JIC swivel fittings.

The completed packer assembly that was lowered into position within the pilot hole included the following components:

- HQ drill rods
- Top sub-assembly
- 280 mm packer
- Inflation hose for 280 mm packer
- 57 mm internal packer
- Inflation hose for 57 mm packer
- Bottom sub-assembly
- 3/4 inch safety cable

The packer assembly was initially installed below the collar of the pilot hole using slings attached to a front-end loader, following which the packer was inflated and secured in position using the 3/4 inch safety cable.

Foot clamp holding HQ drill rods

Sheave wheel for 3/4 inch safety cable at collar of drill hole with packer inflation hoses attached to HQ drill rods

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A deadman bracket was attached to the concrete foundation for the raise bore machine with cable clamps installed to hold the safety cable.

Deadman anchor used to hold 3/4 inch safety cable

A large diamond drill equipped to handle HQ rods was positioned over the pilot hole and elevated approximately one meter above collar elevation with wooden cribbing to provide for personnel access and adequate working space beneath the drill rig at the collar of the drill hole.

Diamond drill elevated above pilot hole collar

HQ drill rods were lowered into the pilot hole and attached to the packer assembly, following which the 280 mm inflatable packer was deflated, allowing the diamond drill to lower the packer assembly into the pilot hole.

On the surface, the 3/4 inch safety cable was laid out on the ground attached to a large tractor to provide a controlled descent of the safety cable under tension as the inflatable packer and cable assembly were lowered into the pilot hole by the diamond drill.

After the packer assembly had reached the target depth of 133 m, HQ drill rods were secured by the diamond drill and 3/4 inch safety cable was secured under tension at the deadman anchor.

Inflation hoses were connected to individual nitrogen tanks and regulators. The 280 mm packer was inflated to complete packer installation within the pilot hole. The 57 mm packer was inflated to close the internal 3-inch drain pipe and prevent groundwater from flowing down the hole.

Nitrogen tank with regulator for inflating packers

After 24 hours, the groundwater level stabilized a few meters below the collar of the drill hole. At the underground breakthrough location, residual groundwater inflow entering the pilot hole below 133 m depth was less than 6 cubic meters per day.

With the pilot hole sealed to provide static water conditions above 133 m depth, drilling and grouting operations were able to proceed using NQ drill holes. Holes were sequentially drilled and grouted one hole at a time.

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Drill hole collars were located 12 m away from the pilot hole. Drill holes were aligned to intercept the water flow fracture approximately 7 m away from the pilot hole. Each drill hole was gyro-surveyed after completion of drilling to confirm actual intercept location.

Drilling NQ grout holes in proximity to pilot hole

The initial stage of drilling and grouting work involved 7 NQ holes that were sequentially drilled and grouted over a 14 day period.

It was quickly determined by water pressure testing that the fracture aperture was relatively narrow, so the decision was taken to use only microfine cement for grouting work, in order to maximize penetration of cement particles into small apertures.

Grout mixture ingredients for each batch were as follows:

- 67 liters water
- 15 liters bentonite slurry
- 0.2 liters superplasticizer
- 40 kg microfine cement

Water pressure testing revealed the following conditions within the water-bearing fracture:

Hole 1: 80 LPM at 200 kPa
Hole 2: 10 LPM at 200 kPa
Hole 3: tight hole
Hole 4: 70 LPM at 200 kPa
Hole 5: tight hole
Hole 6: 8 LPM at 200 kPa
Hole 7: tight hole

Corresponding cement consumption in each drill hole was as follows:

Hole 1: 4,000 kg at 100 kPa
Hole 2: 1,140 kg at 800 kPa
Hole 3: not grouted
Hole 4: 2,160 kg at 100 kPa
Hole 5: not grouted
Hole 6: 540 kg at 700 kPa
Hole 7: 300 kg at 800 kPa

Correlation between gradual reduction in hydraulic conductivity, reducing cement consumption and increasing grouting pressures indicated that it was time to drain groundwater from the pilot hole, deflate the 280 mm inflatable packer and measure the residual groundwater flowing into the pilot hole above 133 m.

The 57 mm diameter internal packer was deflated and groundwater contained in the pilot hole between the surface and 133 m was allowed to drain, while maintaining the 280 mm packer fully inflated.

After allowing sufficient time for draining groundwater from the pilot hole, the 280 mm packer was deflated and raised 3 m to verify that the packer had been released and could be recovered from the pilot hole.

Residual groundwater flow was measured to be 25 cubic meters per day at the underground breakthrough location, an overall reduction of 75% compared with the initial groundwater inflow.

The 280 mm diameter inflatable packer assembly was raised to the pilot hole collar by removing HQ drill rods, along with the recovery of the 3/4 inch safety cable.

Drilling and grouting were then suspended to enable the client to review available drilling and grouting reports with their geotechnical consultants and to assess long-term effectiveness of the grouting work over several months.

After a four month review period, the client directed that additional holes be drilled between existing grout holes in an attempt to further reduce groundwater inflow.

The 280 mm diameter inflatable packer assembly was again lowered to a depth of 133 m and inflated to retain groundwater within the pilot hole. Sequential drilling and grouting work resumed using microfine cement based on the same procedures as utilized for grouting of the initial holes.

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Water pressure testing revealed the following conditions within the water-bearing fracture:

Hole 8: 22 LPM at 500 kPa
Hole 9: 10 LPM at 500 kPa
Hole 10: 5 LPM at 500 kPa
Hole 11: 10 LPM at 500 kPa
Hole 12: 7 LPM at 500 kPa

Corresponding cement consumption in each drill hole was as follows:

Hole 8: 1,000 kg at 1,000 kPa
Hole 9: 800 kg at 2,500 kPa
Hole 10: 840 kg at 2,500 kPa
Hole 11: 320 kg at 2,500 kPa
Hole 12: 240 kg at 2,500 kPa

After drilling and grouting five additional holes, dewatering and deflation of the 280 mm diameter packer revealed residual groundwater had been further reduced to less than 10 cubic meters per day at the underground breakthrough location, an overall reduction of 90% compared with the initial groundwater inflow.

Drilling and grouting equipment were removed from the site and raise boring of the ventilation raise was completed without any complications from residual groundwater.

Peter White, P. Eng., is a senior engineer and grouting specialist with over 25 years of experience working on many different types of pressure grouting operations at hundreds of project locations around the world.