

GEOTECHNICAL BASELINE FOR THE SR 99 BORED DESIGN-BUILD ALASKAN WAY TUNNEL, SEATTLE, WASHINGTON

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ABSTRACT

Washington State Department of Transportation has awarded a contract to design and construct a 17.5 m (57.5 foot) diameter bored tunnel at depths up to 60 m (200 feet) in the glacial soil under downtown Seattle, Washington. Geotechnical investigations resulted in a baseline report, data report and characterization report. The Geotechnical Baseline Report (GBR) and Geotechnical Data Report (GDR) were provided as part of the contract documents and were an integral component of the risk sharing aspects of the design-build contract. An initial assessment of over 300 buildings was conducted to identify those most sensitive to settlement. Mitigation measures include compensation grouting for specific buildings. Extensive construction monitoring is planned. The project also includes cut-and-cover construction at south and north portals for transition between side-by-side roadways and stacked configuration roadway in the bored tunnel. An initial assessment of more than 300 buildings along potential tunnel routes was conducted to identify those most sensitive to settlement. Prequalification of tunnel contractor teams started in late 2009 and resulted in two proposals. The Seattle Tunnel Partners (Dragados and HNTB) were awarded the project for \$1,089,700,002 million. This paper will discuss the considerations that went into development of the GBR, construction monitoring and technical requirements for the bored tunnel.

INTRODUCTION

The proposed SR 99 bored tunnel will be the largest mechanically bored tunneling in the world. It is a very challenging project that has required the application of state-of-the-art tunneling and contracting practices. The project is being advanced using a design-build contracting approach that utilizes various aspects of risk sharing. An extensive geotechnical investigation was conducted along the alignment of the tunnel, which passes directly below the central business district of Seattle, Washington. The data gathered from this investigation was used as source material for the writing of a Geotechnical Data Report (GDR) and Geotechnical Baseline Report (GBR). These reports affected many of the technical requirements of the project, especially the tunnel boring machine to be used. Because settlement was a major concern, a survey was made of buildings and utilities that could be affected, and an extensive settlement monitoring system was planned.

Background

The Alaskan Way Viaduct and Seawall Replacement is a program led by the Washington State Department of Transportation (WSDOT) in partnership with the Federal Highway Administration (FHWA), King County, the City of Seattle and the Port of Seattle. WSDOT is responsible for replacing the double-deck viaduct, which is part of State Route (SR) 99. Constructed in the 1950s, the double-tiered viaduct is nearly 3.2 km (2 miles) long and parallels Alaskan Way. Studies in the 1990s showed that the viaduct was nearing the end of its useful life, apparent by its exposed rebar and weakened columns. The 2001 Nisqually earthquake further damaged the viaduct, forcing WSDOT to temporarily close it for inspection and limited repairs. The viaduct and nearby seawall are vulnerable in another earthquake and continue to show signs of age and deterioration.

To replace the viaduct's downtown waterfront section, a bored tunnel was recommended in January 2009 and identified as the preferred replacement alternative in fall 2010. To complete the project's environmental process, FHWA, WSDOT and the City of Seattle are carrying forward three alternatives—a bored tunnel, cut-and-cover tunnel and elevated structure. These alternatives will be discussed in the Final Environmental Impact Statement, scheduled for release in mid-2011.

Early on, the State elected to use the design-build contracting method to advance the bored tunnel portion of the program. The SR 99 Bored Tunnel Alternative Design-Build Request for Proposals was issued by WSDOT on May 26, 2010. Design-build bids were received Oct. 28, 2010.

Design Build Tunnel Project Description

The SR 99 bored tunnel will begin with a depressed roadway section that contains the mainline and southbound off-ramps and northbound on-ramps. The south portal consists of a retained cut, cut-and-cover tunnel section and a south tunnel operations building. The portals for the ramps and mainline will lead into the cut-and-cover portion of the tunnel that extends approximately 150 m (500 feet) and transitions from a side-by-side roadway to a stacked configuration with two southbound lanes on the upper level and two northbound lanes on the lower level. At this location, the base of the cut-and-cover tunnel will be approximately 27 m (90 feet) below the ground surface, and the top of the tunnel will be about 9 m (30 feet) below the ground surface. A southern tunnel operations building will provide ventilation as well as maintenance and operation capabilities. The lowest level of the building will be about 23 m (75 feet) below the ground surface.

There will be approximately 2.7 km (9,000 feet) of bored tunnel with an approximate outside diameter of 17.5 m (57.5 feet). The bored tunnel will decline at a 4 percent grade and cross under the existing Alaskan Way Viaduct, following a large radius curve. The tunnel will reach a low point when the top of the tunnel will be about 36 m (120 feet) below street level. The tunnel will then rise at a 1.6 percent grade to the north. After 732 m (2,400 feet) it will change to a large radius curve to the north and cross under the street grid of Seattle's Belltown neighborhood at a diagonal. The tunnel at its deepest will be approximately 65 m (215 feet) from the crown of the tunnel to the ground surface. Then the tunnel transitions to approximately four percent grade. The north portal consists of a cut-and cover tunnel section and a north tunnel operations building. The tunnel will transition back to a cut-and-cover section that will unbraided the tunnel's stacked northbound and southbound roadways into a side-by-side configuration that matches the existing grade of SR 99. Where the bored tunnel emerges, the cut-and-cover excavation will be about 25 m (85 feet) deep. There will be a north tunnel operations building, the lowest level of the building will be around 23 m (75 feet) below



Figure 1. SR 99 bored tunnel cross section—design concept

the ground surface. The cut-and-cover section of the tunnel will extend approximately 137 m (450 feet) to a portal.

The entire tunnel will have continuous 2.4 m (8 foot) wide shoulders on the roadway's west side to maximize access to an enclosed emergency walkway along the west side of the tunnel (Figure 1).

GBR USE ON DESIGN-BUILD PROJECTS

Since the early 1990s, GBRs have been used on most medium to large tunnel projects around the United States. The format and content for GBRs for design-bid-build projects was presented in the 1991 report developed by the Underground Tunnel Research Council's Technical Committee on Geotechnical Reports and published in a booklet in 1991 entitled *Geotechnical Baseline Reports for Underground Construction*. A GBR presents the design team's interpretations of ground conditions as a series of carefully selected and evaluated baselines, derived from the geotechnical exploration program, local project experience, and other environmental factors. A well-crafted GBR is a collaborative effort between the geotechnical engineer, the designer, and the owner to assess geotechnical related project risks, appropriate risk mitigation, and selecting the appropriate types of baselines, their ranges and average values. Generally, there is insufficient data to establish an absolutely correct or perfect baseline. Rather, a baseline is generally the team's best estimate of a physical property, condition or behavior, based on the available data and local experience, and framed within the context of perceived risks and impacts on construction costs.

An early version of a GBR, called a Geotechnical Design Summary Report (GDSR), was used by WSDOT in the early 1980s. The GDSR was included as a contract document and was a component of the unique risk-sharing program implemented for the construction of the 19.8 m (65-foot) diameter Mt. Baker Ridge Tunnel as part of the I-90 completion project. Other innovative risk-sharing aspects in the Mt. Baker Ridge tunnel contract included: (1) escrowed bid documents, (2) a Geotechnical Data Report,

(3) payment clauses for escalation in the prices of power, labor and materials, and (4) a Disputes Review Board. All of these contractual risk sharing elements, as well as a test shaft and test adits for pre-bid inspection by the various bidders, were introduced and strongly supported by the design review panel consisting of Al Mathews, Chuck Metcalf and Ralph Peck and implemented in the contract documents by the design team (Parker and Robinson, 1983).

However, GBRs have only been used rarely on design-build projects in the United States. In Washington State, the GBR format was first applied to a design-build project for Seattle Sound Transit's North Link Project in 2000. A Tender Geotechnical Baseline Report (TGBR) was prepared to present baselined ground conditions and ground behavior referenced to an unsupported face condition (Robinson, et al. 2001) as part of the bid documents. The bidders were to develop an assessment of their selected means and methods, and the resulting anticipated ground behavior and incorporate these assessments as part of an addendum to the TGBR. Once a preferred design-build team was selected, the owner's design team was to reach agreement with the design-build team on the contents of a final GBR to be incorporated into the design-build contract documents. Unfortunately the design-build North Link Project was not successfully negotiated for award, and consequently the final phase of a negotiated GBR was never reached.

For the SR 99 Bored Tunnel Alternative Design-Build Project, WSDOT and the design team assessed and eventually elected to implement a GBR. This is the fourth known utilization of a GBR on a design-build project for WSDOT. In this instance the GBR includes sections on:

- Regional setting.
- Relevant ground conditions.
- Design and construction considerations for the approach cuts, portals and tunnel.

The GBR also refers to several reference documents, some of which are provided and others that are reference documents in the Request for Proposals (RFP), which provide additional non-contractual information for the design-build bidders and selected design-build team. These reference documents include:

- Case Histories Report for 16 local and relevant tunnel and cut-and-cover or retaining wall projects.
- Geologic Characterization Report that presents the background for and development of the groupings from over two dozen distinctly different soil layers with similar engineering properties, although with differing ages and genesis, into eight Engineering Soil Units (ESUs).

The purpose of the AWV GBR, as well as most GBRs is to:

- Present relevant project geotechnical and construction considerations and information for the subsurface components
- Enhance the DBs understanding of the key geotechnical features, and important requirements presented in the RFP documents that needed to be addressed during bid preparation
- Assist the DB in evaluating the anticipated ground behavior along the alignments, requirements for elements of the Tunnel Boring Machine (TBM), excavating and supporting the ground, maintaining control fo groundwater, and providing protection for adjacent or overlying structures, utilities or other facilities.

- Guiding the owner and construction manager in administering the contract, reviewing the DB's design, and monitoring the performance during construction.
- Assist in administering the differing site conditions clauses
- Setting the baseline subsurface site conditions expected to be encountered

REGIONAL SETTING

The project alignment is located along the west side of downtown Seattle, in proximity to Elliott Bay. The south end of the alignment originates in the Pioneer Square area, which is about 3 to 6 m (10 to 20 feet) above sea level, where ground conditions consist of 3 m (10 feet) to more than 15.2 m (50 feet) of fill placed on glacially overridden soils to raise tidelands and beach areas above sea level in the early 1900s. As the tunnel alignment progresses northward, the ground elevation gradually increases to about 45 m (150 feet) above sea level.

Seattle is located within the central portion of the Puget Lowland, an elongated topographic and structural depression bordered by the Cascade Mountains on the east and the Olympic Mountains on the west. The lowland is characterized by a series of north-south trending ridges separated by deeply cut ravines and broad valleys, the result of glacial deposition, scouring and sub-glacial erosion. The Puget Sound area is believed to have been subjected to six or more major glaciations during the Pleistocene Epoch (2 million years ago to about 10,000 years ago). During the most recent ice coverage of the central Puget Lowland (Vashon period of the Fraser Glaciation), the thickness of ice is estimated to have been about 900 m (3,000 feet) in the alignment area. The last ice covering the alignment area receded about 13,500 years ago. Geophysical data suggests that top of bedrock in the downtown Seattle area is more than 900 m (3,000 feet) deep. The nearest outcrop of bedrock is observed approximately 4 km (2.5 miles) south of the alignment

Geological Setting

The distribution and interlayering of various soil types in the Puget Lowland is complex, because each glacial advance partially eroded older deposits and deposited new sediments, including glaciolacustrine clays and silt, glacial outwash sands and gravels, glacial till-like soils including diamictite, glaciomarine drift, till and ablation till. It is common for the glacial deposits to contain cobbles and boulders as outwash braids, drop stones, and erratics. Between glacial episodes, partial erosion and reworking and redeposition of some soils occurred; local stream, river, and marine erosion and deposition further complicated the geologic setting.

The glacial and interglacial soil units are typically of limited extent and are inter-layered with, or may contain, blocks of material from other stratigraphic units. Summary descriptions of the Holocene, Vashon and Pre-Vashon units mapped during the subsurface exploration program are summarized below.

- Holocene (Recent) Units deposited since the last glaciation consisting of engineered and non-engineered fill, alluvium, beach, estuarine, and reworked glacial deposits. They are generally of limited extent, but occur in both portal excavations.
- Quaternary Vashon Units are glacial sediments including recessional outwash, recessional lacustrine and ablation till deposits deposited during advance and recession of the ice-sheet. Interpretation of the boreholes suggests an overall horizontal bedding that varies in thickness and extent over portions of the tunnel alignment.

- Quaternary Pre-Vashon Units are both non-glacial (interglacial) soils and soils deposited during glacial episodes prior to the Vashon glaciation. The borings suggest that these soil units vary in thickness and lateral extent, in some instances grading laterally into adjacent units; or may be comprised of slices, blocks, rafts and sedimentary dikes of material, positioned against dissimilar material by glacial, interglacial or tectonic processes. The Quaternary Pre-Vashon units include nonglacial fluvial, lacustrine and paleosols deposits; and glacial advance and recessional outwash, ablation till, lodgment till, till-like, glaciomarine, and glaciolacustrine deposits.

The northern third of the SR 99 bored tunnel, north of Pine Street, will be constructed through what was an approximately 90 m (300-foot) above sea level, north-south trending ridge composed of varied glacial and interglacial soils. In 1910 the upper 30 m (100 feet) of the ridge was excavated as part of the Denny Regrade. Portions of these overburden soils were used to fill topographic lows and the remainder was sluiced out into Elliott Bay.

The subsurface geology encountered along the tunnel alignment includes a complex mix of:

- Overlying Holocene deposits at the south portal, overlain by recent fill soils locally containing abundant wood (logs, timber piles, planks and debris) derived from a lumber mill and overwater piers and in the upper 10 to 12 m (30 to 40 feet) to the south of S. King Street and around Yesler Way,
- Vashon recessional glacial deposits in and above the tunnel horizon,
- Pre-Vashon glacial and non-glacial (interglacial) soils in and above the tunnel horizon.

Hydrogeologic Setting

The complex stratigraphy in the Seattle area results in a complex hydrogeologic regime. The permeabilities of glacial deposits typically differ by orders of magnitude between adjacent soil units and even locally within a single soil unit. Consequently, there are multiple perched groundwater-bearing layers within the complex stratigraphic sequence and multiple piezometric surfaces along the alignment. Because of the size of the tunnel bore, multiple piezometric surfaces will be encountered along the tunnel bore and within its face as it advances. Discontinuous perched groundwater levels have been observed in several borings above the regional groundwater level, which is roughly coincident with sea level.

The direction of groundwater movement is also governed by hydraulic gradients, which may decrease or increase with depth in the stratigraphic section. In borings in the southern end, where multiple piezometers have been installed, there is up to a 3 m (10-foot) difference in elevation between the groundwater levels measured at various depths, and several piezometers indicate artesian groundwater levels at up to 1.5 m (5 feet) above the ground surface.

There is tidal influence to groundwater levels along most of the tunnel alignment, with daily variations of up to 1.5 m (5 feet) noted in several borings. However, the magnitude of the tidal influence varies by depth as well as distance from Puget Sound. Seasonal fluctuation in groundwater is generally less than about 1.5 m (5 feet).

Tectonic Setting

The Puget Lowland is located in the fore-arc of the Cascadia Subduction Zone, where the Juan de Fuca Plate dives beneath the North American Plate, resulting in a north-south compression of about 0.5 m (0.2 inch) per year in western Washington. To

accommodate this compression, a series of west- and northwest-trending thrust faults have been identified, extending to postulated depths of 12.9 to 25.7 km (8 to 16 miles). Movement along these thrust faults and associated faults have resulted in numerous historic and pre-historic earthquakes, with three earthquakes in the last 60 years ranging from magnitude 6.5 to 7.1 and with maximum Modified Mercalli Intensities (MMI) of about VII to VIII in the Seattle area.

The nearest potentially active fault to the project is the 4.8 to 8 km (3 to 5 mile) wide, east-west trending Seattle Fault Zone that extends from Bremerton on the west, just south of downtown Seattle, and eastward south of I-90 through Bellevue toward the Cascade Mountain foothills. South of the Seattle Fault, bedrock is locally present at or relatively near ground surface; north of the fault, top of bedrock is more than 900 m (3,000 feet) deep. Recent geologic evidence indicates that ground surface rupture from movement on this fault zone occurred as recently as 1,100 years ago. Preliminary estimates of recurrence rates for the Seattle Fault are on the order of 3,000 to 5,000 years with a slip rate of 0.08 to 0.1 m (0.03 to 0.04 inch) per year. Earthquake magnitudes of up to 7.5 have been postulated for movement on this fault.

Based on over-water surveys and test trenches accomplished during the last 20 years, the SR 99 bored tunnel alignment is located immediately north of the mapped fault related deformation zone, with the nearest mapped fault splay located more than 600 m (2,000 feet) south of the south portal. There is no direct evidence of discrete fault offsets in the boring exploration logs from the tunnel alignment. Slickensided shears, diked soil, joints, sand dikes, and tilted bedding of some soil layers that were observed in project borings, and that have been observed during the construction of local tunnels such as the Mercer Street wastewater tunnel to the north of the deformation zone, may be the result of various processes including landsliding, tectonic movement, and/or glacial activity.

EXPLORATION

Preparation of the preliminary design and contract documents for this design-build project required an extensive field and laboratory program. A total of 141 geotechnical borings were performed along the alignment of the proposed tunnel bore and in the area of the proposed cut-and-cover/approach areas. The depth of these borings ranged from approximately 6 to 105 m (20 to 345 feet). Approximately 6,250 lineal meters (20,500 lineal feet) of drilling was performed for the project, with typical borehole spacing of 120 m (400 feet) along the length of the proposed tunnel bore.

Borings were typically advanced using mud rotary methods to provide standardized geotechnical data and for follow-on in-situ testing, while the sonic core borings were used to provide continuous samples for detailed geologic evaluation of the highly variable glacial stratigraphy present throughout the project area. Borehole installations typically consisted of a combination of nested vibrating wire pressure transducers and standpipe piezometers.

Groundwater

In order to characterize the hydrogeologic conditions throughout the project corridor, extensive monitoring and hydraulic testing was performed as part of the field investigation. Groundwater monitoring at multiple elevations was performed at 124 locations with tidal monitoring performed at 24 locations. Slug testing was performed in 16 monitoring wells and a total of three long-duration pumping tests were performed to evaluate aquifer parameters and evaluate the feasibility of both dewatering and groundwater reinjection.

In Situ Testing

Extensive in-situ testing was performed during the field investigation to evaluate stratigraphy, strength, and modulus properties of geotechnical units encountered. In-situ testing methods employed included pressuremeter testing, hammer efficiency evaluation, and downhole geophysics. A total of 123 pressuremeter tests were performed to evaluate the strength and deformation characteristics of the Holocene and glacially overconsolidated soils. Downhole geophysics was performed in 18 borings and consisted of suspension logging of shear wave velocity, compressive wave velocity, natural gamma, borehole caliper, resistivity, and spontaneous potential. Well head-space gas monitoring for methane, carbon dioxide, oxygen, carbon monoxide and hydrogen sulphide was conducted at nine locations.

Laboratory Test

Laboratory index, engineering, and environmental testing was performed on samples collected during the field investigation. In addition to standard index testing, more specialized testing was performed to characterize soil strength, permeability, abrasivity, and swell potential. Point load testing was performed to characterize the strength of cobbles and boulders encountered. Testing performed to characterize abrasivity included Miller Abrasion, SAT, and x-ray diffraction.

Environmental testing of both soil and groundwater samples was conducted in all borings completed for the project. This sampling was performed in order to characterize potential for encountering subsurface contaminants during the construction of the project and to provide data for use in future selection of soil conditioners and/or slurry to be used in tunneling operations.

SUBSURFACE CHARACTERIZATION

Engineering Soil Units (ESU)

The geologic units along the proposed tunnel horizon, although differing in genesis, can be combined into eight major ESUs based on similar soil type, index and strength parameters, and behavioral characteristics.

ESU 1: Engineered and Non-engineered Fill (ENF): Predominately consists of very loose to very dense sand with varying amounts of silt and gravel. ESU 1: ENF also consists of silt, clay and organic silt. ESU 1: ENF also consists of debris.

ESU 2: Recent Granular Deposits (RGD): Predominately consists of loose to dense or locally very dense, sand and sandy silt. ESU 2: RGD also contains localized zones of silt, sandy gravel, and gravelly sand with varying lateral extent and thickness.

ESU 3: Recent Clay and Silt (RCS): Predominately consists of soft to stiff, silty clay and clayey silt with variable amounts of sand and gravel and localized zones of medium dense to dense clayey sand. ESU 3: RCS also contains layers, lenses, and dikes of cohesionless sand with varying lateral extent and thickness.

ESU 4: Till Deposits (TD): Predominately consists of a very dense or hard cohesive mixture of gravel sand silt and clay. ESU 4: TD contains fractured cohesive clay and silt with varying lateral extent and thickness. ESU 4: TD also contains interbeds; dikes; and lenses of saturated, cohesionless silt, sand, and gravel with varying lateral extent and thickness.

ESU 5: Cohesionless Sand and Gravel (CSG): Predominately consists of dense to very dense silty sand to sandy gravel. ESU 5: CSG also contains lenses and layers of clay and clayey silt that provide cohesion within soil layers and impede downward/upward and lateral movement of groundwater.

ESU 6: Cohesionless Silt and Fine Sand (CSF): Predominately consists of very dense silt, fine sandy silt, and silty fine sand. ESU 6: CSF also consists of interbeds and lenses of silt and fine sand with minor clay content, which still behave like cohesive-soils and will have varying lateral extent and thickness and will contain fractures.

ESU 7: Cohesive Clay and Silt (CCS): Predominately consists of hard, interbedded silt and clay. ESU 7: CCS also consists of multiple layers, lenses, and dikes of cohesionless silt, sand, and gravel, with varying lateral extent and thickness. ESU 6: CSF is locally intensely fractured, slickensided with very close spacing, and diked. Slickensided fractures, shear zones, bedding planes, and sand partings with the clay mass are planes of weakness

ESU 8: Till-Like Deposits (TL): Consists of high spatial variability and can grade from an unsorted mixture of silt, sand, and gravel to clean or relatively clean sand, in a relative short distance. ESU 8 predominately consists of a heterogeneous mixture of dense to very dense gravel, sand, and fines, and exhibits little to no cohesion. ESU 8: TLD also consists of layers and lenses of glacial till and layers and lenses and dikes of saturated cohesionless and gravel.

Setting Baselines

Baseline values were developed for the predominate material in each ESU including water content, unit weight, horizontal to vertical stress ratio (k_0), cohesion, friction angle, shear strength, shear modulus and horizontal and vertical hydraulic conductivity. The percentage of the minor constituents present in each ESU was baselined, in relation to that ESU.

A Generalized Subsurface Profile was included as a baseline (Figure 2) in the design-build RFP. This involved a great deal of discussion and assessment of what level of detail should be presented on the profile, and even whether or not a profile should be included as part of the baseline, or just provided as a reference profile, as has been done on some other Seattle tunnel projects. Where borings were located on either side of the alignment, the profile was developed by projecting the interpreted average contacts between ESUs from these borings to the profile. Elsewhere, the borings were projected onto the profile.

In a traditional Design-Bid-Build contract, the construction methods and components are generally specified to the degree that baselines can be selected to define pertinent ground properties and anticipated behavior in response to the prescribed construction methods. However, in choosing the baselines for a Design-Build project, where the selection of many of the construction means and methods are intentionally left to the Contractor, the GBR has to address the physical properties of the ground, but should avoid ground behavioral baselines that are dependent on the means and methods to be selected by the Contractor. The degree to which behavioral baselines are presented, depends on the degree to which various construction approaches are specified or excluded in the preliminary design.

Soil properties were baselined for each specific ESU. These properties included soil strengths, unit weight, pH, salinity, groundwater levels and chemistry, in-situ stress conditions, glacially overconsolidated peat, sticky/clogging clays, cobbles and boulders, etc. Since this project includes both the bored tunnel and cutandcover tunnels, it was necessary to baseline parameters that affect TBM operation and parameters that affect the design and construction of the cutandcover tunnels. Properties, considered important for the cutandcover tunnels included permeability, groundwater levels, soil and groundwater chemistry, and wood and debris content. Properties that were baselined in relationship to the bored tunnel included boulders and cobbles; abrasivity; shear zones and fractures; sticky/clogging clays; peat; face stability and mixed face conditions. The GBR also provides comments on maintenance and operational issues

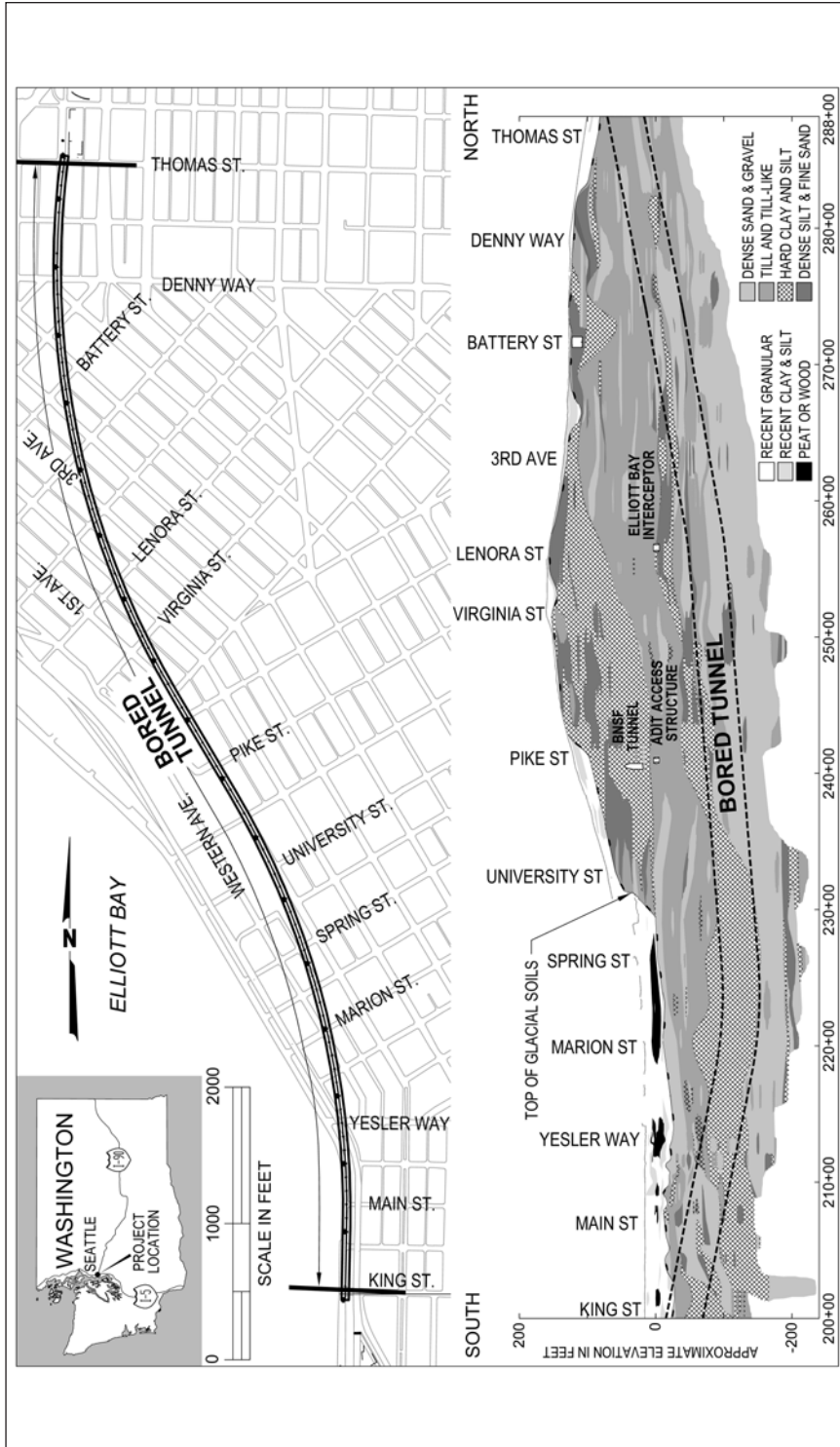


Figure 2. Plan and geotechnical profile

including: the need for frequent cutterhead and muck handling system inspections and maintenance; interventions; instability of the annulus unless immediately filled and supported; ground improvement alternatives (i.e., permeation grouting, soil mixing); scale effects; gas conditions; measurements of excavated quantities; and muck handling and disposal. With this knowledge, it was hoped that the Design-Builder would understand what will be encountered during construction and therefore could choose the best means and methods to deal with the different situations (i.e., high wood debris content).

TECHNICAL REQUIREMENTS

TBM Design and Operation

The technical requirements of the design-build contract documents included a number of requirements to guide in the selection of a TBM. These requirements were intended to reflect the ground conditions described in the GBR. There was not a restriction on whether a Slurry Pressure or Earth Pressure Balance (EPB) TBM could be used to excavate the bored tunnel, only that the TBM have a pressurized face and be able to maintain positive ground control at all times throughout the length of the bore. Due to settlement concerns, it was specified that the TBM operate in closed mode at all times. Various additional requirements were specified for the TBM to help limit problems caused by the ground being excavated. A sampling of these TBM performance requirements follow:

- Excavate through soils containing boulders, wood and concrete debris.
- Maintain water tightness in the sand, silt, and clay soils in the presence of 4–5 bar of water pressure.
- Provide abrasion protection for the cutting head and all TBM components subject to wear due to the abrasive soils along the tunnel drive.
- Provide a remote reading wear indicator system to indicate when cutting tools require replacement.
- Fill the annular void between the shield extrados and excavated surface of ground using a shield gap grouting system through the tailshield in advance of secondary grouting through the lining.
- Use cutting tools capable of cutting and removing hard materials including boulders, concrete and hard soil layers.
- Provide and use conditioners to stabilize the face under all conditions.
- Design the screw conveyor/slurry system for operation in abrasive and corrosive ground conditions and for efficient replacement from within the tunnel.

Building Protection Plan

Analysis was done for 158 buildings, nine other structures, and various utilities located within the projected settlement trough. Based on the results of the settlement analysis and characteristics of each building, the buildings were split into either Group A or Group B. Twenty buildings were considered to fall into Group A, where pre-mitigation would be required. The rest of the buildings were considered to fall into Group B, where no pre-mitigation was required. Different settlement limits were set for Group A (12.7 mm (0.5 in) or 19 mm ($\frac{3}{4}$ in), depending on method) and Group B Buildings (25 mm (1 inch)). Of the 20 Group A buildings it was determined that compensation grouting could be used on 10 buildings and that compaction grouting could be used on eight buildings. The soil conditions were one of the criteria for deciding what method of pre-mitigation would be required. Through a Deformation Mitigation

Submittal, the selected design-builder proved that only six buildings would need pre-mitigation, changing the number of Group A structures. The Deformation Mitigation Submittal was a method for the Design-Builder to prove to WSDOT that a Group A building did not need pre-mitigation and could be moved to Group B.

Construction Monitoring

A comprehensive monitoring plan was developed for this project. Since the instruments are intended to inform both WSDOT and the design-builder of movement, the program is fairly prescriptive. The design-builder will be responsible for final design, installation and collection of data from the instruments. Instruments will monitor movement of the ground, buildings, other structures, and utilities within the expected influence zone of tunnel excavation. The design-builder is required to have an integrated real-time monitoring system that makes data available across the web. The TBM advance rate; the TBM performance, including face pressures, excavated soil weights and volumes, grout pressures, etc.; the compensation grouting grout volume and pressure; the building, utility and ground settlement monitoring data; and the groundwater monitoring data will all be monitored and the real-time data made available on the Internet. The instruments that are to be used to monitor the ground and utilities include, multiple point borehole extensometers, inclinometers and near surface settlement points. Structure monitoring points, crack gauges, tiltmeters and liquid levels are to be used to monitor the buildings and other structures. A Construction Monitoring Task Force is to include staff from the design-builder and from WSDOT. The Task Force is responsible for planning, implementing and processing the results of all monitoring data and undertaking comparison of observed behavior and their predicted results. Also, if necessary, the Task Force has the authority to direct action if readings exceed a preset threshold value that indicates that a problem may be developing.

CONCLUSION

The proposed bored tunnel replacement for Washington's State Route 99 Alaskan Way Viaduct would be the largest mechanically bored tunnel in the world. It is a very challenging project that has required the application of state-of-the-art tunneling and contracting practices. The project is being advanced using a design-build contracting approach that utilizes various aspects of risk sharing. An extensive geotechnical investigation was conducted along the alignment of the tunnel, which passes directly below the central business district of Seattle, Washington. The data gathered from this investigation was used as source material for the writing of a GDR and GBR. These reports affected many of the technical requirements of the project especially the tunnel boring machine to be used. Because settlement was a major concern, a survey was made of buildings that could be affected during tunneling, and an extensive settlement monitoring system was planned. Both the GBR and GDR were included as part of the design-build contract package. The process of creating the GBR for this design-build project included:

- Performing an estimated 80 to 90% of the explorations and laboratory testing thought to be required for design and construction.
- Selecting a range of engineering soil units (ESU) that represent the ground conditions along the tunnel based on their expected behavior.
- Developing well thought out and pertinent geotechnical baselines for boulders, amount of woody debris, abrasivity of soils, clogging and stickiness of clayey soils, etc.

- Creating baselines of the geotechnical conditions that allowed the contractor the greatest amount of freedom in selecting means and methods without compromising safety.

The GBR required several iterations and major rewrites to accommodate input from numerous parties, including the owner, the design team, the project management consultant and the geotechnical engineer.

SELECTED READING

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