Ground Improvement for Ventilation Raise Construction

Location: **Halmahera, Indonesia**

Sector: **Mining**

Case Description

An underground gold mine located in Indonesia required two new ventilation raises to be constructed from surface to a depth of 280 m. Geotechnical investigations revealed that significant sections of the proposed 2.4 m diameter ventilation raises involved very poor ground conditions with limited standup time.

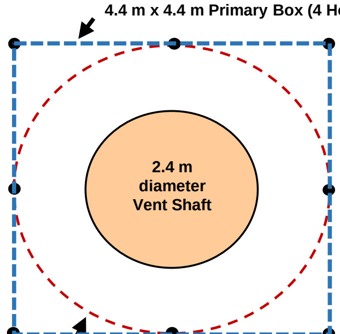
Diamond drill in foreground, grout plant in background

Solution

Ground improvement by cement grouting was implemented to consolidate and strengthen ground conditions prior to raise boring 2.4 m diameter raises.

In preparation for drilling and grouting, detailed procedures were developed to cover all aspects of equipment operation for the anticipated scope of work. Job safety analysis reviews were undertaken to identify risk factors and provide corresponding control measures.

Drilling and grouting operations at the first ventilation raise were underway over a work period of 7 weeks, consisting of eight holes to various depths between 110 and 185 m depth and placement of 26,000 kg cement.



As typically experienced in such projects, cement consumption in subsequent drill holes gradually declined as the grouting work was underway:

	Raise # 1	Raise # 2
# 1	1,900 kg	12,800 kg
# 2	11,000 kg	7,400 kg
# 3	3,200 kg	3,500 kg
# 4	3,900 kg	5,800 kg
# 5	1,900 kg	2,400 kg
# 6	1,800 kg	2,500 kg
# 7	600 kg	1,600 kg
# 8	1,700 kg	

Depending upon ground conditions, hole sequence and stage length, cement consumption per meter of drill hole reached 80-100 kg/m at the commencement of grouting work and gradually diminished to 30-40 kg/m during the final stages of grouting for each raise.

All drilling and in-hole activities (packer positioning and flushing operations) were undertaken using a Boart LM 75 drill rig. Drilling productivity typically ranged between 15 m to 20 m of HQ drill hole each shift. HQ drill rods were handled using an integral rod handling system. BQ drill rods for flushing and grouting were manually handled on/off the drill rig.

Two adapters from BQ thread to JIC thread were fabricated for hookup of grout hoses. One short adapter of 500 mm overall length was typically used for most hookups. One long adapter of 1800 mm overall length was occasionally used for advancing BQ rods when flushing sand and debris from the bottom of the hole, and for positioning of inflatable packer at specific locations.

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One open-ended BQ drill rod with pin-end threads cut off was used on the bottom of the BQ drill rods when flushing the drill hole. A down-hole BQ tool was fabricated to provide tangential air flushing, incorporating a stuffing box for installation at the collar of the casing pipe and a connecting pipe adapter to a 200 mm diameter plastic discharge pipe. One casing adapter was fabricated to enable grout hoses to be connected directly to the drill casing.

The driller's water pump was capable of pumping 65 liters per minute of water. The mine water supply was capable of providing up to 175 liters per minute for assessing relative permeability of drill holes.

Upon completion of drilling of each stage and recovery of HQ drill rods, falling head water tests were quickly undertaken using an electromagnetic flowmeter for rate of flow and cumulative flow measurements that were utilized to assess relative permeability for each stage prior to grouting. In a few instances, where relatively low permeability conditions were encountered, drill holes were deepened prior to grouting of a single longer stage length.

Drill holes were typically air-flushed prior to grouting for the following purposes:

- Confirm approximate water elevation
- Evacuate water from drill holes prior to grouting
- Assess residual rates of water inflow
- Remove residual drilling debris from the hole

Using mine compressed air supply (approximately 6 bar pressure) through open end BQ drill rods, water was typically air-lifted from a depth of 45 m below the collar of the hole, following which more rods were added in increments of 3 rods (9 m), 5 rods (15 m) or 10 rods (30 m) at a time depending upon site conditions.

At the first ventilation raise, typical water level was at depth of approximately 30 m. At the second ventilation raise, typical water level was near the bottom of the drill holes.

For grouting work in HQ drill holes (96 mm dia.), inflatable packers of 73 mm diameter were used, with maximum allowable inflation pressures up to 60 bar and typical inflation pressures up to 40-50 bar.

Two inflatable packers burst while being inflated down-hole. In both cases, insufficient care was taken to set the packer at a suitable location within solid rock, so the packer gland deformed within an oversized portion of the drill hole and burst while inflating. A third inflatable packer was used without incident for the balance of the project duration.

Packers were inflated using inert nitrogen gas regulator assemblies. Inflation hoses consist of a reel-mounted, 3,000 psi, 6 mm inside diameter, 100R2 hydraulic hose attached to a short length of 3,000 psi, 3 mm inside diameter, 100R2 hydraulic hose that was connected to the inflatable packer.

On one occasion, insufficient care was taken when recovering packer and inflation hose from the hole, resulting in the inflation line becoming kinked and jamming the inflatable packer in the hole. The packer and hose were subsequently recovered from the hole but the end of the 6 mm diameter inflation hose was destroyed.

On another occasion, insufficient care was taken when recovering packer and inflation hose from the hole, resulting in the inflation line becoming caught down-hole. The packer was recovered from the hole after ripping apart the 3 mm diameter connecting hose. The 6 mm diameter hose was cut and a new end swaged onto the cut hose end. A new 3 mm diameter hose was installed on the inflatable packer.

Various inflation hose related problems were anticipated, for which spare hose ends and replacement hoses were provided on site. Special care and attention to detail were taken when using inflatable packers to situate packers within solid ground conditions and when lowering and recovering packers.

Inflatable packer showing fixed head (left), inflated gland and sliding head (right)

Deployment of inflatable packers was dependent upon site conditions, stage length and stage depth. When grouting intermediate stage locations, inflatable packers were situated near the bottom of the preceding stage to minimize the length of re-drilling through hardened cement grout to access subsequent stages.

When grouting final stage locations, drill holes were tremie grouted after flushing, with inflatable packer subsequently situated near the top of the drill hole for pressure grouting purposes.

Grouting equipment was set up with both operator and material platforms to provide safe working conditions when handling bags of cement. Wooden pallets were positioned around the grout plant to provide safe working conditions underfoot.

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Typical grout plant setup at surface

Cement grout plant was operated with compressed air and consisted of two 265 liters paddle mix tanks supplying cement grout to a 75 mm diameter duplex plunger pump.

Due to the ground conditions encountered, microfine cement with d_{95} particle size < 10µ was typically selected for grouting purposes and grouting commenced using a fluid "five-bag" grout mix based on the following characteristics per batch of grout:

- 100 kg cement (5 bags of 20 kg each)
- 168 liters water
- 1000 ml superplasticizer
- W:C = 1.7 by weight of cement
- Wet Density = 1.34 kg per liter

Typical grout plant setup underground

Although provision had been made for thicker grout mixes with lower W:C ratio to accommodate encountered site conditions, the majority of grouting operations achieved refusal utilized the microfine cement grout mixture described above. Typical grouting refusal pressure of 30 bar measured at the drill hole collar was used for most grouting operations.

Grouting activities typically involved 4 operating personnel, 1 technician and 1 engineer. A full group of 6 personnel were required for most grouting operations. On occasion, 3 drill personnel and 1 technician or engineer were able to manage grouting operations.

When grouting the initial stages at the first ventilation raise and for a couple of stages at the second ventilation raise where relatively large quantities of cement were consumed, a larger complement of manpower was necessary. When grouting the later stages at both raises, a smaller complement of manpower was sufficient.

Grouting personnel were able to supply cement grout to the drill hole at an initial rate of at least 50 liters per minute, gradually decreasing as grouting pressures increased.

Upon completion of grouting activities, conventional raise boring operations proceeded to construct 2.4 m diameter raises without encountering any ground-related difficulties.

Upon completion of raise boring, it was intended to immediately apply shotcrete lining to the raises but the contractor encountered difficulties operating the remote shotcrete equipment, resulting in delays of several weeks, during which time no ground-related problems or collapses were encountered.

Subsequent operations of both ventilation raises for fresh air supply and return air exhaust were uneventful over the required several years mine operating period.

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.