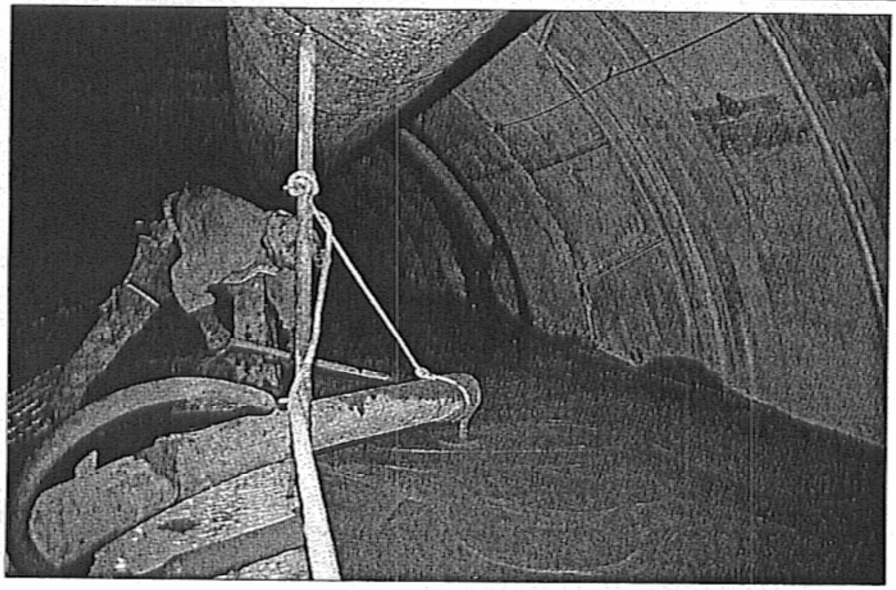

GREAT GROUTS

Particulate grouting has long given challenges and solutions to those in the geotechnical field. But significant developments in the understanding of hydration and rheology control look promising.

CHRIS GAUSE
DONALD A. BRUCE

Modern geotechnical construction projects place increasingly challenging demands on placing particulate grouts. Two significant challenges are hydration (setting and hardening of the mixture) and rheology control (consistency). Such projects also require higher degrees of washout resistance and formation penetrability.

Recent projects, however, have tested and are proving new developments in particulate grouting:

1) Deer Island Outfall Tunnel, Boston, where engineers used grout to backfill a tunnel boring machine (TBM) in place;

2) Channel Tunnel, U.K., where tunnel linings required the grout to set within 15 minutes of being placed under difficult conditions;

3) Barrick Gold Mine, Elko, Nev., where the project required an alternative method to backfill a stope;

4) Inter-Island Tunnel, Boston, where grout had to be pumped over a long distance to fill an annulus without being diluted by high water flows.

Each of these projects required grout with specific components in specific ratios, each tailored to meet the needs of that particular job. The most common particulate grout components are water and some type of portland cement. Other traditional components, such as fly ash and sand, are added to the mix based on the particular performance characteristics required by the job, including setting and hardening times, strength, and water-stopping and load-transferring abilities. In each case, the contractor, along with Master Builders, Inc., Cleveland, developed and tested the grout mixture before placing it.

Time can pose a major challenge for the placement of grout.

DEER ISLAND OUTFALL TUNNEL

The joint venture of Kiewit-Atkinson-Kenny JV (KAK), Winthrop, Mass., completed mining for this 12-km-long, 7.2-m-diameter tunnel for the Massachusetts Water Resource Authority (MWRA) in Boston in September 1996. Because the tunneling extended fully out under Boston Harbor, KAK had to decide how to remove the TBM from the tunnel. To sink a shaft in the harbor or disassemble the TBM and return it to the tail tunnel would have been very costly. So the contractor decided to leave the machine there: they would excavate an additional length of tunnel equal to the length of the TBM, strip it of all worthy components and backfill with grout, leaving its shell in place, beyond the end of the useful tunnel. To compound the challenges of the job, the MWRA specified a grout that would achieve a strength of 10 MPa.

Time also posed a major challenge for the placement of the grout. The contractor was not permitted to truck the materials through local communities to the jobsite, so materials had to be delivered by barge. When the cement and sand reached the docks on the island, the contractor had to then transport the grout to the batch plant. Once crews batched this grout, the transit time from the plant to the point of placement could be as much as five hours. Under these circumstances, the contractor needed a cost-effective grout that had a delayed setting time, was easy to handle up to the time it was placed and achieved a specific strength once it set.

A consultation between KAK and Master Builders led to the decision to use a hydration control system and a chemical foaming agent. The hydration control system, a proprietary liquid admixture acting as a grout stabilizer, would ensure that fresh,

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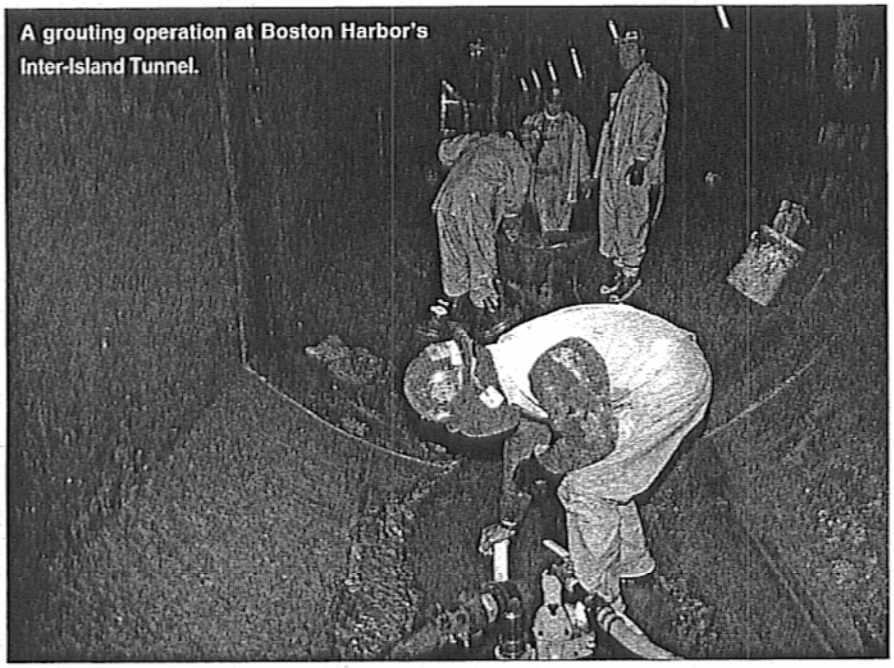
A grouting operation at Boston Harbor's Inter-Island Tunnel.

unhydrated grout could be placed even after an elapsed time of five to six hours from the time of batching. The foaming agent, added in the tunnel, would increase the volume of grout by 20%, thus reducing by the same amount the materials and the mixing required.

The hydration control admixture was added at the batch plant during the mixing. Crews then discharged the grout via a 200-mm-diameter slick line to the tail tunnel, where it was received by three rail cars—each with a capacity of 10 m^3—for transport to the point of placement. There the grout was remixed prior to being discharged into a 450-mm-diameter screw conveyor. Crews then conveyed the grout to a remixer, where they added a preformed foam to increase its volume. Once the grout and foam were thoroughly mixed, crews discharged the grout into a second screw conveyor, which transferred the expanded grout into the hopper of a concrete pump with a 150-mm-diameter cylinder. From here the grout was pumped for distances up to 750 m to its point of placement.

The contractor found that this combination of hydration control and preformed foam was highly advantageous and cost-effective given the challenges. The preformed foam increased the pumpability of the grout and reduced material-handling costs on the surface. The hydration control admixture ensured that fresh unhydrated grout was placed throughout the successful backfill operation.

CHANNEL TUNNEL

The Channel Tunnel consists of three separate tunnels—two running tunnels of 7.5 m internal diameter and one service tunnel of 4.5 m internal diameter. These tunnels were driven through the Lower Chalk Marl, which is a badly jointed lithology with a zero stand-up time in certain places. Some areas were also particularly wet, having saline water

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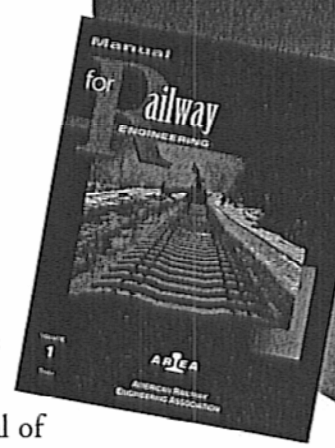

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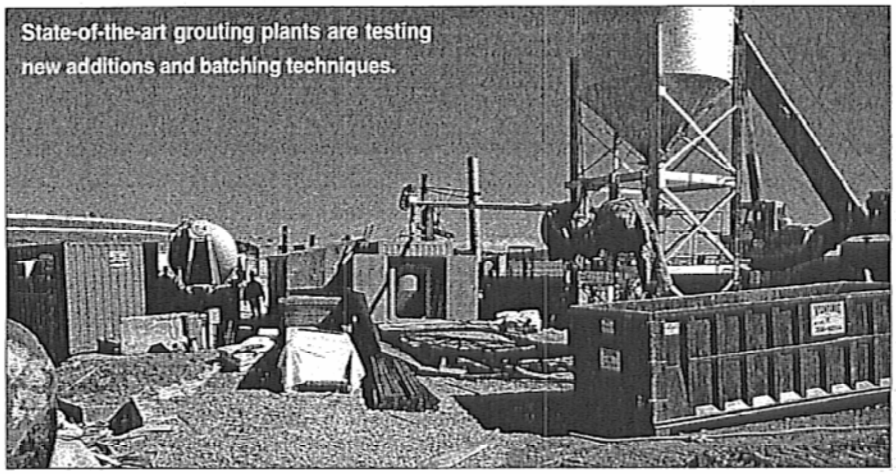
ingress rates of around 120 L/min at over 1 MPa pressure. These circumstances demanded grout with a quick setting time and good antiwashout properties.

In the U.K. sector, TranManche, Dover, U.K., a joint venture of major British companies, used precast concrete segments as the final lining of the tunnels. Between the concrete segments and the chalk was a 20 mm annulus into which the contractor would place the grout. The contractor foresaw tunneling rates of approximately 250 m per week and initially projected a grout volume for the U.K. sector of the tunnel of 55,000 m^3, with each complete ring of precast concrete lining segment requiring about 0.85 m^3 of grout in the annulus. Any delays caused by the grouting operation would have had a dramatic impact on the completion dates of the project.

The project required that the grout develop sufficient early setting characteristics to take the invert load of the segment trains within one hour of grouting; i.e., setting was needed within 15 min of the grout being pumped into place behind the tunnel linings. Not only did the water ingress require the grout to have antiwashout properties, but the large overall volume of grout, which was often placed in relatively small batches, required a long pumping life prior to injection.


State-of-the-art grouting plants are testing new additions and batching techniques.

The contractor outlined the salient characteristics he required the grout to have. These included a minimum strength of 1 MPa at one day and 8 MPa at 28 days; an initial set achievable within 45 min of injection at a temperature of 20C; and a final set achievable in a maximum of 6.5 hours at a temperature of 20C. Also, the grout should not bleed significantly during hydration.

Grouts used previously for such wet conditions incorporated admixtures based on long chain polymers with accelerators added at the packer. These grouts, however, display rapid viscosity evolution and are therefore incompatible with the long pumping times required for this project. Working with Master Builders, the contractor carried out extensive laboratory and full-scale site trials to develop a suitable grout mix and to refine the production and placing techniques. The solution finally chosen dealt specifically with the need to provide a correctly grouted invert in the marine running tunnels, where conditions would otherwise wash out the grout. The grouting systems and materials

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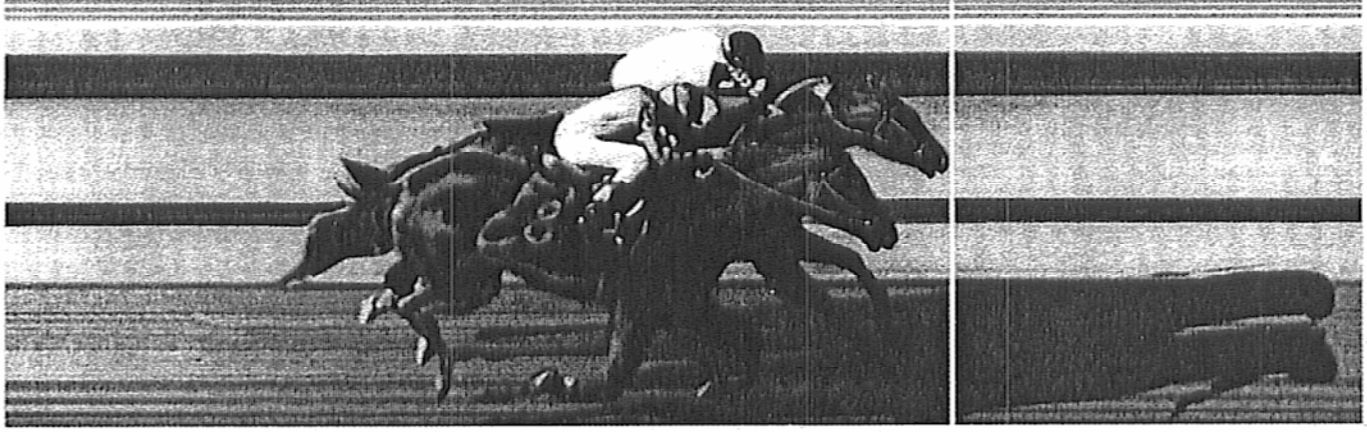

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were designed to be flexible and capable of dealing with both fast and slow rates of tunneling progress.

The base grout was a fly ash/portland cement mixture to which crews added various admixtures to provide the desired fluid properties. These included a superplasticizer and a hydration control stabilizer. The plasticizer ensured ease of pumpability while the use of the stabilizer, as in the Deer Island Outfall project, resulted in fluid grout always being available on demand. To provide rapid set of the grout once in place, crews added a liquid activator to the stabilized grout via an in-line mixer at the grout injection nozzle.

The dry components were held in static bunkers mounted on the TBM sledge, having been transported by transit car from storage silos outside the tunnels. The plant, finally adapted for "wet" conditions, consisted of paddle mixers, moyno pumps and metering pumps. More sophisticated weigh-batching equipment was mainly used in drier conditions.

The contractor used this system throughout the construction of the tunnels with consistent success. Tests proved the grout had the antiwashout characteristics of a long-chain-polymer grout and the pumping properties of a fluid particulate grout. It provided the specified high early strengths while being always available, ready mixed, to meet field demand.

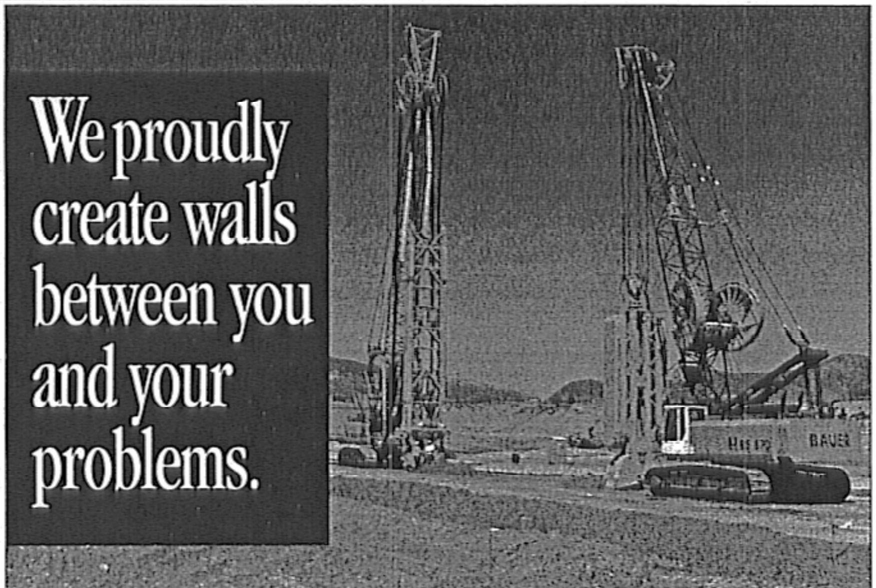
BARRICK GOLD MINE

Underground mines often call for mined areas to be backfilled with lightly cemented waste rock to provide a degree of ground support. Traditional methods include hoisting mine waste rock to the surface, where it is processed through a concrete batch plant. Crews then add cement proportionally, and place the cemented rock in the stope for backfilling.

In the case of the Barrick Gold Mine, a project completed in late 1996, the owner, Barrick Gold, had not yet put up a batch plant to process the cemented rock. But areas they had already mined required backfilling to support stopes and maintain the mining schedule. So Barrick Gold, along with the contractor, Impact Equipment Co., Elko, Nev., and Master Builders, decided on a different method, one that had never before been applied. They would attempt to use particulate cementitious grouts to treat—in situ—the preplaced blasted waste rock. This procedure would provide an interim means of stope backfill pending the construction of the permanent underground batch plant.

Considering the gradation of the waste rock—a poorly graded gravel with sand and silt—a nonsanded mix was chosen for the grouting. The grout was required to produce an ultimate compressive strength of 8 MPa and to retain its originally batched fluid properties for a minimum of two hours.

Based on previous experience with injecting preplaced aggregate, the contractor conducted the injection process via a series of 50-mm-diameter steel pipes placed in the stope. Each set of grout pipes consisted of three separate tubes: one tube extending down the stope to 1 m from the bottom, another extending to 6 m from the bottom and a third extending to 6 m from the bottom of the second tube. The crew color-coded each tube for easy identification during the grouting operation. Any rise in grouting pressure above the normal system pressure (head and line) would constitute refusal, at which time the next tube in the



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series would be injected.

Crews batched the grout into a ready-mix concrete truck in 5 m^3 quantities and then discharged it to the 370 m level of the mine through a 200-mm-diameter slick line. This slick line fed into a 6 m^3 agitator tank, and from there a 100-mm-diameter slick line stretched approximately 120 m to reach the top of the stope, where it was reduced to a diameter of 50 mm for connection to the grout pipes.

The dispersant we chose allowed for increased fluidity and, more important, aided in preventing the cement lumps that sometimes form when batching neat cement and water in a ready-mix truck. The hydration control admixture provided increased workable time for a grout that would otherwise set relatively quickly. This was valuable on occasions when grout remained in the slick line between loads, especially near the stope itself, as the ambient and waste rock temperature was approximately 45C—a temperature that would otherwise prematurely set the grout.

The successful grouting of the replaced waste rock proved the feasibility of the grouting method. The contractor still has to verify the in situ strengths, and cost-effectiveness must still be determined through comparisons with the conventional method, but the pilot program did allow the stope to be backfilled in a timely manner. Barrick Gold is pleased with the results and, together with other local mining companies, is currently considering the use of this method at other locations.

INTER-ISLAND TUNNEL

The Inter-Island Tunnel, part of the Boston Harbor Project, features 7,500 m of tunnel under Boston Harbor from Nut Island via Long Island to Deer Island. With the only access being from shafts on each island, this project required that the specified high-early-strength annulus backfill grout be pumped long distances. To further increase the complexity of the operation, water flows of up to 50 L/s were encountered in the annular space behind the concrete lining of the tunnel.

The contractor, S. A. Healy/Modern Continental JV, Winthrop, Mass., chose a state-of-the-art grouting plant consisting of a colloidal mixer and special pumps to deliver the grout up to 3,300 m through a 25-mm-diameter steel line. In order to achieve early strength, a low water/cement ratio was selected, and to ensure adequate fluidity, a melamine-based dispersant was added at a dosage of 1.25%. Crews added an antiwashout admixture last to prevent loss of the cementitious component when the grout encountered the flowing water. Prior to the use of the antiwashout additive, site tests showed that conventional grouts could not be retained behind the lining. But the new grout the contractor designed completely rectified this situation. The Boston Harbor project is ongoing.

As evidenced by these few grouting projects, demands placed on grouts tend to be unique and frequently contrasting. For example, grouts must be fluid enough to travel long distances, yet must not dilute in the presence of flowing water and still give target strengths. New additives and batching techniques should continue to offer more options and solutions for the ever-demanding geotechnical field.

Chris Gause is sales manager for the underground division of Master Builders Technologies, Cleveland. Donald Bruce, M.ASCE, is a principal at ECO Geosystems, Inc., Venetia, Pa.

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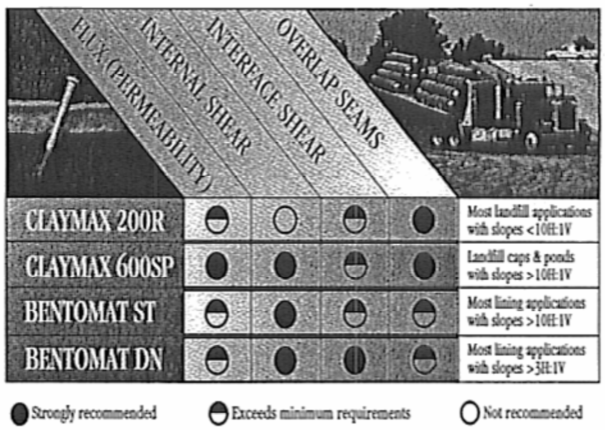

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