

FEATURE ARTICLE

The future of transit tunneling in Washington, D.C.

By the time the latest expansion of the Washington Metropolitan Area Transit Authority (WMATA) system, known locally as Metro and which opened in 1976, is completed in 2020, the system will serve 97 stations and operate on 188 km (117 miles) of track on six interconnecting lines. Metro provides a critical transportation link to a population of approximately six million people within a 3,900-km² (1,500-sq-mile) Washington Metropolitan area and has allowed job growth to expand to all corners of the region. In the 1950s and 1960s, when the system was first conceived and construction began, most jobs were centered in downtown Washington, and most of the workforce commuted by bus or car. Today, transit-oriented development has increased residential, commercial and government facilities near most of the existing 91 stations increasing the importance of the Metro system as a critical transportation link for the region. According to recent American Public Transportation Association (APTA) data, Metro is the second busiest transit system in the United States (after New York City's transit system).

During the nearly 50 years of construction on the Washington Metro system, technology improvements and lessons learned from the global tunneling industry were implemented. Portions of this background and history have been adapted from other work by the authors Roach et al. (2017) and expanded for use herein. For soil tunnels, these improvements included the change from a "two-pass" tunnel lining with a typical initial lining of steel ribs with wood lagging or segmental precast lining erected within the tunnel shield followed by a final lining of cast-in-place concrete to a one-pass lining system of pre-cast concrete gasketed segmental lining. Soil tunnels were originally excavated using open-face tunnel shields, but changed over time. By the late 1980s, tunneling using closed, pressurized-face tunnel boring machines (TBMs) using a one-pass tunnel lining consisting of segmental precast concrete

permitted tunneling in a wider range of soil conditions with much less risk of damaging overlying utilities or structures, greater safety for tunnel construction personnel and without the need

to dewater the soils. However, due to concerns about conditioning clays with earth pressure balance (EPB) TBMs, open face machines were still favored by contractors for their better advance rates, lower cost and ability to deal with boulders that were occasionally encountered in the Coastal Plain Terrace Deposits.

Ground improvement techniques that made tunneling possible in weak or very wet soils at the start of Metro construction were largely limited to cement and chemical grouting and, to a lesser extent, ground freezing. Many early (pre-1978) WMATA tunneling contractors used chemical grout for use in fine-grained soils. This changed over time as technologies evolved for jet grouting (replacement of soil by grout), compaction grouting and compensation grouting where grouting is undertaken as tunneling takes place.

For tunnels in rock, the work started when tunneling technologies were transitioning from the traditional method of drill-and-blast excavation with rock support using structural steel (steel sets) to more modern methods. The first rock tunnel running north from Dupont Circle Station was a single double-track tunnel excavated by drill-and-blast methods. Later, tunnel contractors used hard-rock TBMs between and through the stations. WMATA personnel had concerns about the delays associated with gripper-type TBMs getting stuck for extended periods in weak rock formations (there was no reverse gear) and with replacing worn disc cutters. Consequently, they preferred conventional rock excavation techniques. Drill-and-blast excavation continued out of necessity to excavate station caverns in rock, as well as many smaller-size excavations such as for cross-passages between tunnels.

Design and construction of rock tunnel linings evolved to follow principles of rock reinforcement by using rock bolts and shotcrete, eliminating the use of steel sets. These practices progressed further where rock bolts were replaced by untensioned rock dowels fully encapsulated with cement or resin and shotcrete for initial support and, in some cases, shotcrete as the permanent lining. Ground water leaks were a major problem during early construction. Dry tunnels without leaks became possible when PVC membranes were placed between the initial and final linings of rock tunnels (Sauer et al., 1987). It was part of the early introduction and adaptation of European tunneling methods and initial use in the United States (Heflin 1985) of the New Austrian Tunneling Method (NATM), also known as the sequential excavation method (SEM). This was the first time in the United States where the owner fully accepted the method and used it for later projects. This approach to tunneling integrated the several techniques that had evolved globally

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over the years and was used to successfully excavate tunnels in rock and, for the first time in the United States soil (Heflin et al., 1991).

The contract for the Fort Totten Station and tunnels in 1988 was the only contract out of three offered by WMATA in which the contractor chose to utilize NATM. It was the first use of NATM in soft ground (sands and clays) for a transit tunnel in the United States. The project included 292 m (958 linear ft) of twin tunnels, in addition to a portion of the station excavation located west of the Fort Totten Station. Excavation and ground behavior were monitored during construction by an extensive geotechnical instrumentation program. Specified initial support included shotcrete applied in three stages, with welded wire fabric and lattice girders. Soil anchors were also required for initial support. Additional support was provided by forepoling bars, forepoling sheets and face shotcreting.

The tunnel research work that began on the first projects of the Washington Metro set the stage for geotechnical instrumentation and monitoring for tunneling that is undertaken throughout the world today. Metro engaged the University of Illinois at Urbana-Champaign Department of Civil Engineering to conduct field research on soil tunneling, rock tunneling and cut-and-cover excavations. The lessons learned for instrumentation and procedures for tunneling were published as *Methods for Geotechnical Observations and Instrumentation in Tunneling* (Cording et al., 1975).

Washington Metro engaged a board of experts to peer review and advise on all aspects of design and construction. The Washington Metro Tunnel Board of Consultants (including Ralph B. Peck, Don U. Deere and A. A. Mathews) became the forerunner for what is today a common practice within the underground industry (Roach et al., 2017).

Approximately half of the original 165-km (103-mile) system was constructed underground, including approximately 30 km (19 miles) of rock tunnels, 19 km (12 miles) of mined soft-ground tunnels and cut-and-cover construction. A total of 48 stations are underground, 11 of which were mined in rock, one was mined in soil, and the rest were constructed by cut-and-cover methods. The 30 km (19 miles) of rock tunnels were constructed for the Red Line extending from Dupont Circle Station north to the Rockville Station, approaches to and under the Potomac River between Foggy Bottom and Rosslyn Stations, and the north end of the Red Line between Wheaton and Glenmont Stations.

The local geology straddles the boundary between the Coastal Plain and the Piedmont Physiographic Provinces. From the boundary, also known as the Fall Line, which extends through the metropolitan area from SW to NE, there is an increasingly thickening wedge of Coastal Plain deposits to the southeast underlain by older Piedmont

FIG. 1

Steel pipe arch canopy support for WMATA Silver Line extension in Tyson's Corner. Source: Vojtech Gall/GZ Consultants.



rocks. Coastal Plain soils include interbedded alluvial soils, ranging from clays, silts and sands to cobbles and boulders, deposited by rivers and tributary systems within channels, bars, floodplains, terraces and alluvial fans. The alluvial deposits are underlain by older Potomac Group soils, which were deposited in a marine environment and are generally denser and stiffer than the alluvial deposits. Northwest of the Fall Line, Piedmont residual soils, weathered and hard intact bedrock are evident near the ground surface. These geologic conditions had a significant influence on tunneling and underground construction methods. Also influencing construction were the presence of the Potomac and Anacostia Rivers, Rock Creek and other tributary streams and creeks.

Expansion of the system

In recent years, there have been several expansions of the original Metro system that have included tunneling and underground construction. These projects include the Dulles Corridor Metrorail, also known as the Silver Line, the Rosslyn Station Expansion and Access project, the Medical Center Station Metro Crossing project, and the Purple Line, a new light rail transit system overseen by the Maryland Transit Administration that will provide a circumferential connection between three suburban Metro Stations (Bethesda, Silver Spring and Greenbelt) in Maryland.

The Dulles Corridor Metrorail Project, estimated at more than \$5 billion, extends Metro service from West Falls Church Station through Tysons Corner to Wiehle Avenue Station (Phase I) and to Dulles International Airport, terminating at a station beyond the airport in Loudoun County, VA (Phase II). SEM tunneling was employed for a 520 m (1,700 ft) section through Tysons Corner in Phase I of the project. SEM was used, including a single- and double-grouted steel pipe arch canopy pre-support due

FIG. 2

DC Water's First Street Tunnel EPB TBM "Lucy" as introduced by Mayor Muriel Bowser. Source: Brian Zelenko/WSP at TBM Naming Ceremony on April 14, 2015.



to shallow cover and soft ground (Fig. 1). This design-build project, overseen by the Metropolitan Washington Airports Authority, is funded by various public and private entities, including the Dulles Toll Road, demonstrating how third parties can work together with WMATA to address regional transportation needs and expand the Metro system.

Rosslyn Station is an important underground hub station in Arlington, VA, that serves the Orange, Blue and Silver lines. The station was constructed in the early 1970s and was opened in 1977. As part of a new residential and commercial development, an access improvement project was undertaken in 2009 and completed in 2013 to accommodate expanded station capacity associated with the new development. The work included a new station entrance and a new track-level mezzanine that expands the passenger capacity of the station. Construction included a new vertical elevator and stair shaft entrance from the ground surface, connected by a 11-m (35-ft)-wide by 12-m (40-ft) high mezzanine constructed using SEM techniques leading toward the existing station. Passengers walk through a 6-ft (19-ft) wide by 4.5-m (15-ft) high passageway between the new concourse and the existing escalator entranceway. The SEM approach to design and construction made the complex underground structures possible.

The Rosslyn Station expansion is an excellent example of transit-oriented development leading to privately-financed expansions of the system. In Maryland, the Purple Line will include a new underground entrance to Metro's Bethesda Station to facilitate connectivity between Metro and the Purple Line.

Other recent and future tunneling in Washington, D.C.

The DC Water Clean Rivers Project is a \$2.6-billion program to reduce the occurrence of combined sewer overflows into Washington's local waterways. The project includes several large-diameter conveyance and storage tunnels in the soft ground of the Coastal Plain deep under the city. Some of these new tunnels pass below existing WMATA Metro lines.

The first major tunnel construction started in 2013 and included an 8-km (5-mile) long, 7-m (23-ft) inside diameter (ID) bored tunnel along the Potomac and Anacostia rivers from DC Water's Blue Plains Advanced Waste Water Treatment Plant to a pump station in the Navy Yard. Subsequent contracts included a 3.8-km (2.4-mile) long, 7-m (23-ft) ID tunnel from RFK Stadium under the WMATA Green Line and the Anacostia River to Poplar Point, and a half mile long 6-m (20-ft) ID tunnel in the Bloomingdale neighborhood along First Street (Fig. 2). All these tunnels have been successfully excavated in the Potomac Formation soils with state-of-the-art EPB TBMs. The most recent tunnel contract

of the Clean Rivers Project was awarded in 2017 and will include an 8-km (5-mile) long tunnel connecting the previously constructed Anacostia River and First Street tunnels. This tunnel will also utilize an EPB TBM with pre-cast concrete gasketed segmental lining. The depth of this new tunnel system is between 21 and 49 m (70 to 160 ft) below the ground surface and includes multiple deep shafts and connection tunnels excavated by SEM. Unique to this project is the fact that DC Water used design-build procurement for all the tunnel contracts. To date, DC Water's Clean Rivers project has been successful in terms of work quality and schedule adherence. Those projects with soft-ground tunneling and design-build procurement are solid precedents for any future transit tunneling in Washington, D.C.

A final DC Water tunnel scheduled to be procured in 2020 along the Potomac River will provide additional precedent for tunnel excavation by TBM in rock, mixed-face and soil. As with the other tunnels in DC Water's Clean Rivers project, the Potomac River tunnel is expected to be procured as a design-build contract.

Current transit tunneling in other major U.S. cities

As urban areas grow in population, several major cities in the United States have been expanding their transit systems with tunneling and underground construction. These projects, which minimize impacts to surface streets and structures, are instructive in helping to envision the future of transit tunneling in Washington, D.C. As with the recent DC Water Clean Rivers tunneling program, owners in recent years have been favoring alternative delivery methods, such as design-build.

New York City

Similar to the Rosslyn Station expansion for WMATA, the New York City Metropolitan Transit Authority (NYC MTA) has added station access and increased the size of stations for a number of locations throughout their system, including Columbus Circle, Hudson Yards, Lexington Avenue/63rd Street Station, and South Ferry, just to name a few. The NYC MTA's 2015-2019 Capital Program includes \$7.1 billion to expand the network through major investments. The NYC MTA receives approximately 35 percent of its income from a regional sales tax, regional tax on mortgage receipts and a tax on businesses that refine or sell petroleum-based fuel. In recent years, underground transit improvements have included:

- NYC MTA 2nd Avenue Subway (Phase 1) — \$4.4 billion project includes a 3.2-km (2-mile) long segment from 96th Street to 63rd Street and includes new stations at 96th, 86th and 72nd Streets. The 2nd Avenue Subway (Phase 2), which will extend the system north to 125th Street, has started preliminary design.
- NYC MTA No. 7 Subway Extension and Station — \$2.1 billion project extended the subway line from Times Square Station to the Jacob K. Javits Convention Center at Tenth Avenue and West 34th Street.
- Long Island Railroad (LIRR) East Side Access Project — \$10.8 billion project, still under construction, extends LIRR service from Queens and Long Island to Grand Central Terminal.

Los Angeles, CA

The Los Angeles County Metropolitan Transportation Authority has embarked on a major expansion through Measure R, a voter-approved ballot measure that resulted in a half-cent sales tax for Los Angeles County to finance new transportation projects and programs which has been in place since 2009.

Four segments that include tunneling and underground construction are underway as design-build contracts:

- Crenshaw to Los Angeles International Airport — \$1.3 billion, 13.6-km (8.5-mile) long project includes 3.2 km (2.1 miles) of tunnels and three underground stations.
- Purple Line Extension Segment 1 — \$1.6 billion, 6.2-km (3.9-mile) long tunnel project includes three underground stations and extends to Beverly Hills.
- Purple Line Extension Segment 2 — \$2.4 billion, 4.1-km (2.6-mile) long tunnel project includes two underground stations and extends the Purple Line to Century City.
- Regional Connector — \$1.8 billion, 3-km (1.9-mile) long project through downtown L.A. will connect two existing transit lines and will include three new underground stations.

In 2016, Los Angeles County voters approved Measure M, which will provide an additional \$120 billion in transportation funding over the next 40 years. With the 2028 Olympics set to be in Los Angeles, further extension of the Purple Line (Segment 3) to UCLA, the location of several sports venues are anticipated.

San Francisco, CA

San Francisco is served by both the Bay Area Rapid Transit (BART) system and the San Francisco Municipal Transportation Agency (SFMTA). Several expansion projects are underway or have been proposed.

- SFMTA Central Subway Project — \$1.6 billion, 2.7-km (1.7-mile) long, tunnel project will extend the Muni Metro T-Third Street Light Rail Line from SOMA to Union Square and Chinatown. The project includes tunneling with two EPBMs and three underground stations constructed by SEM and cut-and-cover methods.
- BART 2nd Transbay Tube — this proposed project would build a second tube between Oakland and San Francisco south of and parallel to the existing immersed tube tunnel. It would connect to the new Transbay Transit Center and provide connections to Caltrain and the new California High Speed Rail.

Seattle, WA

Over the past 20 years, Sound Transit has expanded Seattle's transit system with a series of tunnel and underground projects. Since its creation in 1993, the agency has passed three major funding ballot measures. The most recent measure in 2016, Sound Transit 3, provides \$53.8 billion in funding to support expansion of the transit system. The measure is partially funded by increases to sales, vehicle excise, property taxes as well as federal grants. Recent work has included:

- Northgate Link Extension — \$1.9 billion project includes twin tunnels that will extend 5.8 km (3.6 miles) north from University of Washington Station at Husky Stadium.
- East Link Extension — \$3.7 billion project, which includes a 610-m (2,000-ft) tunnel constructed by SEM, will extend light rail 22.5 km (14 miles) from downtown Seattle to downtown Bellevue and Redmond.

Future transit tunneling in Washington, D.C.

The future of Metro's transit tunneling in Washington, D.C. is tied to future capital investments and improvements to the Metro system. This was discussed in WMATA's Momentum Strategic Plan (2013-2025) and subsequently in planning and analyses conducted soon after the Momentum Plan for a 2040 Regional Transit System Plan. Although the 2040 Strategic Plan has not yet

FIG.3

Metro's core and core stations. Source: WMATA, Momentum, The Next Generation of Metro, Strategic Plan 2013-2025.



been finalized and adopted by Metro's Board, some of the planning associated with it has been posted on Metro's planning blog website, PlanItMetro. As highlighted by a 2013 *Washington Post* article that included an interview with Shyam Kannan, Metro's chief planner, Metro identified a need to expand capacity in the system's core to meet future transit ridership demands. This could be accomplished by adding a new core loop that includes approximately 10 new stations and adding capacity and connections at four existing stations.

This investment faces several hurdles. One of the big hurdles that Metro has faced is the lack of a local dedicated funding source, unlike many of the other cities and transit agencies previously noted. Without a dedicated funding source, it will be difficult to achieve the goals of the Momentum Plan. Now, four years since the issuance of the Momentum Plan, a local dedicated funding source was finally established in 2018 with all three jurisdictions (Maryland, the District of Columbia and Virginia) committing funds. Secondly, future investment has been tied to ridership and recently transit ridership numbers have been declining across the country, especially for Metro. According to APTA, national transit ridership was down approximately 1.9 percent over the past two years. Metro's ridership has been down by 14 percent during the same period. For Metro, this is partially due to recent repair work, such as the year-long SafeTrack program, and ongoing reliability challenges. It is also due to the increasing popularity of alternative works schedules, particularly by federal workers, reductions in late-night and weekend service, as well as the popularity of Uber and other ride share companies. However, in the larger, longer view, there will

be a demand for safe, efficient and reliable service that can only be achieved by new tunnels.

Additionally, the future may also include an extension of planned high speed rail by Amtrak in the Northeast Corridor south to a redeveloped Union Station, possibly extending further south to Virginia and the Southeast Corridor. Recent news reports have noted that entrepreneur Elon Musk, chief executive officer of SpaceX and Tesla, is planning to privately finance and develop a new high-speed underground transit system, Hyperloop, between Baltimore, MD and Washington, D.C. Maryland has issued a conditional utility permit to his company, The Boring Company, allowing construction of a 16.5-km (10.3-mile) section of tunnel along the proposed route. These future projects are under consideration because long tunnels and complex underground works are more feasible and can be built with less risk than in the past.

Metro

In the last two years, Metro has focused its efforts on restoring its system to try to correct years of deferred maintenance on an aging system and improving safety and reliability for the travelling public. Programs such as Back2Good, designed to get the system in good repair, and SafeTrack, an accelerated track work plan to address safety recommendations by the Federal Transit Administration and the National Transportation Safety Board, have been implemented. Through SafeTrack, Metro completed approximately three years' worth of maintenance and repair work in approximately one year. Much of the system's maintenance work is related to leaking tunnels constructed in the 1970s and 1980s. Today's tunneling industry has the ability and technology to construct nearly watertight tunnels, representing a huge improvement over past construction methods.

The Momentum Plan identified several key issues, which are common to other major cities in the United States that have invested in transit improvements:

- Improve regional mobility and connect communities.
- Enhance access.
- Add operational redundancy.
- Build for the future.
- Add new sources of predictable funding.

As noted in the Momentum Plan, the region is forecasted to increase 30 percent in population and 39 percent in employment over the next 30 years. And Washington, D.C. is one of the few metropolitan areas where growth is occurring in the city core, inner suburbs and outer suburbs. The Momentum Plan identified core station improvements, including pedestrian underground

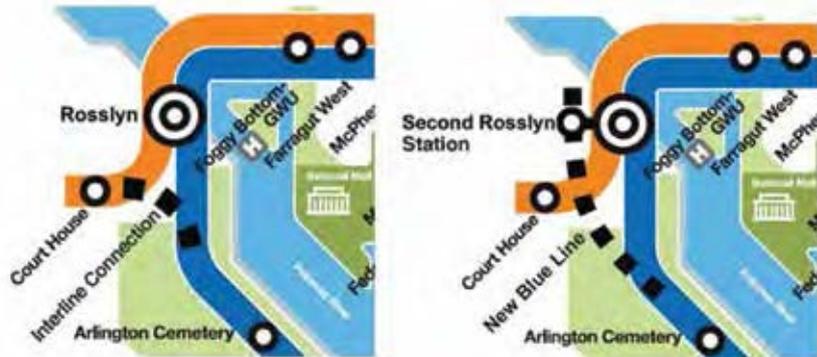
connections, that Metro stated should be completed by 2025 to have maximum impact, increase system and core capacity, and improve the effectiveness of the rail network. These improvements are envisioned at stations such as Metro Center, Gallery Place, Union Station, L'Enfant Plaza, Farragut West, and Farragut North (Fig. 3). In 2012 dollars, they were estimated to have an order of magnitude cost of \$1 billion.

Other conceptual improvements, included in the Momentum Plan, were further evaluated by Metro during the planning effort for a 2040 Regional Transit System Plan. These improvements would be required, in addition to the 2025 Plan Core Station Improvements, to serve the region's transit needs with the projected growth. It noted that as transit patronage reaches full capacity on lines converging at Rosslyn and L'Enfant Plaza Stations, new east-west and north-south transit tunnels through Arlington and Washington, D.C. would be required to accommodate trips and improve capacity through the system core. Some of those improvements, with associated order of magnitude cost in 2012 dollars, related to future transit tunneling include:

- New connection of existing lines at the Pentagon with a new Pentagon Station (\$600 million).
- Silver/Orange Line Express Line from West Falls Church to a 2nd Rosslyn Station to a relocated Blue Line (\$2.3 billion) — this would allow passengers on the Silver and Orange Lines better access to the eastern side of downtown Washington. A second Pentagon station would allow passengers on the Orange and Silver lines to reach the Pentagon without having to switch to the Blue Line. The underground portion of this new line would begin in the Piedmont bedrock at the Rosslyn Station and then transition to Coastal Plain soil deposits at the second Pentagon Station. Tunneling could be completed by an EPB TBM or a Hybrid TBM (Fig. 4).
- Relocated Yellow Line (\$2.7 billion) — this would improve north-south capacity and require a new tunnel south from the Pentagon under 10th Street SW and NW and then west to Thomas Circle allowing the Green and Yellow lines to operate in separate tunnels. As this alignment is generally in the Coastal Plain Deposits,

FIG.4

Conceptual new Metrorail Blue Line connections at Rosslyn Station. Source: WMATA, Momentum, The Next Generation of Metro, Strategic Plan 2013-2025.



tunneling could be accomplished using either a Slurry or EPB TBM.

- Relocated Blue Line (\$3.3 billion) — this would improve east-west capacity by creating a new Blue Line alignment through Rosslyn to Georgetown and then along M Street NW to Thomas Circle. As this alignment is primarily in the Piedmont sections of Washington, D.C., tunneling could be accomplished using a hard rock TBM. Station construction could be completed fully by SEM or cut-and-cover methods. Construction of a station in Georgetown could be completed by SEM construction with significant attention made to protect existing

FIG.5

Proposed 2040 Metrorail network – Core Loop. Source: WMATA Planning Website and Blog. <https://planitmetro.com/>.

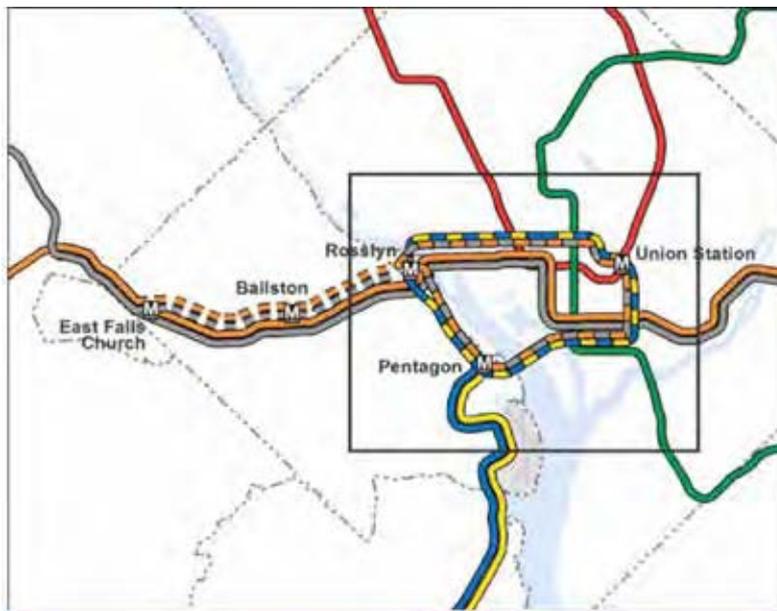
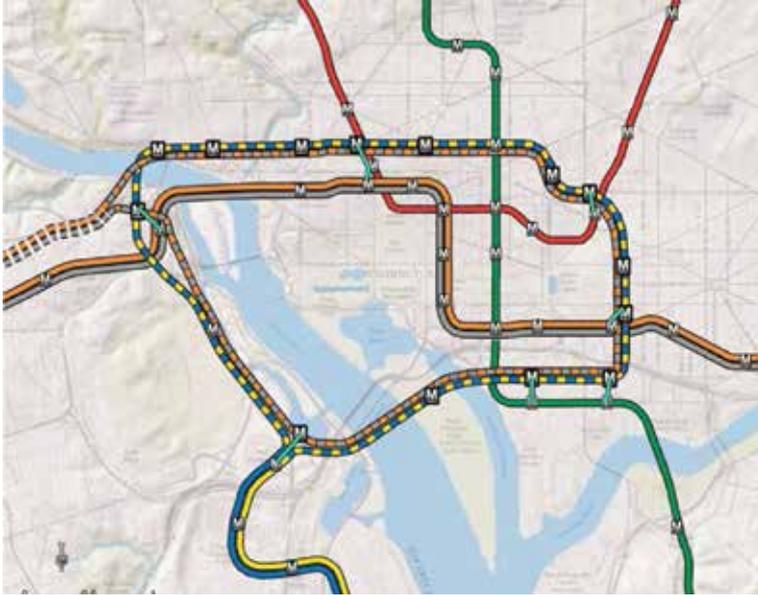


FIG. 6

Proposed 2040 Metrorail network – Core Loop detail. Source: WMATA.



structures through a congested part of the city with the use of ground improvement.

As indicated on the PlanItMetro website, one possible way to increase capacity in the downtown core would be the conceptual development of a Core Loop (Figs. 5 and 6) that extends north from a second Rosslyn Station in a deep tunnel to Georgetown, extends east toward Union Station to a second Metro station at Union Station

FIG. 7

Conceptual proposed WMATA Metrorail line south of Union Station. Source: U.S. DOT Federal Railroad Administration (FRA), 2017, Washington Union Station Expansion Project, Concept Screening Report.



possibly constructed below the existing station while providing connections to the existing Red and Green Lines along the way. As shown in the conceptual figure, the Core Loop could then extend south and west to address the needs from the Relocated Yellow Line noted in Momentum. This work would involve tunneling and underground construction for the stations. These are conceptual drawings and future planning could lead to alternatives such as a continuation of the new line from Union Station to the east, perhaps 3.2 km (2 miles) to RFK Stadium.

Union Station redevelopment

The Union Station Redevelopment Corporation (USRC), in coordination with Amtrak, is planning for a \$7-billion phased expansion and modernization of Washington Union Station. The historic station, which opened in 1907, is proposed to handle triple the number of passengers and double the train service. Major improvements are being planned to add a 3-million SF air-rights development, named Burnham Place after Union Station architect Daniel Burnham,

over the train shed. Additional improvements include increasing capacity along the Northeast Corridor to New York and Boston with the addition of new underground passenger concourses below the existing train shed, and plan for possible High Speed Rail, extension of Maryland Regional Rail Trains to Virginia, as well as possible extension of Virginia Railway Express trains to Maryland.

Constructed in the 1970s, Metro's busiest station is at Union Station on the Red Line. The near-term station access improvements planned by Metro will be included in the Union Station redevelopment. According to the U.S. DOT Federal Railroad Administration (FRA) 2017 Concept Screening Report, a second Metro Line servicing Union Station is being considered in long-term planning (beyond 2040) in order to meet future travel demand. The proposed conceptual alignment is parallel and south of Massachusetts Avenue passing along the southern edge of Columbus Plaza, directly south of Union Station (Figs. 7 and 8). A second Metro Station would need to be constructed below the existing station at Union Station. This station would extend roughly between North Capitol Street and Louisiana Avenue, below existing surface parking lots just south of Massachusetts Avenue. Tunneling using a Slurry or EPB TBM would likely be required, combined with SEM for station construction within the Coastal Plain deposits. Alternatively, the second Metro Line could be located on the north side of Union Station to tie-in with the planned air-rights development. This would allow Union Station to be served by two Metro Lines. However,

the new Metro station would not be a transfer station due to the distance from the existing Metro Station on the Red Line.

High speed rail

High speed rail (HSR) connecting to the Northeast Corridor, which is only being considered in the fourth phase of Union Station Redevelopment, would likely enter the station at a new deep underground level below the existing station and platforms. High speed rail tunnels entering Union Station from the north would likely need to begin somewhere around the Anacostia River crossing, approximately five miles north of the station. As the tunnels enter the station, they would need to be aligned in coordination with the existing large footings which are supporting the existing historic station structure on Coastal Plain Terrace Deposits. For HSR to continue south to Virginia, it is possible that twin-bored tunnels would follow an arc route out of the station and below the National Mall before crossing the Potomac River into Virginia. The FRA, in cooperation with the Virginia Department of Rail and Public Transportation, is preparing a Tier II environmental impact statement for the 198-km (123-mile) portion of the Southeast High Speed Rail Corridor from Washington, D.C. to Richmond, VA. The study begins at the southern terminus of the Long Bridge across the Potomac River in Arlington, VA.

Due to the shallow connection at Union Station, it is anticipated that twin-bore tunnels would be a preferred approach, rather than a single large-bored tunnel with two tracks which would require more complex underpinning. Due to high groundwater levels and Coastal Plain deposits, a pressurized-face TBM, either slurry or EPB, would likely be used to build the HSR alignment south of Union Station. A superconducting maglev program to provide a high-speed connection in tunnels between Baltimore and Washington, DC is also being considered by planners.

Conclusion

Washington, D.C. expects an increase in population, employment and transit oriented development over the next 30 years that will put a strain on the existing Metro transit system. This led WMATA to develop the Momentum Strategic Plan 2013-2025 that identified core station improvements, new east-west and north-south transit lines that would improve access and effectiveness of the network in the system core. These proposed improvements, amounting to more than \$10 billion (in 2012 dollars), would require tunneling and underground structures. In addition, Washington Union Station is about to begin a \$7 billion phased expansion and modernization program that will include significant underground construction at the station and may include tunneling for High Speed Rail from the Northeast Corridor, through

FIG. 8

Conceptual future WMATA Metrorail line and station south of Union Station. Source: U.S. DOT Federal Railroad Administration (FRA), 2017, Washington Union Station Expansion Project, Concept Screening Report.



Union Station and south to Virginia across the Potomac River. These future projects are under consideration because long tunnels and complex underground works are more feasible and can be built with less risk than in the past.

Having a reliable funding source with dedicated funding from the region for the first time ever is a big step for the Washington Metro to meet its future needs. Other major cities such as New York, Los Angeles, Seattle and San Francisco have addressed the funding hurdle for transit capital programs, together with federal support, and are underway with major tunneling and underground construction works. A recent decline in transit ridership, particularly in Washington, D.C., would need to demonstrate signs of recovery before decision makers would be willing to make the substantial investments required to improve the transit system. However, planning and conceptual design work should continue given the clearly identified future demand in the system core. State-of-the-art tunneling and underground construction methods that have been used in other major cities for recent transit tunneling projects have been successfully used in Washington, D.C. for recent Metro expansion as well as the DC Water Clean Rivers Program. Therefore, Washington, D.C. is poised for significant transit tunneling work in the future. (References available from the authors.) ■

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