

A First for Kidd Creek

The first use of the Multiple Packer Sleeved Pipe (MPSP) grouting system in North America.

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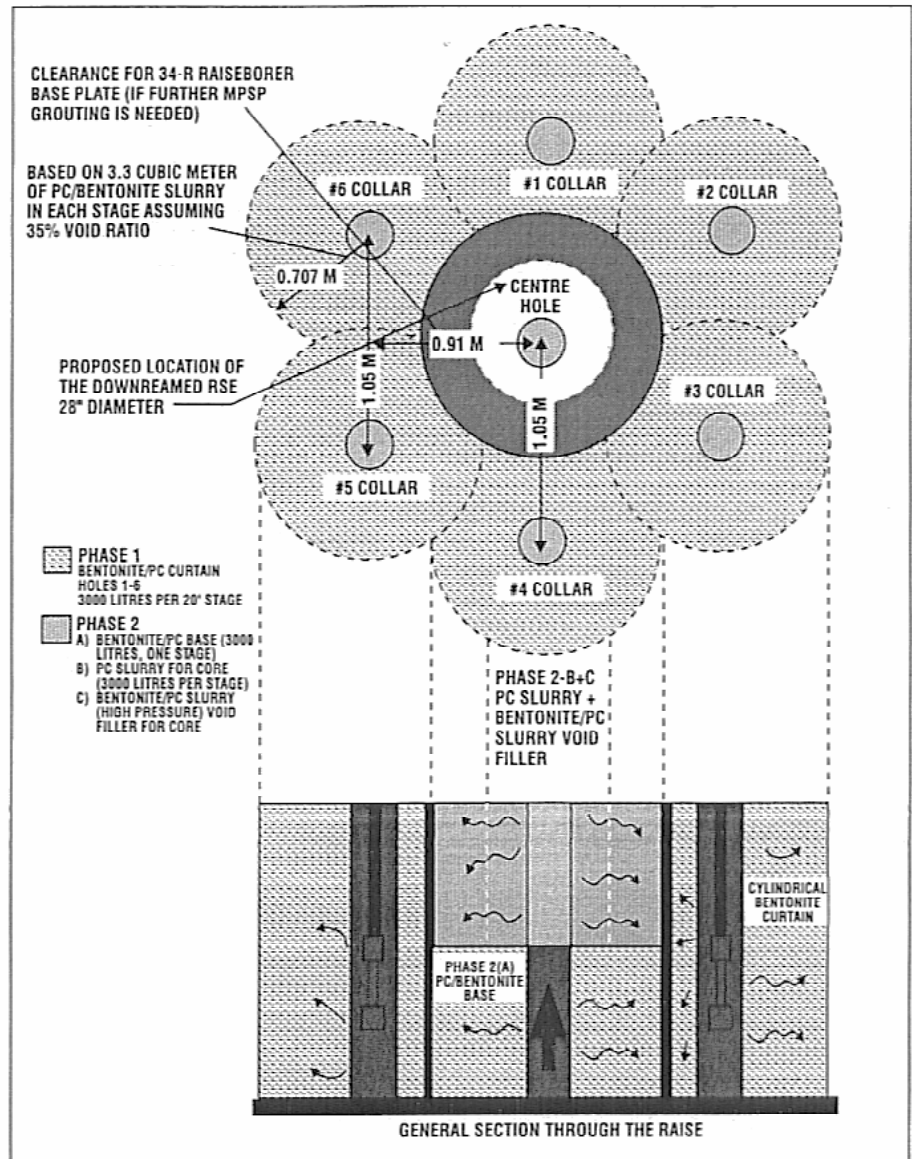
THE KIDD CREEK MINE, near Timmins, Ont. routinely uses consolidated rockfill to fill mined openings. Annually, a total of 2.3 million tonnes of backfill are required. To date, about 80% has been consolidated material, consisting of crushed mine rock — generally less than 150 mm in maximum dimension — mixed with a cementitious binder before being gravity-fed into stopes. The balance has been unconsolidated rockfill or sandfill.

As part of the No. 3 expansion at depth, it will be necessary to backfill at depths in excess of 1,400 metres. To facilitate this, vertical holes reamed to 630 mm in diameter with a raise bore machine, drilled through previously back-filled areas, was projected.

However, early tests in the older filled areas where these holes were required showed that the degree of consolidation of the backfill was highly variable. In some cases consolidation was almost nonexistent. This made conventional drilling exceptionally difficult and led to massive overbreak in the fill — always a major safety concern underground. Clearly, some form of additional ground stabilization was required prior to raise boring. Therefore a research program was initiated.

This program consisted of grouting and then raise boring through two back-filled stopes. In each case, the work was conducted through 60 metres of fill, from the 790-metre level. The first trial was conducted in a crosscut on the 790-metre level (crosscut 735). In addition to proving the system, equipment and materials, this test also permitted the grouted zone to be explored by subsequent down-drilling of the 250-mm diameter pilot hole, and upreaming of the 630-mm reamed hole.

The second test site was located at the same level, but at the 660 crosscut — some 75 metres to the north. This test



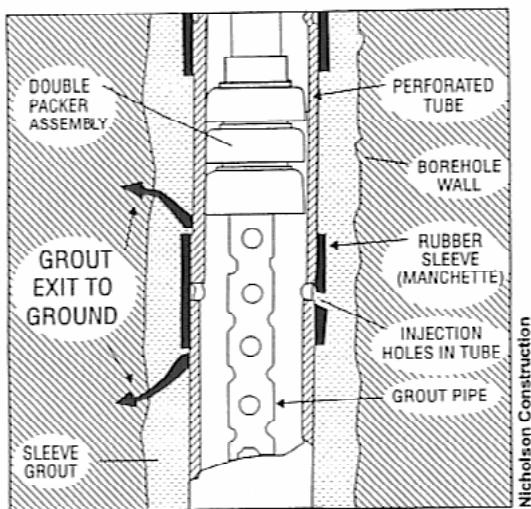
Plan view (top) and section view (bottom) of second MPSP grouting test at the Kidd Creek mine, Timmins.

incorporated modifications based on the first test, but also demonstrated the competence of the grouted fill with respect to up-drilling of the pilot, and down-reaming of the final bore — a far more severe test of the concept.

The properties of the fill varied somewhat within and between the two stopes. However, the fill was generally highly variable in composition and competence,

with a bulk unconfined compressive strength of about 50 bar. The strength of the aggregate itself was over 3,000 bar.

Unstable ground in 735 crosscut demanded the use of a continuous contemporary steel casing, full length, when drilling grout holes. Given the space restrictions, a Krupp double-head drilling system, mounted on a Krupp DHR 80 diesel hydraulic track rig, was used.



The tube à manchette system.

The easiest method of grouting under such conditions is simply to pump grout through the casing as it is slowly extracted. However, another method was necessary here since:

- The highest degree of control over the grout placement and procedure was required;
- And having to use 1-metre-long steel casing would severely interrupt the grouting operation, possibly leading to blockages in the lines, or worse, accidental cementing of the drill casing in the hole.

A grouting method independent of the drill casing was therefore necessary. The Multiple Packer Sleeved Pipe (MPSP) system appeared to be ideally suited to the role.

A pattern of four grout holes was arranged around the position of the subsequent bored raise. Grouting was intended to stabilize the ground in this vicinity to permit the raise bore to proceed quickly and safely. A cement-based grout was considered most appropriate because of:

- The materials available in the mine;
- The suspected nature of the fill;
- And the intended purpose of the grout *in situ*.

Hole positions were carefully laid out on a specially prepared level concrete pad, 7 x 3 metres in plan, cast on the fill and ranging from 100 to 250 mm in thickness. The outer drill casing was 133 mm in diameter and the inner drill rods carried a 100-mm down-the-hole hammer.

As is typical in such programs, the first hole took longer to drill than planned. Drilling confirmed the fill was very loose, and contained frequent very large, very hard rock boulders. However, with adjustments to drilling techniques and hardware, and improvements in air flushing, the holes were drilled with progressively increasing ease.

Penetration time, torque and flush return characteristics were measured continuously. From these data gross changes in the fill every metre could be assessed.

Two holes were drilled and grouted, then two other holes were drilled and grouted. Each hole was designed to break through into the drive on the lower, 850-metre level.

Plastic pipes of 72 mm outside diameter, in 3-metre lengths were used as grouting pipes. Each length of pipe had rubber sleeves at about 1.5-metre intervals, covering groups of holes in the pipes. Every fourth sleeve was fitted with a 600-mm-long fabric bag. This provided stage lengths of 6 metres in the holes. The bags were capable of expanding up to 190 mm in diameter, ensuring a good seal with the ground upon inflation.

After placing the MPSP in each hole, and extracting the steel drill casing, the bags were inflated via a Rodio double packer, using carefully controlled volumes of neat cement grout.

Cement grout at the Kidd Creek mine is prepared under strict quality-controlled conditions on surface and pumped underground through many kilometres of 100 or 150-mm-diameter steel lines.

In this case, the slurry was pumped to a large storage tank near a special mixer/pump used in this trial. Early tests confirmed that, while the slurry was easily pumped and had a long setting period, it was too fluid and unstable to use in this particular application. Therefore, dry cement was added to the slurry at the test site in a Colcrete colloidal mixer.

The grout was then pumped by a Moyno progressive cavity pump through the flexible injection line and inflatable packer. In each hole, grouting was conducted from the bottom up. Flow rates and volumes were regulated by valves on the grout circulation line.

From estimated grout travel distances and theoretical ground porosity, 2,000 litres of grout were injected in each 6-metre stage. Early on, the grout flowed freely, with a considerable amount, especially from the lower stages, draining into the 850-metre level. Leakage occurred up to 4-5 metres radially from the hole breakthrough location. To stop this leakage, sodium silicate solution was

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added from the adjacent hole during grouting. When grout encounters sodium silicate a very rapid or "flash" set occurs — how rapidly depends on the composition and relative amounts of each component.

A total of 76,000 litres of cement grout and 9,000 litres of sodium silicate solution were injected in the four holes. At each stage, there was a slight reduction in flow rate and a slight increase in pumping pressure through each successive phase of grouting. This behavior highlighted a certain degree of "tightening up" in the ground. Typical grout flow rates were 20-30 litres per minute with pressures of about 15-20 bar. These values reflected less on the properties of the ground than the hydraulic characteristics of the injection system. The limiting factor was the 11-mm-diameter grout line.

Seepage patterns on the 850-metre level suggested the grout was not remaining local to the points of injection and was not filling the voids completely. Instead, it was felt that the grout was passing down through the fill, and thoroughly coating the aggregate *en route*. When set, the grout was gluing blocks together as opposed to filling the void between them. This was supported by the much improved drilling performance after the first two holes were grouted.

The collar for this test raise was prepared by bolting the base plates of a Robbins 34R raise bore machine to rebars grouted into the concrete pad. A 250-mm-diameter pilot hole was drilled at a rate of about 2 metres per hour. Deviation from vertical was measured as 2% upon breakthrough. The raise was then successfully reamed to a diameter of 630 mm from the bottom, 850-metre level, to the top, 790-metre level. Reaming was accomplished at a rate of 1.5 metres per hr.

A video camera survey was then conducted to view the effectiveness of the grouting. Grouting had reduced the porosity quite substantially in places, but elsewhere the fill was still relatively open, though stable. It was possible that the rigid plastic pipes, at relatively close centres, had contributed an *in situ* reinforcing effect to the larger fill blocks, helping to stitch them together.

Because of the more arduous reaming requirements of the second test (i.e., reaming from top to bottom), various changes were made:

- Six peripheral holes were drilled, supplemented by a seventh, central hole.
- The peripheral holes and the bottom of the central hole (hole 7) were grouted with a more viscous, stable cement-based grout, incorporating bentonite. The aim was to restrict flow and improve void-filling efficiency. The central hole was grouted with a higher strength, neat cement grout, for additional support.

- The grout station was overhauled to provide higher volumes and pressures and larger-diameter grout delivery lines were installed to facilitate faster pumping.

As in the first test, grouting was done in phases: holes 1, 3 and 5 drilled and grouted, followed by holes 2, 4 and 6 and finally hole 7.

The raise collar for the second test was positioned in the centre of 28-662 stope, about 15 metres from the point where backfill trucks dumped and down-slope from the peak of the fill cone. A very high torque was necessary to rotate the drill casing in all holes. The best performance was obtained with the "Lost Crown" system (Bruce, 1989). This gives an oversized hole (140 mm in diameter) without an eccentric drill bit.

Difficulties were encountered in penetrating unconsolidated backfill. This occurred where the original slurry mix design changed to a slurry-to-aggregate ratio of 3.6% from 6.4%. In most holes, the casing had to be withdrawn temporarily and the drill bit replaced.

Holes 2 and 4 were drilled faster and slightly easier. The first attempt at Hole 6 had to be abandoned, possibly because of an artificial obstruction in the fill. Another hole was drilled to replace it.

Peripheral and plug grouting in this test was executed with a bentonite-enriched slurry. Each 100-litre batch of 60% P.D. mine slurry had almost 6 kg of bentonite added at the colloidal mixer. The target volume was 3,000 litres per 6-metre stage. This was achieved at pumping rates of up to 60 litres per minute.

In contrast to the first test, no leakage of grout into the 850-metre level was recorded. This indicated that the bentonite successfully restricted excessive travel. No sodium silicate was therefore necessary.

A total of 160 cu. metres of bentonite-enriched grout was injected into the six perimeter holes. A further 30 cu. metres of higher-strength cement grout was in-

How the MPSP system works

ONE OF THE 1980s FEW ADVANCES IN ROCK GROUTING is the Multiple Packer Sleeved Pipe (MPSP) system. Devised by the Rodio Group of Companies, of Milan, Italy, it overcomes the problem of collapsed, voided or highly variable ground conditions and has been used to form grout curtains for several high dams in Asia and Europe. In consolidation grouting, it can improve the mechanical properties of rock masses.

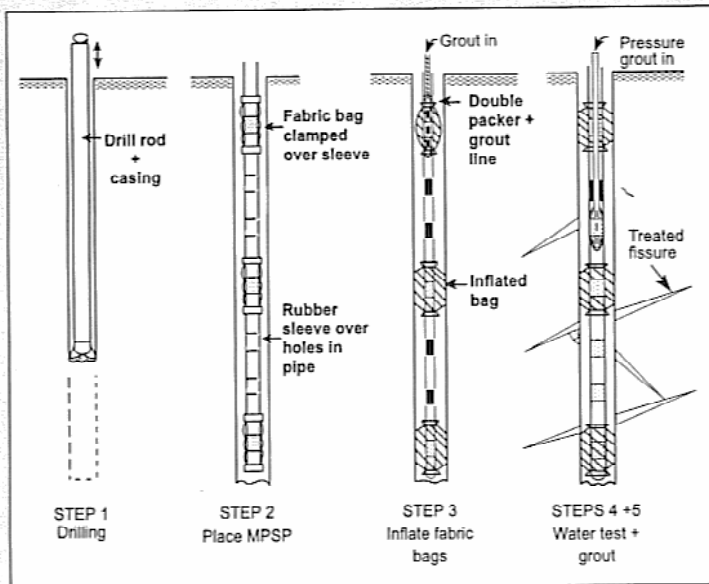
Nicholson Construction of Bridgeville, P.A. is the North American licensee of the technology.

MPSP owes much to the tube à manchette system, developed for use in soils. In the case of MPSP, grouting of the surrounding rock is effected through the ports of a plastic or steel grout tube placed in a pre-drilled hole. However, unlike tube à manchette, no sleeve or annulus grout is used. Instead, the grouting tube is retained and centralized in each borehole by concentric collars — fabric bags inflated *in situ* with cement grout. These collars are positioned along the length of each grout pipe,

either at regular intervals (say 3 to 6 metres apart) to isolate standard stages, or at intermediate or closer centres to ensure intensive treatment of particular zones. All types of grout can be used, depending on the rock mass and the purpose of the grouting.

The typical MPSP construction sequence is as follows:

- A borehole (100 to 150 mm in diameter) is drilled by the fastest available method (usually rotary-percussive). Temporary casing may be necessary to full hole depth, as dictated by the degree of instability of the ground.
- The MPSP is installed. Pipe details can vary, but typically a steel pipe, 50 mm outside diameter, with each length screwed and socketed is chosen. Each 5-metre-long pipe has three 80-mm-long, 4-mm-thick rubber sleeves equally spaced along its length, protecting groups of 4-mm-diameter holes drilled in the pipe. A concentric, polypropylene fabric bag is sealed by clips above and below the uppermost sleeve in each length. Bags are



usually 400 to 600 mm long. For short drill holes, plastic pipes of smaller diameter may be used. The temporary drill casing is then extracted, and any collapsed material simply falls against the outside wall of the MPSP tube.

- Each fabric bag is then inflated, starting from the lowermost pipe length. This is done via a double packer positioned at the sleeved port covered by the bag. A neat cement grout is used at excess pressures of up to 2 bar to ensure intimate contact between the bag and the wall of the borehole. Water seeps out of the grout through the fabric bag, thus promoting high early strength and no possibility of later shrinkage. The choice of bag material is crucial to the effective operation of the system. The fabric must have adequate strength, elasticity and permeability.

- Water testing may be conducted if required, through either of the two "free" sleeves between collars. Tests show that a properly seated fabric collar will permit effective "stage"

water testing at up to 4 bar.

- Grouting is executed in standard tube à manchette fashion from bottom to top via the double packer (usually of the inflatable type). Target volumes are selected to prevent wasteful long-distance travel and target pressures are chosen to prevent dangerous structural upheavals.

Although two stages in the same hole can be treated at different times, once a hole has been grouted once, it cannot be grouted again.

There are significant logistical and work schedule advantages of the MPSP system. Drilling and installation, for example, can proceed without involving with the grout crew. Also, the secure nature of the grout tube prevents the possibility of stuck packers. Grouting is therefore a predictable, smooth operation.

Another advantage of the MPSP system is the thick-walled, robust drill casings used during drilling. These promote straight drilling.

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jected into the upper portion of Hole 7.

Again, a Robbins 34R machine was used to drill a 250-mm-diameter pilot hole to the breakthrough depth of 59 metres. The rate of penetration was an extremely high 12 metres per hour. During reaming, thrust pressure was maintained the same as for the pilot hole, but rotational speed decreased to 16 r.p.m.s from 40. Penetration rate for reaming averaged 4.2 metres per hour.

A subsequent video survey showed that although some zones of coarse,

bonded fill remained, the overall condition of the fill was very stable and well-cemented. The average porosity of the grouted fill was estimated at less than 15%. This compares with an estimate of 35% for typical mine backfill.

This improvement may be due to three factors:

- Location of the raise in the fill cone compared with the first test which was located in the segregation zone;
- And increased intensity of grouting from seven holes instead of four.

- Improved grout mix design;

Fill stabilization at Kidd Creek has proved to be a highly successful application of the MPSP system.

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Donald Bruce is Technical Director of Nicholson Construction of America and Faramaz Kord is Project Engineer for Falconbridge Ltd. in Sudbury. The authors would like to thank Jim Croxall, Clay Wittchen, Doug Duke, Peter Corcoran, Dennis Raab, Slim Jones and Ron Triplett. Special thanks to colleagues in Rodio, Milan, Italy.