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

- 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.

**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 tunnel 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, 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,
A grueling operation at Dutchin Harbor's Intrepid 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 batching 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 m³—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 mixer, 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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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, TramManche, 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 260 m per week and initially projected a grout volume for the U.K. sector of the tunnel of 55,000 m³, with each complete ring of precast concrete lining segment requiring about 0.85 m³ 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 time prior to injection. 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 20°C; and a final set achievable in a maximum of 6.5 hours at a temperature of 20°C. 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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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 antwashout 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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INTER-ISLAND TUNNEL

The Inter-Island Tunnel, part of the Continental IV, Winthrop, Mass. scheme, consists of a tunnel spur extending from Coney Island to New York Harbor. The tunnel is expected to be completed in 1968 and the project began in 1960. With the use of new grouting equipment, crews were able to grout the tunnel in 50 m increments using the conventional method. The grouting was performed in situ and the water flow was successfully stopped. The tunnel is currently being considered for other locations.

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Melamine-based dispersants were added to the grout mix to prevent loss of mix uniformity. The dispersant was added to the grout mix at a dosage of 1%. For each application, a unique and frequently changing dosage was used. A total dosage of 2% was used in each application. The dispersant was added to the grout mix at a dosage of 2%. For each application, a unique and frequently changing dosage was used. A total dosage of 2% was used in each application.

Crews bunched the grout mix into a ready-mixed concrete and placed it in the tunnel. The concrete mix was then reinforced with glass fibers to prevent thermal contraction. The glass fibers were added to the concrete mix at a dosage of 1%. For each application, a unique and frequently changing dosage was used. A total dosage of 2% was used in each application.

As evidenced by these new grouting procedures, Cleveland, Dayton, and Cincinnati are principal centers for the demand for grouting equipment.