2006 Outstanding Underground Project

Weehawken Tunnel and Bergenline Avenue Station

The reconstruction of the Weehawken Tunnel for the New Jersey Transit Hudson-Bergen Light Rail System was recently completed. More than a $145 million dollar contract encompassed the enlargement of running tunnels and the construction of an access shaft for the new underground station and new portals.

More than 17,800 yd^3 (13,620 m^3) of shotcrete was applied during construction of the Weehawken Tunnel/Bergenline Avenue Station project. Shotcrete was used for initial ground support during excavation of the running tunnels, station, and shaft. Additionally, shotcrete was used as part of a temporary earth retaining system at the west portal and through a Value Engineering Change Proposal (VECP) shotcrete was used for the final liner in the tunnel-station transitions and east portal structure.

Fig. 1: Application of initial ground support shotcrete

Fig. 2: Initial ground support shotcrete

Steel-reinforced shotcrete was used for initial ground support during excavation. The shotcrete was required to be applied within a contractually specified time after excavation and in a specified thickness based on ground conditions encountered. Initially, shotcrete was provided by a local ready mixed concrete supplier. Due to varying schedule requirements, however, an on-site batch plant was erected to reduce the delivery time and provide better control of the deliveries. Even with the on-site batch plant, chemical admixtures were required to suspend the hydration process ensuring quality shotcrete without concern of excessive hydration in the delivery truck while the area was properly prepared to receive the shotcrete.

Before installing the waterproofing membrane, a second unreinforced or plain smoothing pass was required to prepare the irregular surface for the waterproofing membrane.

The shotcrete final lining was implemented through a VECP that was developed and accepted. The VECP proposed to substitute the planned cast-in-place concrete lining at the transitions between the station and the running tunnels, the east portal mined section, the transition section to the cut-and-cover section, and the east portal cut-and-cover with a shotcrete lining. The proposed shotcrete lining provides an equal product to the contract's cast-in-place concrete. While providing an equal product, the concrete spray-on process provides for greater flexibility in its application, which in turn provides schedule flexibility for the work associated with shotcrete lining as well as the adjacent activities. A concrete spray-on lining is more efficiently contoured to the varying geometrical configuration required than a cast-in-place concrete lining. In contrast to the contract design, the spray-on process allows for a smooth geometric arrangement of the bifurcation between the tunnel and the trumpet-shaped east portal.

The shotcrete final lining designs entailed structural computations, design drawings that depict the lining geometry, design details, and application procedures along with method statements.

The contract drawings showed a rounded tunnel portal with a complex geometrical form resulting in three dimensionally-curved sidewalls and roof as well as a trumpet-shaped enlargement for the portal area. For the mined section, the contract design specified straight, cast-in-place concrete sidewalls monolithic with the roof arch. The station transitions consisted of varying height cast-in-place vertical walls leading to a varying dimension roof segment.

To optimize flexibility and facilitate tunnel access, the construction method was redesigned in two value engineering efforts. A-frame forms were used for the sidewalls in the mined station sections. The curved sidewalls for the portal structure were converted to straight walls that complied with the contract's geometrical dynamic envelope requirements and enabled similar forming systems for both areas. For the roof portion, reinforced, high-quality shotcrete was used to form the complex contours optimized to the existing rock profile. The shotcrete reinforcement comprised lattice girders, steel wire mesh for the mined sections, and reinforcing bar for the open cut section. The membrane tunnel waterproofing was extended to the portal face wall to protect the permanent portal structure against water infiltration. The portal canopy was backfilled with structural backfill.

The VECP process requires the contractor to delineate and provide the following specific aspects of their VECP:

- Description of the existing contract requirements that are involved in the proposed change;
- Description of proposed changes;
- Difference between existing requirements and the proposed changes, together with advantages and disadvantages of each;
- Itemization of the contract requirements that must be changed if the VECP is approved;
- Justification for changes in function or characteristics of each item and effect of the performance of the end item, as well as on the meeting of requirements contained in the mandatory documents;
- Date or time by which a change order adopting the VECP must be issued to obtain the maximum cost reduction including any effects on the project schedule;

Fig. 3: Portal structure shotcrete application

- Cost estimate for existing contract requirements compared with contractor's cost estimate of the proposed changes; and
- Cost of development and implementation by contractor.

The shotcrete permanent lining generally had to meet the same criteria in terms of durability, reflectivity, and smoothness as specified in the contract design for the cast-in-place concrete lining. The shape and evenness of the shotcrete liner in both radial and longitudinal direction was achieved using lattice girders and indicator pins (tell tales). For further control, straight edges were used when completing the finishing shotcrete layer. The surface quality was typical of state-of-the-art spray-on shotcrete surface and current shotcrete lining standard practices.

The shotcrete surface applied in the transitions, tunnel, and portal arch had little impact on the reflectivity and illumination characteristics of the transition sections. Its surface finish will allow for regular maintenance.

Although the surface finish is rougher than a cast-in-place concrete finish (mainly due to the aggregate size) a negative impact on ventilation performance of the tunnel structure was not anticipated due to the size relationship between the tunnel openings and the very small increase in the surface roughness. The surface and shape qualities of the shotcrete final lining therefore met project requirements. To prevent spalling in the event of a fire, polypropylene (PP) microfibers were added to the mixture. This observation corresponded with the findings of other international tests that have been reported in literature reviewed in preparation for this project. Polypropylenes belonging to the polyolefin group, which are plastics that are extremely resistant to chemical and mechanical influences. Polypropylene (PP) only consists of carbon and hydrogen atoms—no toxic substances are created when they are burned completely. Typical PP fibers melt at 302 to 320 °F (150 to 160 °C). As a result, the permeability of the concrete with PP fibers is increased in the event of a fire. The additional pore volume created when the PP fibers melt enable moisture vapor produced to be better distributed and escape from the surface. This reduces the risk of explosive-like spalling substantially because the concrete's permeability is increased in the event of a fire.[1]

The shotcrete lining design therefore incorporated the addition of 2.0 lb/yd^3 (1.2 kg/m^3) PP fibers in the last (inner) 4 in. (101.6 mm) thick layer. A cement-based, epoxy-enhanced sealing coat was finally applied in the portal vault section that is exposed to annual temperature fluctuations. No special treatments were required in the transition areas because their interior location is not exposed to excessive temperature fluctuations.

Quality assurance was a significant concern and instrumental in obtaining approval of the VECP. Apart from the standard compatibility and strength test of the shotcrete mixture prior to construction, the shotcrete mixtures were tested as to their sprayability. A series of test panels were sprayed using the site equipment to assess the suitability for 100% encapsulation of all reinforcement elements as required for the permanent lining. Particular attention was paid to the ability of fully encapsulating the lattice girders in shotcrete without voids. Following the successful test series of the shotcrete mixture, field trials were carried out on standard test panels 3 ft x 3 ft x 8 in. (0.9 m x 0.9 m x 203 mm) thick with reinforcement that simulated field conditions. Vertical and overhead panels were created. Cores were retrieved and tested in accordance with ASTM. Compressive strength tests were carried out in accordance with the specified strength and strength gain requirements. The test panels were also saw-cut for visual inspection of complete reinforcement encapsulation. With regard to the shotcrete application, the shotcrete nozzlemen experience is a key factor in assuring quality of the shotcrete product. The contractors took the following measures to assure a quality shotcrete application:

- Nozzlemen for the project were qualified in accordance with the guidelines set forth in ACI 506.3R.* Two examiners, approved by ACI, qualified the nozzlemen for installation of shotcrete at the project; and
- Additionally, a procedure was submitted and approved by the owner by which a nozzleman may be qualified by performing field test panels that demonstrate his/her ability in performing the work.

In addition to the preconstruction field trials with standard test panels, a mock-up was constructed that replicated the conditions to be encountered in the tunnel. The entire work cycle from spraying the shotcrete through the first layer of welded wire fabric against the PVC membrane to the application of the finishing layer with the addition of PP fibers had to be simulated by this field trial. The test included spraying through and encapsulating a lattice girder.

Every candidate had to spray a vertical and an overhead panel to demonstrate their skill in shotcreting. Each panel measured at least 30 x 30 x 8 in. (762 x 762 x 203 mm) deep and contained reinforcement that simulated anticipated field conditions.

Subsequently, the panels were saw cut and observed by the project engineer (PB) and two ACI examiners who provided their observations on quality of the test panels and recommendations regarding the use of the nozzlemen on the project. Visual inspection examined reinforcement encapsulation and verified a lack of segregation and proper consolidation.

Fig. 4: Installation of second layer reinforcement

** Editor's comment: ACI 506.3R has now been withdrawn and replaced by the ACI Shotcrete Nozzleman Certification Program as detailed in ACI CP-60 (02).*

The examiners consisted of Consultant George Yoggy and one representative of Gall Zeidler Consultants, LLC. During construction, quality control panels were sprayed concurrently with the shotcrete final lining installation for each 200 yd^3 (153 m^3) of material used in the shotcrete lining. Three core test specimens from three panels were retrieved and tested in accordance with ASTM C 42 for each 200 yd^3 (153 m^3) of shotcrete applied.

The VECP was intended to be installed in four areas of the structure:

- The east tunnel—station transition;
- The west tunnel—station transition;
- The mined tunnel section at the east portal; and
- The east portal open cut section.

On either side of the station, the running tunnel transitioned from approximately 34 x 24 ft (10 x 7 m) high to a 65 x 34 ft (20 x 10 m) wide station cross section.

Approximately 130 ft (40 m) of mined tunnel at the east portal was equipped with lattice girders and a final shotcrete lining. The open cut section then extended approximately 30 ft (9 m) outside the rock portal. Widening of the tunnel cross section commenced within the mined section. The overall tunnel height and width was increased in a smooth transition from the running tunnel size to the maximum height of approximately 23 ft (7 m) and 55 ft (17 m) width.

The application of shotcrete was carried out using robotic spraying equipment operated by trained personnel. Experienced, skilled supervision ensured uniform application and quality in accordance with the project requirements. Hand spraying was only used in the shaft for the initial ground support and smoothing shotcrete application and other small areas with restricted access. High quality wet-mix shotcrete was employed throughout.

Shotcrete was applied in a series of stages where the reinforcement members were progressively encased, thus avoiding the spraying through multiple layers of reinforcement and avoiding shadowing. Reinforcement dowels protruded from the cast-in-place walls into the roof portion, over-lapping with the welded wire fabric. The first shotcrete layer was applied against the waterproofing membrane and the outer reinforcing layer of welded wire fabric. The welded wire fabric facilitated the application of the shotcrete against the membrane and provided a supporting mechanism for the wet shotcrete. The subsequent shotcrete application to the full design thickness was carried out in subsequent steps that were executed within a time frame not exceeding 72 hours. This sequence resulted in an overall continuous shotcrete application.

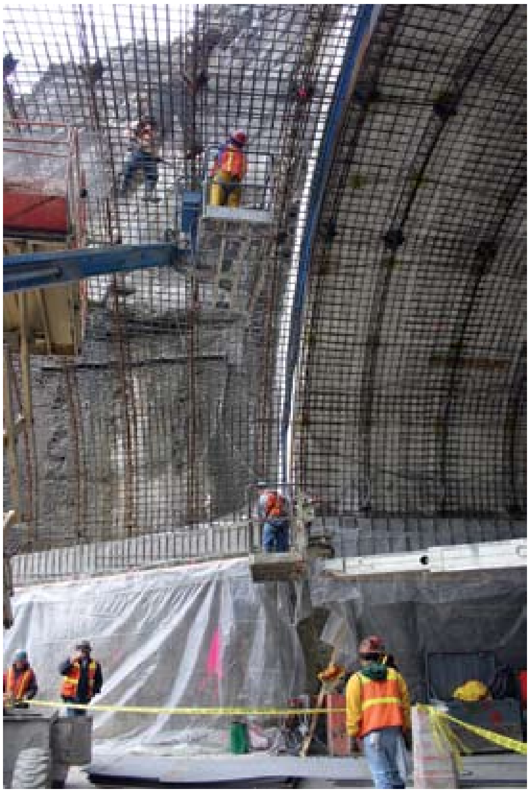

Fig. 5: Reinforcement installation in the open cut section

Grout hoses were installed in the longitudinal tunnel direction to serve as grouting ports for contact grouting any voids after completion of the shotcrete lining installation. The hoses were attached to the PVC waterproofing membrane. A very small amount of contact grout was placed indicative of the high quality shotcrete installation.

Shotcrete was initially applied from the bottom of the haunch proceeding to a maximum of five lattice girder bays and repeated on the opposite side. Following that, shotcrete was placed along the lattice girders in an alternating sequence on both sides of the tunnel until the lattice girder was encased in shotcrete over the entire arch length. Excess shotcrete was then removed from the intrados bar of the lattice girders.

If required, additional deck chairs were mounted behind the exposed mesh reinforcement to strap back any sagging part of the waterproofing membrane. Following that, the bays between the girders were filled with shotcrete, starting from the haunch up to the top of tunnel in alternating sequences from both sides of the tunnel.

The second layer of mesh was fixed on to the tie wires previously placed and protruding from

Fig. 6: Template bars

Fig. 7: Installation of second layer reinforcement in the open cut section

the shotcrete surface. Thickness indication pins were installed in the first shotcrete layer to ensure the required thickness of the second shotcrete layer to be installed following the wire mesh installation. Surveying was used to process data and mark out the neat line. A No. 3 bar, radially installed on the indicator pins, was used to set out the required shape and profile for the second shotcrete layer.

The shotcrete surface forming the substrate for the subsequent shotcrete application was cleaned by power washing. Upon completion, the pins and indicator bars were cut and removed.

To ensure adequate tunnel profile of the final product, studs mounted on the lattice girders were used for thickness and shape guidance.

After completion of the final shotcrete layer at the east portal open cut area, a thin cement-based sealant was applied to enhance concrete durability under variable climate conditions. On top of the east portal open cut shotcrete canopy, a smoothening shotcrete layer was installed covering the expanded metal sheets to prepare for the waterproofing system installation.

Fig. 8: Shotcrete application

Upon completion of the construction of the shotcrete canopy, the portal head wall was constructed and connected by reinforcement protruding from the shotcrete canopy.

The use of the cast-in-place concrete sidewalls in combination with high-quality shotcrete to form the complex transition geometry proved to be successful at the Weehawken Tunnel Project. The timely completion in accordance with the contract quality requirements demonstrated that a combination of traditional and modern construction techniques can provide state-of-the-art solutions to challenging project requirements.

The Weehawken Tunnel/Bergenline Avenue Station Project encountered substantial obstacles. Through the contribution and dedication of the individuals involved, a high quality, technically successful project was constructed.

New Jersey Transit has not endorsed this article. The contents are for informational and educational purposes only.

References

1. Brux, G., “Fire Resistant Shotcrete in the Gotthard Base Tunnel,” Tunnel 5, 2005.

Fig. 9: Completed portal structure

Outstanding Underground Project

Project Name
Weehawken Tunnel/Bergenline Avenue Station

Project Location
North Bergen, NJ, and Weehawken, NJ

Shotcrete Contractors
Joint Venture: Frontier-Kemper Constructors, Inc., J.F. Shea, and Beton- und Monierbau (FKSB)

Design Consultant
Gall Zeidler Consultants, LLC (GZ)

Project Owner
New Jersey Transit/
Hudson-Bergen Light Rail Transit System

Architect/Engineer
Parsons Brinkerhoff Quade and Douglas, Inc.

Material Suppliers
Allentown Equipment LLC, BASF Admixtures, Inc., Propex Concrete Systems, Janod Contractors, and Boulderscape, Inc.

General Contractors
Washington Group International,
21st Century Rail Corporation