ASSOCIATION INTERNATIONALE DES TRAVAUX EN SOUTERRAIN AITES
ITA INTERNATIONAL TUNNELLING ASSOCIATION
ASSOCIATION CANADIENNE DES TUNNELS ACT
TAC TUNNELLING ASSOCIATION OF CANADA

Implementation of Conventional Tunneling in a Design-Build Contract in the US

J. Rudolf[1,3], V. Gall[2,3], T. O'Brien[2,3]
Bechtel Infrastructure Corporation, Vienna, Virginia, USA, [2]Gall Zeidler Consultants, Ashburn, Virginia, USA, [3]Dulles Transit Partners, Vienna, Virginia, USA

1.0 INTRODUCTION

The Metropolitan Washington Airports Authority (MWAA) is constructing the Dulles Corridor Metrorail Project (DCMP) which will extend Washington Metropolitan Area Transit Authority's (WMATA) rail services from the Metrorail Orange Line in Fairfax County, Virginia to Route 772 near Ashburn in eastern Loudoun County, Virginia. The extension will be known as the Silver Line and once completed will add 37 km to the existing Washington Metro System (Figure 1). The project is being constructed in two phases. The Phase I segment is 19 km long and involves 5 stations (two at grade and three elevated) and is scheduled to be operational by 2013. Phase II will extend the rail a further 18 km with a station at Dulles International Airport and a terminus station in Ashburn.

Both phases will be realized under design-build (DB) contracts. Phase I is currently under construction by Dulles Transit Partners (DTP) a Joint Venture of Bechtel and URS (previously Washington Group International). DTP entered in an updated agreement with MWAA to construct Phase I in early 2008. Project partners include the Virginia Department of Rail and Public Transportation (DRPT), Federal Transit Administration (FTA) and the counties of Fairfax and Loudoun.

At US $85 million, the tunnel contract, although from a scheduling point of view on critical path, is just a small fraction of the overall US $2.6 billion cost of Phase I. In the context of underground construction, conventional tunneling for a stretch of 2 x 520 meters tunnel length emerged as the most feasible alternative to practically all other conceivable tunneling methods including open and closed face TBM drives and cut-and-cover techniques. The alignment and tunnel method selection process that led to conventional tunneling at Tysons Corner was described by Rudolf et al. [4].

The twin, 520 m long single track, 6.7 m diameter conventional tunnels are situated in the urban setting of Tysons Corner (Figure 2). Along the tunnel alignment are multiple sensitive structures including an underground parking garage for the Marriott Hotel and Route 123 Overpass bridge piers. The tunnels will also pass beneath International Drive with a shallow overburden of 4.6 m from the tunnel crown. Because of the shallow depth, soft ground conditions, and the need to control settlements, the tunnel design includes use of a double row grouted pipe arch canopy as pre-support for the first 90 m of excavation and a single row pipe arch canopy for the remaining length of tunnels thereafter.

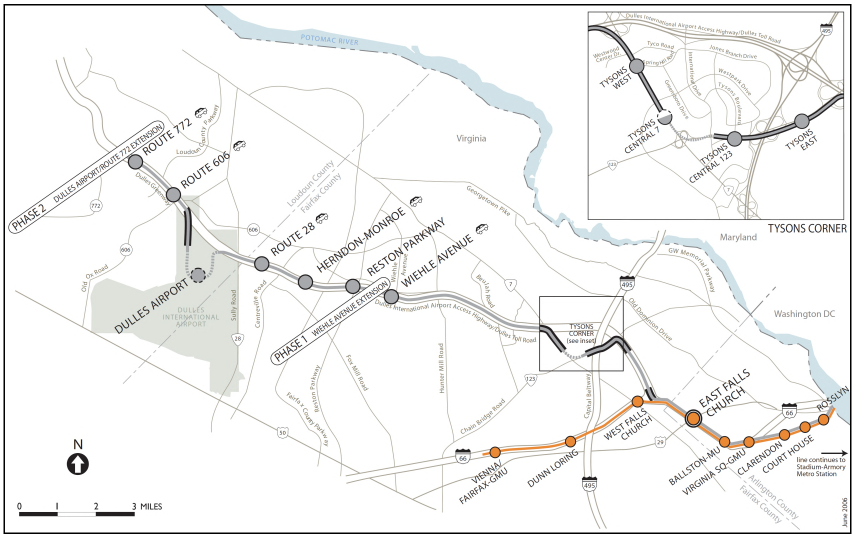


Figure 1. Dulles Corridor Metrorail Project Alignment

2.0 CONVENTIONAL TUNNELING AT TYSONS CORNER

2.1 Alignment and Status of Work

Establishment of the final alignment was accomplished with the selection of the Locally Preferred Alternative (LPA) from several alternative alignments by WMATA and approved by all other agencies involved from the Final Environmental Impact Statement (FEIS). During Value Planning at the beginning of preliminary engineering (PE), horizontal and vertical adjustments of the alignment were adopted for cost reduction. The final alignment showing the 520 meter long conventionally mined (NATM) tunnels and adjacent cut-and-cover sections and ventilation structures in longitudinal section and plan view is displayed in Figure 2. The final design was carried out in Design-Build (DB) for this alignment and the permit for the tunnels was issued in September of 2009 [3] after a rigorous review process by WMATA, Virginia Department of Transportation (VDOT), Virginia Department of General Services (DGS), MWAA, and their many independent consultants.

As of the beginning of February 2010 the outbound (OB) has been excavated to a length of about 100 m starting from the east portal. The inbound (IB) tunnel heading lags about 50 meters behind the heading of the OB tunnel.

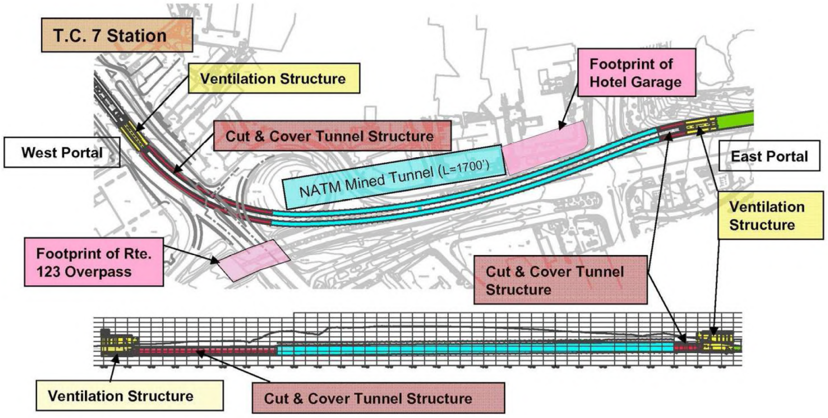


Figure 2. Design-Build Tunnel Alignment

2.2 Ground Conditions

Tysons Corner is located in the Piedmont Province and is underlain predominately by schist, phyllonite, gneiss, and to a lesser extent, igneous intrusive rocks. The project site is just west of the Fall Zone, which is the zone separating the unlithified sediments of the Coastal Plain Province and the rocks of the Piedmont Province.

The soils along the tunnel alignment include mainly residual soils and soil-like completely decomposed rock. The residual soils are the result of in-place weathering of the underlying bedrock and are typically fine sandy silts, clays and silty fine sands. The project soil classification identifies the residual soils as Stratum S, which is divided into two substrata (S1 and S2) based on the consistency and degree of weathering. S1 Substratum produced an average N-value of 12 bpf while S2 Substratum produced an average N-value of 30 bpf. Only to a limited extent where the tunnel is deepest will tunneling encounter decomposed rock referred to as D1 in the bench/invert excavation. The decomposed rock is a soil-like material with higher strength, retains relict structures of the bedrock material, and produces a range of N-values from 60 to 100 bfp. Sitting unconformably on top of the residual soils are remnant Coastal Plain materials consisting of interlayered clay bands and silty gravels and sands (Fig. 3).

Figure 3. Outbound Tunnel Top Heading showing Interlayered Coastal Plain Sediments

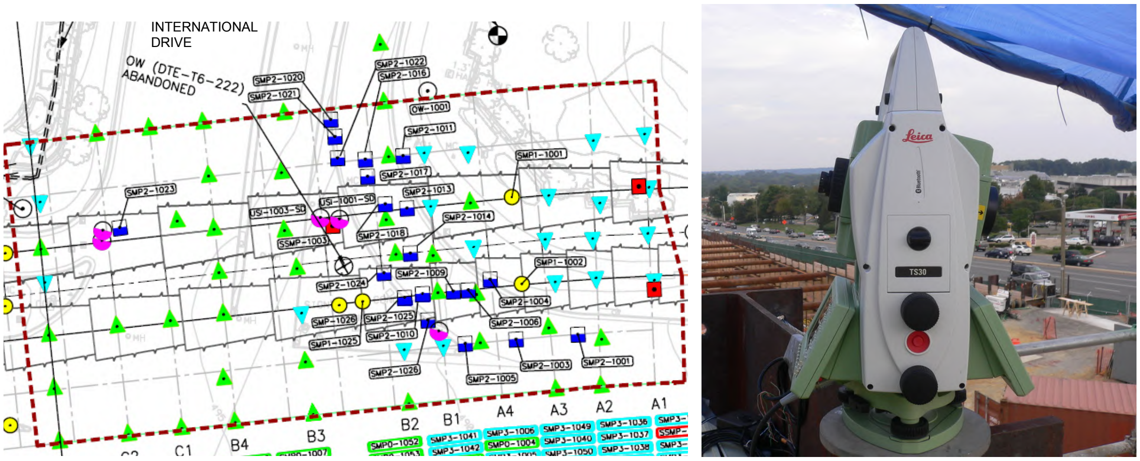
Groundwater is generally at invert elevation at portal locations and rises up to the tunnel spring line at the mid-point of the tunnel alignment. Water observed draining from above one of the impermeable Coastal Plain clay bands in the top heading of the outbound tunnel may have been perched groundwater.

2.3 Instrumentation and Monitoring

One of the most critical sections of the tunnel construction consists of the approximately 90 m in which the tunnels will pass beneath International Drive at shallow depths; as little as 3 m overburden at one point. The shallow overburden concerned VDOT, the owner of the public traffic facilities at Tysons Corner, which requested “Real-time” monitoring of the surface when tunneling the 90 m under the road, which was subsequently labeled the “Intensified Monitoring Zone” or “IMZ” (Fig. 4a). The “Real-time” monitoring entails taking measurements of surface points every hour, which are then automatically placed into graphs and placed onto a website. To accomplish the “Real-time” monitoring, DTP decided to use the Total Station Method which involves the use of a robotic theodolite equipped with a Direct Reflection (DR) Electronic Distance Meter (EDM) (Fig.4b). The theodolite is able to measure “virtual points” on the road surface which are x- and y-coordinates defined in the system. The theodolite locates the defined points automatically and measures the z-coordinate or vertical deformation. The measured z-coordinates are then compared with the initial pre-construction baseline z-coordinates to determine settlement. Using the Total Station method allows the input of as many virtual points needed as is shown by the high density of virtual points on International Drive (Fig. 4a).

In addition to the Total Station Method, the monitoring program also employs monitoring points that require physical measurements using measuring rods and conventional optical methods. Subsurface deformation monitoring instruments are also being used including Shallow Subsurface Monitoring Points (SSMP) for vertical deformation at a depth of about 2.5 m, Utility Settlement Indicators (USI) for vertical deformations directly above utilities, Inclinometers (IC) near sensitive structures such as the Marriott Parking Garage and the Route 123 overpass bridge piers, and crack gages in the Marriott Parking Garage and Route 123 overpass bridge piers. Nine observation wells (OW) have also been installed along the tunnel alignment to monitor groundwater elevation.

Deformation monitoring within the tunnels involves the installation of convergence bolt arrays every 10 m totaling 40 convergence monitoring cross sections per tunnel, IB and OB. Each array consists of 5 convergence bolts (CB) with each CB consisting of a rod embedded in the shotcrete initial lining and a target. Measurement of the arrays provides horizontal (x), vertical (y) and longitudinal (z) movements.



a) b)

Figure 4. a) View of the “IMZ” (dashed line) and the surface settlement monitoring points including the Virtual Points (green triangles) and b) Total Station Theodolite at Tysons Corner

Thus far, excavation of the inbound and outbound tunnels (Fig. 5a & 5b) is proceeding successfully and at the anticipated rate of 1.8 m (2 top headings and 1 bench/invert) per shift, with a slightly lower overall average when taking into account time for installation of the pipe arch canopy pre-support system and probe drilling.

3.0 DESIGN-BUILD CHALLENGES

The design-build contract imposed a series of challenges. Already during the early stages and through preliminary engineering overall cost reduction measures to keep the project within budget limits while achieving adequate safety called for the investigation of a number of tunnel options and designs. The execution of conventional tunneling requires provision of experienced tunneling crews for which in principle two options were evaluated including either the subcontracting to a specialty tunneling contractor or self-performing the work with the addition of highly experienced personnel. Having chosen the latter for tunneling at Tysons Corner, DTP is now responsible for and in control of all relevant submittals required by the design and any engineering needs that arise during construction. With the experienced tunneling personnel in place, tunnel designers are able to work directly with the tunneling staff to best take advantage of the design-build contract framework allowing quick resolutions to problems encountered during tunneling.

3.1 Preliminary Engineering and Study of Tunneling Options for Cost Reduction

The General Plans of the LPA specified construction of the Tysons Central 7 Station by a deep cut-and-cover method, use of a TBM for the majority of the deep tunnel alignment, and transition tunnels by cut-and-cover at either ends of the alignment. The running tunnels were divided into two sections: 1) Eastern Portion – 180 m long with shallow overburden and 2) 1,300 m long with greater overburden and below the groundwater table. Four alternative construction approaches consisting of variations between cut-and-cover, TBM, and conventional tunneling for sections 1 and 2 were developed for the underground structures. A formalized risk and cost analysis was undertaken to evaluate the pros and cons of all 4 alternatives [3].


a) b)

Figure 5. a) View into Inbound and Outbound Tunnels from East Portal, b) Installation of Pipe Arch Canopy in Outbound Tunnel

Ultimately Alternative 4 was selected, for which Section 1 of the tunnels would be constructed using conventional tunneling and Section 2 constructed using a TBM. However, during a formal cost evaluation and value engineering program it was determined that approximately $200 million could be saved by building Tysons Central 7 Station at-grade and eliminating the running tunnels west of the station. Subsequent changes ultimately reduced the length of the running tunnels by over 50% and adjustments in the alignment reduced the depth of the tunnels (Fig. 6). The new alignment (Fig. 2) was incorporated into the PE documents and became the basis of the updated design-build agreement in early 2008 [3].

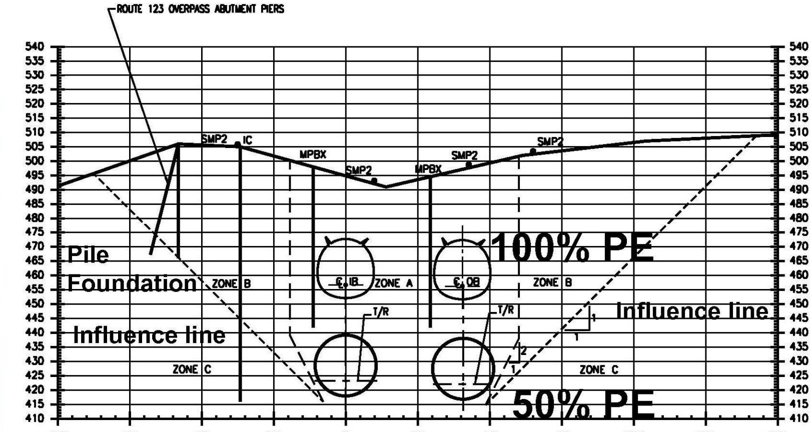


Figure 6. Deep Tunnels of the FEIS Alignment vs. Shallow Conventional Tunnels of the Final Design

3.2 Skilled Personnel - Self-Performing vs. Subcontracting

3.2.1 Background

Conventional Tunneling, as defined by Working Group 19 of the International Tunneling Association, in the US has been initially referred to as tunneling using the New Austrian Tunneling Method (NATM). Different names for the same tunneling approach have been tried and in the recent years the US tunneling community has generally settled on the name Sequential Excavation Method or SEM [2] although NATM is still frequently used at WMATA and MWAA projects. SEM has also been adopted in the Federal Highway Administration's new Road Tunnel Manual [1]. To date, and in line with US contractual tunneling practices, the SEM or, using ITA's nomenclature conventional tunneling, has been executed in a design-bid-build (DBB) framework.

The most recent conventional tunneling projects include the recently opened Beacon Hill Station in Seattle, the Automated People Mover System at Dulles International Airport in Washington, D.C., due to open in 2010, the on-going Devil's Slide Tunnel Project near Pacifica, California, the Caldecott 4th Bore Tunnel project near Walnut Creek in California which was awarded in November of 2009, the Stanford Linear Accelerator Tunnel, and the tunneling at Tysons Corner for the DCMP. Of these recent tunneling projects only the DCMP project utilizes the DB contract form.

3.2.2 Design-Bid-Build (DBB) vs. Design-Build (DB) for Conventional Tunneling

Conventional tunneling is, likely more than any other tunneling methods, very dependent on a high level of experience and skill. This is mainly associated with its observational character and the need to recognize the behavior of the ground and install support elements not only as designed but also as needed according to ground conditions exposed during tunneling. In the first instance this experience is required during the design. Ideally the requirement is then imposed during construction on the executing contractor and the owner's construction management team [1]. This skill set forms the basis for a successful project using conventional tunneling methods.

In a DBB scenario the owner of a tunneling project has inherently many more steps at which control over this qualification requirement can be exerted. First, the owner selects the design engineer, typically in a non-commercial, mainly qualification based environment. Subsequently the owner provides a Geotechnical Baseline Report (GBR) and issues a controlled final design set of drawings and specifications that detail all design and construction requirements in line with state-of-the art conventional tunneling final tunnel designs. Nowadays it is customary to impose a stringent set of risk management tools during design development to assure that construction will be able to cope with contingencies. As part of the bid the owner has the opportunity to develop a set of pre-qualification requirements, enabling the selection of an experienced tunneling contractor, providing experienced key individuals to carry out the actual tunneling process. All bidders will bid the project with these requirements acknowledged as part of their bid. This DBB multiple step process provides the owner with significantly greater control over the establishment of a successful conventional tunneling project by controlling designer and contractor qualifications and the design product itself. This control function becomes even more important in a tunneling market that does not have access to a broad supply of skilled personnel in conventional tunneling as is the case in the US. However, DBB places more responsibilities on the owner than the DB delivery method.

In a DB delivery the owner develops a bid design typically to a preliminary engineering level and relinquishes responsibility of the tunnel design and execution that is provided by a detailed design and qualification based bid in a DBB scenario while maintaining residual control. The responsibility for a successful tunneling project is largely transferred to the design-builder. This responsibility is transferred at a level where many design details are not fully known, for example the full extent of ground conditions, wherefore the DB must develop a Geotechnical Evaluation Report and be fully responsible for the ground conditions encountered during construction. It is also transferred in a low-bid environment, often with less control over the designer's and contractor's qualifications. Consequently the owner has less control otherwise afforded in a DBB frame-work.

Relinquishment of the ability to fully control skill and qualification, however, is offset by the promise of a more harmonic cooperation between the design-builder's tunnel designer and the builder's preferred construction means and methods. In markets that offer a broad range of skilled personnel and traditional experience in conventional tunneling, as for example in Europe and selected Asian countries, the DB process has worked extremely well for conventional tunneling and has in many cases furthered the engineer's ingenuity and the project's economy [6].

3.2.3 Implementation at Tysons Corner

Recognizing the need for skilled personnel for conventional tunnel construction DTP looked into two different approaches: either to subcontract the tunneling work to a specialty tunneling contractor or to self-perform the work. To enable the procurement of a tunnel subcontract DTP tunnel engineers developed a set of documents that would allow the awarding of the subcontract to a tunneling subcontractor in a "DBB-like" framework. This involved detailed design drawings as well as strict qualification requirements.

The tunnel construction request for proposal (RFP) was advertised towards the end of 2008, however, the bids received were higher than anticipated and DTP made the decision to self-perform the tunneling and bring in the experienced conventional tunneling firm Beton-und-Monierbau (BeMo) from Austria to augment the construction staff. The addition of the skilled BeMo staff to the DTP tunnel construction group also preserved the major advantage of the DB contract framework namely a joint cooperation between DTP tunnel engineering and DTP tunnel construction. Consequently the majority of the required tunnel construction submittals were jointly developed. Similarly, and in joint cooperation, adjustments in the field are made to suit to conditions encountered and preferred means and methods are used while preserving the design intent.

3.3 Engineering During Construction

The contract documents and project specifications require a large number of submittals. These submittals encompass necessary pre-construction testing, work plans, and additional pre-construction documentation to establish the means and methods for safe and well-planned construction of the tunnels. The submission requirements for the submittals varied with specific submittals requiring the review and approval by MWAA, while others were required to be submitted to MWAA for information only. With the decision to self-perform, DTP became the responsible party for all construction submittals, schedules, and coordinations. The submittal process was organized according to a schedule created from contract documents specifying the dates by which the submittals were expected to be finalized yet allowing for a rigorous review cycle.

The addition of BeMo acted as a staff augmentation and allows for a close working relationship between all construction and engineering personnel as well as flexibility in regards to responding to problems or new situations that may arise during construction. This flexibility allows any problems to be addressed promptly and safely, preventing any major delays in construction.

4.0 CONCLUSION

The use of a Design-Build contract for the Dulles Corridor Metrorail Project has been beneficial to all parties involved and allowed the smooth transition from design and engineering into construction of the twin conventional tunnels. It has worked especially well because DTP laid the basis for successful execution of conventional tunneling namely the skill set provided from engineering through execution of conventional tunneling. Being the Design-Builder afforded DTP the flexibility to self-perform the tunnel construction retaining close control of proper implementation of the design.

5.0 BIBLIOGRAPHY

[1] Federal Highway Administration (FHWA), Technical Manual for Design and Construction of Road Tunnels – Civil Element, FHWA-NHI-09-010, Washington, D.C., 2009.

[2] J. Gildner, G.J. Urschitz, SEM/NATM Design and Contracting Strategies, in: L. Ozdemir (Ed.), North American Tunneling 2004, Taylor & Francis, London, 2004.

[3] J. Rudolf, V. Gall, A. Nitschke, Selection of Alignment and Tunneling Methods in Urban Settings, in: V.K. Kanjlia, T. Ramamurthy, P.P. Wahi, A.C. Gupta (Eds.), World Tunnel Congress – 2008 Underground Facilities for better Environment and Safety, Central Board of Irrigation and Power, New Dehli, 2008.

[4] J. Rudolf, V. Gall, The Dulles Corridor Metrorail Project – Extension to Dulles International Airport and its Tunneling Aspects, in: M.T. Traylor, J.W. Townsend (Eds.), Rapid Excavation and Tunneling Conference Proceedings, Society for Mining Metallurgy & Exploration, Littleton, CO, 2007.

[5] J. Rudolf, V. Gall, H. Wagner, History and recent developments in soft ground NATM tunneling for the Washington, DC Metro, in: P. Kocsonya (Ed.), Proceedings, ITA-AITES World Tunnel Congress 2009 – Safe Tunnelling for the City and for the Environment, Hungarian Tunnelling Association, Budapest, 2009.

[6] K. Zeidler, T. Schwind, V. Gall, NATM for Singapore, in: L. Ozdemir (Ed.), North American Tunneling 2006, Taylor & Francis, London, 2006.

[7] L. Rein, 18 Feet Done, Many More to Go, The Washington Post, Sunday, October 18, 2009 Issue.