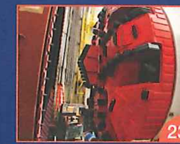
APRIL-MAY 2012

tunnels & tunneling NORTH AMERICA



West Coast
Seismic challenges, environmental limitations, massive TBMs and funding shortages

NAT Conference preview
Who is exhibiting at NAT conference Indiana

WWW.TUNNELSANDTUNNELLING.COM

Make way for the world's largest TBM

Perparations are underway in Seattle for the Alaskan Way Viaduct replacement

Demolition of a section of the Alaskan Way Viaduct to make ready for the 17.4m diameter SR 99 Tunne

To prevent a pancake

Following the 2001 quake, it was feared that another major incident could cause the fragile Alaskan Way Viaduct to 'pancake' from the shaking. Rhian Owen reports on the replacement of the viaduct with more earthquake-resistant infrastructure – a tunnel

On February 28, 2001 one of the largest recorded earthquakes in Washington state history shook Seattle and the surrounding area. During the 6.8 magnitude quake one person died from a heart attack, 400 people were injured, downtown Seattle was faced with power outages, and property damage occurred to the air traffic control tower at Sea-Tac Airport and the Alaskan Way Viaduct, a two-level overpass highway along the waterfront.

The Alaskan Way Viaduct is now considered the city's most dangerous architectural feature. It is an iconic reminder that the city is not yet ready for the next big quake. In October and November 2011, the southern section of the viaduct was demolished in preparation for the launch pit for the viaduct's replacement tunnel.

Since 2001, debate over the viaduct has raged. City planners argued over what is best and most cost efficient for improving Seattle's waterfront safety and proposals included a cut and cover tunnel as well as the deep bored tunnel. In August 2011 the Federal Highway Administration signed a record of allowing the Washington State Department of Transportation (WSDOT) to begin final design and construction of the 1.7 mile (2.7km) bored tunnel beneath downtown Seattle.

The four-lane tunnel will connect to the new Highway 99 south of downtown, and to Aurora Avenue in the north.

"The economic impact, the effect on businesses down at the waterfront and the significant construction staging that it would take to support a cut and cover solution played a significant driver in getting a bored tunnel," says Linea Laird, director of Central & North Projects for WSDOT. "Ultimately, the bored tunnel was selected as the preferred alternative because you could keep the existing waterfront in play and Highway 99 open through most of the duration, and still go forward with new construction."

Choosing the TBM

WSDOT directed Seattle Tunnel Partners (STP), a joint venture of Dragados USA and Tutor Perini, to begin work on the second phase of its USD 1.35bn design-build contract for the 57ft (17.4m) diameter bored tunnel. Japan's Hitachi Zosen is constructing the TBM, which is scheduled for delivery in early 2013 for a start of excavation in early summer of the same year. The contract is worth USD 1.4bn.

An EPBM had been recommended to the contractor, though a slurry machine had been an option as well, to deal with the difficult ground conditions. "The tunnel is to be constructed through a complex regime of glacial till like deposits," says Chris Dixon, STP's deputy project executive. "At no point in time is there expected to be homogeneous soil conditions at the tunnel face. There will be numerous contacts between soils of conflicting properties ranging from high and low permeability soils, non cohesive flowing sands, hard cohesive till like deposits with the potential for boulders within the matrix and sheared intact clay deposits. WSDOT specified that a closed face TBM be utilized for the

Below: Project crews in the process of building underground electrical vaults located northwest of the SODO stadiums under the viaduct. The water seeped into the construction area from the Puget Sound water table

Above: **Malcolm Drilling crews set up the drill rigs that will build the walls for the SR 99 tunnel boring machine launch pit**

project, but left it to the design-build contractor to determine the exact nature of the machine – the contract allowed us to select either a Slurry or EPB. STP has chosen to utilize an EPB TBM as in the Seattle area there has been a variety of tunnelling techniques used but with respect to pressurised spaced the majority of the work has been done with EPBMs."

Dixon says that the machine has been designed to handle all types of conditions that they anticipate encountering along the alignment. "An extensive monitoring regime is to be implemented to enable the performance of the TBM to be analyzed," he explains. All buildings within the zone of influence have been studied and through a risk sharing mechanism with the contractor mitigation measures have been established. For the most critical buildings compensation grouting shafts are to be designed and concurrent grouting applied as the TBM passes beneath. For the location where the tunnel passes under the existing viaduct, the capacity of the structure is to be enhanced by the application of epoxy fiber wrapping to allow the structure to remain operational for its remaining life until the tunnel is commissioned."

In addition, over 600 boreholes have been drilled along the alignment. "The geology is typical for the Seattle area and has been tunneled through on many occasions," says Dixon. "The ongoing Sound Transit extensions to the light rail system north of the city, connecting to the University of Washington are most relevant and the Hitachi Zosen TBM on this project has many of the features that are to be incorporated on AWV replacement."

The tunnel will be 1.7 miles (2.8km) long and reach a depth of 120ft (36.5m) from sea level, while maximum cover is 215ft (65.5m). The maximum horizontal curve is 2,000ft (650m) and the maximum vertical gradient is four per cent. Dixon explains the determining factors for the alignment: "The vertical alignment was determined by WSDOT to be compliant with state highway design requirements. The alignment descends from the south portal at a four per cent gradient in order to attain maximum depth prior to the TBM passing beneath the existing viaduct foundations, 1,750ft (533m) after TBM launch. The alignment then follows the zone of most favorable geology before rising at a four per cent gradient to the north portal."

There are notable challenges to overcome due to the tunnel's large diameter; it will be the world's largest deep bored tunnel, with an outside diameter of 56ft (17m) while the internal diameter will be 52ft (16m). The challenges are primarily ones of scale: the volume of muck excavated per ring is 859 cubic yards (656m³) of bulked spoil per advance, each segment weighs 18t, segment transport on the surface from the precast facility can only carry two segments per truck, spoil handling is to be by conveyor direct to a barge facility to reduce traffic movements and Installed TBM thrust is 392,000kN through 56 thrust jacks.

The TBM has a body injection system to allow injection of bentonite around the machine body to reduce face loss and help mitigate surface settlement. It also includes a two component backfill grout system: "Inter grout is to be piped from surface and the accelerator added immediately prior to injection. This process will supply over 900cubic ft. (25.49m³) of grout per excavation cycle," says Dixon.

The machine is also equipped with probe drilling and injection grouting equipment. "We have the ability to probe ahead," says Dixon. "Also, through those ports we can do grouting ahead. We also have drills mounted at the rear of the shield and the trailing gear, which allows us drill and grout within the shield and behind the shield through the precast concrete segments. We have a variety of drilling tools at various locations that allow us not only to probe but also inject grout."

The project consists of a precast segmental lining system and there will be 10 segments per ring with an average length of 6.5ft (2m). The inside of the tunnel will be lined with a 2ft (610mm) concrete liner. Laird explains that there were special considerations required for lining to meet the design objectives.

"There were design requirements for reinforcing the liners, we're using welded liners and rebar," she says. "Some of it is going to depend on the torque and thrust, but all of it was taken into account when looking at the liner segments."

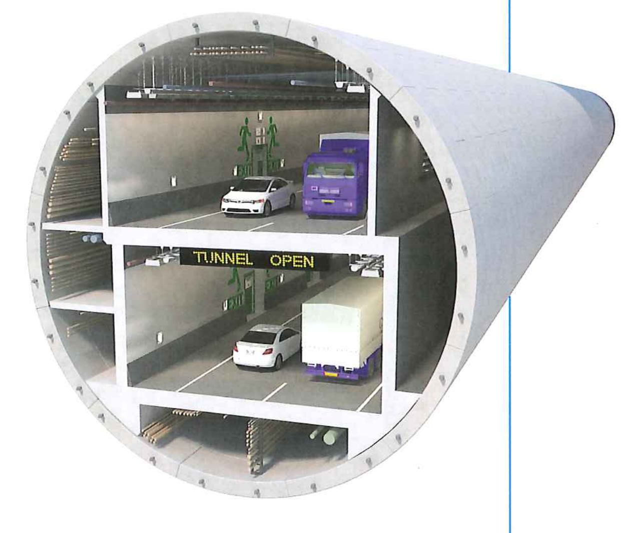
Dixon agrees but adds that how STP complies with the criteria as design builders is left to the contractors. "The 2ft (610mm) thickness was determined by WSDOT as was the amount of reinforcement, but we were left with looking at how we connect the segments and the rings," he explains. "There is design criteria taken into consideration but we also need to consider how we're going to store transport and handle and direct these rings within the tunnel. There are a lot of operational loads that are put on these individual segments before they are actually installed in the tunnel, so that's also taken into account in our design."

In addition, Dixon adds: "The seismic performance of the tunnel liner is achieved as soon as the ring has been constructed and grouted into place and as such the safety within the tunnel in the temporary case is covered by the design requirements. STP is developing a comprehensive training and emergency response strategy to deal with all potential incidents during the construction process."

Excavation schedule

Dixon says that due to the nature of the TBM the team will be stopping periodically to inspect, maintain and repair the cutter head and change the cutting tools. "We've scheduled a variety of interventions along the alignment – we'll be stopping every 300 or 400ft (91 to 122m) to inspect the cutterhead and do what is necessary with respect to the cutting tools before continuing on with the drive. It's not a situation where we get the machine up and running for months and months, we've got planned stops to inspect and maintain the TBM so that it continues to perform well for the entire drive."

Right: **A cross section of the 17.4m diameter SR 99 Tunnel**



The project will be using the safe haven principle, and change cutters in cohesive areas, which can save tunneling time. "Two safe havens are planned in the first 1,800ft (549m) of the tunnel bore to allow the head to be inspected if required, prior to the TBM moving underneath properties and the city streets," says Dixon. "These areas will consist of a secant piled wall, creating a ground treated box, into which the TBM can pass. If required the TBM head can be inspected in increased safety."

"Over the initial 1,800ft (549m) of the tunnel drive the machine excavates between a line of secant and evenly spaced piles that confine ground movement and protect surface infrastructure in the zone of minimal cover. In this initial section of the project, the TBM learning curve process can be completed without impacting on the surface outside of the designed area.

"It's also convenient because the tunnel is quite shallow and we don't have to go to great depths to do this. However, once we're tunneling through the remainder of downtown Seattle, we're going to be some 200ft (61m) below the ground surface, at that point it would get much more difficult to try and create a block of treated ground into which the TBM could bore and stop and allow for an atmosphere intervention at that depth."

In addition, an axial displacement on the cutterhead, which can be pushed out ahead of the shield and brought back creating a space between the cutterhead and the excavated face, will provide space for workers to complete visual inspections of the cutterhead and cutting tools.

Dixon estimates that it will take 15 months to mine the tunnel. "We're going to start off very slowly," he says. "Initially, we're going to begin at about one ring per day, or 6.5ft (2m) and once we're comfortable with that we'll double it to about 12ft (4m) per day. Ultimately, we'll reach a production rate that averages about six rings per day or 36 to 39ft (11 to 12m) for the bulk of the tunnel drive."

The launch site

Currently, south of downtown construction, mobilization for TBM launch pit construction has begun. Dixon explains that while the launch site is a large area "with the scale of the construction to be carried out space is always a constraint".

Dixon adds: "At the south end of the project the ground is categorized as Engineering Soil Unit One. This comprises silt, clay and fill material. Due to the previous land use it is expected that wood foundations and wood debris may be encountered. Extensive boring and ongoing excavation on other projects has validated the baseline assumptions."

The south excavation will be formed of interlocking secant pile walls. "These will be 5ft (1.5m) in diameter and excavated through the overlying fill material to the design depth 85ft (28m) below the surface. Excavation will take place within the dewatered ground and wall supports will be a combination of tiebacks and struts.

"While at the north end the water table and ground conditions allow for a soldier pile and lagging solution to be used as ground support."

Dixon explains that the TBM launch procedure is currently under development by STP. "In an effort to gain schedule advantage the TBM is to be delivered in large pieces – 900t maximum, directly to the adjacent port facility."

Dixon concludes, "The ability for the Hitachi Zosen manufacturing facility and the delivery point in Seattle to the special vessel to carry these components is a major benefit to the project."