The Seattle Pine Street Tunnel

By Bruce Erickson, P.E., S.E.

If you were to drive your car today along Pine Street in downtown Seattle, you would notice one lane blocked off for construction equipment; and, you might see construction materials stacked in a couple of adjacent lots. These sights would indicate some sort of construction activity, but wouldn't give you any idea of the magnitude of construction taking place directly below you. The driving surface below your car appearing to be concrete pavement, but in actuality would be precast concrete planks supported on steel beams spanning across the road. Below these planks and beams, Pine Street Tunnel, which will be part of a future light rail transit line, is being constructed. This new 900-foot long tunnel connects to the existing Downtown Seattle Transit Tunnel, constructed in the early 1980's, that up until now has carried bus traffic. Together, the two tunnels will function as part of a light rail train system that will allow riders to travel from the Seattle-Tacoma International Airport in the South to downtown Seattle in the North.

The Challenges

Construction of the Pine Street Tunnel presented a series of challenges for Sound Transit, the agency responsible for developing the light rail system. These challenges included:

- The requirement that the tunnel meet strict Sound Transit seismic criteria, which included the need for the tunnel to survive a 2500-year earthquake.
- A City of Seattle requirement that street vehicle and pedestrian traffic be maintained at all times during construction.
- The need to maintain service in buried street utilities during construction. These included sewer, water, gas, electrical, telecommunications and steam lines.
- The need to protect adjacent buildings from damage due to potential ground settlements.

Structural Systems

The tunnel structure consists of conventionally reinforced concrete slabs and walls. Roof and bottom slab thicknesses range from 4.5 to 6 feet, and wall thicknesses vary from 2.5 to 3.5 feet. Tunnel interior dimensions vary from 30 to 96 feet wide by 16 feet tall. Most of the tunnel is one level, but one portion of the tunnel has an upper level for ventilation fans and traction power electrical equipment. Maximum depth from street level to bottom of tunnel ranges from about 40 to 70 feet.

The temporary shoring system for the tunnel excavation consists of steel wide flange soldier piles in drilled shafts, with timber lagging between the soldier piles. The soldier piles along the two long sides of the excavation are braced against each other using cross-lot braces constructed of 24- to 36-inch diameter pipe sections. The brace loads are distributed to the soldier piles with steel wide flange wales. The soldier piles at the bulkhead wall were restrained by tieback anchors, since there was no nearby opposing wall against which to brace at this location.

Tunnel excavation underway

Design Criteria

The 1997 Uniform Building Code (UBC), which was the building code for the City of Seattle at the time design began, was selected by Sound Transit as the building code for the tunnel. The tunnel was designed to resist static pressures due to self-weight, soil, hydrostatic, adjacent building surcharge and traffic weight. Seattle is located in an area of high-seismicity, so the tunnel also needed to be designed for seismically-induced ground motions. The UBC's seismic provisions are oriented towards building behavior, and are not appropriate for tunnel design. Therefore, the Sound Transit Design Criteria Manual contains seismic design criteria developed specifically for buried tunnels. The general approach of these criteria is to check the tunnel for imposed racking, vertical seismic, axial elongation and curvature deformations imposed by motions of the surrounding soil during the earthquake. The performance standard is that the tunnel be able to survive a 150-year earthquake without significant structural damage, and a 2500-year earthquake without collapse. The design procedure consists of calculating tunnel structure deformations based on the stiffness of the tunnel and the surrounding soil, then sizing the concrete thicknesses and reinforcing quantities so that strains in the reinforcing steel are kept below limiting values.

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Tunnel excavation underway

Keeping Traffic Flowing

This process of digging a tunnel below a street, while maintaining traffic, was aptly described by one engineer as "removing the cake without disturbing the frosting." The relatively shallow depth of the tunnel and various other constraints precluded boring or mining the tunnel without disturbing the street, so a "cover-and-cut" process was chosen. This consisted of installing a deck over the street to support traffic, then mining the soil from underneath the deck to create the excavation for the tunnel. The traffic deck consisted of precast concrete planks supported on steel beams. The first step was the installation of soldier piles around the perimeter of the future tunnel, which roughly corresponded to the locations of the street curbs. Then, traffic was temporarily confined to the south side of the street while a traffic deck was constructed on the north side of the street. The beam ends located at the curb were supported on the soldier piles, while the beam ends located along the centerline of the street were temporarily supported on concrete footings. Next, the traffic was moved onto the traffic deck on the north side of the street while the traffic deck was installed on the south side of the street. Once decking was installed on both sides of the street, the steel beams were spliced at the street centerline, the temporary footings were removed and the contractor began installing supports for utilites that were to be suspended from the underside of the deck.

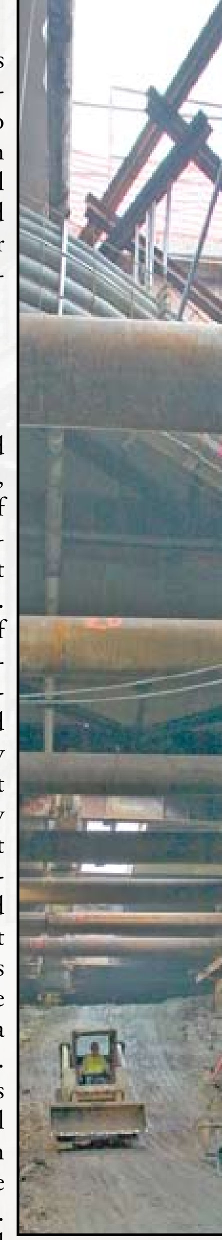
Tunnel excavation completed

Maintaining Utility Service

Existing utilities buried below the street included sewer, water, gas, electrical, telecommunications and steam lines. These services needed to be maintained throughout construction. Some of the utilities were re-routed around the construction site prior to traffic deck installation. Utilities that could not be re-routed needed to be suspended from the underside of the traffic deck during construction. As the contractor began mining soil from underneath the traffic deck, they installed steel frameworks beneath the utilities and connected those frameworks to the underside of the deck with hangers and braces. Once all the utilities were suspended from the deck, the contractor was able to begin mass excavation.

Protecting Adjacent Buildings

The tunnel excavation would be close to existing buildings, and excessive deflections of the shoring system might allow ground settlements that could damage the buildings. Sound Transit and the City of Seattle were particularly concerned about the historic Paramount Theater, which would be only about 10 feet away from the tunnel at the closest point. Because of its relatively brittle brick construction, it would be particularly vulnerable to damage from ground settlements. Other adjacent buildings included two hotels (both constructed within the last 10 years) and a 1960's era highrise apartment building. Shoring system deflections are influenced as much by soil characteristics and installation procedures as they are by the shoring structural stiffness. Accordingly, specifications and drawings contained a variety of provisions to insure that shoring would be installed in a careful and controlled manner. These included requirements that cross braces be installed before excavation proceeded more than two feet below brace level, and that braces be preloaded with jacks to 50% of the design strut load.

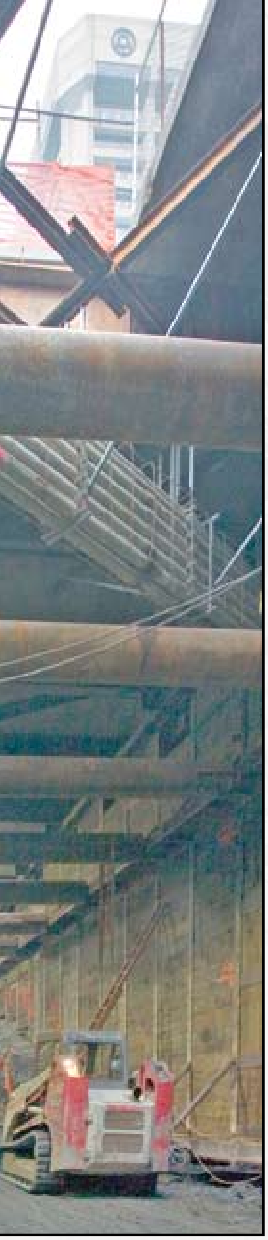


Looking up through deck opening

Another key element in the strategy for preventing damage to adjacent buildings was an extensive monitoring program. The monitoring system included the following elements:

- Soldier piles were monitored for horizontal and vertical movement using optical surveying equipment. Selected piles were installed with inclinometers, which provide a graph of the pile deflected shape along its entire height.
- Adjacent streets and buildings were monitored for vertical and horizontal movements using optical surveying equipment.
- Loads in selected

Tunnel base slab under construction



struts were monitored using strain gages mounted on the struts.

- Existing cracks in nearby buildings were monitored with crack gages.

This monitoring program gave the team the ability to take remedial action if observed movements or forces at a particular location became excessive at any time during construction.

The Results

Not surprisingly, the stringent seismic criteria — particularly the imposed racking deformations — resulted in the need for heavy reinforcing steel in the tunnel. Reinforcing steel sizes were typically governed by racking requirements at interior and exterior faces of slabs and walls except for the bottom reinforcing at the top slab, which was governed by vertical static loads. Typical transverse reinforcing steel in the tunnel walls and slabs was double #11 at 6 inches on center. Note that reinforcing quantities for other tunnels of the same dimensions and using the same seismic criteria at other sites would not necessarily be the same. That is because the site soil characteristics strongly influence the magnitude of the imposed racking deformations.

At the time of writing, the construction on the Pine Street tunnel is approximately 75 percent complete. So far, the challenges identified at the beginning of the project have been successfully addressed. Traffic and utility service have been maintained throughout construction. Measured maximum pile deflections have varied from about 0.25 to 0.70 inches. Settlements of adjacent buildings have varied from negligible to roughly 0.35 inches. To date there has not been any significant observed damage to the existing adjacent buildings or suspended utilities.

Rail service on the Sound Transit line is scheduled to commence in 2009. Riders will pass through the 900-foot long Pine Street Tunnel in a mere instant, reaping the benefit of all the work that the Sound Transit team did to bring the tunnel to reality ▪

Completed tunnel segment

PROJECT CREDITS

Owner: *Sound Transit*

Prime Design Consultant for Final Design: *KPFF Consulting Engineers*

Geotechnical Consultant and Instrumentation Designer: *Shannon & Wilson, Inc.*

Construction Manager: *URS Corporation*

Prime Contractor: *Balfour Beatty Construction Inc.*

Prime Design Consultant for Preliminary Design: *Puget Sound Transit Consultants*

*Bruce Erickson, PE, SE is a structural engineer with the Seattle office of KPFF Consulting Engineers. He can be contacted at **Bruce.Erickson@kpff.com***

All photos by Denny Sternstein, KPFF Consulting Engineers