Design and Planning of New Passageway Tunnel for Circulation Improvements at Grand Central—42nd Street Station, New York City

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ABSTRACT

The design and planning for the construction of a new passageway to improve access and circulation to better accommodate anticipated increased passenger flow within Grand Central—42nd Street Station. The passageway includes the break-in of an over 100-year-old station cavern with an innovative design implementing a protective structure above the existing track to allow for safe train operations and passenger circulation during construction. Construction of the new passageway follows the Sequential Excavation Method. This paper will present the innovative solutions that went into the preliminary design and planning considering construction access, site logistics, risk management, structural retrofitting, instrumentation and monitoring, and impact assessments.

INTRODUCTION

To relieve congestion and overcapacity issues between the Lexington Avenue Line and the Flushing Line at Grand Central—42nd Street Station, which are expected to worsen with increased ridership into and out of the station, Metropolitan Transportation Authority Construction and Development (MTA C&D) is planning to implement several projects to improve access and passenger circulation for the interchange, including widening of existing stairways from the northbound 4/5/6 Line and the construction of additional stairs and passageway to the Flushing Line. This paper focuses on planning of the new passageway connecting the existing passageway with the Flushing Line at Grand Central—42nd Street Station.

Grand Central Terminal serves as a transportation hub for New York City and connects the Metro-North Railroad and New York City Transit (NYCT) systems. NYCT's Flushing Line at Grand Central Terminal is a highly used, multi-level underground structure mainly located underneath 42nd Street and thus, presented many challenges for constructing a new tunnel with minimal disturbance to station operation.

The selected procurement method for the Circulation Improvements at Grand Central—42nd Street Station is Design-Build (DB) with the selection process following a Request for Qualifications (RFQ) and Request for Proposals (RFP). Planning and preparation of the procurement documents included Parsons (Prime Engineer), Gall Zeidler Consultants (Sub-Consultant for Tunnel Engineer and Station Connection), Sowinski Sullivan (Sub-Consultant for Architecture), Mueser Rutledge Consulting Engineers (Sub-Consultant for Geotechnical Services), and NAIK Group (Program Manager).

The technical and contractual requirements for the project were included in the RFP documents. The RFP documents comprised of: Invitation to Bidders (Volume 1), Design-Build Agreement & General Provisions (Volume 2), Division 1 General Requirements (Volume 3), Project Requirements & Design Criteria (Volume 4) and Reference Documents which included Reference Design Drawings, As-Built Drawings, Standard Drawings, Utility Drawings and Surveys, Environmental Drawings, Reports & Surveys, Geotechnical Data Report and Geotechnical Baseline Report (Volumes 5–10).

The RFP documents require the Design-Builder to perform the final design of the underground structures including temporary and permanent works in accordance with the Project Requirements and Design Criteria (PRDC).

A project specific PRDC was developed which included mandatory requirements related to: scope of work, codes & standards, loads & load combinations, design life, materials, durability, minimum spaceproofing & train clearances, mined tunnel excavation, initial rock support, shotcrete, tunnels & underground structures, watertightness & waterproofing, subsurface investigation, ground characterization & geotechnical parameters, instrumentation & monitoring, protection of existing structures, support excavation, pre-construction and post-construction condition surveys, noise & vibration and settlement monitoring.

HISTORICAL BACKGROUND

The planning and construction of Steinway Tunnels under the East River—connecting Queens, New York with Manhattan, New York—dates back to the late 1800's. The construction of the tunnels was delayed and temporarily ceased due to difficult tunneling conditions, funding issues, and in some instances, tragic accidents. As a result, it took many years to complete the Steinway Tunnels. The tunnels under the East River were complete by mid-1907, followed by the completion of an approximately 150-ft long Station Cavern (see Figure 1 and Figure 2).

For roughly the initial 15 years, the Flushing Line at Grand Central—42nd Street Station operated with a loop at the current west end of the station (see Figure 3). Shortly after opening the Flushing Line to Manhattan the platform was extended approximately 450-ft to meet the ridership demand. This upgrade to the station included the construction of a mid-platform staircase. This station upgrade took place between circa 1914 and 1916.

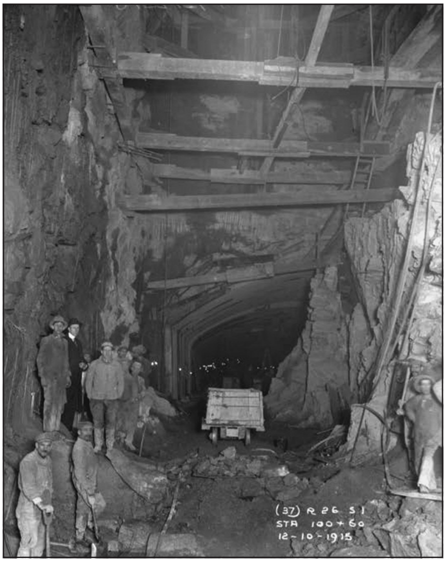

Figure 1. Construction of Grand Central—42nd Street Station (courtesy of NYCT)

Grand Central—42nd Street Station operated with this configuration until circa 1927 when the Flushing Line was extended to Times Square Station. The station undertook another upgrade in circa 1951, again to meet increased demand with the construction of a second mid-platform staircase. The next upgrade to the station did not occur until circa 1995 with the construction of an elevator near the west end of the platform.

Figure 2. Completion of Grand Central—42nd Street Station prior to opening (courtesy of NYCT)

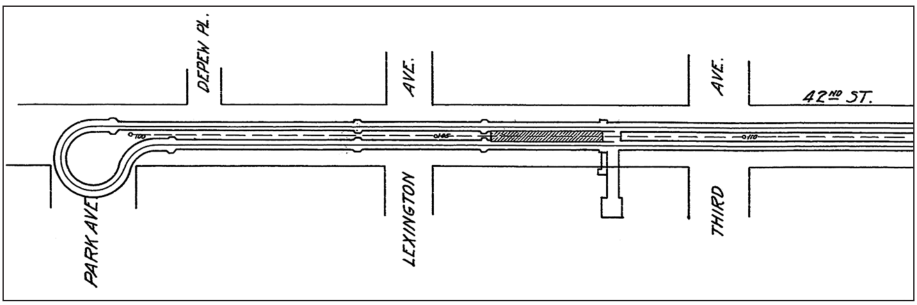

Figure 3. Archive record of Grand Central—42nd Street Station (courtesy of NYCT)

Detailed planning for the next major upgrade at Grand Central—42nd Street Station for circulation improvements began in early 2019. To enable construction of the new passageway tunnel, a vertical shaft has been included to provide construction access (see Figure 4).

GROUND CONDITIONS

The regional geology (Bedrock) of the project location consists of interlayered schist, gneiss, granofels, and amphibolite of the Hartland Formation. Younger intrusive granitic pegmatite dikes, less than a meter in thickness, and sills, more than a meter in thickness, have been documented within the Hartland Formation. Soils atop bedrock consist of glacial till, and compact granular fill. The stratigraphy at the project location is shown in Figure 5.

A small ground investigation program, consisting of two (2) boreholes and a surface geophysical survey of the project site, was conducted for development of the local subsurface conditions at the project location. The primary aim of the investigation was determination of the bedrock topography and for the development of geotechnical

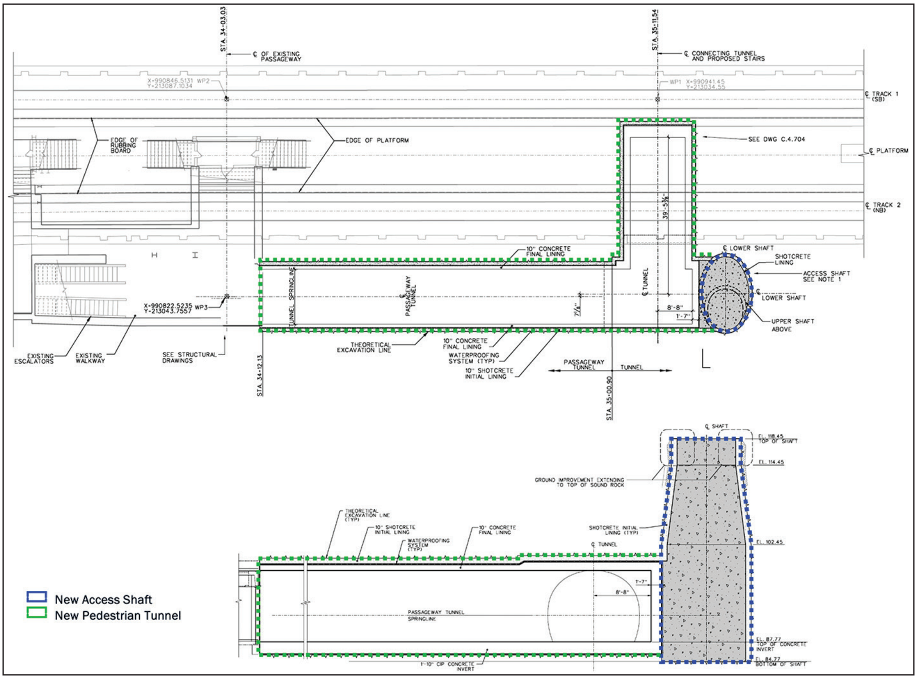

Figure 4. Plan view (top) and longitudinal section (bottom) of new passageway tunnel at Grand Central—42nd Street Station

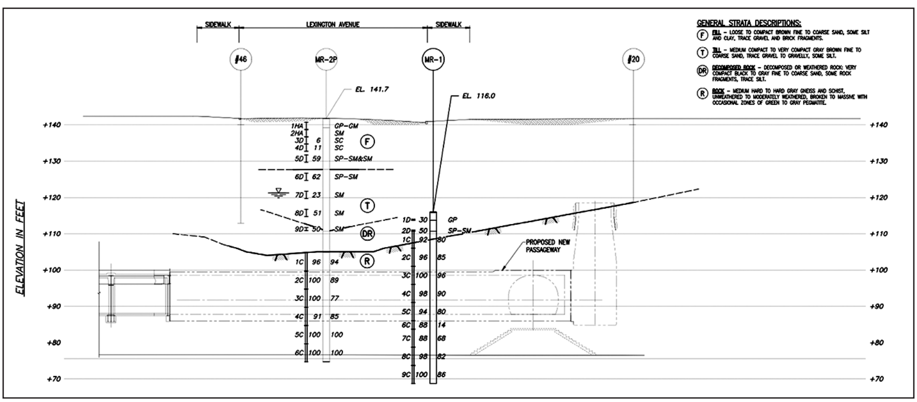

Figure 5. Geologic longitudinal section along new passageway tunnel

parameters for preliminary design. Groundwater monitoring established the groundwater elevation at +120.9 (approximately 11-ft above tunnel).

Bedrock foliation is well developed, generally dipping between 20° and 60° toward NW-WSW. A conjugate joint set is also present, with a strike similar to that of the foliation and dips between 25° and 66° ESE-SSE. Ungrouped localized joints are also present within the project area. Joint surface conditions ranged from rough or irregular to smooth and planar. Iron staining was typical on the joint surfaces with some altered surfaces, consisting of silty coatings or mineral coatings, also observed.

The bedrock topography was a critical element for consideration of excavation and support sequencing for construction of the new passageway. A combination of project/historic boreholes, geophysical surveys, and published geological mapping suggests a local linear depression of the bedrock surface, which results in apparently shallow cover (< 5 ft) along part of the passageway's alignment parallel to East 42nd Street.

PROJECT CHALLENGES

Construction of a new passageway from within an active station presents a number of challenges.

The main project challenges considered during the preliminary design and planning of the project included: excavation and rock removal during construction, maintaining train operations and limiting track outages during construction, pedestrian access/egress during normal operations and emergencies, coordination of work with on-going and planned adjacent contracts, site access for personnel & materials, limited available space for construction laydown/staging areas, protection of existing structures in particular during tunneling and the breakthrough of the station cavern, unforeseen conditions (ground conditions, existing structures, systems and utilities).

Considering the surrounding infrastructure of the new passageway and the importance to limit impacts from noise and vibrations, alternative means-and-methods were required as opposed to more traditional drill-and-blast method for hard rock tunneling as was done during the initial construction of the station. Examples of alternative rock excavation methods included the use of rock splitters and hydraulic breakers.

Initially, project plans did not envision the need for a construction access shaft. Early plans for construction without a shaft were complicated due to the limited space at the existing passageway and work restrictions (construction laydown, access path, operation, work windows, track outages, etc.). The construction access shaft was introduced as an option as the project was developed. This not only helped construction logistics, but it also helped limit the number of track outages for nights and weekends which was a goal from early in project planning.

While it was agreed to further develop the shaft further, the project still needed to evaluate where the shaft could be located and how this would be accessed from the street surface. A trade-off study was performed to select an optimum location for the construction access shaft. Figure 6 shows the two preferred locations. The main difference between the two concepts is the location of the shaft; either before or after the tunnel turn towards the Flushing Line station cavern.

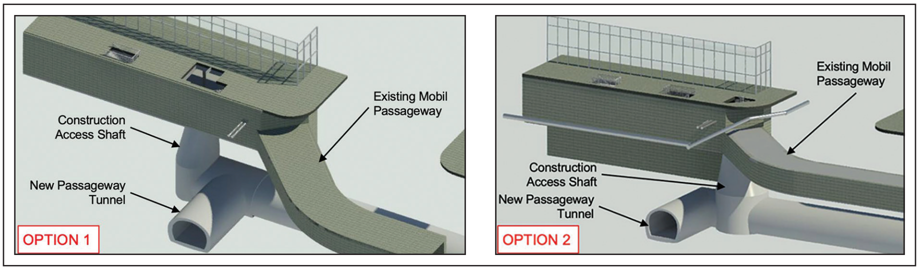

Figure 6. Preferred locations for the construction access shaft

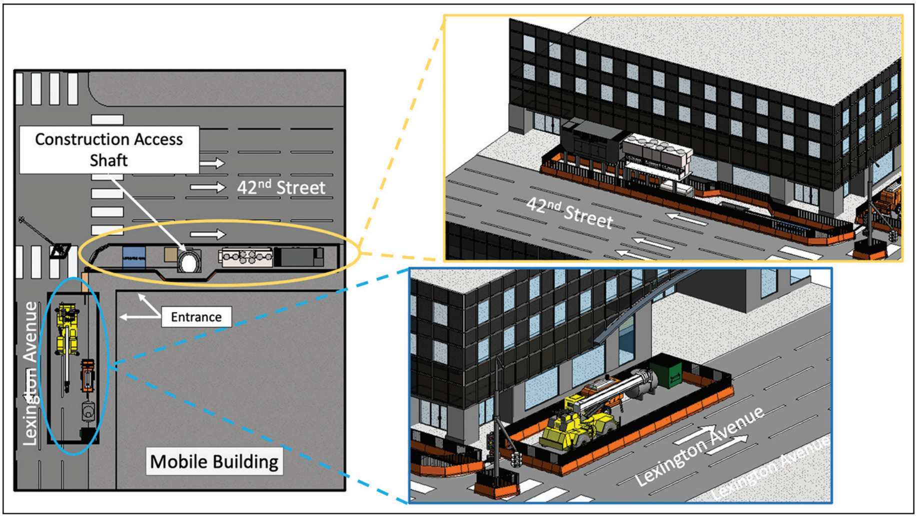

Figure 7. Site laydown area and organization developed for planning purposes

Each shaft location had its benefits, challenges, and risks. While Option 1 provided the largest access shaft diameter and most traditional shaft-to-tunnel interface, it required the most demolition for internal elements and impacted MTA's back of house. Alternatively, Option 2 had the flexibility to be constructed from within the existing Mobil Passageway or the from street surface, however, it required structural modification of the headwall at the interface with the Mobil Vault and Mobil Passageway Tunnel. Since there was not a clear benefit for one over the other, the preferred solution for the procurement was Option 1, however, the DB Team was given the flexibility to adjust the position of the construction access shaft.

As the project progressed with the shaft location based on Option 1, further planning at the street surface commenced. The shaft shown is located along 42nd Street outside the Mobil Building, near the southeast corner of 42nd Street and Lexington Avenue. To limit disruption to traffic at a busy intersection, a compact construction laydown area was considered split along 42nd Street and Lexington Avenue (see Figure 7). This configuration allows the site to maintain operation of both pedestrian and vehicle traffic during daytime hours along the sidewalk and street, respectively. During overnight construction hours, the two individual sites would be connected and expanded one additional lane along 42nd Street to allow for deliveries and removal of excavated rock. This concept was provided as part of the procurement documents to be further developed and finalized by the DB Team.

DESIGN AND CONSTRUCTION CONSIDERATIONS

Design Considerations

The new passageway extension consists of a construction access shaft, passageway tunnel and the connection tunnel to the existing station cavern. Tunnel design and construction for the passageway follows the Sequential Excavation Method (SEM) approach with installation of initial support following every excavation round. Strengthening of the existing station cavern arch around the new opening is enabled by installation of permanent supports using steel columns jacked against the arch before any tunnelling above the station cavern arch and any cutting/demolition of the arch commences. Temporary protective measures are required at the opening location to ensure safe operation of the station during construction.

To include flexibility in the DB procurement, the DB team had the ability to adjust the final position of the connection to suit their means-and-methods as well as optimize the project cost and schedule while considering associated risks for the ultimate selection. An isometric view of the new passageway tunnel is shown in Figure 8 with the maximum allowed length of the new passageway. The shortest possible location on the connection would coincide with the lowest rock cover above the tunnel.

Figure 9 shows the existing conditions at each end of the new passageway tunnel. The design for the new passageway has to consider, among others, train clearance to temporary and permanent support, installation of the column foundation, structural reframing at the existing passageway, relocation of suspended services and potential

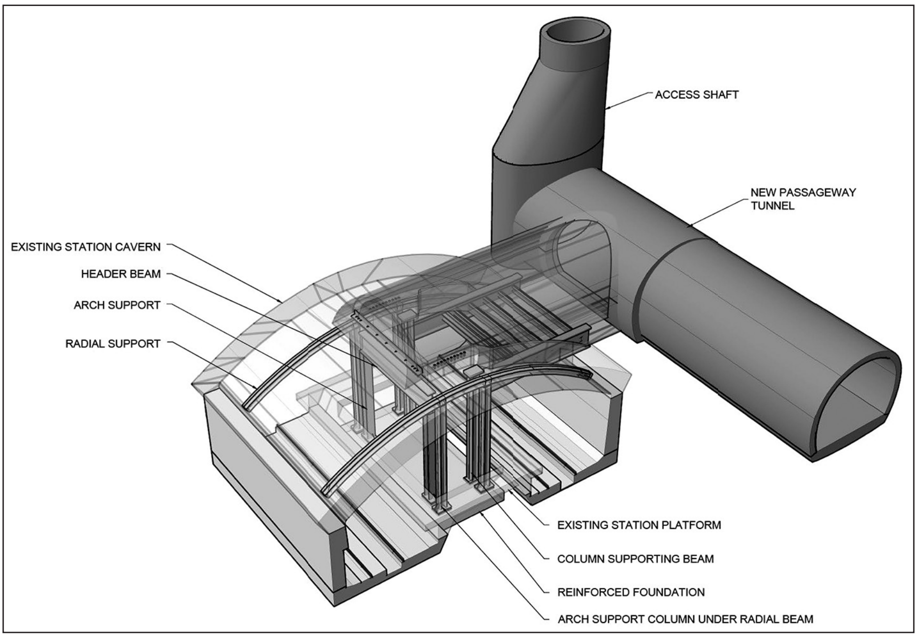

Figure 8. Isometric view of the new passageway tunnel, station connection and access shaft

Figure 9. Connection at the flushing line station platform (left) and existing passageway (right)

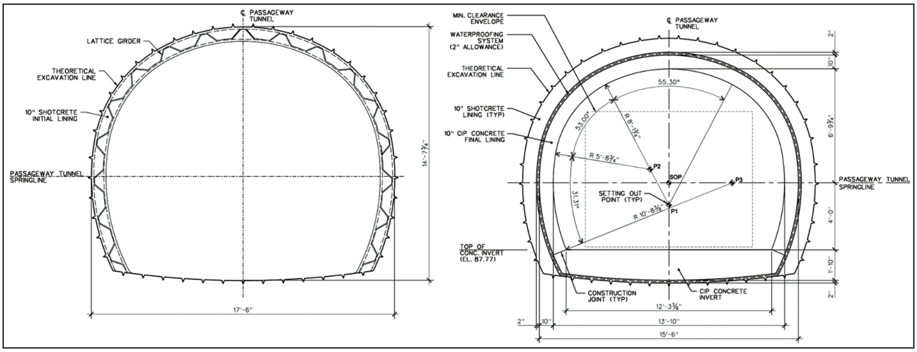

Figure 10. Initial tunnel support (left) and permanent lining support (right)

under platform services, rerouting of passengers, maintain staircase and escalator usage, and the platform boarding area.

Preliminary excavation and support sequencing for the tunnel envisioned a maximum full face 4-ft excavation round, followed by the installation of 10 inches of fiber-reinforced shotcrete and lattice girders (see Figure 10) with an allowance to adjust to rock bolts and reinforced shotcrete when sufficient rock cover is present to develop a reinforced rock arch. Meanwhile, at the low rock cover area, contingency measures include spiling ahead of the advance and pre-excavation grouting.

With the permanent opening frame installed and excavation completed, the break-in to the station cavern can proceed. Upon completion of the break-in, a waterproofing system is applied followed by the installation of a reinforced concrete final lining. The waterproofing system will comprise a geotextile and PVC membrane and will be terminated at the existing station cavern.

The preliminary design considered a comprehensive surface & subsurface instrumentation and monitoring program that included in-tunnel, geotechnical, and structure monitoring within the tunneling zone of influence. The project requires monitoring data to be evaluated on a continuous basis to facilitate adjustments of tunneling works, as needed, to minimize construction impact and enable execution of the works in a risk-managed approach. Considering the potential influence of the break-in on the Flushing Line Station Cavern, a real-time monitoring system is planned through the installation of continuous shape arrays. This monitoring approach was selected over a more traditional prisms target with automated total stations due to limited site distances and to minimize the requirement for maintenance of the monitoring system over the duration of the project. For instance, accessing the prisms for realignment or cleaning would require track outages, disrupting station operation.

To ensure the protection of existing structures and utilities, the Design-Builder is required to evaluate and prepare a damage assessment report documenting the impact of the work on existing overlying and adjacent structures and utilities. Pre-construction and post-construction condition surveys of foundations, interior and exterior of buildings, properties, railroad, utilities, appurtenances, and structures are also required within the tunnel zone of influence.

During the preliminary design and planning of the project, it was determined that the Design-Builder shall identify and develop mitigation measures for potential risks associated with the execution of the tunneling works. Per the project requirements, the Design-Builder shall consider the following:

a. Unforeseen ground conditions and low rock cover along the passageway and connection to the existing station cavern.
b. Under platform services and surface mounted not previously identify that require relocation and/or modifications.
c. Conflicts or additional work with above ground utilities and services that will need to be relocated if an access shaft is utilized by the Design-Builder.
d. Unable to perform additional supplemental geotechnical investigation due to access and/or schedule constraints of the project.
e. Impacts to the existing Station Cavern and Mobil Passageway due to tunnel excavation and structural modifications including service interruptions.
f. Delays to access potentially impacted properties within the ZOI to perform pre-construction condition survey and install instrumentation as part of the I&M program.
g. The need for additional staging and laydown areas.
h. Delays due to unable to efficiently remove excavated/muck material.
i. Delays due to unavailable/cancelled track outages and station closures.
j. Delays due to work by Adjacent Contractors.

Considering the project's location and scope of work, during the preliminary design and planning of the project it was established that the Design-Builder shall not begin mined tunnel excavation including demolition of existing structure until the following conditions (work restrictions) have been met:

a. Required submittals have been submitted and approved.
b. Pre-construction survey of existing structures, facilities, utilities and railroad infrastructure has been completed by Design-Builder and pre-construction documents have been provided.
c. Installation of geotechnical instrumentation for required monitoring program (subsurface, surface and building) has been completed and instrument baselines have been established.
d. Ground improvement, where required, to facilitate mined excavation has been completed and efficacy verified.
e. Approved temporary bracing (propping) to support existing tunnel has been installed where required to facilitate mined excavation. Unless otherwise noted, keep temporary bracing in place until final structural concrete has reached minimum specified design strength.
f. Prior to tunnelling above the existing station cavern and making any openings in existing cavern arch, the permanent structural steel system shall be installed to resist and transfer all vertical and lateral loads around the openings.
g. All issues related to health and safety have been met and submittals have been made in accordance with OSHA requirements, and other applicable codes and regulations of Federal, State of New York, and local agencies having jurisdiction.

The project requirements mandate that the Design-Builder prepares and submits for approval the following work plans associated with the tunneling work: Sequential

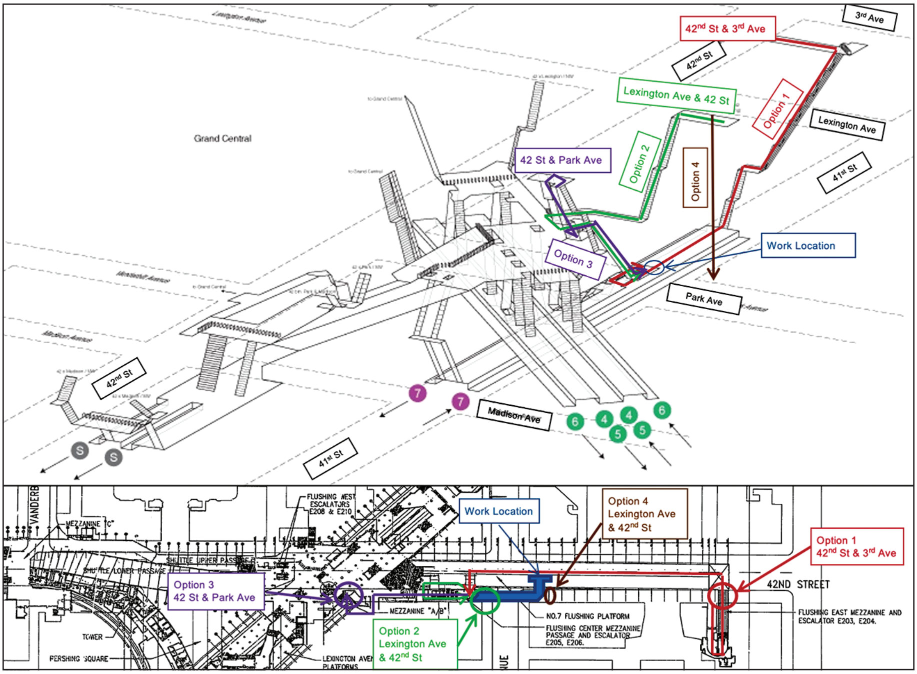

Figure 11. Alternative construction access routes from street surface

Excavation Method (SEM) work plan, Pre-Excavation Grouting work plan and Instrumentation & Monitoring work plan.

Construction Considerations

While the construction access shaft was the ultimate decision for project planning, there were three (3) other alternatives without a construction access shaft reviewed as part of project planning. Each of these options provided access from different entrances to the Flushing Line at Grand Central—42nd Street Station (see Figure 11). The entrance to Option 1 at 42nd Street and 3rd Avenue connects to the east end of the Flushing Line platform. Meanwhile, Option 2 and Option 3 connected from different street access locations to the existing passageway via Escalator 205/206. Of the three (3) options, Option 3 proved to provide the most direct access for construction and logistics. However, each of these options were ultimately eliminated due to heavy disruption to station operation as they required significant laydown space and several nightly track outages.

Once the project ruled out these three (3) options, the shaft option began to be investigated and a choice had to be made to have the shaft extend to the street surface or to limit the shaft to the Mobil Passageway level (see Figure 12). As shown, there is limited working height within the Mobile Passageway for construction. For this location, it was anticipated that structural reframing was required to create additional working height by demolishing the base slab and potentially deepening of the original excavation profile. Even with this enabling works, all lifting of materials, muck and equipment would be limited to a small capacity gantry system. Ultimately, the decision was made to create a shaft from street surface outside of the Mobil Passageway.

Figure 12. Shaft access from street (left) versus Mobil Passageway (right)

CONCLUSION

Since the original construction of the Grand Central—42nd Street Station, improved access and passenger movement necessitated the upgrading of the station. A number of transformations have occurred since the early 1900's with the next planned upgrade commencing in early 2023. The major difference between previous upgrades and this current plan is the limitation of construction access and the demand to maintain station operation throughout construction. As a result, preliminary studies were undertaken to find an optimized solution to carry out the construction of a new passageway tunnel. While a number of iterations for preliminary design and planning were required to have alignment from all parties involved, a clear priority to minimize disruption to station operation early on in the project helped guide the refinement of each alternative and ultimate selection of the construction access shaft. The introduction of a construction access shaft to project planning increased the magnitude and scope of the project, however, it simplified construction and logistics planning. The shaft allows for direct access for, among other, material deliveries, construction services, personnel, and muck removal.

The project challenges presented for the Circulation Improvements at Grand Central—42nd Street Station are common to station upgrades elsewhere in urban settings. This paper presented a unique solution for the construction of a new passageway tunnel and the connection tunnel to an existing station cavern with minimal disruption to the operation of the station.

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