Fast Tracking a New Interlocking at PATH’s Exchange Place Station

Presented By

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Abstract

As a result of the September 11, 2001 terrorist attacks on the twin towers in New York City, the Port Authority of New York and New Jersey undertook a Herculean task to rebuild the PATH transit station at the World Trade Center. As part of the restoration project the Port Authority chose to lengthen platforms and relocate a five-track interlocking at Exchange Place in New Jersey, which is 80 feet under ground in solid rock. This paper will address the evolution of the modifications at Exchange Place station and interlocking.

Early on many decisions were made and revisited throughout the project to see if improvements could be incorporated while maintaining the aggressive goal of re-opening revenue service at Exchange Place by June 2003. The track design and, in particular, the alignment were on a critical path. Time sensitive decisions were scrutinized to ensure that
the schedule would be met. This was a fast track project in the true sense. Designers were selected from existing on-call consultant lists to augment in-house staff, vendors were contacted and their ability to supply was determined, while a contractor was selected based on qualifications and a bid percentage addition to cost to perform net cost (time and materials) construction.

Introduction

It has been three years since those tragic events on September 11, 2001 and over a year since rail service has returned to PATH’s Exchange Place Station. Exchange Place, located west of Manhattan in Jersey City, New Jersey, was not forced “out-of-service” because of flooding or damage from the September 11th events, but because without turn-back capabilities trains would be trapped in the station. This cessation of service affected 67,000 daily commuters. (See Figure 1)
Previously, plans had been considered to lengthen Exchange Place station platforms for 10-car trains by extending to the east further into the Hudson River. This project was fraught with environmental issues. With the station out of service it was determined to take advantage of the closure and lengthen platforms to the west. Also with the World Trade Center complex out of commission, it was thought that modifications at Exchange Place could be incorporated more quickly and there would be an opportunity to allow turn-back service for trains coming from the west. This turn-back capability would allow trains coming into Exchange Place to return to Newark and Hoboken. This turn-back movement was never previously available at Exchange Place, yet with the World Trade Center Station out of service for a long duration, Exchange Place would, for the near term, have to operate as a terminal instead of a line station.

However, there was one major hurdle: A five track interlocking just west of the station platforms. This interlocking would have to be shifted approximately 150 feet to the west. Additionally, this interlocking would have to be modified to allow turn-back trains to return to Newark or to Hoboken from either station track and new connecting tunnels would be required. On the surface, this does not seem to be to onerous, but Exchange Place station is located approximately 80 feet below grade, in solid bedrock. (See Photo 1)

To achieve the fast track schedule, PANY&NJ established an unconventional partnership between PANYNJ, contractors and many design consultants. The design consultants were selected from on-call lists based on their respective area of expertise. Additionally
the PANYNJ called upon their in-house staff of engineers as well as those from PATH, the rail operating subsidiary, to assist in this effort. The Downtown Restoration Program, as it became known, was divided into three main elements; Temporary World Trade Center Station; Exchange Place Improvements; and Tunnels E&F, which are the two tubes under the Hudson River connecting World Trade and Exchange Place.
The 1900’s Layout of Exchange Place and Adjacent “Wye” Junction

The PATH system including Exchange Place station was constructed by the Hudson Tunnel Railroad company starting in 1874 and with train service commencing in 1908. The Exchange Place station was constructed using drill-and-blast technique, with the rock excavations lined with un-reinforced concrete. The station and the connecting tunnels remained unaltered since the early 1900’s.

In the descriptions that follow, direction is referenced to geographic direction of any tunnel regardless of the assigned normal direction of train traffic. Also, reference should be made to Figure 2 as an aid to understanding the configuration. The cast iron segmented downtown tunnels traverse a horizontal curve moving west at the bulkhead line and enter “basket handle” shaped sections mined in rock 80 feet below grade under the former Pennsylvania RR Station at Exchange Place. The two tracks, E on the north and F on the south are on 125 foot centers with the passenger station platforms on those sides of the basket handle sections between the two tracks. The platforms were barely 370 feet long, enough to just accommodate a H&M (Hudson and Manhattan Railroad, the original operator) 8-car train consist. It must be pointed out that for all rolling stock of the H&M, from the 1907 A-Class cars to the 1957 K-Class cars (the last cars prior to the 1965 PA-Class cars designed and procured by the Port Authority), the front side door of the head car and the rear side door of the last car were locked out (kept in a closed condition at all stations), thus effectively requiring the equivalent of only seven car lengths of platform berthing distance for an 8-car train or about 360 feet. It was necessary
to have the eastern end of the station located at the bulkhead line to provide a convenient
location for the passenger elevators that went to the Pennsylvania RR’s waiting room,
which was at the river’s edge where the railroad’s connecting ferries landed.

**Figure 2 – Exchange Place Interlocking and Lower “WYE”**

Referring to Figure 2, turnouts from tunnels E and F diverged from the main tracks to
form short ladder or crossover tracks leading to tunnels G and H and also these ladder
tracks merged at a trailing equilateral turnout to enter a fifth tunnel, L. The common
element for this interlocking at Exchange Place was the No. 4 turnout. All turnouts were
lateral except for the equilateral proceeding into Tunnel L. That turnout, however, had
curves that were the equivalent of the lateral No. 4’s. Turnouts of No. 4 size would seem
to the modern designer to be very sharp but in fact were typical of other mainline
locations in the H&M tunnel system and on other contemporary rapid transit systems as
well.
The Port Authority Acquires and Upgrades the H&M

The Port Authority of New York and New Jersey is a bi-state agency of the two states, operated for the public’s benefit. Its purpose is the construction, leasing, acquisition, or operation of transportation facilities within the port region and the promotion of commerce and economic activity in that region. By 1962 the operation of the H&M was no longer an economically viable proposition for the private entity as was typical of many local transit operations in the nation. Because H&M railroad service has been vital to the New York/New Jersey region, the H&M property was acquired by the Port Authority Trans-Hudson Corporation or PATH, a wholly owned subsidiary of the Port Authority in September 1962. PATH began an aggressive capital improvements program that included a virtual replacement of the entire fleet of rolling stock, the renewal of the signal system, major repairs to structures, enhancements to system safety, remodeling of passenger stations, reconstruction of track, and a replacement terminal for the original Hudson Terminal: a new terminal under the World Trade Center.

Initial Improvements at Exchange Place

Around 1980, the interlocking layout at Exchange Place became simplified when the crossover from Tunnel G to Tunnel L was removed. This meant that the stub track in Tunnel L could be entered only from the eastbound tracks F or H by trailing over switch 27 and then making a reverse “wrong rail” into that track over switches 27 and 29. This interlocking lost the capability of allowing even shorter-length trains coming from downtown New York to “turnback” if there was a line blockage to the west. The old
H&M No. 4 turnouts were replaced by the new PATH design No. 4 rail transit turnouts, which are based on AREMA switch point details.

As part of an upgrading program at the station, including new escalators, head house, and architectural wall finishes, the existing west end of the westbound platform was revised. This revision involved the demolition of a former interlocking tower which permitted the vacated space to be utilized as passenger platform space for 8-car trains then being implemented for the Newark service instead of the former 7-car trains. Switch 25, which was a PATH design No. 4 which was replaced with a PATH (AREMA-type) No. 5 ½ turnout for reasons of obtaining satisfactory car door edge to platform edge gaps within the limits of the turnout.

**Need for Further Improvements at Exchange Place**

In the mid 1980’s an economic revitalization of the Hoboken and Jersey City waterfront areas came into being. New high-rise office and residential buildings were erected. A new rail system, Hudson-Bergen Light Rail, went into construction in the late 1990’s and its initial segment opened for service in 1999, thereby enhancing further economic activity. The light rail’s Exchange Place station is adjacent to PATH’s station and is an important transfer point between these two rail systems. PATH felt that it was worth revisiting the concept of a turn-back stub track in Tunnel L. The new turnouts would be comparatively easy to implement. The former connecting tunnel from Tunnel G to Tunnel L had been used for a signal bungalow (relay room). The relays in this bungalow would have to be relocated to make way for the new track and this would be more
expensive to implement. The most daunting and expensive element of the proposed project was the required lengthening of Tunnel L at its western end. The original Tunnel L could only accommodate a 6-car train and this would require lengthening its western stub-end to hold any 8-car trains of PATH’s Newark-service. Due to the events of September 11th the implementation of these improvements changed.

**September 11th and Its Impact on PATH’s Exchange Place Station**

It is not generally realized, but once a train leaves Grove Street, or Hoboken, or 33rd Street, or World Trade Center it cannot make any crossover moves to the adjacent tunnel until it reaches its destination because there are no crossover tracks. When there is a line blockade, whether due to plant or equipment problems, or due to police action resulting from an incident, the trains are blocked. They have to either wait for the problem to be cleared or else all trains have to be backed out of the tunnel to their originating terminals. Fortunately, such blockages are uncommon occurrences. When the attacks of September 11th occurred, the World Trade Center and the PATH terminal in its basement were totally destroyed. This was the first instance of such massive damage to the railroad’s fixed plant in its history. Additionally, the interior equipment (track structure, signals, and electrical equipment) of the downtown tunnels were ruined on account of flood waters caused by water from fire fighting efforts and broken water mains. However, the structural integrity of the tunnels themselves was not compromised and the water flooding was not caused by a breach of the tunnels, but the Exchange Place station was
instantly rendered unusable for train service primarily because of the lack of turn-back capability and not because of any damage it suffered.

**Rational for a New Interlocking at Exchange Place**

The design goal was to give Exchange Place the capability of turning back trains from the west (as opposed to turning back trains from the east as in the pre-September 11\textsuperscript{th} study) to restore this station and PATH service as soon as possible to this important commercial district. It was also desired to achieve a “universal” crossover capability but as explained later in this paper, this was only partially achieved due to constraints of existing alignments and profiles. It was estimated that it would take additional schedule time to get the under river tunnels and a downtown terminal for PATH restored than the time required to reopen Exchange Place even with a scenario of a revised interlocking. Therefore, it was deemed to be worth the effort to revise the interlocking to give a turn-back capability. Also, there is always the possibility of future blockages occurring to the east of Exchange place and even if such incidents are not as horrible and damaging as the attacks of September 11\textsuperscript{th}, they are still disruptive to PATH operations and the service quality rendered to the passengers. Having a turn-back capability at a key station will mitigate and reduce the impact of any future service disruption. Because the station was out of service, ongoing construction operations could be conducted around the clock and not interfere with train service at the station.

**Benefits of the Adopted Design for the New Interlocking**

The design for the new interlocking at Exchange Place had to consider the interconnected technical factors of train operations (including track-train dynamics), tunnel design
(including rock mechanics) and route alignment (including considerations of wayside clearances and of details of turnout geometry). Also to be factored in were a very ambitious schedule, coordination with other elements of PATH’s recovery, and the efficient management of this complex program.

Because of the latitude of design provided by the possibility of tunneling new passageways at the mainline tunnels, it was feasible to locate the main connections of two tracks into five tracks west of the existing 5 degree curve in the railroad’s alignment. The design team considered it desirable to locate most of the turnouts to the west of this 5 degree curve rather than their being located within the limits of that curve. This was because standard turnouts could be used, which meant both more favorable alignments for good train operations and more rapid procurement of standardized turnout materials as well as easier maintenance.

The original interlocking for the most part, was based on common size No. 4 turnouts. Consideration was now given to differentiating between “through routes” and the “turn-back or crossover routes.” It was an obvious decision to favor the through routes with larger turnouts, because they would constitute the vast majority of trains and riders when the World Trade Center Terminal service was restored. The turn-back routes could utilize smaller sized turnouts because they would constitute a small percentage of train moves in the long term scenario. Also there were considerations of limited longitudinal space for the interlocking and the need for close mutual coordination of design between the geotechnical engineers and the track engineers. Generally, smaller sized turnouts were
preferred by the geotechnical engineers, to reduce tunnel size, while the track engineers preferred larger turnouts for better train movements. (See Figure 3)

![Figure 3 – Isometric of Original and New Tunnels (Looking West)](image)

**Track Profiles and Turn-back Capabilities**

Full turn-back capability for trains coming from Newark and from Hoboken was desired. The design requirement was achieved for Newark but not for Hoboken because it was impractical for crossover trains to get from Tunnel G to Tunnel E moving westward. Considering the fact that Tunnel L not only had to be extended in length but its profile dramatically raised from ½ % to 3 ½% by mining out the tunnel’s roof, it would have been feasible to lower Tunnel E’s profile by mining out its invert. But the grades then
required to gain the required elevation would have been unacceptable. It was possible for
the interlocking to still provide turn-back service for Hoboken with the following
operational procedure: train comes from Newark goes wrong rail into track E of
Exchange Place; reverses ends it departs for Hoboken; it returns from Hoboken going
into track F of Exchange Place; reverses ends it departs for Newark going through
switches 27, 29, 35W, and crossover 41. Every train had to alternately run on the
Hoboken service, Newark service, Hoboken service, etc. while Exchange Place was in
operation as a turn-back. (See Figure 2)

Project Management and Approach
The major challenges and needs for this project were as follows;

- Secure the tunnels and station environment from the effects of 9-11
- Organize designers and start designs with only a concept plan
- Solicit a contractor without the benefits of a completed design
- Begin construction without a completed design
- Complete design investigations and complete construction on a set schedule in a
  very confined space

Track and Design Challenges
While the tunnel and station cleanup was on going, the new track alignment and details
began. One of the most important first steps in this undertaking was the development of a
workable track layout which would support the reconfiguration and desired operational
requirements of the lengthened station and new interlocking. This alignment and profile
was needed immediately as all other work would be placed in relation to the track location. To accomplish this PANYNJ Civil Engineering department prepared a detailed layout which worked operationally and fit physically. This layout was then in turn given to the track/civil designer for incorporation into the work. The designer’s responsibility evolved over time into the following categories;

- Develop plain line track and special trackwork procurement documents which could be given to one of three identified suppliers. The track design would be based on NYCT standards as they would be more readily available and very nearly meet PATH standards. The procurement did allow for the inclusion of European design or tangential geometry turnouts. However the selected vendor went with traditional design AREMA type rail transit turnouts. This layout included a 1220 foot radius turnout for switch 25, the largest ever used in the PATH tunnels.

- Coordinate survey of the existing track, tunnel and appurtenances and develop a final coordinate geometry alignment and profile.

- Develop existing cross sections for the tunnels and determine clearance requirements for setting tunnel cross sections and location of new appurtenances within the tunnels.

- Coordinate with the selected trackwork vendor (Cleveland Track Materials of Cleveland, Ohio). The vendor was given preliminary layouts to bid on and to begin fabrication. Adjustments were made to the fabrication as a result of clearance or layout related issues including a requirement that the vendor supply
layout drawings that matched the designers’ centerline alignment such that clearances could be verified.

**Clearance Investigations**

All design elements were being progressed concurrently and it was determined early on that a lead needed to be established to coordinate tunnel/appurtenance/train clearances for all designers. It was decided that since the trackwork designer was setting the alignment and profile that it would be best for that designer to in turn coordinate and check all other design elements to assure that they would “fit” within the new tunnel cross section. This included of course the revenue trains and work equipment.

Clearance investigations involved four main areas as follows;

1. Determination of the required tunnel cross sections based on the track geometry and the morphing train cross section as it transited through the tunnel
2. Clearance checks of existing tunnel sections and appurtenances which would remain but have a new track alignment
3. Coordination of placement of appurtenances within the new tunnel sections to assure clearance to passing trains
4. A curved station platform with a turnout within the platform area which would meet ADA requirements

It was an obvious goal to have to remove as little rock as possible while providing adequate clearance for the train and appurtenances and at the same time giving some flexibility for the contractor by providing a limited tolerance. To accomplish this, Vehicle Dynamic Outlines (VDO) were established in plan and cross section for every
point along the new alignment and in the areas of the existing alignment where changes were evident. The VDO represented the most extreme positions of the car body and undercarriage as a result of curve offset, vehicle sway and roll and a tolerance of 4 inches horizontally and 2 inches vertically. In discussions with the tunnel geotechnical engineers it was determined that the contractor would erect a pattern of lattice girders to support the new tunnel liner. The lattice girder cross sections and shotcrete cover would be used to establish the limit of rock removal. (See Photo 2)

Photo 2 - Installation of lattice girders in new tunnel cross section

The track engineers in turn used those lattice girder locations to set the lattice girder cross sections by developing cross sections at those specific locations. The cross sections at those locations were created by running CADD lisp routines within an AutoCAD
software platform that determined the mid and end overhang offsets realized by the worse case PATH transit vehicle as it would navigate the alignment. These lisp routines were run through all portions of the alignment including the normal and diverging side of turnouts. With the new vehicle footprint modified cross sections were created at each designated locations to replicate the VDO.

Once the track alignment was finalized and all cross sections determined, the contractor began his excavation. The rock removal was checked using dibit surveys that indicate the amount of rock removed and whether it was adequate or inadequate based on pre-determined limits.

Prior to running trains the contractor created a clearance rig “brush car template” and using predetermined setting provided by the trackwork engineer, the rig was progressed through the tunnel at five foot increments and the clearances checked. To the delight of all, very few modifications were necessary.

The fourth clearance assignment required slightly different criteria. This was setting the new platform edge for the west extension of the Exchange Place platform. This section of the platform was in curved track and additionally contained the switch area of a new turnout. The PANY&NJ wanted to make sure that the clearances required for the new platform would not create a platform to car threshold offset that would violate the ADA requirements. A similar analysis to that performed for the determination of tunnel clearances was conducted; however there was one significant difference, the VDO was
not included in the calculations. Instead the vehicle would be considered to be in its steady state condition when it was at rest. In fact many platforms are designed with two elements to accommodate the VDO of moving vehicles. These elements are the end of platform taper, which is designed to catch and guide a vehicle which is swaying or tilted towards the platform back to its steady state condition. The second element is the rub edge which is usually a softer material which the car body or more likely door threshold can rub against as the car travels through the station platform area.

Calculations were performed based on the train being stopped within a set range of approximately six feet either side of the car marker locations. Once the clearances were checked to assure a minimum of one inch of clearance and no more than three inches at at least one point on each car threshold, the platform edge was then defined and given to the contractor for construction. Test train runs have shown a perfect fit. (See Photo 3)
Geotechnical and Design Challenges

Construction of the new crossover tunnels at Exchange Place presented several geotechnical challenges. Track level in the Exchange Place tunnels is approximately 80 feet below street grade. Between 35 and 40 feet of granular overburden soils and 25 to 30 feet of foliated mica schist rock (known locally as the Manhattan Schist) overlie the tunnels. A cross sectional view of the tunnels is given in Figure 3. The tunnels are typically horseshoe shaped having a base width of 17 feet and a height of 15 feet. A substantial pillar of rock separates each of the existing tunnels, allowing overburden stresses to arch around the tunnels. Office buildings supported on the rock are located directly above large portions of the work area.

With construction of the crossover tunnels connecting two and sometime three of the existing tunnels, openings spanning as much as 60 ft were created. The rock cover above the tunnels, 25 to 30 feet thick, was relatively small compared to the span width. Thus, a method of excavation and support of the rock arch that would minimize rock movements and the consequent potential for damage to the overlying buildings had to be developed. One of the challenges of the track alignment task was to stagger the locations of the crossovers to the extent possible so as to minimize the size of the unsupported spans.

Because of the critical need to restore PATH service to Exchange Place and to downtown Manhattan as quickly as possible, work began based on a somewhat conservative preliminary design, with design studies and confirmatory field investigations continuing
as the work progressed. Field mapping of the rock was done during construction and rock bolt patterns were modified, as required. The project was divided into a series of work packages for specific aspects of the work such as liner removal and installation of pre-support rock bolts, tunnel excavation and support, utility installations, track and signal installation, and station finishes.

The design and construction process required considerable coordination between the owner, the designers, and the contractor. Considerable flexibility was required on the part
of the contractor to move work crews and equipment around in the limited work space available to accommodate changing conditions and revised design requirements.

**Tunnel Excavation**

The method traditionally used for tunnel excavation in the New York area is drill and blast. The Manhattan Schist rock is typically a hard rock with unconfined compressive strengths of 20,000 to 30,000 psi and blasting is usually required for rock removal. The tunnel excavation work at Exchange Place initially began with drill and blast operations. Because of the limited work areas within any one tunnel, moving equipment around for drilling, blasting, and particularly for removing muck after a blast was a very slow operation. Further, because of the foliations in the rock, control of overbreak from blasting was difficult. Excessive overbreak meant increased cost for muck removal and tunnel construction and raised concerns about excessive loss of rock at the crown in areas already having relatively thin rock cover.

When laboratory unconfined compression tests on rock cores became available and indicated strengths in the range of 4,000 to 5,000 psi, use of roadheaders became a viable option. Tests with a Dosco roadheader, brought in from Virginia, showed that the schist rock could be excavated efficiently with a roadheader. A decision was then made to complete the remainder of the rock excavation work using roadheaders. At the height of the work, three roadheaders were in use: An ABM 330 Alpine Miner, and two Voest-Alpine machines (AM-50 and AM-75). (See Photo 4)
The rate of production with the roadheaders was far greater than with drill and blast techniques. More importantly, control of excavation limits in a complicated geometry was more easily accomplished with the roadheaders.

**Tunnel Support**

Based on evaluation of case history precedents for construction of large span openings in rock, and of numerical modeling and rock stability analyses, the recommended ground support consisted of a combination of prestressed rock bolts, steel lattice girders, and steel fiber reinforced shotcrete (SFRS). Prior to starting tunnel excavation activities, contact grouting behind existing concrete tunnel liners and installation of pre-support
rock bolts was done. Rock reinforcement for pre-support of the tunnel liners and for support of the rock excavation consisted of galvanized, No. 9, Grade 75, resin grouted rock bolts, pre-tensioned to 40% of the bar yield strength. Rock bolt lengths and spacing varied from 8 to 15 feet and 4 to 5 feet, respectively. The recommended ground support system is shown schematically in Figure 4 and the installation is shown in Photo 5.

This project represented the first application of SFRS as a permanent tunnel lining in a mass transit system in the New York metropolitan area. Nominal shotcrete thickness varied from 6 to 11 inches, depending on the length of the excavated span. The shotcrete was used in conjunction with pre-fabricated steel lattice girders spaced 5 feet on center.

![Figure 4 – Typical Ground Support Detail](image-url)
SFRS was applied using ‘wet-mix’ techniques with the fibers added to the mix at the batch plant. Use of SFRS as a permanent liner saved considerable time during construction compared to placement of forms and pouring of conventional cast-in-place concrete.

**Monitoring Activities**

As a precaution, pre- and post-construction condition surveys were conducted in the buildings overlying the work area. Monitoring of movements of the streets and structures above was done with conventional surveying techniques. Crack monitors across existing cracks were installed in the buildings to verify that no changes occurred. Borehole
extensometers were installed in the rock overlying the tunnels to monitor movement of rock, if any, as excavation proceeded.

The condition surveys showed that conditions observed in the buildings prior to construction were essentially unchanged after construction. Survey and borehole extensometer measurements indicated small, insignificant movements.

**Summary and Conclusion**

The project offered many challenges including uncharted territory for the engineers, managers and contractors. The partnerships which evolved between the PANYNJ, the various design consultants and the contractor were unique yet everyone felt comfortable in their role knowing full well the mission behind it all.

It is sorely hoped that the conditions that precipitated the need for this fast track assignment never occur again. There is some solace in the fact that under extreme circumstances the engineering and construction communities came together and with team work were able to carry on the tradition of digging in to lend a helping hand. Many of the lessons learned from this project will be carried forward and applied to future assignments.

On June 29, 2003 the PATH trains returned to Exchange Place Station, and the PANYNJ took another major step towards returning to normal operations. (See Photo 6)
Photo 6 – PATH service returns to Exchange Place Station

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