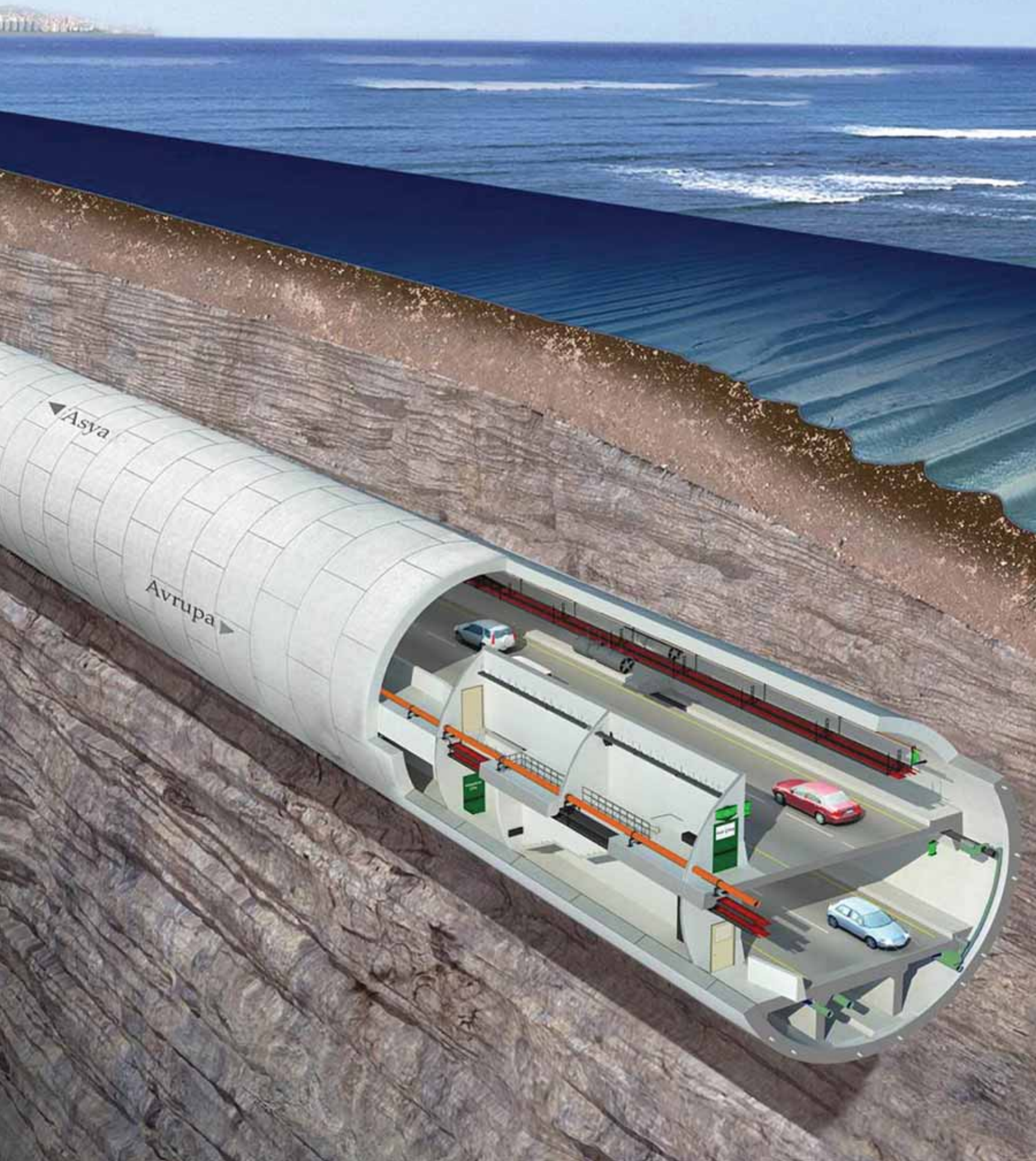
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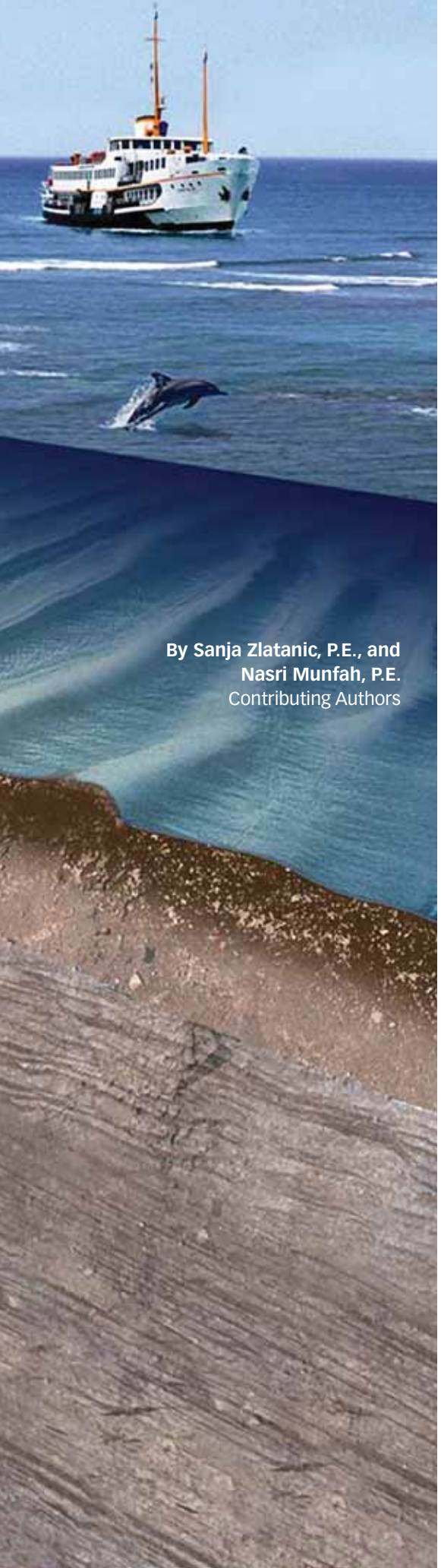

Sea and seismicity

Istanbul Strait Tunnel overcomes unique set of risks

By Sanja Zlatanic, P.E., and Nasri Munfah, P.E.
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To reduce congestion over the Bosphorus, a 2.3-mile-wide waterway separating Europe and Asia, the Turkish government is constructing a 3-mile road tunnel 360 ft below sea level.

The risk elements of extreme water pressure combined with the location's propensity for seismic activity and the tunnel's large-diameter, double-decker configuration make the Istanbul Strait Road Tunnel Crossing one of the world's most exceptional and technically complex undertakings.

Calming the crowd

Istanbul, Turkey's largest city, has a population of more than 13.5 million—three times the size of the city of Los Angeles and nearly 20% of Turkey's population. If the population's growth trend continues, Istanbul will be Europe's most crowded city by 2020.

Like many American megalopolises, Istanbul struggles with congestion, especially over the Bosphorus, one of the city's major bottlenecks. The Turkish Ministry of Transportation has resolved to relieve the congestion with several major transportation initiatives targeting the chokepoint, including the Marmaray Crossing, the world's deepest submerged commuter rail and transit tunnel. In addition to a third bridge, now under construction, the ministry is considering two more tunnels under the Bosphorus: one for rail and one for vehicles. Both are in the planning stages.

But it is the $1.25 billion build-operate-transfer tunnel project, initiated in 2011, which will have the widest implications for the growing region. Not only will the tunnel increase capacity across the Bosphorus by 100,000 vehicles a day, it is the first road transport public-private partnership (P3) to close under the new Turkish P3 initiative for infrastructure. As such, the Istanbul Strait Road Tunnel project will provide a blueprint for funding future infrastructure projects in the Turkish Republic.

The concessionaire, a joint venture of Yapi-Merkezi and SK Engineering & Construction, has 55 months from the day the contract was executed in 2012 to put the tunnel in operation. Once the project is completed, the joint-venture team will own and operate the facility for 26 years, charging about $4 per vehicle plus a value-added tax (similar to a U.S. sales tax) to use the tunnel in exchange for saving motorists up to 45 minutes of commute time.

Two sides and a crossing

Slated for completion in 2017, the 9-mile project route is broken into three segments:

1. The European side consists of five new U-turns, two new underpasses, seven pedestrian crossings and modifications to the European approach, including widening portions of the existing Kennedy Boulevard along the waterfront.

One of the most sophisticated TBMs ever

Constructed to address a large-diameter tunnel, the slurry-shield TBM is specially designed for the geotechnical conditions and the extreme water pressure under the Bosphorus.

The German-made TBM will arrive at the project site in September 2013. Assembled, it stands four stories tall, has a diameter of 46 ft, weighs 1,500 tons and is 426 ft long. It is expected to excavate almost 33 ft per day, reaching its destination in 1.5 years or less.

2. The Bosphorus Crossing includes construction of the 3-mile tunnel, consisting of a tunnel-boring-machine-(TBM)-bored tunnel, twin New Austrian Tunneling Method (NATM) tunnels on the Asian side, cut-and-cover tunnels, U-sections, portal structures, transition structures, toll plazas, ventilation facilities, a tunnel operation building, electrical and maintenance works and operation and maintenance equipment.

The centerpiece of the project is the TBM-bored tunnel. The single-bore, large-diameter tunnel will measure 44 ft across and house a double-decked lane configuration with the top deck carrying eastbound traffic and the bottom deck westbound motorists. The tunnel will accommodate cars and minivans only.

3. The Asian side includes widening of a stretch of existing highway and improvements to several interchanges.

The project is in construction and on schedule. At the writing of this article, the TBM, custom-made by Herrenknecht AG in Germany, was expected to arrive at the project site in September 2013 to begin mining.

Quite the pair

The Istanbul Strait tunnel project takes place in one of the busiest waterways in the world and has presented several technical challenges with two of the biggest risk elements being:

- Extreme hydrostatic pressure. The tunnel will be excavated directly under the Bosphorus, where the geological conditions are mixed, poor ground, resulting in direct connectivity of the water to the tunnel level. As a result, one of the owner's requirements is to design the tunnel to withstand 11 bars of groundwater pressure. The highest water pressure any TBM has ever been subjected to is the Lake Mead Water Tunnel in Las Vegas at 17 bars; however, the diameter of that tunnel is nearly half the size of the Istanbul tunnel. The deepest tunnel in the world is the Seikan

railroad tunnel in Japan at a depth of 787.4 ft from the water surface. To address this challenge, a slurry-type TBM will be used for excavation. It is critical to the success of the tunnel project that the excavation's face and its full perimeter be controlled at all times to minimize losses of ground and movements of the overlying ground. The mixed-shield slurry TBM will operate in closed-face mode to minimize the possibility of large, uncontrolled ground losses and resulting subsidence. It is designed to be in and out of mixed-face tunnel conditions along the alignment.

- High seismicity. Earthquake records spanning two millennia indicate that, on average, at least one medium-intensity earthquake has affected Istanbul every 50 years. Less than 1 mile south of the tunnel alignment is the North Anatolian fault, capable of producing an earthquake of 7 on the Richter magnitude scale. For earthquakes of lesser intensity, the owner has specified no impact to the tunnel. In the event of a magnitude 7 earthquake, there will be no collapse, only the potential for minor, repairable damage. To address the issue of seismicity, the tunnel is designed to accommodate differential displacements by introducing seismic/flexible joints at proper locations. Considerations have been given to design seismic joints at the transition zones between rock and soft soils. The general procedure for seismic design of the tunnel structures is based primarily on the ground-deformation approach. During earthquakes, the tunnel structures will move together with the surrounding geologic media and, therefore, are designed to accommodate the deformations imposed by the ground.

The tunnel has been designed with a precast concrete segmental tunnel lining. The lining has been designed for the in situ and internal loadings, including earth and hydrostatic loads imposed by the surrounding

Landmark transaction

The Eurasia tunnel is the first major public-private partnership in Turkey's road sector with predominantly foreign financing. The European Bank for Reconstruction and Development's $150 million loan completes the $1.25 billion financing for the Eurasia project. Other contributors include a $350 million loan from the EIB and a package of financing and guarantees from Korea's Eximbank and K-Sure with SMBC, Standard Charter and Mizuho participation. The hedging facility for the transaction is provided by some of the lenders, as well as Deutsche Bank.

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ground and surcharges above, as well as loads imposed during the tunneling process and the seismic impacts.

Seattle similarity

HNTB Corp. was retained by the joint-venture team to perform a design review and a Category 3 independent check of segment two of the project.

As independent design verifier, HNTB is evaluating the design to ensure it meets technical requirements (i.e., Turkish Ministry of Transportation design requirements and American and European standards and codes for materials, design and construction practices) and to identify and mitigate risks appropriately.

HNTB is reviewing and verifying the geotechnical parameters and performing independent analyses for the bored tunnel, NATM tunnels, cross passages, transition structures, cut-and-cover segments, seismic analyses, ventilation and fire-life safety.

Seattle's Alaskan Way Viaduct tunnel and the Istanbul project have many similarities. Both tunnels are single-bore, large-diameter tubes being excavated with TBMs in difficult ground under high water pressure in a seismic zone, and both address fire-life safety aspects to meet American National Standard NFPA 502.

HNTB was the final designer on the Alaskan Way tunnel, and from that project, HNTB has been using its extensive design experience in independent reviews of the Istanbul Strait crossing tunnel, especially in terms of reviewing the fire-life safety aspects, the interior structures and final liners, as well as applying the latest seismic codes and state-of-the-art numerical analysis coupled with a thorough approach to fire-life safety and the methodology for handling difficult ground conditions and potential settlements.

HNTB's design review recommendations have targeted increased safety of the structure, expediting the construction schedule, enhancing constructability and achieving cost savings:

- A sophisticated, nonlinear numerical seismic modeling and a work plan to determine whether highly expensive seismic specialty joints are absolutely necessary—or if they could be eliminated;
- Enhancing fire-life safety and the ventilation facilities; and
- Recommendations regarding the impact of extreme events within the tunnel, improving its fire-life safety and operational functions. **R&B**

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