Shotcreting on Frozen Ground

By Paul H. Madsen

The Northern Boulevard Crossing (NBX) is the keystone portion of the massive multi-billion-dollar East Side Access (ESA) Program by the Metropolitan Transit Authority Capital Construction (MTACC) to bring Long Island Railroad trains into and out of New York City's Grand Central Terminal. NBX constitutes the link between the Queens Tunnels and Manhattan Tunnels portions of ESA. The crossing consists of 120 ft (37 m) of 2000 ft^2 (186 m^2) cross-sectional area tunnel through soft ground, constructed using the sequential excavation method (SEM) under the protection of a structural frozen arch (Fig. 1).

NBX extends under an active five-track-wide subway box, a major six-lane highway, as well as through the foundation piles of operating elevated subway line structure. All of the above presented a unique challenge to the owner and contractor. NBX is the first and only soft-ground SEM tunnel project within the five Boroughs of New York and was constructed by a joint venture of Schiavone Construction Co., LLC, and Kiewit Infrastructure Co. (S/K).

Construction on NBX started in February 2010 with the SEM excavation starting in April 2012 following access chamber excavation, grouting, and ground freeze. Excavation was completed in

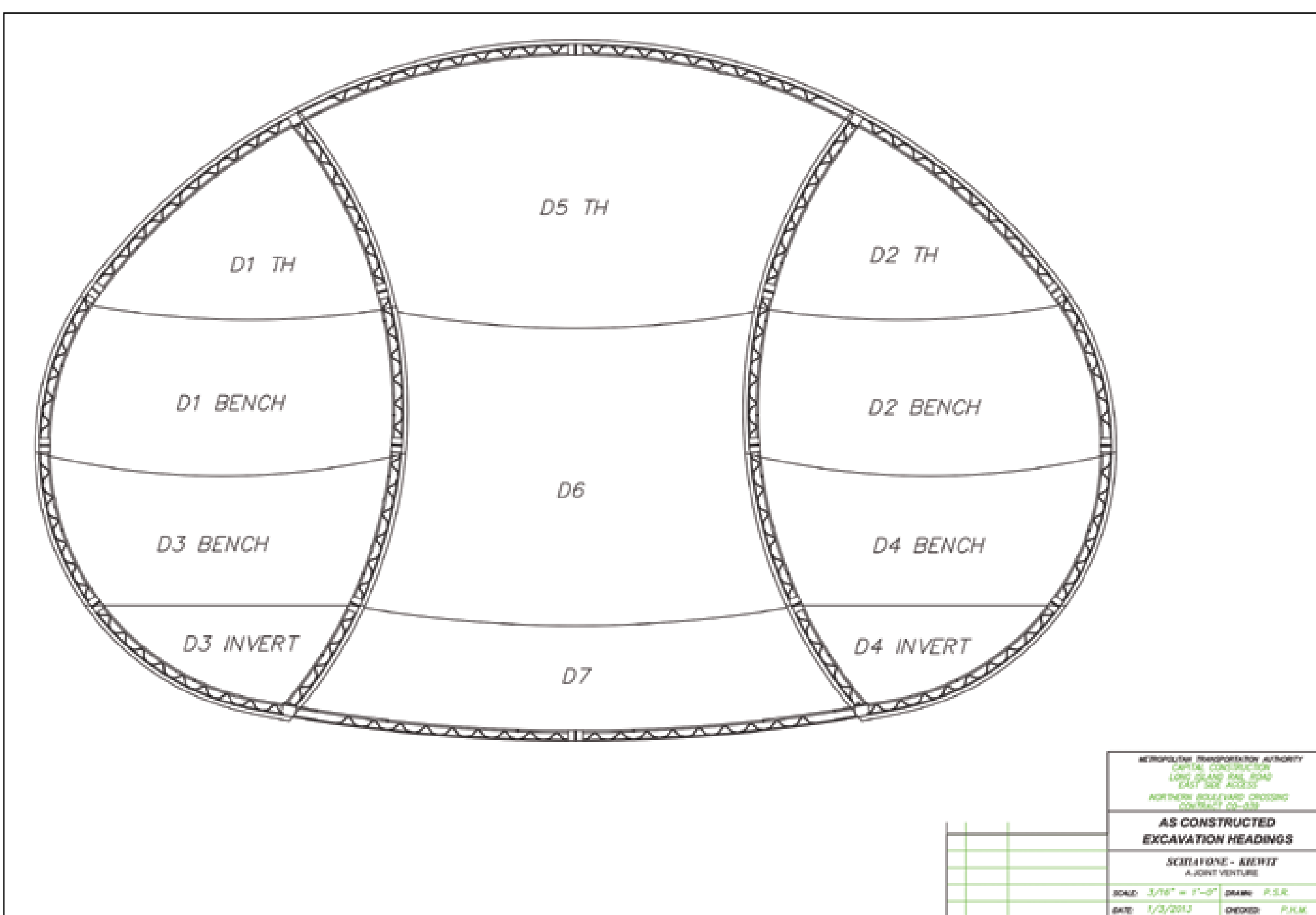


Fig: 1: Drift layout

November 2012 and was followed by PVC waterproofing installation and final lining.

This article describes lessons learned from the shotcreting on frozen ground during the SEM excavation and support.

Subsurface Conditions

The tunnel envelope of the NBX tunnel is predominantly within mixed glacial deposits that consist of brown-gray to olive-brown medium-stiff to hard non-plastic to low-plasticity silts and clays. The stratum was predominantly varved with fine micaceous sands and fine gravel. Gravel, cobbles, and boulders were also observed. The Unified Soil Classification System (USCS) group symbols are generally ML to CL. Parts of the crown encountered very loose to very dense coarse to fine micaceous sands and silts with gravels.

Tunnel Design

The tunnel was designed by the General Engineering Consultant (GEC) for MTACC. The design incorporated a frozen soil arch that served as pre-support and water cutoff. The frozen arch had to span the entire 120 ft (37 m) length of the tunnel from the slurry wall on the east side of Northern Boulevard to the slurry wall on the west. The frozen arch had to be socketed into the bedrock at the invert level of the tunnel to isolate the soils below the frozen arch from any water infiltration and allowing for drainage of the soils inside the arch.

Full drainage of the soils under the frozen arch were required prior to removal of the slurry walls' temporary bracing in front of the tunnel portal, and to ensure stand-up time of the soils during tunnel excavation.

The initial tunnel lining consisted of a 3 in. (75 mm) insulating shotcrete layer and 12 in. (300 mm) structural shotcrete reinforced with two layers of 4x4-D4xD4 welded wire reinforcement (WWR). Lattice girders were required at 4 ft (1.2 m) centers, equal to the excavation round length. The temporary sidewalls had the same reinforcement with a 12 in. (300 mm) total shot-

Fig. 2: Mockup of Drift 1

crete thickness. Temporary inverts between the upper and lower sidewall drifts were 9 in. (225 mm) of shotcrete reinforced with one layer of WWR. Specified shotcrete strength was 100 psi (0.7 MPa) in 1 hour, 500 psi (3.5 MPa) at 6 hours, 1800 psi (12 MPa) at 24 hours, 3500 psi (24 MPa) at 7 days, and 5000 psi (34 MPa) at 28 days.

Lessons Learned

Compatibility testing and early set tests were conducted on several accelerator sources prior to selecting a supplier. This was followed by yield tests and strength testing in the lab.

Because shooting shotcrete panels has little in common with applying shotcrete in a tunnel environment around lattice girders and WWR, it was agreed with the owner to eliminate shotcrete panels as the method of verifying the nozzlemen's skills and instead construct a full-size mockup section of an upper sidewall drift, Drift 1 (Fig. 2).

This allowed S/K to evaluate the nozzlemen's capabilities to maneuver the robot and the nozzle around the girders and see if they understood the sequence of application. One primary and one backup nozzleman were approved for each shift.

Shotcrete panels were shot for verification of the mixture performance both before and during construction. Early-strength testing was done using penetration needle and the powder-actuated nail pullout test.

All shotcrete was delivered by a ready mix supplier because it was not possible to set up an on-site batching facility due to site restrictions. A retarding admixture was added to the shotcrete mixture because the trucking time from the batch plant to the site varied from 20 minutes to over an hour, depending on traffic.

Shooting shotcrete on frozen soil, especially overhead, creates certain challenges that had to be solved. The design required a 3 in. (75 mm) insulating layer to be applied to the frozen ground as flashcrete prior to lattice girder installation.

After application of the 3 in. (75 mm) flashcrete, the heat of hydration from the flashcrete thawed the first inches of frozen soil, causing the unfrozen soil and the flashcrete to delaminate from the frozen soil and causing fallout from the crown. Additionally, on vertical walls where the flashcrete did not fall off, the freezing energy from the ground would refreeze the thawed soil and the flashcrete during lattice girder installation, hence resulting in the structural shotcrete being applied on a frozen surface and defeating the intent of having the flashcrete insulate the structural shotcrete.

Because there were no stability issues with the frozen soil requiring flashcrete, it was decided with the acceptance of the owner's design representative to apply the flashcrete/insulating layer together with the initial structural shotcrete layer. Additionally, the outside layer of wire mesh was stiffened with No. 7 (No. 22M) reinforcing bars to allow the shotcrete to build up without sagging due to deflection of the mesh.

Fig. 3: Drift 1 top heading

Due to safety concerns over having crews working directly below freshly applied shotcrete while installing the inside layer of WWR, it was decided to apply all overhead shotcrete in two passes. Using this approach, the inside WWR of a round was installed during the outside mesh and girder installation of the following round. Identically, the second shotcrete pass of a round was applied immediately after placing the initial pass on the following round. Using this approach, the next operation following shotcreting was excavation and no personnel—only the stick of the excavator—was exposed to potential shotcrete fallout (Fig. 3).

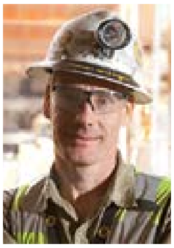
Shotcrete was applied using a small track-mounted robot, except for the invert shotcrete in the center drift, which was applied using a 2 in. (50 mm) hand nozzle suspended from the stick of the excavator. This solution was required to properly shoot the tight areas at the connection points to the lower sidewall drifts below the temporary sidewalls.

The shotcrete was pumped from the surface to the headings through a 4 in. (100 mm) slick line using shotcrete pumps with an integrated accelerator dosing system. This setup allows for proper quality control of the accelerator dosing and ultimately the strength performance of the mixture.

A dry-mix shotcrete setup using bagged materials was kept as backup for the two wet-mix shotcrete pumps and in the event that there was an issue with the wet-mix material supply.

Summary

The project provided an opportunity to learn about the challenges of applying shotcrete on frozen ground. Using WWR, No. 7 (No. 22M) reinforcing bar, and lattice girders, it was possible to shotcrete an initial self-supporting shell that could support the structural shotcrete thickness and prevent any loss of ground (Fig. 4).



Paul H. Madsen *received his BSc in civil and construction engineering at the Engineering College of Copenhagen, Copenhagen, Denmark, and his MSc in soil and rock mechanics at Heriot Watt University, Edinburgh, Scotland. He has over 20 years of underground experience as a contractor's Geotechnical and Tunnel Engineer as well as Tunnel Superintendent and Project Manager with Kiewit Infrastructure Co. Projects include Storebaelt Tunnel in Denmark, Devil's Slide in California, and recently the Northern Boulevard Crossing in New York.*

Fig. 4: Completed tunnel