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ABSTRACT

When the World Trade Center was destroyed the transit link connecting Lower Manhattan and New Jersey, the Port Authority's Trans Hudson system or PATH, was cut. The PATH station, which was located beneath the WTC, was destroyed, the two tunnels under the Hudson River were flooded, and the first PATH station in New Jersey was rendered useless for train movements. Immediately after Sept 11, the re-establishment of the downtown PATH service was identified as a key element in the revitalization of Lower Manhattan. The re-establishment of PATH service required that three elements of major construction be completed. These were the construction of a new temporary PATH station in the basement of the old WTC, the complete refurbishment of the Hudson River tunnels, and creation of a temporary terminal station at Exchange Place. The new WTC PATH station is founded on footings on bedrock, while the connecting pedestrian corridors are founded on the caissons that originally supported the WTC Plaza. The reconstruction of the PATH river tunnels required the complete gutting of the tunnels to remove all the electrical systems, duct banks, and track bed, which were 100 years old. The electrical and signal systems were replaced with modern systems and the original timber tie and ballast track bed was replaced with a direct fixation rail system. In order to reconfigure the Exchange Place station into a terminal station a system of track crossovers was mined through rock on the west side of the station. The tight 18-month schedule hinged on the new tunnel lining design. The schedule would not permit construction of traditional cast-in-place concrete linings. The Port Authority selected a more rapid construction option for the final lining, fiber-reinforced, sprayed-on-concrete. To maintain schedule, traditional drill and blast mining methods were abandoned and mechanical roadheaders were used to excavate the bulk of the rock removal.

INTRODUCTION

When the World Trade Center (WTC) was destroyed, nearly 30 million square feet of office space was damaged or destroyed. This was 30% of the total Lower Manhattan market. The loss was equivalent to all the commercial office space of either Atlanta or Miami. The impacts on the neighboring communities and regional economy were incalculable.

Aside from the horrific loss of life and commercial property, the WTC also contained a number of key transit lines that are vital to New York City's economy. One of these lines is the commuter rail link that connects Manhattan with New Jersey—the Port Authority's Trans-Hudson System or **PATH**.

PATH'S HISTORY

Construction of the PATH system, originally the Hudson Tunnel Railroad Company, was started in 1874. After many financial and technical difficulties, trans-Hudson service commenced in 1908 and the system was completed in 1911. The heart of the PATH system are the two sets of twin "tubes" that connect New Jersey with midtown and downtown Manhattan. The PATH tubes were some of the first shield driven tunnels in the world (Fig.1). The downtown service originally terminated beneath the Hudson Terminal Building. This twin 22-story office building was the largest office complex at the time. In the 1960's, the building was demolished to make way for the WTC, which in its day was also the world's largest office, complex. The original station was then abandoned after a new PATH station was opened in the basement of the WTC complex.

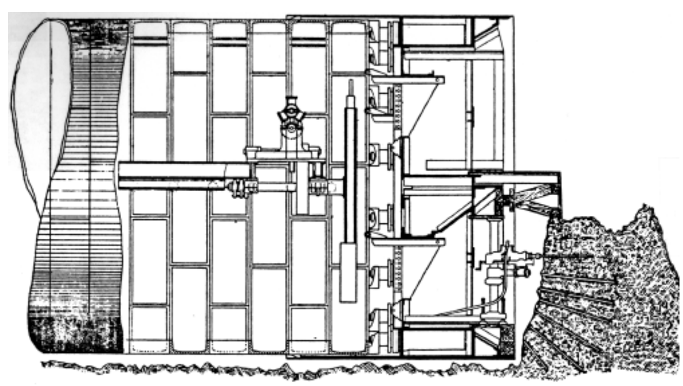
Shield in Soft Material Overlying Rock.

Fig.1 Tunnel Shield circa 1900

Prior to September 11, sixty-seven thousand commuters a day used the downtown PATH service. It provided a vital link for New Jersey residents to the Wall Street area (Fig. 2). In addition, the downtown service provided a reverse commute link for many New York residents commuting to major back office facilities located in Jersey City. When the PATH link was severed alternate commutation routes were established. For many this meant traveling to mid-town Manhattan and then traveling downtown on the New York City subway system. For others, the downtown commute was made by ferry. Two additional ferry slips were constructed on an expedited schedule, providing commuters with access to East, West and South areas of lower Manhattan.

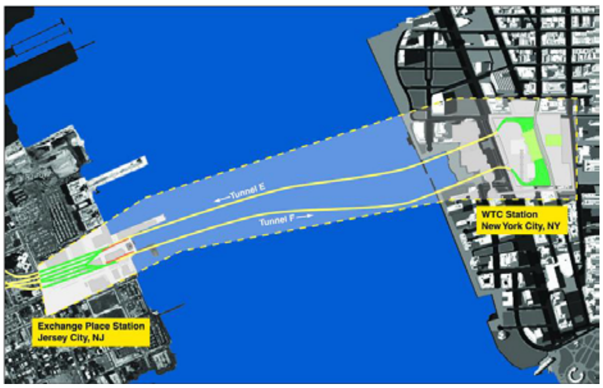

Fig. 2 Downtown PATH Service

Re-establishment of the downtown PATH service has been a key element in the reconstruction and revitalization of the lower Manhattan economy. Although the reconstruction of the WTC site may take many years, the Port Authority recognized that PATH service had to be brought on line as quickly as possible. As an indication of how important the agency viewed restoring PATH service, engineering staff started planning work for the replacement PATH service on September 13, 2001.

CONSEQUENCES OF 9/11

The destruction at the WTC site was nearly complete (Fig. 3). The PATH station was situated immediately east of Tower 1 and the tracks leading into the station passed directly under Tower 2. Although portions of the station were still intact after the towers had collapsed, these could not be preserved during the massive removal process. The track work within the WTC site was also a loss, either being crushed or totally fouled with debris materials.

Hudson River water was used to suppress the WTC fires. This water flooded the river tunnels and caused significant damage.

Fig. 3 WTC Devastation

The Exchange Place station, the first PATH station in New Jersey, was also closed as a consequence of the WTC station destruction. Since Exchange Place station could not operate as a terminal station, train service was diverted away from the waterfront to either the midtown or Hoboken PATH services. Thus, the many thousands of commuters who worked in the Exchange Place area had to walk approximately a mile from the nearest PATH station.

WTC - TEMPORARY STATION

The temporary PATH Station is being built at the same location as the destroyed facility within the WTC basement (Fig. 4). This site selection greatly expedited the track alignment and configuration design, and mitigated the need for property acquisition. The temporary station is a three platform and five-track configuration, similar to the former WTC station. Above the platforms, a mezzanine level has been constructed with stairs and elevators connecting the two levels. The original escalator passageway from the PATH station was found intact and has been incorporated (with new escalators) into the temporary station for egress.

The original column grid and foundations have been reused wherever possible to minimize additional excavation and foundation work. The new PATH station platforms are founded on spread footings bearing on bedrock. The mezzanine and pedestrian corridors, leading from the station to the main entrance on Church Street, are supported on the caissons that once supported the WTC Plaza levels and WTC 5 Building.

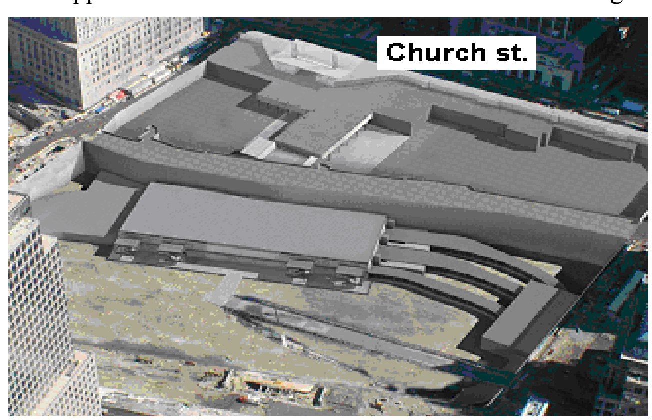

Fig. 4 Temporary PATH Station

Access to the temporary station will be from the east, Church Street. An additional access shaft has been built adjacent to the underpass to provide additional pedestrian and handicap access via stairs and an elevator to street level (Fig. 5). At the Church Street level, existing undamaged structural slabs will be used and restored as needed.

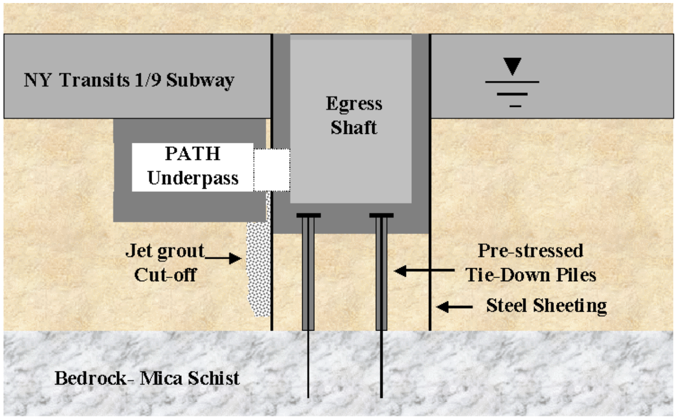

Fig.5 Tied-Down Egress shaft

Local repairs to the original WTC diaphragm wall have been necessary to secure the area for public use. This has entailed the removal of spalled concrete, reattachment of dislodged rebar and the application of sprayed on concrete to reinstate the wall sections. In areas of major damage and areas that had undergone significant deflection due to 9/11, interior wall liners have been constructed to reinforce these distressed sections.

Another component of the development at the WTC site is construction of a public viewing fence and sidewalk. First opened to the public on September 11, 2002, the project involves a reconstructed Church Street sidewalk, public viewing access along Church and Liberty Street, and a fence designed to display graphic panels that describe and illustrate the history of the site, the World Trade Center, and the events of September 11th, including a listing of names of the victims.

RECONSTRUCTION WITHIN RIVER TUNNELS

The river tunnels were flooded shortly after the WTC collapsed. The primary source of water was millions of gallons of seawater water pumped to suppress the fires. The tunnels, being situated at the bottom of the WTC basement, were a natural drain. As the water rose, high capacity pumps were mobilized at Exchange Place and these were able to maintain the water level in the tunnels and prevent flooding of the entire PATH tunnel system. Since the stability of the WTC basement walls was in question, concrete plugs were constructed in the tunnels immediately east of Exchange Place. These were a precautionary measure in the event the walls collapsed and the basement became inundated with groundwater.

The flooding caused significant damage to the under river tunnels. The track ballast became fouled with the fine materials washed out of the WTC debris, and the century old electrical power and control duct banks were flooded with corrosive seawater. This damage was sufficiently severe to require the gutting of the tunnels and the replacement of the track system, tunnel duct banks, electrical systems, and mechanical systems. In addition, the century old tie and ballast track system was replaced with a modern direct fixation rail system. (Fig. 6)

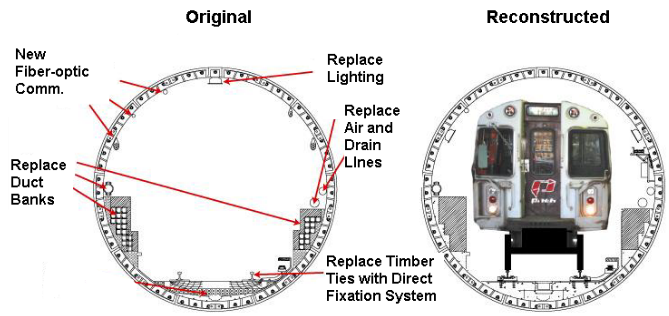

Fig. 6 River Tunnel Reconstruction

Fortunately, the original cast iron tunnel lining was not damaged and had undergone only minor deterioration in the past 100 years. Only minor bolt replacement and leakage repair work was required as part of this reconstruction effort.

EXCHANGE PLACE IMPROVEMENTS

The construction of the track crossovers on the New Jersey side of the Hudson required the merging of five existing rock tunnels (Fig. 7). These were situated beneath three office buildings near the waterfront in Jersey City, NJ.

Fig. 7 Exchange Place Cross-Overs

To meet the accelerated design schedule, subsurface investigations and laboratory tests were conducted concurrent with the design. The proximity of the overlying buildings made sampling in many areas impossible. Thus, in critical areas (i.e. cross-over chambers) rock cores were taken from inside existing tunnels. The rock was mapped using oriented cores to establish rock structure orientations.

The Exchange Place station is situated in a mica schist known as the Manhattan Schist (Fig. 8). The schist has a relatively high mica content and compressive strengths averaging 30 mN (4,500 psi). This is not typical for the Manhattan Schist, which can have rock strengths in excess of 70 mN (10,000 psi). Although the rock strength at Exchange Place is low, the rock quality is high, (RQD aver. 84% and TCR aver. 96%).

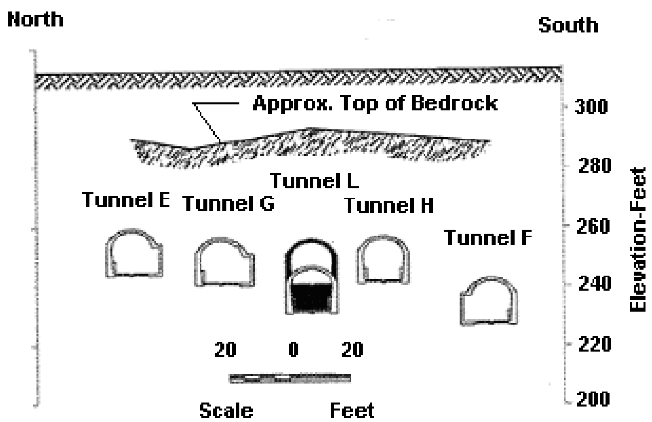

Fig .8 Section through Tunnels

The cross overs required the excavation of rock chambers ranging from 14.5 to 18 m in width. The rock cover above these chambers ranged from 7.7 to 11 m, and thus required a combination of judicious rock removal and the installation of pre-stressed rock bolts, lattice girders, and shotcrete (Fig. 9). Fiberglass rock pins were also used to provide interim rock support to accommodate the complex staging between the various tunnel headings.

The original Exchange Place station was completed in 1910. It was mined using black powder and relatively uncontrolled blasting methods, which resulted in significant perimeter over break. Core samples taken of the existing concrete liners indicated that the liner thickness ranged from 0.3 to 1.2 m, as compared to the design dimension of 0.6 m. The coring also revealed that there were significant and pervasive voids above the tunnel crown.

Crown voids made it imperative that contact grouting be performed in areas adjacent to the enlarged tunnel openings. First cutting slots through the crown of the tunnel, then constructing concrete bulkheads, and then injecting neat cement grout to fill the void, accomplished this. In addition, pre-stressed rock bolts were used in these transition areas to ensure that the lining was engaged and to reinforce the adjacent rock mass.

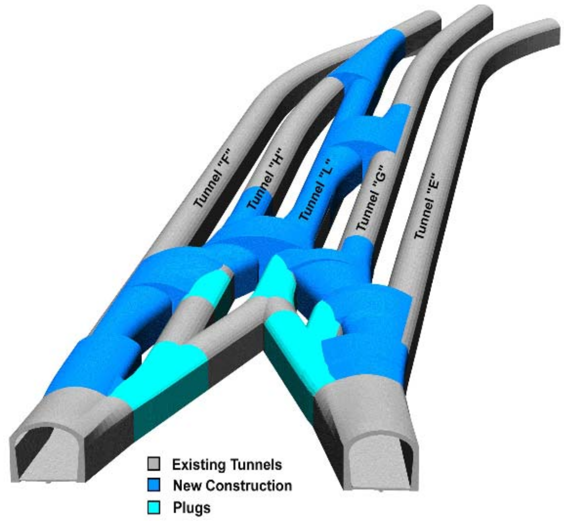

Fig. 9 Crossover Isometric

The combination of the rock removed for the original tunnels and the required rock removal for this project would have created rock cavern dimensions in excess of the rock span capacity. In order to keep rock arch and pillar stresses within acceptable limits, sections of the existing tunnels were backfilled with mass concrete (plugs). This required that voids above the tunnel, between the lining and rock, be contact grouted. Then mass concrete backfill was formed and placed, followed by contact grouting of any voids that may have formed between the concrete backfill and the lining (Fig. 10).

The viability of accomplishing the crossover construction on the tight, 18-month, schedule hinged on the new tunnel lining design. The schedule would not permit the construction of traditional cast-in-place concrete linings. So the Port Authority had to consider a more rapid construction option. Fiber-reinforced shotcrete was selected as the final lining for the new tunnel work. This was selected for the following reasons: rock quality was very high and experience in the area indicated that water inflow would be very low.

Fig.10 Formwork for Tunnel Backfilling

The sprayed-on-concrete lining system consisted of a fast setting concrete mix. The mix was designed to provide an initial strength of 7 mN (1,000 psi) at 8 hours, and a 35 mN (5,000psi) strength at 28 days. The mix was reinforced with 2.5-cm long, high strength (950 mN) steel fibers, at a rate of 47 to 58 kg per cubic meter. The concrete was applied with a wet mix process. The wet mix material was delivered to the tunnels through access pipes drilled from street level. The contractor was required to have equipment available for dry mix application for emergency concrete placement. Fortunately, this was never required and wet mix deliveries were frequent enough to satisfy the lining needs.

The original intent was to use controlled blasting to remove the rock. In an outreach effort, the project team met with the owners of the buildings situated above the work area to explain the blasting methods that would be used, and the instrumentation that would be put in and around their buildings to monitor the blast vibrations and document damage, if any. This instrumentation included crack monitors, seismographs, settlement monitors and bedrock strain extensometers. Initial test blasts indicated that the resulting vibration levels would be sufficiently low to preclude building damage. Although the test blasts were successful from the vibration point of view, over-break control was inadequate. The foliations of the schist were not favorable and over-breaks of 1.5 m were observed in some blasts. This poor blast control, the relatively low strength of the rock, stringent work rules associated with the use of explosives, and added security resulting from the 9/11 attacks prompted the team to investigate the use of roadheaders.

Fig. 11 Roadheader

Traditionally, the Manhattan Schist has been mined using blasting, the schist being considered too hard to be mined economically with roadheaders (Fig. 11). With compressive strengths averaging 30 mN, this region of the Manhattan Schist appeared suitable for roadheader excavation. A small roadheader was brought in from West Virginia and tested. The machine was very productive when it was operating, but required an inordinate amount of repair work to keep running. However, it demonstrated that roadheaders could effectively remove the rock. Orders were immediately sent out for two higher capacity machines and by the time the project reached completion a total of three roadheaders were in operation.

Muck removal and dust control presented another set of challenges. Aside from the logistics of working in five parallel tunnels, all the muck had to be removed through two of the operational PATH tunnels on off-peak commuter hours. In addition, sufficient muck had to be kept on hand to create embankments for the roadheaders to reach the higher arch levels. The other major challenge was dust control. Aside from health considerations, which required workers to use respirators on nearly a continuous basis, a number of dust suppression measures had to be taken to prevent dust from migrating down the tunnels and into stations in the active portion of the system. The measures included foam sprays at the roadheader cutter-heads, scrubber and bag house, temporary tunnel bulkheads, and water curtains.

SUMMARY

This critical program met and exceeded all target dates. The implementation strategy required that multiple design teams carry out their work in a sequence dictated by the critical path of the construction schedule. The various design teams met this challenge. The Contractor also met the challenge. He was constructing elements as soon as the designs were completed, with critical materials identified and procured well beforehand. Tremendous cooperation was required among the project team and decisions made and kept on a fast track basis to prevent any bogging down of the process. To everyone's credit, the cooperative attitude was evident throughout this very successful project.

Exchange Place was put in service on June 29th, 2003 and the temporary WTC station is scheduled to open in the fall of 2003. Designing and building $460 million of construction in less than two years is a major achievement. The Port Authority, its consultants and the contractor team have good reason to be proud.