Exchange Place Station Subsurface Reconstruction and Improvements

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Abstract: The Port Authority Trans Hudson (PATH) Railroad's Exchange Place Station has undergone major renovation and improvement as part of a Port Authority passenger safety program. The station was constructed in the early 20th century, in poor ground conditions at the edge of the Hudson River. As a result of recent increases in passenger volume and a concern for passenger safety, The Port Authority of New York and New Jersey planned and constructed major improvements to the station. Existing train rooms were refurbished and a new at-grade station was constructed at water edge with new escalators and stairways descending to the deep station platforms. This paper describes the conditions encountered at the facility and the engineering decisions that were made in order to accommodate existing structures and the difficult ground conditions. Various construction techniques were necessary for the successful completion of the new construction without endangering the operating railroad or the public. The project was completed without incident and without disruption to the operating facility.

Introduction

This paper describes the design and construction of subsurface facilities necessary for the redevelopment of the Port Authority of New York and New Jersey's Exchange Place Station in Jersey City, New Jersey. The station is a mainline station on the commuter railroad that links the World Trade Center in New York City with New Jersey.

Transportation planning and functional design features are discussed elsewhere (Kelly and Ehrmann 1988). This paper describes the geotechnical, foundation, and underground structural features of the project as well as the unique constraints that are a part of this project.

History of Site

To understand better the geotechnical and structural problems faced by the designers, it is helpful to review the history of the site. Fig. 1 presents a progression of the site history starting around the turn of the century, through the intervening years and ending at the present time (1990). This is shown as a longitudinal cross section looking north.

At the turn of the century [see Fig. 1(*a*)] the Pennsylvania Railroad terminated on an elevated platform at the site. The railroad terminal consisted of 25 tracks arriving one level above the street on an embankment and trestle structure and enclosed by an arched shed whose foundations remained and were partially visible at the start of present construction.

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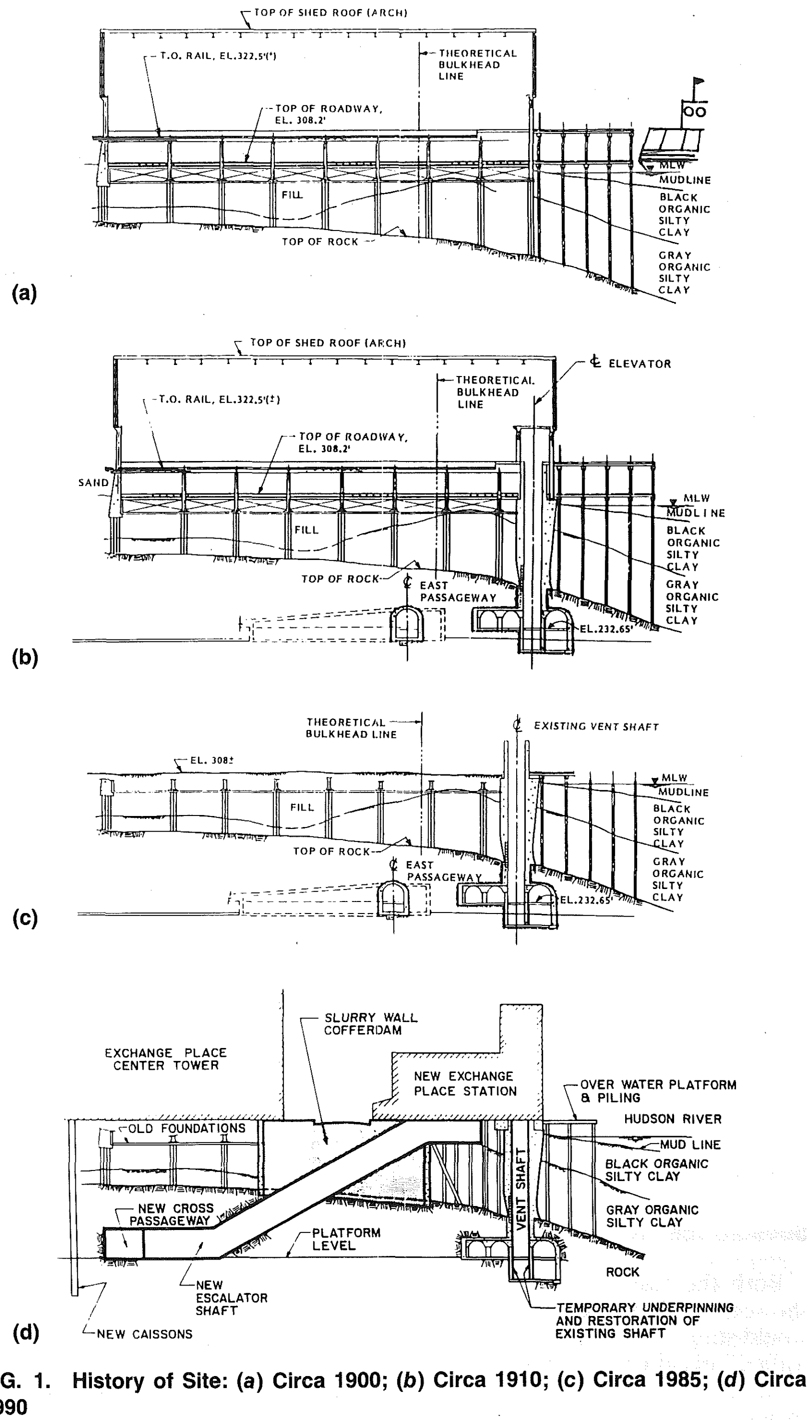

FIG. 1. History of Site: (*a*) Circa 1900; (*b*) Circa 1910; (*c*) Circa 1985; (*d*) Circa 1990

Passengers descended from this terminal to the street or to ferry boats to complete their trip to New York. Later, the Hudson and Manhattan Railroad Company constructed a commuter railroad station and tunnels under the site and across the river, extending rail service into Manhattan [Fig. 1(*b*)]. A deep elevator shaft was constructed, which connected the elevated railroad terminal with the commuter station about 75 ft (23 m) below street level.

The existing PATH trainrooms, the electrical substation vault and the cross-corridors were all mined, entirely in rock, approximately eight decades ago under the weight of soil, rock, and the busy train station above. Remnants of this original construction were visible at the start of construction [Fig. 1(*c*)], particularly the old elevator shaft on the river's edge and the original construction access tunnel to the south. This access tunnel provided remote access to the works and is unlined for much of its length. From an inspection of the tunnel it was determined that the rock was intact with very little weathering. Water seeps were almost nonexistent.

The Pennsylvania Railroad discontinued use of the above-grade station after construction of the present AMTRAK tunnels under the river. In the early 1950s, the station was demolished and the site, above grade, was left vacant [Fig. 1(*c*)].

Current Development

Redevelopment plans [See Fig. 1(*d*)] called for:

1. Construction of an escalator shaftway from a new entrance at the river's edge down to the existing platform level, connecting horizontally to an existing cross-passageway.
2. A new esplanade deck to be built to the east over the water, to abut a pier to the north, an office building on the west, and a Jersey City recreation pier on the south.
3. Utilization of the old elevator shaft structure (at the time used as vent shafts), as shafts for heating, ventilation, and air conditioning (HVAC) and electrical services.
4. Reconstruction of the "existing" bulkhead as required.

Thus at the start of design, five well-defined tasks were to be performed:

1. Provide a new escalator shaft to existing platforms.
2. Provide new foundations for a building and esplanade.
3. Provide a new structural platform.
4. Incorporate the existing vent shaft into the new facility.
5. Restore the bulkhead as needed.

Subsurface Investigation

Both the test borings and an inspection of the existing access tunnel showed that, below a fractured upper layer, the rock was of excellent quality, would support high-capacity piled foundations, and would permit "smooth-walled" blasting for tunneling. The borings also showed that the overlying materials consisted of 10–30 ft (3–9 m) of soft organic silt and clay overlain by loose fill of irregular thickness, ranging between 15 and 25 ft (5–8 m).

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A visual inspection of the existing vent shaft suggested that the shaft was in a distressed condition and that major rehabilitation would be required before it could be utilized in the new project. Substantial infiltration of water was clearly visible near the top of rock, particularly on the west side (landward) and the spalling of concrete encasement of the steel columns supporting the shaft suggested structural damage.

Test pits were dug in order to locate the bulkhead shown in early drawings and determine its method of construction; none of these pits revealed any evidence of a bulkhead at the site.

Construction records indicated that "shot rock" from the Pennsylvania Railroad (PRR) cut through the nearby Palisades was used to fill the site. Inspection of old drawings for the PRR terminal showed that the trestles and ferry slip works were originally supported on timber piles, most of which remained and could be seen in the river. The presence of the "shot rock" and the piles would obviously be a problem to the contractor.

Examination of as-built drawings of the vent shaft indicated that the shaft was significantly modified during original construction. Several papers and reports describe the difficulties during construction. Davies (1909) and Jacobs (1910) discuss the events which led to the final configuration. These reports were a clear warning of difficult site conditions.

The designers were able to secure old photographs that showed the rock excavation during construction of the station in 1907. They show that the cut line was very uneven and indicated that voids could be expected between the unreinforced concrete lining and the rock. They also showed that very little temporary shoring was used during construction.

Design Decisions

In light of the foregoing, the following decisions were made by the designers and general design criteria were adopted:

1. The supporting foundation for both the new building and deck must not impose additional loading on the existing trainrooms and vaults below.
2. It was imperative that the steel columns supporting the vent shaft be exposed and inspected and that a systematic process be developed for their restoration or complete removal and replacement.
3. A completely new bulkhead would have to be provided across the site.
4. High tidal levels and poor soil conditions dictated that a rigid cofferdam be provided for the construction of the escalator shaft.
5. The rock tunnelling should be carried out using rock bolts, steel sets, and shotcrete.

Foundation Units

The choice of high-capacity end-bearing piles for the promenade, aboveground station, and deck was dictated by the poor quality of the overlying soils and the relatively shallow depth to sound rock. The piles were 14-in.- (355-mm-) diameter steel pipe piles, sealed at the bottom with a reinforced plate and filled with concrete. The piles, driven vertical or at various batters, were located to not be directly over the tunnels or vaults below and to provide stability against lateral loads. Fig. 2(*a*) shows a plan of the site that indicates both the column locations and the extent of the existing mined

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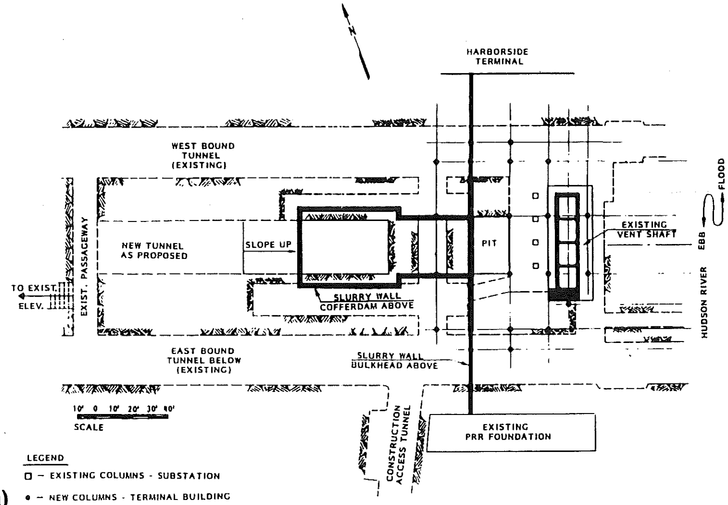
(a)



(b)

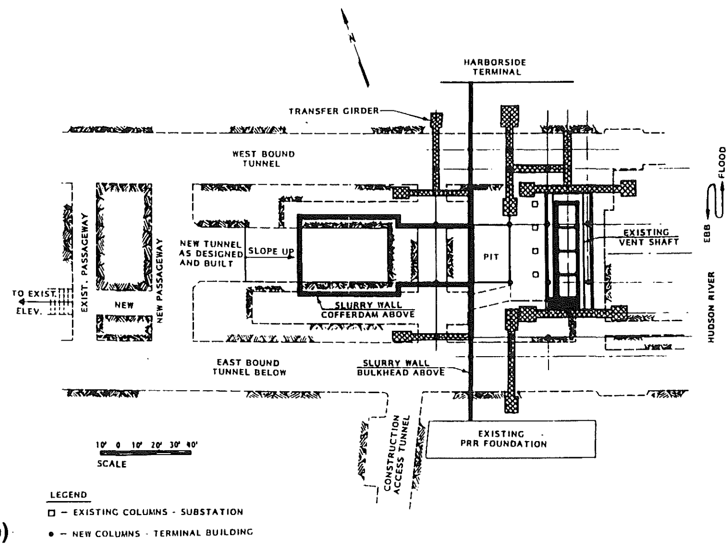


FIG. 2. Plan View: (*a*) as Planned; (*b*) as Constructed

areas below. It is interesting to note that with rare exception, the new station columns were located directly over the mined areas.

The design criteria prohibited the application of additional load on the shallow thickness of rock bridging over the vaulted areas. Deep posttensioned girders were used at grade level to transfer these column loads to the pile groups at their ends. Fig. 2(*b*) shows this arrangement. In order to limit the risk to the existing concrete linings, to the electrical substation, and to the operation of the railroad, the specified driving energy and final blows were kept as low as possible to achieve an 85-ton (77-tonne) working capacity for platform piles and 120-ton (109-tonne) working capacity for the battered piles that provide support for the bulkhead. Buckling considera-

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tions limited platform pile capacity in open-water areas while higher capacity was obtained with the same pile at the bulkhead where the outboard berm reduces the unsupported length of the pile. Fig. 3, a cross section looking west, shows the juxtaposition of the new station building, the transfer girders, the piles, and the existing headings and tunnels that could be affected by this construction. Shown also is the new rock tunnel passageway and beyond, its cross-passageway connection to the platforms.

Inspection and Reconstruction of Vent Shaft

The existing ventilation shaft, which formerly contained four elevators connecting the PRR terminal above grade to the PATH platforms below, is a reinforced concrete structure supported on 10 steel columns as shown in Fig. 4. This shaft is located directly at the edge of the river and could provide a direct conduit between the river and Exchange Place Station if accidentally breached. If this structure were ever overtopped or penetrated by the river, the extent of flooding could include virtually the whole underground part of the PATH system, the World Trade Center lower levels, and possibly parts of the New York City subway system. Clearly, the security against flooding was of prime importance.

Visual inspection of the damaged concrete encasement of the 10 support columns suggested that the steel cores might have suffered corrosion over the years and might require restoration or replacement. It was also evident that there was leakage into the shaft. Previous surveys showed that the shaft

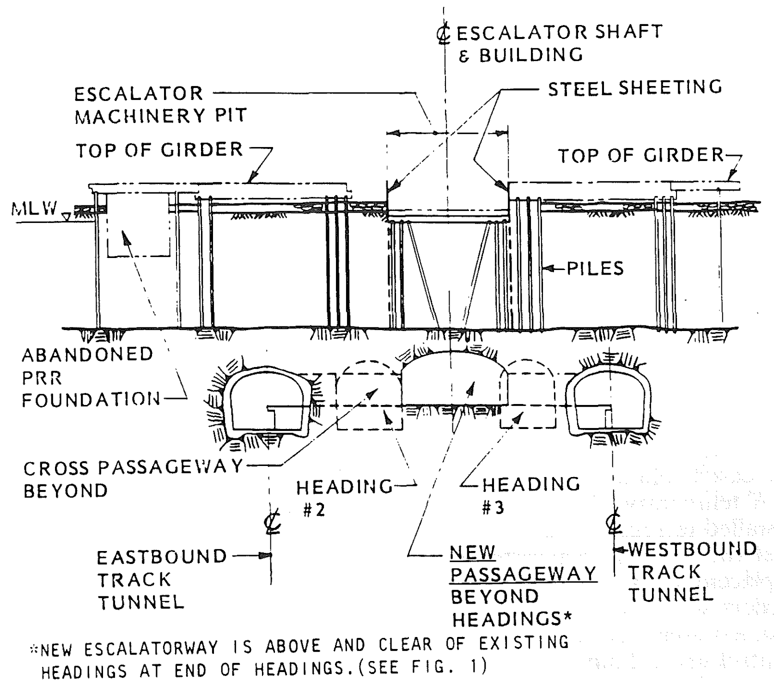

FIG. 3. Cross Section Looking West (Preexisting Tunnels and New Construction)

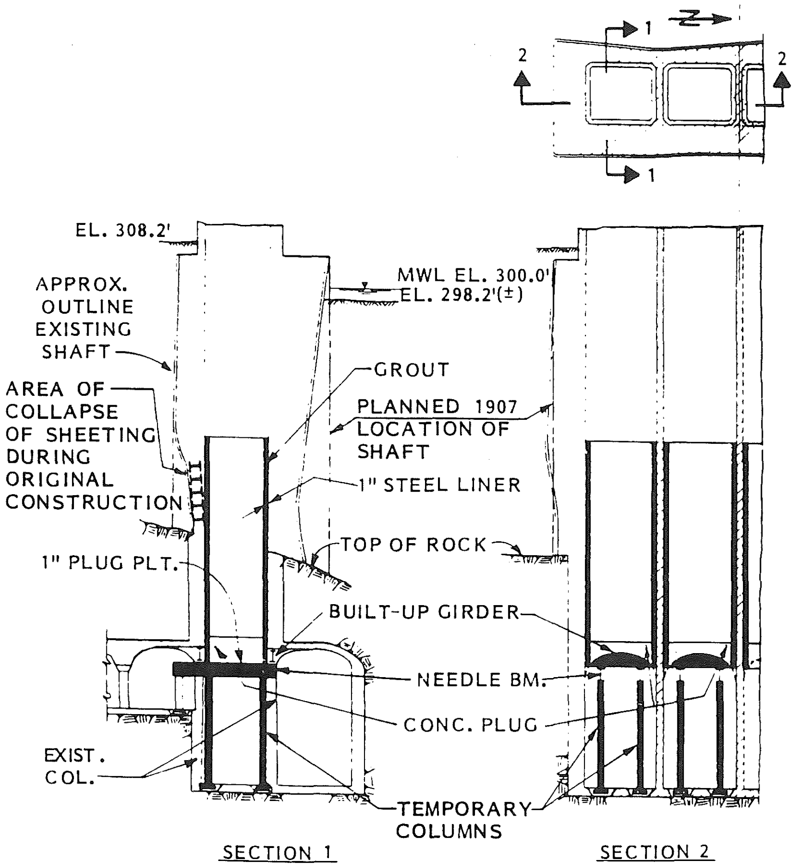

FIG. 4. Preexisting Ventilation Structure (Former Pennsylvania Railroad Elevator Shaft)

was out of plumb, probably due to an unbalanced lateral earth pressure loading that pushed the shaft toward the river.

It was concluded that a comprehensive examination of this structure was required and that a scheme for rehabilitation had to be developed and implemented prior to the start of any other improvements. A detailed analysis was performed in order to determine the loads that these columns might now carry. Much of the load previously carried had since been removed by demolition of the old PRR terminal; however, the unbalanced soil pressure increased column loading on the river side.

A temporary underpinning frame of structural steel was designed and installed to protect the shaft during exposure of the steel and in the event that columns might have to be removed either for rebuilding or complete replacement. This frame, shown in Fig. 4, included the fabrication of deep girders with a curving upper flange that conformed to the shape of the groined arches of the vault. The frame was jacked into place in order to control vertical movement.

As-built drawings indicated that the cross section of the vent shaft was necked down due to a collapse of the sheeting during original construction and that the actual cross-sectional area was much reduced from that initially intended. As a result, the shaft was vulnerable to a shear failure at the rock line. There was some evidence that this process had already begun. In order to preclude further shear displacement and tipping, a 1-in.- (25-mm-) thick high-strength, corrosion resistant, steel plate liner tube was designed and installed in each of the four vent ducts. To lessen the risk of further movement and damaged during construction, the area inboard from the shaft was dredged to reduce the unbalanced lateral loading. Although it may be argued that installation of a steel liner to take unbalanced loading followed by removal of the loading seems conservative in the extreme, the degree of watertightness and the structural security against unexpected loading provided by the linear justified the effort and expense.

New Bulkhead

Since there appeared to be no bulkhead at the site, a decision was made to construct a new bulkhead from the northernmost property line, abutting Harborside Terminal to the southernmost limit, abutting an old PRR terminal shed masonry abutment that was visible at grade level (Fig. 2). Consideration was given to constructing the bulkhead on a line beyond the bulkhead line in order to provide additional protection to the vent shaft. This scheme was finally rejected since its very construction seemed to expose the shaft to unwarranted risk. While it was desirable to protect the vent shaft externally, doing so would expose the shaft to great danger of construction accident. Finally it was decided that the bulkhead should follow the alignment of the U.S. Bulkhead Line.

In view of the difficulty experienced driving sheeting for the initial construction of the vent shaft, the writers concluded that slurry wall construction was the only practical method of assuring that the new bulkhead would be constructed to the required line and grade. Lateral support was provided by batter piles on the outboard side. Permanent rock anchors were rejected for horizontal support because of the concern of penetrating one of the existing vaults or tunnels and because anchor shafts could provide a conduit for water infiltration.

During the design stage it was decided that the bulkhead would be required to resist earthquake as well as earth pressure. This requirement dictated that lateral support be provided by piles at a relatively flat batter of 2 V:1 H. The weight of wall is comparatively light; therefore tiedowns would be required in order to resist the upward component of reaction from these piles. These tiedowns consisted of short Dywidag-type rock anchors in the wall grouted into rock.

Provision for a horizontal reaction at the toe of the slurry wall was complicated by the shallow rock cover over the existing tunnels, as little as 10 ft (3 m) in some areas. The customary practice of chiseling a socket into rock was not permitted since there was concern that the impact of the heavyweight drop chisels would endanger the integrity of the linings. The horizontal reaction was obtained by pretensioning the Dywidag threadbar units in order to increase the friction between the bottom of the wall and the rock. The installation of threadbars caused much less vibration than chiseling; thus the existing linings were exposed to a reduced level of risk.

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SLURRY-WALL COFFERDAM

Since the expected obstructions would impose real difficulties if driven sheeting were selected, it was decided that a slurry wall cofferdam would be appropriate and that it could be made contiguous with the bulkhead. It was further decided that the cofferdam would be designed as the permanent structure enclosing the escalator shaftway. The wall thickness for the bulkhead and the cofferdam are 24 in. (600 mm) and 30 in. (750 mm), respectively. All slurry walls at this site are of the "soldier beam" type in which wide flange (WF) sections are used as reinforcement and as the stop-end forms. The final design configuration of the slurry-wall is shown as the bold line in Fig. 2. The east end of the cofferdam is in the plane of the slurry-wall bulkhead and is adjacent to the river. A shallow escalator machinery pit was to be provided just east of and adjoining this wall.

Several special details had to be developed in the design of the cofferdam:

1. Provide a connection between the steel sheeting for the machinery pit and the slurry-wall bulkhead.
2. Provide security against flooding of cofferdam during driving of sheeted pit and construction of permanent concrete enclosure. Security against flooding was thought to be particularly critical as the 100-year storm level at this location is expected to surge to an elevation of 308.5 ft (94 m), slightly above existing grade at an elevation of 308 ft (93.9 m) and less than 6 ft (1.8 m) above mean high water at an elevation of 302.7 ft (92.8 m).
3. Develop a scheme to permit a change of thickness from 30-in. (750-mm) slurry wall to 24-in. (600-mm) wall at a T panel.
4. Provide for installation of a future grade beam for the Exchange Place Centre Building that would pass through the Southwest corner of the cofferdam.
5. Provide temporary vertical support for the portion of western slurry wall located directly over the escalatorway rock cut.

ROCK TUNNEL AND PENETRATIONS AT PLATFORMS

As originally conceived, the escalatorway was to descend to platform level and connect to a short horizontal passageway of constant width that would penetrate the existing cross-passageway near the western end of the station. From the outset, it was seen that this would be a particularly difficult task since the escalator shaft would descend from grade passing between existing headings 2 and 3. These headings contained sensitive electrical and communication equipment and required positive structural protection and rock-bolt reinforcement. The geometric relationship between these tunnels is shown in Figs. 2 and 3. The new escalator shaft passed within 3 ft (1 m) of heading 3 at the closest passing. In addition, the escalator shaft would pass about 7 ft (2 m) below the west end of the slurry-wall cofferdam. Although the rock at the site, below the surface fractured layer, is of excellent quality, the foliation has a distinctly unfavorable dip for this penetration and there were uncertainties as to what condition the rock might be in as a result of chiseling the slurry-wall socket. Fig. 5 shows the sequence planned for establishing the portal at the top of rock and the associated protection of the slurry wall.

Early in the design phase it was decided that the existing cross-passageway was inadequate in width for the projected passenger traffic and that a new cross-passageway should be provided closer to the midlength of the platform.

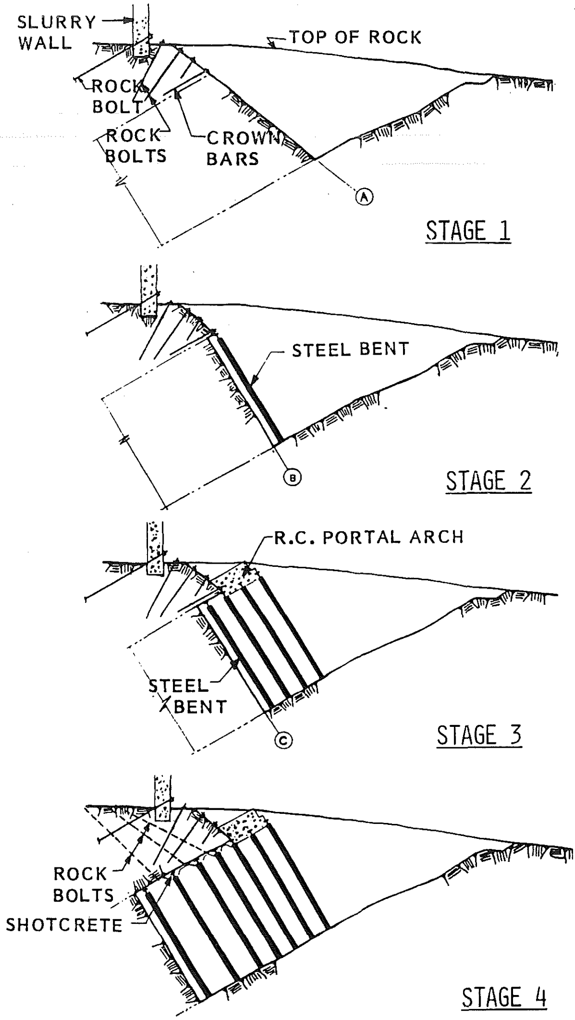

FIG. 5. Excavation Stages under West Slurry Wall

It was also decided that a short passageway or annex drift be provided between the existing cross-passageway and the new cross-passageway (both run north-south) and in line with the existing stairs that connect to a pair of elevators that were then in use.

These revisions were seen to improve the function of the station but they introduced a number of complications into the design:

1. Penetrations now had to be made into platform areas while maintaining patron service and safety.
2. The train-room arch had to be underpinned at the proposed opening from the cross-passageway.
3. A complex rock tunnel junction had to be analyzed and staged, in which

a barrel arch section (main passageway) intersects a rectangular section (cross-passageway) that terminates at horseshoe sections (train rooms).

At the same time all of this was happening, the Exchange Place Center Building was being erected over the PATH tunnels. Building caissons (typically 42 in. [1 m] in diameter) had already been installed and required protection. The theoretical line of the new main passageway is less than 6 ft (2 m) away from the face of two of these caissons. The tunneling contractor was permitted to blast in their vicinity only under the most strict controls. Extensometers were installed in the rock and were monitored closely in order to document the behavior of the rock during excavation.

The platforms at Exchange Place are only 12-ft (3.6-m) wide and were to be kept open to the public except for short periods of time in the early hours of the morning or weekends and holidays. All temporary underpinning or shoring at the proposed portal was restricted to a small width. Because it was necessary for the contractor to clear the area of excavation debris in

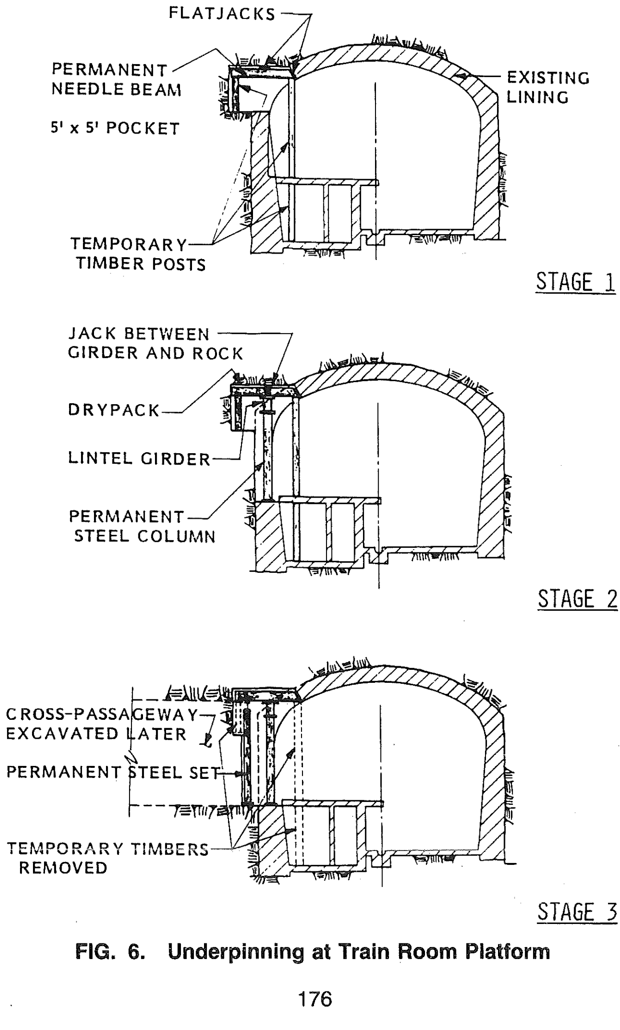

FIG. 6. Underpinning at Train Room Platform

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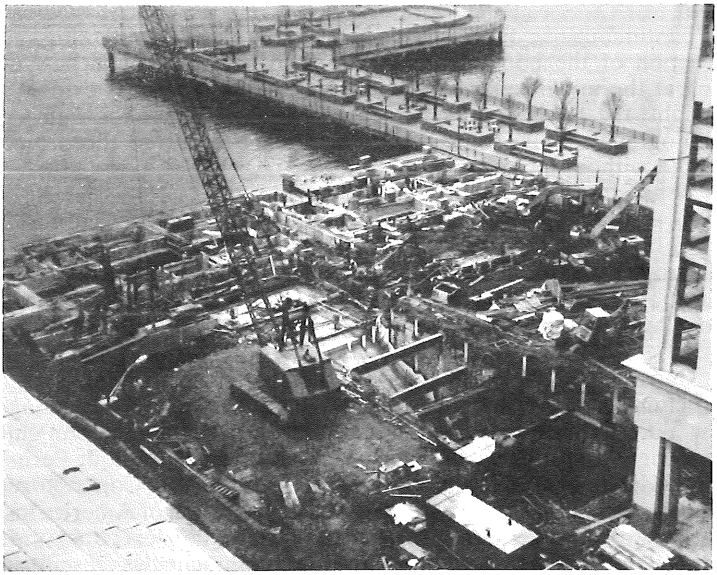

FIG. 7. General View of Site During Construction

time for the next morning the work was sequenced in small steps that could be completed within the abbreviated work shift. Similarly, the traffic density on the rail line itself precluded encroachment into the track area.

One of the methods considered for providing underpinning of the trainroom arch was a pattern of rock bolting. While attractive from the point of view of traffic obstruction, there was serious reservation about the quality of contact between the unreinforced liner and the rock surface behind it. The photos (circa 1908) showing the results of black-powder blasting indicated that the surfaces were highly irregular and that voids should be expected. Furthermore, these voids might be expected to carry water. It was decided that the liner should not be penetrated at all except of course for the portal itself and that a scheme of positive structural underpinning should be installed from the inside surface of the liner as the portal was opened.

Fig. 6 shows the construction sequence of portal development at the trainroom platforms and in the preexisting cross-passageway. The first step [Fig. 6(*a*)] is to cut a 5-ft (1.5-m) square pocket into the lining and rock, install a needle beam and two temporary posts. This frame is preloaded against the overlying rock and against the arch as shown in the figure. This operation was performed five times at the platform. The second step [Fig. 6(*b*)] is installation of the lintel girder and the permanent columns, which are just clear of the spring line of the interior wall of the train room. This girder was predeflected using jacks in order to transfer the load from the temporary posts to the permanent steel columns. In the third and final step [Fig. 6(*c*)] the first steel set in the cross-passageway is placed and the temporary posts are removed. All of the permanent steel was then encased in concrete.

CONCLUSIONS

Design, planning, and detailed consideration of construction procedures and sequences permitted the safe and timely completion of the work. Each

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phase of work was executed and completed in a sequence that permitted secure continuous use of the station by the commuting public. Fig. 7 shows construction of the above-grade portions of the work. The new deck is forming at the upper left while the slurry wall cofferdam is evident at the lower right; the Exchange Place Centre Building frames the right edge of the photograph. While some schedule slippage occurred the project was completed without incident.

Acknowledgments

This project was successfully completed by the combined efforts of many organizations and individuals. The overall concept design was developed by the Port Authority of New York and New Jersey. Deleuw Cather and Co. of Washington, D.C., provided the coordination and the structural design of the transfer girders and the station building itself, as well as all of the nonstructural components, such as HVAC and electrical. Kaiser Engineers of New York was the construction manager and provided helpful guidance to the design team during the constructability review period; Perini Corporation, Metropolitan New York Division, was General Contractor for the Foundation and Deck Construction; ICOS Corporation of America installed the slurry walls; while Grow Tunneling Corporation executed the rock-tunneling work. Mueser Rutledge Consulting Engineers was responsible for the design of the components described in this paper.

The writers wish to acknowledge the assistance of their colleague Dr. James P. Gould, whose efforts during the rock tunneling phase were most valuable.

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