Alaskan Way Viaduct & Seawall Replacement Program

U.S. Department of Transportation Federal Highway Administration | WSDOT | King County | Port of Seattle | City of Seattle

Memorandum

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Date: May 3, 2010

Subject: SR 99 Alaskan Way Viaduct Phase 2 EIS
Proposed SR 99 Bored Tunnel – Cross-Section Verification Technical Memo

Reference: Y-9715 Task No. CL.13/MDL No. PE.BR.02.11
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SUMMARY

This memorandum documents that two stacked roadways, with required signage, systems, egress, and ventilation would fit within a 49-foot-diameter circle. This conclusion was based on the assumption that the roadways would be 30 feet wide (southbound stacked on top of northbound) with a 15-foot minimum vertical clearance. Additional assumptions include a 2-foot signage envelope, a continuous egress walkway, a common ventilation duct supporting single point extraction (SPE) ventilation, all required conduits and piping for lighting, sprinklers, and systems, and adequate space for egress and tunnel systems. Key configuration assumptions were two 11-foot-wide lanes, 2-foot- and 6-foot-wide shoulders (2-11-11-6) with the 6-foot-wide shoulder on the west side of the tunnel, and maximum 2 percent superelevation carried across the full width of the 30-foot roadway. Deviations from Washington State Department of Transportation (WSDOT) standards required approval. The minimum diameter for construction is anticipated to be 50 feet, which allows for construction tolerances in boring the tunnel. Assuming a 24-inch-thick tunnel lining, the outside diameter (OD) would be 54 feet and would require an approximately 56-foot diameter tunnel boring machine (TBM). This study has brought together the studies, trial designs, and evaluations of the tunnel cross-section. The study provides “verification” that there has been sufficient planning and engineering to give assurance at this time that the tunnel cross-section complies with engineering, operations, safety, cost, and WSDOT requirements. Key considerations for establishing the tunnel cross-section were highway geometrics, fire/life safety, constructability, and project budget. The tunnel cross-section was a critical item that must be fixed in order for Reference Drawings and many other documents to be prepared for the Final Request for Proposal (RFP) for the proposed State Route (SR) 99 Bored Tunnel, which is scheduled for release in May 2010.

PURPOSE OF STUDY

The purpose of this study was to document the proposed bored tunnel configuration decisions. The tunnel project is, to varying degrees, dependent on the physical size of the tunnel. Establishing the cross-section was a critical project decision that needed to be made early in the RFP preparation process. This study documents that there has been sufficient planning and engineering to give assurance that the tunnel configuration complies with engineering, operations, safety, and WSDOT requirements; would be constructible within current technology and expectations of cost; and would be acceptable to WSDOT. This document is an extension of and builds upon, the 9 July 2009 report titled "SR 99 Bored Tunnel Alternative – Cross-Section Development".

PROGRAM DESCRIPTION AND BACKGROUND

Background

The Alaskan Way Viaduct and Seawall Replacement Program (AWVSRP) is 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. The program's goal is to replace a critical element of Seattle's infrastructure – the viaduct section of State Route (SR) 99 – and the adjacent seawall that supports the Alaskan Way surface street.

Constructed in the 1950s, the double-tiered viaduct is nearly two miles long and parallels Alaskan Way. The viaduct is a vital local and regional transportation link and carries about 110,000 vehicles each day in the mid-town area. The seawall, built from concrete and timber between the 1910s and 1930s, extends along Seattle's waterfront and supports the soil behind it.

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.

On Jan. 13, 2009, the Governor, the King County Executive, the Seattle Mayor, and the Port of Seattle's chief executive officer endorsed a plan replacing the central waterfront portion of the Alaskan Way Viaduct with a bored tunnel beneath downtown. As part of this recommendation, the City would build a new surface street and new public open spaces along the waterfront, improve other city streets, and replace the seawall between Colman Dock and Pine Street while the County would invest in expanded transit service (Figure 1). The recommendation was based on collaboration with a 29-member Stakeholder Advisory Committee representing communities, economic interests, and cause-driven organizations; eight public meetings; and hundreds of public comments. During its 2009 session, the Washington State Legislature passed a bill that endorses the tunnel recommendation and provided funding for the state's projects. Governor Christine Gregoire signed this legislation into law on May 12, 2009.

FHWA, WSDOT, and the City of Seattle are leading the environmental review process for the viaduct's central waterfront replacement. Because of the recommendation of a bored tunnel, which had not previously been studied in-depth, a second Supplemental Draft Environmental Impact Statement (Supplemental Draft EIS) that analyzes the bored tunnel alternative has been initiated. The Supplemental Draft EIS builds upon the previous review of the cut-and-cover tunnel and elevated structure alternatives and would be published for public review in 2010. The Final Environmental Impact Statement and Record of Decision are expected to be issued in 2011.

Figure 1. Alaskan Way Viaduct Program Elements

Tunnel Project Description

The Tunnel Project is a part of the Alaskan Way Viaduct (AWV) Program (illustrated in Figure 1) and contains three major components: the South Access Project; the Design Build Tunnel Project; and the North Access Project.

South Access Project Description

The South Access Project would provide access to the tunnel at a portal near Qwest and Safeco Fields. The south portal area would be located on Alaskan Way, between S. Royal Brougham Way and S. Dearborn Street, and would consist of an at-grade mainline roadway and ramps leading to a depressed mainline and ramp roadways adjacent to the mainline tunnel and ramp portals. In addition, at least one new surface cross street would provide a connection between SR 99, Alaskan Way, and First Avenue S.

Design Build Tunnel Project Description

The Design Build Tunnel Project would begin between S. Royal Brougham Way and Charles Street with a depressed roadway section that contains the mainline and southbound off-ramps and northbound on-ramps. The portals for the ramps and mainline would be in the vicinity of Charles Street. They would lead into the cut-and-cover portion of the tunnel that extends approximately 1,000 feet and transitions from a side-by-side roadway to a stacked configuration at a bored tunnel that would begin immediately south of S. King Street under Alaskan Way. The roadway structure inside the bored tunnel would stack the roadways 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 would be approximately 90 feet below the ground surface, and the top of the tunnel would be about 30 feet below the ground surface. A southern tunnel operations building located east of SR 99 between S. Dearborn Street and S. King Street would provide ventilation as well as maintenance and operation capabilities. The lowest level of the building would be about 75 feet below the ground surface.

There would be approximately 8,800 feet of bored tunnel with an approximate outside diameter of 54 feet. The bored tunnel would decline at a 4 percent grade and pass under Alaskan Way, cross under the existing viaduct, follow a large radius curve beginning just south of S. Washington Street, then pass under Western Avenue to be parallel with First

Avenue. The tunnel would reach a low point under Madison Street where the top of the tunnel would be about 120 feet below street level. The tunnel would then rise at a 1.6 percent grade to the north as it continues under First Avenue to near Stewart Street, where it would follow a large radius curve to the north and cross under the street grid of Seattle's Belltown neighborhood at a diagonal. The tunnel would reach a depth of 215 feet from the crown of the tunnel to the ground surface at Virginia Street. At Lenora Street, the tunnel transitions to approximately a 4 percent grade. The tunnel would transition back to a cut-and-cover section north of Thomas Street. The cut-and-cover section would unbraid the tunnel's stacked northbound and southbound roadways into a side-by-side configuration that matches the existing grade of Aurora Avenue N. near Mercer Street. Where the bored tunnel emerges at Thomas Street, the cut-and-cover excavation would be about 85 feet deep. There would be a north tunnel operations building over the tunnel on the east side of Sixth Avenue N. between Thomas and Harrison Streets. The lowest level of the building would be around 75 feet below the ground surface. The cut-and-cover section of the tunnel would extend approximately 450 feet to a portal on the north side of Harrison Street.

The entire tunnel would have continuous six-foot shoulders on the roadway's west side to maximize access to an enclosed emergency walkway along the west side of the tunnel (Figure 2).

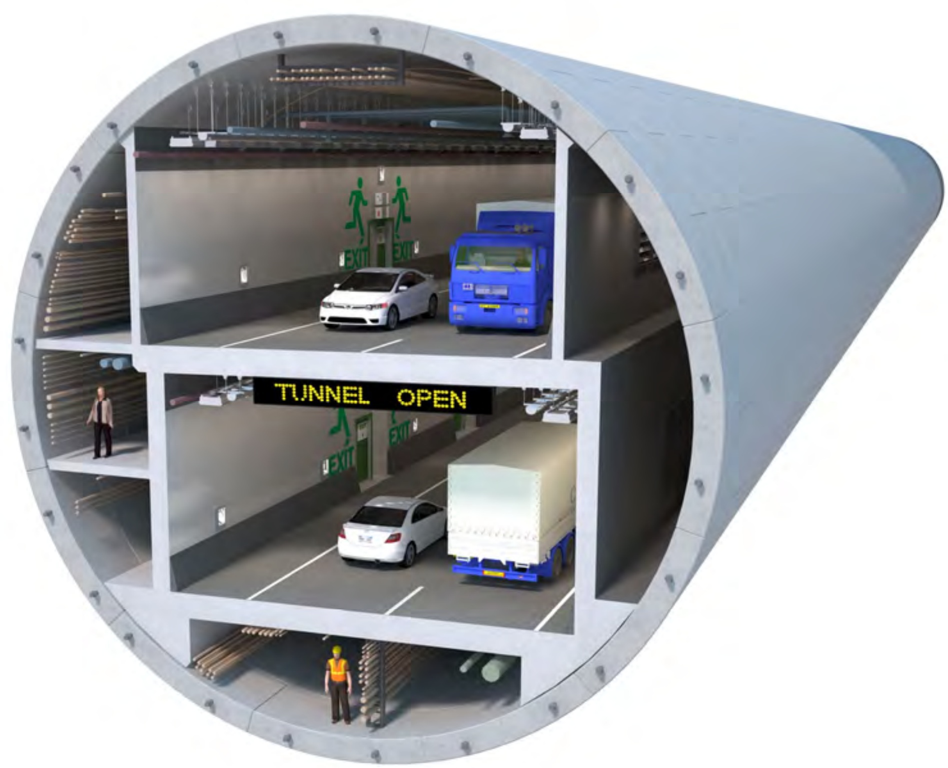

Figure 2. Proposed Bored Tunnel Cross-Section

North Access Project Description

The depressed at-grade roadway extending north from the tunnel portal at Harrison Street to the existing alignment of Aurora Avenue N. would comprise the bulk of the North Access Project. There would also be surface roadway modifications to work with the new on- and off-ramps leading to and from the tunnel that merge into Republican Street, as well as the mainline merge with Aurora Avenue N.

At the north portal area, Sixth Avenue N. would be extended from Harrison Street to Mercer Street, and John, Thomas, and Harrison Streets would be reconnected across Aurora Avenue N. Ramps would be constructed to provide northbound off and southbound on movements to and from SR 99 at Republican Street. Northbound on-ramps and southbound off-ramps to and from the intersection of Harrison Street and Aurora Avenue would also be constructed.

Description of Other Program Elements

Several elements, both roadway and non-roadway, would complete the program strategy and provide transportation benefits in the downtown Seattle area. Along the waterfront, these elements would include demolishing the existing viaduct, a new Alaskan Way surface street built in the footprint of the existing viaduct after it is demolished, a connection to Elliott and Western Avenues from the new Alaskan Way surface street by constructing a new bridge structure along the footprint of the existing viaduct, a new promenade adjacent to the seawall between S. King and Pike Streets, and seawall improvements. In the tunnel's north portal area, the Mercer Street corridor between Interstate 5 (I-5) and Elliott Avenue would be improved, and Broad Street would be removed between Ninth Avenue N. and Taylor Avenue N. New peak-period transit service to downtown would also be provided. These other program elements, led by the City of Seattle and King County, would improve access and mobility to and through downtown while enhancing Seattle's waterfront and adjacent neighborhoods.

TUNNEL REQUIREMENTS

The tunnel configuration must accommodate numerous requirements, including various codes (such as fire and life safety), current tunnel design and construction practices (TBM-excavated tunnel with one-pass precast concrete tunnel lining), and Alaskan Way Viaduct and Seawall Replacement goals.

The cross-section verification process was iterative, beginning with civil/highway criteria, followed by structural layout of roadways and walls to create the roadway envelope within the circular tunnel, followed by layout and arrangement of tunnel systems within tunnel section. This process involved developing numerous scenarios that varied tunnel size and internal layout details with checks on maintaining the minimum roadway geometrics (clearances) and space for tunnel systems for a specific scenario. The process was generally as follows:

- <u>Overall tunnel</u>: roadway layout established according to minimum acceptable civil geometric criteria, such as highway curves to accommodate design speed, sight distance, etc.
- <u>Tunnel interior structure</u>: tunnel interior structural members configured and sized to accommodate traffic loading, seismic performance, openings and space for utilities, and allowance for fireproofing. Pre-cast vs. cast-in-place concrete structural elements, and combinations of the two, were considered. Specific consideration has been given to constructability, egress, and space (cross-section area) to accommodate tunnel systems.
- <u>Tunnel systems</u>: mechanical (ventilation and drainage), electrical (power and lighting), Intelligent Transportation Systems (ITS) and other systems laid out to reserve space within the tunnel section for each tunnel system. Consideration was given to allocating space for potential leased utilities. Layouts first considered the two-dimensional tunnel cross-section to establish space for conduit and routing of utilities, such as drainage, from one level to the other through side walls, haunches, and floors. A three-dimensional check was subsequently made to confirm that tunnel systems could be accommodated along the full length of the tunnel.
- <u>Tunnel cost</u>: cost estimates were prepared for different sizes and compared to the budget for the tunnel. For different tunnel sizes, quantities varied for excavation, muck disposal, and reinforced concrete.
- <u>Constructability and Risk</u>: limited evaluations were made of practical factors for using a TBM that is larger than the current precedent size. The risks of damage to nearby buildings and utilities due to settlement resulting from boring a large diameter tunnel were evaluated along with general risks associated with constructing a very large bored tunnel in complex geology in an urban environment.

The *WSDOT Design Manual* is the primary reference for the tunnel geometric design. All references to this manual refer to the December 2009 Edition. AASHTO *Geometric Design of Highways and Streets, (AASHTO Green Book)* was used for guidance when a criterion in the *WSDOT Design Manual* could not be satisfied. All references to this manual refer to the 5th Edition dated 2004. SR 99 would consist of two northbound and two southbound lanes. Inside the tunnel, the southbound roadway would be located above the northbound roadway (see Corridor Analysis, February 2010). Emergency egress would be on the west side of the tunnel and connects the upper and lower roadways to each other and to exits located at each portal.

The basic requirements are addressed in the following categories:

- Highway Geometrics
- Tunnel Systems
- Tunnel Egress
- Interior Structure For Roadways, Egress, and Systems

Figure 3 shows a typical tunnel cross-section. The numbers called out in the figure ("1," "2," …) refer to critical locations for establishing the interior roadway structure. Locations 1 and 2 are the top corners of the vehicular clearance envelope for the top roadway; in some cross-sections studied, the tunnel systems were allowed to encroach into the sign clearance. Location 3 is an egress corridor with a minimum width of 44 inches and a minimum height of 6 feet 8 inches. Location 4 is where a roadway drainage pipe must pass between the liner and the roadway. Location 5 indicates a minimum cross-section area required for the ventilation duct. Location 5 controls when the tunnel diameter is below 49 feet. The interior surface of the liner was drawn around these five locations. See later sections for specific dimensions of clearances.

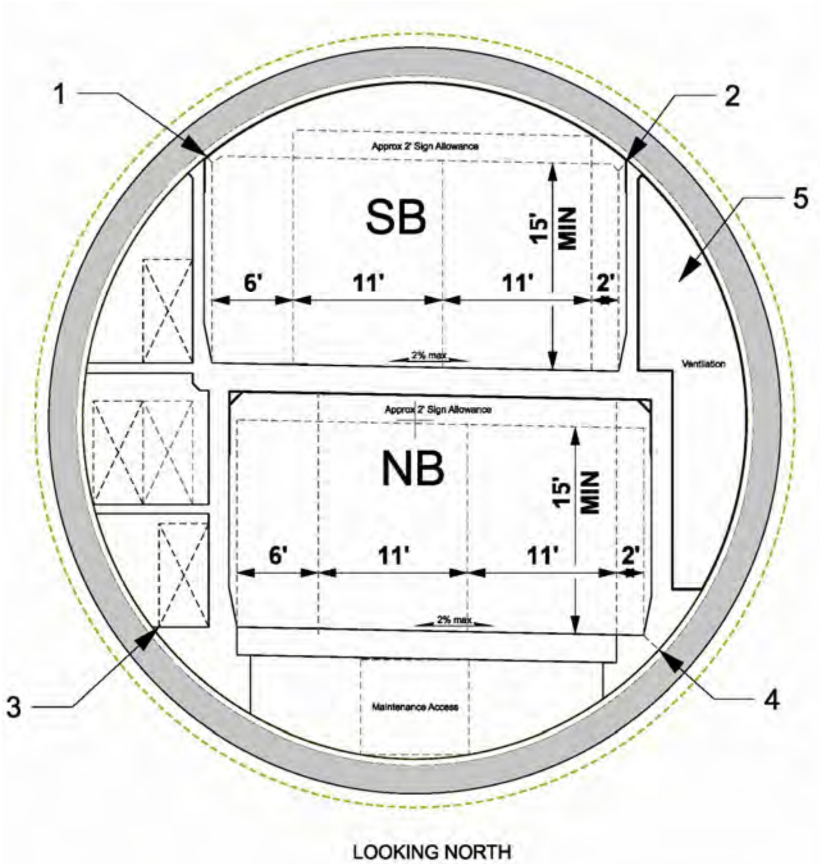

Figure 3. General Tunnel Cross-section Identifying Critical Points

HIGHWAY GEOMETRICS

Roadway Alignment

From the standpoint of service to traffic, the design criteria for tunnels should not differ materially from those used for grade separation structures. The same design criteria for alignment and profile and for vertical and horizontal clearances generally apply to tunnels except that minimum values are typically used because of high cost and restricted right-of-way (*Green Book*, pp.353). The roadway alignment must accommodate the physical route and a design speed of 50 mph (see Corridor Analysis – February 2010). The SR 99 facility has a design classification of Urban Managed Access Class 1 (UMA-1). The bored tunnel alignment has two large-radius curves and substantial reaches of straight tunnel. The radius of curves in the tunnel is controlled by fixing the design speed and amount of superelevation. With 2 percent superelevation and a design speed of 50 mph, the minimum radius curve is 6,000 feet. With 6,000-foot radius curves in the tunnel and a design speed of 50 mph, the safe stopping sight distance does not control provided a minimum shoulder width of 2 feet is provided.

Horizontal Roadway Clearances

Lanes

In accordance with the *WSDOT Design Manual,* the travel lanes are typically 12 feet wide for a design speed of 50 mph or 11 feet wide with justification. The *AASHTO Green Book* provides similar guidelines for tunnel design: lanes for two-lane tunnels should have a minimum width of 12 feet. Lane widths of 12 feet are desired over 11 feet when freight traffic is present or on National Highway System highways. Lane widths of 11 feet were justified and approved in the February 2010 Corridor Analysis.

Shoulders

Shoulders enhance roadway safety and capacity by extending sight distance, providing emergency vehicle access, and allowing stalled vehicles to stop outside of the travel way. Reduction of shoulder width reduces the ability to provide these safety features. However, it is common to consider reducing shoulder width to maintain lane width. Reduced lane widths can result in reduced capacity. Shoulder area can vary depending on needs and available width while remaining within design standards.

The *WSDOT Design Manual* recommends an outside shoulder 10 feet wide and an inside shoulder 4 feet wide for a UMA-1 roadway.

The *AASHTO Green Book* details the layout of tunnel cross-sections and allows shoulders to vary in width from 0 to 10 feet provided a minimum clearance of 30 feet is maintained between walls. Providing the two 11-foot travel lanes (*AASHTO Green Book, Exhibit 4-17*) leaves 8 feet available for shoulders. *AASHTO Green Book* guidelines suggest that if shoulders are not provided within the tunnel, around-the-clock emergency services should be considered to promptly remove stalled vehicles. A shoulder width of 6 feet on the west side of the tunnel – adjacent the emergency egress doors and walkway – and a shoulder width of 2 feet on the east side would be provided. These shoulder widths have been approved by WSDOT Headquarters Design and FHWA and are documented in the Corridor Analysis, February 2010.

Edge Treatment

Edge treatment can consist of barriers, curbs, or sidewalks. WSDOT Standard Plan D-2.16.00 details a noise wall mounted on a single-slope barrier. WSDOT does not have a companion standard plan for a tunnel. The toe of the barrier projects 8 ¾ inches from the vertical face of the noise wall. This standard plan is an example of a roadside barrier and wall combination that could be applicable to a roadway within a tunnel. A standard single-slope barrier per *WSDOT Bridge Design Manual* is 15 ¾ inches wide and 32 inches tall. The current cross-section concept assumes a 7-inch width for the projection of the sloped barrier from the vertical wall.

Another option is a raised curb or sidewalk in accordance with the *AASHTO Green Book*. The design code requires widths of curbs and sidewalks within a tunnel to be a minimum of 1.5 feet. Total clear distance between walls, however, should be a minimum of 30 feet. The roadway width and the curb or sidewalk width can be varied as needed within the 30-foot minimum wall clearance. The preferred section in accordance with the *AASHTO Green Book* is 44 feet wide and contains two 12-foot lanes, a 10-foot outside shoulder, a 5-foot inside shoulder, and 2.5-foot sidewalks on each side. The reference design provides 2-foot shoulders on the east side of the roadways and 6-foot shoulders on the west side of the roadways. The intent was to place the wider shoulder adjacent the emergency egress walkway access doors. This would be ideal for the southbound roadway but would result in the narrow shoulder being on the right side of the northbound roadway (facing in the direction of travel).

Vertical Roadway Clearance

Vehicular

Minimum required vertical clearance for vehicular traffic varies from 14 feet to 16.5 feet. The *WSDOT Design Manual* Section 1120.03 recommends 16.5 feet of roadway clearance including a 0.5-foot allowance for overlay.

The *AASHTO Green Book* Chapter 4 Tunnels Section requires a minimum clearance of 16 feet on freeway routes and 14 feet on non-freeway routes. An allowance for future overlays is desirable.

RCW 46.44.020 stipulates a maximum legal height of 14 feet for all unpermitted loads. A 15-foot minimum clearance over the roadway with specific exceptions in the southbound shoulders has been approved by WSDOT Headquarters Design and FHWA and was documented in Deviation 2 within the Design Approval Memorandum, May 2010.

Signing

Highway sign clearances and sizes are typically not applicable to tunnel construction as the clearance within tunnels is limited. Variable Message Signs (VMS) and fixed signs, varying from 2 to 3 feet high, are commonly used in tunnels. Two-foot-high VMS signs would be used along roadway throughout the tunnel.

Clearance between the roadway and the sign is also commonly decreased to match the vehicular clearance. Such clearance would be less than that required by both the *WSDOT Design Manual* and the *AASHTO Green Book*. *WSDOT Design Manual* Section 820.04 requires 17.5 feet of clearance between the roadway and overhead sign assembly with lights. The clearance is 19.5 feet for a sign assembly without lights. The *AASHTO Green Book* Chapter 8, Vertical Clearance Section states that sign trusses should be a minimum of 17 feet above the roadway. On urban routes with less than 16 feet of clearance, the vertical clearance to sign trusses should be 1 foot greater than the minimum clearance for other structures. WSDOT Headquarters Design and FHWA have approved a vertical clearance under signs in the tunnel of 15 feet; this was documented in Deviation 2 within the Design Approval Memorandum, May 2010.

Overlay

It was assumed that the roadway surfaces would be ground, as needed, to smooth out worn pavement and an overlay applied.

Superelevation

Vertical clearances must allow for roadway superelevation. The maximum superelevation required would be 2 percent. For a 30-foot-wide roadway, the superelevation slope can be across the full-width of the roadway including shoulders. Where the roadway is on a tangent (straight), a 2 percent cross slope is normally used.

Maximum superelevation for each roadway affects the size of the entire tunnel. Superelevated roadway can be created by adding thickness to the minimum structural roadway deck required. For a 30-foot-wide roadway with 2 percent slope across the full width, this is about 0.6 feet. Superelevation can also be achieved by sloping the structural roadway. A maximum superelevation of 2 percent was determined in accordance with *WSDOT Design Manual* criteria.

TUNNEL SYSTEMS

Many systems are required in the tunnel. A working assumption of the design process was that the tunnel systems would be fit into the tunnel cross-section after the basic roadway dimensions were established. Experience with other tunnels has shown that space for the many systems can be identified or created as a requirement, such as a tunnel enlargement for a mid-tunnel sump. However, at this time, it is thought that tunnel enlargement would not be required to fit the systems in the tunnel. Special efforts were undertaken using a 3D model of the tunnel and all known system elements in creating a 3 dimensional model of the tunnel systems that demonstrated a practical layout of tunnel systems could be achieved. The model also showed that there was sufficient space in the tunnel cross-section and along the tunnel for the tunnel all anticipated tunnel systems.

Figure 4 shows the general arrangement for tunnel systems in a 49-foot inside diameter (ID) tunnel.

Tunnel Mechanical Systems

Ventilation

The ventilation system adopted for this tunnel would be a SPE system, which provides a special form of semi-transverse ventilation. The SPE would be used in conjunction with the longitudinal ventilation system to accommodate extreme conditions, especially fire emergencies. The SPE system has vane-axial fans in the tunnel operation buildings at either end of the tunnel; it would extract air through a continuous ventilation duct for the full length of the tunnel. As shown in Figure 4. Tunnel Cross-section – Tunnel Systems, this ventilation duct requires a substantial portion of the tunnel cross-section. The SPE would extract air (or smoke in a fire scenario) through large dampers (openings of 96 square feet spaced at 110 feet along each roadway or equivalent) in the tunnel sidewalls. The dampers would be operated remotely. In a fire emergency, the dampers would be closed and the SPE fans would start. Only those dampers adjacent to the fire would be opened as needed. For non-fire emergency conditions, dampers would be opened along the tunnel if more exhaust were needed to maintain acceptable air quality, typically during conditions of heavy traffic.

Fire Suppression/Fire Fighting

Fixed Water-Based Fire-Fighting System (Roadway)

- Drop deluge type discharging water through open nozzles simultaneously over a coverage area.
- Arranged in approximately 110-foot-long deluge zones along each roadway.
- Sized to allow simultaneous discharge of two adjacent deluge zones for cases where fire overlaps two zones.
- Automatic operation by signals received from the automatic fire detection system in the tunnel.

Manual Fire-Fighting Systems (Roadway)

- Combined Class I standpipe and hydrant supply system to provide distribution both through two 2½ inch standpipe fire hose connections and through one 4-inch hydrant outlet.
- Dual feeds from the public water system and external 4-way fire department connections at each portal to permit pressurization by fire department apparatus.
- Fire hose valve cabinets recessed into tunnel wall spaced at 250 feet along each roadway.
- Sized to provide a minimum of 1,000 gpm at 20 psi for any single hydrant outlet flowing independently and 1,500 gpm at 20 psi with any two hydrants flowing simultaneously.

Fixed Water-Based Fire-Fighting System (Non-Roadway Spaces except tunnel invert)

- Closed head automatic sprinklers would be provided in all paths of emergency egress, waiting areas, stairwells, hallways and passages designated as emergency egress pathways, and electrical and mechanical areas.

Fire Proofing

Fire proofing would be necessary to meet NFPA 502 requirements for maximum allowable temperatures of reinforcing steel and concrete. It is anticipated that 1 inch of silica fiber board on the inside of the roadway structures would provide this protection.

Figure 4. Tunnel Cross-section – Tunnel Systems

Drainage

Drainage systems are required to collect and discharge water inflow that primarily results from tunnel washing, use of fire suppression systems, and the minor but normal seepage that can be expected with an underground structure below the groundwater table. Tunnel drainage systems are typically designed to be independent of inflow from sources outside the tunnel. For this project, the open approaches near or at the portals would be provided with independent stormwater catchments to intercept and prevent stormwater from running into the tunnel.

Tunnel drainage systems must also be designed and equipped to accommodate contaminants that are not legally permitted to be discharged through an outfall. These include flammable liquids from a fuel spill, detergents, particulates, and minor oily waste. Tunnel drainage would be discharged to a sewer system.

The collection system in each tunnel would consist of cast iron grated drop inlets designed for truck loading. They would be spaced at approximately 75-foot intervals to allow for cleaning between inlets. The drop inlets would connect to a main drainpipe below the roadway slab that would convey all water to the tunnel pump station. The longitudinal profile of the tunnel allows the collection system to operate by gravity.

Tunnel Electrical Systems

The electrical systems that must be accommodated in the tunnel are summarized below. A brief description provides a perspective of the substantial number of systems required. This has been adapted from tunnel system criteria, which should be consulted for additional details.

Power

Two independent power supplies with separate substations would be provided at each portal. A 26 kV tie feeder would be required between each portal through the tunnel. Uninterruptable power supply and diesel generated power (outside of tunnel) for emergency loss of both feeds would also be required.

Primary Switchgear

Primary switchgear would be included in a substation outside of the tunnel.

Secondary Power Distribution, Switchgear, and Transformers

Secondary power distribution, switchgear, and transformers would be required in the tunnel to provide power to equipment.

Motor Controllers

Motor controllers would generally be grouped in motor control centers. Motors within the tunnel would only be required for drainage pumps.

Lighting

Roadway lighting would be provided throughout the tunnel and would be placed within the sign clearance envelope. Other lighting for egress pathways and equipment areas would also be provided.

Fire Alarm

Manually operated fire alarms would be provided along the tunnel and at all egress points. Automatic fire detection and alarms would be provided in the roadway and in egress and equipment areas.

Supervisory Control and Data Acquisition (SCADA)

Tunnel SCADA system would permit monitoring and control of the various tunnel mechanical, electrical, traffic, and security systems. Equipment in the tunnel would be tied to the WSDOT Traffic Systems Management Center located at the Dayton Avenue Facility in Shoreline, Washington.

Conduit and Wiring

Substantial conduit and wiring would be required for ITS, electrical, security, and control systems. Wireways may be used in some situations.

Intelligent Transportation Systems

The ITS would monitor, manage, and control traffic within the tunnel and on connected approach roadways. The primary ITS equipment within the tunnel consists of Tunnel Control Signs (TCS) and Lane Control Signs (LCS), closed circuit television (CCTV), and vehicle detection in the form of loops. The ITS equipment would be supported by conduit throughout the tunnel and shared equipment cabinets in the electrical rooms within the egress area.

Traffic Signals

Signals at the tunnel portals would be used to stop traffic from entering the tunnel in case of incidents or maintenance activities within the tunnel.

Lane Control Signs

LCS would alternate with tunnel control signs; they would be installed at regular intervals within the tunnel. LCS would be used to indicate lane status and speed control.

Incident Detection

Incident detection would be a video-based system consisting of fixed cameras installed over the traffic lanes at a predetermined interval to provide full coverage of the roadway and adjacent shoulders; they would be used as the primary means of detecting vehicular incidents within the tunnel. In pavement, loops would provide secondary data to the Incident Detection System.

Tunnel Control Signs

TCS would provide information to motorists including traffic advisories, speed control, lane control, potential toll information, and information and instructions during emergencies. TCS would be installed at regular intervals within the tunnel and at the tunnel portals. TCS would be installed at alternate locations with the LCS.

Close Circuit Television

CCTV cameras would be provided with pan, tilt, and zoom capabilities for roadway surveillance. The cameras would be spaced above the roadway at predetermined intervals to provide full coverage of the roadway within the tunnel.

Tunnel Communication and Security Systems

Emergency and MaintenanceTelephone

Motorist emergency call boxes would be installed in roadways at 250-foot intervals and in egress corridors. Maintenance phones would be installed in the electrical rooms and at regular intervals within the invert section.

AM/FM Radio Re-broadcast

Rebroadcast of AM and FM signals would provide motorists with continual radio-listening capabilities. The system would include radiating antenna cables installed on both sides of each roadway along the upper walls of the tunnel. The system would have ability to override re-broadcast signals to communicate throughout the tunnel with pre-recorded or incident-specific advisor messages during an emergency.

Two-Way Radio

The system would provide complete above and below ground radio coverage for WSDOT maintenance and operations staff and other agencies. The system would include radiating antennas installed above the roadway at predetermined intervals along the tunnel to provide full radio coverage throughout the tunnel.

Cellular Telephone

Wireless telephone companies would be provided opportunities to install equipment in the tunnel to provide motorists with uninterrupted cell phone services. No specific space is being reserved in the two-dimensional tunnel cross-section, other than provisions for a 3-inch diameter empty conduit that would be installed for the length of the tunnel.

Security

Security monitoring would be relevant to the tunnel and portals. It would include access control systems and intrusion detection for non-egress areas of the tunnel typically housing equipment.

Maintenance

Maintenance access would be required below the northbound roadway slab. A clear space 8 feet wide and 8 feet tall was requested for this access as the tunnel cross-section was being developed. A maintenance access corridor of these dimensions is not required by code but would be beneficial to tunnel operations. Maintenance staff would also use the emergency egress walkway to gain access to facilities along the tunnel. However, the height of the maintenance access in the tunnel invert below the roadway directly affects the tunnel diameter - greater height requires a larger diameter tunnel. For the current cross-section, the height at the centerline of the tunnel is about 7 feet; it is 6 feet 9 inches at the sides of the 8-foot-wide space. Figure 5 shows a 3D rendering of the lower maintenance access.

Figure 5. Typical Cross-section - Lower Maintenance Access

EGRESS

Getting people safely out of the tunnel during emergencies, in particular during a fire emergency, is of paramount importance. Compared to the open roadway, a traffic accident and the consequences of a fire in a tunnel are typically much greater. Past incidences involving tunnel fires have driven the current practices and fire/life safety codes. Having a safe evacuation route, or egress, is essential.

For very short tunnels where the portals and the open roadway can be seen, egress would be along the roadway. For longer twin tunnels for transit or highways, egress is to the adjacent tunnel through a cross-passage. For a modern, single, long tunnel, egress is sometimes through a separate smaller-diameter tunnel connected regularly to the main tunnel much like cross-passages for two tunnels. The Alaskan Way Tunnel is planned to be constructed as a single large-diameter tunnel, the egress would be by a continuous walkway that is protected from a fire emergency in the roadway. The egress requirements and the limited space within the tunnel force the egresses to be located on the same side of the tunnel – in this case the west side. See Figure 3.

Critical Dimensions for Egress - Clearances

Discussions with the Seattle Fire Department have established a tentative agreement to supply a clear width of 3 feet 8 inches in accordance with National Fire Protection Association (NFPA) 502 Section 7.14.7, comparable to those found in some high-rise buildings.

NFPA 101 Section 7.1.5 governs headroom within egresses requiring a minimum clear height of 7.5 feet. The minimum ceiling height would be maintained for not less than two-thirds of the ceiling area if the remaining ceiling area is not less than 6 feet 8 inches.

Access to egresses would be spaced at a maximum of 656 feet (200 meters) in accordance with NFPA 502 Section 7.14.7. Egresses from each roadway would lead to stairs connected to the adjacent roadway and to a continuous walkway that would extend the entire length of the tunnel and lead to access points near both portals.

Area of Refuge

An area of refuge is required in addition to the egress. The refuge provides persons unable to self rescue to a safe location to wait until emergency help arrives. An area of refuge, approximately 20 feet long, adjacent to the stairwell leading up to the continuous emergency egress walkway, has been agreed upon with the Seattle Fire Department. A longitudinal elevation of the tunnel at the roadway egress doorway is shown in Figure 6a. The expected paths of egress are shown on the 3D rendering in Figure 6b.

Figure 6a. Section and Plan of Egress

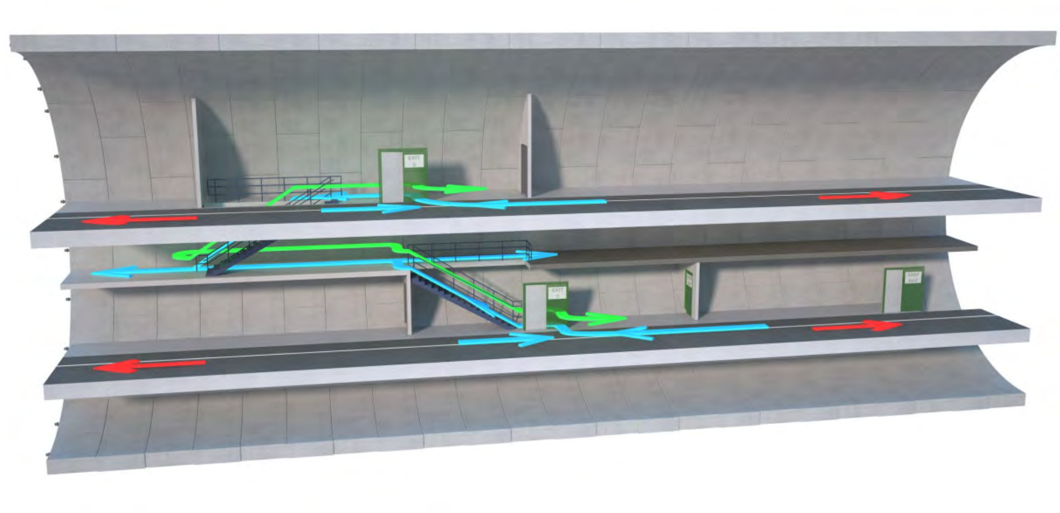

Figure 6b. Rendering of Egress

INTERIOR STRUCTURE FOR ROADWAYS, EGRESS, AND SYSTEMS

The interior cross-section (see Figure 3) is proposed to be constructed by using a combination of cast-in-place (CIP) and precast concrete members. The sequence for constructing the interior structure was considered in detail as a necessary step in determining the impact on overall diameter. Several construction stages would be required to build out the interior structure.

Precast vs. Cast-in-Place Concrete

Constructability of each stage was evaluated. Where sensible from the schedule and practical perspectives, precast concrete was proposed. For the lower roadway, the basic roadway deck would be precast beams with a 6-inch CIP concrete deck, rotated as required for superelevation and drainage. Lower roadway walls would be vertical CIP concrete. CIP concrete for the upper roadway would be placed to the required cross-slope for superelevation and drainage.

The upper walls were initially considered to be built as precast concrete panels. Several constructability issues were identified: practical ability to fit precast panels between the CIP roadway barrier and the as-built tunnel lining, sealing for duct air pressure, and accommodation of the SPE louvers. After evaluation, the upper roadway walls being considered are CIP concrete.

DETERMINING TUNNEL DIAMETER

Cross-Section Studies

Each constraint discussed in the previous sections, requirements for the tunnel, highway geometrics, tunnel systems, and egress, was evaluated for its effect on the tunnel diameter. Three of these constraints were considered limited in their variability due to design codes or engineering practice. The constraints held constant were sign clearance, egress width, and type of ventilation. All cross-sections were developed using the following dimensions:

- Sign clearance = 2 feet
- Egress width = 3 feet-8 inches
- Ventilation = single point extraction

The ventilation duct area varied as a dependent variable; however, a minimum value of 135 square feet was held.

The remaining constraints were varied and placed within an accommodating bored tunnel liner. The constraints are as follows:

- Shoulder width = 0 to 10 feet
- Vertical clearance = 14 to 17.5 feet
- Edge treatment width = 0 to 3 feet
- Lane width = 11 to 12 feet
- Liner thickness = 2 to 2.5 feet (based on tunnel diameter)

The liner and final tunnel diameter were dependent on the interior structure and clearances. The critical points defining the interior are shown in Figure 3.

During the study, the area of the ventilation duct was kept dependent upon tunnel diameter and the interior structure configuration, which reduced the complexity of the study. If required, the ventilation area can be increased by enlarging the tunnel diameter while the interior configuration remains constant. This would be necessary if the available area is below an acceptable limit as determined by analysis. Preliminary sizing suggests that 135 square feet of duct area without obstructions would be adequate for ventilation. This cross-sectional area is the net free space after fire proofing has been applied to the duct surface. The thickness of the fire proofing material was assumed to be 1 inch for preliminary design purposes.

The thicknesses of structural members within the bored tunnel were kept constant throughout the study. Both roadway decks were proposed to be 2 feet thick. The top walls were set at 10 inches thick and the lower walls at 18 inches thick. These preliminary sizes may change as the design progresses. Changes in these thicknesses would affect the tunnel diameter in a similar manner as the roadway width and clearance dimensions.

As engineering work progressed, WSDOT directed the roadway to have 2- and 6-foot shoulders, 11-foot lanes, and 15-foot vertical clearance without encroachment. These decisions focused the study and resulted in the conceptual cross-section selection.

PROCESS TO ESTABLISH TUNNEL SIZE FOR RFP

Space Proofing of Tunnel Systems

Three-dimensional visualization of the layout facilitated the engineering process and communication of the results with reviewers. A workable tunnel system arrangement was demonstrated for a 49-foot ID tunnel, or in other terms, the systems were successfully “space proofed.” Figure 7 shows a rendering from the space proofing exercise.

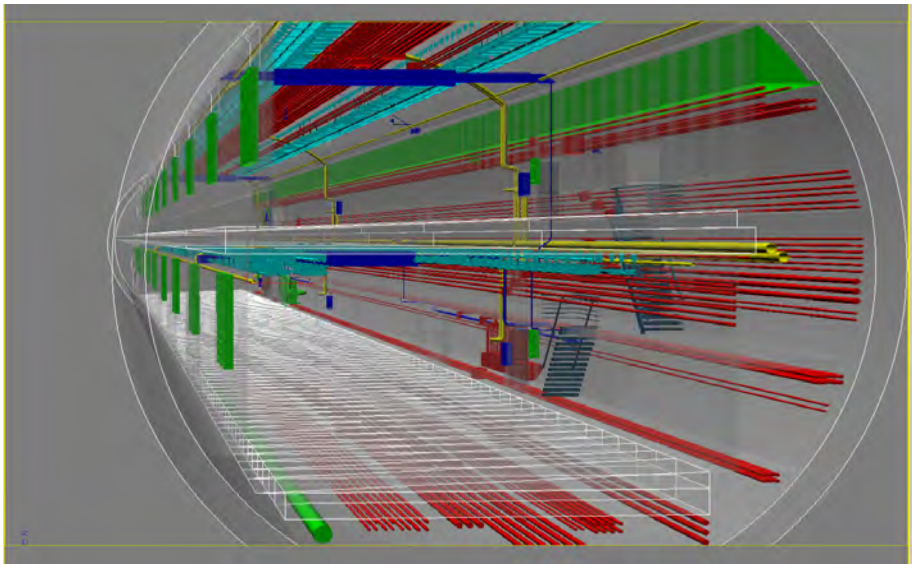

Figure 7. Computer Rendering of 3D Space Proofing of Tunnel Utilities

Additional Size Required for Construction Tolerance

Practical TBM construction of a tunnel in soil must allow for the as-built tunnel deviating from the design line and grade. How much is allowed becomes the specified tolerance (called a “bulls-eyes”) and must be achievable within the context of good workmanship for the tunneling. The bulls-eye also must be such that deviations from line and grade are small enough that the desired roadway alignment can be achieved. A tolerance of +/- 6 inches in line and grade was chosen, which gives a bull-eye shape of a 6-inch radius circle, or 12 inches on the tunnel diameter. Accordingly, the ID of the tunnel was increased for construction tolerances by 12 inches to make the tunnel ID 50 feet. The roadway and systems requirements have been spaced proofed for a 49-foot diameter, which would fit into the 50-foot ID tunnel that would be built.

Liner

The interior structure dimensions and the systems established the ID of the tunnel lining, to which the liner thickness was added to establish the final tunnel lining diameter. For the evaluations, a fixed 2-foot-thick tunnel lining was selected. This was based on looking at the as-built plans of other large diameter tunnels to select a starting place for conceptual design. Preliminary structural analysis has shown this dimension to be reasonable. Therefore, 2 feet was added to the radius or 4 feet to the diameter, going from an ID of 50 feet to an OD of 54 feet.

Constructability – Large Tunnel Boring Machine

Using a TBM several feet larger than precedent was a major constructability concern.

Tunnels constructed with a TBM of about 42.6 feet (13 meters) in diameter are well established as being within precedent. Globally, the precedent for tunnel size has increased in more or less 3.3-foot (1 meter) increments over time. The state of the practice is at about the 49.2 feet (15 meter) diameter range, with a Shanghai tunnel setting the precedent largest size TBM with a diameter of 50.6 feet (15.4 meter). Demand for larger-sized TBM exists in the long term market projections.

For tunnel design, the tunnel size is typically referred to by the OD or ID of the lining, but the TBM manufacturer thinks in terms of the outside diameter of the TBM. This distinction is important when comparing tunnel case histories to what is being proposed, and to be clear about the frame of reference for a quoted size or dimension. The TBM must be larger than the OD of the lining to accommodate several factors including structural thickness of the tail shield of the TBM, tolerance to erect the lining within the tail of the TBM, tail seals, and overcut at the leading edge of the TBM. For the size of tunnel being considered, the TBM would be about 1.5 feet in diameter larger than the OD of the tunnel lining. Construction would require an approximately 55.5-foot diameter TBM, which is about 5 feet larger than precedent (55.5 – 50.6 = 5 feet rounded).

CONCLUSION

A tunnel with an ID of 50 feet and OD of 54 feet and a TBM of about 56 feet has been shown to meet project requirements from an engineering perspective. The necessary components of the tunnel including roadway clearances, systems, egress, and ventilation would fit within a 49-foot circle. This was achieved while maintaining the approved lane configuration of (2-11-11-6), a 30-foot-wide roadway, spaces for the tunnel systems, an egress passageway, and the required 135 square feet for the ventilation duct. Due to the construction tolerance, the outside diameter of the tunnel lining was shown to be 54 feet, which means that a TBM of about 56 feet would be necessary to construct the tunnel. A review of current and anticipated tunneling technology and conversations with two large diameter TBM manufacturers has provided assurance that a TBM of this size is feasible.

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