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The Dulles Corridor Metrorail Project – Tunneling aspects of the Metrorail extension to Washington, DC Dulles International Airport Phase I and Phase II

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ABSTRACT: The Virginia Department of Rail and Public Transportation (DRPT) is currently undertaking the extension of Washington Metropolitan Area Transit Authority's Metrorail service to Washington Dulles International Airport. The 37 kilometers long Metrorail alignment is scheduled for completion in 2015. The project features two single-track, 700 meter long NATM tunnels at shallow depths in soft ground. At Dulles Airport two 3.3 kilometer long, single-track tunnels will be bored by TBM in siltstone rock. A 25-meter deep station will be constructed using NATM techniques. The total cost of the Metrorail project is estimated to be approximately US $4.0 billion (2006 dollars). Upon completion of preliminary engineering in early 2007 the design build contractor, a joint venture of Bechtel and Washington Group International and referred to as Dulles Transit Partners (DTP) will submit a negotiated, firm, fixed price to DRPT and the project will be implemented under a public private partnership agreement.

1 INTRODUCTION

The Dulles Metrorail project will extend WMATA's rail services from the Metrorail Orange Line in Fairfax County, Virginia to Route 772 near Ashburn in eastern Loudoun County, Virginia. This corridor encompasses several activity centers including Tysons Corner, Reston, Herndon, and International Airport Dulles (IAD) as well as emerging activity centers in eastern Loudoun County. The project alignment within the Dulles Corridor is displayed in Figure 1.

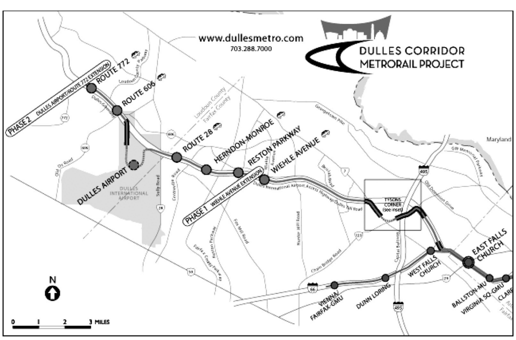

Figure 1. Dulles Corridor Metrorail project.

Rapid Transit for the Dulles Corridor was initially explored in the 1950's as part of the planning process for Dulles Airport. At that time it was decided to reserve the median of the Dulles Airport Access Highway for future transit access to the airport. Preservation of this median allows the alignment to be at grade for most of its length within the corridor. Since the initial planning the need for transit in the Dulles Corridor had been studied and although rail transit in the corridor was not part of WMATA's originally adopted rapid transit system, rapid transit service for the corridor remained a local and regional goal (Schrag, 2006).

The strong growth of the activity centers within the corridor in particular during the1990's and recent 2000's that continues today has led to inception of Metrorail in the Dulles Corridor. Current and projected, future regional growth data exemplify the need for rapid transit and its timely implementation (Dulles Transit Partners, 2006):

- Tysons Corner is the largest employment center in Virginia with 115,000 jobs and close to 4 million square meters of commercial space.
- Reston/Herndon is home of 70,000 jobs and 2.7 million square meters of commercial space.
- In Fairfax County employment is expected to increase 63 percent in the next 20 years.

– Loudoun County grew by 49 percent in the last 5 years and is currently the fastest growing county in the US.
– In the last nine years traffic on the Toll Road in Loudoun County has increased from 50,000 to 90,000 cars per day.
– Dulles International Airport employs more than 18,000 people and serves 23 million passengers per year and presently is being expanded and modernized. Modernization includes a new underground automated people mover system with multiple stations at main and mid terminals.

Regional growth and progress result however in urban and social challenges:

– Washington, DC region has the 3rd worst congestion in the US.
– The annual delay amounts to 69 hours per traveler resulting in a "congestion cost" of US $2.5 billion per year.
– 5 of 8 main roads in the corridor will be gridlocked by 2010.

The much-needed implementation of the project began with Preliminary Engineering in 2004 under a public private partnership agreement between DRPT and DTP. Other funding partners in financing the preliminary engineering effort are the Federal Transit Administration (FTA), the Metropolitan Washington Airports Authority (MWAA), WMATA, County of Fairfax, Loudoun County, and the towns of Reston and Herndon.

This extension to be known as the Silverline once completed will significantly extend the existing Metrorail system. The original system as conceptualized in the 1960's included 103 miles (166 kilometers) and was designed and built between 1969 and 2001. Additions including the Largo Line were accomplished between 2001 and 2004 extending the total system length to about 171 kilometers. The planned extension to the Airport will therefore constitute an addition of some 23% in length.

2 WMATA METRORAIL SYSTEM – COMPONENTS AND TUNNELING EXPERIENCE

A summary of the existing WMATA Metrorail system components is provided in Table 1 followed by a summary of WMATA's tunneling experience of the three decades between the early 1970's through late 1990's.

WMATA's over 80 Kilometers of subway construction provides many examples of tunneling methods and types of tunnel construction and displays a continuous development of tunnel design and construction methodology spanning some 30 years.

Table 1. Current Metrorail system.

Systemwide	Double track length (Km)	Stations (Number)
Subway Includes cut-and-cover construction	80.55	47
Surface	70.41	32
Aerial	14.84	7
Metro System (Total in 2001) Without Largo segment	**165.79**	84
By Jurisdiction		
District of Columbia	61.64	40
Maryland	61.55	24
Virginia	47.43	20
Total Metro System With Largo segment added in 2004	**170.62**	86

In the 1970's WMATA had employed tunneling methods nowadays considered an "old-standard." In soft ground methods involved mandatory dewatering for tunneling with open face digger shields, breasting and temporary support by steel ribs and lagging. These soft ground tunnels were designed for loading conditions assuming a load equivalent to full overburden. Consequently, the final tunnel lining was a rigid, heavily reinforced cast-in-place concrete structure with PVC waterstops in contraction joints as the only means of positive waterproofing. Such construction was used on the Inner City A-Redline, D-Orangeline, and Outer G-Blueline. During that time there are examples of utilizing cast iron bolted segmental lining with lead waterproofed joints between the liner segments. Cast iron linings were used for the Potomac River tunnel crossing on the Orangeline and the Waterfront Tunnel on the F-Greenline. Immersed ("sunken") tube construction was used across the Washington Channel (L-Yellowline).

For tunneling in rock drill-and-blast methods were used for excavation with steel ribs and cribbing as temporary support followed by cast-in-place reinforced concrete for final tunnel support. During this period WMATA already used a modern, gripper-type rock TBM when good bedrock conditions were present, with cast-in-place reinforced concrete lining as final tunnel support. An example is a section on the A-Redline. For the construction of large, approximately 20 meters wide mined station vaults pilot tunnels followed by multiple drift mining were employed. These openings were supported by heavy rock bolting and massive steel ribs embedded in shotcrete for both temporary and permanent support. The final structure was established as an independent architectural precast concrete structure within the mined vault. For the design of the permanent support in rock some arching effect was considered. Tunnel construction on the A-Redline under Connecticut and Wisconsin Avenues is an example for such rock tunneling.

In the 1980's soft ground tunneling was accomplished using sophisticated Earth Pressure Balance Machines (EPBM) and a single pass segmental, pre-cast concrete lining with gaskets fabricated with tight tolerances. The tunneling was performed under the Anacostia River in adverse ground conditions with 3 bar hydrostatic pressure. It resulted in a very successful waterproofing largely as a result of well-designed and tight tolerances that were required for segment construction and gasket fabrication. This EPBM tunneling was used on two different sections under M Street namely Sections F3a and F3c on the Greenline. Successful installation of bolted segments depended on contact grouting within the time specified. On other sections an open face TBM was utilized. On a section with a low hydrostatic pressure compressed air was employed to control ground water. On another section with an open face TBM systematic dewatering was performed. Both open face TBM drives utilized a one-pass segmental, gasketed, pre-cast concrete lining which was successfully installed.

Also, in the 1980's WMATA allowed new, at that time progressive tunneling and waterproofing approaches. Consequently, in 1984 WMATA accepted the use of NATM rock tunneling proposed by the contractor. This was the first application of a dual lining NATM with PVC waterproofing in the US. It was utilized for running tunnel and station construction on the B-Redline to Wheaton, MD. The design considered arching of the surrounding ground and interaction between ground and the initial lining. Un-reinforced, thin, cast-in-place concrete lining was used for final support. Tunnel and station waterproofing was by an "umbrella type" PVC membrane with fully immersed sidewall drains on both sides of the vault. This resulted in completely dry tunnels in contrast to the A-Redline tunnels experiencing persistent leaks. At the end of the 1980's and at the beginning of the 1990's NATM tunneling was used again, but this time in soft ground for running tunnels and complicated, split station vault construction. The station was built using five different drifts. The first center drift was excavated for installation of a column line located in the middle of the station platform. Both, station and running tunnels were fully encased by a PVC membrane (Fort-Totten Station on the E-Greenline).

In the mid 1990's the NATM was used again for soft ground tunneling by employing dewatering from inside the tunnel and a grouted pipe arch as a crown pre-support to control surface settlement. The grouted pipes were installed by "directional drilling" methods under the Rock Creek Cemetery from a shaft at New Hampshire Avenue. This section was part of the Mid-City E-Greenline.

Also in the 1990's WMATA adopted a "two-pass" lining system for the circular soft ground tunnels excavated by the open face digger shield method (Outer E-Greenline tunnels; Sections E6e and E8a). Besides the need for dewatering this method also required the use of ground modification techniques such as chemical grouting systematically applied from the surface prior to tunneling (Mid-City E-Greenline tunnels; the Under/Over tunnels at Park Road & 14th Street Tunnels). The two-pass tunnel in soft ground with an initial pre-cast concrete liner usually considered as "throw-away" temporary lining was accounted for in the design of the final lining support system. The premise for this assumption was that solid, closed concrete rings were used for the initial support by not allowing any wooden wedges between segments. Rather, the pre-cast lining was required to be fully stabilized before the final concrete lining was cast. The combined liners for final support were designed considering flexibility of the initial lining and soil-structure interaction for "Short Term Loading" and all WMATA loading combinations including full hydrostatic pressure acting on the final lining for "Long Term Loading." Using these assumptions the initial pre-cast and the final cast-in-place linings share the loading combination. This allowed the use of an un-reinforced, cast-in-place final concrete lining. For the initial liner segments installed as expanded rings, success depended upon chemical pre-grouting, dewatering, immediate expansion by jacking the segments against the ground.

Depending on the nature of the soils, ground water level and difficulty in dewatering, such as from aquifers of artesian nature, it was necessary to use EPBM technology again but with the initial liners of non-expansion type but bolted segments similar to those in single-pass installations but with temporary gaskets. This installation was followed by an un-reinforced cast-in-place concrete lining and referred to as "Modified Two-Pass" with a PVC waterproofing membrane between initial and final linings. Such systems were used on the Outer F-Greenline, Sections F6a and F6c, Suitland Parkway to Branch Avenue. Here, the two-pass lining system was used for the first time with the EPBM tunneling method on the WMATA system. In this application the usual rings of four (4) reinforced concrete segments with added key segment forming rings are lightly bolted in the longitudinal joints. The gaskets in joints and the initial liner are designed for temporary hydrostatic pressure as the final waterproofing is achieved by the PVC membrane installed around the entire lining circumference. This system obviously is more costly, but it was necessary to overcome the most adverse ground and water condition where dewatering was not allowed due to environmental concerns. For the initial liner the segments were installed as bolted rings, and success depended upon water control, proper erection scheme and accomplishing contact grouting immediately behind a sealed tail of the TBM shield (Rudolf, 1997).

3 DULLES CORRIDOR METRORAIL PROJECT DESCRIPTION

The project description concentrates on the tunneling aspects of the work at Tysons Corner (Phase I) and at Dulles Airport (Phase II). The preliminary engineering of Phase I essentially followed the general plans of the Locally Preferred Alternative (LPA) selected by WMATA out of many alternate alignments studied including a tunnel at Tysons Corner. The LPA as portrayed in the approved Final Environmental Impact Statement (FEIS) is designed mainly as an aerial guideway with short tunnels through Tysons Corner.

Late in the preliminary engineering of Phase I WMATA in conjunction with a Spanish contractor and an Austrian design group strongly supported by a local developer proposed an all-underground option for the roughly 6.0 kilometers long segment at Tysons Corner. The envisioned tunnel would have been a large bore, 12 m-diameter TBM driven tunnel to accommodate two over/under tracks and stacked station platforms. It was based on a deep tunneling experience gained at the Barcelona Light Rail system recently constructed (Della Valle, 2002 and 2005). Despite strong support of an underground option by all parties involved, its realization was found to cost from US $250 to $800 million more, based on various estimates, than the mostly elevated and partially at-grade alignment. Furthermore the tunnel option would have significantly deviated from the NEPA selected and approved alignment as portrayed in the preliminary engineering documents. This new tunnel concept would have involved another environmental approval process, and additional geotechnical studies to be followed by a new preliminary engineering. This in turn would have resulted in a project delay of some 2 1/2 to 3 years. The additional projected cost for the tunnel alternative would have practically led to the loss of funding by the Federal Transit Administration (FTA). Due to these factors and the fact that delaying the relief of every-day traffic congestion in Tysons Corner by another up to 3 years, the option was found unacceptable and therefore not pursued further.

3.1 *Phase I tunneling*

The mined tunnel segment includes twin single track NATM tunnels at a length of 700 meters each and an emergency cross-passage. Short cut-and-cover sections will be utilized at the portals. These tunnels will be constructed in soft ground and will be located adjacent to existing structures and utilities that are sensitive to ground movements.

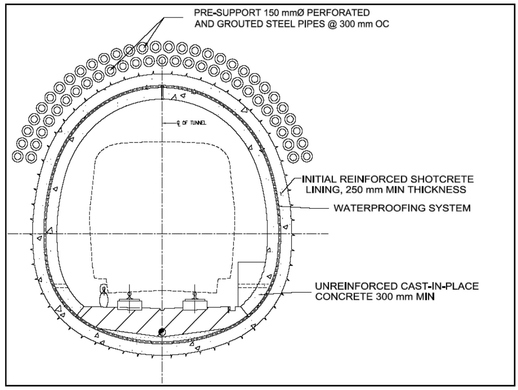

Figure 2. NATM tunnel with pipe arch pre-support.

The soils include mainly residual soils and soil like, completely decomposed rock. The residual soils encountered along the alignment are the result of in-place weathering of the underlying bedrock and are typically fine sandy silts and clays, and silty fine sands. Ground water at portal locations is generally at invert elevation, in mid-point of the tunnel alignment it rises up to the tunnel spring line.

Prominent building and infrastructure elements located in the tunnel's vicinity include an underground parking garage at a distance of some 8 meters from the outbound tunnel wall and bridge piers of the Route 123/Route 7 overpass, at a clear distance of approximately 15 meters from the inbound tunnel, as well as International Drive, a six-lane divided highway located about 4.5 meters above the future tunnel crowns. Deepest overburden cover exists at about mid-point of the alignment with nearly 12 meters. At the west portal and in the center of Route 7 the overburden cover is just 4 meters.

Because of the shallow depth, the prevailing soft ground conditions, the relatively short tunnel length, and the need to control settlements the NATM has been chosen as the preferred tunneling method. To enhance stand-up time of the soils and minimize settlements a single row of a grouted pipe arch umbrella will be utilized for the entire length of the tunnels. This will be sufficient for pre-support where the overburden is greater and surface structures are less sensitive. An additional row of pipe arch umbrellas, using closely spaced 150 mm diameter sleeved steel pipes (tube-a-manchette) will be used on the first 100 m length at the portals where tunneling is shallow with less overburden under International Drive. Figure 2 displays the double row pipe arch umbrella above a typical single track NATM tunnel with shotcrete initial lining, closed PVC membrane waterproofing system and a cast-in-place concrete final lining.

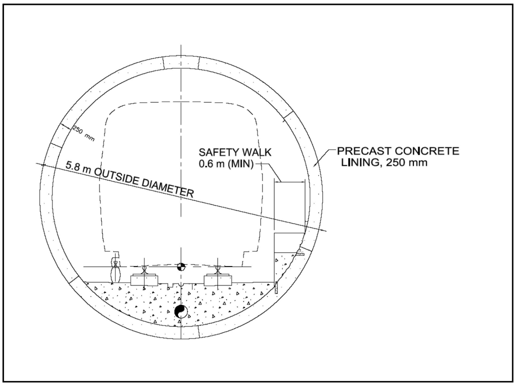

Figure 3. Typical TBM tunnel section.

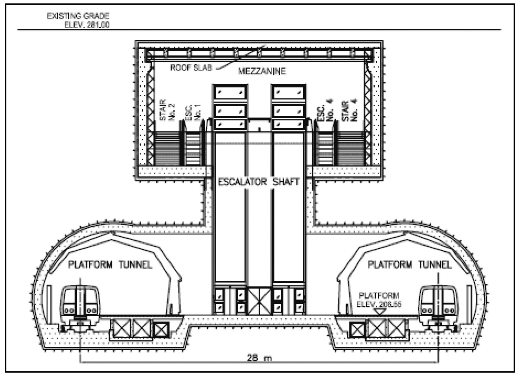

Figure 4. Station typical structural cross section.

Figure 5. Station tunnel rendering (by diDo menico + Partners, Architectural Design Consultant).

3.2 *Phase II tunneling*

The underground segment of Phase II lies within Dulles International Airport property with the metro station referred to as Dulles Airport Station in front of the main terminal. The main terminal has considerable traffic and existing infrastructure with much of the project area having a high concentration of existing utilities. The underground structures include twin single-track TBM tunnels, emergency cross passages, shafts and mined caverns for the Dulles Airport underground station. These structures will be constructed in bedrock and will be located below existing structures and utilities that are sensitive to ground movements. The host geologic formation for tunneling will be generally competent siltstone bedrock whereas the over burden includes fill, residual soils, and decomposed rock.

The TBM tunnels have an approximately 6 meter outside diameter and are about 3.31 kilometers long each. The tunnels will be constructed by either a shielded rock TBM using a single pass, pre-cast concrete, gasketed lining or a rock gripper type TBM with an initial rock support followed by installation of a PVC membrane waterproofing and a final cast-in-place concrete lining. Figure 3 displays a typical, single pass lining cross section for the TBM tunneling.

The mined portions of Dulles Airport Station will be constructed using NATM techniques in sedimentary, typically siltstone bedrock. Excavation will be by road headers. Initial support will consist of rock reinforcement and shotcrete lining. All mined station and associated structures will be waterproofed using an open, "umbrella type" waterproofing system with sidewall drain pipes. Figure 4 displays a typical station tunnel configuration at the central cross passage with 5.2 meters wide platforms. The station platform is about 25 meters below the ground surface.

To allow for a twin station tunnel configuration, where there are two parallel station vaults, the centerline track-to-track distance is 28 meters. Both station platform tunnels are 183 meters (600 feet) long and unobstructed by vertical circulation. The station platforms are connected with cross-passages between the station tunnels. Access to the platforms is provided by a central access structure located between the two station vaults. Architectural rendering for the station tunnel configuration is shown in Figure 5.

All station construction will be mined except for the mezzanine and ancillary rooms, which will be constructed using cut-and-cover techniques. Mined station construction has been selected to minimize disruption to airport activities. Surface disruptions will therefore generally be limited to Mezzanine and ancillary room construction using cut-and-cover excavation while maintaining airport pedestrian circulation above, except for the time period when the mezzanine box will be connected to an existing pedestrian tunnel "Node" that will provide Metrorail Station access.

4 IMPLEMENTATION

4.1 *Public Private Partnership (PPP)*

The project is being implemented in a Public-Private-Partnership under the Public Private Transportation Act (PPTA) an innovative project delivery framework as established by the Virginia Department of Transportation (VDOT) in 1995. Its implementation is in accordance with the guidelines as amended by the General Assembly in 2005 (The Commonwealth of Virginia, 2005). The essential goals of the PPTA are to encourage investment in the Commonwealth by creating a more stable investment climate and increasing transparency and public involvement in the procurement process. According to the guidelines the private entity charged with project implementation is required to provide certain commitments or guarantees and enters into a mandatory risk sharing.

4.2 *Design and construction*

The project is being realized under a design-build contract. The design-builder, Dulles Transit Partners (DTP) is required to initially develop preliminary engineering for the rail project. The cost for the preliminary engineering is shared between the design-builder and the project partners, DRPT, FTA, MWAA and the counties of Fairfax and Loudoun. The preliminary engineering then forms the basis to develop a fixed firm price by the design-builder. To maintain previously established budget limits this results in design challenges and the need to optimize design and construction methods to build to budget. Consequently, many design iterations are required during preliminary engineering. The design and construction team constantly weighs the benefits of underground space to keep everyday routines undisrupted versus its increased cost when compared to at grade and above ground construction.

Value Planning (VP) and Value Engineering (VE) exercises are a central activity of the design development in pursuit of the most economical approach with least impact on the surroundings. In Phase I these exercises led to a series of transformations of the underground segment at Tysons Corner. This alignment was initially envisioned as deep, 1.6-kilometer long twin TBM tunnels and a roughly 24 meter deep underground station constructed by cut-and-cover methods within Route 7, a busy traffic artery. Analysis of construction cost however favored the implementation of the short NATM tunnels with a quasi at-grade station within the median of Route 7 at a cost saving of roughly US $200 million. In Phase II the VP exercises led to selection of a deep TBM tunneling and NATM station construction in rock instead of a cut-and-cover excavation for station and running tunnel construction originally depicted in the FEIS. Since the rock formation at the Airport is close to the surface this selection resulted in considerable cost and schedule savings. This construction will also considerably reduce impacts on the Airport operation. VE exercises, which are to follow, will search for further cost reductions; if successful these will become the basis for construction.

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