SR 520 Bridge Replacement and HOV Project

Assessment of Tunnel Concept I-5 to Lake Washington

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1. INTRODUCTION

Through the course of SR 520 planning, several stakeholders have suggested that placing the highway in a tunnel might be preferable to rebuilding it at ground level and/or on bridges. The Trans-Lake Study Committee reviewed options for tunnels and submerged tubes under Lake Washington early in its development of options for SR 520 (1997-1999). More recently, citizens from the Madison Park and Roanoke neighborhoods suggested looking at constructing the segment of SR 520 that extends from I-5 to the western end of the floating bridge in a tunnel. The SR 520 Bridge Replacement and HOV Project team reviewed the tunnel concept, investigated engineering, evaluated key environmental considerations, and identified preliminary cost ranges. This Report summarizes the results of these evaluations.

2. BACKGROUND

The citizen tunnel concept for placing the segment of SR 520 from I-5 to the western end of the floating bridge was introduced to the SR 520 Bridge Replacement and HOV Project team (by citizens from Madison and Roanoke neighborhoods) during the fall of 2005. Over the course of the fall and winter of 2005, the tunnel concept was presented to multiple community councils and other groups in Seattle. In December of 2005, the SR 520 project team began a review of the citizen concept for a tunnel.

Figure 1 identifies the citizen tunnel concept. The tunnel would begin at the I-5 interchange, where the existing ramps to SR 520 would be located in tunnels under I-5 and under the existing SR 520. The tunnel would continue east under Portage Bay, the Montlake community, and Union Bay about 2.5 miles before connecting to the floating bridge over Lake Washington. A major interchange would occur north of Foster Island, where traffic would be routed north in tunnels under Union Bay (about 0.5 mile), and then split into two directions (near the north shoreline): west (about 0.25 mile) to Montlake Boulevard (just north of the University of Washington's (UW) intramural building) and east (about 0.25 mile) to Mary Gates Way Memorial Drive.

Local access to SR 520 would occur at several locations in the tunnel concept: (1) the vicinity of Fairview Ave E; (2) the vicinity of Boyer Street; (3) an additional connection in the vicinity of McGraw Street and 11th Avenue East; (4) Montlake Boulevard (at the existing interchange location); (5) Montlake Boulevard (north of the UW intramural building); and, (6) at Mary Gates Memorial Drive.

3. INITIAL CONCEPT REVIEW

To evaluate the citizen tunnel concept, the SR 520 project team reviewed the initial tunnel concept between I-5 and the floating bridge and identified preliminary engineering design issues. A presentation to the Madison Park Community Council was given by the SR 520 team on December 19, 2005. Preliminary review of the tunnel concept identified the following issues:

- The local connection to E. Roanoke Street and Harvard Avenue E would be lost if the I-5 ramps are located in a tunnel.
- Tunnels between I-5 and Portage Bay would need to be bored due to the underground depth required.

- The proposed interchanges and local access connections would be difficult to design within the length of the tunnel segment.
- Interchanges in tunnels would be extremely difficult to design and construct.
- Major environmental impacts to Marsh and Foster islands would result from the excavation and dredging associated with immersed tunnel construction.
- The transition from the tunnel to the floating bridge would be challenging due to the navigation channel and steep underwater slopes.
- It is unknown where the bike/pedestrian trail would be located across the Arboretum.
- Safety issues in tunnels would need to be addressed, such as pedestrian escape routes, fire suppression, and ventilation.
- Large ventilation facilities would be required for the tunnel concept.
- Construction costs of a tunnel between I-5 and the floating bridge would be greater than for a surface infrastructure over this same distance.
- Additional right-of-way may be needed for the tunnel concept to accommodate local access connectors.

4. CONCEPTUAL ENGINEERING

Following the initial review, WSDOT investigated the tunnel concept to identify possible solutions for several of the key engineering issues identified above. To assist with this investigation, the SR 520 project team retained the services of a tunnel engineering expert from Parsons, Brinckerhoff, Quade and Douglas, Inc. to review the tunnel concept. Conceptual plan profile and cross-section drawings were developed by the SR 520 team to facilitate a review of the tunnel concept (see **Figures 2 through 8**). The drawings reflect current highway geometry standards, tunnel technology, and typical tunnel engineering practice. The results of these additional investigations by the SR 520 project team were presented at a second meeting on January 5, 2006 with the tunnel proponents. Following is a summary of the tunnel concept review performed by the SR 520 team.

4.1 Highway and Tunnel Engineering Considerations

Development of the tunnel concept by the SR 520 team included review of practical engineering standards and design considerations that typically apply to highway engineering and construction of interchanges. These include:

- Interchange ramps require 2000 feet (or more) on either side of the crossroad.
- Interchanges spaced closer than one mile apart require complicated ramp configurations to accommodate the close spacing.
- Horizontal and vertical alignments must be designed to meet sight distance and safety for the chosen design speed. (The SR 520 project assumes a design speed of 60-mph on the SR 520 mainline, and 35 mph for ramps and cross streets.)

The feasibility of using a tunnel (instead of a surface structure) for highway construction would depend on multiple design considerations including available tunnel technology, the feasibility of constructing interchanges, number of lanes, roadway widths, soils stability, safety, and ventilation. These design considerations are outlined below.

- **Tunnel Technologies**. Types of tunnels include machine-bored tunnels, immersed tubes, tunnels constructed with sequential excavation methods and tunnels constructed with cut-and-cover methodology (see **Appendix A**).

    - Bored tunnels are typically used when the tunnels are deep underground and where long sections of tunnel are constructed. Bored tunnels vary in size up to a maximum of about 50-feet in diameter. Bored tunnels should be separated by the distance of the bored-tunnel diameter when underground and in between adjacent tunnels. Staging areas are required at the starting location of the boring machine, and typically can extend up to 400 feet in length.
    - Immersed tubes are used underwater; the tunnel is typically buried in a shallow trench under the soil. Tunnel sections are constructed off-site and floated to the tunnel location.
    - Sequential excavation can be used where the soil can be excavated and tunnel linings can be placed after the excavation. Soil stabilization techniques may be required throughout soft soils or where there are groundwater issues.
    - Cut-and-cover tunnels are used when the tunnel is at a shallow depth under land. The trench is excavated and the tunnel is constructed using typical concrete placement construction methods.

- **Location of interchanges** within bored or immersed tunnels is extremely difficult due to structural stability limitations and the expanded width necessary for the interchange ramps.
- **Roadway section widths** in tunnels are typically reduced due to the additional cost per square foot of tunnel compared to on-land or on-structure roadways.
- **Number of lanes** is dependent on maximum dimensions of selected tunnel technology.
- **Soils** must provide stability during seismic events and during construction.
- **Safety features** must be included in tunnel design. These include pedestrian escape routes, fire suppression, and ventilation systems.
- **Ventilation systems** for long tunnels would necessitate buildings that house large fan systems, air discharge stacks, and electrical control rooms. Representative illustrations of ventilation buildings are included in **Appendix A**.

4.2 Geometric Design

The highway and tunnel engineering standards and considerations outlined above were used by the SR 520 team to lay out the tunnel concept along the SR 520 corridor using the assumed 60 mph design criterion for the mainline corridor and the 35 mph design criterion for ramps. The alignment considered interchange locations, interchange spacing, horizontal geometry, and vertical geometry. The tunnel would extend generally from the I-5 Interchange with SR 520 to the east end of Union Bay, where it would link to the floating bridge. Several tunnel technologies were evaluated for the tunnel concept including boring, immersed and cut and cover. The tunnel would transition to the fixed SR 520 structure and floating bridge by means of a man-made transition island that would be located near Foster Island. **Figure 2** shows the proposed alignment and tunnel technologies considered for this evaluation.

Interchanges and Local Access

Profiles of the I-5/SR 520 interchange were reviewed to determine if the interchange ramps could be placed in tunnels. Previous work by the SR 520 team showed that the southbound-to-eastbound ramp could be placed in a tunnel under I-5. The profile for this ramp would go under I-5 and slope east to a point under SR 520. The ramps would be more than 100 feet deep under the existing SR 520 roadway near the Delmar Drive crossing. This depth of tunnel would require the use of either boring machines or sequential excavation technology for construction. Although the SR 520 team did not evaluate all the ramps at the I-5/SR 520 interchange, it is assumed that these ramps could also be designed with a similar profile.

The I-5/SR 520 interchange ramps would need to be relocated and placed in a tunnel. The ramps would need to ensure that the portal (access) locations could accommodate the entrance of a boring machine. The construction staging areas and entrance platforms may need to extend several hundred feet in length. Maintaining the existing Harvard off-ramp would not be possible due to the elevation differences between the SR 520 mainline tunnel and the elevation at the intersection of Harvard Avenue E. and E. Roanoke Street. The new ramp locations would also affect the adjacent interchanges on I-5 north and south of SR 520. Specific evaluations of possible ramp configurations have not been completed at this time. An HOV ramp connection to I-5 could not be accommodated with a tunnel connection.

An alternative design was evaluated by the SR 520 team that would help address some of the design complications at the I-5/SR 520 interchange. **Figure 3** shows this alternative design concept, which would use the same surface-level I-5 interchange proposed in the SR 520 6-Lane Alternative. The Harvard Ave E off-ramp and the HOV ramp would be maintained. SR 520 would be constructed as an above-ground structure over Portage Bay. This design would eliminate the need to bore tunnels under North Capitol Hill and Portage Bay, maintain the desired local connections and HOV ramps at I-5, and reduce the construction effects of the tunnel across the sensitive natural shoreline areas of Portage Bay.

Generally, interchanges should be located about one mile apart. For shorter distances, complex interchange designs are required to provide safe and efficient traffic flow. The citizen tunnel concept includes four interchanges between I-5 and the floating bridge (a distance of about 1.75 miles). Due to the short spacing between interchanges, this design would likely not be feasible. A more realistic solution would be to include one interchange at I-5 and one for the Montlake/University area. **Figure 2** shows the Montlake/University interchange, with ramps located within structure types conducive to interchanges. The ramps west of the interchange would be constructed in a cut and cover section in the vicinity of Montlake, and the ramps east of the interchange would be constructed in a fixed structure section, north of the Madison Park community.

The citizen tunnel concept shows an immersed interchange from SR 520 that crosses under Union Bay and splits the roadway to connect to Montlake Boulevard and Mary Gates Memorial Drive. Roadway geometry design standards are not conducive to this aspect of the tunnel concept because the distance between the split and the local street is too short to provide safe designs for the vertical and horizontal alignment necessary to split the roadways and create a safe intersection at the local street. The SR 520 team evaluated possible alternative local connections to the Montlake and University areas. **Figure 4** shows four separate one-way ramps in separate tunnels under the Bay. This design would simplify construction of the interchange under Union Bay. **Figure 5** shows a cross-section of the ramps under Union Bay. On the north end of Union Bay, where the tunnel enters land, cut-and-cover construction would

be used to weave the one-way roadways and to create a typical four-lane street section, prior to the connection to NE 45th Street. Traffic operations for this intersection have not been analyzed, but the large volumes of traffic anticipated would make it difficult to provide an acceptable intersection level of service (LOS) without adding many lanes for the intersection and acquiring additional right-of-way.

Tunnel Alignment

Geometric requirements determine roadway curvature at a 60-mph design speed. As such, the tunnel alignment would not be able to avoid Foster and Marsh Islands. On the graphics presented by community members (see **Figure 1**), the tunnel alignment is shown north of Foster Island and curves south of Marsh Island. However, the alignment required to transition the tunnel from north of Foster Island to land near the Museum of History and Industry (MOHAI), would require complete excavation of Marsh Island and substantial excavation of Foster Island. In addition, the tunnel would need to be located under the bottom of the 30-foot-deep navigation channel, which would require a 70' to 80' deep dredged excavation in Union Bay beneath the channel. **Figure 2** shows a "cut" line that approximates the 500' to 800' wide limits of the dredging and excavation that might be required for placement of the immersed tunnel section.

Traffic During Construction

Traffic during construction must also be considered when evaluating replacement options for SR 520. The proposed above-ground structure options would allow continued use of SR 520 by vehicles. For the tunnel option, vehicles would be able to travel on certain portions of the existing SR 520 during construction; however, traffic on several segments would be difficult to maintain within the corridor. For example, near Foster and Marsh Islands, the tunnel is north of the existing alignment (refer to **Figure 2**). As such, a tunnel could be constructed while traffic crosses the existing SR 520 structure. However, under the Portage Bay and Montlake area, the tunnel would likely need to be constructed under the existing SR 520 alignment. Maintaining traffic flow across the existing SR 520 structure would be very difficult and would increase the cost of a tunnel alternative. Detour bridges and temporary roadways would be required to maintain traffic on portions of the corridor.

4.3 Structural Tunnel Design

Tunnel technology indicates that several types of tunnels would be required to accomplish the citizen tunnel concept. The profile in **Figure 2** depicts the assumed tunnel and/or structure types for each section of the corridor. The following issues must be considered prior to selecting a tunnel construction method: the depth underground (shallow under I-5 and deep under SR 520 near 10th Avenue E); type of soil; maintaining traffic during the tunnel construction; availability of staging areas near tunnel portals; and interchange locations within the tunnels.

For comparative purposes, bored tunnels have been assumed between I-5 and Portage Bay; however, sequential excavation methods could prove to be better suited for this section if suitable soils are present. **Figure 6** shows a cross-section of the bored tunnels near the I-5/SR 520 Interchange area. The four I-5 ramps are shown in separated bored tunnels. Immersed tunnels are assumed under Portage Bay, which would require a cut-and-cover section to transition from bored tunnels to immersed tunnels.

Cut-and-cover techniques are likely across the Montlake area, where a portion of the interchange would be located. As the tunnel enters the Arboretum area, immersed tunnels are, again, the likely structure type for the tunnel to cross the Arboretum and make local connection to the north under Union Bay. **Figure 7** shows a cross-section of the immersed tunnels near Foster Island. The cross-section shows the 70' to 80' depth of the structure under the navigation channel and the approximate 500' to 800' width of excavation required to create the trench for the tunnel. **Figure 5** shows the cross-section of the immersed tunnel under Union Bay (70' to 80' deep and 400' x 600' wide).

Transition Section

A transition section is required to connect tunnels with above-grade structures, and would be needed for the tunnel to connect from beneath Montlake to the floating bridge. Many examples of transition sections exist across the world; all of them use a man-made soil island for the transition. An example transition island photograph is shown in **Appendix A**. Locating the transition of the east end of the tunnel would be challenging due to the structural constraints of the floating bridge, the navigation channel, and the underwater soils and topography.

Analysis explored both "tunnel-under" and "structure-over" designs for SR 520 to cross the navigation channel near the existing west high rise. If the transition island were located so that the tunnel was under the navigation channel, the profile would be similar to that shown in **Figure 8**. A steep underwater slope exists under the west high rise, which has had a history of underwater land slides. Locating a fixed structure or the transition section on this unstable slope would require complex engineering and construction to protect the integrity of the transition island. These issues suggest the "structure-over" design for SR 520 would be less complicated than the "tunnel-under" design. The profile in **Figure 2** assumes that the SR 520 corridor is over the navigation channel on above grade structure and the transition island is located west of the floating bridge just east of Foster Island. However, due to the space constraint between the floating bridge and the navigational channel near Foster Island; the ramps would be located on the floating bridge as seen in **Figure 2**, which makes it complex to maintain the required structure balance and integrity of the floating bridge. No ideal design was determined for this transition location, but it is clear that the solution would require complex engineering.

Construction Limitations

Both bored and immersed tunnel technologies have limitations on the tunnel section. Bored tunnels are limited to diameters less than 50 feet due to structural concerns. Also, each bore has a fixed dimension which cannot change part way through the tunnel. Immersed tunnels are typically constructed off-site and floated to the construction site. They can be made of steel or concrete, and can be round or rectangular. Transport of immersed tunnels to the project site would have to consider navigation limitations due to clearance requirements within the ship canal between Puget Sound and Lake Washington. It might be possible to find a construction site on Lake Washington; however, such a site is more likely to be located outside the lake system. In this case, the width and water depth of the Ballard locks would limit the size of the tunnel section that could be floated to the site. The tunnel sections shown in **Figures 5 and 7** indicate sections that could be floated through the locks and ship canal.

5. PRELIMINARY ENVIRONMENTAL REVIEW

The SR 520 environmental team conducted a brief review of key environmental issues associated with the project team revised tunnel concept. Following is a brief summary.

5.1 Ecosystems

Construction effects on sensitive ecosystems would be a primary concern associated with the tunnel concept. Of key concern would be impacts on wetlands' aquatic and fisheries habitat. The tunnel concept would require large amounts of excavation and dredging, and construction of a new soil transition island at the east tunnel portal. The tunnel would need to transition from below ground to above ground in the Arboretum area, which would create substantial disruption to the ecosystems there. Much of the habitat on Marsh and Foster island consists of complex wetland areas that would be destroyed during construction (all of Marsh Island would likely be excavated). Excavation and dredging for the tunnel concept would create high levels of turbidity in Lake Washington, Union and Portage Bays and would be likely to affect fisheries. Shorelines along Foster Island and the northern end of Union Bay would be substantially altered and would likely affect habitat for endangered salmon and bull trout. While mitigation could be possible, it would take several decades for the ecosystems to recover. Because of the magnitude of these effects, there is a strong likelihood that resource agencies with jurisdiction would be unwilling to issue required permits for tunnel construction.

5.2 Geology and Soils

The bed of Lake Washington and Union Bay is covered with a thick layer of peat deposits, which would complicate tunnel construction due to soils stability issues. Considerable fill material would be required to provide an adequate foundation and backfill for the tunnel sections. Construction of the tunnel would require substantially more excavation than an above-ground structure. Achieving seismic and slope stability would require extremely invasive procedures and permanent alteration of existing soils. There is a likelihood that hazardous materials would be encountered North of Union Bay at an old landfill on University of Washington property.

5.3 Water Quality

Stormwater runoff from the tunnel sections would be pumped into the sewer system and treated by the regional wastewater plants. As described above under Ecosystems, increased turbidity associated with tunnel construction could affect fisheries. Long-term impacts to water quality have not been identified.

5.4 Noise

Noise walls have been considered extensively throughout the project, in accordance with FHWA criteria. Placing part of SR 520 into a tunnel would reduce noise levels adjacent to the tunnel sections to a greater extent than above-grade options. However, noise levels near tunnel access points would be similar to those near an above-grade structure. Areas adjacent to the tunnel in the North Capital Hill, Portage Bay, Montlake and Arboretum neighborhoods would experience a greater decrease in noise levels than under the 4-Lane and 6-Lane Alternatives. There would be no changes to noise levels anticipated in the Madison Park and Laurelhurst neighborhoods.

5.5 Air Quality

Regional air quality would not be affected by a tunnel alternative. Air quality would be improved at local receptors adjacent to the tunnel, such as residences or businesses. Large ventilation buildings would be used to exhaust the tunnel air to several locations throughout the tunnel corridor (specific ventilation facility locations have not been evaluated at this time). As a result, air pollutants from cars within the tunnel would be concentrated in a smaller area near the ventilation facilities rather than dispersed along the corridor. One suggestion in the citizen concept was to include air scrubbers at the ventilation facilities. Air scrubber systems are typically designed for industrial applications where the pollution levels are more concentrated and would not be practical in this scenario.

5.6 Cultural Resources

Tunnel construction would require substantially greater excavation in the SR 520 corridor between I-5 and Lake Washington than an above-ground option with supporting columns. As such, the likelihood of encountering archaeological resources would be substantially greater with the tunnel option. Foster Island, where major excavation would occur, is a known cultural resource site and considered a sacred site by some Native American tribes. Tunnel construction could affect the Montlake historic district (NRHP eligible) through potential acquisition of properties.

5.7 Views

Construction of a tunnel between I-5 and Lake Washington would improve views from surrounding neighborhoods, in comparison to an above-ground structure. Locally, ventilation buildings could obstruct views from adjacent residences. Views from Madison Park and Laurelhurst would include the floating bridge, above ground structure, transition ramps, and an artificial island. Through Portage Bay, where the solution could be an above ground structure, views would not change.

5.8 Parks and Recreation

In the long term, the tunnel concept would reduce air quality and noise effects associated with an above-grade highway on nearby park and recreation facilities along the corridor. However, near-term effects on the Washington Park Arboretum would be severe. Marsh Island would be essentially eliminated, and severe construction effects would occur to Foster Island. Substantial mitigation under federal Section 4(f) regulations would be required, including park replacement.

5.9 Land Use

With a widened above-grade structure, land now used for other purposes would be converted to WSDOT right-of-way. With a bored tunnel, land above the tunnel would not be converted to a highway right-of-way. With a cut-and-cover tunnel, land above the tunnel would be excavated during construction, but could be used or converted for public use following construction. Due to the shallow depth of the cut and cover tunnel, private land use would likely not be allowed above the tunnel.

6. PRELIMINARY REVIEW OF TUNNEL COST

Exact cost estimates are difficult to produce based on the conceptual level of engineering accomplished to date. Historically, tunnel construction costs are not as well documented as structure costs. This is partly due to the fact that few tunnel projects are constructed in the US each year and because each tunnel project is unique in its surroundings, challenges, and complexities. This makes estimating the cost of tunnels at the conceptual level difficult.

The SR 520 team reviewed a tunnel project of similar complexity to the SR 520 tunnel project that is being considered for the Gowanus highway in Brooklyn, NY. Detailed costs estimates have been prepared for this planning level project that include multiple tunnel types, underwater tunnels, and interchanges within the tunnels. The Gowanus project estimates range between $12 and $15 Billion for a project that is approximately twice as long as the SR 520 tunnel proposal. Based on the Gowanus estimate, the SR 520 project team estimated that, in general, a tunnel concept between I-5 and the floating bridge could cost approximately $8 billion. Currently, the 6-Lane Alternative (assuming an above-ground structure) for the entire project between I-5 and I-405, is estimated to be between $2.6 and $3.1 billion (includes the options). Changing the west side from above-ground structure to tunnel would add billions of dollars to the project's costs.

7. CONCLUSION

Construction of portions of SR 520 within a tunnel would benefit certain areas of Seattle in terms of reduced noise levels, localized improvements to air quality, and views. However, the conceptual analysis indicates that there are major engineering challenges associated with construction of a tunnel between I-5 and the floating bridge. Tunnel design and construction would be significantly more complex than for an above-ground structure and could require one-of-a-kind construction techniques. The tunnel concept would provide fewer opportunities for local traffic to access SR 520. The reduction in access could result in increases in street congestion in some locations. Effects to the fragile ecosystems of the Arboretum, Marsh, and Foster Islands would be substantial. Restoration of the natural environment would take decades. There is a strong likelihood that resource agencies with jurisdiction would be unwilling to issue required permits for tunnel construction. This tunnel concept would add billions of dollars to the SR 520 project costs.

Based on the analyses and evaluations summarized in this document, the SR 520 team is not evaluating the tunnel concept further as an alternative, in future environmental and engineering efforts.

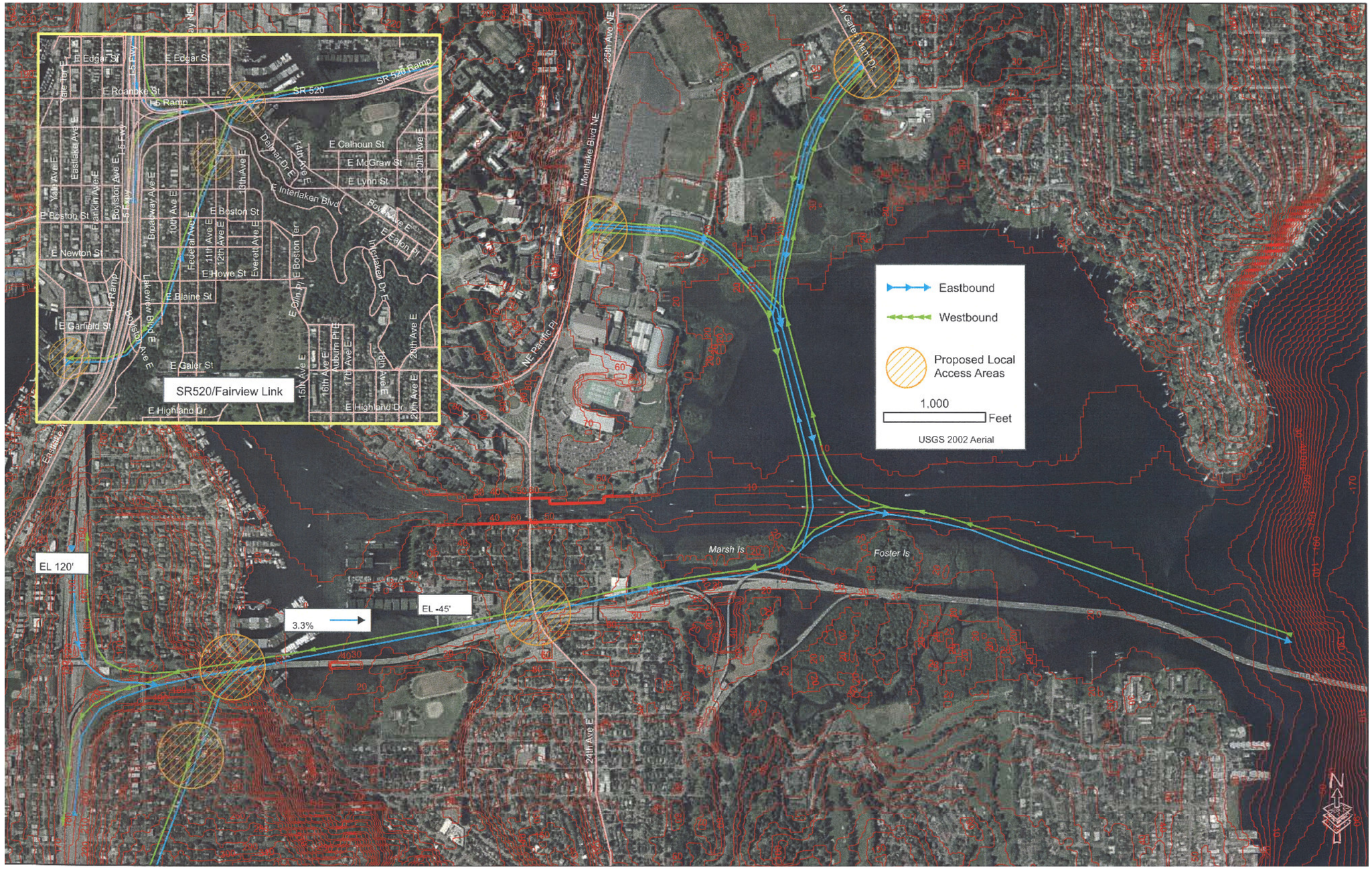

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Figure 1
Community Proposal

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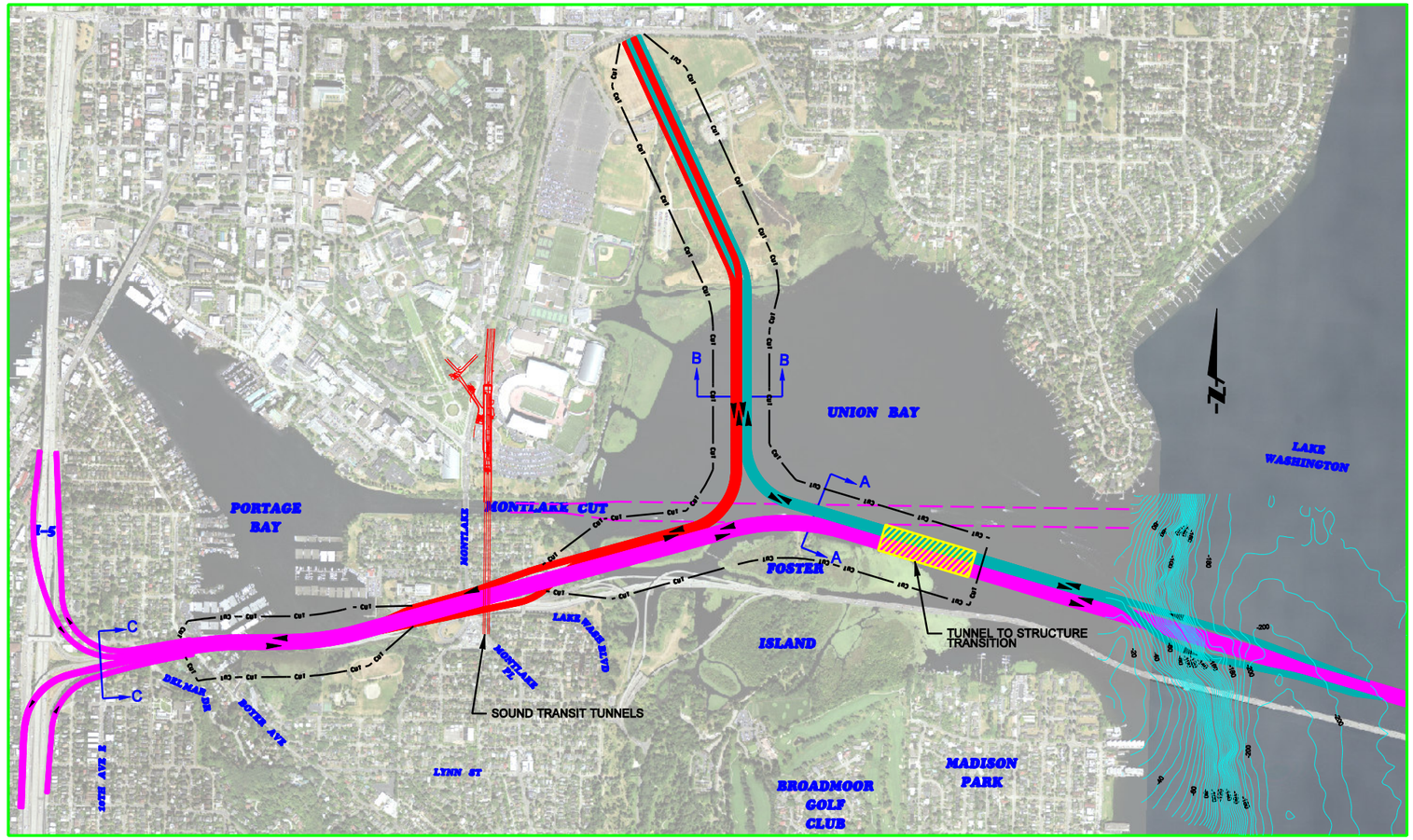

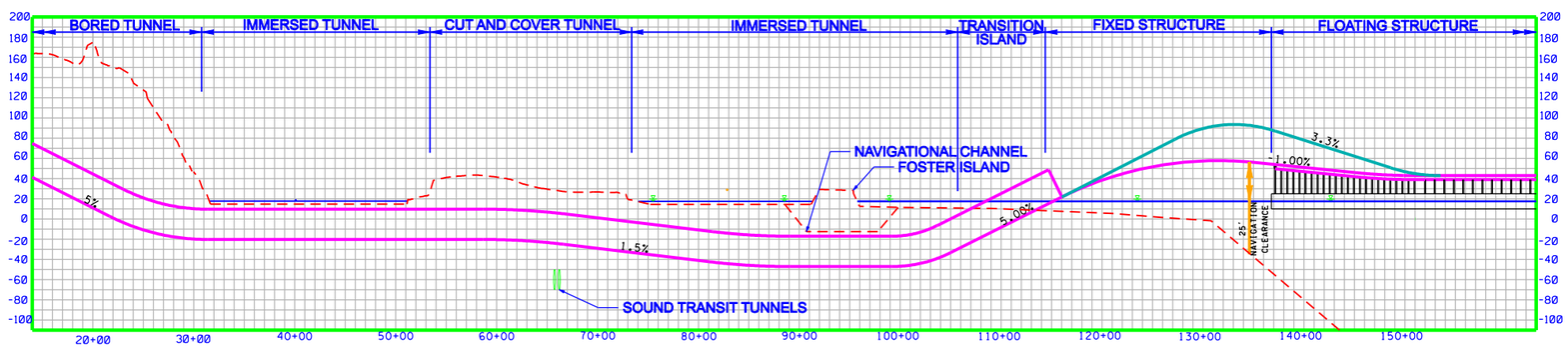

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FOR ALTERNATIVE COMPARISON ONLY

Figure 2
Tunnel from I5 to Floating Bridge

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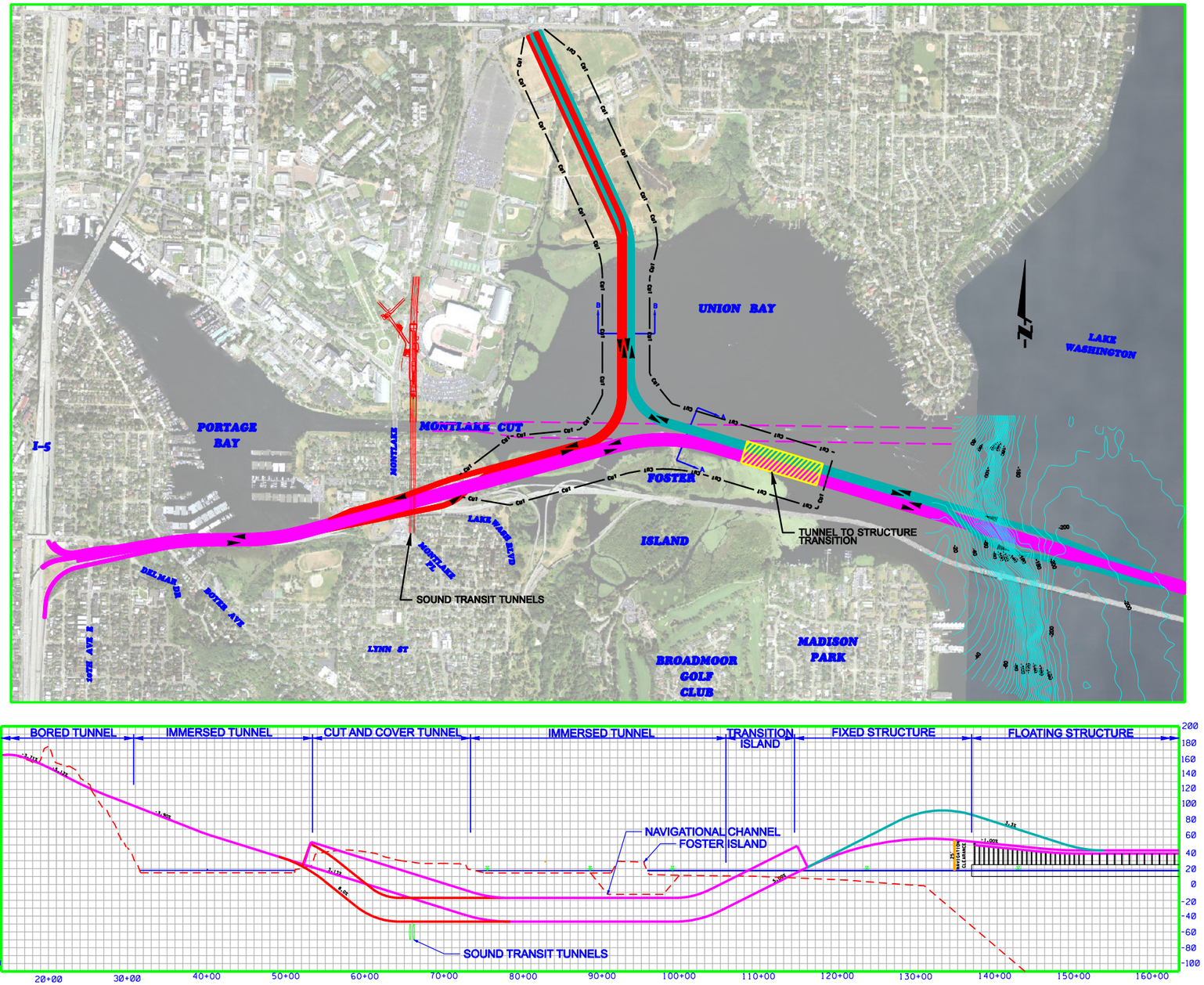

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Figure 3
Portage Bay Bridge Option

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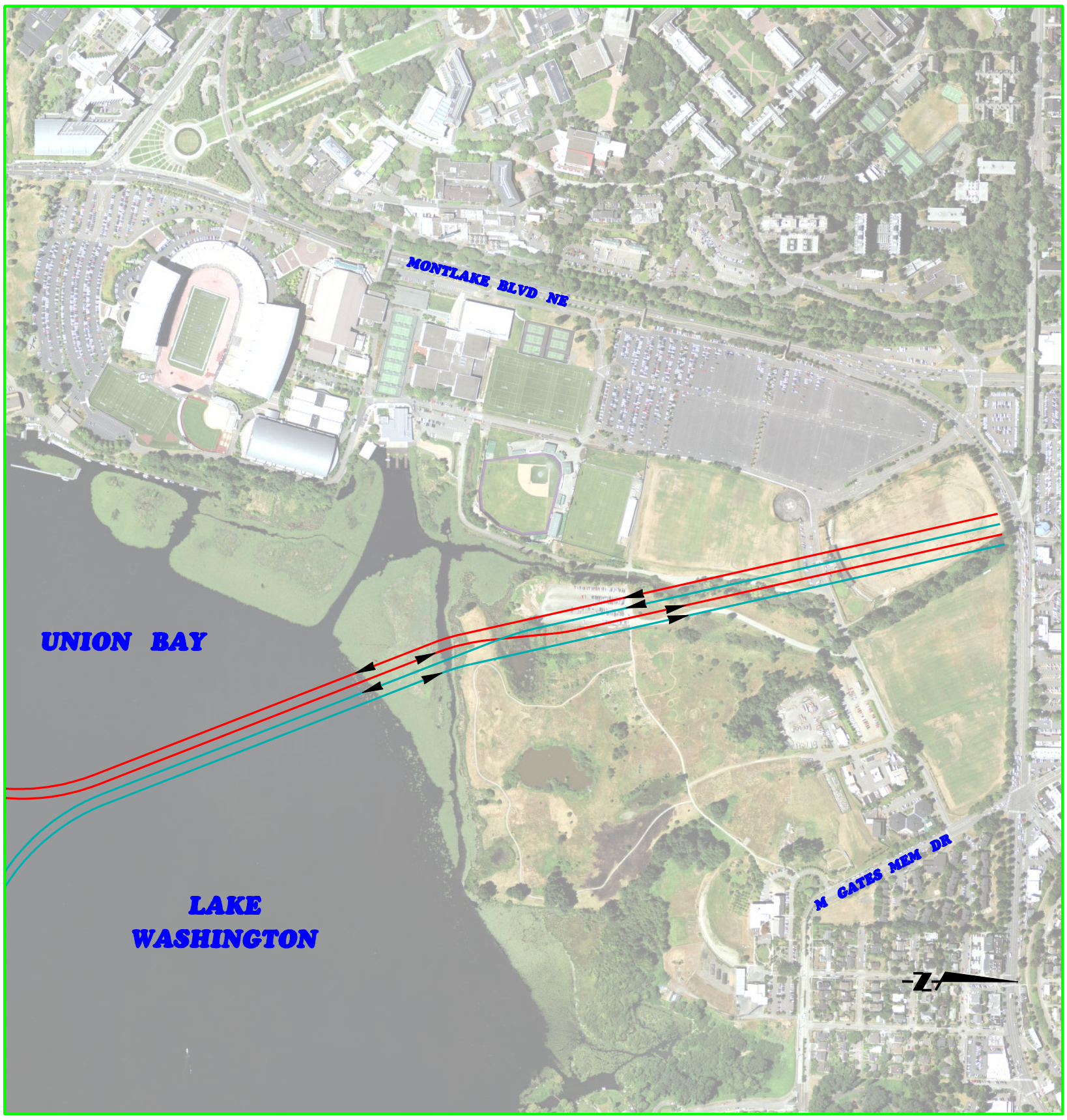

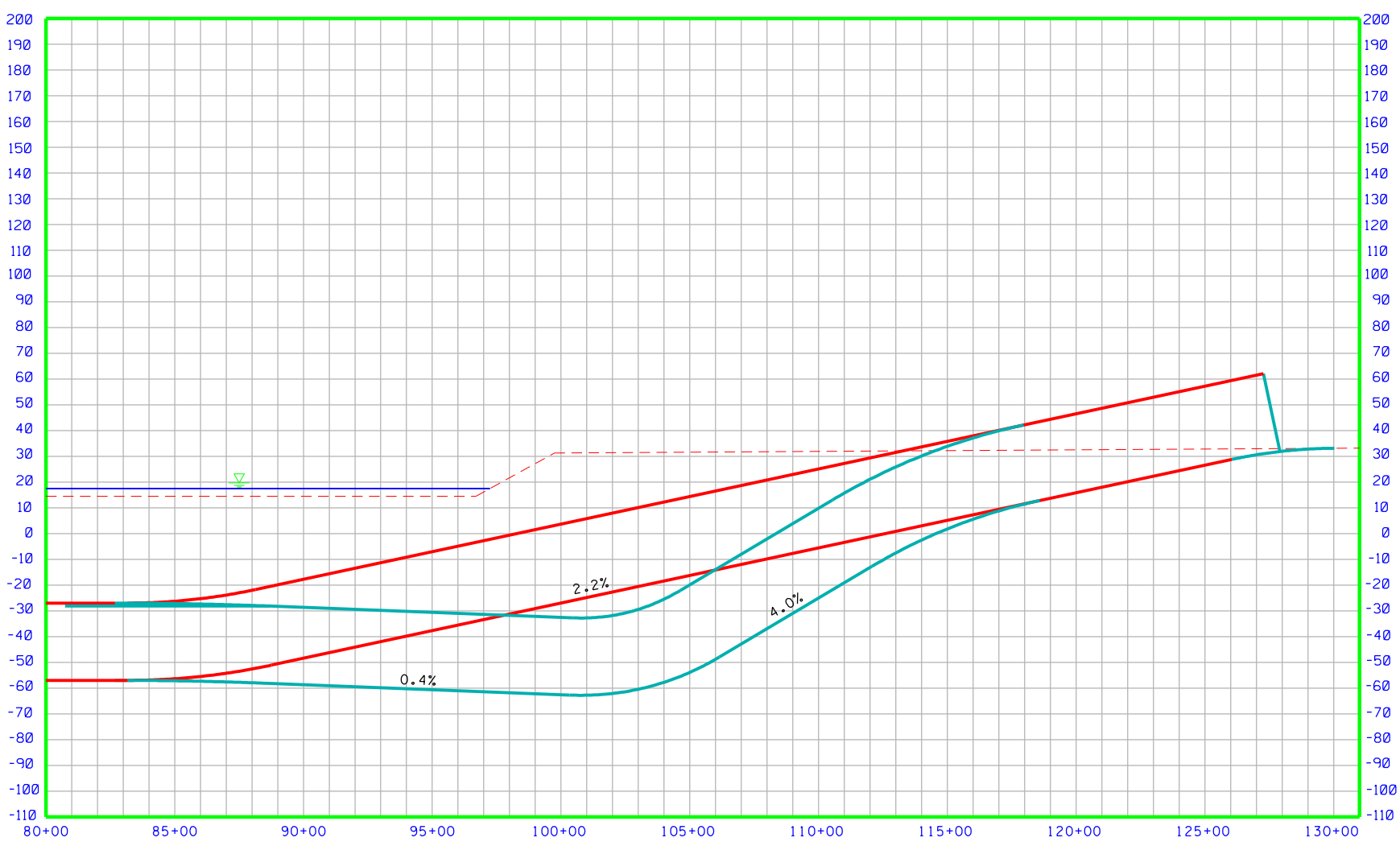

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Figure 4
Union Bay Local Access

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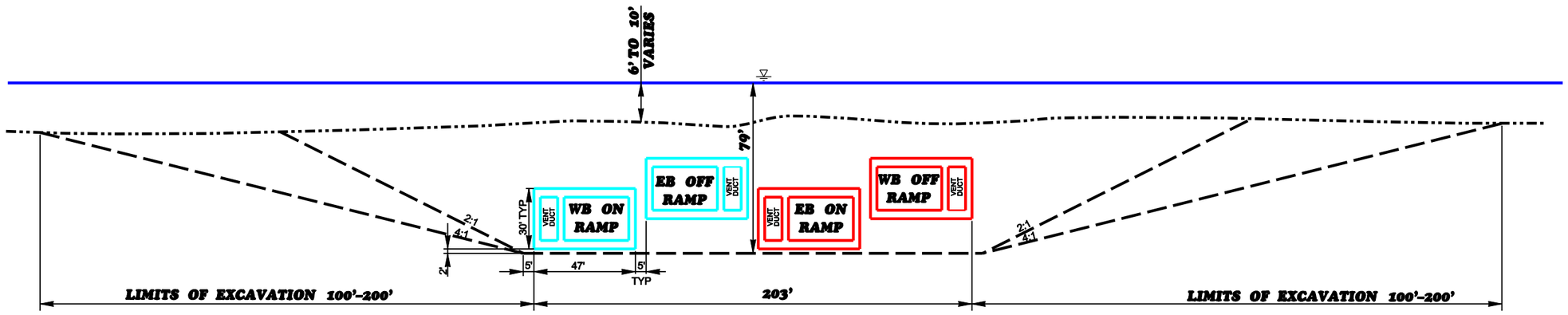
6' TO 10'
VARIES
70'
30' TYP
VENT DUCT
WB ON RAMP
EB OFF RAMP
VENT DUCT
VENT DUCT
EB ON RAMP
WB OFF RAMP
VENT DUCT
2:1
4:1
2:1
4:1
2'
5'
47'
5'
TYP
LIMITS OF EXCAVATION 100'-200'
203'
LIMITS OF EXCAVATION 100'-200'

SECTION B-B

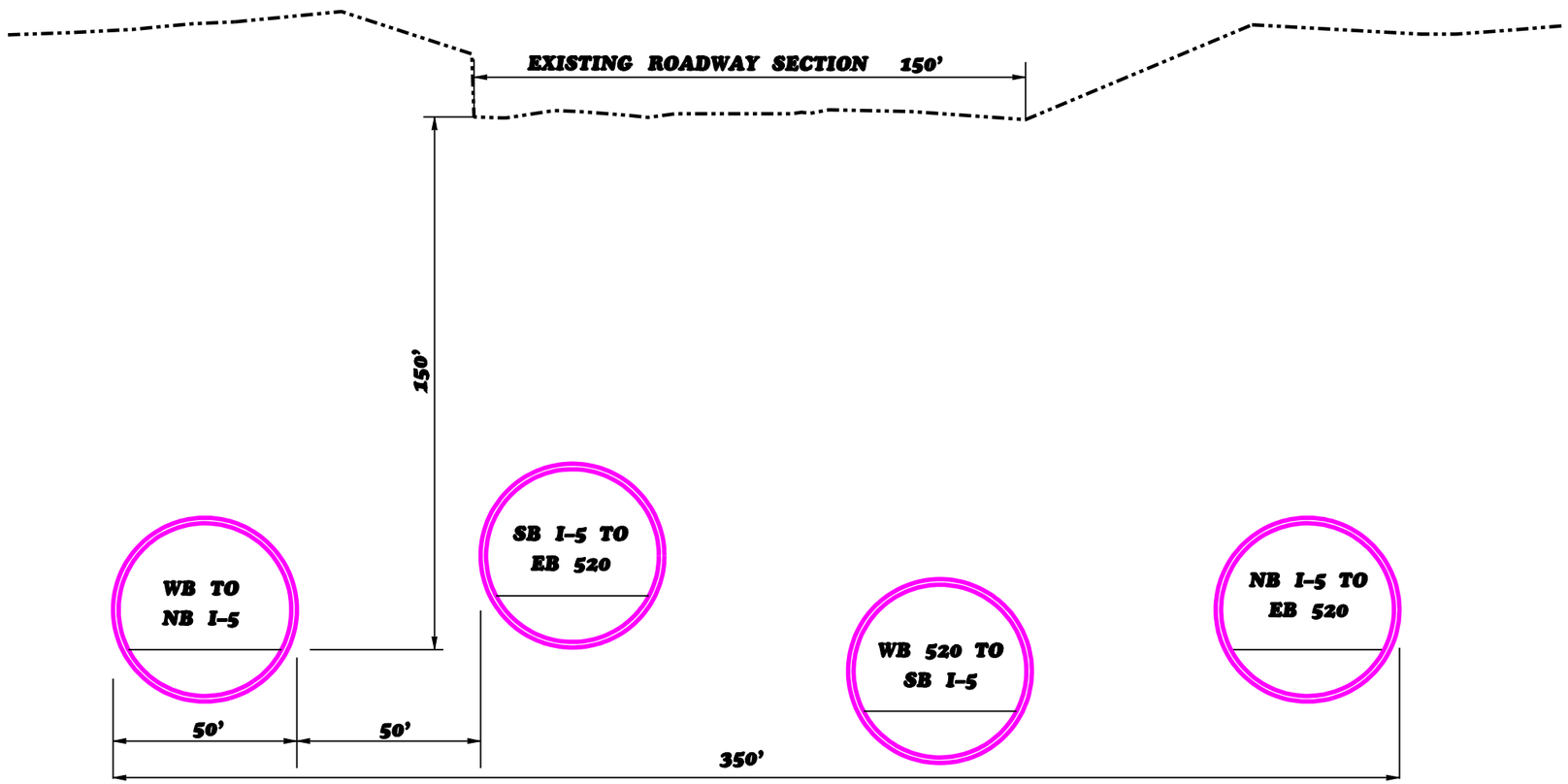

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Figure 6
SR 520 Delmar Drive Cross Section

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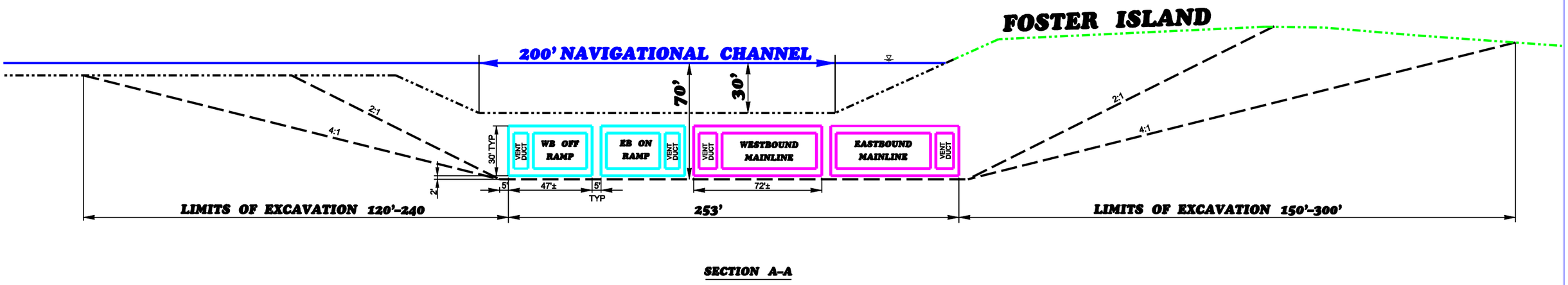

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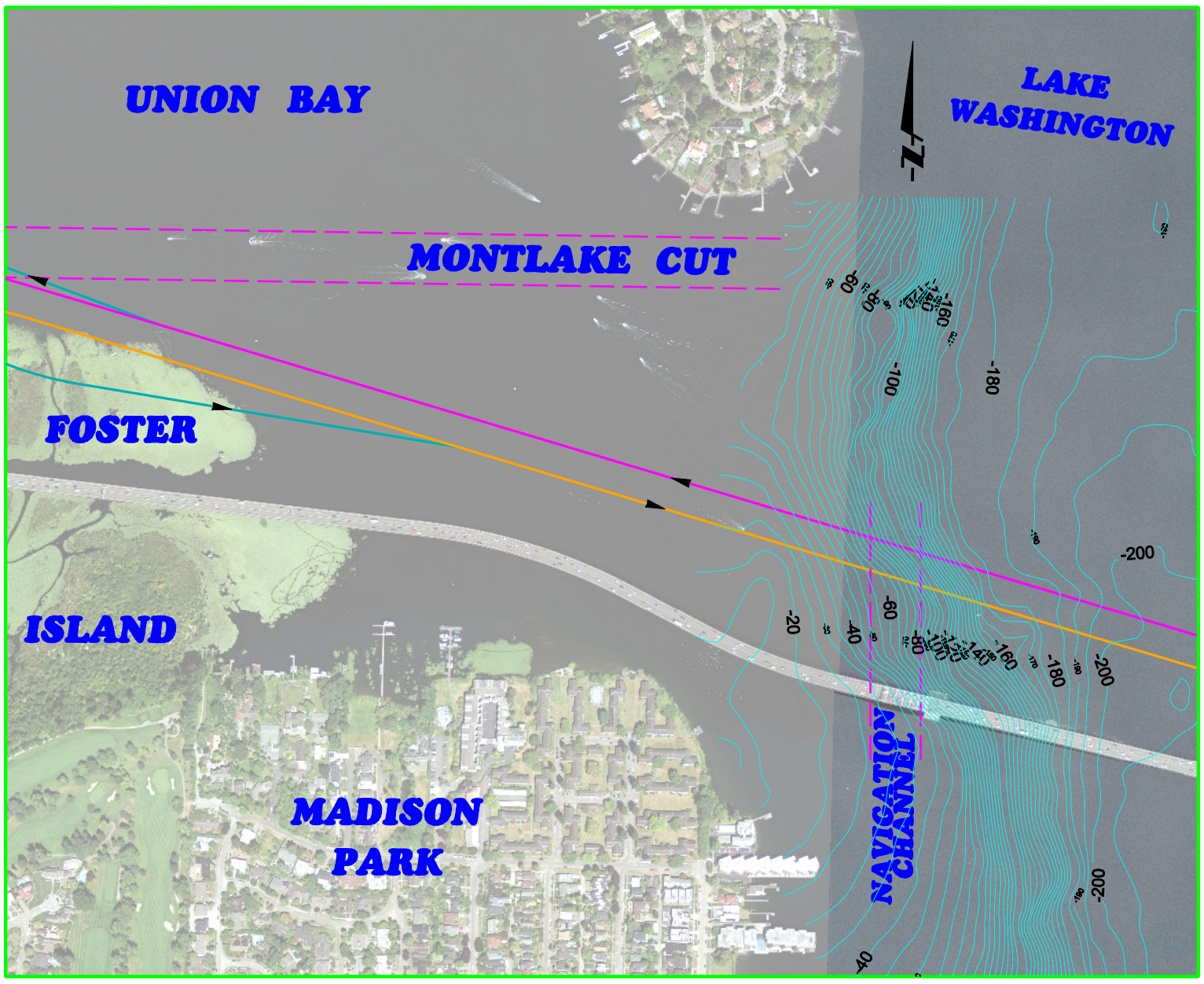
Figure 7
SR 520 Foster Island Cross Section



SR 520 Bridge Replacement and HOV Project

Washington State
Department of Transportation

DRAFT

FOR ALTERNATIVE COMPARISON ONLY

Figure 8
Tunnel Transition Option

sotoe 4/10/2006 11:35:11 AM T:\CAD\6-lane\Alternative-Options\Tunnel\Tunnel_Figure1.dgn

Appendix A: Tunnel Technologies

Cut and Cover Tunnels

CONCEPTUAL
FOR DISCUSSION PURPOSES ONLY

Washington State Department of Transportation

Ground Treatment

- Freezing
  - From above, on land
  - Through face, underground

- Chemical injection

- Compaction Grouting

CONCEPTUAL
FOR DISCUSSION PURPOSES ONLY

Washington State Department of Transportation

Tunnel Boring Machine

Elbe River – Germany – 46’ Dia

CONCEPTUAL

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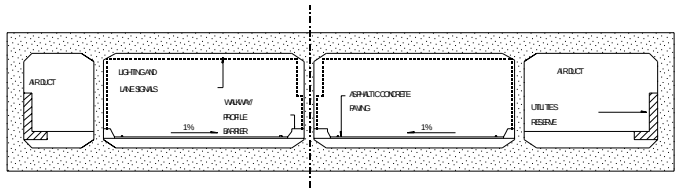
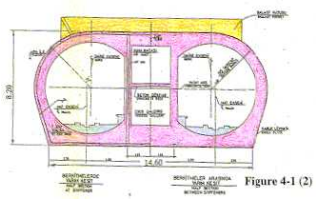
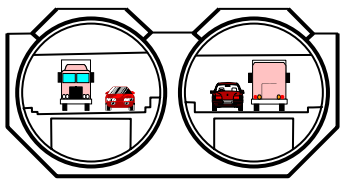
Types of Immersed Tunnel

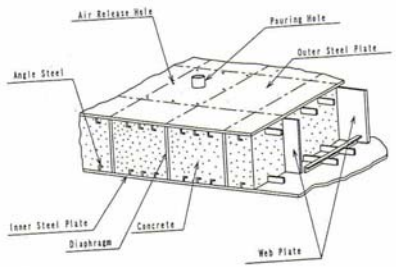
- Concrete



- Steel
  - Single Shell
  - Double Shell (USA)
  - Sandwich (Japan)







CONCEPTUAL
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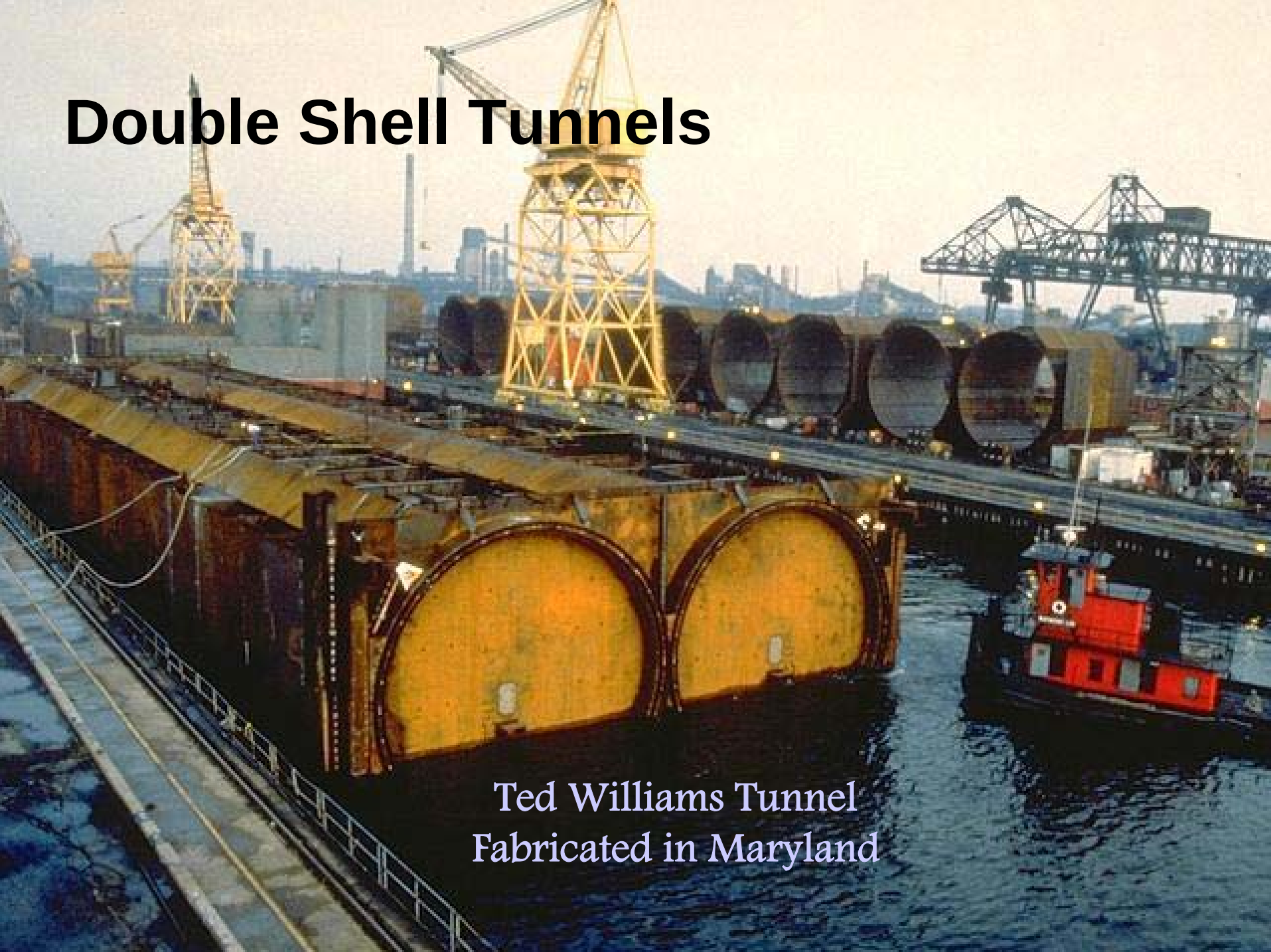
Concrete Immersed Tunnels

- Formwork
- Concreting

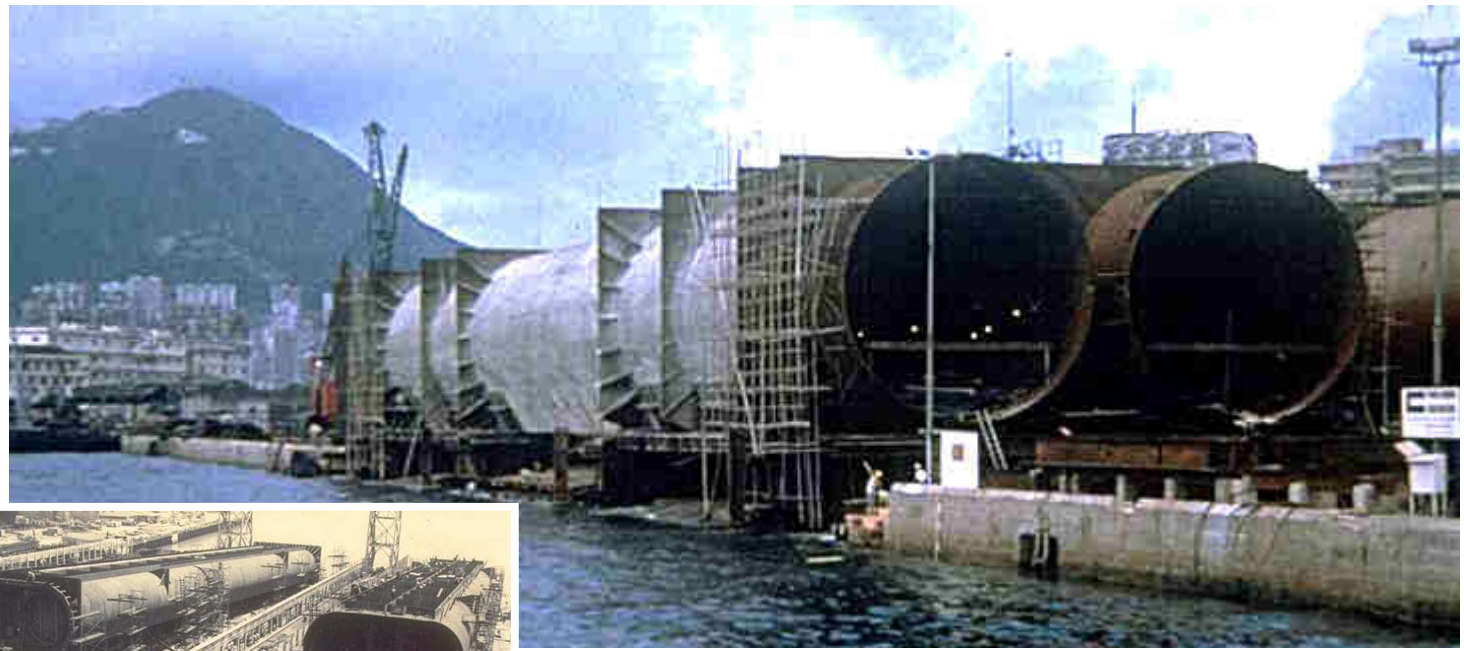
Western Harbour Crossing
Hong Kong

Double Shell Tunnels

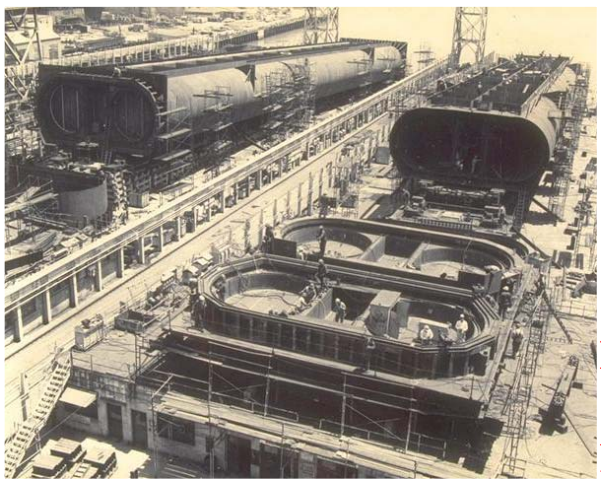


Ted Williams Tunnel
Fabricated in Maryland

Single Shell Tunnels



Cross Harbour Tunnel, Hong Kong



BART, San Francisco

Washington State Department of Transportation

Artificial Island Monitor-Merrimac

CONCEPTUAL
FOR DISCUSSION PURPOSES ONLY

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Ventilation Structure

Boston, MA

CONCEPTUAL

FOR DISCUSSION PURPOSES ONLY

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Ventilation Structure

I-90 Seattle, WA

Exhaust stacks are shown, ventilation building is located underground and is not shown.

CONCEPTUAL

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