WORLD TUNNELLING

WORKING TOGETHER PRODUCES RESULTS IN WEEHAWKEN

Under a public-private partnership between New Jersey Transit and Washington Group's 21st Century Rail Corporation, a light rail transit line is being constructed between Bayonne and Ridgefield via Jersey City, Hoboken, Weehawken, and North Bergen. The Weehawken Tunnel Project consists of the rehabilitation of a 1,275m long, 7m wide excavated tunnel from a double-track freight rail to a double-track light rail system. The project includes a large underground station cavern, a 12m diameter elevator shaft, and extensive portal slope stabilisation and drainage measures.

The Weehawken Tunnel and Bergenline Station project cannot be viewed as a typical highball tunnel project, the construction is more like a dental procedure requiring infinite skills and experience. It is an endeavour to complete a very difficult and challenging job safely and rapidly, and is being constructed successfully only through a spirit of cooperation between the four major entities involved.

New Jersey Transit has contracted out Design Unit N30 construction and operation of the Hudson-Bergen Light Rail Transit System, The Weehawken Tunnel-Bergenline Avenue Station, to Twenty First Century Rail Corporation, a consortium comprising Washington Infrastructure Corporation, the American arm of Japanese rolling stock builder Kinki Sharyo, and Itochu Rail Car. Parsons Brinkerhoff (PB) designed the Tunnel and Station for New Jersey Transit. Washington Infrastructure Corporation is managing the construction by the joint venture of Frontier-Kemper Constructors Inc., J.F. Shea Construction, Beton und Monierbau Gesellschaft M.b.H. (FKSB) which is the tunnel contractor under a subcontract to Washington Infrastructure Corporation. Jacobs Associates also worked as a subconsultant for 21st Century, the Design-Build-Operate-Maintain (DBOM) contractor to the Hudson-Bergen Light Rail System.

Night view of the New York skyline from the Weehawken tunnel's east portal

History

The existing Weehawken Tunnel approximately 1,269m long construction was started in 1881 using drill blast methods with 10 headings from 4 shafts (2 per shaft) and two portals east and west. 450 men were engaged in the excavation and the tunnel was completed and put in service in 1883 for the owner, New York West Shore and Buffalo Railroad. Approximately 70 per cent of the tunnel was unlined with the rock unsupported, nine sections required brick support in the crown and rock masonry sidewalls. The brick lined sections ranged from 6.7m to 108m; the four rectangular shafts approximately 2.43m by 4.9m in plan were spaced at intervals of 258m along the tunnel. One shaft remained open to the surface the remainder were bricked and backfilled. The tunnel provided the first train access through the Palisades to the Hudson River, the costs and ensuing problems resulted in the bankruptcy of the railroad and the company sold to the New York Central Railroad (NYC) in 1885 and re-organised as the West Shore Rail Road Company.

Within a few years, the NYC finished the Weehawken Freight Terminal complex completing the original plan. This included; a dozen piers, two grain elevators, passenger, ferry and freight terminals, locomotive roundhouse and turntable marine repair shops and an ice house all serving twelve piers that occupied over a mile of Hudson River waterfront. With its completion the Weehawken Terminal became the NYC's major freight facility in New York Harbor.

The West Shore Railroad promoted suburban development along its route and farmland was transformed into middle-class housing developments. However, rider ship declined following the opening of the George Washington Bridge in 1931. Then in 1937, the Lincoln Tunnel provided a second automobile route almost parallel to the West Shores Weehawken 42nd Street ferry crossing, finally the construction of the Tappan Zee Bridge and New York Thruway in the 1950's spelled the doom of the passenger service on the line.

Until 2001, Conrail's River Line used the West Shore right of way including the tunnel to carry most of the rail freight to and from New York Harbor through New England, upstate New York and Canada. This service shifted west to the Conrail Northern Branch Line to allow for construction of the current Hudson-Bergen Light Rail passenger service that now follows the West Shore alignment through the rehabilitated Weehawken Tunnel north into Bergen County.

Geology

The project area is very similar in geology to the Bergen Tunnel Project recently completed a few miles south. The tunnel is located in a mountain range commonly known as the Palisades that extend along the west shore of the Hudson River from the Newark, New Jersey area to Rockland County, New York. The Palisades Sill is made up of a two-layer intrusive mass that is up to 305m thick, along the contact margins the sandstones were metamorphosed to quartzite and the shales to hornfels. The bedrock of the Palisades is a grey to dark grey fine to medium-grained, diabase composed primarily pf pyroxene and plagioclase feldspar, the majority of tunnel excavation is in this formation. The rock is extremely hard and difficult to drill and blast.

Project Description

The Weehawken Tunnel was divided into two running tunnel sections separated by the Bergenline Cavern Station in between. The running tunnel east is about 636m long with five brick-lined zones, and the running tunnel west is about 228m long with three brick lined sections. The existing tunnel is approximately 8.2m wide and 6.7m high. The design requires the running tunnel to be enlarged to about 10.4m wide and 7.3m high to facilitate placement of a final concrete lining and other structures for the light rail system. Initial support will be with number 9 grade 70 epoxy coated deformed bars and 100mm of shotcrete designed for long term ground support. The dowels are fully encapsulated cement grouted. At some localised areas, the running tunnel will remain unlined. The areas chosen are considered good quality rock. The final tunnel lining will consist of 300mm to 400mm reinforced cast-in-place concrete.

Centre heading and station slash rounds being drilled

Bergenline Station Cavern

At the station cavern area, the tunnel will be enlarged up to about 19.8m wide and 10.4m high. Station depth from top of rail to finish ground line at Bergenline Avenue is approximately 49m. Ground conditions for excavation of the station cavern are classified as fair (4 to 10) according to the Q-System. Excavation sequences and maximum opening widths and round lengths are specified to maintain opening stability. Rock dowel lengths vary between

MBT at Weehawken

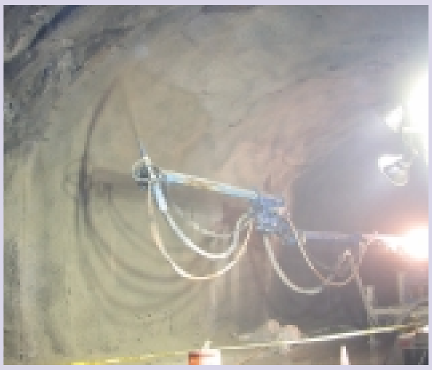
The plan to refurbish the Weehawken tunnel began several years ago, and Master Builders Underground Construction Group was involved from the start, providing a "total solutions package" of products, equipment and expert service.

Members of Group worked closely with the joint venture partners to design and optimise a "MBT/UGC Total System Concept" of concrete mixtures, equipment and service for the specific challenges of the Weehawken Tunnel project.

Excavation and Ground Support

During the excavation process, Master Builders helped to develop and service this innovative ground support system consisting of anchored rock bolts and/or high performance shotcrete products to ensure structural stability and safety on the project.

The concrete for ground support throughout the project is being supplied by Eastern Concrete. Together with the Master Builders UGC specialists, several steel fibre reinforced shotcrete mixes were developed to provide structural support. Depending on specific requirements, shotcrete mixes for ground support utilise various combinations of high performance Master Builders admixtures. Glenium 3030 high-range water-reducer is being used to provide excellent shotcrete pumpability while maintaining a low water-to-cement ratio. Rheomac SF 100 silica fume mineral admixture is incorporated for improved strength and durability, which eliminates the welded wire fabric specification. Delvo Stabilizer admixture is included to control the open time of shotcrete to match the logistical and application needs, eliminating unnecessary disposal of shotcrete after 90 minutes. Novotex (0630) steel fibres provide the necessary toughness indices required for ground support. Meyco SA 160 shotcrete accelerator provides early strength development, also necessary for ground support, and Meyco RBA Grout is used for anchoring all rock bolts and dowels because of its non-shrink, high strength pumpable grout properties.



Meyco shotcrete robot in use at the Weehawken tunnel

Shotcrete is being applied in the tunnel using an MBT Meyco Potenza robotic shotcrete machine for applications in unsupported ground. The robotic arm extends to reach unsupported areas while the operator works from a safe distance. Shotcrete in the station and in the escalator shaft is being applied using an Allentown Elite 40 Pump. The Elite is a pump designed exclusively for shotcrete application and it features an integrated dosing system for the accelerator that results in superior overall material performance.

Work Above Ground

In addition to work underground, there is also work above grade on the Weehawken Tunnel project. The East Portal entrance to the tunnel is near the Hudson River, highly visible to the public, so aesthetics are very important. The rock face of the portal above the entrance is being preserved and strengthened by installing grouted rock bolts covered with shotcrete that will ultimately be "carved" to mimic the natural face and will provide a more stable, safer structure. An Allentown Magnum pump is being used to grout the rock bolts that will later be coated with dry process shotcrete to reinforce the rock cliff using the Allentown Piccola pump. Master Builders is providing CHROMIX coloring admixtures to help match the colors of the surrounding rock facades.

3m to 5.5m depending on cavern and transition opening width. To check the adequacy of the rock dowel pattern against block failure mechanism, the computer program UNWEDGE (1992) was used. Support along the sidewalls consists of pattern rock dowels depending on the height of the sidewall. Final lining will consist of 600mm of reinforced cast-in-place concrete on the sidewalls and crown of the station and lattice girders and fibre-reinforced shotcrete in the crown of the transition area in both running tunnels.

Bergenline Station Shaft

The shaft excavation is 12.8m in diameter and about 30m deep. The ground conditions for excavation in the shaft are classified as fair to good (7.5 to 12.5), according to the Q-System, as modified for shaft construction. Size, length and spacing of the rock reinforcement necessary to resist rock wedge forces were checked using UNWEDGE. The program analysed the stability of wedges formed by three joint sets. The analysis indicated that the rock dowel pattern would provide a minimum safety factor of 1.5. Based on these considerations, a staggered rock dowel pattern 1.5m (vertical) by 1.8m (circumferential) with 3m long dowels was shown. Rock surface protection mesh (welded wire fabric) or fibre reinforced shotcrete will be placed to provide support of loosened rock between the patterned dowels. A 450mm thick reinforced cast-in-place concrete liner will be installed.

Waterproofing

A waterproofing and drainage system will be installed to minimise seepage into the running tunnels, station and shaft, and provide a drainage path for groundwater behind the final concrete lining. The system consists of a drainage fabric, a waterproofing membrane, and attachments. To minimise the potential for damage to the drainage fabric and waterproofing membrane during installation over the initial ground support and rock surface, application of plain smoothing shotcrete will be required to reduce rock surface irregularities and to cover rock dowels. Specifications include leakage criteria.

- 0.82 litres/m^2 of lining per day over 91m of tunnel
- 0.0012 litres/sec from any single leak.

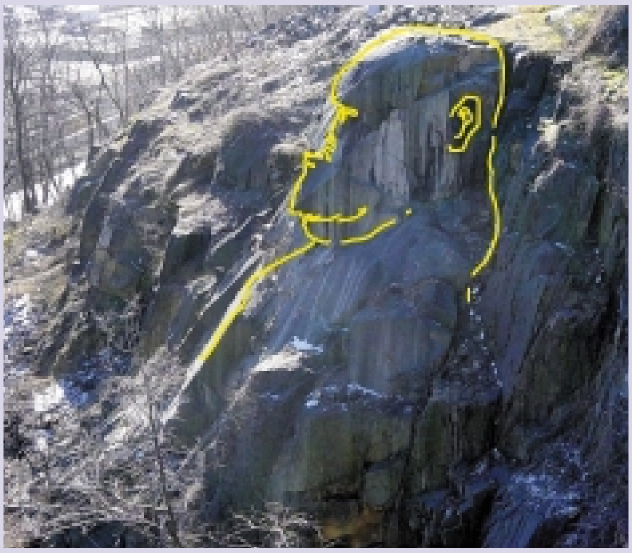
Construction

With the award of the subcontract, the joint venture mobilised on site and subcontracted to Fleet Wash the removal of soot, built up from over 100 years of coal and diesel locomotive operation in the tunnel. To satisfy environmental requirements the soot had to be removed is such a manner to prevent its disbursement, necessitating complete containment including the wastewater.

FKSB performed the initial high scaling of the rock cliffs surrounding the east tunnel portal utilising a suspended personnel platform. With the initial scaling completed FKSB demolished the existing east portal structures. Janod, a Canadian specialised firm (see separate box), was subcontracted to do extensive additional high scaling

Weehawken tunnel east portal

Weehawken Tunnel Portal Stabilisation



Representation of the Gorilla's Head rock

The Tunnel Portal was a difficult stabilisation project for a number of reasons. The original design called for pattern bolting and wire rope nets to stabilise and contain any loose material. The original design did not take into consideration the historic and visual importance of the Palisades. The mayor of Weehawken, Richard Turner, found the concept of having wire rope nets draped all over the slope unacceptable. Mayor Turner knew how important the visual impact of the slope was to his constituents.

There was one structure in the slope the locals referred to as the 'gorilla's head'; the original design recommended removing it before the installation of the mesh and bolts. If the work was allowed to proceed the rock face would have been altered. The mayor had put a stop order on the work at the portal until an acceptable solution could be found.

Janod Inc. and Golder Associates came forward with the proposal of stabilising the slope using a combination of rock bolts and steel fibre reinforced shotcrete and then non fibrous shotcrete to sculpt and colour to make all the remedial work "disappear". This innovative approach was accepted by Mayor Turner, the stop work order was removed and the work proceeded. In order to coordinate the work being performed in the tunnel and the work on the portal, Janod and Golder worked off ropes for all the drilling and part of the shotcrete operations. This allowed Frontier Kemper to use the area below the slope as a temporary storage area for the muck coming out from the East end of the tunnel. Flagmen were posted at the portal entry to make sure that the area was safe before any men or equipment were allowed to pass below the crews working on the slope.

Because of time restrictions on the project it was set up as a design build. This allowed the design to proceed as the work was performed. The first step was to scale the slope to allow the engineering geologist to rappel down and visually survey the rock structures before deciding on the final design. The engineering geologists worked hand in hand with the rock remediation technicians to come up with the final quantities for bolts and shotcrete. Drill logs were taken and the actual final lengths of bolts were decided in the field. The final quantities for the remedial work are as follows:

Rock Bolts	2,538 linear metres
Steel Fibre Reinforced Shotcrete	181 cubic metres
Coloured Sculpted Shotcrete	3,420 square metres

In the end this project proved that remedial measures can be performed without having a negative visual impact and can go on without affecting work at the base of the slope.

followed by bolting of the rock cliffs surrounding the east tunnel portal. Special derricks were erected and cables were installed to handle the men, equipment and materials to produce a clean safe face. After the removal of the soot, FKSB proceeded with the removal of the existing ballast and lowering the high rock areas along the tunnel invert to required grade with several hydraulic hammers mounted on hydraulic excavators. The excavator size was determined by width that would permit tunnel trucks to pass and enable working in several areas at one time without blocking the tunnel. The excavator selection dictated the maximum hydraulic hammer size. The hammers were also utilised to create drainage troughs at both ends of the tunnel.

The Weehawken tunnel houses two electric duct banks with existing in-service 230-kV oilostatic (pressurised oil conduit) in place along the invert sidewall corners of the tunnel. Both banks had to be relocated to a pair of new duct banks within the tunnel invert. This work was critical as the power cables are part of the Northeast Electric Grid supplying power to the area, and had to remain in service until the new ducts were in place.

Prior to relocating the existing duct banks, the elevator pit was excavated. The pit, located at the bottom of the station-shaft intersection, was excavated as close as 0.7m from the existing service. Specifications outlined blasting limitations, blast design requirements, and blast monitoring requirements for blasting close to the duct banks. Two-test blasts were conducted in the tunnel to correlate powder factors and distance to observed strain and vibration level on the duct banks. The pit was successfully excavated within the very close criterion of 500mm/sec for vibration levels in the duct bank.

Demolition of the existing structures in the area known as Kennedy Plaza was completed and the site cleared. Moretrench American Corporation was subcontracted for the installation of drilled in place soldier piles and lagging in the overburden for temporary support of the excavation. The overburden excavated and the foundation footprint of the elevator

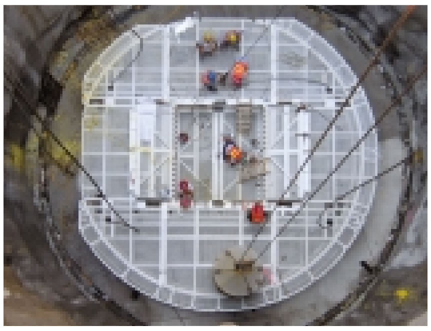
Liebherr excavator fitted with side bucket used to rip off old brick lining

headhouse building that will be erected over the shaft was excavated in rock. Two concrete pedestals were constructed to provide a level surface and support the raise bore equipment substructure framework.

Frontier-Kemper's Ingersoll Rand RBM-7SP raise bore drill and support equipment was utilised to drill a 350mm (14in) diameter pilot hole and then raise a 2.5m (8.25ft) diameter bore. Once the pilot hole was completed. The raise bore head was carefully aligned and blocked on cribbing for attachment to the drill steel. The collaring of the raise had to be done perfectly to prevent unbalanced forces that were created by the irregular surfaces as well as curvature of the existing tunnel arch. Frontier-Kemper's extensive experience in drilling hundreds of raises to great depths for mine ventilation provided the necessary skills required for a successful operation.

The raise bore unit with all accessory equipment and foundation was removed and a plug manufactured to cover the raise opening after completing the raise. On May 14th hydraulic and pneumatic track drills were utilised to drill out the rounds. The material blasted was loaded into the raise using a backhoe where it fell to the tunnel floor and was loaded into articulated rock trucks, taken to the East portal, stockpiled and later removed using tri-axle highway trucks for off site disposal. The shaft support consisting of rock bolts and shotcrete was placed and the shaft approximately 30m deep was excavated to the new crown elevation of the station with 8 lifts and completed on September 23rd. A shaft cover was erected with two New Era 40 HP stage winches anchored to handle the contractor fabricated work platform and form carrier. The PVC membrane-waterproofing system was installed the full depth of the shaft and concrete-lining operations started using the shaft work platform and form carrier. At the time of the visit November 4th the first 5m pour was completed and the form raised, there are four additional 5m pours and one shorter pour that will complete the shaft and encompass the foundation slab of the elevator headhouse building.

Enlarging the running tunnels in the brick section was accomplished using a Liebherr model 932 excavator with an articulating boom section. The boom articulation in conjunction with a quick tool coupling permits the utilisation of buckets, rippers or an hydraulic hammer enabling the operator to select the best attachment as well as align to the brick contour to rip, pull or pulverize the brick. The enlargement in the rock section utilized three hydraulic drill jumbos. An Atlas Copco H-245 two boom and basket unit, an Atlas Copco H-145 two boom and basket unit and a Tamrock two boom and basket Paramatic 205. The tunnel transition zones were completed with initial rock dowel and ground support installed. Excavation in the station transition was completed to the station cavern. Shot rock left in the invert provided an elevated working area for the jumbos to reach the cavern crown.



Work deck stage in shaft

In the transitions zones, sidewalls 3.048m high and 457mm thick will be placed on top of footings then a smooth coat of shotcrete will be placed along the transition arch and a PVC waterproofing membrane system installed. Lattice girders will then be installed on top of the sidewalls and shotcrete placed in the crown for the permanent lining. The station cavern excavation will performed utilizing conventional drill and blast methods. The excavated area is initially support using pattern rock dowels and shotcrete. A MEYCO spraymobile and an Aliva AL-500 spraying mobile, one on either side of the tunnel are applying all of the shotcrete. The 304.8m long station will have a centre platform for the two tracks; three elevators will service the platform from the surface. The crown will be concrete lined and the sidewall columns will enable the rock to be visible from the Station area.

The existing west portal is to be demolished after the material above is excavated and stabilised by stepping back in four benches using an excavator and hydraulic hammer. The benches will be shotcreted and bolted with 5.5m and 8.2m bolts. A new portal will be constructed to replace the demolished area. A large catch basin is being excavated in sandstone on the side and above the portal to trap and divert the groundwater to the invert.

Two trenches have been excavated along the rib in the west tunnel and a concrete wall approximately 1m high placed. A 203mm perforated pipe cast in popcorn concrete for drainage sits on top of the wall and the starter strip of the PVC waterproofing membrane system attached to the surface. PVC pipe connections stick through the waterproof membrane to carry the drainage to a central drainage discharge pipe to be installed below the track slab. Concrete footings will be placed and the tunnel formed for lining to the transition.

Presently, the drilling and controlled blasting of the station sidewalls and crown in the station area is almost complete. Bench and footing excavation is proceeding from the transition areas through the station to complete the rock excavation. To enhance concrete availability an on site concrete batch plant and material storage bins are being erected on a concrete foundation.

Conclusion

As expressed earlier this is a dental job requiring scheduling rivalling a ballet choreography. An extremely aggressive schedule exasperates the planning. Every step of the excavation sequence had to be carefully planned to allow multiple work areas. Beginning with the initial track removal and soot cleaning, the electrical duct replacement with no interruption of service and the meshing of the shaft excavation while the tunnel work kept progressing during this time was a feat in itself. The restrictions required by the State of New Jersey limiting the blasting operations to only a short window during the day and all personnel must evacuate the tunnel during a blast severely limits the time period that work can be accomplished.

Talking with the Owner, Engineer, Construction Manager, Inspectors and Quality Assurance personnel a common theme emerged. It is a very difficult project and we have had problems, but these appear to be receding and cooperation between all the parties is coming to the forefront. Working together, including harmony between all the trades, while maintaining safe conditions in effort to complete the project in a timely fashion are the paramount mutual goals.

Acknowledgements

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