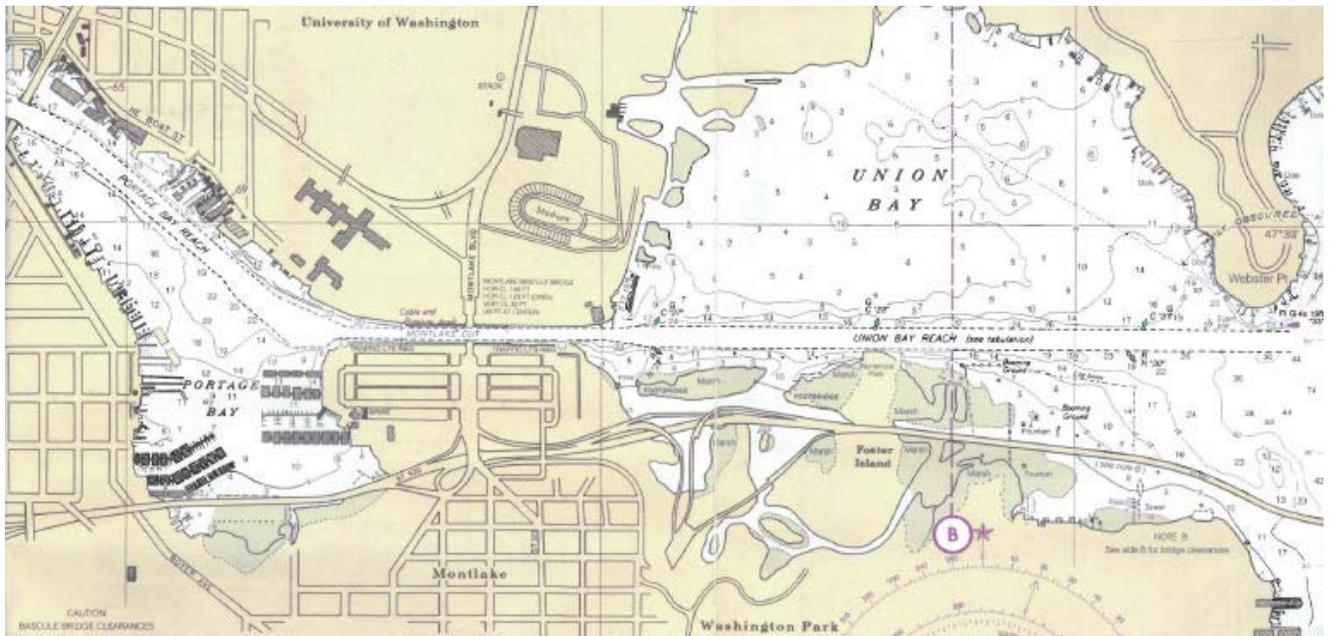


# SR 520 Project Montlake Cut Tunnel Expert Review Panel Report



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# 1. EXECUTIVE SUMMARY

## 1.1. INTRODUCTION

As part of the SR 520 Mediation process required by the Washington State Legislature, an alternative was developed called “The Parkway Plan,” also known as “Alternative K.” This alternative envisions an interchange connection from the SR 520 mainline just east of Montlake, to the University of Washington area via a tunnel under the Montlake Cut.

The tunnel was described in a report by COWI, the Mediator’s engineering and construction consultant, released March 17<sup>th</sup>, 2008 and titled “Tunnels at East Montlake and the Arboretum, Conceptual Design and Cost Estimate, Part 1.” COWI had previously examined several tunnel methods, including Cut-and-Cover, Immersed Tunnel, Bored Tunnel and Sequential Excavation. The March 17<sup>th</sup> report focused on an immersed tunnel type of construction for a tunnel passing under Union Bay approximately 200 feet east of the Montlake Cut. The tunnel included two 12 foot wide travel lanes in each direction, four foot shoulders on each side and provision for wider shoulders to permit the required sight distance on the inside of the curve.

A plan view of this alignment is shown in Figure 5 – “General arrangement of the COWI Immersed Tunnel Proposal.”

The immersed tunnel construction proposed by COWI would have environmental effects to the Montlake area, Montlake Cut and Union Bay. Tribal fishing rights would also need to be considered with the COWI proposed method. The mediation panel asked for consideration of other tunneling options that would reduce these effects and consider tribal fishing rights. This report responds to that request.

## 1.2. ENVIRONMENTAL CONSIDERATIONS

The Expert Review Panel considered environmental and community impacts identified during their assessment of potential construction methods and alignments. The panel met with mediation participants to hear the specific concerns of the neighborhoods and individuals.

Environmental topics include:

- Fisheries and fish habitat
- Wetlands and riparian vegetation
- Historic and cultural resources
- Tribal rights
- Parks and recreation

The list of concerns and their relationships to the tunneling methods and alignments, with potential avoidance, mitigation and minimization strategies, are listed in Table C in the body of the report. These concerns, with the associated avoidance, mitigation and minimization strategies and issues, will be a strong determinant of acceptability of tunneling methods and possible alignments.

Fish and fish habitat protection are strong considerations and severely restrict available work windows in the water and on the near shore. Table D in the body of the report lists salmonid migration timing in order to establish possible work-windows in the Montlake Cut and Union Bay.

## 1.3. TUNNELING METHODS CONSIDERED

Three tunneling methods were identified as feasible construction methods for a tunnel that connects the SR 520 mainline and Pacific Street. These methods are:

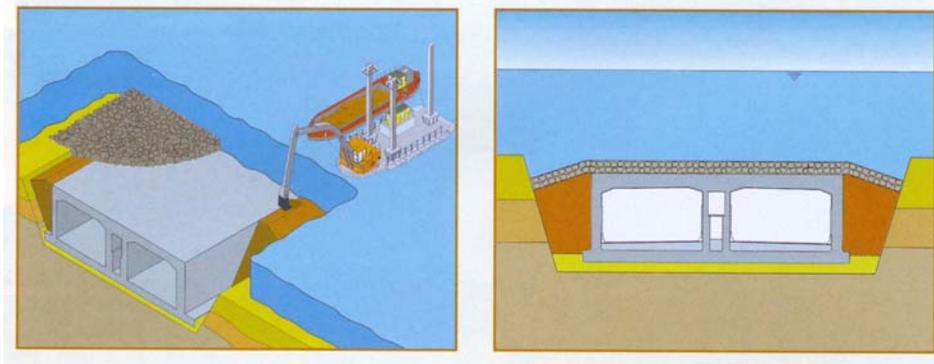
1. Immersed tunneling method: A concrete or steel tube or tunnel would be constructed in an adjacent “dry dock” within the alignment. The dry dock would then be flooded and the immersed tunnel unit floated into position and lowered into an excavated trench across the Montlake Cut or

Union Bay shipping channel depending on the alignment. The width of the concrete or steel tunnel would be approximately 80 feet.

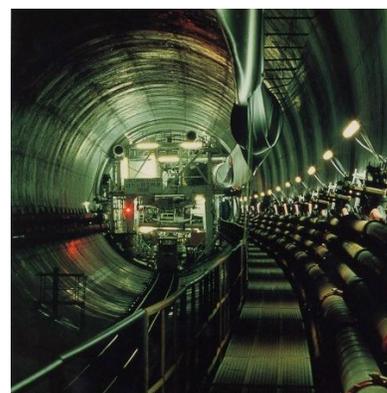
2. Bored tunneling method: A tunnel boring machine (TBM) would be directed under the Montlake Cut or just east in Union Bay, to create two parallel tunnels. Typical cross-sections of each tunnel are shown in the body of the report. The out-to-out width of the tunnels plus a center earth support pillar would be approximately 150 feet.
3. Sequential excavation method (SEM), including ground stabilization measures such as ground freezing: Sequential excavation would be directed under the Montlake Cut or nearby in Union Bay to create two parallel tunnels. Typical cross-sections are shown in the body of the report. The out-to-out width of the tunnels plus a center earth support pillar would be approximately 150 feet.

Cut-and-cover construction will be necessary in combination with the three tunnel options listed above. Cut-and-cover construction will be required for the approach ramps to the tunnel on both the south and north sides of the Montlake cut. Cut-and-cover construction for the approach areas will allow the tunneling to begin at a suitable elevation and in appropriate geotechnical material.

Details of the tunneling methods considered are given in the body of the report. Typical examples and cross-sections of the three tunneling methods are shown in Figures 1-3 following.



*Figure 1 - Immersed Tunnel Construction (General)*



*Figure 2 - Tunnel Boring Machine (Elbe River, Hamburg)*





*Figure 3 – Sequential Excavation Method (Beacon Hill Tunnel, Seattle)*

All tunneling methods require adjacent cut-and-cover sections of variable lengths. Several cut-and-cover construction scenarios are feasible as described in the report. Only the immersed tunnel method will require cut-and-cover activities immediately adjacent to the shoreline and through designated wetlands on the south side of the Montlake Cut. The bored tunneling or sequential excavation methods can avoid these sensitive areas.

The three tunneling alternatives were evaluated in consideration of potential environmental impacts, expressed community issues and concerns, site constraints, highway requirements and standards, construction means and methods, safety issues and, geotechnical conditions.

#### **1.4. GEOTECHNICAL CONSIDERATIONS**

Suitable geotechnical conditions are necessary for the tunneling and sub-surface structures. Data from nearby projects indicate that the soils at the east end of the Montlake Cut are likely to be favorable for tunneling, as they consist of a mix of hard to very dense clay, till, sand, and gravel with water levels somewhat higher than the lake levels. The tunnel boring or sequential excavation methods must be located in these good soils with approximately one tunnel diameter of competent material over the crown of the tunnels. In addition, the tunnel boring and SEM require a width of one tunnel diameter horizontally between the tunnels. The immersed tunnel does not require this top cover or horizontal allowance.

In Union Bay, the depth to the top of the competent soils increases moving east from the Montlake Cut. In Union Bay these competent soils are covered with an increasing thickness of very soft. peat and very soft. clay reaching over 100 feet thick. These soil conditions extend to the north in Union Bay and are not suitable for tunnel boring or sequential excavation. The conditions would also not be suitable for use as a foundation beneath the sunken tube or cut or cover structures. These concerns have been taken into consideration for the alignments and specific tunneling methods discussed in the report.

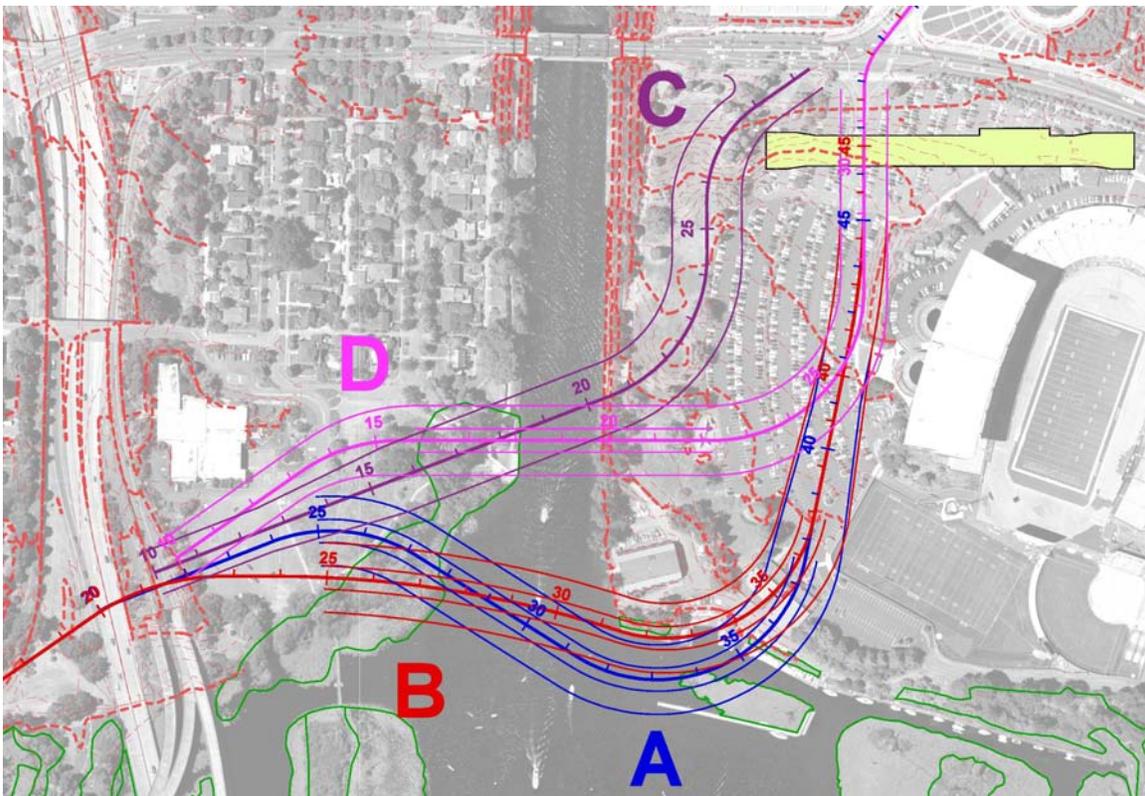
It should be noted that the available subsurface data on which the report is based is derived from several borings within 500 feet of the various alignments. These borings are of varying quality and reliability and span over 50 years. Due to the wide variety of sampling methods, the brevity of many of the classifications, and the lack of information on reference elevation datums, an accurate portrayal of the various glacial and interglacial soils is not possible at this time. While the conclusions of this report are believed appropriate, the specifics of the soil data – depths, soil types, strengths etc. – will need to be verified for further work to be done.

## 1.5. ALIGNMENTS CONSIDERED

The Expert Review Panel discussed several alignment options within the designated study area, as shown in Figure 4 below. The east alignment limit is constrained by the rapid drop off of the lake bottom and the associated increasing depth of the hard, competent material required for the bored and sequential excavation tunneling.

To the west, the alignment is limited by the short lengths of the ramps, which require steep ramp grades in order to pass over the top of the Sound Transit Light Rail station cross-over box (shown in yellow in Figure 4 following). Three of the alternative alignments evaluated (A, B and D) must pass above the cross-over box which is a vertical constraint (the cross-over box has a six foot notch included in the design to better allow the road ramps to pass over). We note that the cross-over box has 3 levels – track level plus two mechanical levels. If it were possible to utilize the top mechanical level for the road ramps, Alignments A, B and D could be designed with better ramp grades.

One alternative, Alignment C, was evaluated with the alignment passing just to the south of the Sound Transit vent shaft. This alignment allows the ramps to descend more quickly from Pacific Street by eliminating the cross-over box's vertical restraint and would also keep construction further away from the stadium and car parking area. However, this alignment currently results in ramp grades of 13 to 16 percent.



*Figure 4 - Plan of tunnel alignments A, B, C and D considered*

The total length and the underwater length of the tunnel both increase as the alignment extends east into Union Bay. Because the environmental concerns increase as the alignment moves further east, with a longer alignment in Union Bay and more impacts to shoreline and wetlands, a shorter water crossing is preferable if it can be achieved with acceptable ramp grades.

Several tables and descriptions are provided in the report which describe comparisons between, and characteristics of, the alignment alternatives. Included are considerations of the construction methods, the characteristic dimensions and potential environmental impacts. A summary of the methods, alignments and corresponding roadway grades is listed in Table A following.

## 1.6. METHODS, LENGTHS, GRADES AND MINIMUM SOIL COVER

Table A following summarizes the alignments considered with key characteristics for the different alignments and tunneling methods. The grades shown are generally computed at the centerline of the alignment, that is mid-way between the inbound and outbound ramps. This means the down-grade will be slightly higher and the up-grade slightly lower than the value shown.

Alignment	A - in Lake	B -in Lake	C - across Cut	D -across Cut
<b>Length considered</b>	2000	1800	1400	1500
<b>Sequential Excavation Method (SEM)</b>				
Length of SEM	700 -1000*	700 - 950*	300 - 500*	250 - 400*
Length of Cut and Cover	1300 - 1000*	1100-850*	1100-900*	1250-1100
Road grade north %	11	9.5	16	13.5
Road grade south %	9	7	8	8.5
Cover over tunnel **	25	25	20	20
<b>Immersed Tube Method</b>				
Length of Immersed Tube	300 - 900	260 - 850	250	200 - 250
Length of Cut and Cover	1700-1100	1540-950	1150	1300 - 1250
Road grade north %	8	7	13.5	10.5
Road grade south %	7	5.5	5.5	6
Cover over tunnel ***	6	6	6	6
<b>Bored Tunnel Method</b>				
Length of Bored Tunnel	1550	1450	1050	1150
Length of Cut and Cover	450	350	350	350
Road grade north %	11	9.5	15	12.5
Road grade south %	9	7	7.5	8
Cover over tunnel **	20	20	20	20

### Alignments & Notes:

A - swings east furthest into Lake Washington to cross the channel

B - swings east to cross the channel just east of the UW Boat House

C - crosses the Montlake Cut at an angle, alignment is south of Sound Transit Vent Shaft

D - crosses the cut at 90 degrees west of the UW Boat House

\* SEM - the longer length doesn't impact the wet lands, the shorter length does

\*\* Cover (ft) = minimum depth over the tunnel crown of stable firm glacially overridden soils

\*\*\* Cover (ft) for the immersed tunnel is for protection, not a structural requirement

*Table A – Alignments, Lengths, Road Grades and Minimum Cover*

### Alignment B - Modified

Because the grades for these alignments are, in most cases, greater than the WSDOT Design Manual maximums (see following) a modification to Alignment B has been examined. This alignment reduces the north road grade from 9.5 percent to 8.5 percent.

### Alignment B modified

Length of Tunnel	500-700
Length of Cut and Cover	1300-1100
Road grade north %	8.50%
Road grade south %	7.50%
Cover over tunnel **	20

*Table A-1 – Alignment B Modified*



## 1.8. FINDINGS REGARDING THE TUNNELING METHODS CONSIDERED

The following general findings are presented regarding the tunnel construction methods and alignments considered by the Expert Review Panel. More detail regarding these findings and considerations is given in the body of the report.

### General:

1. It is considered feasible to tunnel the SR 520 ramps under the Montlake Cut or close-by in Union Bay, subject to further specific evaluation of geotechnical conditions
2. Because of maximum ramp grade requirements, even considering variances to these requirements, only some tunneling methods are possible for certain alignments. These combinations are:
  - a. Sequential Excavation Method (SEM) with Alignment B modified.
  - b. Bored Tunnel (TBM) with Alignment B modified.
  - c. Immersed Tunnel with Alignments A and B, B modified and D modified.
3. The bored tunnel method is not considered feasible for several reasons, as noted below and in the report.
4. The sequential excavation and immersed tunnel methods are considered capable of being successfully constructed in this location.
5. The sequential excavation method can avoid in-water work and impacts to the near shore environment and wetlands.
6. The immersed tunnel method will require in-water dredging and operations and will have impacts to the near shore environment and wetlands.

### Specifics regarding the methods:

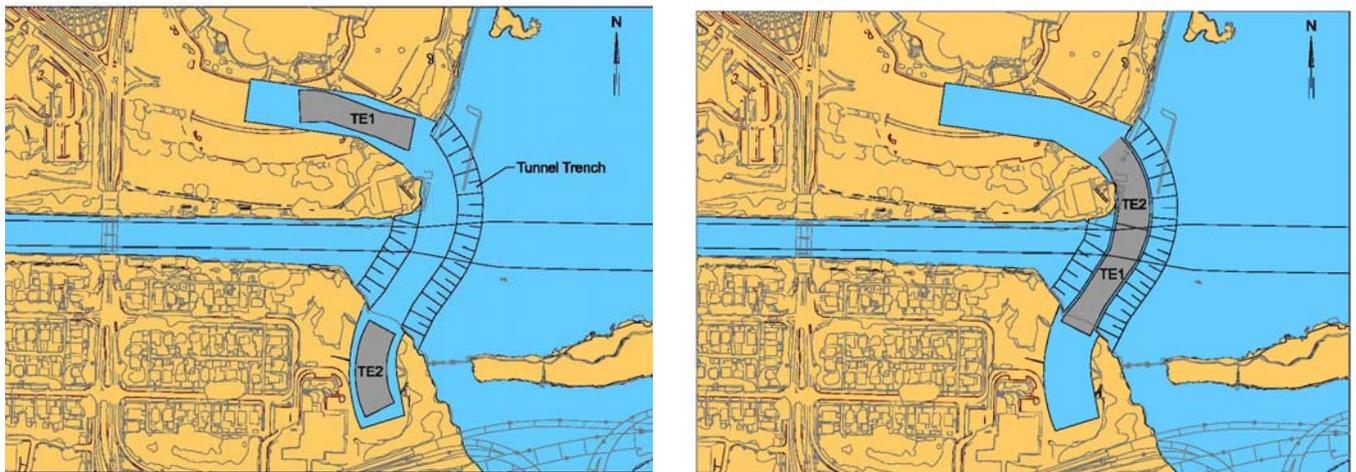
1. Sequential excavation method (SEM)
  - a. The SEM provides flexibility to change the cross-section and vary the pillar width along the alignment. These changes are made to accommodate sight lines and other safety requirements.
  - b. The SEM requires the deepest cover under the channel and will have steep grades on the shortest alignment but has acceptable grades for Alignment B modified.
  - c. The SEM requires time to condition the ground over the tunnel by freezing the soil. On the longer alignments, under Union Bay (Alignments A and B) the SEM could require sequential freezing operations during the tunnel excavation to ensure that the ground is completely frozen ahead of the tunneling. This will add time to the schedule.
  - d. The SEM method does not require any in-water work.
2. Bored tunneling method
  - a. The bored tunnel requires a very large tunnel boring machine. This size of machine would require a long lead time for procurement and set up for a relatively short length of tunnel.
  - b. The bored tunnel involves steep grades and tight radius curves, requiring complex machine control and trained operators.
  - c. It is possible that no manufacturer would be able to supply a TBM that could negotiate the tight radius (325 feet) in this location.
  - d. This method does not require in-water work.
  - e. This method is not recommended for this location or alignment.
3. Immersed tunnel
  - a. The immersed tunnel can be constructed with the shortest length of tunnel across the cut.
  - b. The ramps, constructed in the cut-and-cover sections, would have the lowest grades because the immersed tunnel does not require the additional cover of competent soil.
  - c. The immersed tunnel plus cut-and-cover will have the shortest construction duration.
  - d. Unforeseen soil conditions have little or no effect on the alignment, profile and constructability of the immersed tunnel.
  - e. Variations in the cross-section of the roadway can be easily accommodated.
  - f. This method requires in-water work and significant environmental mitigation.

## 2. REPORT, SR520 EXPERT PANEL, MONTLAKE CUT TUNNELS

### 2.1. INTRODUCTION AND BACKGROUND, THE COWI REPORT

As part of the SR 520 Mediation process, required by the Washington State Legislature, an alternative was developed called “the Parkway Plan”, also known as “Alternative K.” This alternative envisioned an interchange connection from the mainline of SR 520, just east of Montlake, to the University of Washington area routed in a tunnel under the navigation channel east of the Montlake Cut to the University area. The tunnel was described in a report by COWI, the Mediator’s engineering and construction consultant, released March 17<sup>th</sup>, 2008 and titled “Tunnels at East Montlake and the Arboretum, Conceptual Design and Cost Estimate, Part 1.”

That report considered using an immersed tunnel type of construction, passing under Lake Washington approximately 200 feet to the east of the end of the Montlake Cut as shown below. The tunnel included two 12 foot wide travel lanes in each direction, four foot shoulders on each side and provision for wider shoulders to permit the required sight distance on the inside of the curve.



*Figure 5 – General arrangement of the COWI Immersed Tunnel Proposal*

For various reasons, including the significant environmental impact to the Montlake Cut and Lake Washington, the mediation panel asked for consideration of other tunneling options that would reduce those environmental impacts. This report responds to that request.

#### **This Document**

This document presents the SR 520 Montlake Cut Tunnel Expert Review Panel (ERP) findings, technical considerations and report in response to the mediation panel’s request to review other possible methods to tunnel under or adjacent to the Montlake Cut.

#### **Project Context**

In 2006, Governor Gregoire endorsed the four general purpose and two high occupancy vehicle (HOV) lane configuration for the SR 520 corridor. The current roadway includes four general purpose lanes, but does not include HOV lanes. In 2007, the State Legislature and Governor Gregoire approved a mediation process for the Seattle side of the project. The mediation process led to the development of Alternatives A, K and L.

Earlier this year, the Governor announced that the SR 520 project would meet an expedited schedule including the four-lane floating bridge open to traffic in 2014 and a six-lane corridor complete by 2016.

## Expert Review Panel, convening and objectives

As part of their participation in mediation, the Washington State Department of Transportation, in cooperation with the Governor's office, convened an expert review panel (ERP) to consider the technical issues, opportunities and concerns related to the suggested tunnel under the Montlake Cut. The panel was convened in response to the interests and concerns expressed by mediation participants, as well as regulatory agencies. The resumes of the ERP members are provided in Appendix C.

The panel was asked to review and as possible with the available data and in the time allowed consider and evaluate possible tunneling methods and alignments which would address the constraints of the project area and the intent of Alternative K. The design and construction methods need to consider sensitive environmental issues, fish passage and habitat, Tribal fishing rights, geotechnical conditions, navigation requirements and road design constraints.

The expert review panel consisted of consultants with extensive tunnel design and construction experience who participated in the review and developed findings. The panel also included a member with expertise in the effects of tunneling on fisheries resources. The panel included:

John Reilly, P.E., C.P.Eng.	John Reilly Associates International
Brenda Böhlke, Ph.D. P.G.	Myers Böhlke Enterprise
Vojtech Gall, Ph.D., P.E.	Gall Zeidler Consultants
Lars Christian Ingerslev, P.E.	PB
Red Robinson, C.E.G., R.G.	Shannon and Wilson
Gregg Korbin, Ph.D.	Geotechnical Consultant
John Townsend, C.Eng.	Hatch Mott MacDonald
José Carrasquero-Verde, Principal Scientist	Herrera Environmental Consultants

## Input from the Project and Mediation Panel Members<sup>1</sup>

The SR 520 Project encouraged the panel to consider various tunnel construction methods to determine their feasibility for this project and this application. The resource agencies and Tribal nations are concerned with both temporary and long-term environmental impacts of the project including fish migration, Tribal fishing rights, shoreline areas, wetlands, dredging, water quality, and navigational access. The endangered species act (ESA) needs to be considered regarding Chinook salmon, steelhead, and bullhead trout - which live in or migrate through the Montlake Cut, Union Bay and Lake Washington. The likely window without fish migration is October through December, but steelhead (as well as other fish species listed at the state level as species of concern and game fish) can be found year-round. Work windows for in-water construction, however, have not been finalized with the resource agencies. It was noted that the communities adjacent to the SR 520 project area are interested in minimizing the noise, visual and traffic effects of the project, as well as effects to the University of Washington and the Arboretum.

The project noted that the goal of the ERP is to consider tunnel construction methods which would assist WSDOT in responding to the interests of the mediation participants, resource agencies, and Tribal nations. Communities are interested in improving traffic and connecting with the Sound Transit light rail station. Based on feedback regarding the COWI tunnel proposal, an immersed tube and tunnel may not be possible to permit because of its impacts on fish migration, Tribal fishing rights, wetlands, and navigational access. Sedimentation and water quality degradation are also of concern because of the possibility of dredging and construction activities in and near the water.

<sup>1</sup> The panel received a briefing from SR 520 Project management at the beginning of the workshop and heard from mediation panel members regarding their concerns at the end of the first and second days. Notes of these end-of-day meetings are attached to this report in Appendix A.

### **Cost of the alternatives not addressed**

The panel was not charged with developing cost estimates for the possible tunnel alternatives. It is probable that WSDOT will address cost through the Cost Estimate Validation Process (CEVP<sup>®</sup>) in association with the west side alternatives, once they are sufficiently defined.

## **2.2. EXPERT REVIEW PANEL - WORKSHOP**

The work of the ERP was conducted in a three day workshop in Seattle, May 19<sup>th</sup> through 21<sup>st</sup> with logistical support from WSDOT and the SR 520 Project team.

The following basic data items were provided to the panel members:

- Plan and profile alignment
- Traffic and civil considerations
- Structural envelopes
- Geotechnical and environmental data
- Information on adjacent structures and topography
- Reports and considerations related to previous planning and design alternatives
- Mediation summary data

### **Considerations**

The following design and construction aspects were considered by the panel:

- Options that are worthy of consideration
- Technical feasibility of the options
- Environmental considerations and impacts on Tribal fishing rights and surrounding areas
- Related geotechnical considerations
- Design considerations and potential construction methods
- Key issues to be considered and resolved
- Interface with adjacent facilities and Sound Transit construction

## **2.3. PROPOSED MONTLAKE CUT TUNNEL – PROJECT CONSIDERATIONS**

### **Tunnel - configuration, coordination and considerations**

On Day 1, SR 520 Project staff briefed the ERP on considerations and constraints for the Montlake Cut area, including a description of the tunnel report produced by COWI. The communities do not want the tunnel to be a through-route for local traffic. Therefore, the tunnel would serve as an on-and-off ramp for SR 520 and should meet the design standards for a highway ramp. The communities also want to reduce traffic on Montlake Boulevard, since the existing Montlake bridge is a chokepoint.

As proposed, the tunnel would intersect with Montlake Boulevard and Pacific Street north of the Montlake Cut. The intersection is near the future Sound Transit Light Rail Station and the University of Washington football stadium. The intersection must also accommodate pedestrian movements and transit access.

The tunnel would also connect to a single point urban interchange (SPUI) at east Montlake. Current plans are to signalize the interchange to accommodate traffic movements. While the traffic models suggest this will not lead to back-ups on the mainline, it is near capacity. The panel requested additional information regarding traffic operations at the interchange.

Sound Transit (ST) will be constructing bored light-rail tunnels under the Montlake Cut connecting to a cross-over structure with a vent shaft then into a station on University of Washington property in front of Husky Stadium. They have arranged to use part of the University's property during construction. Construction of a tunnel for the SR 520 Project would need to avoid the Sound Transit tunnel, cross-over, ventilation shaft and station.

There is on-going coordination with the University of Washington regarding construction staging areas, access to the athletic facilities, loss of parking, preservation of the historic boathouse, and the potential for future development of University property. Alternative alignments for the tunnel may be possible, but the length of the tunnel must accommodate acceptable roadway grades.

The interchange of the tunnel ramps with the SR 520 mainline could be on multiple levels since the ramps are planned below ground to reduce their visual impact to the surrounding communities. East of the proposed interchange location, the roadway surface is close to water level. Marsh Island to the east of the proposed interchange is an environmentally sensitive park area. West of the interchange, the highway will be covered by a lid. The ESA concerns for fish migration are focused on the waters around the Montlake Cut while access for traditional Tribal fishing areas is primarily to the east. The panel requested profiles for the east Montlake interchange area.

### **SR 520 Project Schedule**

The project schedule outlines the release of the final EIS in 2010 and a record of decision (ROD) in 2011. Construction is planned to start in early 2012. A four-lane floating bridge will be open to traffic in 2014, six-lanes will open in 2016 and the full corridor will be completed by 2018. It is recognized that this is a very aggressive schedule.

## **2.4. INITIAL DELIBERATIONS AND CONSIDERATIONS**

The panel considered possible tunnel options and alignments to connect the SR 520 mainline under the Montlake Cut to Pacific Street, consistent with acceptable grades and clearances. These alternative alignments were in addition to that proposed by COWI. The project team explained that the base cross-section for the northbound and southbound ramps each include two 12 feet wide lanes with a 4 feet wide shoulder on one side and 8 feet on the other, including provision for sight distance around the curves. It may be possible to use part of the interior shoulder as a walkway for maintenance and emergency access. The northbound and southbound traffic lanes are separated. It is important for the tunnel to be sufficiently deep to avoid the environmental impacts of concern to the resource agencies.

The panel agreed that the center chamber proposed by COWI was unnecessary if the tunnel is separated for each direction of traffic. Instead, emergency access could be accommodated with direct access provided between the two sections.

The panel identified three tunnel types which might be possible at the Montlake Cut:

1. Immersed tunnel (similar in principle to the COWI proposal)
2. Bored tunnel / tunnel boring machine (TBM)
3. Mined tunnel / sequential excavation method (SEM)

Each of these options would be combined with the use of cut-and-cover tunnels for the approach sections. The mined and immersed tunnel methods would use larger lengths of cut-and-cover, while the bored tunnel could minimize the length of cut-and-cover construction. The panel noted that moving the tunnel alignment to the west, near the University of Washington boathouse on the north side of the Montlake Cut, would reduce the need to go as deep since the soil quality in this area is expected to be better for tunneling. Changing the alignment could also minimize the impact to the shoreline.

It is approximately 1,100 to 1,800 feet, depending on the alignment selected, from the Montlake Boulevard / Pacific Street intersection to the bottom of the Montlake Cut. The intersection with the SR 520 mainline is below the mainline roadway. There are plans to lower the intersection at Pacific Street from its existing level which will be helpful to achieve more acceptable grades. This may be limited by the Sound Transit cross-over box.

The panel noted that roadway grades might be improved by moving the alignment south of the Sound Transit station (cross-over) area. This would also change the traffic operations at the Montlake Boulevard

and Pacific Street intersection. With the suggested realignment, a traffic circle could be incorporated to improve safety, calm traffic, and allow traffic to flow in all directions. Alternatively, a smaller traffic circle combined with a traffic signal could be used if a larger traffic circle is not feasible.

The panel discussed how each of the tunneling construction methods might meet environmental and community concerns, as well as the technical feasibility and possible grades for each. They acknowledged that there will be trade-offs for each of the methods and alignments.

### **3. ENVIRONMENTAL CONSIDERATIONS**

#### **BACKGROUND**

All major projects that WSDOT undertakes, including the SR 520 project, must comply with the requirements of the National and State Environmental Policy Acts (NEPA and SEPA). These regulations are designed to ensure that environmental impacts are considered at an early stage of the project decision-making process. In compliance with NEPA and SEPA, WSDOT published a draft environmental impact statement (DEIS) on the SR 520 Project in August 2006. The document evaluated a 6-Lane Alternative, and several design options of the 6-Lane Alternative, but it did not evaluate any alternatives or options involving a tunnel under the Montlake Cut. A supplemental draft environmental impact statement (SDEIS) is planned for publication in late 2009. That document will consider alternatives and design options identified through the SR 520 mediation process, including tunnel options. WSDOT will solicit public comment on the SDEIS, and plans to publish a Final EIS, which will include responses to comments on both the DEIS and SDEIS, in late 2010.

After the EIS process is complete, WSDOT must obtain a number of permits to build the project. These permits are issued by federal, state, and local agencies with legal responsibilities for stewardship of various environmental resources. WSDOT also must work with Native American tribes to ensure that cultural resources and treaty fishing rights are protected. Some of the key permits and approvals that WSDOT will need to obtain for SR 520 are:

- Section 404 permit under the Clean Water Act, issued by U.S. Army Corps of Engineers (regulates dredging and filling in water bodies and wetlands, and requires that the “least environmentally damaging practicable alternative” be selected)
- Section 10 permit under the Rivers and Harbors Act, issued by U.S. Army Corps of Engineers (regulates impacts to navigation)
- Section 9 permit under the Rivers and Harbors Act, issued by the U.S. Coast Guard (regulated construction of bridges or causeways in navigable waters)
- Compliance with Section 7 of the Endangered Species Act, administered by the National Marine Fisheries Service and the U.S. Fish and Wildlife Service (requires issuance of an “incidental take” permit for activities that may adversely affect listed species under ESA and compliance with other federal acts that protect marine mammals, migratory birds, and essential fish habitat)
- Compliance with Section 4(f) of the Department of Transportation Act, administered by the Federal Highway Administration, which forbids the use of park land and certain historic properties for transportation facilities unless no “feasible and prudent” alternative exists
- Compliance with Section 6(f) of the Land and Water Conservation Act, administered by the National Park Service, which requires that recreational lands purchased with certain federal funding be replaced in kind
- Compliance with Section 106 of the National Historic Preservation Act, administered by the Washington Department of Archaeology and Historic Preservation (requires protection of historic and cultural resources)

- Hydraulic Project Approval from the Washington Department of Fish and Wildlife under the Washington Hydraulic Code (regulates all work within water bodies)
- Section 401 Water Quality Certification from the Washington Department of Ecology (required to protect water quality for most projects that need a Section 404 permit)
- Shoreline permits from local jurisdictions under the Shoreline Management Act (regulate work within 200 feet of the ordinary high water mark)
- Critical areas permits from local jurisdictions under the Washington State Growth Management Act (regulate work in designated critical areas, including wetlands, streams, steep slopes, and wildlife habitat)

The text below discusses several of the key environmental considerations related to a tunnel crossing beneath the Montlake Cut. Because of the preliminary nature of the tunneling proposal, these considerations are discussed at a very conceptual level of detail, and will need to be fully addressed under NEPA, SEPA, and the other environmental regulations described above. Agencies with jurisdiction over environmental resources should also be consulted with during the design process to ensure that design is compatible with permit requirements. Table C provides a comparison of tunnel construction methods with respect to their potential environmental effects.

### **3.1. ENVIRONMENTAL ELEMENTS**

#### **Fisheries and Fish Habitat**

Lake Washington supports a number of fish species that have recreational, commercial, and/or tribal importance. These include three species listed as threatened under the Endangered Species Act (ESA): Puget Sound Chinook and steelhead salmon and bull trout. Kokanee are proposed for listing under the ESA. Other species that are considered vulnerable include chum salmon, rainbow trout, and coastal cutthroat trout.

The Montlake Cut is the migration corridor for all species of fish that migrate through the Lake Washington system and from the lake to Puget Sound, including both adult and juvenile salmonids (trout and salmon species). As such, it is designated as critical habitat for chinook salmon and bull trout. (Steelhead were listed only recently under ESA, so critical habitat for them has not yet been designated.)

Because it is a highly modified environment with limited cover, prone to routine disturbance by heavy boat traffic, the Montlake Cut is not believed to provide significant habitat for salmonid rearing, and does not contain any known spawning habitat. The less disturbed shoreline areas located toward the northeast and south corners of the cut, along with the wetland area on its southeast side, may provide some habitat for rearing and foraging.

Tribal fishing is an important use of Lake Washington, and Tribal fisheries managers work with state and federal agencies to manage fisheries resources. Under Federal treaties signed in the mid-1800s, Washington tribes are assured the right to fish at “usual and accustomed grounds and stations.” This right was affirmed by court decisions in the 1970s. The Lake Washington system, including the Montlake Cut, is a usual and accustomed fishing area for the Muckleshoot Indian Tribe and the Yakama Indian Nation.

For projects that involve construction in the water, primary fisheries considerations include protecting habitat, ensuring that migration is not disrupted, and maintaining access for tribal treaty fishing. Since the Montlake Cut area is designated as critical habitat, any in-water construction must avoid or minimize modifications to the shoreline and channel, which could reduce habitat quality still further. Construction disturbance (noise, turbidity, presence of equipment, etc.) can change migration patterns, expose fish to increased predation, and stress fish, reducing their rate of survival. State regulations provide for a migration window in the Montlake Cut of April 15 to October 1 to protect Chinook salmon and bull trout. During these time periods, in-water work activities may not take place, and other sources of disturbance, such as turbidity and underwater noise, must be kept within established thresholds. Under some circumstances, it is possible that resource agencies may agree to a smaller window that avoids the critical

period of juvenile outmigration. Table D shows salmon migration periods for ESA-listed species in the Montlake Cut.

Table C shows the potential effects of different tunnel construction methods on fish habitat, adult and juvenile fish migration, and tribal fishing access. Overall, the SEM and bored tunnel methods would reduce effects on fisheries as compared to other methods because no construction would occur within the water column. On-land, cut-and-cover methods used in conjunction with SEM or bored tunneling would still need to be designed and built to avoid impacts such as erosion into surface waters. The immersed tunnel construction technique would involve substantial amounts of work within the water, which has the potential to adversely affect populations of fish migrating into and out of Lake Washington to spawn or rear in marine waters. Even if fish migration windows were complied with and measures used to minimize turbidity and other water quality effects, there would still be potential for effects on fisheries, including listed species. The potential would also exist for construction equipment and activities to disrupt tribal fishing access. Obtaining permits from resource agencies would be more difficult for these methods than for those that do not require in-water construction. A summary of available information on the migratory timing of these species is provided below.

### Chinook Salmon

Adult Chinook salmon migrate through the Ballard Locks and into the Lake Washington basin over a broad period beginning in late June and extending through mid-October. Migrating individuals may be seen as early as June 1 and as late as November 1, but this is very rare. However, in most years the vast majority of adult Chinook, over 95 percent, will pass through the Montlake Cut between July 1 and October 1, with the peak of the run in mid-August (Fresh 2007).

Migration of juvenile Chinook salmon generally occurs throughout spring and early summer. The WRIA 8 Chinook Recovery Planning is using a migration period of April 24 to June 24 for population modeling purposes, meaning that juvenile Chinook could be present in the cut anytime within this period. However the vast majority of fish begin to appear after May 1 (King County 2005). This is consistent with studies of juvenile migration timing using PIT tags conducted by the Corps of Engineers and the City of Seattle, which found migration through the cut starting in mid-May and effectively finished by early July (Devries 2004).

For regulatory purposes, avoiding in-water activities and disturbances (e.g., turbidity and underwater noise) exceeding established thresholds during a July 1 to October 1 migration period should effectively minimize the potential exposure of adult Chinook to adverse effects (Fresh 2007). Avoiding these activities during a period from May 1 to July 1 would effectively limit the potential for juvenile Chinook exposure.

### Steelhead

The Lake Washington stock of winter-run steelhead has historically spawned in the major tributaries of Lake Washington between December and June, with the native migrant peak occurring in mid-to-late March (WDFW 2007). Hatchery steelhead occurring in the system, which typically migrate and spawn earlier than wild fish, are not included in the DPS (WDFW 2007). While spawning may last from January to as late as June in the major tributaries to the lake, adult migration is effectively over by the end of April (WDF et al. 1993).

Data on juvenile steelhead migration timing is somewhat more limited. Steelhead have a complex life history that often involves one or more years of juvenile rearing in freshwater habitats. They often display bi-directional migration behavior while rearing, moving upstream and downstream between summer and winter rearing habitats. Extended rearing and foraging in Lake Washington is possible. Given these behaviors, there is some potential for juvenile steelhead to be present in the Montlake Cut at any time of the year. However, the probability of rearing steelhead being present in large numbers for extended periods is discountable because, as discussed, conditions for rearing and foraging are poor in comparison to other available habitats in the lake and tributary streams.

The Washington Department of Fish and Wildlife has monitored smolt outmigration in major tributaries to Lake Washington, including Issaquah Creek, Bear Creek, and the Cedar River, since 1997 (Seiler et al. 2003). Screw traps are used to capture a representative sample of outmigrant juveniles of all salmonid species occurring in each system, and mark/recapture techniques were used to extrapolate the total outmigrant population. Outmigrant steelhead begin to appear in capture samples starting in mid-April and peak in May. The migration is effectively finished by mid-June (Seiler 2003).

The occurrence of juvenile steelhead in the Montlake Cut is dependent on the amount of time required to migrate from their natal streams. While this has not been studied explicitly for steelhead, the shortest Chinook migration from the same stream systems to the Ballard Locks is approximately 15 days, becoming more rapid toward the end of the migration period (Seiler et al. 2003). Assuming that migrant steelhead have the same migration speed to the locks, juvenile steelhead could begin appearing in the Montlake Cut in significant numbers in late April / early May, coincident with the beginning of the juvenile Chinook outmigrant run, and effectively be finished by the first of July.

On this basis, avoiding in-water activities and disturbance (e.g. turbidity and noise) exceeding established thresholds during the period between December 15 and April 15 should effectively limit adult steelhead exposure. Avoiding these effects between May 1 and July 1 should similarly avoid juvenile exposure.

### Coastal/Puget Sound Bull Trout

There are currently no identified migratory populations of bull trout in the Lake Washington basin (King County Department of Natural Resources 2000). A resident population of bull trout is present in the upper Cedar River watershed, and migratory bull trout are known to use Lake Washington as foraging and overwintering habitat (WDFW 2004). Hence, this species would also use the Montlake Cut as a migratory corridor (USFWS 2004). The specific timing of occurrence in the cut is not well known; however, bull trout have been observed and would be expected to frequent areas where prey species are abundant. Confirmed observations of bull trout in the migratory corridor between Lake Washington and the Ballard Locks have generally corresponded to periods during the spring when outmigrant salmon smolts are present in abundance (King County Department of Natural Resources 2000). The probability of foraging bull trout being present in the Montlake Cut for extended periods outside of the juvenile migration season is discountable because prey availability is expected to be poor due to unsuitable habitat conditions for refuge and for forage species.

### **Wetlands and Riparian Vegetation**

Wetlands are found along the shoreline of Union Bay, including an area just southeast of the Montlake Cut in East Montlake Park and much of Marsh and Foster Islands. Wetland areas provide many important functions, serving as habitat for plant and animal species and detaining and filtering stormwater runoff. As a result, dredging and/or filling in wetlands is tightly regulated by federal, state, and local agencies. Under Section 404 of the Clean Water Act, the Corps of Engineers is required to evaluate all practicable alternatives for a proposed action and determine that the one chosen is the least environmentally damaging. This means that a project might not receive a Section 404 permit if an alternative is available that results in less wetland destruction.

Riparian vegetation (that is, vegetation at the water's edge) is often associated with wetlands and provides desirable shading for fish and other aquatic species that use nearshore environments. It is also a source of large woody debris, which improves habitat for salmonids. Many of the wetlands on the fringes of Union Bay have substantial riparian vegetation. Mature vegetation can take years to decades to recolonize after construction, so even temporary impacts can result in long-term ecological effects.

As shown in Table C, the immersed tunnel and in-water or wetland cut-and-cover construction methods would affect wetlands, potentially to a significant degree. These methods would also require clearing of riparian vegetation to allow excavation in shoreline areas. The SEM and bored tunnel methods would have less potential for wetland effect, because their on-land cut-and-cover segments could be sited to

avoid or minimize wetland impacts. They would avoid removal of riparian vegetation because they would be constructed underground within the shoreline area.

Another consideration when working in or near wetlands is maintaining wetland hydrology, the flow of surface and/or groundwater that sustains wetland characteristics. The immersed tunnel, in-water and wetland cut-and-cover methods may have temporary effects on wetland hydrology, if a water-tight excavation support were not used and there was a general water-table drawdown outside the construction area. However, a water-tight excavation support system is recommended.

### **Parks and Recreation**

The south side of the Montlake Cut in the area proposed for tunneling is bordered by East Montlake and McCurdy Parks, which extend north from SR 520 to the water. East and south of these parks lie Marsh and Foster Islands, part of the Washington Park Arboretum. A waterfront trail system begins in East Montlake Park, crosses east to Marsh Island, and then crosses southeast to Foster Island. All of the parks are protected by Section 4(f) regulations, while the waterfront trail and parts of the Arboretum are also protected by Section 6(f) regulations. Both of these regulations provide very strong restrictions on the use of park lands, requiring that alternatives to such use be thoroughly studied and that (in the case of 6(f)) land used for project right-of-way be replaced with land of similar value and function in a location satisfactory to the agency with jurisdiction over the property.

All of the tunneling alternatives would require at least temporary use of land from East Montlake and McCurdy Parks and/or the Arboretum, including the waterfront trail. Depending on the alignment, the south tunnel portal location could involve permanent acquisition of right-of-way from one or more of these facilities. The constraints imposed by the 4(f) and 6(f) regulations would require WSDOT to demonstrate that the method chosen would minimize permanent effects on park lands compared to alternative methods. This analysis would need to be done within the overall context of the SR 520 corridor, since it is possible that increased effects in one location could be offset by reduced effects in another. At this point in the design process it is not possible to determine whether one tunneling method would have greater effects than another. However, minimizing the use of park land should be a key consideration as the design process moves forward.

### **Historic and Cultural Resources**

The Montlake and Arboretum areas are important in both the history and prehistory of Seattle, and contain many resources eligible for protection under Section 106 of the National Historic Preservation Act. The Montlake Cut and Montlake Bridge are both listed on the National Register of Historic Places (NRHP), as is the University of Washington's Canoe House on the north shore of the cut. The SR 520 DEIS identified the Montlake historic district, which extends both north and south of SR 520, as eligible for NRHP listing. Foster Island is a place of traditional significance to Native American Tribes that has continuing importance in their modern culture. As such, it may be eligible for the NRHP as a "traditional cultural property."

The effects of any of the tunnel options on historic and cultural resources would depend on their alignment and final design. Direct permanent impacts—for example, tunneling excavations across Foster Island outside the SR 520 right-of-way, or demolition of historic structures identified in the DEIS—should be avoided. However, siting and design must also take into account the potential for impacts that would alter the historic setting of properties protected by Section 106. For example, alterations to Lake Washington Boulevard on the south side of SR 520 could affect the setting of the historic homes along the boulevard. Further design efforts for the proposed tunnel should include consultation with the Washington State Department of Archaeology and Historic Preservation to identify ways of avoiding and/or reducing effects.

### 3.2. ENVIRONMENTAL EFFECTS

During their evaluation, the Tunnel Expert Panel considered a long list of environmental and community impacts in their assessment of the construction methods and the alignment. Daily meetings with the community representatives were held to address the specific concerns of neighborhoods and individuals. The panel also considered a list of environmental issues and concerns expressed by regulatory agencies responsible for issuing project permits. Every attempt was made to consider these issues, many of which are included in the summary evaluation table below. Table C below lists the relative impacts and potential avoidance and minimization strategies, if available.

*Table C - Comparative Environmental Effects of Tunnel Construction Methods*

<b>Potential Impact by Activity</b>	<b>Sequential Excavation Method (SEM)</b>	<b>Immersed Tunnels (including COWI)</b>	<b>BORED TUNNELS (TBM)</b>	<b>On Land Cut and Cover</b>	<b>In Wetlands Cut and Cover</b>	<b>In Water Cut and Cover</b>
Surface disruption	Approaches	Approaches	Nominal	Yes	Yes	N/A
Ground heave	Frozen ground may result in ground heave and when thawed it may settle somewhat	No	Possible	No	No	No
Ground disturbance	No	Yes	No	Yes	Yes	Yes
Dredging	No	Yes	No	N/A	Yes	Yes
Ground subsidence	Minor (2 inches max)	No	Minor (2 inches max. unless operated improperly)	No	No	No
Underwater noise	No	Yes (piling installation)	No	N/A	Likely	Yes (piling installation)
Underwater shading	Minimal (below disturbance threshold)	Yes (from construction barges)	Minimal (below disturbance threshold)	Possibly	Yes (barges)	Yes (barges)
Release of pollutants	No	If present in the disturbed substrate, but possible to control	No	If present in the disturbed soil, but possible to control	If present in the disturbed substrate, but possible to control	If present in the disturbed substrate, but possible to control
Water pH considerations	No	Yes, but localized - due to concrete use	No	No	Yes but localized - due to concrete use, but can be minimized through best management practices (BMPs)	Yes but localized - due to concrete use, but can be minimized through best management practices (BMPs)
Turbidity	No	Yes, but can be minimized through BMPs	No	N/A	Likely, but can be minimized	Yes, but can be minimized through BMPs

Potential Impact by Activity	Sequential Excavation Method (SEM)	Immersed Tunnels (including COWI)	BORED TUNNELS (TBM)	On Land Cut and Cover	In Wetlands Cut and Cover	In Water Cut and Cover
		based on performance standards			through BMPs	
Water temperature due to ground freezing	Some effect possible but can be controlled	N/A	N/A	N/A	N/A	N/A
Tribal fishing	None	Potentially; can be minimized by incorporating seasonal tribal fishing windows into construction schedule, but mitigation will be required if impacts occur	None	N/A	None	Potentially; can be minimized by incorporating seasonal tribal fishing windows into construction schedule, but mitigation will be required if impacts occur
Salmonids (adult and juvenile) and resident fish	No	Construction disturbance can change migration patterns, expose fish to increased predation, and reduce survival; avoid migration windows to minimize impacts Fish handling may be required for juvenile salmonids and resident fish	No	N/A	No	Similar to immersed tunnels
Essential Fish Habitat (EFH)	No	Yes, but with no adverse permanent effect	No	N/A	Yes, long term impacts if riparian vegetation is affected	Yes, but with no adverse permanent effect
Critical Habitat (ESA)	No	Yes, but with no adverse permanent effect	No	N/A	Yes, long term impacts if riparian vegetation is affected	Yes, but with no adverse permanent effect
Shoreline modification	No	Yes	No	N/A	Yes	Yes
Shoreline armoring	No	Yes (small coffer dam)	No	N/A	Yes (along cut)	N/A



Potential Impact by Activity	Sequential Excavation Method (SEM)	Immersed Tunnels (including COWI)	BORED TUNNELS (TBM)	On Land Cut and Cover	In Wetlands Cut and Cover	In Water Cut and Cover
	permanent impacts in on-land cut-and-cover sections	permanent impacts in on-land cut-and-cover sections	permanent impacts in on-land cut-and-cover sections	permanent impacts	permanent impacts	permanent impacts
Cultural and Historic Resources	Potential temporary and/or permanent impacts in on-land cut-and-cover sections	Potential temporary and/or permanent impacts in on-land cut-and-cover sections	Potential temporary and/or permanent impacts in on-land cut-and-cover sections	Potential temporary and/or permanent impacts	Potential temporary and/or permanent impacts	Potential temporary and/or permanent impacts

Species/Life History Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult chinook migration							Red	Red	Red	Red		
Juvenile chinook migration				Yellow	Red	Red						
Adult steelhead migration	Red	Red	Red	Yellow								
Juvenile steelhead migration				Yellow	Red	Red						
Bull trout migration <sup>a</sup>					Red	Red						

**Notes:**

Red areas restrict in-water construction operations

Yellow areas represent times when limited migration may occur



Tribal fishing seasons are not shown in this table, but need to be recognized and may restrict in-water work beyond time frames shown here.

Bull trout migration may occur outside the time period shown.

*Table D – Salmonoids Migration Timing for ESA Listed Species in Montlake Cut<sup>2</sup>*

## 4. GEOTECHNICAL CONDITIONS NEAR MONTLAKE CUT

### Background

The Montlake and University of Washington areas are primarily on land consisting of glacially deposited and overridden soils, whereas the adjacent Union Bay to the east and Portage Bay to the west have been gouged out by glacial advance and retreat, leaving deep depressions, reaching depths of over 100 feet in Union Bay, that have been subsequently filled with soft lacustrine clay and thick layers of very soft compressible peat. Peat deposits present beneath fill to the east end of Husky Stadium, at the practice field to the north of the stadium, and beneath the east end and north of MOHI, all suggest that lake levels have been higher and extended 300 to 500 feet further to the west than present day. The peats and underlying soft clays are not strong enough to support or provide confinement for tunnel structures and thus were avoided in selecting tunnel alignments.

### Ground conditions

Past construction projects in the vicinity of the cut provide useful indications of ground behavior and conditions. Excavation of the Montlake Cut was completed in 1916 primarily through layers of hard clay and till, and 2 to 30 feet thick layers of dense sand and gravel. The generally stable walls of the cut were

<sup>2</sup> Source: Devries 2004; Fresh 2007; King County 2000 and 2005; Seiler et al. 2003; WDFW 2004; WDF et al. 1993.

excavated at slopes of about 56 degrees near the center of the cut, and flatter slopes of about 33 degrees, beginning about 300 feet east of the bridge, and eastward. The approximately 90 feet wide base of the cut was excavated to el -14 (NAV 88 Datum), approximately 34 feet below Lake Washington and Lake Union water level. The Northlink sewer was excavated through hard clay, till, and sand and gravel in close proximity to the alignment of the future Montlake Bridge, approximately 10 feet below the base of the cut ca. 1910, to form a 4 feet cast-in-place reinforced concrete pipe.

### **Subsurface Data - Cautions**

The available subsurface data is derived from several borings within 500 feet of the various alignments. The available borings are of varying quality and reliability and span over 50 years. Due to the wide variety of sampling methods, the brevity of many of the classifications, and the lack of information on reference elevation datums, an accurate portrayal of the various glacial and interglacial soils is not always possible.

### **Alignment and depth considerations**

However, the available boring data does provide sufficient information to assess general ground conditions. In general the top of hard glacially overridden soils indicates the downward trend of the top of firm soil conditions to the east into Union Bay. It is likely that all alignments will be at least partially in glacial till, dense outwash sand, hard fractured glaciolacustrine clay, and glaciomarine drift. Tunnel alignments and profiles will need to be adjusted to maintain sufficient competent ground cover over the tunnels to permit safe tunnel construction and long-term stability, while providing acceptable highway grades and turn radii.

Extrapolated contours of the top of firm glacially-overridden soils below peat, soft clay and fill have been derived from over-water probe data and boring data, primarily from explorations undertaken around 1965 for the proposed, but never built, Thomson Expressway (Shannon & Wilson, 1967). The contours of the top "firm soils" indicate that the bottom of Union Bay falls off rapidly to the east, thus limiting the eastern extent of viable tunnel alignments or forcing potential eastern alignments much deeper than acceptable vertical alignment grades would allow.

All alignments require that the cut and cover approaches (or at least the bottom of the support walls) be excavated deep enough to be founded in stable "firm" glacially overridden soils. The immersed tunnel should also be founded on these stable soils or a pile foundation may be required. The tunnel options, both SEM and TBM, need to be located with a minimum of 20 feet (TBM) and 25 feet (SEM) of cover beneath the top of "firm" glacially overridden soils to provide sufficient safety, confinement, support for construction of the tunnels.

The extent and depth of the soft peat and clay may impact the acceptable locations for tunnel portals, and the suitable design and construction methods for the approach cuts, particularly on the south end near the Museum of History and Industry. Additional subsurface explorations will be required to adequately define the soil conditions specific to the selected alignments for further evaluation.

## **5. ALIGNMENT ALTERNATIVES**

After review of the project, the general site conditions, and environmental constraints, and determination of the applicable methods to consider, the panel worked to determine if one or more alignments could be found that would provide the conditions suitable for safe and reliable construction, meet or exceed the highway and safety criteria and avoid or mitigate any environmental impacts.

In addition to the construction methods and their requirements, the panel outlined a number of assumptions to consider in the evaluation of the alignment alternatives. These included:

Minimum impact on other site structures and facilities and their related activities including:

- University of Washington facilities - Husky Stadium, boathouse and Waterfront Activities Center
- Sound Transit station box, cross-over and vent structures
- Foster Island's culture and wetland areas
- Shipping activities through the channel
- Riparian and wetlands on the north and south ends
- Avoid impact on local fish and fisheries
- Nearby structures

#### Assumptions relative to the lake

- Minimize disturbance of the lake bed
- Avoid excavation of soft peat in the lake bed
- Minimize disturbance in the water column
- Channel is dredged and free of, or with insignificant depth of, soft sediments

#### Geometric assumptions and constraints:

- Each alignment is defined by the width necessary to accommodate exit and entrance ramps
- The width of alignments in plan ranges from 100 feet for the immersed tunnel and up to about 150 feet for the twin SEM tunnels and separation pillar.
- Length of tunneled section varies depending on the constraints of the method and the site conditions
- Minimum acceptable radius curve in ramp is 325 feet for 25 mph speeds
- Lane configuration widths are 8-12-12-4 feet (with 8 feet shoulder on inside curve for sight line)
- Minimum vertical clearance required is 18 feet (16'-6" standard roadway clearance plus 1'-6" for variable message signage), measured above the high-point of the road.
- Outside the short tunnel section under the cut, provision for ventilation jet-fans (approximately 3 feet in diameter) is necessary. Fans are usually located over the travel lanes, where overhead clearances are tight sometimes they are located in the upper corners of the cross-section.
- Minimum cover of "good ground" over the tunnel crown varies for each method and ranges from 6 feet (or possibly less) for the immersed tunnel to 25 feet for the SEM. This controls the grades necessary to pass under the Montlake Cut and meet the road profiles at the adjacent intersection locations.

Additional constraints may be imposed by the final traffic flow and signaling at the SR 520 mainline intersection and at the Montlake/Pacific Avenue interchange.

## 5.1. ALIGNMENTS CONSIDERED

For purposes of evaluating the range and tradeoff in geometry against length, the Expert Review Panel reviewed four alignments (A, B, C and D) within the generally preferred alignment area shown in Figure 6. Modified D and B alignments were subsequently evaluated to better achieve acceptable ramp grades.

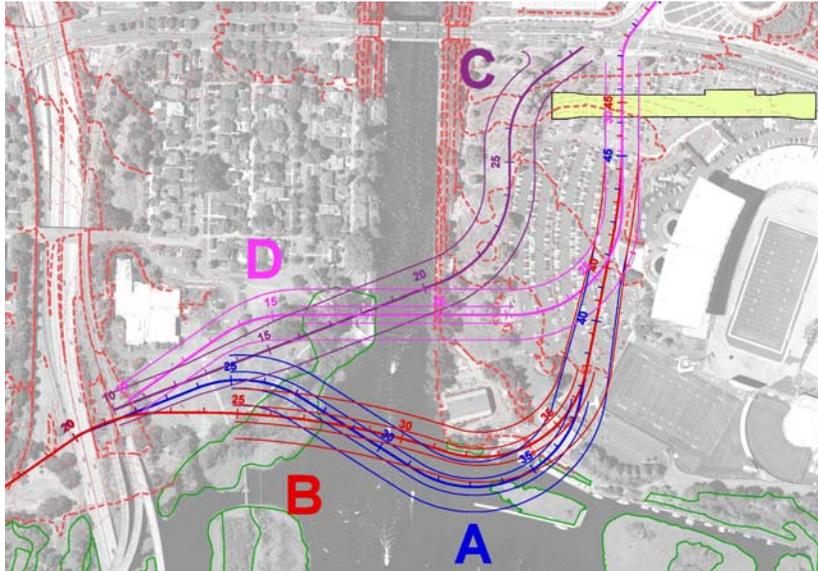
The eastern limits of these alignments are generally constrained by the rapid drop-off of the lake bottom (i.e. the top of the hard glacially over-ridden soils) accompanied by an increasing depth of very soft peat overlying those soils. To the west, the designated study area of our investigation is limited by the shortness of the ramps and increasing gradients with reduction in overall length.

Three of the alternative alignments considered - A, B and D - pass above the proposed Sound Transit station cross-over box, which is a vertical constraint resulting in grades steeper than would otherwise be necessary at the northern end of alignments.

An alignment C, passing just to the south of the Sound Transit station cross-over box and surface vent shaft was considered in order to eliminate this vertical constraint. This would also keep construction

further away from the Husky Stadium and car parking area. However, this alignment results in a grade steeper than 13-16 percent.

The most eastern alignment (A), being the longest, gives the lowest grades but has significantly higher risks associated with the unknown geology and bottom profile details (see “Subsurface Data – Cautions” in the Geotechnical Section of this report). The plan layout of the four alignments considered is shown in Figure 6 following:



*Figure 6 - Plan of tunnel alignments considered*

Alternative A is essentially the alignment used by COWI in their proposal.

Alternatives A and B are in the lake (farthest east) and swing out into Union Bay in an attempt to increase the total length in order to minimize the road grades. The total length as well as the underwater length increases as each alignment is taken further east into Union Bay. Because environmental concerns also increase as these alignments move further east into Union Bay, the shortest water crossing is preferable both environmentally and technically.

A modification to Alignment B was also examined. This alignment reduces the north road grade from 9.5 percent to 8.5 percent – see “Table E-1 – Alignment B Modified” in section 5.2.

The eastern alignments for the TBM and SEM methods are constrained by the offshore bottom profile (which has a rapid drop off) and the associated increase in the thickness of the soft peat and increasing depth of good tunneling soils (glacial clays). For the immersed tunnel method this is not a consideration (since it does not require a cover of good tunneling soil). All easternmost alignments require trade off studies in the grades, length of in-water construction impacts (immersed tunnel only) and, additional length of construction with associated cost and schedule increases.

Alignments C and D lie further west in what appears to be better ground conditions and are shorter in overall length. Alignment C, moved south to avoid the Sound Transit vent structure, marks the western limits beyond which any additional movement to the west would more seriously impact curve radii. Alignment D provides additional length of tunneling in an attempt to reduce the grades.

Alternative D is an example of an alignment within the study area that could be optimized in the next phase. A modified D alignment, located some 300 feet to the east from that shown in Figure 6, was

considered in order to improve the road grades and reduce environmental impacts – see “Alignment D modified” in the immersed tunnel section of this report.

### Considerations regarding the Alignments

Each of the four alignments was evaluated with the constraints, dimensions, and geometries required by each of the three construction methods, considering the presence of the wetlands (on both north and south shores of the cut) and the environmental requirements as noted in the environmental section of this report.

The tunnel vs. cut-and-cover length is determined by a requirement of approximately 20 feet of competent ground cover at the start and end of either the bored or SEM tunnels. Given this configuration none of the bored or SEM tunnel alignments need impact the wetlands. All alignments contain tight horizontal curves (325 feet radius) and vertical curves (which occur together). This means investigation will be required to see if it is possible to design and manufacture a special tunnel boring machine (TBM) which would be capable of successfully negotiating such tight curves without significant settlements and loss of ground.

## 5.2. METHODS, LENGTHS, GRADES AND MINIMUM SOIL COVER

The following table summarizes the alignments considered with key characteristics for the different alignments and tunneling methods. The grades shown are computed at the centerline of the alignment, that is mid-way between the inbound and outbound ramps. This means the down-grade will be slightly higher and the up-grade slightly lower than the value shown.

Alignment	A - in Lake	B -in Lake	C - across Cut	D -across Cut
<b>Length considered</b>	2000	1800	1400	1500
<b>Sequential Excavation Method (SEM)</b>				
Length of SEM	700 -1000*	700 - 950*	300 - 500*	250 - 400*
Length of Cut and Cover	1300 - 1000*	1100-850*	1100-900*	1250-1100
Road grade north %	11	9.5	16	13.5
Road grade south %	9	7	8	8.5
Cover over tunnel **	25	25	20	20
<b>Immersed Tube Method</b>				
Length of Immersed Tube	300 - 900	260 - 850	250	200 - 250
Length of Cut and Cover	1700-1100	1540-950	1150	1300 - 1250
Road grade north %	8	7	13.5	10.5
Road grade south %	7	5.5	5.5	6
Cover over tunnel ***	6	6	6	6
<b>Bored Tunnel Method</b>				
Length of Bored Tunnel	1550	1450	1050	1150
Length of Cut and Cover	450	350	350	350
Road grade north %	11	9.5	15	12.5
Road grade south %	9	7	7.5	8
Cover over tunnel **	20	20	20	20

#### Alignments & Notes:

A - swings east furthest into Lake Washington to cross the channel

B - swings east to cross the channel just east of the UW Boat House

C - crosses the Montlake Cut at an angle, alignment is south of Sound Transit Vent Shaft

D - crosses the cut at 90 degrees west of the UW Boat House

\* SEM - the longer length doesn't impact the wet lands, the shorter length does

\*\* Cover (ft) = minimum depth over the tunnel crown of stable firm glacially overridden soils

\*\*\* Cover (ft) for the immersed tunnel is for protection, not a structural requirement

*Table E – Alignment, Method, Lengths, Road Grades and Minimum Cover*

Because the grades for the above alignments are, in most cases greater than the WSDOT Design Manual maximums (see Table F following), a modification to Alignment B was examined. This alignment reduces the north road up-grade from 9.5% to 8.5%.

Length of Tunnel	500-700
Length of Cut and Cover	1300-1100
Road grade north %	8.50%
Road grade south %	7.50%
Cover over tunnel **	20

*Table E-1 – Alignment B Modified*

### 5.3. ACCEPTABLE RAMP GRADES

WSDOT Design Manual M22-01 Dated January 2005 gives the following maximum ramp grades for various design speeds. For the SR 520 ramps, with 25 to 30 mph speeds, the normal maximum grades would be 7 percent up-grade and 9 percent down-grade.

#### **(3) Grade**

The maximum grade for ramps for various design speeds is given in Figure 940-2.

Ramp Design Speed (mph)	25-30	35-40	45 and above
Desirable Grade (%)	5	4	3
Maximum Grade (%)	7	6	5
On one-way ramps down grades may be 2% greater.			

#### **Maximum Ramp Grade**

*Figure 940-2*

*Table F – WSDOT Design Manual, Maximum Grades for Ramps*

WSDOT has indicated that they would evaluate a higher up-grade for this project. If the B modified alignment, with an up-grade of 8.5 percent were possible, the tunneling options, *on this basis only*, would be:

Sequential Excavation Method (SEM)	Alignment B modified
Bored Tunnel (TBM)	Alignment B modified
Immersed Tunnel	Alignments A and B, B modified

## 6. TUNNELING METHODS CONSIDERED

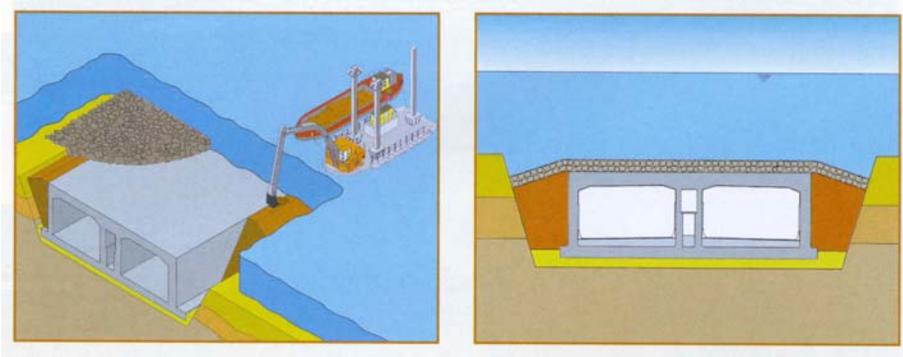
After reviewing the proposal for Alternative K, visiting the site and receiving a briefing from WSDOT describing the SR 520 Project, the ERP evaluated various means to construct the roadway under the Montlake Cut. Tunneling under the cut permits clear passage of all boats and ships and can minimize environmental impacts. Two parallel tunnels are required, one for a two-lane northbound roadway and one for a two-lane southbound roadway. When establishing the alignments, each tunnel, if mined or bored, generally requires a horizontal separation distance of at least one tunnel width between the tunnels.

The expert review panel considered a number of construction options for crossing the Montlake Cut, including jacked tunnels and cut-and-cover tunnels, however the three methods considered worthy of further study are:

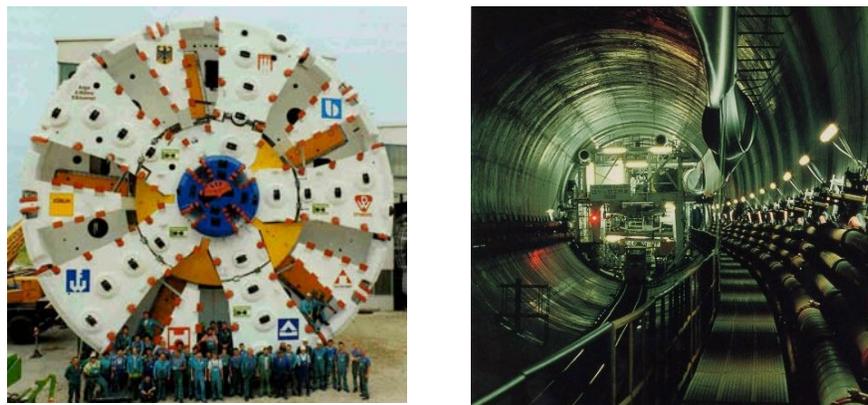
1. Immersed tube tunneling whereby a concrete or steel tube or tunnel is constructed in a dry dock and buried in an excavated trench across the shipping channel.
2. Bored tunneling, using a tunnel boring machine (TBM) to excavate the full tunnel face
3. Mined tunneling with a focus on the “sequential excavation method” (SEM)

Cut-and-cover construction will be needed in combination with all three tunnel options listed above to establish a proper and economical tunnel portal location and to connect the tunnels to the SR 520 mainline and to the Montlake Boulevard and Pacific Street intersection.

Specific details of the three tunneling methods are given in the body of this report – some typical examples and cross-sections of the methods are shown below - additional material on these methods is available in the references section (Appendix B).



*Figure 7, Immersed Tunnel Construction (General)*



*Figure 8 - Tunnel Boring Machine (Elbe River, Hamburg)*



*Figure 9 – Sequential Excavation Method (Beacon Hill Tunnel, Seattle)*

All three methods require the use of cut-and-cover sections of variable lengths. Several cut-and-cover construction methods are feasible, however, only the Immersed Tunnel methodology will require cut-and-cover activities immediately adjacent to the shoreline, including the wetlands on the south side of the cut.

The three alternatives were evaluated against a set of variables and constraints based on the site constraints, potential environmental impacts, highway configurations, and safety issues - as well as community issues and concerns. The study area that provided the connections and satisfied the boundary conditions defined by the various categories of issues is shown in Figure 6. As noted previously, this area was bounded to the east by the drop off of good tunneling soil in the lake and to the west by alignment restraints.

## Discussion

The following tables are relevant to this discussion:

1. Table C details the potential effects and impacts for tunneling and cut-and-cover construction on environmental and other considerations. Mitigation possibilities are indicated
2. Table D summarizes windows for in-water work in and adjacent to the Montlake Cut
3. Table E summarizes, for alignments A, B, C and D, the tunneling methods, lengths of tunnel and cut-and-cover, minimum cover over the tunnels and, road grades north and south of the Montlake Cut
4. Table E-1 shows the above data for Alignment B modified
5. Table F shows the WSDOT Design Manual normally acceptable road grades for low-speed ramps

Recent tunneling projects for Sound Transit tunnels and stations and the Brightwater Sewer project are being built using all of the methods discussed here with the exception of the immersed tube tunneling method. Each of these methods are deemed possible and feasible, however there are tradeoffs - each has advantages and disadvantages for the site conditions, constraints, design requirements and surface impacts.

Each construction method has a different width for the twin parallel tunnels plus the separation pillar in the middle. In the case of the immersed tube and cut and cover portions, the separation pillar is relatively narrow, and consists of reinforced concrete. In the mined and bored tunnels, the separation pillar of soil between parallel tunnels is generally equivalent to at least one tunnel width or diameter, but can be reduced in the approaches to the portals. The width of the twin tunnel ramp is an important geometric constraint in the evaluation of the alignment alternatives against each method.

For the mined tunneling method, cut and cover sections would extend as close as possible to the banks of the Montlake Cut (but outside the designated wetlands) with the mined tunnel extending from the wall of the cut-and-cover or portal under the cut and into the north side cut-and-cover section. This means a longer length of cut-and-cover is associated with this method compared to the bored tunnel alternative where a longer tunnel length is used, and the cut-and-length cover minimized, to take full advantage of the high cost of purchasing a tunnel boring machine.

Generally the minimum cover of good tunneling soil over the tunnel is one tunnel diameter. Exceptions can be made for short lengths in good ground or with ground stabilization. For this report, the ERP adopted a cover of at least 20 feet for the bored tunnel at the portals and under the channel. With the SEM, a cover of 20 to 25 feet is required (see following). This cover requirement adds significantly to the challenge of finding a vertical alignment with acceptable grades for the SEM and bored tunnel method.

The mined tunneling method provides the greatest flexibility to change dimensions and ground conditions, but at the price of more complex, costly and time consuming pre-construction ground stabilization, such as freezing, and added quality control measures to properly manage risks.

## 7. SPECIFICS OF EACH CONSTRUCTION METHOD

### 7.1. SEQUENTIAL EXCAVATION METHOD (SEM) TUNNELING

#### General

Use of the sequential excavation method (SEM) is believed possible under the Montlake Cut, for alignments B modified, C, D and D modified provided that there is at least 20 feet of firm glacially consolidated soils above the tunnel crown. Past exploration programs and experience from construction of the Montlake Cut indicate that, subject to confirmation by new geotechnical exploration, tunneling in this location will be in firm, glacially overridden soils – and not underneath the soft lacustrine clays and compressible peats that blanket the bottom of Union Bay.

Using the SEM, two unidirectional tunnels will be constructed to accommodate two-lane traffic in each direction. Tunneling will involve ground freezing for ground improvement implemented prior to the start of tunnel construction. The SEM tunnel bores will be constructed from cut-and-cover boxes adjoining the SEM tunnel sections. Depending on the alignment chosen, the tunnel lengths are anticipated to be between 250 and 1000 feet for each bore.

#### The Sequential Excavation Method (SEM)

The sequential excavation method (SEM) has been used on a large number of urban transit projects nationally and internationally. The SEM has recently been applied at Sound Transit's underground Beacon Hill Station project for the development of the station, concourse, and a variety of other connection and service tunnels.

The SEM offers flexibility in geometry such that it can accommodate almost any size and shape of opening. The regular cross section generally involves an ovoid shape to promote smooth stress redistribution in the ground around the newly created opening. By adjusting the construction sequence expressed mainly in drift size and round length, timing of support installation and type of support, it allows for tunneling through a wide range of ground conditions. A key support element is shotcrete (pneumatically applied quick-setting concrete), mainly due to its capability to provide an early, interlocking, continuous support to the ground. Implementation of ground improvement measures in the form of dewatering, grouting, ground freezing and of pre-support measures in the various forms of spiling<sup>3</sup> and grouted pipe arches have further widened the range of SEM applications mainly in urban and soft ground tunneling. The SEM tunneling process addresses:

- Ground and excavation and support classification based on a thorough ground investigation
- Definition of excavation and support by:
  - Round length (maximum unsupported excavation length)
  - Support measures (shotcrete lining and ground reinforcement)
  - Subdivision of heading into multiple drifts (top heading, bench, invert, side wall drifts)

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<sup>3</sup> A ground improvement measure carried out by inserting bars, rods or tubes at the face so as to form a splayed arch ahead of the tunnel (ITA Glossary)

- Ring closure requirements
- Timing of support installation (typically every round)
- Pre-support by spiling and fore-poling<sup>3</sup>
- Instrumentation and monitoring
- Ground improvement measures applied prior to tunneling.

The SEM has been utilized in challenging ground and under difficult built-over conditions. One example is the recently completed transit tunnel at Russia Wharf in Boston, MA where ground freezing was used to temporarily support a building while tunneling underneath. Ground freezing has also been utilized in combination with the SEM for the crossing of rivers. Examples include the Limat River crossing in Zurich, Switzerland and the River Main in Frankfurt, Germany. Ground freezing has the possibility of slightly lowering the temperature of the water in the Montlake Cut, but this effect can be controlled and it is not expected to alter water temperatures outside the normal seasonal range.

### **Extent of Tunneling and Alignment**

SEM tunneling would be suitable for tunneling under the Montlake Cut as shown in Alignments B modified, C and D and D modified - mainly to minimize the efforts needed for implementation of ground improvement by ground freezing. For these alignments tunneling lengths would be between 250 and 700 feet. Should favorable tunneling conditions be confirmed for alignments A and B, then the SEM tunnels could be as long as 1,000 feet.

It is anticipated that the clear distance required between the two tunnel bores will be between ½ to 1 tunnel diameter (25 and 50 feet respectively). Therefore, the adjoining cut-and-cover sections will be laid out such as to accommodate a total width of up to 150 feet.

From the SEM tunneling point of view, the vertical tunnel alignment is dictated by the need to achieve a sufficient cover of firm ground above the tunnel. This ground cover must also allow for implementation of the ground improvement measures by ground freezing. It is anticipated that an approximately 6 feet thick soil section around the tunnel circumference will be frozen. For the purpose of this assessment and based on the available information on ground conditions, a cover of between 20 to 25 feet above the tunnel crown was assumed. The cover is assumed possibly less for alignments C and D than for A and B due to the anticipated ground conditions (which are better known within the Montlake Cut). This cover will be sufficient to implement all ground improvement measures without the need to disrupt the Montlake Cut bed or lake bottom. While it will be desired not to impact the wetlands located near the cut and the Union Bay shore lines, the final decision on the exact interface locations between the mined and cut-and-cover tunnels can be made after a detailed assessment of tunneling conditions, wetland and surface impacts, and construction cost and construction schedule.

All operations necessary for SEM tunnel construction will be accomplished from the adjoining cut-and-cover sections and no surface activities above the tunnels will be required.

### **Comments on alignment, SEM Tunnel Method**

For the SEM alignments the tunnel length has been kept as short as possible without impacting the Montlake Cut. Options which may impact the wetlands (but not the cut) have also been considered. Cut-and-cover construction is used from the end of the SEM tunnels until the tunnel “daylights” at the portals.

Alignment A provides the longest length of SEM tunnel and on the tightest curve. The drawback with this alignment is that the freezing operation becomes more difficult due to increased risk of misalignment of the freeze pipes. If the pipes are misaligned then there is a possibility of a “window” or un-frozen area in the otherwise frozen ground. One way to reduce this risk would be to tunnel (say) one third of the way and then conduct a second freezing operation, however, this would significantly increase the schedule duration. The length of the SEM for this alignment is approximately 1000 feet however if 200 feet of wetland could be impacted on the south side and approximately 20 feet on the north side then the SEM length can be reduced to 750 feet.



Alternatively to the typical tunnel cross section shown in Figure 10, a binocular arrangement could be considered. A binocular configuration would implement each lane and shoulder/sight width in a smaller tunnel tube. These smaller tunnel tubes would be joined by a middle tunnel wall. Binocular tunnel sections are employed to reduce the overall tunnel height. With a binocular tunnel arrangement the tunnel roadway alignment could be situated somewhat higher compared to the single bore SEM tunnel cross section. The

binocular tunnel would allow the tunnel linings to be designed more efficiently, however at a cost of greater construction complexity. Construction staging would call for the construction of the final lining in the first tunnel section prior to constructing the adjacent tunnel section of the binocular tunnel.

### **SEM Tunnel Construction**

SEM tunnel excavation would only start after the establishment of the frozen ground around the future tunnel envelope and application of any additional ground improvement measures, which may be required within the frozen ground envelope. Additional ground improvement measures may include local dewatering and grouting of permeable lenses and layers that contain silt and fine sands.

The tunnel heading would breakout from the cut-and-cover portal walls constructed by slurry wall techniques. The overall tunnel cross section would be subdivided into multiple headings to positively control the individual excavation faces. Subdivision of the cross section and tunnel excavation and support would be by either:

- Excavation of two separate sidewall drifts followed by the excavation of a middle drift
- Excavation of the cross section in two larger, but adjoining sidewall drifts

A final decision on the use of either excavation method would generally be based on considerations that involve the design and extent of the frozen ground, management of ground deformation, construction staging, schedule, and level of risk management. Figure 11 shows a typical excavation using two separate sidewall drifts followed by a middle drift. The overall tunnel diameter is about 40+ feet. Figure 12 shows excavation and support in two adjoining sidewall drifts of an about 30+ feet wide tunnel. Both excavations were carried out at the Beacon Hill Station project.



*Figure 11 - Excavation and Support by two Separate Sidewall Drifts followed by a Middle Drift.*



*Figure 12 - SEM Excavation and Support by Two Adjoining Sidewall Drifts*

The individual drifts are excavated and supported sequentially as follows:

- Each drift is subdivided into distinct top heading, bench, and invert excavations
- The excavations are carried out in excavation rounds of typically not more than 3 to 4 feet lengths in the top heading and 6 to 8 feet in the bench/invert
- Following excavation of each round, a flashcrete layer of a 2-inch minimum is applied to immediately seal the exposed ground in tunnel walls and tunnel face. In frozen ground shotcrete applications typically a 2 to 3 inch thick sacrificial layer is added to serve as insulation and allow for adequate hydration and strength development of the structural shotcrete lining
- The structural shotcrete initial lining is completed to full design thickness (15-inch minimum)

The shotcrete initial lining is reinforced by lattice girders and steel fibers or welded wire fabric. Prior to excavation, a probe drilling program is applied to investigate the ground conditions ahead the tunnel face. If lenses or bands of permeable ground are encountered, dewatering and/or grouting measures are applied to systematically improve such soils prior to excavation. Probe drilling involves about 40 to 60 feet long exploration holes applied in each drift. Typically some 6 to 8 drills would be applied per drift with a higher probe hole concentration in the top heading. Probe drilling is carried out about every 20 to 40 feet to allow an overlap of 20 feet between probe holes.

Figure 13 shows the three-lane Fort Canning highway tunnel in Singapore after excavation and installation of the shotcrete initial lining. The SEM was used to construct the tunnel at a length of about 520 feet and a width of about 50 feet under very shallow overburden ranging from about 10 to 30 feet. In both size and length the tunnel is very similar to the proposed SEM tunnel option for the SR 520 Project



*Figure 13 – SEM, Shotcrete Initial Lining Completed in a 3-Lane Highway Tunnel*

The tunnel excavation in soft ground conditions is generally carried out by backhoes. Backhoe excavation would generally be used for the majority of the excavation, supplemented by boom cutting tools (similar to road headers) mounted on backhoes to excavate the frozen ground along the tunnel circumference. Shotcrete would generally be applied using robotic equipment.

Upon completion of the shotcrete initial lining the tunnel waterproofing would be placed, followed by installation of the cast-in-place reinforced concrete lining completing the tunnel structure.

#### **Ground Improvement Measures for SEM**

The alignment must situate the tunnel in the firm, glacially overridden soils that consist of very stiff, silty clays and clayey silts. The clays contain lenses and layers of silt and fine sand. To effectively improve the strength characteristics of the anticipated soil conditions and achieve a reliable ground water cut-off, ground freezing has been selected over other methods such as jet grouting. At this stage of the study we have assumed that ground freezing may be accomplished using nearly horizontally installed freeze pipes around the entire tunnel perimeter creating a frozen ring of about 6 feet thickness. Brine will be used as coolant circulated in freeze pipes which will be supplied from freeze plants located at the tunnel portals.

The freeze pipes will be installed in directionally drilled holes of some 8 to 10 inches in diameter and spaced at about 4 feet center to center distances. The installation of freeze pipes will be from the adjoining cut-and-cover box portal walls and for the entire length of the tunnel for Alignment C and D. For longer tunnel sections in Alignments A and B it will be desired to also install all freeze pipes from the portal walls but due to the curvature of the tunnel and limits of directional drilling it may be required that sections of freeze pipes may have to be installed from within the tunnel in a staged operation. All pipe casings installed to house the freeze pipes will be surveyed for accuracy of their location. Drilling methods and equipment must be selected to suit the ground conditions and if necessary, to cope with boulders if present.

A review of ground characteristics shows that the permeability of the soils is low (to be verified), creating ground water flows that will generally not have an effect on the build up of the frozen soil mass. Due to the source of the ground water, salinity which negatively affects the freezing process is not of concern. A review of case histories with similar ground and ground water conditions shows that such soils can be

efficiently frozen to create competently frozen ground zones that provide stand-up time and ground water cut-off for SEM tunneling. Freezing of hard clays potentially damages their soil structure that in turn causes consolidation settlements upon thawing. Based on the selected alignments that place the tunnels mainly under the Montlake Cut, no negative impact as a result of the settlements caused by the thaw process is anticipated.

The success of ground freezing and closure of the frozen soil mass is assessed and verified by systematically installed temperature measurement pipes. While ground freezing will create the required ground water cut-off around the tunnel envelope limited ground improvement measures will be applied prior to tunneling within the tunnel cross section to drain and as needed consolidate existing sand and silty lenses and bands by grouting. Depending on the materials, cementitious or chemical grouts may be used. The existence of lenses and bands of water saturated materials will be detected by the systematic probe drilling that will be part of the ground exploration during SEM tunneling as described above. If water saturated materials are encountered during probe drilling, additional probe drills are installed to detect their extent and to estimate the need for dewatering and ground improvement measures.

### Relevant Case Histories

Two case histories have been selected that are directly relevant to the proposed SEM tunneling approach with ground freezing. These involve tunneling under very shallow cover under rivers in generally difficult ground conditions and are as shown in Tables G and H below. In particular, the ground freezing carried out in Frankfurt for the crossing of the Main River is of interest as it involved freezing of interbedded clays with sand and silt lenses.

<b>Metro Frankfurt - River Main Crossing, Contract Section 81</b>	
Location:	Frankfurt am Main, Germany
Nature of Work:	Twin metro tunnels under the Main river
Construction Period:	<ul style="list-style-type: none"> <li>• 1976 to 1981</li> <li>• Start of the freezing operation began on 12 Apr 1977 and the first tunnel hole through occurred on 10 May 1978</li> </ul>
Project Details:	
Tunnel Cross Section:	• 2 x 38.5 m <sup>2</sup> (Diameter: 7 m)
Tunnel Length:	• 2 x 193 m, entire length of frozen ground of 154 m under the river
Geotechnical Conditions:	• Frankfurt clay with limestone banks with sand and silt lenses
Tunneling Under:	• River bed (river Main)
Depth of Cover:	• 6.0 - 9.5m
Freezing:	<ul style="list-style-type: none"> <li>• Brine with a freezing plant with two stages with 200,000 to 400,000 kcal/h</li> <li>• Maximum brine output 25,000 l CaCl<sub>2</sub> / hour</li> <li>• Lengths of freezing stages 32 to 43 m with 14 to 18 freezing pipes installed using a horizontal drilling system</li> </ul>
Method:	• Tunneling by shotcrete support method (SEM)

*Table G - River Main Crossing, Frankfurt, Germany*

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**Limat Crossing, Zurich, Switzerland, Contract Section 2.04**


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Location:	Zürich, Switzerland
Nature of Work:	Double track railroad tunnel under the Limat river
Construction Period:	<ul style="list-style-type: none"> <li>• 1987</li> </ul>
Project Details:	
Tunnel Cross Section:	<ul style="list-style-type: none"> <li>• 13.50 x 10.50 m</li> </ul>
Tunnel Length:	<ul style="list-style-type: none"> <li>• Approximately 80 m</li> </ul>
Geotechnical Conditions:	<ul style="list-style-type: none"> <li>• River deposit gravels, lake deposits, glacial till</li> </ul>
Tunneling Under:	<ul style="list-style-type: none"> <li>• Limat River</li> </ul>
Depth of Cover:	<ul style="list-style-type: none"> <li>• 2.5 to 3.5 m</li> </ul>
Freezing:	<ul style="list-style-type: none"> <li>• Horizontal freezing pipes, brine freezing plant with 200,000 to 430,000 kcal/h</li> <li>• Insulation at the river bed</li> </ul>
Method:	<ul style="list-style-type: none"> <li>• SEM by road header</li> </ul>

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*Table H - River Limat Crossing, Zurich, Switzerland*

### **SEM Risk Management**

The tunnel design and construction will need to employ, thorough risk management, tools to assure high quality implementation of ground freezing and SEM tunneling. The following is a list of risk management aspects associated with SEM tunneling:

- The ground freezing at this stage of assessment is laid out conservatively in that it allows for a closed ring around the entire circumference. The need of freezing in the invert section and required frozen soil thickness will further be assessed during a detailed design that uses solid information on ground conditions and properties.
- Prior to, and during tunnel construction, systematic probing ahead of the face will be implemented to detect tunneling conditions and employ ground improvement measures.
- The extent and closure of the frozen soil will be assessed by temperature measurements prior to and during tunneling.
- The performance of the frozen soil is not sensitive to temporary loss of power supply to the freeze plant as thawing involves a long-term process.
- The SEM excavation and support will be controlled by tunneling in limited size drifts and short excavation rounds.
- Tunneling performance will be evaluated by a thorough instrumentation and monitoring program for tunnel deformations and shotcrete initial lining stresses.
- SEM tunneling and ground freezing must be carried out by qualified personnel with a long and proven history of applying such construction methods.

## 7.2. BORED TUNNELING WITH A TUNNEL BORING MACHINE (TBM)

### Methodology

A bored tunnel uses a full face tunnel boring machine (TBM) to excavate mixed ground conditions and counter-balance ground and groundwater pressures expected along the alignment. Advances in the TBM industry have expanded the range of geologic and groundwater conditions in which a tunnel can be constructed, with each TBM specified and built specifically to meet the site conditions, geology, groundwater and the alignment geometry. The bored tunnel is circular with a necessary diameter of about 46 feet to accommodate the road width required – see Figure 17. Figure 14 shows an example of twin bored

road tunnels with wide separation (the intervening pillar area) and connecting cross passage. This size tunnel puts the TBM that would be required for the Montlake Cut tunnel into a category which includes the largest TBMs in use worldwide<sup>4</sup>.



*Figure 14 – Madrid M30 Tunnel Cross-Section & TBM Machine*

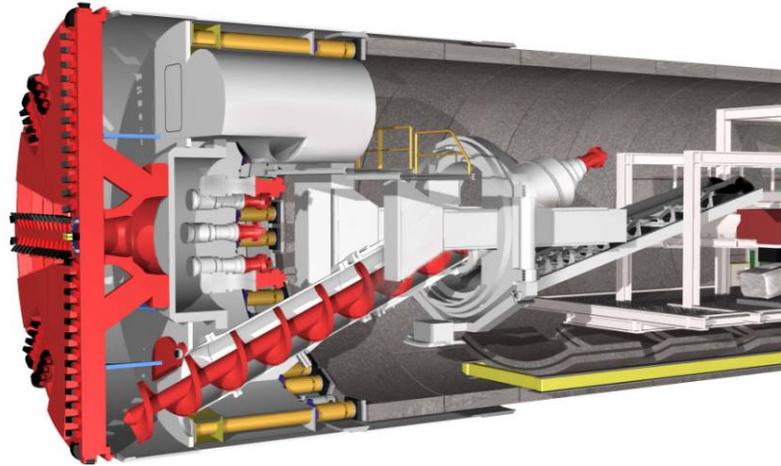
Tunnel boring machines are primarily employed for high production and allow for the possibility to mine and line the tunnel in one operation. Because of the significant investment in both time and cost to assemble the plant and equipment they are mainly used for long tunnel drives. While very short drives, on the order of several thousand feet have been mined with a TBM, they are usually smaller diameter bores where a used machine is employed and the setup and refurbishment time is relatively short (less than 6 months).

Very large diameter machines, on the order of 46 feet, as would be required here, are specifically designed for the project requirements, especially when the very tight turning radius is considered (325 feet for 25 mph alignment in this application). A new machine would usually take 12 months to manufacture and cost around \$50 to \$60 million. If an appropriate used machine were available at time of bid (unlikely), it would normally take 6 to 9 months to rebuild the machine to suit the specific conditions. However, modifications necessary to achieve the tight turning radius would be extensive and would most likely eliminate any potential advantage in cost savings and time over a new TBM. For reference, the 50 foot diameter TBM used to construct the 12,000 feet long M30 highway tunnel in Madrid is shown in Figure 14.

<sup>4</sup> A 46 ft. diameter TBM created the tunnel under the Elbe River in Germany and then worked on a ring-road tunnel in Moscow; a 50 ft. diameter TBM mined a 2-track high-speed rail line in the Netherlands, the Madrid M-30 road tunnel is a 50 ft. diameter TBM and two 50 ft. diameter TBMs have recently completed a road project in China.

Ground conditions are generally favorable for the use of an earth pressure balance (EPB) type TBM. As illustrated in Figure 15, the machine is essentially a submarine where the outside water and earth pressures are isolated and maintained by a closed tunneling system. This system is comprised of the TBM and a water-tight tunnel lining. The TBM is designed to excavate the ground in front of the machine in a controlled manner such that the amount of soil extracted into the tunnel equals the volume of material excavated.

To accomplish this, water, foams and other additives are injected to condition the excavated material in order to reduce friction or adhesion, allowing for a uniform pressure drop along the length of the auger that transports the material from behind the TBM cutterhead into the tunnel opening for disposal. The TBM is steered and advanced by hydraulic rams pushing off the tunnel lining which is installed within the TBM tail shield after every shove of the machine.



*Figure 15 – Earth Pressure Tunnel Boring Machine*

The tight turn radius required, 325 feet, and steep decline followed by an incline to pass under the channel will require a special TBM and segment design. Furthermore, if ground conditions are not as favorable as expected (i.e., very stiff clay), ground improvement will most likely be required in order to maintain line and grade. (Note: one major TBM manufacturer considers this turn radius to be impractical while another indicates it is possible, but would be difficult to accomplish).

Tunnel linings are typically comprised of precast concrete segments used to build a complete ring. For a large tunnel on the order of 46 feet diameter, the ring would be comprised of 8 to 10 pieces. Each piece would be about 2 feet thick, 4 to 5 feet long, and cover 36 to 45 degrees of arc; however, a thicker liner could be necessary to counteract buoyancy. Segments are aligned and held in place with dowels and/or bolts, and the perimeter is fitted with a gasket to form a water tight seal. Examples of transporting precast concrete segments within the completed tunnel and the installation of a segment within the TBM tail shield are shown in Figure 16.

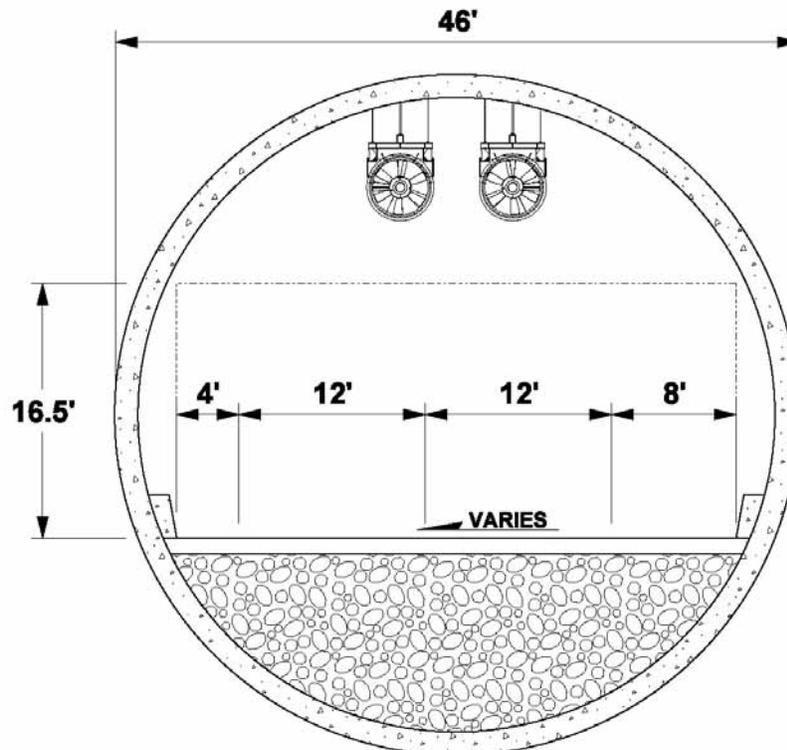


*Figure 16 - Transporting & Installing Precast Segments*

### Configuration and Construction Sequence

As indicated in the various alignment plan and profiles, the tunnel drive lengths utilize the TBM to the maximum extent possible to eliminate the deepest, most expensive part of the cut and cover reaches. Placement of a temporary fill above the tunnel to increase ground cover near the portal for TBM startup and operation can be used to farther extend the tunnel drive lengths as long as the fill does not impact the wetlands.

As previously indicated, the excavated diameter of the tunnel would be on the order of 46 feet to accommodate the two lanes of traffic, shoulders with appropriate site line and an emergency sidewalk for access to the cross passages. An approximate tunnel section is shown in Figure 17.



*Figure 17 – Tunnel Boring Machine Cross-Section*

Typically, the two parallel tunnel bores are separated by one tunnel diameter (about 46 feet); however, it is possible to reduce this separation, closer to one radius, especially near the portals to improve roadway configuration and to reduce the width of the intersecting cut and cover reach. Interconnecting cross passages linking the two tunnels are required for emergency exit and are typically spaced every 600 feet. The construction method for the cross passage configuration would be SEM, most likely with ground freezing. The tunnel-cross passage configuration for the M30 highway tunnel in Madrid is illustrated in Figure 14.

As previously described, the tunnel grade for the various alternative alignments is to a large extent defined by the distance between the top of the excavated tunnel and the bottom of the channel. Given our limited knowledge of the ground conditions, a glacial till comprised of both stiff clay and outwash sand is assumed and a minimum cover of 20 feet is prudent. However, if the ground conditions are found to be more favorable (relatively uniform, stiff clay), less cover could be used provided measures to counteract the effect of buoyancy are employed (such as heavier or thicker tunnel segments or backfilling of the tunnel invert, or bottom area, for weight as excavation proceeds).

TBM drives with minimal cover under lakes or rivers are not unusual as illustrated by the St. Clair Railroad Tunnel which was driven beneath the 2,100 feet wide St. Clair River channel located between Michigan and Ontario. This 31 feet diameter EPBM excavated stiff glacial till, similar to that expected here, when boring within 10 to 13 feet of the river bottom, of which some portion nearest the channel was river bed alluvium, not till (as we have in the SR 520 Project). Other examples are the 40 feet diameter Port of Miami Tunnel which is designed with a minimum of 17 feet cover between the channel and tunnel crown, and the yet to be constructed 21 feet diameter Sound Transit tunnels located within 10 feet of the channel bottom.

As for the construction sequence, all work will take place within the designated construction area south of the channel. After construction of the cut-and-cover box leading to the south tunnel portal, the TBM is assembled within the box and the first of the two bores is driven to a retrieval pit which is part of the open cut within the University parking lot. The backup equipment is detached from the TBM and pulled through the completed tunnel to the starting location while the TBM itself is disassembled for transport by truck or barge to the south portal where it is reassembled for the second drive. After the second drive is completed, the machine is disassembled and removed. Finally, any required cross passages are constructed (it is likely that only one or two will be needed depending on the alignment selected).

### **Environmental Impacts (effects, impact avoidance and minimization)**

Because all work is underground, there is no direct impact to the surface environment within or near the channel. Every effort would be made to tunnel under the wetlands to avoid impacting sensitive areas near the channel.

Some ground settlement as a result of tunneling is likely. Depending on ground conditions, the potential for significant settlements is greatest where the TBM must negotiate sharp horizontal (325 feet radius) and vertical curves turns requiring an overcut of several inches to facilitate the maneuver. However the tunnel does not cross under any sensitive structures and the channel itself would not likely be impacted.

Tunneling with an EPB type TBM prevents groundwater inflow into the tunnel. Accordingly, the ground surrounding the tunnels is not dewatered and potential settlements or disturbance to wetland hydrology related to dewatering should not occur. If, however, the machine is operated improperly such that earth and groundwater pressure balance are not achieved, some flow of ground and/or groundwater could occur. In a worst case, a sink hole to the ground surface or channel bottom could develop and there would be a direct connection to the surface, but the amount of water ingested would be limited and controlled through the use of positive discharge pumps installed on the TBM auger.

Supply of precast segments and removal of the excavated tunnel soil is from the south portal work area. Due to the wet nature of the excavated and conditioned soil, all trucks used to remove the material from the site should be lined to avoid leakage onto the roadways. The tunnel work is typically carried out over a 5 day work week with maintenance on Saturday. Ventilation fans would use silencers to reduce noise impacts and trucking to and from the work site would most likely be limited to specific hours, however any restrictions on truck traffic will necessitate stockpiling of materials and tunnel muck on-site. Sound walls may be needed to limit noise impacts to the neighborhood immediately west of the south portal construction site.

### **Comment on schedule and progress**

Typically, the startup process is relatively slow as the newly assembled TBM is being broken in and the crews become familiar with the machine (the learning curve). Because of the relatively short drive lengths and the complex alignment with both horizontal and vertical curves, relatively slow progress is to be expected. On average, each heading is likely to require 5 to 6 months not including time for TBM setup and disassembly. The length of drive is not a major factor in the construction duration as the learning curve controls production on both headings.

## **Alignment considerations**

For the various alternatives considered, the tunnel grade is largely controlled by the cover under the channel, a minimum of 20 feet. Tunnel portal locations are determined by the minimum ground cover above the tunnel needed for stable ground arch formation and initiation of earth pressure balance, and to resist uplift from buoyancy – this means a cover of about one radius or 20 feet. When evaluating the possible portal locations at either end, the use of a temporary fill, up to 10 feet above the existing ground surface, could be considered as a part of final design to maximize the tunnel drive lengths and minimize the deepest part of the cut and cover reach.

### Alignment A

This alternative results in the longest tunnel drives, approximately 1550 feet, however, it also has the greatest geotechnical risk of all alternatives due to the relatively long drive under the lake where ground conditions are poorly defined. The southern portal, where the TBM is assembled and the drive starts, are well removed from the wetlands, located approximately between Stations 22+00 and 25+00, at a convenient location for good access. Northern portals, where the TBM is retrieved, are around Stations 38+00 to 40+00.

### Alignment B

Alignment B is slightly shorter than Alignment A, about 1450 feet. Again, the southern portal is well removed from the wetlands, located between approximate Stations 22+00 and 25+00, at a convenient location for good access. Northern portals are around Stations 37+00 to 39+00.

### Alignment B modified

Alignment B modified moves the tunnel slightly to the east near the transition from the Montlake Cut to Union Bay, in order to lengthen the road from the Montlake Boulevard and Pacific Street intersection so as to reduce the grade as much as possible while still keeping the tunnel in good tunneling materials.

### Alignment C

Alignment C was designed to traverse south of the University stadium parking lot and light rail vent structure and to avoid passing over the Sound Transit cross-over box. The tunnel drive lengths are relatively short, approximately 1050 feet, and the north ramp grades are high, around 15 percent. The southern portal is well removed from the wetlands, located between Stations 12+00 and 15+00, at a convenient location for good access. Northern portals are between Stations 23+00 and 26+00.

### Alignment D

Alignment D is a slight improvement over C, but the short drive length, 1150 feet, also results in high ramp grades. The southern portal is well removed from the wetlands, located between Stations 12+00 and 15+00, at a convenient location for good access. Northern portals are around Stations 24+00 to 26+00 after which the ramps pass over the Sound Transit cross-over box. This alignment, which crosses the cut near the mouth of the channel, has the advantage of a short length under the waterway where excavation for the channel has likely removed the soft sediments. In terms of ground conditions, Alignment D is considered more favorable than Alignment A which traverses below the lake bed.

## **Advantages and disadvantages, Tunnel Boring Machine**

Advantages include relatively high degree of safety against flooding and ground collapse, as the TBM isolates the ground and groundwater from the tunnel proper. Contractors are becoming increasingly familiar with the use of EPB type TBMs in North America but, however, not in this size range (this would be largest North American EPBM employed to date). The ability to excavate and install water tight, precast concrete segments as the final tunnel lining in one pass is another advantage of this method.

The major disadvantage of this method is the high initial capital expenditure for the TBM and the long lead time to manufacture, ship, assemble and test the machine, plus the normal inefficiency related to the learning curve on startup. Another disadvantage is the very large circular tunnel section required to accommodate the traffic lanes, shoulders and sightline, which for vehicular tunnels is not a very efficient

use of space. This also leads to buoyancy issues and the required mitigation when minimum cover under the channel is employed. Also, there is a potential for the loss of line and grade given the very tight turn radius required and steep decline followed by incline to pass under the channel.

Competition of TBM manufacturers will be limited as some have not, and most likely will not, produce a machine with this capability. If the machine is improperly operated, formation of a sink hole into the channel is possible. North American tunneling contractors do not have experience with EPB type TBMs of this size or with this tight turn radius, and accordingly, some type of joint venture with international contractors would be essential, again limiting competition.

In general, this construction method is not considered to be appropriate for tunnels of this size with this very short drive length - less than 1600 feet.

#### Advantages:

1. The ability to excavate and install water tight, precast concrete segments as the final tunnel lining
2. Does not disrupt the cut or disturb boating or ship traffic, fish or fisheries
3. A relatively high degree of safety against flooding and ground collapse, as the TBM isolates the ground and groundwater from the tunnel proper
4. Long tunnel drives typically achieve significant advances rates including installation of the final liner (not applicable here)
5. Contractors are becoming increasingly familiar with the use of EPB type TBMs in North America, but not in this size range (would be largest North American EPBM employed to date) or with this tight turn radius, and accordingly, some type of joint venture with international contractors would be essential
6. Bored tunnels have the lowest impact on the surface, including the impact on the southern wetlands; however, attention must be paid to proper machine operation to limit the surface settlement

#### Disadvantages:

1. A minimum width required for the parallel tunnels is approximately 100 to 150 feet (closer spacing near the portals) and requires a cut and cover section of slightly larger dimension at the portal locations to allow for clearance inside slurry or secant walls.
2. To reduce grade, the longer alignment is best suited for the TBM; however, the trade off is a high cost and longer schedule, and longer reach of higher risk tunneling under Union Bay's western shore where investigation of the lake bottom profile and the depth of loose peat deposits has not been yet carried out.
3. A major disadvantage of the large bore TBM method is the high initial capital expenditure for the TBM and the long lead time to manufacture, ship, assemble and test the machine, plus the normal inefficiency related to the learning curve on startup.
4. Another disadvantage is the very large circular tunnel section required to accommodate the traffic lanes, shoulders and sightline, which for vehicular tunnels is not a very efficient use of space.
5. Larger bores have a greater potential for the loss of line and grade given the very tight turn radius required and steep grades to pass under the channel.
6. With inexperienced crew, during early operation, ground losses could cause settlements greater than the tolerances; these will require monitoring and contingency plans to restore the hydrologic environment.
7. Because of the short length of TBM tunnel, the drive is entirely within the "learning curve" of the machine operation; accordingly, advance rates would be low, especially with the tight horizontal and vertical curves in the alignment.
8. A worst case scenario -- if the machine is improperly operated, formation of a sink hole into the channel or wetlands is possible.

### TBM Risk Management Measures necessary

1. Pre-qualification of contractors to limit bidders to experienced contractors.
2. Ground improvement, as required, to reduce risk of line and grade loss.
3. Detailed geotechnical investigations considering large footprint of the facilities.
4. Employ innovative contracting practices to attract qualified bidders.
5. Verify that a machine can be fabricated that can successfully negotiate a 325 foot radius horizontal curve while also negotiating a vertical curve.

## **7.3. IMMERSED TUNNELS**

Immersed Tunnels have been constructed in waters as shallow as 6 feet deep to water depths of 180 feet. This construction method is one of several that are applicable to the Alternative K Montlake Cut tunnel alignment that crosses the dredged shipping channel in either Union Bay or the Montlake Cut.

Immersed tunnels consist of very large precast concrete or concrete-filled steel tunnel elements. They are fabricated in convenient lengths on shipways, in dry docks, or in improvised floodable basins, sealed with bulkheads at each end, and then floated out. They may require outfitting at a pier close to their final destination before being towed to their final location, immersed, lowered into a prepared trench, and joined to previously placed tunnel elements. After any further foundation works have been completed, immersed tunnels are backfilled and the river or channel bed reinstated.

Whichever method of construction is used, the final weight of a tunnel element must be the same for a given internal area; as a consequence, the quantities of steel and concrete do not differ greatly between methods.

### **Alignment and Profile**

The expert review panel discussed several alignment options. Three of these pass above the proposed Sound Transit cross-over structure, which is a vertical restraint resulting in grades steeper than would otherwise be necessary at the northern end. Despite the late stage of the Sound Transit design, it would still be worth while exploring the possibility of lowering the station cross-over box roof and eliminating (or at least reducing) the vertical profile restraint at that location. It should be noted that the sharp curves cause the effective grade for the inside ramp alignment to be steeper and that of the outside ramp to be less steep (the profile grades are generally computed on the centerline of the total width).

One additional option considered, Alignment "C," passing just to the south of the cross-over structure and eliminating this vertical restraint, would also keep construction much further away from the stadium and its car parking area. Taking this alignment directly across the channel at the eastern end of the Montlake Cut, results in a grade steeper than 13 percent unless a longer and more s-shaped alignment could be adopted.

For the three alignments passing above the station, the underwater length increases as each alignment moves further east into Union Bay. Since the required depth of an immersed tunnel would be the same in each case, the gradients on each side become shallower as the length of the crossing increases. Furthermore, because the perceived environmental concerns also increase as the alignment moves further east, primarily getting into fish habitat (longer and longer shallow underwater stretches) and greater amounts of soft peat, the shortest water crossing is preferable. The total length of wetlands traversed is much the same for each of the four alignments.

The internal height of the immersed tunnel will need to take into account the roadway cross-slope, provided for drainage. A 16'-6" traffic clearance is required with an additional minimum of 1'-6" inches for overhead lane markers, lighting, variable message signs, etc. This should be revisited during later stages of design. The roof thickness can be expected to be about 4 feet. While it is usual to provide about 6 feet of cover above a tunnel to cushion it against the effects of sunken ships and falling anchors, analysis of actual shipping might show that this can be reduced or alternatively sacrificial concrete slabs

could be provided over the tunnel instead in order to reduce the cover, if so desired. The top of this cover should be provided with protection against expected currents during periods of high water flow through Montlake Cut. The top of the selected method of tunnel protection should be no higher than the underside of the dredging tolerance. Hence the highest point on the roadway could be 26'-6" or less below the dredging tolerance.



*Figure 18 – Immersed Tunnel section with adjacent cofferdams on land*

In principle, the end of any immersed tunnel section can be located in the water, ashore close to the water's edge, or continue inland through wetland and deep soft areas. Decisions on the extent of immersed tunnel should be based on environmental issues (cut-and-cover may be wider than the immersed tunnel if used as a casting basin, cofferdams in water may be undesirable), options available for casting the immersed tunnel (cost, overall width if twin immersed tunnels result, ensuing space for local construction insufficient or reuse causes too long a construction period), cost (comparison between methods), difficulty of constructing cut-and-cover in deep soft material (if relevant, will also affect cofferdam construction in water if an option, for example to reduce excavation in water), etc..

#### Alignment A

Alignment A traverses about 200 feet of wetlands plus about 90 feet of shallow water area (to 16 feet depth) on the south side and 65 feet of wetlands plus 285 feet of shallow water area on the north side. There is a distance of about 300 feet of deeper water between these two areas. A 300 feet long tunnel element would have a maximum dip of 9 feet due to the vertical profile. One such element could be flanked by cut-and-cover tunnels in 60 feet deep cofferdams in the water and wetlands or by additional elements at each end to give a total immersed length of 900 feet, much of it curved in plan. The curvature at the southern end makes it impractical to use this area for a graving basin unless it is widened enough or realigned to get tunnel elements out. Even so, the greatest length available is unlikely to exceed 400 feet unless good soil material exists beneath the wetlands.

#### Alignment B

Alignment B traverses about 180 feet of wetlands plus about 80 feet of shallow water area (to 16 feet depth) on the south side and a small area of wetlands (0.05 acres) plus 300 feet half in the shallows on the north side. There is a distance of about 260 feet of deeper water between these two areas. A 260 feet long tunnel element would have a maximum dip of 7 feet due to the vertical profile. One such element could be flanked by cut-and-cover tunnels in cofferdams in the water and wetlands or by additional immersed tunnel elements at each end to give a total immersed length of 820 feet, much of it curved in plan. Perhaps

the best arrangement would be a second element at the south end and cofferdam only partially in the water at the north end.

### Alignment C

Alignment C traverses about 230 ft. of wetlands only on the south side. The skew crossing would require a straight tunnel element about 250 ft. long to reach from shore to shore, since the water drops off fairly rapidly. A 250 ft. long tunnel element would have a maximum dip of nearly 10 ft. due to the vertical profile. Cut-and-cover tunnels would be constructed at each end of the immersed tunnel.

### Alignment D

Alignment D traverses about 210 ft. of wetlands only on the south side. This crossing, the shortest distance across Montlake Cut, would require a straight tunnel element about 200 ft. long to reach from shore to shore, since the water drops off fairly rapidly. A 200 ft. long tunnel element would have a maximum dip of over 5 ft. due to the vertical profile. Cut-and-cover tunnels would be constructed at each end of the immersed tunnel.

### Alignment D modified

There is room to extend this alignment by moving the crossing point eastwards by about 150 feet for the immersed tunnel without significantly impacting the adjacent historic building located to the east side; this would reduce the grade at the north end from 10.4 percent to 9 percent. This would have the advantage of decreasing the wetland impact on the south side of the Montlake Cut to only 90 feet without changing the construction method outlined above. If the tunnel element were extended southwards by 50 feet, the dip would be 7.5 feet. If used as a casting basin, the approach would need to be widened to accommodate the longer tunnel element, so that it can be floated out.



*Figure 19 – Alignment D Modified*

<b>Alignment</b>	<b>COWI</b>	<b>A</b>	<b>B</b>	<b>C.</b>	<b>D (Mod)</b>
Approx. length	2,890 ft	2,882 ft	1,850 ft	1,970 ft	2,120 ft
Max grade	6.9%	7.0%	13.1%	10.4%	9.0%
Wetlands	265 ft	200 ft	230 ft	210 ft	90 ft
Shallow water	375 ft	380 ft	0 ft	0 ft	90 ft
Deeper water, Min. immersed	300 ft	260 ft	250 ft	250 ft	200 ft
Max. immersed	900 ft	820 ft	250 ft	250 ft	250 ft
Dock space S. end	Unlikely	Yes	Yes	Yes	Can be

*Table I - Summary of Immersed Tunnel Alignments/*

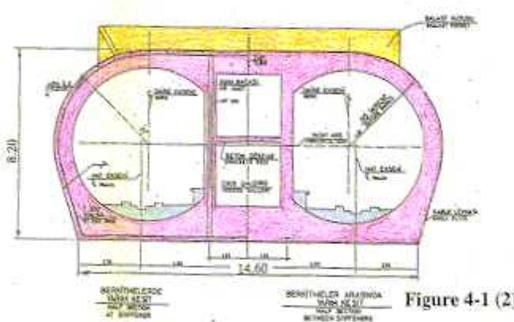
Reviewing the data in Table 1 it would appear that modified Alignment D has the least impact, but if a 9 percent grade is too steep, then the easternmost alignment (i.e. Alignment A) should be selected. From the environmental point of view, it would be better to bring cut-and-cover close to the water's edge. For both methodologies, it may be very difficult to get authorization to physically impact the wetlands - hence minimizing the length of wetlands impacted would be the best option, i.e., Alignment D modified eastwards as suggested above.

### Type of Immersed Tunnel

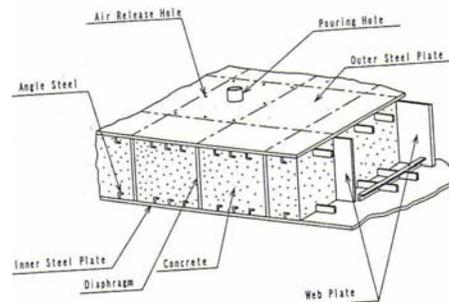
The traditional shape of immersed tunnels in the United States has been circular, providing space above and below the roadway for fully-transverse ventilation as used in very long bored highway tunnels. The size of an immersed tunnel using that method would therefore match that of bored tunnels. However, for a short tunnel such as is required here, jet fans provided within the cut-and-cover approaches would provide more than adequate ventilation, so the extra space above and below the roadway would be superfluous. The circular shape also means that providing additional lanes or wide shoulders drives down the depth of the roadway.

The majority of immersed tunnels world-wide are rectangular and it is proposed that this be used here too, minimizing the depth of roadway below the surface. The three methods of construction commonly in use for rectangular tunnels are:

- Concrete, either reinforced or prestressed. For most tunnels, external waterproofing is used, steel plate used as formwork being one type used.
- Steel single-shell, where the external structural shell plate works compositely with the interior reinforced concrete and the shell plate requires corrosion protection. The BART tunnel, though not rectangular, is typical of this type.
- Steel sandwich, where internal steel diaphragms connect structural steel plates, both internal and external, and the space between them is subsequently filled with unreinforced non-shrink self-compacting concrete. This type of tunnel is a relatively recent development in Japan. Osaka South Port and Kobe Port tunnels were constructed by this method, the latter carrying three lanes per duct.



*BART Single Shell*



*Sandwich Tunnel Construction*

An immersed tunnel element is a length of tunnel that is floated and immersed as a single rigid unit. For a few Dutch tunnels and the Øresund tunnel (between Denmark and Sweden), the rigidity of the concrete tunnel elements has been temporary and was later released, elements consisting of a number of discrete segments about 50 to 70 feet long, stressed together longitudinally for ease of transportation and placing. After placing and release of the segments, each may act as a mini-element free to move at the segment joints. The convenience of using discrete segments depends mainly upon subsurface conditions, acceptable displacements, and sufficient capacity to resist seismic effects. It is probable that discrete segments are inappropriate for Seattle.

Although a few concrete tunnels have been constructed without a waterproofing membrane, the cost of repairing potential leaks may far exceed the cost of providing waterproofing; furthermore, should

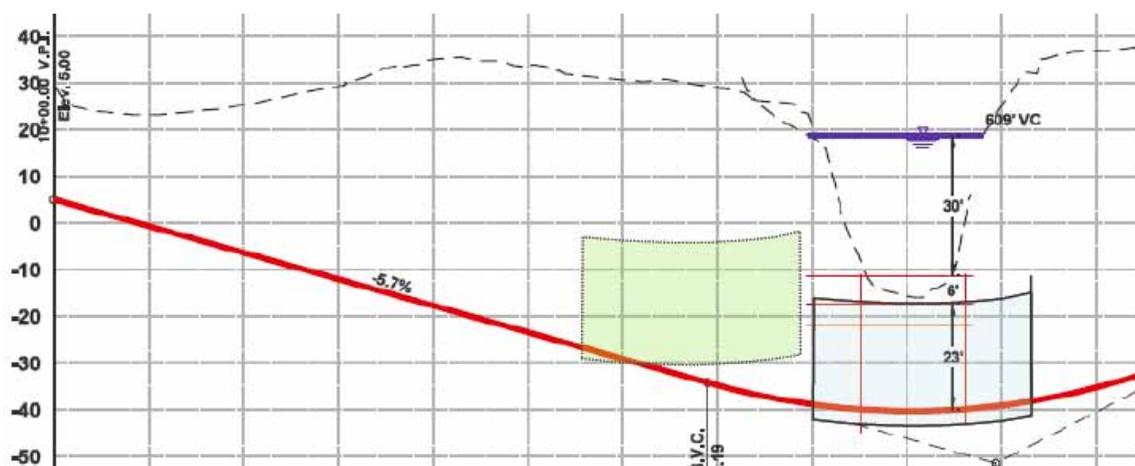
significant cracking occur as a result of seismic activity greater than anticipated, waterproofing capable of bridging large cracks can ensure the tunnel stays dry and usable while the damage is repaired. For a steel single-shell or sandwich tunnel, the steel plate also acts as the waterproofing membrane.

### Fabrication Facility – off site

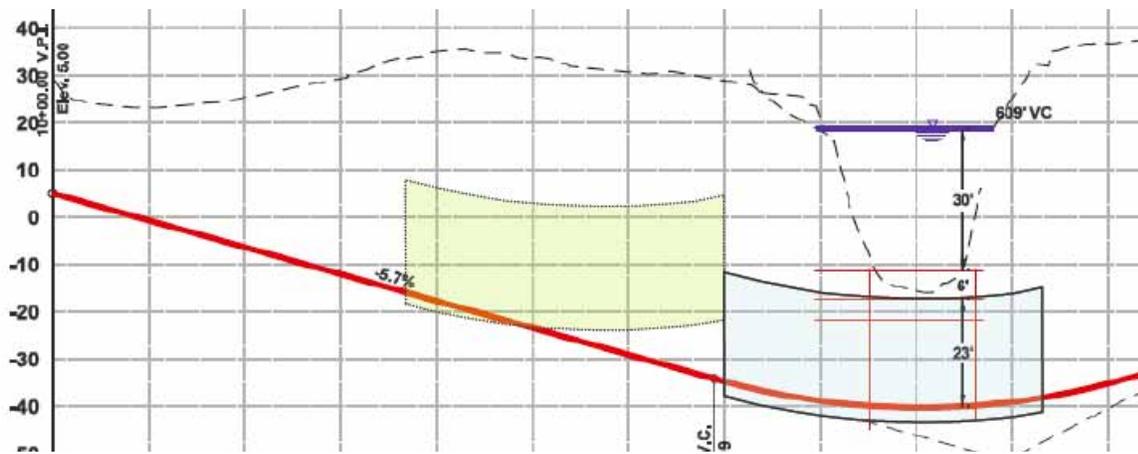
A straight immersed tunnel element providing two lanes 12 feet wide and two shoulders 4 feet wide in each direction will be about 72'-6" wide and can therefore fit through the locks. This possibility may apply only to alignment D. The draft of an element can be adjusted to suit the available water depth by placing some of the concrete after passing through the locks. A completed tunnel element will be about 27.5 feet deep and is usually sized to float with only a few inches of freeboard. Vertical curvature to suit the tunnel profile will add to the necessary draft and may make it necessary for vertically curved tunnel elements passing through the locks either to be floating high (needing more ballast later) or to be reduced in length to lessen the dip. With minimum shoulders, it is therefore possible to fabricate the tunnel element outside Lake Washington, perhaps using existing facilities for pontoon fabrication for the floating bridge. If wider shoulders are needed or the tunnel elements need horizontal curvature, probably for Alignments A, B and C, two parallel immersed tunnel elements, one for each direction, would be needed if they must pass through the locks. Unless the tunnel elements are extremely short, additional dredging would be required in order to rotate the tunnel elements into position transverse to the navigation channel.

### Fabrication Facility – on site

Since the proposed alignments are below water level on the south side of the cut, there is an opportunity to use the adjacent cut-and-cover section as a fabrication facility for the immersed tunnel elements. Because of the significant vertical curvature, the floor of any fabrication facility will need to be shaped to match the profile, and for the dock floor to have sufficient draft for the deepest section of the tunnel element to be floated out. This will necessarily mean that the final excavation for the cut-and-cover sections cannot be completed until after the immersed tunnel has been floated out. Some additional width will be needed above that required for the approaches, but this will be minimal (see Figure 22). Only one use of the dock would be required for Alignments C and D, and this should not extend the construction period. If the maximum length of immersed tunnel is used for Alignments A and B, reuse of the dock might extend the construction period by about 8 months and require a reusable gate, which is relatively simple to provide. As can be seen in Figures 20 and 21, a section of tunnel can always clear the dock floor at the gate (the sill) when floating out, even when it has vertical curvature.



*Figure 20 - Immersed tunnel 230 feet long constructed within alignment*



*Figure 21 - Immersed tunnel 330 feet long constructed within alignment*

### Size of Immersed Tunnel

The basic roadway width is considered in this report is 36 feet wide using two 12 feet lanes plus one 4 feet wide shoulder and one 8 feet shoulder (see above for considerations of size to pass through the locks if the units were to be fabricated away from this site). If curbs or barriers are required to protect the walls against vehicular impact, these would increase the width further. If emergency walkways are required against the central wall, this would also be extra (emergency cross-passage doors can easily be provided at regular intervals). As a guide, the basic width of a the twin roadway tunnel would be 80'-6" assuming 3 feet thick outside walls and a 2'-6" thick central wall. Twin unidirectional tunnels will be a little wider than half this value. With a 4 feet thick base slab and 3'-8" thick roof slab, the height at any one location is 27'-4". This provides a nominal freeboard (ignoring any dip) of about 10 inches (a little high perhaps) for a 200 feet long tunnel element and allows for permanent internal ballast concrete below the roadway to prevent accidental flotation.

The length of immersed tunnel selected will be dependent on many factors including schedule, cost, environmental issues and alignment. In order to minimize disruption to marine traffic in the navigation channel, it is preferable to place a single tube across the channel.



*Figure 22 - Gap between Immersed Tunnel and Dock Wall*

## **Immersed Tunnel - Environmental Issues**

Because immersed tunnels are placed within an excavation made from the surface, there are environmental and construction issues associated with this type of tunnel that do not occur with TBM and SEM tunnels. These relate to the dredged trench into which the immersed tunnel elements are placed. Soils excavated may be contaminated, raising issues of disposal; however modern dredging techniques allow this material to be satisfactorily excavated. Issues associated with dredging, such as dispersion of silts can be controlled; recent immersed tunnel projects at the entrance to the Baltic (Øresund) and in the Bosphorus Straits (Marmaray) have been closely monitored and results have been acceptable to the agencies concerned. Lastly, the federal Endangered Species Act has resulted in several listed species that will severely limit work windows, unless special permits are allowed for a limited “take” of endangered species. Since migration of these species may not follow exact calendar dates (see Table D in the environmental section of this report), monitoring of areas in the vicinity of work areas should be used to confirm permissible work windows.

If currents in the vicinity of the work area are low enough, silt curtains could be used to limit water turbidity and the dispersion of unwanted silts if proved necessary. In the very soft organic surface deposits of Union Bay, the angle of repose of excavated side slopes is likely to be a significant issue, less so the further west the alignment is. It may have stable slopes of 3:1 or even as flat as 5:1. This will significantly increase the volume of material removed. The quantity of material to be removed may be limited, if necessary, by providing an underwater barrier around the anticipated top of excavation of the layers beneath. One suggestion made during the workshop was to gently place stone-filled gabions in this soft material and building a wall of these up to the surface of this soft layer. If necessary, they could later be removed. Further investigations would be required to see whether these volumes could be reduced using sheet piles underwater, or other methods. Short-term side slopes in underlying materials, allowing for some sloughing, of 1:2 or 1:3 are usual; however the Montlake Cut slopes are fairly steep in glacial till and clay, perhaps at 1:1.

Water removed from within construction areas during construction and from within the tunnel at the low point and at the tunnel portals after completion would need treatment before discharge into the lake. Areas of wetland and parkland would need to be restored after construction; it would therefore be advantageous to keep such areas affected small.

## **Immersed Tunnel Construction**

Aside from its environmental impacts requiring work to occur within specified windows of opportunity (primarily late fall, probably starting around October 1<sup>st</sup>), construction activity need not greatly affect marine traffic in the Montlake Cut except during placement of the immersed tunnel. Because the tunnel would effectively block most water flow for a few hours during placement, it would be most easily done during periods of low flow. During excavation and placement of an underlying gravel foundation layer, larger vessels could be permitted to pass much of the time without prior notice; at other times, operations could be temporarily suspended, for example during certain hours. During tunnel element placement, all marine traffic will need to be stopped. Effects during placement of the protective covering above the tunnel would be similar to those during excavation. None of these construction activities need be lengthy.

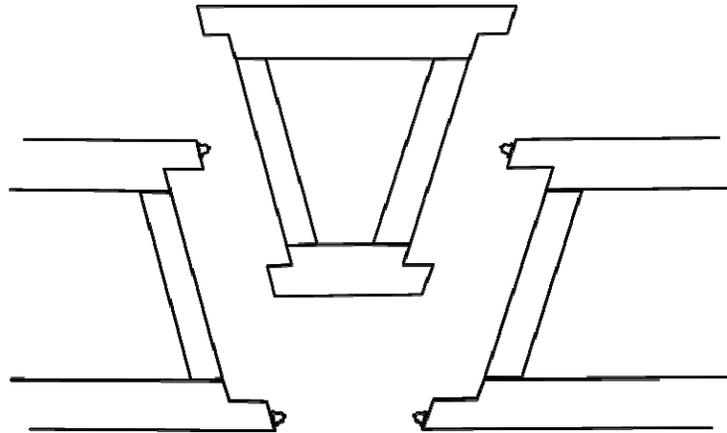
Before the arrival of the tunnel element, the tunnel trench would probably be excavated using closed clamshell buckets. If the material proves too hard, a backhoe with a long dipper arm could be used with teeth on the bucket. Some final dredging beneath the “gate” area of a fabrication area may be required before the element is floated out. Dredging methods can be similar to those conducted elsewhere in the vicinity of Seattle. Disposal of unsuitable excavated material may be possible at the Elliott Bay disposal site. Once dredging is completed, a gravel foundation using the scraging<sup>5</sup> method can be completed within a day; the stone is placed directly to the required level using a computer-controlled tremie pipe. Other methods of producing a foundation can also be used, though these would take longer; various

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<sup>5</sup> Scraging is a method pioneered by the Dutch firm Boskalis to place and level the gravel bed prior to the immersion of the tunnel sections.

methods are available that allow completion of the foundation to be done either before or after placing the tunnel element.

If a tunnel element is constructed outside the alignment in the special case where it is to span directly between the ends of the cut-and-cover sections, then it would be advantageous to construct the mating surfaces at both the cut-and-cover ends prior to installing the element. This can be done using a sloped mating surface arrangement as shown schematically in Figure 23.



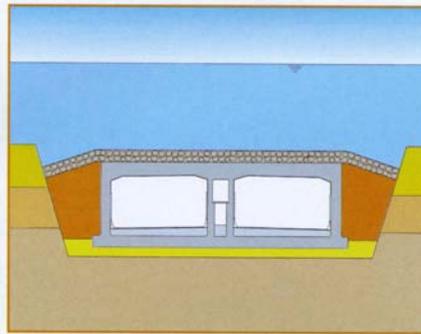
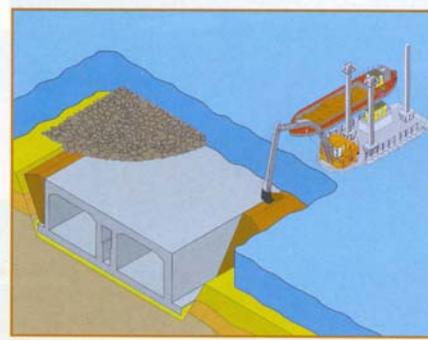
*Figure 23 - Inserting final section of immersed tunnel*

In all other cases, a vertical mating surface would be made at, say, the southern end of the northern cut-and-cover section. If the immersed tunnel is fabricated within the alignment on the southern side, the dock area would be flooded and material at the gate area removed. The simplest procedure would then be to winch the now floating tunnel element into position across the Montlake Cut. If within reach (Alignments C and D), the tunnel element could be held by land-based cranes on each shore while additional ballast is added sufficient to enable it to be lowered into position using guides. Alternatively, buoyancy cylinders (Figure 24) coupled with progressive ballasting could be used, or winch-equipped pontoons. For Alignments A and B, the tunnel elements would have to be positioned by tugs or barges, then controlled using anchors and lowered using one of the two latter methods and the placement position verified using survey towers such as those in Figure 18. Once all the necessary equipment is in place, a tunnel element can be moved into position and lowered into position, usually within a few hours. After access into the interior through bulkhead doors to verify correct position, backfilling can proceed immediately if founded on a gravel bed shaped to match, otherwise as soon as the foundation is completed, possibly from within. Finally, if needed, scour protection is placed on the backfill.

Following the placement of the final immersed tunnel element, the end will need to be sealed into the surrounding bank's excavation support system. Clay can be useful for this purpose, but other methods can be at least as effective. Once the seal is effective, the area behind the seal can be dewatered, any remaining excavation completed and the cut-and-cover tunnels completed.

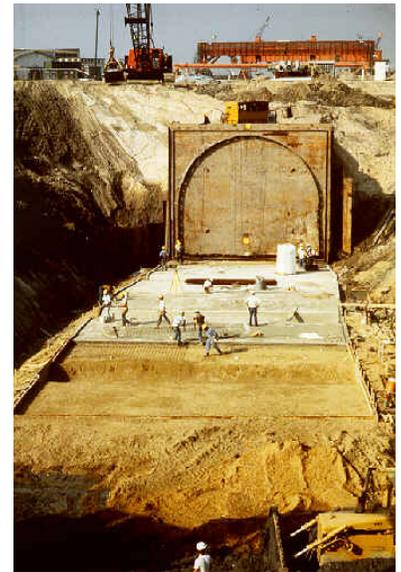


*Figure 24 - Buoyancy cylinders atop an immersed tunnel element*



*Figure 25a (above) - Immersed Tunnel Construction (General)*

*Figure 25b (right) – Exposed end of Immersed Tunnel with cut-and-cover construction in foreground*



#### **7.4. CUT-AND-COVER TUNNELING METHODS<sup>6</sup>**

Cut-and-cover tunnels are built by excavating a trench, constructing the concrete structure within the trench and covering it with backfill. Cut-and-cover construction is used when the tunnel profile is shallow and the excavation from the surface is possible and generally acceptable. For depths down to 30 or 40 feet, cut-and-cover tunneling tends to be more economical than bored or mined tunneling but depths to 60 feet or more are not uncommon. The depths for the cut-and-cover here vary from approximately 20 feet to 80 feet (possibly 100 feet for some methods and alignments).

Cut-and-cover tunnels are usually designed as a rigid frame box structure. When available space is limited, the tunnel may be constructed within vertical walls using an internally-braced or tied-back excavation. Where there is sufficient construction space and it is permitted, it may be more economical to employ open cut construction. The tunnel boxes may be constructed in place or by using precast sections. Tunnels are constructed by one of two primary methods, either bottom-up or top-down. In both cases, the tunnel is constructed within an excavation and is covered with backfill upon completion. The bottom-up method is further subdivided by the method of excavation support. More than one method of construction and excavation support may be used to form a tunnel, depending, for example, upon soil conditions, depth, cost, space available, effects of dewatering, and maintenance and protection of traffic.

<sup>6</sup> Chapter 5, Unpublished Draft. Technical Manual: Design and Construction of Road Tunnels, FHWA and NHI, May 2007

## Excavation Support Systems

Excavation support systems fall into three general categories, open-cut slope, temporary and permanent. Temporary structures do not contribute to the final load carrying capacity of the tunnel structure and are either abandoned in place or dismantled as the excavation is being backfilled - examples include soldier piles and lagging, sheet pile walls, slurry walls, secant piles and tangent piles. Permanent structures form part of the permanent final tunnel structure - examples include slurry walls, secant pile walls and tangent pile walls.

The different support types vary in footprint, dewatering requirements and stiffness.

Open cut slope (stable)

- Large footprint,
- Will dewater surrounding area

Temporary flexible walls: Soldier piles and timber, concrete or shotcrete lagging, sheet piles

- Small foot print
- Will dewater surrounding area (soldier piles and timber, concrete or shotcrete lagging) or not (sheet piles)

Temporary rigid walls: Soldier piles with soil mix

- Small foot print
- Limited dewatering

Temporary or permanent rigid walls: soldier pile tremie concrete (SPTC) walls, secant and tangent piles, and slurry walls

- Small foot print
- Dewatering only within the box

A sheet pile wall consists of a series of interlocking sheets that form a corrugated pattern in plan. The sheets are either driven or vibrated into the ground. The presence of rock, boulders, debris, utilities, or obstructions will make the use of sheet piling difficult since these features may damage the sheet piles. It is unlikely that sheet piles will be used in the vicinity of the Montlake Cut tunnel, because of noise, alignment and the possibility of encountering boulders.

A soldier pile wall consists of structural steel shapes forming columns spaced 4 to 8 feet apart and either driven into the ground or more likely placed in predrilled holes. The soldier piles extend well below the level of the bottom of excavation for stability. As the excavation progresses "lagging" is placed between the soldier piles to retain the earth behind the wall. The lagging could be timber, sprayed concrete or concrete planks. Soldier piles are relatively flexible and are capable of supporting only modest heights of soil without bracing. As the excavation progresses, bracings or tie-backs are installed at specified intervals. Soldier piles can also be installed in a greater variety of ground conditions than can a sheet pile wall. The spacing allows the installation of piles around utilities. The relatively small dimensions of the pile enables them to be installed in drilled holes through obstructions and into rock, making the soldier pile and lagging wall more versatile than the sheet pile wall.

Each of the wall types will need to be supported as the excavation proceeds and this can be done with ground anchors or steel struts. Soil anchors provide the best working space for the excavation but do need additional right-of-way. The anchors can be left in place, or if desired, de-stressed and removed as the excavation is filled with the structure. Soil anchors will be poorly suited to areas where suitable soils for anchoring lie too deep.



*Figure 26 – Soldier Pile excavation (left); Secant Pile Excavation (right)*

In this particular area a number of considerations must be taken into account:

- Limited working area and the desire to keep the construction and final foot print as small as possible
- Potential damage to adjacent structure if widespread dewatering is undertaken
- Proximity of Husky Stadium, for some alignments and the potential for settlements or movements if a flexible support structure is installed

Given these considerations a stiff support structure that does not dewater the surrounding area is preferable. Secant pile walls and slurry walls will meet these parameters. Tangent piles are unlikely to provide a water cut-off and are therefore considered unsuitable. It is interesting to note that Sound Transit's station excavation will be constructed using a slurry wall method, presumably for much the same reasons.

### **Bottom-Up Construction**

In conventional bottom-up construction, a trench is excavated from the surface within which the tunnel is constructed and then the trench is backfilled and the surface reinstated. The trench can be formed using open cut (sides sloped back and unsupported), or with vertical faces using an excavation support system. In bottom-up construction, the tunnel is completed before it is covered up and the surface reinstated.

A typical sequence of construction may consist of:

- Install excavation support wall system, if used, such as soldier pile and lagging, sheet piles, slurry walls, or tangent or secant pile walls. If slurry walls or secant piles are used then they can be temporary or become the permanent walls of the cut and cover structure. In wet ground, the excavation support system may have to form an enclosure
- Dewater and excavate within the excavation support system. Once that is finished, the floor of the tunnel is constructed. If a high hydrostatic pressure exists at floor level, i.e. a high water table, temporary lowering of the water table within the excavation will be required or a thick tremie slab must first be cast to provide a seal below floor level
- Construct the tunnel structural floor
- Construct the walls and then the roof, apply waterproofing as required
- Backfill to final grade and restore the ground surface

Bottom-up construction offers several advantages:

- It is a conventional construction method well understood by contractors
- Waterproofing can be applied to the outside surface of a structure
- The inside of the excavation is easily accessible for construction equipment and the delivery, storage and placement of materials
- Drainage systems can be installed outside the structure to channel or divert water away from the structure

Disadvantages of bottom-up construction include:

- The ground surface cannot be restored to its final condition until construction is complete
- Requires temporary support or relocation of utilities
- May require dewatering that could have adverse affects on surrounding infrastructure

### **Top-Down Construction**

With top-down construction, the excavation support system becomes the tunnel walls, usually slurry or less commonly secant pile, and is constructed first. Excavation then proceeds to the underside of the tunnel roof slab, dewatering and providing temporary support elements as required. Next the roof is constructed and tied into the support of excavation walls. External waterproofing of the roof slab can then be provided, followed by backfilling and the surface reinstated; this work can continue at any time from this point onwards. After construction of the roof slab, the remaining excavation can be completed, but under the protection of the top slab.

Once excavation is finished, the floor of the tunnel is constructed and tied into the walls. If a high hydrostatic pressure exists at floor level, i.e. a high water table, temporary lowering of the water table within the excavation will be required until the floor slab is in place. A drainage system is usually provided inside the tunnel immediately adjacent to the excavation support system to collect any water that might leak through it. Secondary finishing walls are provided within the drainage system and the remainder of the interior finished. For wider tunnels, additional temporary or permanent piles or wall elements are sometimes installed along the center of the proposed tunnel to reduce the span of the roof and floors of the tunnel.

Top-down construction offers several advantages in comparison to bottom-up construction:

- It allows early restoration of the ground surface above the tunnel
- The temporary support of excavation walls can be used as the permanent structural walls
- The structural slabs will act as internal bracing for the support of excavation thus reducing the amount of tie-backs required
- It requires less width for the construction area
- Construction of the roof is easier since it can be cast on grade rather than using bottom forms

Disadvantages of top-down construction include:

- Inability to install external waterproofing outside the tunnel walls
- More complicated connections for the roof, floor and base slabs
- Potential water leakage at the joints between the slabs and the walls
- Risks that the exterior walls (or center columns) will exceed specified installation tolerances and extend within the neat line of the interior space
- Access into the excavation below the roof is limited to the portals or through shafts through the roof
- Limited space for excavation and construction of the bottom slab
- Requires temporary support or relocation of utilities

## **7.5. CONSTRUCTION SEQUENCES**

### **For the Sequential Excavation Method.**

1. Construct freeze pits on both sides of the Montlake Cut using slurry wall techniques. Use two rigs one on the north side one on the south side. Once the freeze pits slurry walls are complete commence cut-and-cover and trough walls on both the north and the south sides.
2. Excavate the freeze pits, install freeze pipes from both pits and freeze the ground under the cut.
3. Commence SEM excavation from both sides of the cut.
4. As cut-and-cover slurry walls are completed, excavate, cast concrete base slab and cast concrete roof sections.
5. Once tunnel excavation is complete install waterproofing membrane, and cast-in place concrete liner.
6. Install roadway and finish works.
7. Install road systems, i.e. ventilation fans, power, lighting, communications and emergency stations.
8. Final testing and commissioning.

### **For the Immersed Tunnel Method**

1. Construct casting basin on the south side using slurry wall techniques.
2. Construct slurry walls for the cut-and-cover and trough sections on the north side.
3. Excavate casting basin and construct one immersed tube element.
4. Excavate north cut-and-cover, cast base slabs and walls and complete the first section of cut-and-cover on the north side ready to receive the immersed tunnel element.
5. Dredge trench across the Montlake Cut approx 30 feet deep, by 80 feet wide.
6. Remove the Montlake Cut walls, flood the casting basin, float out immersed tunnel element and dock against the north cut-and-cover section.
7. Seal off and pump out the casting basin.
8. Complete construction of cut-and-cover and trough sections on the north and south sides including casting of the concrete base slabs and roof sections.
9. Install roadway and finish works.
10. Install road systems, i.e. ventilation fans, power, lighting, communications and emergency stations.
11. Final testing and commissioning.

### **For the Bored Tunnel Using TBM**

1. Order tunnel boring machine (TBM).
2. Construct cut-and-cover section on the south side including base slab but not roof sections as TBM launching pit.
3. Set up the TBM and commence mining north.
4. Construct cut-and-cover section on the north side including base slab but not roof sections ready to receive the TBM.
5. Remove the TBM for the north end, transport back to the south end and re-commence mining on the second bore.
6. Commence cross-passage excavation as two bores become available.
7. Remove the TBM from the north receiving pit.
8. Complete cross-passages, cut-and-cover roof sections and troughs.
9. Install roadway and finish works.
10. Install road systems, i.e. ventilation fans, power, lighting, communications and emergency stations.
11. Final testing and commissioning.

## 8. RISKS

Every infrastructure project has a number of risks to consider throughout the life of the project, from concept through construction, including categories which include political, local, institutional, legal, environmental, geological, engineering and construction risks. Most of the risks identified are avoided or eliminated in the early stages of planning and concept development, while others are mitigated or eventually managed through the design and construction utilizing many of the standard practices and protocols and legal instruments available. The most important issue required is that the owner assign proper responsibilities for the management of risks to the most appropriate responsible party, for each category of risk, throughout the duration of the program.

In this section, we have focused our list on those technical risks, that are affected by the engineering, construction and environmental processes included as part of our evaluation. This is not meant to be exhaustive but is a start to identify the means by which the risks can be mitigated for the SR 520 Project.

The two categories of risks which have the most obvious and potentially the greatest consequences on this project are the environmental issues and the geological-hydrological environment which may affect the tunneling. Clearly, specific information is lacking and therefore assumptions have been made for this conceptual level report. Proper geotechnical site investigation over the area of consideration and along the specific alignment including: offshore geophysical surveys, exploratory borings and sampling, and an array of laboratory tests are recommended and required to characterize the materials with respect to permeability, compressive strengths, shear strength, water content, groundwater levels, local stratigraphy and its variations, occurrence of boulders etc. Once this information is available, then optimization of the alignment can be performed with the attendant result of mitigation of some, if not most, of the impacts identified in this early conceptual analysis.

A general listing of risks for each construction method follow.

### 8.1. SEM RISKS

- Incomplete freezing due to hole deviations (deflected by boulders), long drill lengths, flow gradients of groundwater, leaking freeze pipes, unknown contamination of groundwater (as experienced on the 1<sup>st</sup> Avenue tunnel crossing beneath the Duwamish River).
- Inadvertent thawing of frozen ground due to power loss or shutdown as was experienced in the lake tap shaft for Fort Peck Reservoir.
- Loss of face stability in zones (lenses, dikes, pipes, etc.) of sand and gravel containing perched water that will cause the soils to become unstable and flow when encountered unexpectedly by excavation. These zones may be relatively discrete, and difficult to locate with probing, as was experienced at Beacon Hill
- Lack of construction companies and personnel experienced in the use of SEM. The Beacon Hill project went through over 500 construction staff for about 100 positions
- With any sort or breach of the freeze wall, there is little or no backup for major ground losses and substantial inflow of lake or canal water
- Need to assess required depth of cover to preclude freezing from impacting fish and vegetation
- Tunnel spoils may have high pH due to shotcrete rebound – which is costly to dispose of

### 8.2. TBM RISKS

- Loss of face support and development of sink holes in sand or gravel seams
- Continuous double curvature alignment will be challenging for alignment control
- Unique TBM design required for tight radius curves
- Challenges in getting experienced and qualified staff for relatively short period of work.
- Damaged tunnel segments and leakage caused by misaligned segments
- Excessive settlement due to curved alignment, zones of sand or gravel, and/or breaking through to soft soils/peat

- Steep grades make for less safe/more risky construction and hauling of tunnel excavation spoils and large precast concrete segments

### **8.3. IMMERSED TUNNEL RISKS**

- Project delayed while getting permits
- Shutdowns due to excess turbidity
- Delays in fabrication or excavation extend schedule beyond allowable fish window
- Irregularities in top of firm soils requires additional excavation and placement of granular fill or grout

### **8.4. APPROACH CUT AND COVER RISKS**

- Excavated spoils may have high pH due to contamination by cementitious material from slurry walls and cylinder piles and require higher cost disposal
- Excessive ground losses and settlements may occur adjacent to excavated cuts without proper controls
- Excavation of slurry wall panels or secant piles may be inhibited by presence of boulders
- Irregularities in top of “firm ground” may require adjustments and cost increases during construction
- Permits for construction within 200 feet of shorelines may be challenging to get and to meet erosions, sedimentation, noise and vibration constraints
- Wetlands and related permitting
- Some methods will dewater adjacent areas resulting in potential settlements

## **9. OBSERVATIONS ON THE ALIGNMENTS AND METHODS**

The overall widths required to build each option as twin parallel tunnels are approximately 100 feet for the immersed tunnel alternative and up to 150 feet wide for the bored or SEM construction methods. The widths of the footprints for each method will affect the horizontal alignment as will efforts to reduce work in the wetlands along the south shore of the cut.

The summary table of the alignments alternatives and construction methods given in Table A (or E) provides the comparative description of the alignments, showing the range in lengths of tunneling by method, length of cut-and cover approaches, minimum cover above the tunnel, approximate range of grades on the north and south sides of the cut and length of tunnel section. From this table it is clear that the longest and most eastern alignment provides the best grades, however it increases the length of sub-aqueous tunneling and the impact to wetlands along the shore. Optimization of the alignment can be advanced when there is additional geotechnical information and the alignments have been further examined in association with other SR 520 and environmental considerations.

### **9.1. OBSERVATIONS REGARDING CONSTRUCTION AND THE METHODS**

1. Each construction method can be further optimized to find the best alignment to suit the specific parameters of the method once the geotechnical, hydrographic data and full configuration constraints are known.
2. All methods and all alignments pass under the Montlake Cut and/or under Union Bay
3. Onshore, cut-and cover methods are required for all alignments to build the approaches to and tunnel portals and are necessary in areas of low cover over the tunnel crown.
4. Despite the late stage of the Sound Transit design, it would still be worth while exploring the possibility of lowering the cross-over box roof and eliminating (or at least reducing) the vertical profile restraint at that location. The adjacent intersection will also cause a constraint – but this means that the cross-over box roof may not have to be lowered greatly.
5. It should be noted that the sharp curves in the alignment would cause the effective grade at the inside tunnel face to be steeper than at the outside face.

6. All methods require significantly more information about the geology and hydrology in the project area and along the preferred alignments to reduce the interpolation and extrapolation of data and to optimize the alignments.
7. Although four alternative alignments plus two alignment modifications were tested against the construction methods, we can assume that each construction method has a unique alignment that provides the best configuration, best satisfies the geometries, cover requirements, horizontal and vertical curves. This can be refined once the geotechnical site investigation information is available.
8. The greatest surface impacts are created by the cut-and cover construction used in the approaches of all three tunneling methods.

### **9.2. MINED TUNNELING USING SEQUENTIAL EXCAVATION METHOD (SEM) PLUS THE CUT-AND-COVER APPROACHES:**

*Construction by mining (SEM) shows the best promise for construction that satisfies construction requirements, meets acceptable grades, avoids environmental impacts to the Montlake Cut and Union Bay. Possible drawbacks include a long schedule in order to freeze the ground completely over the tunnel construction and possibly stage the freezing process along the longer alignments east of the cut, plus the difficulty in securing skilled workers for this type of work and increased risk as noted in the risk section.*

Advantages and disadvantages of this method and implementation for the SR 520 Project include:

1. Method conforms to efficiency and stable tunnel size and configurations required for highway ramps geometry and clearances.
2. SEM method does not disturb the cut and can extend onshore into cut-and cover.
3. SEM is adaptable to geology and Montlake groundwater with adoption of ground stabilization methods.
4. SEM applied here requires ground improvement using ground freezing to stabilize the saturated sands known to occur as layers within the hard clays.
5. Freezing adds time and costs to the project and requires thorough and constant vigilance to ensure soils are thoroughly frozen in advance of the excavation.
6. The alignment for the SEM should be the most western alignment possible and close to the cut that will provide acceptable grades to pass under the channel.

### **9.3. BORED TUNNELING WITH TBM PLUS THE CUT-AND-COVER APPROACHES:**

*Construction by a tunnel boring machine is not recommended for this length of tunnel, location and considering the alignment criteria for the reasons listed below. Observations relevant to this project that support this finding include:*

1. A minimum width required for the parallel tunnels is approximately 100 to 150 feet (the closer spacing near the portals) and requires a cut-and cover section of slightly larger dimension at the portal locations to allow for clearance inside slurry or secant walls.
2. To reduce grade, the longer alignment is best suited for the TBM; however, the trade off is a high cost and longer schedule and a longer reach of higher risk tunneling under Union Bay - where investigation of the lake bottom profile and the depth of loose peat deposits has not been carried out.
3. A major disadvantage of the large bore TBM method is the high initial capital expenditure for the TBM and the long lead time to manufacture, ship, assemble and test the machine, plus the normal inefficiency related to the learning curve on startup.
4. Another disadvantage is the very large circular tunnel section required to accommodate the traffic lanes, shoulders and sightline, which for vehicular tunnels is not a very efficient use of space.
5. TBM drives have a greater potential for the loss of line and grade given the very tight turn radius required and steep grades to pass under the channel.

6. With inexperienced crew, during early operation, ground losses could cause settlements greater than the tolerances; these will require monitoring and contingency plans to restore hydrologic environment.
7. Because of the short length of TBM tunnel, the drive is entirely within the “learning curve” of the machine operation; accordingly, advance rates would be low, especially with the tight horizontal and vertical curves in the alignment.
8. A worst case scenario -- if the machine is improperly operated, formation of a sink hole into the channel or wetlands is possible.

*However, advantages for the bored tunnel include:*

1. The ability to excavate and install water tight, pre-cast concrete segments as the final tunnel lining.
2. Does not disrupt the cut or disturb boating or ship traffic, fish or fisheries.
3. A relatively high degree of safety against flooding and ground collapse, as the TBM isolates the ground and groundwater from the tunnel proper.
4. Long tunnel drives, much longer than proposed here, typically achieve significant advances rates including installation of the final liner.
5. Contractors are becoming increasingly familiar with the use of EPB type TBMs in North America, but not in this size range (would be largest North American EPBM employed to date) or with this tight turn radius, and accordingly, some type of joint venture with international contractors would be essential.
6. Bored tunnels have the lowest impact on the surface, including the impact on the southern wetlands; however, attention must be paid to proper machine operation to limit the surface settlement.

#### **9.4. IMMERSED TUNNEL TUNNELING PLUS THE CUT-AND COVER APPROACHES**

*The Immersed Tunnel and cut-and-cover construction method for constructing the SR 520 ramps has the lowest technical risk, shortest duration, best meets grade requirements for alignments A and B, has flexibility for scheduling but has the most environmental impacts to the Montlake Cut and Union Bay.*

1. Immersed tunnels accommodate the shortest possible alignment, the shortest possible sub-aqueous section, and acceptable grades, but require approvals and permitting to work in the Montlake Cut, where the work will only be possible during very restricted construction schedules.
2. Geometry is extremely flexible. If necessary, cover over the tunnel can be reduced to nothing as long as the tunnel roof is designed to resist falling anchors and/or sinking ships.
3. Immersed tunnels are the safest way to go if unexpected ground conditions may be suspected.
4. Because immersed tunnels usually have an effective density less than the soil they displace, they can be constructed in poorer soil conditions than any other tunneling method.
5. Because the tunnels are precast in the dry, excellent quality can be achieved.
6. Immersed tunnels are usually dryer than other tunnels (leak less) and can be encapsulated within a waterproofing membrane (which could be steel).
7. Efficient space and dimensions because surplus space within the tunnel need not be provided.
8. Immersed tunnel with cut-and cover section is the shortest duration.
9. Method is adaptable to geology.
10. Construction schedule windows can mitigate impact on shipping and fish.
11. The footprint is the narrowest footprint because of the structure wall separating the two tunnels (or nominal separation with individual tunnels for the exit and entry ramps).
12. An onsite casting basin built along the alignment in place of the cut-and cover section could be constructed on the south shore of the channel, reducing time and simplifying logistics for placing the tunnel.
13. Aquatic impacts are unavoidable, but can be minimized through best management practices based on performance standards, and standard marine construction practices.
14. It has the longest length of surface disturbance.

## 10. SCHEDULE CONSIDERATIONS

The following pages indicate the relative schedules for the various tunneling and construction methods considered in this report and also their relationship to the currently planned Sound Transit station and tunnels construction. Currently, we do not anticipate that there will be a major conflict between the SR 520 and Sound Transit construction activities although construction access and activities in the Husky Stadium parking lots may overlap. It is possible that some of the activities can be compressed and/or overlapped but the panel did not go into this level of detail at this point in time.

### 10.1. IN GENERAL:

- The environmental process and Record of Decision will take until the end of 2011.
- The immersed tunnels and the SEM tunnels would be expected to take 3 to 3.5 years after the Record of Decision until about the 2<sup>nd</sup> quarter of 2015.
- The bored tunnels, due to the long lead time to procure and fabricate the TBM, would take about 4 years after the Record of Decision, until about the 1<sup>st</sup> quarter of 2016.
- These dates are within the overall schedule for the SR520 Project.

### 10.2. INTERFACE WITH SOUND TRANSIT

Sound Transit's construction schedule for the University Light Rail Station has been agreed with the University and a detailed plan of occupancy of some of the University property has been memorialized. Sound Transit's current plan allows for the completion of the station by December 2014. Access through the station for systems installation and testing will be required until the scheduled operation date of mid 2016.

Until such time that an alignment and construction method is determined it is difficult to fully identify interface issues however the following items will need further consideration:

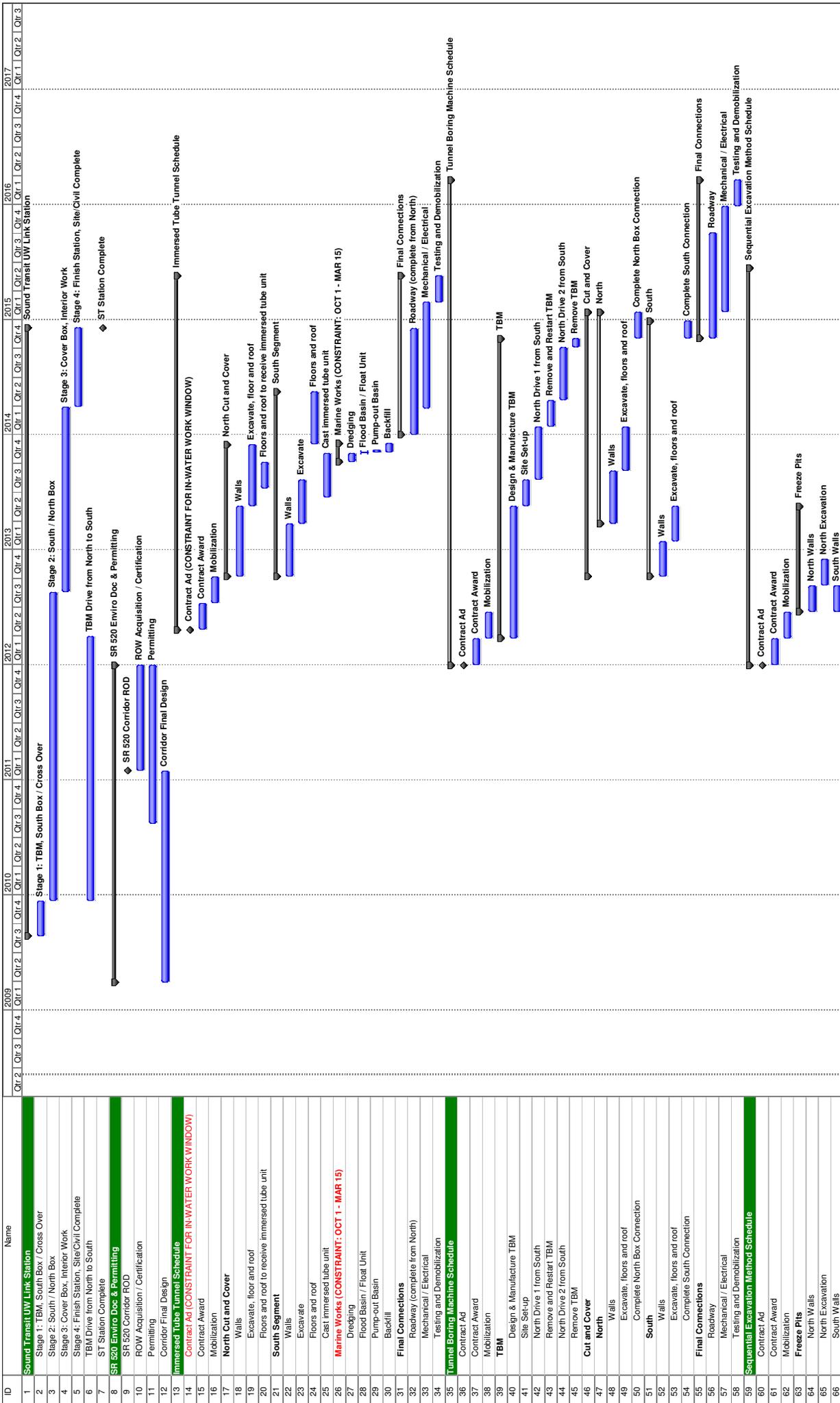
- Possible increase to the depth of the notch in the Sound Transit station cross-over structure to reduce grades in the road tunnels
- Scheduling of the work on University property. A number of alternatives exist:
  - Delay work on the north side of the Montlake Cut until such time that the Sound Transit Station is completed. In this case it is unlikely that the road can be completed by 2016
  - Minimize overlap with Sound Transit work by holding back work on the north Side of the cut until absolutely necessary, thereby achieving the 2016 completion date
  - Overlap as much work as possible with the Sound Transit station construction so that the University can take full possession of their property at the earliest opportunity

Discussions will be needed with both Sound Transit and the University of Washington to determine an acceptable solution.

A preliminary assessment of construction schedules for the SR 520 Project and Sound Transit Light Rail Station construction and the various tunneling and cut-and-cover methods is shown on the following schedule diagrams.

### 10.3. SCHEDULE - SR 520 AND SOUND TRANSIT CONSTRUCTION ACTIVITIES

The following schedule sheets outline the approximate durations and inter-relationships for the tunnel alternatives and Sound Transit construction.



ID	Name	2009	2010	2011	2012	2013	2014	2015	2016	2017
1	Sound Transit UW Link Station									
2	Stage 1: TBM, South Box / Cross Over									
3	Stage 2: South / North Box									
4	Stage 3: Cover Box, Interior Work									
5	Stage 4: Finish Station, Site/Civil Complete									
6	TBM Drive from North to South									
7	ST Station Complete									
8	SR 520 Enviro Doc & Permitting									
9	SR 520 Corridor ROD									
10	ROW Acquisition / Certification									
11	Permitting									
12	Corridor Final Design									
13	Immersed Tube Tunnel Schedule									
14	Contract Ad (CONSTRANT FOR IN-WATER WORK WINDOW)									
15	Contract Award									
16	Mobilization									
17	North Cut and Cover									
18	Walls									
19	Excavate, floor and roof									
20	Floors and roof to receive immersed tube unit									
21	South Segment									
22	Walls									
23	Excavate									
24	Floors and roof									
25	Cast immersed tube unit									
26	Marine Works (CONSTRANT: OCT 1 - MAR 15)									
27	Dredging									
28	Flood Basin / Float Unit									
29	Pump-out Basin									
30	Backfill									
31	Final Connections									
32	Roadway (complete from North)									
33	Mechanical / Electrical									
34	Testing and Demobilization									
35	Tunnel Boring Machine Schedule									
36	Contract Ad									
37	Contract Award									
38	Mobilization									
39	TBM									
40	Design & Manufacture TBM									
41	Site Setup									
42	North Drive 1 from South									
43	Remove and Restart TBM									
44	North Drive 2 from South									
45	Remove TBM									
46	Cut and Cover									
47	North									
48	Walls									
49	Excavate, floors and roof									
50	Complete North Box Connection									
51	South									
52	Walls									
53	Excavate, floors and roof									
54	Complete South Connection									
55	Final Connections									
56	Roadway									
57	Mechanical / Electrical									
58	Testing and Demobilization									
59	Sequential Excavation Method Schedule									
60	Contract Ad									
61	Contract Award									
62	Mobilization									
63	Freeze Pits									
64	North Walls									
65	North Excavation									
66	South Walls									



## 11. APPENDIX A – MEETINGS WITH MEDIATION PANEL REPRESENTATIVES

Summaries of ERP meetings on May 19, 20 and 21 with SR 520 mediation panel representatives follow.

**MEETING SUMMARY**  
**SR 520 Alternative K – Montlake Cut Tunnel**  
**Expert Review Panel – Meeting with Mediation Participants**  
**Monday, May 19, 3:30 p.m. – 4:30 p.m.**  
Plaza Building, 600 Stewart St, Suite 520, Seattle

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Julie Meredith, SR 520 program director, thanked the mediation participants for attending and provided an overview of the Tunnel Expert Review Panel (ERP). The panel will review and evaluate strategies to design and construct a tunnel under the Montlake Cut as proposed in Mediation Alternative K.

After introductions, John Reilly, ERP facilitator, explained that the panel had spent its first day learning about the SR 520 project and visiting the project area. He encouraged the mediation participants to share their interests and considerations for the design and construction of a tunnel across the Montlake Cut.

A representative from the University of Washington noted that the north end of the tunnel would land in the University of Washington Husky Stadium parking lot.

- The University is interested in how the Sound Transit tunnel and the proposed SR 520 tunnel projects would overlap. Sound Transit will be constructing the light rail tunnel starting in 2009 and construction is estimated to continue for six years. The Sound Transit project will use approximately six acres during the construction phase, resulting in the loss of parking and access to parking in this area. It also is important to consider how the SR 520 project will work around the Sound Transit ventilation area.
- The short- and long-term loss of parking for the University must be considered. The University is interested in the possibility of mitigating effects by incorporating a parking garage.
- The University is concerned with how the Pacific Street intersection will be configured to work with the additional pedestrians using the Sound Transit station.
- The COWI tunnel proposal included the use of 15 acres for staging areas. There are, however, a maximum of only 11 acres available near Husky Stadium.
- The University is concerned with the potential effects to the surrounding areas from dewatering, including Husky Stadium.

A representative from the Laurelhurst neighborhood echoed the concerns of the University.

- The Laurelhurst neighborhood is interested in how a tunnel can balance traffic flows and accommodate adequate speeds through roadway grades. The Pacific Street intersection should encourage connectivity between transit, bicycles, and pedestrians, as well as ensure safety.
- The neighborhood is sensitive to the height and width of the structure's profile through the Arboretum and McCurdy Park. It is important to minimize the road width and profile in order to reduce the visual impacts on the surrounding communities.
- Finally, the Laurelhurst neighborhood is concerned with protecting the integrity of Union Bay by minimizing the environmental impacts to fish and wetlands.

A representative from the Montlake neighborhood expressed hopefulness that the tunnel can functionally improve transportation and the Montlake neighborhood.

- The Montlake neighborhood representative encouraged the panel to be creative in its deliberations. He noted that the neighborhood is open to multiple alignment scenarios. The primary concerns that the panel must address are functionality, feasibility, affordability, and permitting of the tunnel.
- The Montlake neighborhood is interested in how the tunnel will encourage connectivity for transit. Bicycle and pedestrians movements should also be considered.
- The tunnel portals, ramp alignment, and intersection should be configured to reduce traffic impacts to neighborhoods and improve the existing Montlake Bridge bottleneck.
- The neighborhood is concerned with how to narrow the surface footprint of the roadway to minimize the effects on surrounding communities and parks, as well as developing an east-west greenbelt.

A representative of the Ravenna-Bryant neighborhood noted that the SR 520 bridge runs through a very sensitive area. Any project in this area should do no harm to the communities, parks, and environment.

- The Ravenna-Bryant neighborhood does not want a new interchange north of the Montlake Cut.
- The neighborhood is concerned with the type of tunnel construction method since the soils in the area are of poor quality and could result in liquefaction during a seismic event. More information is needed concerning the possible use of freezing methods for tunnel construction.
- A graving dock, as proposed by the COWI tunnel construction method, is an inappropriate use for McCurdy Park. Additionally, University property should not be used for the purpose of constructing a tunnel.
- The tunnel must not negatively affect salmon. The panel must consider how fish windows affect construction sequencing and feasibility.
- The neighborhood would like to see realistic cost estimates for a tunnel project, but noted that this may be dependent on the construction method.
- Sound Transit will be removing all excavation materials by truck. Sound Transit was prohibited from using barges to transport materials. The neighborhood would not support an increase in barge or truck traffic for transport of excavated materials from construction of a SR 520 tunnel.

A representative from the University District recommended that the panel review the comments submitted in response to the SR 520 draft environmental impact statement (DEIS). He also suggested that the panel consult with University of Washington Professors concerning fisheries and Tribal fishing rights.

- The University District neighborhood is concerned with the impacts to the University of Washington property including the loss of the University of Washington Waterfront Activities Center and Husky Stadium parking areas. How will the University replace this lost property?
- The effects to fisheries, fish migration patterns, and wetlands from construction of a tunnel are of concern.
- The neighborhood is interested in how traffic will be managed at the Pacific intersection, as well as meeting the grade and curve standards for a tunnel.
- Utilities below Montlake Avenue and Pacific Place will be displaced.
- Emergency access for ambulances and fire trucks must be maintained at all times. The University Hospital is located at the Pacific intersection.
- Mitigation for the Arboretum is not necessarily tied to construction of a Montlake tunnel.
- The most important consideration is whether or not to build a tunnel. The University District favors not building a tunnel.

The project team will provide the panel with copies of the March mediation session summary, which include the comments expressed by Mike Grady, NOAA-NMFS. He expressed concern with blocking the Montlake Cut for tunnel construction, inhibiting fish migration and navigational access.

A representative from the Arboretum expressed support for Mediation Alternative K because it minimizes the noise, visual, and traffic impacts to the Arboretum, by removing existing ramps, narrowing the SR

520 highway, and incorporating lids. The tunnel under the Montlake Cut is a critical element of Alternative K.

- The Arboretum believes that the tunnel will improve the environment and transportation once it is complete. The project, however, must be feasible and able to be permitted.
- Emergency vehicle access, as well as freight truck movements, can be accommodated via the existing Montlake Bridge.
- The University boathouse and Waterfront Activities Center could be moved or restored after construction of the tunnel is complete.

The Museum of History and Industry (MOHAI) property could be converted from parking lot to park space. The Arboretum and the University own parts of this property. The property use also is limited by Section 4(f) and Section 6(f) regulations.

John Reilly stated that the panel is charged with balancing the community and environmental concerns for a tunnel. The panel will consider these issues and provide its report, scheduled for June 11. He noted that the panel is not limited by the COWI tunnel report and had begun to preliminarily consider three construction methods:

1. Immersed tunnel
2. Bored tunnel / Tunnel Boring Machine (TBM)
3. Mined tunnel / Sequential Excavation Method (SEM)

The panel will evaluate the tradeoffs of each approach, as well as the risks involved. This information will be used to help support WSDOT in conducting an in-depth engineering assessment and cost estimating process, leading to the development of the supplemental draft environmental impact statement (SDEIS).

**MEETING SUMMARY**  
**SR 520 Alternative K – Montlake Cut Tunnel**  
**Expert Review Panel – Meeting with Mediation Participants**  
**Tuesday, May 20, 3:30 p.m. – 4:30 p.m.**  
Plaza Building – 600 Stewart St, Suite 520, Seattle

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### Introduction

Julie Meredith, SR 520 program director, thanked the participants for attending. She explained that this meeting would serve as an interim check-in of the Montlake Cut Tunnel Expert Review Panel (ERP). She provided a brief overview of the purpose of the panel and the planned schedule.

### Geological Considerations

Red Robinson, ERP member, reviewed the geological conditions near the Montlake Cut. He explained that ground boring samples have been taken in the area by the Sound Transit project and others. There is evidence of hard glacial tills and hard clays layers under the Montlake Cut, which are good mediums for a tunnel. Toward the east, however, the top layers are increasingly soft peats of poor quality for tunnel construction. The panel will consider alignments that would allow for tunneling through solid materials.

### Alignment Considerations

John Reilly, ERP facilitator, stated that the panel is considering multiple alignments for the tunnel. While higher quality soils are more easily accessible under the Montlake Cut, there also are considerations for

roadway grades and the interface with the Sound Transit light rail station, including scheduling and availability of staging areas near the tunnel's north portal. The panel continues to assess the balance between these various factors.

### Bored Tunnel

Gregg Korbin, ERP member, explained that the bored tunnel option uses a tunnel boring machine (TBM). The largest TBMs are 50 feet in diameter; this project would require a TBM with a diameter of 40 to 45 feet. The TBM is expensive to purchase; it also takes time to ship, assemble and test the machine. He estimated it would take 15 to 18 months before excavation could begin. It also is difficult to find used equipment due to high demand. Few TBMs of this size are in existence.

Gregg proposed that for this project, one TBM would be used to drive the two bores, each starting from the south portal. The TBM would need to be retrieved after the first bore and returned the staging area at the south shore before starting the second bore. The extensive weight of the machine will make it difficult to transport from the north to the south side of the Montlake Cut. He suggested this could be done via barge.

Typical TBMs are used for projects which extend for several miles in order to be cost and time effective. The TBM has a learning curve for the initial 1,000 feet of the project. A minimum of 20 feet of good soil is needed for cover above the top of the tunnel. The tight radii of the curves for the proposed tunnel alignments would be difficult to navigate. It is, therefore, estimated that this project with a relatively short length would progress at approximately 10 to 20 feet per day.

Gregg provided a video animation to explain the excavation process using a TBM.

### Immersed Tunnel

Lars Christian Ingerslev, ERP member, explained that soil conditions are a less important consideration for the immersed tunnel option. This is the shallowest tunnel option, so the road grades are less steep. Only six feet of cover below the Montlake Cut is recommended for an immersed tunnel. He noted, however, that moving the tunnel alignment farther to the east would require a longer immersed tunnel section with increased excavation and environmental concerns.

The immersed tunnel section could be constructed on-site or at another location. The south area will need to be excavated for the cut and cover approaches, so he recommended using this area to initially construct the immersed tunnel section. The immersed tunnel could be built in one or two segments, depending on the alignment and concerns for blocking the Montlake Cut. He estimated that excavation for the immersed tunnel would take approximately one to two weeks with placement of the tunnel section occurring in one day. The channel would only be fully closed to navigation for the hours during placement. At no time, would fish migration be completely blocked. After the immersed tunnel is placed, cofferdams could be used sequentially on the north and south shorelines to connect the cut and cover tunnel approaches. To avoid cofferdams, the immersed tunnel section could be extended. Near Husky Stadium, slurry walls could be used instead of dewatering.

### Mined Tunnel

Vojtech Gall, ERP member, provided an overview of the sequential excavation method (SEM) to construct a mined tunnel. This option would require approximately 20 feet of cover to manage risk from the water above and without the need to place insulation blankets at the bottom of the Montlake Cut. The SEM portion of the tunnel could extend a total of 500 feet in order to avoid impacts to the shorelines and wetlands. The north and southbound tunnels would be excavated separately, but they could be advanced

at the same time. Additionally, SEM technology allows the tunnel curves to be wider to accommodate sight distance requirements.

This method could use a staging area from the south portal. Freeze pipes would be installed using horizontal directional drilling to circulate coolant. Further investigations would be needed to determine whether freezing must occur around the full circumference of the tunnel or only for the tunnel's crown. Once the ground freezing is completed, Vojtech estimated that excavation could progress at two feet per day. After each segment of excavation, a thick layer of shotcrete is sprayed to form the tunnel, followed by placement of a waterproof lining, and a final concrete liner finish.

### Environmental Considerations

José Carrasquero-Verde, ERP member, provided an overview of the environmental issues that the panel must consider. The concerns include fish, fisheries, pollutants, shorelines, turbidity, water temperature, noise, and shading. He suggested that the SEM construction option may have the least environmental impacts, while alignments under the Montlake Cut may reduce the effects on wetlands. He noted, however, that there are trade-offs for each of the construction methods and alignments, as well as opportunities to minimize and mitigate the effects.

### Next Steps

Larry Kyle, SR 520 program engineering manager, explained that the project team is in the process of assessing the grades for each of the proposed construction methods and alignments to provide to the panel members. This information would allow the panel to evaluate the different alignments

John Reilly noted that additional information would be available at Wednesday's report out, as well as in the panel's final report.

**MEETING SUMMARY**  
**SR 520 Alternative K – Montlake Cut Tunnel**  
**Expert Review Panel – Meeting with Mediation Participants**  
**Wednesday, May 21, 3 – 4:30 p.m.**  
Plaza Building, 600 Stewart St, Suite 520, Seattle

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### Introductions

Julie Meredith, SR 520 program director, reviewed the purpose of the Tunnel Expert Review Panel (ERP). She noted that this was the last of three meetings between the panel and the mediation participants to report on the preliminary findings. A final report will be available in June.

John Reilly, ERP facilitator, reviewed the agenda for the meeting. The panel's scope of work was to review and evaluate strategies to tunnel across the Montlake Cut while addressing the constraints of the project area and the considerations of the mediation participants. The panel assessed three construction methods which could be used for a Montlake tunnel:

1. Immersed Tunnel,
2. Bored Tunnel / Tunnel Boring Machine (TBM), and
3. Mined Tunnel / Sequential Excavation Method (SEM).

### Geotechnical Considerations

Red Robinson, ERP member, provided an overview of the geotechnical considerations near the project area. He explained that the Montlake Cut is made up of materials similar to those found in the Mount Baker Ridge Tunnel in Seattle. The presence of hard glacial tills and clays are good mediums to accommodate tunneling. Groundwater in-flows also must be considered.

Each of the construction methods will be evaluated to minimize the staging areas on the north side. While the panel considered other options for the northern termini of the tunnel, there are geological constraints to changing this intersection. The soils to the north of Husky Stadium are poor quality marsh areas and a former landfill.

### Alignment Considerations

Brenda Bohlke, ERP member, noted that the panel began by reviewing Mediation Alternative K and considering how to accommodate the various project constraints. The panel considered a variety of alignment scenarios. While proposed alignments toward the west within the Montlake Cut provide a shorter tunnel length, this has a trade-off for steeper roadway grades. Each of the three construction methods may be better matched with a different alignment.

The panel will continue to work with the project team to identify optimum alignments for each of the tunnel construction methods based on traffic considerations, grades, curve radii and sightlines. This information will be presented in the panel's final report.

### Immersed Tunnel

Lars Christian Ingerslev, ERP member, explained that an immersed tunnel has the advantage of higher elevations than the other construction methods, since less cover is needed above the top of the tunnel. The Sound Transit ventilation area for the light rail station is a control that limits the reduction of the roadway grades for all of the tunnel options. Dave Dye, Deputy Secretary of Transportation, clarified that the WSDOT guidelines suggest grades up to seven percent, but this may be flexible depending on the conditions. The grade for the tunnel could be improved by working with Sound Transit regarding the alignment through the light rail station box. More information will be provided in the panel's final report.

An immersed tunnel would work best for a shorter tunnel alignment across the Montlake Cut in and to minimize encroachments on the wetlands. Christian noted that the dense materials within the channel would result in fewer suspended solids in the water, reducing concerns about sediment contamination. In-water excavation could be completed within one to two months. The Montlake Cut would only be blocked for navigation during the one day on which the immersed tunnel section was placed. Excavated materials could be "air lifted" to a barge over one to two days. A community representative, however, stated that Sound Transit was not allowed to remove excavated materials via barge and a similar restriction may be likely for the SR 520 project. Christian also noted, if the retaining wall in the Montlake Cut is unstable, it could be held back or replaced.

The immersed tunnel would connect to cut and cover sections on each side of the channel. The area to south in McCurdy Park could be used to construct the immersed tunnel section, since it would need to be excavated anyway. This is similar to the COWI tunnel proposal but on a smaller scale. Alternately, the immersed tunnel section could be constructed off-site and transported to the project area. The tunnel should be able to fit through the Ballard Locks in one section, or split into smaller sections.

### Bored Tunnel

Gregg Korbin, ERP member, reviewed the bored tunnel construction method, which uses a tunnel boring machine (TBM). This project is not typical for the TBM method due to the large diameter of the tunnel and the relatively short tunnel length. The project would require a TBM with 40 to 45 feet in diameter. Additionally, the alignment options for this tunnel crossing range from 1,000 feet to 1,800 feet in length, while in most cases TBMs are used for tunnels over one mile long.

He approximated that the cost to purchase the TBM would range from \$40 to \$50 million. It would take one year to order a new TBM, followed by six months to assemble and test the machine. Opportunities to jointly purchase the TBM with another project would depend on the local contracting laws. He noted, however, that the purchaser takes full responsibility for the machine. Used machines of this size are rare and would require refurbishing at the factory before re-use, which would take several months.

The bored tunnel needs a minimum cover of 20 feet of good soils above the top of the tunnel, resulting in higher grades than the immersed tunnel option. The initial grade assessments ranged from eight to 14 percent, but further geotechnical analysis will be necessary to confirm the grades. Gregg reiterated the constraints imposed by the Sound Transit ventilation box.

The staging area for the TBM would be on the south side of the Montlake Cut. On the north side of the channel, the only construction activity would be the retrieval of the TBM for the second boring. The TBM is a very heavy machine that would need to be moved using a barge and large crane. Additional considerations will be needed to determine how to transport the TBM from the north to the south for the second bore.

All excavated materials would be removed via truck. Gregg estimated that the amount of excavated materials for a tunnel 1,500 in length and 45 feet in diameter would be 130,000 yards per bore, which is equivalent to 2,000 truck loads. This is significantly less than the amount of materials that will be excavated by Sound Transit.

### Mined Tunnel

Vojtech Gall, ERP member, provided an overview of the sequential excavation method (SEM), which is frequently used to accommodate shorter tunnels in urban areas. He noted that SEM has more flexibility than the other methods, such as the ability to adapt to various rounded geometries and to be widened through a curve to increase sightlines. The SEM would work best with a shorter tunnel alignment. The SEM portion of the tunnel could be 200 to 500 feet in length with cut and cover approach sections. Approximately 20 feet of good soil cover is needed above the top of the tunnel. Since this increases the grades, the panel will need to work with the project team to optimize the alignment options.

Vojtech presented a sample tunnel cross-section based on the SR 520 lane configurations, showing a total width of 48 feet and height of 36 feet. The tunnel would be excavated in small segments from both the north and south portals. Each portal would have a deep cut with slurry walls. Longitudinal freeze pipes would use a coolant to freeze the ground 10 feet around the circumference of the tunnel. Then, a 15 inch thick layer of shotcrete would form the outer layer of the tunnel, followed by a waterproof membrane, and a cast-in-place concrete lining. Finally, the mechanical and electrical systems would be installed. While it may be possible to reduce the total height of the tunnel by incorporating a binocular shape, ventilation fans and signage will need to be accommodated.

Vojtech noted that SEM would use approximately four megawatts of electricity for the freezing process. The TBM also would use electricity. Sound Transit was able to negotiate its electricity needs with Seattle City Light.

The project team will need to weigh various factors in evaluating each of the tunnel construction methods including size, grades, cost, structural integrity, and schedule.

### Cut and Cover Sections

John Townsend, ERP member, explained that each of the tunnel construction methods would use cut and cover areas for the approaches. The immersed tunnel uses the most cut and cover, while the bored tunnel uses the least. The main concern for cut and cover areas is dewatering. The cut and cover areas can be constructed using soldier pile and lagging walls, interlocking concrete walls, or slurry walls. Slurry walls are the preferred method if hard clay soils are available, since this prevents dewatering settlement and minimizes settling movements. There should be no impact to groundwater flows using slurry walls, but there may be impacts with the other methods. Additionally, the area is unlikely to have groundwater flows since the materials are very dense.

The immersed tunnel would incorporate a small casting basin on the south side with cut and cover areas from each shore. This method is estimated to take approximately three years for total construction.

The bored tunnel would use small cut and cover sections. This method would take approximately four years for construction.

The mined tunnel would use freeze pits on both sides of the channel. While this may overlap with Sound Transit construction, the freeze pits are not large. Once Sound Transit construction was complete, then the cut and cover area on the north side would be extended to the intersection. The SEM would take at least three years for construction.

### Environmental Considerations

José Carrasquero-Verde, ERP member, reviewed the environmental concerns associated with a tunnel. The project includes sensitive areas for fish and wildlife habitat. He noted that the SEM and TBM would have the least environmental impacts for aquatic habitat and wetlands, assuming they can avoid in-water construction. These options would avoid in-water construction effects, alleviating concerns for Tribal fishing rights, fish passage, and water quality.

The immersed tunnel option, however, could use best management practices to avoid or minimize impacts associated with turbidity, fish migration, and noise. José noted that there is a two to three month window without migration for endangered species act (ESA) listed fish. The immersed tunnel could complete all in-water work within one season, from October to December. Fish could be diverted toward other areas away from the construction zone. Alignments within the Montlake Cut could avoid wetland impacts, but there may be potential shoreline modifications. He suggested that it may be possible for the immersed tunnel option to avoid significant impacts by using performance standards and incorporating avoidance and minimization methods.

If forested wetlands are disturbed near the shoreline, it may take over 50 years to return them to their current state. The emerging vegetation and shrub areas will take less time to recover. The near shore underwater environment, however, may be improved through removal of the millefoil invasive species.

The water near the University of Washington Waterfront Activities Center is approximately 10 feet deep. There are a lot of soft soils in this area, however. When construction of the tunnel is completed, the waterfront could be restored to provide recreational access.

### General Comments and Questions

The panel reconfirmed that each of the construction methods may best match with a different alignment. Additionally, the project team may want to consider alternative connections to the Pacific Street intersection, but this may introduce other constraints and concerns.

The immersed tunnel method may have lower construction costs, depending on the alignment. It could, however, have higher mitigation costs. Further evaluation is needed to fully compare the costs of the three construction methods.

Ventilation of the tunnel would be required. Jet fans are the preferred ventilation method. Using the shorter alignment alternative, the fans could be located in the cut and cover sections. The fans would not usually be running during normal operations; they would generally only be needed in emergency situations. All of the construction methods will require fire and life safety considerations, but a large ventilation tower is not needed. The three methods are comparable for seismic and safety considerations. Additionally, there is no substantive difference in maintaining the tunnel based on the construction method selected.

The panel acknowledged the possibility of using jacking methods for tunnel construction and John Townsend provided an overview of this method. Based on the curve and grade requirements, however, the panel recommended against using the jacking method for this project. There may be increased risks from the jacking method due to the water above the tunnel, so freezing may be required. It also is a more expensive option.

The panel recommended that WSDOT consider initiating discussions with Sound Transit regarding the flexibility of the light rail station box. More information is needed to determine whether and how this may impact design and operations for the light rail station, as well as construction staging. If the box height is flexible, this may improve the roadway grades and provide alternative intersection opportunities.

The panel noted that if it is possible that the tunnel could be converted to light rail at a future point, additional considerations would be needed concerning grade limitations, since the geometric requirements for light rail are different than for roadways.

Julie Meredith thanked the panel and the mediation participants for attending. Additional information will be provided in the panel's final report, including alignment maps and grade assessments. The panel's report will be available at the mediation session on June 17.

## 12. APPENDIX B - REFERENCES

### Tunneling

1. Abbott, E.L. and Bolan, R.K., 1995 "Port of Miami Tunnel Study: Bored or Immersed Tubes?", RETC, Proc., Chapter 105, p.1289-1302.
2. Babendererde, S, 1993, "Conceptual requirements for soft ground tunnel boring machines", Proc. International Tunneling Association, Options for Tunneling, Amsterdam, pp. 377-390
3. Charalambu, H. and Finch, A.P., "The New St. Clair River Tunnel", 1993 RETC Proceedings, Chapter 58, p. 945-962.
4. Grasso, P., Guglielmetti, V., Mahtab, A. & Xu, S., 2007 "Mechanized Tunnelling in Urban Areas" Taylor & Francis, UK, ISBN: 9780415420105
5. Holzmann, P., 1988, "Freezing Method for Construction of a Metro Tunnel Under the Limmat River in Zurich," Project Brochure.
6. Holzmann, P., 1977, "Metro Section 81, Frankfurt, Germany, Crossing of the River Main", Project Brochure.
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8. ITA 1997 "Immersed and Floating Tunnels Working Group State-of-the-Art Report," Second Edition, Pergamon, April
9. Isaksson, T 1998, "Tunnelling in poor ground - choice of shield method based on reliability" Proc XI Danube - European Conference on Soil Mechanics and Geotechnical Engineering: 527-534 (Balkema, Rotterdam)
10. ITA 1997, "State of the Art report in Immersed and Floating Tunnels", Tunnelling and Underground Space Technology, Vol. 12, Nr. 2, pp. 83-354
11. ITA 2000 "Recommendations and Guidelines for Tunnel Boring Machines (TBMs)" Report of Working Group 14
12. ITA 2004 "Guidelines for Tunnelling Risk Management", International Tunnelling Association, Report of Working Group 2, Eskensen, S., TUST Vol. 19, No. 3, pp 217-237.
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16. Robinson, R., Cox, E & Dirks, M., 2002, "Tunneling in Seattle - A History of Innovation" presented at the North American Tunneling Conference, Seattle,
17. Robinson, R., 2005 "Tunneling in Seattle - the long and short of it", Tunnels and Tunneling North America, pgs. 29 - 30, June
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19. Shannon & Wilson, Inc. 2007 "Preliminary 10 Percent Design Geotechnical Report" for SR520 Project, WSDOT/HDR Inc., May 30
20. Technical Manual: Design and Construction of Road Tunnels, FHWA and NHI, Unpublished Draft, Chapter 5. May 2007

**Environmental**

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24. King County. 2005. Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan. Technical Appendices. Volume III, Appendix C. Available at: <<http://dnr.metrokc.gov/wrias/8/Chinook-conservation-plan.htm>>.
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27. WDFW. 2004. Washington State Salmonid Stock Inventory: Bull Trout/Dolly Varden. Washington Department of Fish and Wildlife, Olympia, Washington.

**13. APPENDIX C – EXPERT REVIEW PANEL MEMBERS, RESUMES**

Resumes of the Expert Review Panel are given following.

**JOHN J. REILLY, P.E., C.P.ENG.**

**Experience:**

45 years of responsible experience in the management, design and construction of large, complex, infrastructure programs, including tunnels and underground facilities.

**Focus Areas:**

Organization and strategy for Transportation Agencies - program management, management oversight and assistance, partnering, team alignment, design review processes, integrated cost and risk processes (WSDOT's CEVP®), application of advanced technologies for transit systems, tunnels and underground engineering.

**Award winning projects:**

Include design development, GEC management and engineering for Boston's \$1 billion Southwest Corridor Transit, Rail, Highway and Urban Design Project - winner of the US President's Design Award and the ASCE Outstanding Civil Engineering Achievement of 1988.

**Expertise/Practice Areas:**

- Management/organization of agency and consultant teams for major infrastructure projects - airports, highways, rail and rapid transit systems including tunnels and underground facilities.
- Risk identification and mitigation systems with links to cost-range determination and strategic risk management.
- Strategic approaches to management and delivery – leadership, new paradigms, partnering and alliancing
- Partnering, teambuilding and structured work sessions, defining goals and objectives, key results, critical activities and performance measures. Intervention, mediation and issue resolution sessions
- Application of advanced engineering technologies for transit, bridges, tunnels and complex underground and infrastructure programs.

**Years of Experience:**

Management / Project Consulting	27
Management / Engineering Design	<u>18</u>
Total, Management and Engineering	45

**Education:**

M.S. 1964 Structural Engineering,  
University of California, Berkeley, California  
B.E. (Honours) 1963 Civil/Structural Engineering,  
University of Sydney, Sydney, Australia.

**Professional Registration:**

Massachusetts	1978, Structural
Australia	1972, Chartered Engineer
First registered	1965, British Columbia

**PROFESSIONAL**

- President**, American Underground Construction Association (July 1999-June 2001)
- Chair**, ITA Working Group 13 "Direct and Indirect Advantages, Underground Facilities" 1999-2002
- Chair**, ITA Working Group 20 "Urban Problems, Underground Solutions" 2002 -2005
- Chair**, North American Tunneling Conference, NAT2000, Boston, June 2000
- Chair**, "Management, Policy and Contracting for underground construction" AUA/ITA Conference. April 1996, Washington DC
- Member**, American Society of Civil Engineers
- Member**, Project Management Institute
- Member**, Institution of Civil Engineers Australia
- Member**, International Tunneling Association
- Member**, Australian Tunneling Association
- Member**, British Tunnelling Society



**TECHNICAL INTERESTS**

**"Management and organization of major urban infrastructure construction programs"**.

Management and organizational approaches including Policy, Planning, Management, Contracting, Media and Political Involvement, Partnering, Alliancing, Risk Assessment and Mitigation, Cost Estimating and Cost Validation, Media and Communications.

**"Risk-based Cost Estimating"** – primarily WSDOT's Cost Estimate Validation Process (CEVP®) – initially conceived by John Reilly, Mike McBride and Dave Dye (WSDOT) in January 2002.

**"Innovative Contracting and Delivery"** – improved project delivery options including design-build, design-build with incentives, General Contractor/Construction Manager and Alliancing (UK & Australian system)

See also "Publications & Presentations" and other key topics on John Reilly's Website:

[www.JohnReilly.us](http://www.JohnReilly.us) ..

## TRANSPORTATION PROJECTS – SELECTED LISTINGS

### WSDOT MANAGEMENT + ORGANIZATIONAL ASSISTANCE + CEVP® COST / RISK

Management and strategic assistance for the Washington State Department of Transportation's Urban Corridors Mega-Project Program. Organizational development, alignment and program implementation. With WSDOT, development and implementation of the Cost Estimate Validation Process (CEVP®) which integrates cost assessment with risk identification and mitigation to produce more reliable estimates of cost and schedule ranges. 2002-Present.

### WSDOT – ALASKAN WAY VIADUCT & SEAWALL REPLACEMENT PROJECT

Identification and presentation of a range of options for replacement of the Alaskan Way Viaduct and Seawall – a 50 year old elevated highway structure. 2001-2003 Organizational Review of the Project's structure for WSDOT, recommendations for improvement. 2004

### TORONTO WATERFRONT REVITALIZATION

CEVP®, cost estimating /validation, risk and contracting and delivery options for this multi-billion waterfront / public realm / development in Toronto. 2006-Present

### LONDON UNDERGROUND - PARTNERING

Partnering and management assistance to Bombardier, and Westinghouse for new signal systems and rolling stock - Bakerloo, Central, Victoria, District, Circle and Metropolitan lines. Part of the overall upgrade, approximately £8 billion. 2003-4

### MASSACHUSETTS TURNPIKE EXECUTIVE HIGHWAY/TURNPIKE/CENTRAL ARTERY

Facilitation, high-level work-out session for executives of the Massachusetts Turnpike, Central Artery Project and Highway Department to combine their staff. 1999.

### ATLANTA TRANSIT SYSTEM, REORGANIZATION / WORK-OUT SESSIONS

Management consulting and team alignment sessions for the reorganization and integration of the design, construction, systems and infrastructure maintenance groups. 2002-2003

### BAY AREA RAPID TRANSIT VEHICLE REHAB PROGRAM

Partnering process and management recommendations for BART's \$350 million vehicle rehabilitation project for Agency and Manufacturer. 1995-1998.

### TORONTO TRANSIT COMMISSION (TTC), RAPID TRANSIT EXPANSION PROGRAM

Development and implementation of the teambuilding process required to implement a fully integrated TTC/consultant team for the \$3 billion Rapid Transit Expansion Program (RTEP).

### TORONTO TRANSIT COMMISSION ENGINEERING / CONSTRUCTION DEPT.

Alternatives for design and construction organizational changes, based on the RTEP mega-program. 1995

### SEPTA M4 VEHICLE PROCUREMENT

Implementation of a partnering-based intervention process for improvements to management communication and working relations to resolve manufacturing problems. Customer satisfaction was substantially improved. 1996-99

### MBTA DESIGN & CONSTRUCTION DIRECTORATE - REORGANIZATION

Assistance to the Deputy General Manager for a review of organizational alternatives for the agency, focusing on capital planning and re-organization of the Design and Construction Directorate. 1991-93.

### MBTA DESIGN & CONSTRUCTION CONSULTANTS /CM SERVICE LEVELS

Recommendations for the appropriate use of MBTA staff compared to outside consultants, including augmentation of MBTA's design and design management capability. Staff levels compared with similar agencies, on a construction-volume normalized basis, and staffing profiles by discipline. 1993

### SFIA – 'AIRTRAIN' PEOPLE MOVER SYSTEM

Partnering, new People Mover Airport Transit System at San Francisco International Airport. 1998.

### BOSTON SOUTHWEST CORRIDOR PROJECT

Program Director, GEC, for MBTA's \$1 billion Southwest Corridor high-speed rail/transit/arterial road/development project – ASCE Outstanding Civil Engineering Achievement of 1988. 1978-86

### LOGAN AIRPORT + REGIONAL TRANSPORTATION PLANNING

Project Manager, Massport's Cross Harbor and Regional Transportation Project. Long-range terminal and access alternatives for Logan Airport including regional transportation and South Boston development. 1985-86

### WASHINGTON METRO

Project engineering and technical management of 14 Washington DC Metro Rapid Transit design sections. Coordination of designs and section designers, management of scopes of work and design fees. Projects included rock tunnels, soft earth tunnels, cut-and-cover stations and the WMATA headquarters building with revenue collection facility. 1968-72

## TUNNELING & UNDERGROUND CONSTRUCTION – SELECTED

- Secretary, Board of Engineering Consultants, Washington DC Metro System 1969 - 1972
- Engineering coordination and technical management, underground cut-and-cover and NATM rock stations; NATM rock tunnel line sections; cut-and-cover stations, earth tunnels, underpinning of buildings by jacked-piles and permanent slurry walls. Planning for machine bored line tunnels in rock. Washington DC Metro System 1969 - 1972
- Technical consulting, Federal buildings, Washington DC for impact, cost reduction and mitigation of effects caused by earth tunnels adjacent to historic buildings. GSA 1974 - 1978
- Project and design management, permanent slurry wall system acting as underpinning and final tunnel wall. MBTA, Southwest Corridor Project, Boston 1982 - 1985
- Evaluation of advanced European underground engineering and construction technologies for the US market. Technologies, value and cost competition, new capabilities and acceptance. Systems included earth pressure-balanced shields in soft ground with extruded concrete lining, soft ground NATM construction, specialized diaphragm and cut-off walls. Hochtief AG with Dames and Moore, 1987
- Engineering alternatives including cost and technical merit for large underground interaction chambers, 54 miles of precast jacked tunnels, access and ventilation shafts. US Superconducting Supercollider, Florida proposal to DOE 1987
- Construction management and inspection, underpinning of historic buildings, Back Bay, Boston Massachusetts, 1987 - 1989
- Mined Transit Stations task force, Los Angeles. Management of a technically focused team to evaluate options and technical implications of using alternative construction methods - including full underground mining - for the heavy rail transit stations of the Red Line, Segment 2. Los Angeles Metro, Rail Construction Corporation, 1991
- Opinion, technical merit and value, related to elimination of reinforcement for the final tunnel liner, Los Angeles Metro System. Scope included soil-structure interaction, concrete integrity, durability, dynamic analysis and earthquake forces in real time. 1992
- Chair of 2 International Tunneling Association Working Groups regarding underground facilities benefits and advantages.
- See also papers and publications (following)

## RELEVANT PUBLICATIONS

1. Reilly, J J 1996a w. Ball, J G & Shirlaw, J N "Procurement and Contracting Strategies - Toronto's Rapid Transit Expansion Program" North American Tunnelling Vol. 2, pp 541-546 AA Balkema ISBN 90 5410 802 9
2. Reilly, J J 1997, 'Owner responsibilities in the selection of tunnel boring machines with reference to contractual requirements and construction conditions' Tunnels for People Vienna April Proc pp 749-756 AA Balkema
3. Reilly, J J 1998a w. Isaksson, T & Anderson, J 'Tunnel Project Procurement and Processes – Fundamental Issues of Concern' Conference on "Reducing Risk in Tunnel Design+ Construction", Basel, December
4. Reilly, J.J 2004c w. McBride, M, Sangrey, D, MacDonald, D & Brown, J. "The development of CEVP® - WSDOT's Cost-Risk Estimating Process" Proceedings, Boston Society of Civil Engineers, Fall/Winter 2004
5. Reilly, J.J 2005b "Key Problems and Tunnel Boring Machine Application in the West Line of the Mega South to North Water Diversion Project in China", (TBMSN-2005) Symposium Proc, Beijing, Sep. 12
6. Reilly, J.J 2007c, "Alternative Contracting and Innovative Project Management", Proc. Rapid Excavation & Tunneling Conference, Toronto, June.

## **BRENDA MYERS BOHLKE, Ph.D. PG**

Principal Consultant

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Dr. Bohlke brings 30 years experience in large multidisciplinary programs focusing on large complex infrastructure projects. She currently works as a consultant in the fields of underground design and construction, water and transportation planning. Her diverse background and experience working for federal, state and local agencies, as a design consultant, and time spent on Capital Hill have given her a unique and big picture perspective, and creativity to solving project issues and getting “go”. Whether she’s managing a billion dollar project or serving as an advisor for a high-profile plan, Dr. Bohlke has the leadership capability to bring widely varied stakeholders together, resulting in creative solutions to complicated projects. Her underground and tunnel experience encompasses a number of applications, methods, and materials: soft ground, rock and transitional materials.

Recognizing an industry need to resolve contractor, owner and engineering disputes, Dr. Bohlke organized and convened the industry-wide Geotechnical Baseline Forum. This unique group of concerned industry leaders produced the watershed publication that improved the contracting documentation for underground and large geotechnical programs with the Geotechnical Baseline Report.

Currently, Dr. Bohlke is the principal consultant for the Chesapeake Crescent Initiative, a coalition of private and public entities coalesced around the concept of implementing a Regional framework for the Mid-Atlantic Region focused on the replacing critical tunnels in Baltimore and DC to improve the north-south flow of freight and passenger rail traffic. She recently returned from Panama where she served as the Program Manager of the Panama Canal Program Management Advisory Services Contract overseeing the Master Planning for the expansion of the canal. The Expansion program as approved by the Panama Canal Authority Board of Directors includes the design and construction of new larger 3-step locks system with water saving basins on the Atlantic and the Pacific, new approach channels, and deepening and widening of the existing canal. A comprehensive evaluation of the operational needs, physical constraints of the existing system and the economics of the existing and new canal systems were evaluated. Her emphasis and training of the staff of the ACP on principles of large project scheduling, and cost estimating and their sensitivity to various project risks. Estimated cost of the locks will be approximately \$5.5 Billion.

Dr. Bohlke also has 20 years experience in the intercity rail industry, specializing in high speed rail and maglev. She has led numerous program studies and advised state leaders on the merits and implementation issues and led a new design for a US Maglev system under the National Maglev Initiative. She was Program Manager for the Baltimore Washington Maglev Project for EIS and Preliminary engineering for a 45 mile, \$4.5 billion high speed maglev project connecting Baltimore and Washington, DC with a three urban tunnels. The design resulted from a consensus among numerous meetings with various communities, businesses and local and national stakeholders. The program addresses intermodal stations, innovative financing and definition of a multi-jurisdictional ownership authority to operate and plan for system expansion.

Before seeking her PhD, Brenda began her career at the Smithsonian Institution in environmental and coastal processes and water quality research, and the National Oceanic and Atmospheric Administration. She managed the marine geotechnical testing laboratory for the NOAA-Atlantic Oceanic and Meteorological Laboratory in Miami.

### **Education**

Ph.D., M.S. University of California, Berkeley—Geological Engineering and Underground Design and Construction  
MS University of Miami –Marine Geology and Geophysics  
B.S. U. of Maryland -Geology

### **Professional Affiliations**

Chair of the Underground Construction Association of SME; American National Research Council, former member of the Board on Infrastructure and the Constructed Environment (BICE); National Science Foundation--Advisory Committee to the Engineering Directorate; Transportation Research Board High Speed Guided Transport Committee and Tunnels and Underground Design Committee; Defense Special Weapons Agency Task Force on the Use of the Underground to Protect Critical Infrastructure; Underground Technology Research Council; former High Speed Rail/Maglev Association;  
Congressional Fellow 1988-1989

### **List of Signature Projects:**

Value Engineering for Western Regional Conveyance Tunnel  
Rocky Mt. High Speed Rail – tunnel consultant (current)  
Tysons Tunnel -- Dulles Rail Extension: (Community Client Rep.)  
Waster and Wastewater tunnels (St.Louis, Detroit, DC, Hawaii)  
Sydney M5 Motorway  
Singapore Deep Tunnel Sewerage System  
Boston Sewer Outfall Tunnel  
Port of Miami Tunnel  
Panama Canal Expansion Program  
Washington, DC Metro  
Los Angeles Metro  
Nuclear Waste Repository Program  
Baltimore Washington Maglev Project-3 tunnels  
National Maglev Initiative



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## **Vojtech Gall, Ph.D., P.E.**

Principal  
Senior Tunnel Engineer

### **Years of Experience**

22

### **Education**

Ph.D., Civil Engineering, University of Maryland  
M.Sc., Mining Engineering, The University of Alabama  
M.Sc., Civil Engineering, Technical University (RWTH) Aachen, Germany

### **Professional Registrations**

California (2008, pending), Colorado, 2007 (41345), Illinois, 2005 (29298), Michigan, 2005 (6201052822), North Carolina, 2005 (031304), New Jersey, 2003 (GE04454700), New York, 2003 (081226), Maryland, 2003 (29298), Texas, 2001 (88716), Washington, 2000 (36752), Massachusetts, 1997 (40318), Alaska, 1997 (CE 9628), Pennsylvania, 1996 (PE-050281-E), Virginia, 1995 (025740)

### **Professional Associations**

International Tunneling Association; American Society of Civil Engineers; Society for Mining, Metallurgy, and Exploration, Inc.; American Concrete Institute; American Underground Construction Association; Disputes Review Board Foundation; American Rock Mechanics Association; International Society for Rock Mechanics

### **Key Qualifications**

Vojtech Gall has extensive experience in the design, supervision and construction management for underground projects. Having held key positions in fields ranging from structural engineering to project management and project oversight, he was directly involved in all aspects of tunnel engineering; evaluation of geologic conditions, compilation of geotechnical data for structural analyses carried out by numerical methods, design and design coordination, preparation of contract drawings and specifications. On numerous tunneling projects he has managed construction phase services. He has been instrumental in introducing the flexible membrane based waterproofing technology for cut-and-cover transit structures. Relevant tunneling projects include:

### **Railroad /Transit**

- New Jersey Transit Trans Hudson Express Tunnels, Newark, New Jersey, to New York, New York. New railway tunnel and terminus station in Manhattan and two new 1.5-mile long tunnels under the New Jersey Palisades and the Hudson River. Highly varied geological conditions (soft glacial lake deposits, estuarine deposits, hard Jurassic Diabase, sandstone, and various hard rocks including Manhattan Schist). Manhattan side soft soil and mixed face conditions require frozen soil techniques for pre-stabilizing and shotcrete linings for initial support (NATM) for the TBM receiving tunnels. Cross passages under the Hudson River require similar pre-stabilizing by ground freezing and NATM tunneling. Involvement includes preliminary design of these NATM and ground freezing aspects and

consulting for other NATM/SEM tunnels of the project including rock caverns in Manhattan Schist and in the Palisades.

- Virginia Department of Rail and Public Transportation (VDRPT) and Metropolitan Washington Airports Authority (MWAA), Dulles Corridor Rapid Transit Project, McLean/Dulles, Virginia: Tunnel consulting and design services related to tunnel alternative analyses and tunnel engineering at Tysons Corner and at Washington Dulles International Airport utilizing cut-and-cover, TBM and NATM soft-ground and rock tunneling designs for running tunnels and an underground station at Dulles Airport.
- London Underground Shepherd's Bush Station, Central Line, London, UK. Upgrading of the existing underground station, improvement of passenger access to the platforms, provision of access to the platforms and additional escape routes, and relocation of selected utilities and systems. Provide constructability review and Category III design check.
- London Underground King's Cross Station Redevelopment, London, U.K. Provide independent review of excavation and support systems proposed for the upgrade and improvement of three old London Underground stations including new pedestrian link and concourse tunnels above and between the station tunnels. Tunnel construction is beneath these historic buildings, a live railway station, under shallow cover. Advise on the waterproofing and permanent lining, and provide support for contractual and technical decisions and inspection services during construction.
- New Jersey Transit Authority Hudson-Bergen Light Rail System Weehawken Tunnel, North Bergen, New Jersey. In the framework of a Value Engineering Change Proposal (VECP) provided a shotcrete final lining design to the contractor of this project. The shotcrete final lining was implemented in lieu of a cast-in-place concrete lining within the transition sections between the two-track running tunnels and the station platform tunnel as well as in the transition section at the east portal. Its installation was against a PVC waterproofing system. Special features of the shotcrete final lining included implementation of micro polypropylene fibers to enhance the fire resistance of the lining. Provided quality control services during shotcrete final lining installation.
- Metropolitan Transportation Authority (MTA) / Long Island Railroad (LIRR), East Side Access project, New York, New York: Provide technical lead for / advise on design of tunnels using hard rock tunnel boring machines and drill and blast methods. The project encompasses the Manhattan running tunnels with a length of approx. 25,000 ft, cross over caverns and two large station caverns for direct LIRR service to Manhattan's Grand Central Terminal. The alignment starts at the bulkheads of the existing 63<sup>rd</sup> Street Subway tunnels at 63<sup>rd</sup> Street and Second Avenue and continues to the terminus of the tail tracks at East 38<sup>th</sup> Street and Park Avenue.
- Sound Transit, Beacon Hill Station and Running Tunnels, Seattle, WA: Provide construction support services and develop working drawings for West Portal support of excavation design including break-out eye for TBM drive, develop excavation and support sequence drawings for SEM ventilation structures, adapt waterproofing system (strengthening and enhance repair measures) to suit "walking of TBM" through the station platform tunnel on invert concrete.
- Massachusetts Bay Transportation Authority (MBTA) Contract E02CN15, Russia Wharf Segment, Boston, Massachusetts: Design of binocular bus/light railway NATM tunnel to be constructed underneath historic Russia Wharf Building in marine clay, organic clay, fill material in conjunction with ground freezing. Conceptual and detail design of ground freezing, design of excavation and support sequence, instrumentation and monitoring program, shotcrete and concrete lining, waterproofing system, connections to box tunnel structures. Construction support services.
- MTO Contract B221, Wilshire/Normandie Station and Running Tunnels, Los Angeles, California: Expert witness services related to the utilization of a HDPE membrane waterproofing system for

running tunnels and station.

- Washington Metropolitan Area Transit Authority (WMATA) Outer Branch Route, Section F-6b, Washington, DC: Design of two parallel 1,500 ft. long NATM tunnels through clays and sandy material. Development of regular tunnel cross section of about 350 sqft, layout of two different excavation and support sequences to account for the two different soil layers, P1 clays and P2 sands. Design of the shotcrete lining, waterproofing and concrete inner lining. Development of structural calculations for the linings and analysis of subsidence for buildings affected by the tunnel operation.
- Washington Metropolitan Area Transit Authority (WMATA) Greenbelt Route, Sections E4a and E3a, Washington, DC: Waterproofing design for Georgia Avenue-Petworth and Columbia Heights stations constructed in cut-and-cover and top-down construction methods. Use of reinforced and non-reinforced PVC waterproofing membranes around entire structure (closed system). Waterproofing installation against support of excavation walls consisting of soldier piles and lagging as well as slurry walls as part of permanent structures.
- Washington Metropolitan Area Transit Authority (WMATA) Greenbelt Route, Sections E4b and E3b, Washington, DC: Waterproofing design for cut-and-cover ventilation, emergency access shafts and cross-over structures. Use of non-reinforced PVC waterproofing membranes around entire structure (closed system). Waterproofing installation against support of excavation walls consisting of soldier piles and lagging as well as secant piles.
- Washington Metropolitan Area Transit Authority (WMATA) Greenbelt Route, Section E4b, Washington, DC: Constructability review and inspection during construction for 20 ft diameter single track tunnels driven according to NATM principles under the Rock Creek Cemetery in Washington D.C. Constructability review comprised selection of site installation for shotcrete plants, mucking areas and selection of tunneling equipment. Due to the sensitivity of the Rock Creek Cemetery, special pre-support measures were analyzed, including grouted spiles ahead of the face using chemical grouts, methods of dewatering, appropriate initial and final tunnel support.
- Washington Metropolitan Area Transit Authority (WMATA) Greenbelt Route, Section E3b, Washington, DC: Feasibility study for an over/under alignment (stacked scheme) of two single track, shield driven tunnels in soft ground/mixed face conditions. Recommendations led to adoption of the scheme by the Washington Metropolitan Transit Authority.
- Rupertus Tunnel, Salzburg, Austria: Twin NATM tunnel for the Austrian Railway Authority in gravel, silt and sandy materials, including two cut-and-cover sections using the canopy construction technique. Design and structural design computations using embedded frames with emphasis on backfilling of the shotcrete canopy and crossing of construction vehicles with low cover.
- Dallas Area Rapid Transit (DART) Light Rail System, Dallas, Texas: Development of a tunnel inspection manual for all underground structures of DART's light rail system; including underground station and adjacent ancillary rooms, ventilation and emergency access/egress structures, mined and cut-and-cover running tunnels and their cross passages. Developed procedures for a regular inspection program as well as irregular and emergency inspections, a defect rating system and a detailed inventory based on accepted formats including FTA's TCRP (Transit Cooperative Research Program) Synthesis 23, Inspection Policy and Procedures for Rail Transit Tunnels and Underground Structures.
- Dallas Area Rapid Transit (DART) Line Section NC-1B, CityPlace Station, Dallas, Texas: Preliminary and final NATM design of CityPlace station in Austin chalk including two station tunnels, cross passages, service rooms, escalator tunnels as well as emergency shafts and tunnels. Structural design computations for initial steel fiber reinforced shotcrete linings and final concrete and shotcrete final linings. Support during construction.

- Washington Metropolitan Area Transit Authority (WMATA) Red Line, Section B11a, Washington, DC: Construction support services for Section B11a of the Washington, D.C. Metro Red Line in Wheaton, Maryland; two 5,400 ft long single track NATM tunnels, ca. 20 ft. diameter through mixed face and hard rock conditions and two deep shafts. Excavation was by drill and blast, supported by a reinforced initial shotcrete lining. Services included advice to inspectors on documentation techniques for claim prevention, review of contractor's performance and operational techniques, selection of ground support and support installation, inspection of final lining placement for concrete and shotcrete final linings, participation in partnering meetings and recommendations on above items, as well as independent review of construction schedule.
- Dallas Area Rapid Transit (DART) North Central Rail Lines, Segments NC1-A1 & NC1-A2, Dallas, Texas: Structural design computation for the tunnel linings of the DART light rail tunnels in soft ground, mixed face and Austin chalk for two alternative designs: NATM and conventional (TBM). Subsidence analyses and investigations of the impact of tunneling operations on adjacent structures including piers, buildings, and sewer lines.
- CrossRail Project, London, U.K.: In the position of General Consultant to the CrossRail project, which encompasses approx. 8 miles of soft ground tunnels (mainly London clay) underneath the center of London, including five mined stations. Development of design criteria for soft ground tunnels and stations using sequential excavation methods (NATM).
- Brasilia Metro, Brasilia, Brazil: Twin NATM tunnel for the Brasilia Metro in porous clays. Redesign of excavation and support sequence to minimize surface and subsurface settlements using hip-sidewall drift approach. Structural design computations for the modified cross-section and specifications.

### **Highway Tunnels**

- Caltrans District 4 Devil's Slide Tunnels, San Pedro Mountain on US Highway 1 between Half-moon Bay and Pacifica, California. The tunnels bypass US Highway 1 in an area prone to landslides. NATM is used with five different support categories including rock reinforcement and pre-support elements including pipe arch canopies. Provide integrated on-site NATM consulting services to the contractor, shop drawings for excavation and support sequences, portal canopy, waterproofing and final linings, ground structure interaction (FE) analyses, and evaluation of NATM instrumentation and monitoring results.
- Singapore Land Transport Authority Fort Canning Tunnel and Realignment of Stamford Road. Singapore. Historic park area and an overburden cover of only 10 to 32 ft (3 to 9.5 m) above the proposed Fort Canning Tunnel posed challenges for design and construction. The initial design that called for construction with cut-and-cover methods was rejected and substituted by an NATM design utilizing a two-pass lining system for the mined portion of the tunnel.
- Boston Central Artery / Tunnel (CA/T), Contract C19E1, Boston, Massachusetts: Mined Tunnel Option (MTO-NATM) design for two-lane ramp tunnels (approximately 130m<sup>2</sup> excavation cross section area) in urban area and rail yard in marine clay, organic silt and fill material. Design of excavation and support sequence, instrumentation and monitoring program, shotcrete and concrete lining as well as the waterproofing system. Construction required utilization of various ground improvement and specialty construction techniques including the doorframe slab method, a horizontal pipe dewatering system and groundwater cut-off using secant jet grout walls and slurry walls.
- Boston Central Artery / Tunnel (CA/T), Contract C11A1, Boston, Massachusetts: Value engineering change proposal for a mined tunnel alternative according to the NATM for MBTA's Red Line South station underpinning. The design proposed the use of a between 60 to 72 ft wide NATM tunnel drive under the station structure with only some 10 feet of ground cover. The design included installation

of a pre-support grouted arch umbrella and excavation and support in multiple drifts using the side wall drift method. The design was supported by extensive numerical modeling to demonstrate that the impact on adjacent structures, namely One Financial Center, South Station and Federal Reserve Bank would be within CA/T project defined limits. A systematic risk analysis was performed for the project evaluating the various tunnel construction methods.

- Pennsylvania Turnpike Commission, Allegheny Tunnels By-Pass Study, Somerset, Pennsylvania: Study of by-pass alternatives for the existing Allegheny Mountain tunnels. Based on the need to improve the current alignment with respect to safety and to accommodate future traffic growth, a study into traffic improvements was performed, including rehabilitation and widening of existing tunnels to the construction of two new 3-lane and 4-lane tunnel configurations. Tasks included development of tunnel configuration (cross section, and excavation and support), portal locations, assessment of tunnel construction cost, construction scheduling, as well as operation and maintenance cost at a feasibility study completion level.
- Kaoshiung-Pingtun Tunnels, Second Freeway Project, Taiwan, ROC.: Design of two 1,700m long 3-lane NATM highway tunnels through weak rock formations, including fractured shales, sandstones and plastic mylonites, and faulty areas in earthquake active regions. Development of regular cross sections, excavation sequences and support, structural computations and specifications.
- Texas Turnpike Authority, Addison Airport Tunnel, Dallas, Texas: Preliminary design and cost estimate for 1,650 ft long, 2-lane NATM road tunnel under existing runways in mixed face conditions and Austin chalk. Use of the doorframe slab method to reduce surface disruptions to airport traffic.
- Pennsylvania Turnpike Commission (PTC), Lehigh Tunnel No. 2, Allentown, Pennsylvania: Engineering support services during construction of the 4,300ft long two-lane highway NATM tunnel, including three cross passage ways to the existing Lehigh Tunnel No. 1, through the central part of the Appalachian Mountains in shale, limestone, and sandstone.

### **Tunnel Rehabilitation**

- PATH System Rehabilitation, New York, New York: Consultant for construction ventilation; development of contract documents (specifications, layouts), check of contractor's ventilation design.
- Rehabilitation of the Bergen Tunnels, New Jersey Transit, Bergen, New Jersey: Outline design for the re-lining of an approx. 120-year old brick and stone masonry lined tunnel according to NATM. Development of the geotechnical investigation program, layout of excavation and support sequences, recommendations on waterproofing, drainage system and final, concrete lining layout.
- Fan Plant No. 7235, 125<sup>th</sup> Street, New York, New York: Design for and site supervision of remedial grouting for waterproofing.
- City of Alexandria, Cameron Run Tunnels Rehabilitation Project, Alexandria, Virginia: Rehabilitation design for seven 20 ft diameter, each about 175 ft long, storm water drains beneath the CSX railroad embankment at Cameron Run in the City of Alexandria. These approximately 25-year-old tunnels, supported by corrugated steel liner plates exhibited inward lining deformations of up to approx. two feet. Rehabilitation design foresaw implementation of a jacking device to partially expand the existing deformations to an optimized and hydraulically required perimeter, supported by steel sets and shotcrete. Rehabilitation is carried out beneath operating rail tracks in two stages to assure sufficient water flow for the Cameron Run. The services include construction management.
- Port Authority of Allegheny County (PAT), Berry Street Tunnel, Pittsburgh, Pennsylvania: Value engineering change proposal (VECP) design for Mosites Construction Company for enlargement of approximately 2,650 ft of existing 130-year-old horseshoe brick-lined tunnel (26 ft dia.) into a two-lane busway tunnel (40 ft dia.) using NATM. Project management for design of excavation and

support sequence, instrumentation and monitoring program, shotcrete and concrete lining, waterproofing system, cut-and-cover structures built by the shotcrete canopy method. Project management and oversight during construction period.

- East London Line Thames Tunnel, London, U.K.: Refurbishment of approximately 1200 ft of existing 150-year-old twin side-by-side horseshoe brick-lined tunnels using the observational (NATM) approach. Development of the structural calculations and design of the shotcrete and concrete inner linings as well as the waterproofing.
- Pennsylvania Turnpike Commission (PTC), Allegheny Tunnel No. 1, Somerset, Pennsylvania.: Study of a rehabilitation alternative: use of a longitudinal ventilation system using booster fans in connection with a remedial waterproofing system applied at the tunnel arch using flexible membrane techniques and drainage with protective shotcrete lining. Assessment of ventilation requirements based on calculations and review of European tunnel case histories.
- Pennsylvania Turnpike Commission (PTC), Lehigh Tunnel No. 1, Allentown, Pennsylvania: Construction supervision related to implementation of a rehabilitation waterproofing applied in the airduct of the tunnel which was built in 1957. The waterproofing comprises of a flexible plastic membrane, insulation layers and a sidewall drainage system in the air duct.

#### **Other Facilities**

- Washington, DC Dulles International Airport, Automated People Mover System (APM), d2 Development, Dulles, Virginia: Program and Construction Management Services for the Metropolitan Washington Airports Authority (MWAA). These services are related to the design oversight and subsequent construction management and inspection of all underground work for the East and West Domestic Corridor APM tunnels (Package 3E and 3W), the Pedestrian Walkback Tunnel and the West Utility Building tunnel. These structures are constructed by cut-and-cover, TBM and NATM construction methods. Following completion of the structures the construction management and inspection work relates to finish-out work including electrical and mechanical installations.
- Washington Dulles International Airport, Automated People Mover System (APM), Dulles, Virginia: Independent Peer Review of designs for the West Utility Building tunnel, East Domestic Corridor and West Domestic Corridor.
- University of Virginia Steam Tunnel and Storm Water Improvements, Charlottesville, Virginia: Alternative shaft arrangement study, detailed design, specifications, structural design calculations, instrumentation and monitoring, construction phase services.
- Indian Creek Drainage Basin Segment IV, Atlanta, Georgia: Shaft feasibility study, detailed design, specifications, structural design calculations, construction support services.
- Washington DC, Dulles Washington International Airport, Walkback Tunnel, Dulles, Virginia: Detailed design for a Pedestrian Walkback Tunnel (approximately 100 m<sup>2</sup> excavation cross section area) beneath airport taxi lanes and taxi ways in residual soil, weathered and competent siltstone. Design of NATM excavation and support sequence, instrumentation and monitoring program, reinforced shotcrete and concrete linings, and waterproofing system. The mined tunnel option replaced an initially planned cut-and-cover construction at comparable bid cost. The taxi lanes and ways remain operational while tunneling was carried out underneath.
- Pocomo Dam Spillway Modification, County of Los Angeles, California, Department of Public Works: Redesign of the final tunnel lining for the enlargement of a spillway tunnel in a value engineering frame work. Comparison of in-situ rock conditions exposed upon tunnel enlargement with ground conditions depicted in the contract documents warranted a redesign of the final tunnel lining. The redesigned lining consisted of 8-inch shotcrete lining vs. a 15-inch cast in place, double

layered reinforced concrete.

- Interquarry Tunnel, Luckstone Quarry, Leesburg, Virginia: Design of this about 800 sqft cross section and 300 feet long rock tunnel connecting two quarries through diorite. Layout of NATM excavation and support sequence, shotcrete lining, monitoring instruments, preparation of bid documents, including drawings and specifications. Site supervision during construction.

### **Tunnel Ventilation**

- Lindbergh Tunnels at Lambert - St. Louis International Airport, St. Louis, Missouri: Review tunnel ventilation design (CFD analysis) for recommendation on airport specific location.
- Route 29 Tunnel, New Jersey: Third party review of ventilation design according to the longitudinal ventilation system using jet fans. In particular review and recommendation on the design, fire scenario and escape ways.
- Atlantic City / Brigantine Connector Tunnel, New Jersey: Preparation of a ventilation system analysis for a two-lane each direction cut-and-cover, approx. 2,000 ft long vehicular box tunnel. The analysis included air flow modelling and calculation of requirements for a longitudinal jet fan based ventilation system for specified traffic and emergency (fire) situation and recommendations for a jet fan layout. The analysis was carried out in close cooperation with the Institute for Internal Combustion Engines and Thermodynamics of the Technical University Graz, Austria.

### **Technical Papers and Publications**

- THE DULLES CORRIDOR METRORAIL PROJECT – TUNNELING OPTIONS FOR TYSONS CONER, 2008 North American Tunneling Conference Proceedings, June 8-11 (with Rudolf, J.)
- PRE-SUPPORT MEASURES FOR SHALLOW NATM TUNNELING IN URBAN SETTINGS, 2008 North American Tunneling Conference Proceedings, June 8-11 (with Zeidler, K.)
- THE DULLES CORRIDOR METRORAIL PROJECT – EXTENSION TO DULLES INTERNATIONAL AIRPORT AND ITS TUNNELING ASPECTS, 2007 RETC Conference Proceedings, June 10-13 (with Rudolf, J.)
- NATM THROUGH CLEAN SANDS - THE MICHIGAN STREET EXPERIENCE, 2007 RETC Conference Proceedings, June 10-13, 2007 (with Madsen, P., Younis and Headland, P.)
- THE DULLES CORRIDOR METRORAIL AND ITS TUNNELING ASPECTS, 2007 World Tunnel Congress and 33<sup>rd</sup> ITA General Assembly, May 5- 10 2007 (with Rudolf, J. and Zeidler, K.)
- ESTIMATING LATERAL SUPPORT PRESSURE FOR ROCK CUTS AT WASHINGTON DULLES INTERNATIONAL AIRPORT EXPANSION, Proceedings 1<sup>st</sup> Canada – US Rock Mechanics Symposium, May 27-31 2007, Vancouver, B.C. (with Martin, C.D. and Rehwoldt, E.B.)
- NATM FOR SINGAPORE, North American Tunneling 2006 Proceedings, North American Tunneling 2006 Conference, Chicago, Illinois, June 10 – 15, 2006 (with Schwind, T. and Zeidler, K.)
- SHOTCRETE FOR TUNNEL FINAL LININGS – DESIGN AND CONSTRUCTION CONSIDERATIONS, NAT 2004 Proceedings, North American Tunneling Conference, Atlanta, Georgia, April 17 – 22, 2004 (with Zeidler, K., Munfah, N. and Cerulli, D).
- BERGEN TUNNELS REHABILITATION – ABSUCCESS AFTER ALL, Proceedings, 2003 RETC Proceedings, Rapid Excavation and Tunneling Conference, New Orleans, Louisiana, June 16 - 18, 2003 (with Zeidler, K. and Mergentime, St.).
- DESIGN CRITERIA FOR LARGE TUNNELS IN SOFT GROUND, Proceedings, International Conference on Tunnels and Underground Structures, Singapore, November 27-29, 2000 (with Zeidler, K.).
- FROZEN GROUND FOR BUILDING SUPPORT - PPLEMENTATION OF INNOVATIVE ENGINEERING CONCEPTS FOR TUNNELING AT RUSSIA WHARF, Proceedings, North American Tunneling 2000, Boston, Massachusetts, June 6 - 11, 2000 (with Urschitz, G. and Zeidler, K.).

- THREE PILLARS FOR AN EFFECTIVE WATERPROOFING SYSTEM, Proceedings, North American Tunneling 2000, Boston, Massachusetts, June 6 - 11, 2000.
- FLEXIBLE APPROACHES FOR URBAN TUNNELING, Seminar Proceedings, ASCE MET Section Construction Group - Innovative Construction Means and Methods, New York, N.Y., March 6-7, 2000.
- CONSTRUCTION OF MISCELLANEOUS UNDERGROUND STRUCTURES FOR SUBWAY PROJECTS, Seminar Proceedings, ASCE MET Section - State of the Art Technology in Earth and Rock Tunneling, New York, N.Y., May 26-27, 1999 (with Sauer, G. and Zeidler, K.).
- SHOTCRETE LINING DESIGN CONCEPTS FOR NEW AND REHABILITATED TUNNELS, Proceedings, Shotcrete for Underground Support VIII, Campos do Jordao, Brazil, April 11-15, 1999 (with Zeidler, K.).
- RENOVATION OF THE BERRY STREET TUNNEL, Tunnels and Tunnelling International, April 1998 (with Claassen, M.).
- REHABILITATION CONCEPTS FOR BRICK LINED TUNNELS IN URBAN AREAS, Proceedings, World Tunnel Congress '98 "Tunnels and Metropolises", Sao Paulo, Brazil, April 25 - 30, 1998 (with Zeidler, K., Predis, Walter, T and J.).
- OPTIMIZATION OF TUNNEL PRE-SUPPORT - UNDERGROUND NATM AT WASHINGTON, D.C. METRO'S SECTION F6B, Proceedings, North American Tunneling '98, Newport Beach, California, February 21 - 25, 1998 (with Zeidler, K., Bohlke, B.M. and Alfredson, L. E.).
- LONDON BRIDGE STATION, JUBILEE LINE EXTENSION, 1997 RETC Proceedings, Rapid Excavation and Tunneling Conference, Las Vegas, Nevada, June 22 - 26, 1997 (with Zeidler, K.).
- ACHIEVING DRY CUT-AND-COVER STATIONS – A MEMBRANE BASED WATERPROOFING SYSTEM FOR UNDERGROUND STRUCTURES, Proceedings, North American Tunneling '96, April 21 - 24, 1996 (with Mergelsberg, W. and Sauer, G.).
- INSTRUMENTATION AND ITS IMPLICATIONS - PROTECTION OF CITY PLACE STATION, DALLAS, TX, Proceedings, North American Tunneling '96, April 21 - 24, 1996 (with Ugarte, E. and Sauer, G.).
- LINING THE LINE, ASCE Civil Engineering Magazine, March 1996 (with Mergelsberg, W. and Sauer, G.).
- COMPUTER CALCULATIONS SPEED TUNNEL-LINING DESIGN, ASCE Civil Engineering Magazine, July 1994 (with Bauer, E. and Sauer, G.).
- DESIGN OF TUNNEL CONCRETE LININGS USING CAPACITY LIMIT CURVES, Proceedings, 8th International Conference of the International Association for Computer Methods and Advances in Geomechanics, Morgantown, West Virginia, May 22-28, 1994 (with Sauer, G., Bauer, E., and Dietmaier, P.).
- THE DOORFRAME SLAB METHOD, BARREL VAULT METHOD AND CONVENTIONAL NATM APPLIED TO THE BY-PASS AT OBERRIEDEN, Germany, 1993 RETC Proceedings, Rapid Excavation and Tunneling Conference, Boston, Massachusetts, June 13 - 17, 1993 (with Sauer, G. and Zeidler, K.).
- EFFECTIVE ITERATIVE TECHNIQUE IN NUMERICAL MODELING TO SIMULATE PROGRESSIVE FAILURE IN UNDERGROUND COAL MINES, Proceedings, 31st U.S. Symposium on Rock Mechanics, Colorado School of Mines, Denver, Colorado, June 17 - 20, 1990 (with Park, D.).
- LARGE SCALE THREE-DIMENSIONAL NUMERICAL SIMULATION OF LONGWALL MINING, Preprint 90-24, 119th SME Annual Meeting, Salt Lake City, Utah, February 26 - March 1, 1990 (with Park, D.).
- SUPERCOMPUTER ASSISTED THREE-DIMENSIONAL FINITE ELEMENT ANALYSIS OF A LONGWALL PANEL, Proceedings, 30th U.S. Symposium on Rock Mechanics, West Virginia University, Morgantown, West Virginia, June 19-22, 1989 (with Park, D.).

- IBID (refereed Version), COGS Computer Contributions, V 5, No. 2, August, 1989 Journal.
- LOW COST AUTOMATIC DATA ACQUISITION AND ANALYSIS FOR UNIAXIAL ROCK TESTING, Proceedings, Geotech 88, Lakewood, Colorado, Oct. 1988 (with Park., D Patton, S.)

### **Lectures**

- Waterproofing Shotcrete / Cast-in-Place Liners, 2007 George A. Fox Conference, “Waterproofing of Underground Structures: An East Coast Perspective” New York City, New York, January 30, 2007.
- West Utility Building Tunnel – NATM at Washington Dulles International Airport, 2006 George A. Fox Conference New York City, New York, January 24, 2006.
- State-of-the-Art in the Application of Sequential Tunneling Methods (NATM), Parsons Brinckerhoff Quade and Douglas New York 2005 Tunneling Seminar, Newark, New Jersey, June 14, 2005.
- Utilization of Lattice Girders in Underground Shotcrete Support, Engineering Assessment of Lattice Girder Options, Presentation to American Commercial, Inc., Bristol, Virginia, October 1, 2002.
- Softground Tunnels for Transportation, Water and Wastewater Conveyance, Recent Innovations in the Science of Underground Development, Annual Meeting of the American Association for the Advancement of Science, Boston, Massachusetts, February 2002.
- Flexible Approaches for Urban Tunneling, ASCE Metropolitan Section Annual Seminar of the Construction Group, Innovative Construction Means and Methods, Cooper Union, New York City, New York, March 6-7, 2000.
- NATM in Soft Ground for Big Digs, American Society of Civil Engineers Annual Convention, Boston, Massachusetts, October 18-21, 1998.
- State-of-the-Art in Design and Construction for Vehicular Tunnels, Tunneling Seminar by Invitation of the Chilean Ministry of Public Works, Santiago, Chile, November 19-20, 1996.

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## **CHRISTIAN INGERSLEV, P.E., C.Eng., F.I.C.E., Eur. Ing.**

Assistant Vice President  
Principal Professional Associate (Immersed Tunnels)  
Senior Engineering Manager

### **Years of Experience**

42 (22 with PB; 20 with others)

### **Education**

M.A. (Structures), Trinity College, Cambridge, England, 1969; B.A., Mechanical Sciences, Trinity College, Cambridge, England, 1965

Additional Studies: Arbitration Course, Institute of Arbitrators, U.K., 1975; Professional Engineer Review Course, Cooper Union, New York, 1986; Construction Mediation Workshop, Hong Kong Construction Association, Ltd., 1990

### **Professional Affiliations**

American Society of Civil Engineers: Fellow, New York Metropolitan Section President (2001-2002), President-Elect (2000-2001), Vice President (1999-2000), New York Metropolitan Section International Group Chair (1997-1999);  
Structural Engineering Association of New York: Director (1999-2000)  
Institution of Civil Engineers (U.K.): Fellow, New York Metropolitan Area Local Association Chair (1999-2001); Vice-Chair (2001-Present)  
International Tunneling Association Working Group on Immersed and Floating Tunnels (1989-Present), Animateur [Chair] (2005-Present)

### **Professional Registrations**

Professional Engineer: New York, 1987 (16 063252); New Jersey, 2003 (24GE04471400)  
Chartered Engineer: U.K., 1971 (405801 44)  
European Engineer: European Common Market, 1988 (0078.36B)

### **Key Qualifications**

Christian Ingerslev has extensive experience in the design and construction of transportation facilities, including immersed, bored, and cut-and-cover tunnels as well as bridges. He has held project management and supervisory design responsibilities on a number of large-scale projects in the U.S. and Southeast Asia. Based in Parsons Brinckerhoff's (PB) New York headquarters, Christian provides project management and structural engineering services for endeavors in North America as well as overseas.

### **Highway Tunnels**

- City of Windsor Short Tunnels Study (Canada): Reviewed the 2007 GreenLink report. Prepared alignments, conceptual design and cost estimates for about 7 km of highway, one option with 2-lane mostly bored tunnels each about 6.4 km long portal to portal and another with six shorter cut-and-cover tunnels totaling 3.8 km.
- Gowanus Expressway, Brooklyn, New York: project manager responsible for the Draft Environmental Impact Statement (DEIS) tunnel alternative design, and for a conceptual study for replacing the existing 4-mile (6.4-kilometer) viaduct and elevated interchanges with tunnels through glacial deposits. He was also project manager for a prize-winning submission containing innovative concepts for rehabilitating the existing viaduct while maintaining traffic.
- Provided draft chapters for FHWA tunnel handbook on planning, on geometrical configuration, on cut-and-cover tunnels and on immersed tunnels.
- Seattle Route 520: Reviewed community immersed tunnel schemes in Portage Bay and developed a number of related modified conceptual schemes meeting design criteria.

- Singapore Marina Coastal Expressway: Concept design for an immersed tunnel under the Singapore River estuary with five contiguous traffic lanes in each direction and full shoulders. If constructed, this would be nearly twice the width of the largest immersed road tunnel ever built.
- Eisenhower/Johnson Memorial Tunnels, I-70, CO: Feasibility study for permitting vehicles carrying hazardous cargos to have free access through the tunnels.
- Limerick Tunnel, Ireland: provided technical input to a proposal for an immersed tunnel.
- Hampton Roads Third Immersed Tunnel, Virginia, USA: Prepared scope of work proposal for immersed tunnel consultancy services to Owner. Awaiting notice to proceed.
- Hampton Roads Third Immersed Tunnel: Provided initial concept drawings to a contractor for a design-build road and rail immersed tunnel crossing in a variety of arrangements with cells up to three lanes wide carrying two high-speed rail lines and at least five lanes of traffic. This project is on hold.
- Coatzacoalcos Tunnel, Vera Cruz, Mexico: Reviewed the RFP design of an immersed tunnel for potential improvements that a Mexican contractor proposed to bid upon.
- Lake Zurich: Performed feasibility study of both a floating tunnel and an immersed tunnel across Lake Zurich and presented the results to the Owner.
- Sand Island, Hawaii, USA: Initial concepts for an immersed tunnel crossing of the harbor entrance as part of a feasibility study.
- Pinnars Point Tunnel (Second Midtown Tunnel), Norfolk, Virginia: team leader for a proposal to place a second 2-lane immersed tunnel adjacent to the existing one to double the capacity.
- Fort Point Channel, I-90, Boston, Massachusetts: Peer Review of this most irregularly shaped immersed tunnel, 6 elements.
- Lake Washington, Seattle, Washington, USA. Studied immersed and floating tunnel options for both highway and rail crossings of Lake Washington for feasibility study.
- Posey and Webster Street Immersed Tunnels, San Francisco, Seismic retrofit: Investigation and recommendations for retrofitting requirements for these two old concrete immersed tunnels that were not designed for earthquake.
- Detroit-Windsor Tunnel, USA to Canada. Cover reinstatement project, including hazard analysis, and strength and stability design checks for this 670 m long 1930 immersed tunnel in 13 m of water.
- Western Harbour Tunnel, Hong Kong: project manager and team leader responsible for a feasibility study and preliminary, tender, and final designs of this immersed tunnel that crosses Hong Kong Harbour. The immersed tunnel is 0.9 miles (1.4 kilometers) long and has three vehicular lanes in each direction. Options such as two lanes of traffic in each direction, concrete and steel alternatives, and provisions for rail traffic lanes were also considered during the preliminary design phase.
- Shanghai Ring Road, Peoples Republic of China: provided immersed tunnel specialist input to a design/build proposal for an eight-lane highway crossing of the Huang Pu River.
- Variable Message Sign (VMS) Support Structures: responsible for development of innovative design methods for these structures which span highways and carry heavy signs subject to vertical wind blasts from passing trucks.
- Miller Highway, New York City: responsible for concept design of the tunneled section. PB, as prime consultant to the New York State Urban Development Corporation (UDC), prepared a combined project design report/Environmental Impact Statement (EIS) for relocating a 0.75-

mile (1.2-kilometer) elevated section of Miller Highway between West 59th Street and West 72nd Street in Manhattan, from its existing location eastward (away) from the Hudson River.

- Beirut International Airport Multistory Carpark, Lebanon: responsible for design checking.
- Izmir Tunnel, Turkey: provided concept design of immersed tunnel and cut-and-cover tunnel alternatives for a downtown bypass.
- Singapore Underground Road System (SURS): tunnels manager for preliminary design of 24.8 miles (40 kilometers) of road tunnels in and around Singapore's central business district (CBD) that form a ring road around the city. The tunnels will carry two lanes of traffic in each direction, thus increasing highway capacity by 40 percent and relieving surface congestion in the city's CBD. They pass through variable geologic formations and will include 19.5 miles (31.5 kilometers) of cut-and-cover, 5.3 miles (8.5 kilometers) of bored tunnels and two immersed tunnels. Tight constraints in this dense urban environment led to intensive design efforts to limit movement and loading caused by tunnel construction. PB also designed ventilation, mechanical, and electrical systems (lighting, fire protection, surveillance) for the SURS network.
- Central Kowloon Route, Hong Kong: responsible for tunnel engineering for a 1.5-mile (2.4 kilometer) tunnel (mainly in rock) that will connect the planned West Kowloon Expressway in Yau Ma Tei with the planned North-South Highway in To Kwa Wan. The Central Kowloon Route is a toll road that includes the tunnel and two grade-separated interchanges.
- Guadalquivir Tunnel, Seville, Spain: responsible for tender design and design review of this four-lane, 2,600-foot-long (800-meter-long) single shell, steel immersed tube tunnel.
- Green Island Link, Hong Kong: project manager and tunnel team leader for a feasibility study and preliminary design of a proposed dual two- and three-lane, 2.2-mile-long (3.5-kilometer-long) immersed tunnel below the 82-foot-deep (25-meter-deep) main shipping channel into Hong Kong Harbor.
- Central Artery/Tunnel Project, Boston, Massachusetts: supervising engineer responsible for the design of cut-and-cover structures, depressed roadways, viaducts, bridges, and ancillary buildings on the South and East Boston sides of the Ted Williams immersed tunnel, including two major interchanges and 14.9 miles (24 kilometers) of roadways. Elements of the design included:
  - Preliminary design and checking of 100-scale concept submission for South and East Boston
  - A study of the temporary Summer Street viaduct in South Boston, a two-, three-, and four-lane, 1,200- to 1,800-foot-long (360- to 550-meter-long) temporary structure with approaches
  - Preparation of a proposal report, approved by the Federal Highway Administration (FHWA), on the use of permanent tie-down anchors in lieu of using gravity slabs up to 24 feet (7.3 meters) thick to stabilize depressed highway sections subject to hydrostatic uplift
  - Type studies and preliminary (25 percent) design of tunnels, depressed roadways ("boat" sections), bridges over depressed roadways, viaducts, and buildings
- Various Projects: supervising structural engineer responsible for existing condition surveys of three highway tunnels in the U.S.

#### **Rail and Transit**

- New York Metropolitan Transit Authority: Review of existing underwater bored and immersed tunnels.
- Access to the Region's Core, Manhattan, New York and New Jersey: team leader responsible for the conceptual structural and alignment design, constructability review, and concepts for tunnels in rock and soft ground, and the underpinning of existing structures. The project

includes two new tracks from the New Jersey Meadowlands into Midtown Manhattan, and for a number of alternative alignments within Manhattan, including connecting Penn Station to Grand Central Terminal and on to the 63rd Street Tunnel. Complex issues included constructability, pedestrian access, and passing beneath and underpinning skyscrapers, transit lines, and the train terminals.

- Access to the Region's Core Hudson River Crossing: Concept studies for a new two-track rail crossing into Manhattan from New Jersey on the Northeast Corridor Line. Tunnel sizes investigated included commuter rail, the superliner and double-stack freight. Tunnel options include bored or immersed tunnels in the soft-ground below the Hudson River, and suitable methods for use in rock and soft ground elsewhere. Carried out FEIS studies for a train storage yard for over 50 trains on a soft ground contaminated site. Carried out Preliminary Engineering primarily for the Hudson River crossing and associated fan plants and shafts, but also for other below-ground structures between the Meadowlands and Penn Station New York. Reviewed Preliminary Engineering Documents for all areas. This project is now known as THE Tunnel.
- Bosphorus Crossing, Turkey. Reviewed earlier work and responsible for the bored and 55 m deep immersed tunnel input to the proposal for services. Prepared in joint venture design and construction requirements for the FIDIC design-build bidding documents. Design Supervisor Immersed Tunnel for services to the Owner during preparation of tender documents and the design-build construction contract. Reviewed the design-build bids and the successful contractor's design and construction proposals. Responsible for review of Contractor's design to ensure conformity with requirements. The area is highly seismic and expects a tsunami.
- New York Harbor Freight Rail Tunnel: Provided review of feasibility study reports for the proposed soft ground and immersed tunnels.
- Pittsburgh, Pennsylvania, USA. Prepared concept design of an immersed tunnel rail crossing of the Allegheny River.
- Newark-Elizabeth Rail Link, New Jersey: team leader for structural analysis of 1,600 feet (488-meters) of new cut-and-cover tunnel connections to the existing Newark subway system.
- Patroclus Island Development, Greece: responsible for the concept design of a 1-mile-long (1.7-kilometer-long) immersed tunnel connection containing four rail track ducts and either one or two major utility ducts.
- East Side Access to Grand Central Terminal, New York City: structural team leader for the deep station conceptual design for this project which is being developed to provide Long Island Rail Road access to Grand Central Terminal.
- Fehmarn Belt Feasibility Study, Denmark/Germany: provided head office analysis and support for concept designs for road, rail, and mixed-use tunnels and further concept design development in Denmark of an 11.2-mile (18-kilometer) immersed tunnel for two rail tracks in water depths up to 125 feet (38 meters).
- Hudson-Bergen Light Rail Transit (LRT) System, New Jersey: project manager of the design of mezzanine connection structures at New Jersey Transit's Pavonia/Newport and Hoboken Port Authority Trans-Hudson (PATH) Terminals. PB is serving as general design consultant to NJ Transit for the \$1.2 billion, 20.5-mile (33-kilometer) LRT system expected to improve transit mobility in heavily congested northern New Jersey. The system will comprise 30 stations, extend from the foot of the Bayonne Bridge in southern Hudson County to the Vince Lombardi Park-Ride on the New Jersey Turnpike in Bergen County, and include a westward spur to State Route (SR) 440 in Hudson County.

- Hsintien River, Taiwan: Feasibility study of immersed and staged cofferdam river crossing solutions, and final design review of the adopted staged-cofferdam design for the Panchiao Railway Extension
- Mass Transit Systems, Bangkok, Thailand: project manager of a feasibility study and environmental impact assessment of new transit systems, one above a canal and three in expressway rights-of-way, including a new immersed tunnel crossing of the Chiao Phraya River. Besides surface options, tunneling included soft ground, cut-and-cover and bored tunnels. This project was conducted for the Expressway and Transit Authority (ETA).
- Panchiao Railway Extension, Taipei, Taiwan: provided specialist technical input for a feasibility study on relocation of an at-grade, two-track railroad system to a tunnel in existing right-of-way through the heart of Taipei. A southward extension of the system, comprising twin 5.6-mile (9-kilometer), two-track tunnels and three new stations (two underground and one at-grade) was also studied. Provisions to accommodate conventional and high speed rail lines were incorporated into the design and construction planning. Construction of the extension occurred with minimal disruptions of existing rail service. Christian also conducted technical reviews of the detailed design (created by the detailed design consultant) of the staged cofferdam cut-and-cover crossing of the Hsintien River and the below-ground Panchiao Station (seismic area).
- Bangkok Elevated Transport System, Thailand: provided specialist technical review assistance to the State Railways of Thailand (SRT) in connection with the design of a 37.3-mile (60.1-kilometer) integrated rail/roadway facility. This project involved: relocation of an existing at-grade passenger and freight railway onto an elevated viaduct; incorporation of a new mass transit community train (CT) capable of handling three million passengers per day onto the same viaduct; and construction of a six-lane urban toll road above the rail lines. This \$3.1 billion effort is a unique build-operate-transfer (BOT) project in which the developer will finance, design, build, and operate the system. The Thai government will assume ownership of the facility from the developer after a 30-year concession period.
- Jakarta Mass Rapid Transit System, Indonesia: project manager of implementation planning for priority lines in this rapid transit system. Christian also provided structural and electrical engineering services during system design. With a grant from the U.S. Trade and Development Association (USTDA), PB investigated design and system implementation during development of a 16.2-mile (26-kilometer) portion of the two first-priority mass transit routes in Jakarta: Kota Blok M, a north-south route; and Tangerang Bekasi, an east-west route. The system will incorporate up to 48 stations and maintain a peak capacity of 80,000 passengers daily.

#### **Other Tunnels**

- Singapore Tuas Tunnel: responsible for the preparation of specifications for an immersed utility tube and access tunnel at a power station, and for final review of the final design drawings.
- Delaware Aqueduct and New Croton Aqueduct: Design review of existing bored and soft ground tunnels, together with concept design for repair of existing cracks and potential breaches

#### **Bridges**

- Philadelphia Naval Basin Lift Bridge, PA: Schematic designs for a bidder for dismantling, refurbishing and re-erecting the bridge with greater clearance beneath the lift span.
- Sikorski Bridge spanning the Housatonic River, CT. Design reviews of tall piers.
- Talmadge Memorial Bridge Replacement, Savannah, Georgia: responsible for the design of pier caps and hollow concrete pier shafts up to 160 feet (48.8 meters) high. PB, in joint

venture, designed the concrete alternative for replacement of the Talmadge Memorial Bridge over the Savannah River, a structure originally designed by the firm in 1952. A structural system using precast segmental I-girder drop-in construction was chosen for the high-level approach spans. PB also designed the low-level trestle structure. The 1,100-foot-long (335.3-meter-long) concrete main span is Georgia's first cable-stayed structure.

- Steel Railway Trestle Bridge, Buffalo, New York: responsible for preliminary design of this structure.

#### **Marine Facilities**

- Land Level Ship Construction Facility, Newport News, Virginia: Designed mooring dolphins and concrete and steel sections during PB's provision of conceptual engineering and design services for a 132,000-square-foot (402,333-square-meter), two-bay assembly building containing bridge cranes, a central core of office and support areas, and wings with shops and other services. The facility was used initially for modular construction of submarines, but can be used for any type of vessel.
- Independent Technical Review (ITR) on the Detailed Design Report for West of Algiers Canal Hurricane Protection, Sector Gate Complex.

#### **Previous Experience**

Prior to joining PB, Christian participated in numerous projects involving the design, construction, and inspection of bridges, tunnels, rail facilities, and other structures. His specific project experience includes:

- Saudi Arabia-Bahrain Causeway: responsible for offshore site supervision during construction of a high-level section in the middle of a 1.9-mile (3-kilometer) low-level bridge. This work included glued-segmental, balanced-cantilever main navigation spans, two of which were 262 feet (80 meters) in length, the other 492 feet (150 meters), and 10 adjacent, 164-foot (50-meter) side spans on each side for two independent roadways. These side spans were founded on precast bored 11.5-foot-diameter (3.5-meter) piles surmounted by a submerged precast pile cap and precast pier shafts. The main span piers were founded on precast submerged caissons with in situ concrete fill and in situ pier shafts. Christian also checked the contractor's construction drawings and reviewed and approved construction site design changes. He was responsible for utility diversion planning and served as a liaison to Bahraini authorities for 6.2 miles (10 kilometers) of approach roadway in Bahrain. He also was a member of a committee with both Bahraini and Saudi representatives that considered new telephone cable installation.
- Kaohsiung Cross Harbor Tunnel, Taiwan: chief project engineer responsible for finding a viable solution to provide a piled wharf for construction, in poor soils, of a bridge over the Kaohsiung Cross Harbor Tunnel. Christian was also a project engineer responsible for the preparation of specifications and contract documents, competitive bid design, and final design of the immersed cross-harbor tunnel, located in a highly seismic area. The tunnel was formed by a closed two-cell concrete box; each cell contained two vehicular lanes and a raised motorcycle lane. Six 394-foot-long (120 meter) precast float-in tunnel units, founded on sand injected below, were reached from cast in situ tunnels at each end. The approach ramps, which pass through ground prone to liquefaction during earthquakes, were designed as light structures on tension piles.
- Northwest New Territories, Hong Kong: prepared preliminary design and cost estimates for proposed major highway links and a fixed-track passenger transit system to be constructed by the turn of the century. Project elements included five major routes, associated link roads, and six "rail routes and systems.
- Lantau Island Fixed Crossing, Hong Kong: responsible for preliminary design of three immersed tube tunnel alternatives for a fixed road/light rail crossing of Hong Kong Harbor.

The dual two- and three-lane tunnels were designed for construction in rock at depths up to 131 feet (40 meters).

- Mass Transit Railway (MTR) Corporation Tseun Wan Extension, Hong Kong: resident engineer supervising construction of station substructure and a 1.9-mile (3-kilometer) railway viaduct.
- Wanchai to Tsim Sha Tsui Cross Harbor Immersed Tunnel, Hong Kong: executive engineer and deputy resident engineer responsible for tunnel surveying, immersing, and placing operations and review and approval of the contractor's 1,400 working drawings. The crossing included 14 precast, float-in, 328-foot-long (100-meter-long) tunnel elements and two float-in ventilation buildings.
- Offshore Structures, Various Locations: senior engineer and team leader responsible for development and design of various offshore structures, including:
  - Oil platforms suitable for North Sea locations at depths of 492 to 656 feet (150 to 200 meters) and capable of being built at a shallow water site in Scotland
  - Hybrid platforms that were subject to quality assurance by Lloyd's Register of Shipping
  - Feasibility designs for gravity platforms in the Danish sector of the North Sea at depths of 98 to 197 feet (30 to 60 meters)
- Hendon Urban Motorway, England: section manager responsible for construction of a 1-mile (1.6 kilometer) segment of roadway and, subsequently, responsible for bid estimate preparation.
- Highway Project, Cardiff, Wales: section engineer responsible for construction of 0.7 miles (1.2 kilometers) of retaining walls and a 197-foot (60-meter), three-span bridge along an urban freeway. Christian also prepared claims and designs of temporary works and assisted in the preparation of project bid estimates.
- Gateshead Western Bypass, England: responsible for alignment, interchange, and curved slab bridge design.

#### **Publications**

- "Immersed Tunnels State-of-the-Art", AITES-ITA 2007 World Congress, May 2007.
- "Immersed Tunnels Continue to Meet the Challenges of Water Crossings", co-author AITES-ITA 2007 World Congress, May 2007.
- "Measurement and evaluation of the hydrodynamics and secondary currents in and near a strait connecting large water bodies—A field study", co-author, *Ocean Engineering*, Volume 33, Issue 13, September 2006, Pages 1718-1748
- "Considerations and strategies behind the design and construction requirements of the Istanbul Strait immersed tunnel", TUST, AITES-ITA, Article in Press as of Oct 2005.
- "Case Study – Immersed tube tunnels and the Marmaray Project", *Megatunnels Conference: Dealing with the challenges of large-scale tunneling projects*, New Civil Engineer, London May 2005.
- "Marmaray project: requirements for the design and construction of the Bosphorus Tunnel", AITES-ITA 2005 World Tunnel Congress, May 2005.
- "Marmaray project: designing an immersed tunnel for the Bosphorus", AITES-ITA 2005 World Tunnel Congress, May 2005.
- "Immersed and Floating Tunnels across Lake Zürich", AITES-ITA 2004 World Tunnel Congress, May 2004.
- Coauthor, Chapter 20 Tunnel Engineering, *Standard Handbook for Engineers*, 5th edition, Ricketts et al, McGraw Hill, 2003.

- Coauthor, Chapter 15B Tunnel Structures, Structural Engineering Handbook, 2003 Update for ENGnetBASE, Edited by Wai-Fah Chen and Lian Duan, CRC Press, 2003.
- "Understanding immersed and floating tunnels," AITES-ITA 2003 World Tunnel Congress, April 2003.
- "Immersed Tunnels - Durability and Maintenance," AITES-ITA Downunder 2002 World Tunnel Congress, March 2002.
- "Immersed Tunnel Foundations," AITES-ITA 2001 World Tunnel Congress: Progress in Tunnelling after 2000, Proceedings pp209-216, Milan, June 2001.
- Coauthor, Chapter 15B Tunnel Structures, Structural Engineering Handbook, 2000 Update for ENGnetBASE, Edited by Wai-Fah Chen and Lian Duan, CRC Press, 2000.
- "Underground Options for the Gowanus Viaduct," Challenges for the 21st Century, pp. 225-232, Balkema, Rotterdam, 1999.
- "Water Crossings—the Options," Tunneling and Underground Space Technology, Vol. 13, No. 4, pp. 357-363, Elsevier Science Ltd., 1998.
- "Underground Transportation Facilities: U.S. & Asia," ASCE, Manila, Philippines, February 1998.
- "A Guide to Civil Engineering Projects In and Around New York City," ASCE Metropolitan Section International Group, June 1997. He assisted in developing, editing, producing, and formatting the guide.
- "International Tunneling Association Immersed and Floating Tunnels Working Group State-of-the-Art Report," Second Edition, Pergamon, April 1997. He served as author, contributor, and technical editor.
- Coauthor, "Consortium Teams—How to Make Them Work Multinational," ASCE Annual Conference, November 1996.
- "Development in Immersed Tunnels," Options for Tunneling Conference, Amsterdam, The Netherlands, 1993.
- "Construction of the Bahrain Causeway," Concrete International, Vol. 12, No. 5, May 1990.
- "Precast Concrete for the Bahrain Causeway," Concrete International, Vol. 11, No. 12, December 1989.
- "Concrete Immersed Tunnels: The Design Process," Conference on Immersed Tunnel Techniques, Manchester, England, 1989.
- Coauthor, "The Case for a Hybrid," a paper on the Design and Construction of Offshore Structures for the Institution of Civil Engineers, London, 1976.
- Editor, "Guidance on the Design and Construction of Offshore Installations," 2nd Edition, U.K. Department of Energy, 1976.

## **Robert A. Robinson, LEG** | Senior Vice President

*DIRECTOR OF UNDERGROUND SERVICES*

### **EDUCATION**

Graduate Studies, Engineering Geology, University of Illinois, 1974  
BS, Geology, University of California at Los Angeles, 1970

### **REGISTRATION**

Licensed Engineering Geologist: WA, #1975, 2002  
Certified Engineering Geologist: OR, #429, 1978  
Registered Geologist: OR, 1978

### **PROFESSIONAL ASSOCIATIONS**

American Railroad Engineers Association  
American Underground Space Association  
Association of Engineering Geologists  
Consulting Engineers Council of Washington  
Rapid Excavation and Tunneling Conference Executive Committee  
Underground Technology Research Council  
Society of Mining Engineers

### **PROFESSIONAL SUMMARY**

Since joining Shannon & Wilson in 1974, Robert Robinson has participated in a wide variety of geotechnical projects throughout the United States and Canada. His technical experience includes subsurface exploration, design, plans and specifications, construction monitoring, and expert witness testimony on projects such as tunnels, slope stabilization bridges, retaining walls, building foundations, and shafts in soil and rock. Robert has performed in situ and laboratory tests on soil and rock tests, geological and geophysical site investigations, computerized analyses, and the design and implementation of instrumentation programs for slopes, tunnels, and foundations. Much of his work over the last 30 years has dealt with various forms of underground construction on over 300 tunnels, including: drilled and raised bore shafts; horizontal directional drilling, pipe jacking, microtunneling, earth pressure balanced and slurry pressure balanced machines; 10- to 80-foot-diameter tunnels driven by roadheader, tunnel boring machine (TBM), and drill-and-blast methods; chambers up to 70 feet wide by 600 feet long; and solution mining, all in a wide range of soil and rock conditions.

Robert is currently on several professional committees, including the executive committee for the Rapid Excavation and Tunneling Conference, the tunneling committee for the Association of Engineering Geologists, and the executive committee for the Underground Technology Research Council. He has written or co-authored over 60 papers for professional publications, made over 200 technical presentations and was section editor for 17 papers on transportation projects for the Washington State Centennial volume produced by the Association of Engineering Geologists (AEG).

## RELEVANT EXPERIENCE

***King County, Denny/Lake Union CSO, Seattle, WA.*** As Project Manager, Robert directed a team of engineers, geologists and hydrogeologists in a multi-phased exploration program, developing design recommendations, and assisting with CM for a 6,000-foot-long, 15-foot O.D. CSO tunnel, access shafts, outfall pipe into Puget Sound, control facility, and treatment plant from Lake Union to Elliott Bay. The exploration program included: 30 borings, 2 pump tests, 20 slug tests, an in-depth laboratory program, design recommendations for tunnel excavation and support procedures, dewatering requirements, stabilization of liquifiable soils at the control facility, and support and anchoring systems for the subaqueous outfall. The tunnel was successfully constructed through glacial soils with over 200 feet of soil cover and with water heads greater than 100 feet. The tunnel was constructed with an earth-pressure balance tunnel machine (EPBM) and gasketed, bolted concrete segments.

***WSDOT Alaskan Way Viaduct Replacement, Seattle, WA.*** Senior Level Review. Shannon & Wilson provided geotechnical expertise in a study to develop alternatives for the replacement of the Viaduct. Five build designs are under consideration. Options include cut-and-cover tunnels, mined tunnels, two-level and/or single-level aerial structures, and at-grade alignments. Robert provided senior level review and task input for the assessment of large diameter tunneling options for several concepts of Viaduct replacement. If built, these tunnels would be the largest diameter soil tunnels excavated by tunnel boring machine in the world.

***WSDOT, Interstate 90 Mt. Baker Ridge Highway Tunnel, Seattle, WA.*** Prepared design recommendations, specifications, and developed and implemented a major monitoring program for the 80-foot inside diameter, 1,300-foot-long Mt. Baker Ridge highway tunnel, the world's largest diameter soft ground tunnel. Historically unstable slopes at each portal required special access pit designs including cantilevered cylinder pile walls and cut slope designs. Instrumentation included: inclinometer/sondex casings, multi-position sonic probe borehole extensometers, concrete stress meters, Carlson joint meters and linear potentiometer joint meters that were designed especially for this project, tape extensometers, and strain gages. Due to well written specifications and carefully thought out installation procedures, the instrumentation experienced a 95 percent survival rate after 5 years of construction. The semi-automated data collection systems and rapid computerized data reduction allowed the data from these instruments to be used to guide and control construction procedures and thus greatly reduced the potential for adverse ground behavior and damaging surface settlements.

***Sound Transit, Link Light Rail Tunnel Project, Seattle, WA.*** Robert was Project Manager for the final phase of geotechnical explorations for this fast-track project. Shannon & Wilson mobilized up to 10 drill rigs working concurrently to complete over 130 borings (28,000 feet of hole) in a period of less than 4 months for the 5 miles of twin bore tunnels, four deep mined stations, and one cut-and-cover station. The exploration program also included in situ tests including: borehole pressuremeter tests, downhole seismic shear wave tests, geophysical tomography, groundwater pumping tests, and the first use of vibrocore methods for soil sampling in the Seattle area. Geotechnical recommendations were developed for the earth pressure balance tunnel boring machines gasketed concrete sequential lining and deep underground stations constructed by the sequential excavation method.

***Sound Transit, Link Light Rail Beacon Hill Section, Seattle, WA.*** Robert was Principal-in-Charge for a multi-phased geotechnical exploration program, geotechnical design input for preliminary through final design, preparation and/or review of geotechnically sensitive portions of

the plans and specifications, and assistance with construction management and monitoring. The Beacon Hill project segment consists of about 1 mile of twin 18.9 ft diameter transit tunnels, a deep underground binocular station with twin 550-ft long by 36 ft diameter platform tunnels, one deep main and one deep ancillary ventilation and emergency egress shafts, a headhouse at the top of each shaft, a west portal structure beneath Interstate 5 and opening towards the downtown and an east portal structure that provides access to Rainier Valley. The twin tunnels will be constructed with an earth pressure balance tunnel boring machine (EPBM) and precast, gasketed, bolted concrete segments. The shafts will be supported with slurry wall panels. The station tunnels will be constructed by the sequential excavation method (SEM), with a variety of ground conditioning and support systems to accommodate the complex glacial soils. Explorations have occurred over several phases and included 92 borings totaling 13,675 feet of mud rotary, split triple-tube rotary core and vibra-sonic borings, 3 test pits and a test shaft. A wide range of state of the art field tests, including: downhole pressure meter, downhole seismic velocity, and cross-hole tomography were used to define in situ soil properties.

***King County, Brightwater Treatment Plant Sewer Tunnel, King and Snohomish Counties, WA.*** As Project Manager, Robert directed explorations and provided conceptual design input and portions of the draft EIS for over 20 miles of possible tunnel alignment. He assisted in reviewing tunnels vs. trench options, evaluation of possible tunneling and shaft construction techniques, and development of geologic profiles to assess geotechnical issues and considerations for tunneling.

***City of Tacoma, New Pipeline, Tacoma, WA.*** As Project Engineering Geologist, Robert prepared design and construction recommendations for a 520-foot-long, 8-foot-diameter pipeline. The tunnel was excavated with the first slurry-pressure balanced tunneling machine used in the Northwest through saturated normally consolidated silts, sands, and clays beneath 33 sets of railroad tracks in an active railyard with as little as 7 feet of soil cover. The project also reviewed recommendations for dewatering, temporary shoring, trench excavation, and trench backfill. The tunnel was excavated without significant settlement or disturbance to the overlying railroad tracks.

***Baltimore Region Rapid Transit System, Tunnel Monitoring, Baltimore, MD.*** Robert was the Project Manager for the design of the monitoring systems for tunnels and braced cuts in soil and rock. He developed the overall monitoring philosophy for the entire project, and also implemented a monitoring program for the Bolton Hill Station and Tunnel Section. The tunnels were excavated with an open-faced digger shield under compressed air. Settlements were minimized in the silts, sands, and gravels with compaction grouting.

***City of Los Angeles, North Outfall Replacement Sewer, Los Angeles, CA.*** Robert served as Project Tunnel Engineering Geologist. He reviewed geotechnical aspects and assisted in the preparation of plans, specifications, and a geotechnical design summary report (GDSR) for the North Outfall Replacement Sewer (NORS) in Los Angeles. The project included over 8 miles of main trunkline and diversion tunnel and passes beneath the Los Angeles International Airport, San Diego Freeway, expensive residential areas, and a number of oil fields with abandoned wells. Ground conditions include several major faults, potentially “gassy” conditions, and soils ranging from hard clays to clean, free-flowing dune sands and sections with alluvial soil containing cobbles and boulders. Specified tunneling approaches included earth pressure balance tunneling machines, gasketed segmented linings, and compressed air augmented with compaction grouting and chemical grouting for ground/settlement control.

**King County, Royal Brougham Sewer Tunnel, Seattle, WA.** Robert was responsible for reviewing geotechnical conditions and providing input on the design and specifications for two pipe-jacked 10-foot-diameter sewer tunnel alignments. Both alignments were 100 feet long with 10 to 20 feet of soil cover through saturated medium dense sand fill. The 10-foot-long reinforced concrete pipe sections were advanced with an open-faced shield with orange-peel breasting doors to control the soil face through dewatered soils.

**King County, Downtown Seattle Transit Project (DSTP), Seattle, WA.** As Project Manager, Robert participated in all phases of design and construction for the DSTP including 1.2 miles of twin 21-foot-diameter tunnel alignment and four cut-and-cover stations in saturated glacial soils and adjacent to up to 50-story buildings. He assessed the potential “fatal flaw” for feasibility studies for the DSTP, including a review of geotechnical conditions along alternative alignments and methods for supporting or underpinning the Burlington Northern Railroad tunnel where it crossed the alignment. He also assessed ground conditions and their impacts on tunnel construction methods and underpinning requirements for final design of the DSTP. He was Project Manager for the implementation of a comprehensive construction monitoring program for the DSTP, which included the monitoring and evaluation of ground and soil and water conditions, liner deformations, support stresses, building deformations, and the effectiveness of chemical and compact grouting, jet grouting, and ejector/eductor wells in a variety of glacial soil and water conditions ranging from flowing silts and dense to very hard bouldery clayey silty till. He reviewed submittals, evaluated construction procedures and assessed claims.

**Central Artery Project, Boston, MA.** Robert was Tunnel Engineer for the assessment and design of over 3000 feet of utility line. Relocation was required as part of the Central Artery construction. The utility relocations occurred beneath a very busy portion of Boston, beneath a commuter train terminal, through buried quays, piers, and marine walls along an old shoreline and filled bay area, and through highly variable soils. Robert also provided microtunneling methods assessments for the 5 separate tunnel sections, including pipe angering, earth-pressure balance, and slurry-pressure balanced microtunneling methods.

**King County, Alki Transfer / CSO Project, Seattle, WA.** Robert assisted with construction management, including a review of submittals and senior level reviews. The project included two miles of 15-foot-diameter tunnel in dense silts, sands, gravels with boulders and cobbles, and hard clays. The tunnel was excavated with a partial EPBM and supported with gasketed concrete segments, the first use of the combined tunnel excavation and single-pass support methods in Seattle. Compaction grouting was used to improve ground control and minimize settlements. A slurry-balanced microtunneling machine was used with gasketed concrete pipe for a 600-foot-long sewer line beneath the Duwamish River. The project was completed with a combination of EPBM tunneling, microtunneling, and trenching.

**King County, Henderson / M. L. King CSO, Seattle, WA.** Robert was responsible for the evaluation of geotechnical conditions along alternate alignments during conceptual design, and for developing explorations, geologic interpretations, and geotechnical input for final tunnel design. The two-mile-long alignment included seven variations in percentage of tunnel vs. trench, location of pumping and treatment facilities, and variations in alignment. The final design included a 4000 ft long EPBM tunnel, several microtunnels and two shafts up to 80 feet deep. Horizontal directional drilling (HDD) was used in combination with geophysical tomography to explore ground conditions beneath I-5 and the BNSF and UPRR mainline tracks to locate potential obstructions to tunneling. The HDD, EPB tunnel, and 5 microtunnels were completed successfully.

## PUBLICATIONS

Mr. Robinson has prepared over 50 professional papers on tunneling, instrumentation, mining, and slope stabilization for technical publications. He has also made several hundred technical presentations to technical and non-technical groups on recent major projects. Following is a partial list of his publications.

“Construction Control Instrumentation Used During Tunnel Enlargement,” by R.A. Robinson, R.P. Miller, and D.L. Monson, Proceedings, Rapid Excavation and Tunneling Conference, Las Vegas, Nevada, 1976, p. 742-758.

“Surface Mine Spoil Stability Evaluation, Interior Coal Province,” by R.P. Miller, P.M. Douglass, R.A. Robinson, D.A. Roberts, and W.T. Laprade, U.S. Bureau of Mines, 1979, 737 p. (available from National Technical Information Service, PB 80-211113 and PB 80-211121).

“Surface Mine Spoil Stability in the Interior Coal Province,” by R.A. Robinson, presented at the Northwest Metals and Minerals Conference, Seattle, Washington, 1980.

“Geotechnical Monitoring Report, Pilot Tunnel Instrumentation Program, Cumberland Gap Tunnel,” by R.A. Robinson and J.R. Salley, Federal Highway Administration, 1981.

“Empirical Relationships for Predicting the Stability of Surface Coal Mine Spoils,” by R.A. Robinson and D.A. Roberts, Proceedings, Annual Meeting of the Illinois Mining Institute, Springfield, Illinois, 1981, p. 59-80.

“Report on Mt. Baker Ridge - The World’s Largest Diameter Soil Tunnel,” by H.W. Parker and R.A. Robinson, Underground Space, Vol. 7, No. 3, November, 1982-January, 1983, p. 175-181.

“Geotechnical Aspects of the Mt. Baker Ridge Tunnel Design,” by R.A. Robinson, H.W. Parker, and S.R. Thompson, Proceedings, Rapid Excavation and Tunneling Conference, Chicago, Illinois, Vol. 1, Chapter 22, 1983, p. 343-362.

“Pre-Excavation Methods for Predicting Surface Coal Mine Spoil Pile Stability,” by R.P. Miller, R.A. Robinson, and D.A. Roberts, Proceedings, Indonesian Coal/Lignite Development and United States Technology Symposium, Jakarta, Indonesia, October 18-21, 1983, 24 p.

“Design and Construction of the Mount Baker Ridge Tunnel in Seattle,” by R.A. Robinson, Proceedings, Tunneling Association of Canada Annual General Meeting, Vancouver, British Columbia, October, 1984.

“Operation and Maintenance Manual for Tunnel Monitoring and Alarm System,” by R.A. Robinson and D.A. Roberts, Contract CX-2000-9-0020, U.S. National Park Service, 1985.

“Ground Deformations Ahead of and Adjacent to a TBM in Sheared Shales at Stillwater Tunnel, Utah,” by R.A. Robinson, E.J. Cording, D.A. Roberts, N. Phienweja, J.W. Mahar, and H.W. Parker, Proceedings, Rapid Excavation and Tunneling Conference, New York, New York, Vol. 1, Chapter 4, 1985, p. 34-53.

“Ground Liner Behavior During Construction of the Mt. Baker Ridge Tunnel,” by R.A. Robinson, M.S. Kucker, A.I. Feldman, and H.W. Parker, Proceedings, Rapid Excavation and Tunneling Conference, New Orleans, Louisiana, 1987.

“Construction Behavior of an Innovative Liner Design for the World’s Largest Diameter Soil Tunnel,” by R.A. Robinson and H.W. Parker, Proceedings, International Symposium on Unique Underground Structures, Denver, Colorado, Vol. 2, 1988, p. 88-1 to 88-20.

“Engineering Geology on Transportation Routes: Introduction,” by R.A. Robinson, Engineering Geology in Washington, Washington Division of Geology and Earth Resources Bulletin 78, Vol. II, 1989, p. 727-728.

“Geotechnical Impacts on Design and Construction of the Mt. Baker Ridge Tunnel, Interstate Highway 90, Seattle,” by R.A. Robinson, Engineering Geology in Washington, Washington Division of Geology and Earth Resources Bulletin 78, Vol. II, 1989, p. 831-844.

“Foundation and Excavation Conditions in Washington,” by W.T. Laprade and R.A. Robinson, Engineering Geology in Washington, Washington Division of Geology and Earth Resources Bulletin 78, Vol. I, 1989, p. 37-48.

“Ground Behavior in Glacial Soils for the Seattle Transit Tunnels,” by R.A. Robinson, M.S. Kucker, and H.W. Parker, Proceedings, Rapid Excavation and Tunneling Conference, Seattle, Washington, Vol. I, Chapter 7, June, 1991, p. 93-117.

“Design and Construction of the World’s Largest-Diameter Soil Tunnel,” by R.P. Miller, H.W. Parker, and R.A. Robinson, The Art and Science of Geotechnical Engineering at the Dawn of the Twenty-First Century, Symposium honoring Ralph B. Peck, Prentice-Hall, Inc., 1989, p. 538-55.

“Pipejacking, An Engineer’s Perspective,” by R.A. Robinson, presented at the Seattle Annual ASCE Short Course on Pipejacking and Microtunneling, April 1994, 24 pgs.

“Engineering Geology and Risk Assessment of the Hiawatha Trail Tunnels, Bitterroot Mountains, Idaho and Montana,” by S.R. McMullen, J.R. Laird, R.A. Robinson, and H.L. Ellis: Proceedings, 32nd Symposium on Engineering, Geology, and Geotechnical Engineering, Boise, Idaho, 1997, pp. 199-214.

“Tunneling in Seattle: A History of Innovation,” by R.A. Robinson, E. Cox, and M. Dirtec: Proceedings of the North American Tunneling Conference, Seattle, WA, 2002.

“Application of Design-Build Contracts to tunnel Construction,” by R.A. Robinson, M.S. Kucker, and J.P. Gildner: Proceedings of the North American Tunneling Conference, Seattle, WA, 2002.

“Tunnel Rehabilitation in North American,” by H.W. Parker, R.A. Robinson, P.M. Godlewski, W.A. Hultman, R.J. Guardia: Proceedings of the International Tunneling Association Conference, Milan, Italy, 2001.

“Earth Pressures on Deep Shafts,” by R.A. Mikhail, M.S. Kucker, G.R. Fischer, R.A. Robinson, and P.M. Godlewski, Proceedings of the North American tunneling Conference, , 2000.

“Coping with Boulders in Soft Ground Tunneling,” by P. Dowden and R.A. Robinson, Proceedings of the Rapid Excavation and Tunneling Conference, San Diego, California, 2001.

“Models for Predicting Surface Settlements Due to Soft Ground Tunneling,” by Z.W. Wang, K.L. Sampoco, G.R. Fischer, M.S. Kucker, and R.A. Robinson, Proceedings of the North American Tunneling Conference, 2000.

“Evolving Soft Ground Tunneling in Seattle,” by J. Cochran, R. Robinson, L. Moday, and D. Davis, Proceedings of the Rapid Excavation and Tunneling Conference, 2005.

“Conceptual Design for a Deep Underground Science and Engineering Laboratory,” by H.C. Haxton, J.F. Wilkerson, R. Robinson, and R. J. Guardia, Proceedings of the Rapid Excavation and Tunneling Conference, 2005.

“Impacts of Geotechnical Issues on Design of the Beacon Hill Tunnel and Station Project,” by R.A. Robinson, M. S. Kucker, M. J. Lehen, and S. Warren, Proceedings of the Rapid Excavation and Tunneling Conference, 2005.

“Rehabilitation of the Cape Creek Highway Tunnel Under Traffic,” by R.A. Robinson, T. Shell, R.J. Guardia, and S. Rudolf, Proceedings of the Rapid Excavation and Tunneling Conference, 2005.

“Predicted Versus Actual Obstructions for two Pipe-Jacked Tunnels of the Henderson CSO, Seattle, Washington,” by B. Cowles, R.J. Guardia, R. Robinson, R.M. Andrews, and D. Molvik , Proceedings of the Rapid Excavation and Tunneling Conference, 2005.

# Gregg E. Korbin - Resume

## Background

Born: 22 September 1949, U.S. citizen.  
Address: 1167 Brown Ave., Lafayette, CA 94549  
Phone/fax: (925) 284-9017  
E-mail: gekorbin@earthlink.net

## Education

Department of Civil Engineering, University of California, Berkeley: 1973-75 Ph.D., Major Field - geological engineering, Minor fields - soil mechanics and engineering analysis; 1967-72 B.Sc. and M.Sc. in civil and geological engineering.

## Positions

1981-Present: Independent geotechnical consultant; 1980: Senior consultant with Lachel-Hansen & Assoc., CO; 1978-79: Post Doctoral Exchange Fellow from U.S. Department of Transportation to Transport and Road Research Laboratory, England in tunneling technology; 1975-78: Lecturer and Assistant Research Engineer at U.C. Berkeley.

## Research and Publications

Dr. Korbin has performed research and published over 30 papers and technical reports in the following areas: model and field studies of ground pre-reinforcement, modeling and analysis of squeezing ground and standup time, tunnel support and pressure tunnel liner design, behavior of tunnels in active faults, aspects related to underground disposal of nuclear waste, and factors influencing the performance of tunnel boring machines.

## Professional Experience

Since 1975 Dr. Korbin has consulted on over 100 projects including dams, hydroelectric facilities, and subway, water, railroad and highway tunnels. Consulting work has included site investigations, field and laboratory testing programs, dam foundation and slope stability analysis, instrumentation system design and installation, tunnel support and liner system design, selection of excavation methods, construction plans and specifications, construction prebid evaluation and claim analysis, and the assessment of TBM performance.

Experience from over 40 projects where TBM's were employed or proposed include: East 63rd.St. Subway, NY; Kielder Water Tunnels, England; Tunjita Valle and Rio Negro Water Tunnels, Colombia; Milwaukee Sewer Tunnels, WI; WMATA Contracts K-1 and A10a, Wash., D.C.; Hanford Basalt Waste Isolation Project, WA; Foothills Water Tunnel, Denver, CO; Buffalo LRRT Subway, NY; Los Angeles Metro, CA; Kerckhoff 2 Hydroelectric Project, CA; Sandbar Hydroelectric Project, CA; Mediterranean-Dead Sea Hydroelectric Project, Israel; Rogers Pass Railroad Tunnel, Canada; State of California Superconducting Super Collider Project; Boston Harbor Cleanup, MA; Waste Isolation Pilot Project Brine Experiment, NM; Muck Valley Hydroelectric Project, CA; North Fork Stanislaus River Hydroelectric Project, CA; Metropolitan Water District of Southern California Inland Feeder; Passaic River Basin Flood Control Project, NJ; Grizzly Powerhouse Project, CA; Stanley Canyon Tunnel, CO; MetroWest Water Supply Tunnel, MA; Alumysa Project, Chile; Cowles Mountain Tunnel, CA; Baspa Hydro Electric Project, India; CSO Dearborn, MH; Westside LRT Tunnel, OR; LA Metro Red Line, C0311 and East Side Extension, CA; Porce II Hydro Electric Project, Colombia; Point Loma Tunnel Outfall, CA; South Bay Tunnel Outfall, CA; River Mountains Tunnel No.2, NV; Berryman Water Tunnel, CA; Second Manapouri Tailrace Tunnel, New Zealand; North Dorchester Bay and Reserved Channel CSO Facility, Boston; Chattahoochee Interceptor Relief Tunnel and Nancy Creek, West Area and No Business Creek CSOs, Atlanta; Westside and Eastside CSOs, Portland; and Port of Miami Tunnel proposal.

Hydroelectric projects or pressure tunnels with field testing and/or design involvement include Seboyeta Pump Storage, NM; Balsam Meadow Pump Storage, CA; North Fork Stanislaus River, CA; Dinkey Creek, CA; Jigüey-Aguacate, Dominican Republic; Grizzly Powerhouse, CA; Stanley Canyon, CO; Tazimina

Hydroelectric Project, AL; Potomac Bi-County Supply Main, Wash., D.C.; Inland Feeder Project, CA; MetroWest, Boston; Alumysa, Chile; SM3 and Pingston Hydroelectric Projects, Canada; and Lake Hodges Pumped Storage, San Diego.

In addition, general design and instrumentation work has been performed on the following: Bonneville Railroad Tunnel, WA; Dwight D. Eisenhower Road Tunnel, CO; East 63rd St. Subway, NY; Los Angeles Metro; North Fork Stanislaus River Hydroelectric Project; Abiquiu Seepage Adits, NM; WSSC Bi-County Water Tunnel, Wash., D.C.; Superconducting Super Collider Prototype Injector Facility, TX; EBMUD Tunnels Seismic Improvements, CA; Jarvis Wine Caves, CA; Crystal Springs, Calaveras, Coyote Dam Outlet Tunnel, South Bay Tunnel Outfall and Lake Hodges Pump Storage Tunnel, all in CA; and more than 10 large underground caverns for wine caves and other facilities in northern CA.

Dam, penstock and foundation design and investigations include: New Spicer Meadow rockfill dam, Beaver Creek and Raising Pardee concrete gravity dams, McKays Point thin arch dam, Buckhorn earth fill and New Lyons dam feasibility studies, Beaver Creek and Camino Penstocks, and New Carquinez Suspension Bridge foundation, all in CA. This has required extensive interaction with regulatory agencies (DSOD and FERC).

Technical and/or expert witness testimony were provided for claims on: WMATA Contracts K-1, Wash., D.C.; Foothills Water Tunnel, Denver, CO; Buffalo LRRT Subway, NY; Kerckhoff 2 Hydroelectric Project, CA; Rogers Pass Railroad Tunnel, Canada; Muck Valley Hydroelectric Project, CA; WSSC Bi-County Water Tunnel, Wash., D.C.; Kemano II Completion Project, Canada; Grizzly Powerhouse Project, CA; Stanley Canyon Tunnel, CO; Cowles Mountain Tunnel, CA; Westside LRT Tunnel, OR; Boston Harbor Outfall Tunnel, MA; Main Spine Tunnel, Providence, RI.; MWD, Arrowhead Tunnels; and Seymour-Capilano Twin Tunnels, Vancouver.

Dr. Korbin has served on or is serving on the technical/design review boards of the following major projects: Passaic River Basin Flood Control Project, NJ; River Mountains Tunnel No.2, NV; LA Metro East Side Extension; MWD Inland Feeder Project; MWD Lake Mathews Outlet Facilities; Dorchester Sewer Tunnel, Boston; East Side Access Project, New York; Chattahoochee Interceptor Relief Tunnel, and Nancy Creek, West Area and No Business Creek CSOs, Atlanta; East Central and Northeast Interceptor Sewer Tunnels, City of Los Angeles; Narragansett CSO Deep Tunnel Project, RI; Riverbank Infiltration Tunnel at Payne Water Treatment Plant, Louisville; EBMUD Southern Loop Pipeline Project; Claremont Tunnel Upgrade, Oakland; Westside and Eastside CSOs, Portland, OR; No. 7 Subway Extension, NY; Devil's Slide and Caldecott Highway Tunnels, CA; MUNI New Central Subway and Downtown Extension Projects, San Francisco; Brightwater Sewer Tunnels, Seattle; SFPUC Polhemus and Bay Division Pipelines Tunnel Project; SNWA Lake Mead Intake 3 and Clean Water Coalition SCOP, Las Vegas; WSSC's Bi-County Water Supply Main, Wash.DC; and LA County Tunnel and Ocean Outfall.

Dr. Korbin has served on the following disputes review boards (DRB): Folsom East Interceptor Section 2B Project, Sacramento; El Dorado Irrigation District Mill-Bull Tunnel; Dougherty Valley Tunnel & Trunk Sewer, San Ramon; Upper Northwest Interceptor, Section 7 and Lower Northwest Interceptor, Section 9, Sacramento; SLAC-LINAC Project, Stanford, CA.

Dr. Korbin has been a Lecturer at U.C. Berkeley and an invited speaker at a number of workshops and professional meetings; chairman of consultants group, UTRC-GDSR Workshop in Wash., D.C.

### **Professional Affiliations and Awards**

Member ASCE and Chi Epsilon.

U.S. National Committee for Rock Mechanics, Outstanding Student Research Award (1977).

**Education**

BSc, Civil Engineering,  
City University, London,  
1978

**Registration**

Chartered Engineer

Fellow of the Institution of  
Civil Engineers

**Years in Practice** - 27

**Memberships**

British Tunnel Society

Member of the American  
Society of Civil Engineers

Rapid Excavation &  
Tunneling Conference -  
(RETC) Executive  
Committee Member

**Experience Summary**

Mr. Townsend has more than 20 years of experience in planning, design, construction, and project management of both hard and soft rock tunnels. He has experience of cut and cover, immersed and bored tunnels under water. He has extensive experience with tunnel boring machines for both hard and soft tunnels, tunnel grouting for both ground improvement and to control water inflows, and various types of excavation support including reinforced concrete gasketed one-pass linings, steel rib, shotcrete, and rock bolts. He is very experienced in all aspects of contract bid preparation, constructability review, contract administration, and contract negotiations. He has implemented claim avoidance strategies, and successfully representing clients in claims negotiations at disputes review board hearings.

**Selected Experience****Various Projects, Hatch Mott MacDonald, Pleasanton, CA**

As Regional Manager for the Western U.S. responsible for profit and loss for all Western U.S. operations, which include offices in the East Bay, San Diego, Seattle, Sacramento, Provo, and numerous project offices. Responsible for major projects pursuits such as the Measure A Highway and Transit PM/CM for SCVTA, the Silicon Valley Rapid Transit System extension of BART to San Jose; the Arrowhead Tunnels project construction management; design of the Seattle Sound Transit LRT extension to the airport; the Sacramento Lower Northwest Interceptor Tunnel design under the Sacramento River, and the Phoenix Sky Harbor APM Tunnel design.

**Measure B Highway Program, Santa Clara Valley Transportation Authority (SCVTA), San Jose, CA**

JV Board member - The Joint Venture administered the \$600-million Highway Program for the VTA. VTA assignments included design, right-of-way, utility, and construction management services. The JV also providing program control and construction management services for I-880 Widening, 101 Widening, 85/87 Direct Connector Ramps, 85/101 North Interchange Reconstruction in Mountain View, 237 / I-880 Interchange in Milpitas, 85/U.S. 101 South Interchange in San Jose, and 87 North HOV Lane Project contracts.

**Silicon Valley Rapid Transit Project, Santa Clara Valley Transportation Authority, San Jose, CA**

JV Board Member - Tunnel Segment and Project Management Services. This \$5.2 billion construction project will extend the existing BART third rail transportation system 16.3 miles from Warm Springs to Milpitas, San Jose, and Santa Clara. The first 11.8 miles will be at-grade, elevated or in trench, and the next 4.5 miles will underground through downtown San Jose, passing through four cut-and-cover stations, two ventilation structures, and a crossover to arrive at the west portal in Santa Clara.

**Beacon Hill Station and Tunnels, Sound Transit, Seattle, WA**

JV Board Member and Technical Advisor. The \$160 million project consists of subsurface excavation and support of 4,800 feet of twin bore 21-foot-diameter running tunnel, retained cut-and-cover portals, a NATM-mined station shell, station finishes, and ventilation shafts.

**Medway Immersed Tube Road Tunnel, Kent, U.K.**

Resident Designers Representative. Responsible for the construction supervision of all civil and electrical mechanical work for the \$115 million "design and build" contract involving a 2,356-foot-long immersed tube and cut-and-cover road tunnels under the River Medway. Established and monitored the operation of QA and QC procedures. Supervised a small inspection team to ensure the construction was carried out in accordance with the design.

**Singapore Rapid Transit Corporation, Singapore**

Resident Engineer. Responsible for the review of methods of construction, quality of materials and workmanship, and progress of the \$2.98 billion program. Supervised the construction of 1.44-mile-long, 17.55-foot-diameter bored tunnel in free and compressed air through a variety of ground conditions and the construction of 585 feet of reinforced concrete cut-and-cover tunnel to a maximum depth of 91 feet below the Singapore River. This tunnel was constructed with a bolted gasketed segmental liner.

**Great Belt Eastern Rail Tunnel, Denmark**

Senior Tunnel Engineer. Responsible for compliance with design criteria and construction supervision of the twin tunnels, 260 feet below sea level, using EPBMs. This \$900 million tunnel was constructed using a bolted gasketed segmental liner to withstand ground water pressures of up to eight bar.

Senior Design Engineer. Responsible for the internal tunnel works and for ensuring design activities were completed within the tight schedule and budget. Also responsible for coordination of gasket and segmental liner packer testing and testing of annular grouts.

**Inland Feeder Project, Metropolitan Water District (MWD) of Southern California, San Bernardino, CA**

Project Manager. Responsible for the administration of HMM's contract with MWD on this \$1.2 billion project. Responsible for ensuring that staff resources were identified and employed in accordance with the agreed upon budget and schedule.

Resident Engineer—Arrowhead Tunnels Project. Responsible for all aspects of site supervision and contract administration for this \$240 million contract to construct two rock tunnels totaling 42,000 feet lined with 12-foot-diameter steel pipe. Tunnel construction included dewatering and pre-excavation grouting to control ground water inflows. Responsible for construction management during construction of 6,600 feet of 12-foot-diameter pipeline between the two tunnel portals. Participated in constructability and specification reviews during the redesign of the Arrowhead Tunnels Project.

Resident Engineer—Riverside Badlands Tunnel. Responsible for all aspects of site supervision and contract administration for this \$113 million contract to construct 42,000 feet of rock tunnel lined with 12-foot-diameter steel pipe. Tunnel construction included dewatering and pre-excavation grouting to control ground water inflows.

**LA Metro Red Line—North Hollywood, Los Angeles County Metropolitan Transportation Authority, Los Angeles, CA**

Resident Engineer. Responsible for all aspects of site supervision and construction management on \$150 million contract to construct 2.5-mile-long twin bore rock tunnels and other underground excavations between Hollywood and Universal City (part of the \$1.3 billion Red Line Extension). Extensive pre-excavation grouting was used to control groundwater inflows.

**Piccadilly Line Extension to Terminal Four, London**

Assistant Resident Engineer/Resident Engineer. Responsible for the initial stages of three, machine-driven tunnels on this \$3 million project. Tunnels were lined with expanded concrete lining and constructed through sound London Clay. Also responsible for hand excavated ventilation shafts constructed with cast iron linings.

**London Transport, U.K.**

Assistant Engineer. Design and construction of railway structures including platforms, staircases, footbridges, and road bridges. Involved in all aspects of design and construction including survey, cost estimates, detailed design, site supervision, working drawings, bills of quantities, and contract documents.

**Published Papers**

P Praesius, J. Townsend, "Storebelt Eastern Rail Tunnel Review of Construction Works", 40<sup>th</sup> *Geomechanics Colloquy* (Salzburg, 1991)

G. Kramer, M Roach, J. Townsend and S Warren, "Grouting of TBM Rock Tunnels for the Los Angeles Subway" *ASCE - Geotechnical Special Publication #80* (1998)

Biggart, Hawley & Townsend, "The North Hollywood Project, Los Angeles", *Proceedings of the Institution of Civil Engineers, Transport, 141 Issue 1*, (London, February 2000, Institution of Civil Engineers' Overseas Prize 2001)

Biggart, Hawley, Townsend & Brenner. Ed. Brierley & Hatem, "Design-Build Subsurface Projects Construction Phase Issues" (Phoenix, 2002)

J Arabshahi, S Klein, J Waggoner, J. Townsend, "Riverside Badlands Tunnel, Inland Feeder Project: The Challenges Between Concept And Completion", *Rapid Excavation and Tunneling Conference*, (New Orleans 2003)



**HERRERA**  
ENVIRONMENTAL  
CONSULTANTS

## Credentials

M.S. in Fisheries, University of Washington School of Fisheries, 1997

B.S. in Fisheries, University of Washington School of Fisheries, 1995

## Specialties

Fisheries and marine biology

Geomorphic habitat assessment

ESA Compliance

Habitat restoration

Lacustrine ecology

Coastal and fluvial ecology

Project impact assessment

## José Carrasquero, M.S.

### *Fisheries Principal*

José Carrasquero is a fisheries biologist with 19 years of professional experience in fluvial and coastal ecological studies, instream habitat characterization, fish population assessment, habitat impact assessment, stream restoration, and ecological studies of lacustrine systems. Mr. Carrasquero conducts all forms of biological assessments for habitat restoration, construction, and maintenance projects and participates in the design of instream, off-channel, and wetland habitat projects.

He participated in the impact assessment of the proposed Sound Transit tunnel underneath the Montlake Cut. In this assessment, impacts to Chinook, steelhead, and bull were considered.

Through his experience as a research fisheries biologist with the National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA Fisheries), Mr. Carrasquero has become well versed in the habitat assessment techniques used for evaluating project impacts and benefits.

Carrasquero has assisted Washington State Department of Transportation (WSDOT) and other state, federal, and local agencies in complying with the Endangered Species Act (ESA) and other environmental regulations. Mr. Carrasquero has also assisted local, state, and federal agencies and Tribes in complying with the ESA on several projects. He has also reviewed numerous construction projects for compliance with ESA requirements.

These project reviews have involved reviewing construction plans, recommending best management practices (BMPs) and mitigation measures, and coordinating with individual project managers to include BMPs and mitigation measures in the project design to facilitate the concurrence process with regulatory agencies. In addition, Mr. Carrasquero has assisted tribes and federal, state, and local agencies in complying with the National Environmental Policy Act (NEPA) on numerous projects. In addition, he has coordinated environmental permits including Clean Water Act section 404 and 401 permits, joint aquatic resource permit applications (JARPA), State Environmental Policy Act (SEPA) checklists, local permits, and Hydraulic Project Approval (HPA) permits.

## Key Project Experience

### **Sound Transit University/Central Link ESA Compliance and Critical Habitat Analysis**

Seattle, WA

The University Link Light Rail project is an element of the Sound Move Regional Transit Plan adopted by the Central Puget Sound Regional Transit Authority (Sound Transit) Board in May 1996. In 2000, the Federal Transit Administration (FTA) received letters of concurrence from the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS). These letters concluded the informal ESA section (7) consultation process for the original University Link Light Rail project design. Mr. Carrasquero assisted Sound Transit with reinitiation of consultation in 2005 to address the subsequent designation of critical habitat for the Puget Sound Chinook salmon Evolutionarily Significant Unit (ESU) and the Coastal/Puget Sound bull trout Distinct Population Segment (DPS). Subsequent to these actions, the Puget Sound steelhead DPS was listed as threatened (proposed

May 2006, effective June 2007) and there were changes to key elements of the project design that required a reanalysis of potential effects. Specifically, newly discovered site conditions required raising the roof of the transit tunnel underneath the Montlake Cut closer to the channel bed. This presented the potential for increased underwater noise and vibration that could alter ambient noise levels and potentially disturb bottom sediments. Both the listing of steelhead, which occur in the affected habitat, and the potential for effects that were not considered in prior consultations on Chinook and bull trout are grounds for reinitiation. Mr. Carrasquero developed the necessary analyses and documentation needed to ensure FTA's compliance with the ESA, and did so within a short timeframe to meet permitting deadlines for critical geotechnical investigations informing the revised design. Mr. Carrasquero reviewed available data and information, evaluated the changes in project design, and developed an assessment of the nature, extent, and duration of anticipated ecological stressors. This information was used to interpret potential direct and indirect effects on all listed species and critical habitats, and develop the appropriate effect determinations. Mr. Carrasquero's assistance ensured FTA's compliance with the ESA and helped to keep this critical regional transportation project on schedule.

### **EIS and Discipline Report Review for Ecology on the Northwest Pipeline Capacity Replacement Project Sumas and Washougal, WA**

Mr. Carrasquero participated on the team of technical experts providing support to the Washington State Department of Ecology (Ecology) as that agency provides review and input to the NEPA EIS being prepared by the Federal Energy Regulatory Commission (FERC) for the Northwest Pipeline Capacity Replacement Project. The Northwest's existing 26-inch natural gas pipeline extends 268 miles between Sumas and Washougal, Washington and crosses a large number of lakes, rivers, streams, and wetlands. Mr. Carrasquero reviewed and provided comment on the Fish, Wildlife, and Vegetation and Endangered and Threatened Species reports and the administrative draft EIS, and provided review of the public draft EIS. This included an assessment of potential project impacts due to tunneling activities under lakes, rivers, streams, and wetlands. He quantified environmental impacts for various conveyance configurations that involve near surface tunneling and open trenching options.

### **Environmental Screening for Alternative Facility Sites and Conveyance Routes Selection for the Brightwater Wastewater Treatment System Seattle, WA**

Mr. Carrasquero provided biological technical support for the screening of alternative facility sites and conveyance routes for the proposed North End Treatment Plant, referred to as Brightwater. His critical role during the screening process involved collecting data on streams and wetlands that could be affected by construction of facility sites and conveyance routes. He quantified environmental impacts for various conveyance configurations that involve deep-tunneling, near surface tunneling, and open trenching options. These impacts were inputted into a matrix model that determined the relative impacts among the various conveyance alternatives.

### **Sound Transit University/Central Link ESA Compliance and Critical Habitat Analysis Seattle, WA**

The University Link Light Rail project is an element of the Sound Move Regional Transit Plan adopted by the Central Puget Sound Regional Transit Authority (Sound Transit) Board in May 1996. In 2000, the Federal Transit Administration (FTA) received letters of concurrence from the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS). These letters concluded the informal ESA section (7) consultation process for the original University Link Light Rail project design. Mr. Carrasquero assisted Sound Transit with reinitiation of consultation in 2005 to address the subsequent designation of critical habitat for the Puget Sound Chinook salmon Evolutionarily Significant Unit (ESU) and the Coastal/Puget Sound bull trout Distinct Population Segment (DPS). Subsequent to these actions, the Puget Sound steelhead DPS was listed as threatened (proposed May 2006, effective June 2007) and there were changes to key elements of the project design that required a reanalysis of potential effects. Specifically, newly

discovered site conditions required raising the roof of the transit tunnel underneath the Montlake Cut closer to the channel bed. This presented the potential for increased underwater noise and vibration that could alter ambient noise levels and potentially disturb bottom sediments. Both the listing of steelhead, which occur in the affected habitat, and the potential for effects that were not considered in prior consultations on Chinook and bull trout are grounds for reinitiation. Mr. Carrasquero developed the necessary analyses and documentation needed to ensure FTA's compliance with the ESA, and did so within a short timeframe to meet permitting deadlines for critical geotechnical investigations informing the revised design. Mr. Carrasquero reviewed available data and information, evaluated the changes in project design, and developed an assessment of the nature, extent, and duration of anticipated ecological stressors. This information was used to interpret potential direct and indirect effects on all listed species and critical habitats, and develop the appropriate effect determinations. Mr. Carrasquero's assistance ensured FTA's compliance with the ESA and helped to keep this critical regional transportation project on schedule.

### **Co-author of the Environmental Impact Statement for the Brightwater Wastewater Treatment System**

Seattle, WA

Mr. Carrasquero contributed to the Animals chapter of the draft and final environmental impact statement (EIS) for the Brightwater Regional Wastewater Treatment System project. He characterized the affected environment, construction and operational impacts, and provided mitigation measures for three pipeline conveyance alternatives associated with the two treatment plant alternatives. Characterization of potentially affected aquatic resources (e.g., wetlands, streams) and uplands with high habitat value, included mapping efforts, classifying and rating according to federal, state, and local guidelines, evaluating plant communities, and identifying wildlife and plant species with special designations (e.g., threatened) according to federal and state agencies. A variety of impacts were assessed such as lost habitat from vegetation clearing, wetland fill, dewatering to streams, buffer impacts, stormwater runoff, and noise effects to wildlife. Some proposed mitigation measures included employing timing restrictions to avoid noise impacts to sensitive wildlife, complying with federal, state, and local guidelines for mitigating unavoidable impacts to sensitive areas, and employing best management practices during construction to minimize erosion, sedimentation, and accidental spills.