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Political, price volatilities unsettle markets (p. 49)

CONNECTING CONTINENTS

Backed by international talent, a Turkish-Korean team builds the first vehicular link under the Bosphorus Strait (P. 22)

A bnp PUBLICATION

ISTANBUL INNOVATION

The new $1.3-billion vehicular crossing deep under the Bosphorus Strait has extremely stringent safety standards

By Aileen Cho in Istanbul

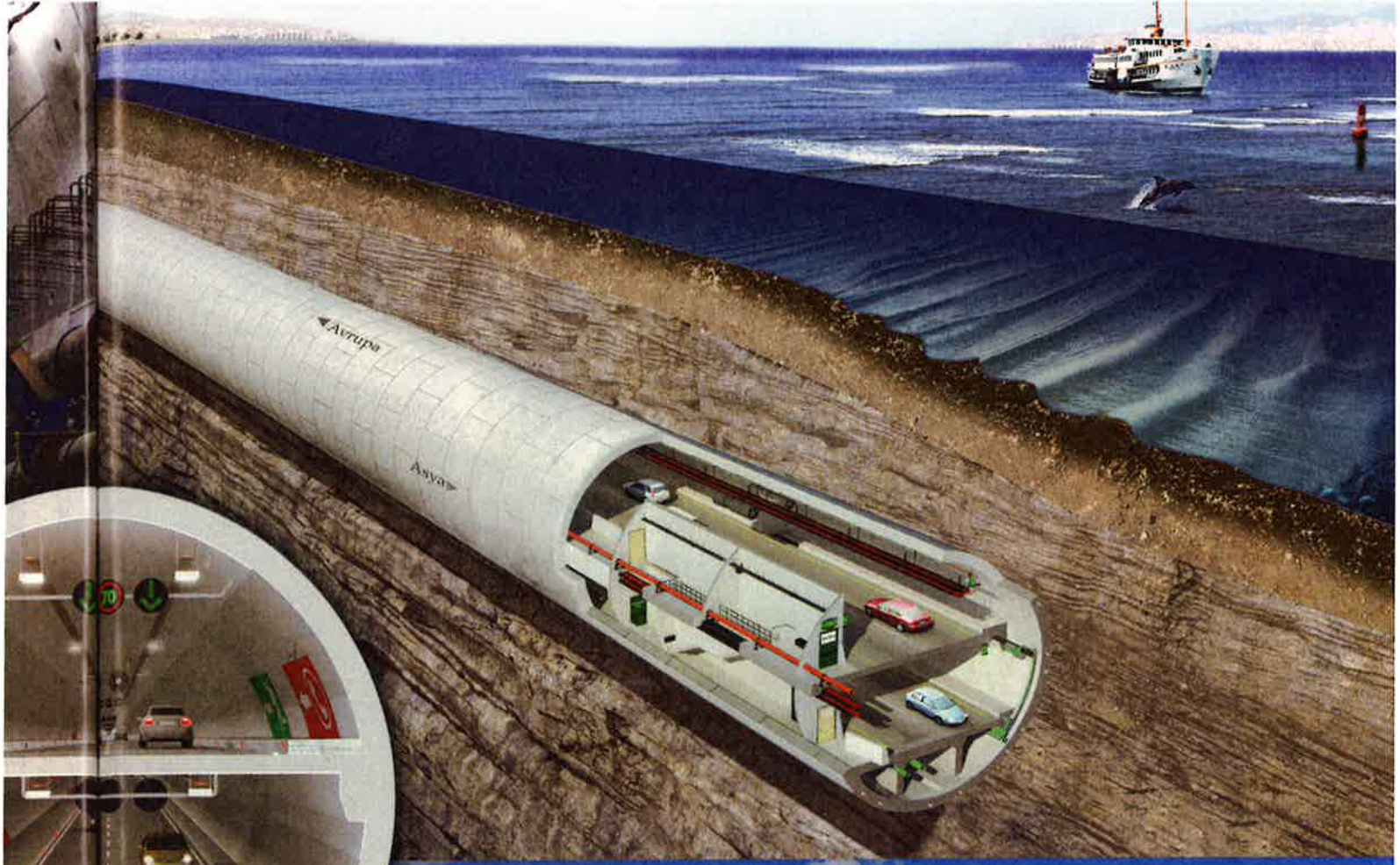
COVER STORY
INFRASTRUCTURE

When it comes to world-record superlatives, the Istanbul Strait Road Tube Crossing never quite hits the top in several categories. It is the second-deepest road tunnel, at 106.4 meters below sea level, with the second-greatest water pressure, at 11 bars. It has the world's sixth-largest diameter, at 13.2 m, and it is the second tunnel to be built under the Bosphorus Strait.

But when all these things are taken together—along with the tunnel's double-deck configuration, its location in an area of high seismic activity and mixed geologic conditions, and its status as the first in Turkey to use a long-term build-operate-transfer (BOT) concessionaire contract—it becomes a project of enormous challenges.

Two of the biggest challenges, however, have been overcome. One hurdle was to excavate a 3.4-kilometer-

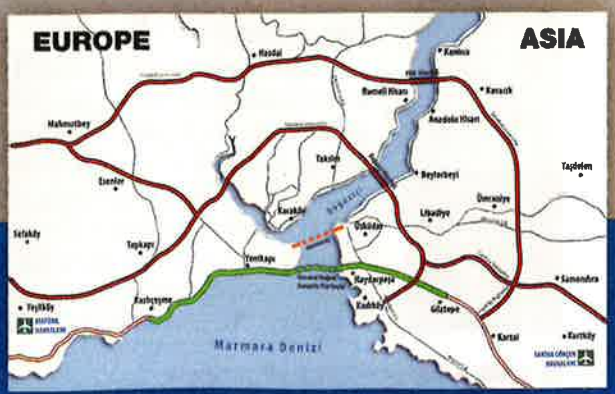
PHOTOS AND GRAPHICS COURTESY OF YNSK



A CRUCIAL CONNECTION BETWEEN TWO CONTINENTS, ONE CITY

The Istanbul Strait Highway Tunnel burrows 106 m below sea level, passing through two geological formations of poor material and within one of the world's most active seismic zones.

When opened, it will provide the first vehicular tunnel between Istanbul's Asian and European sides, helping to ease nonstop traffic that currently travels across two bridges.



PHOTOS AND GRAPHICS COURTESY OF YMSK

EUROPEAN ALIGNMENT
The team is realigning and widening 5.5 km of highway on the European side, including underpasses and new access to a major planned development.

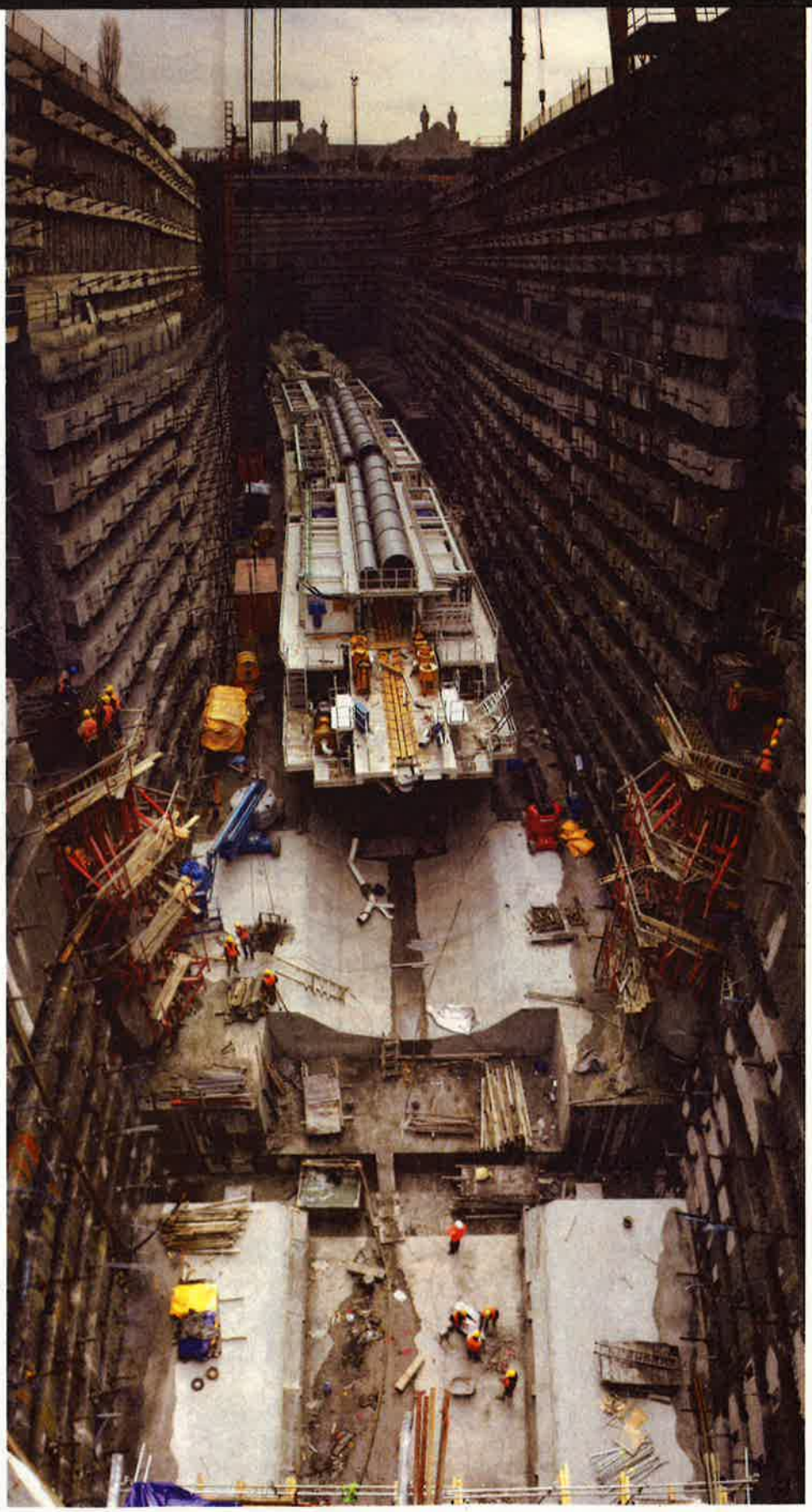
long, single-bore 13.2-m-dia tunnel. Using a tunnel-boring machine with a cutterhead of 33 kW of power per sq m, that excavation concluded in August. It is a key piece of the overall, 14.6-km-long road link between Kazlıçesme on the European side and Göztepe on the Asian side—a link that, when opened, will help to handle the choking traffic on two existing highway bridges. Project officials say the average commute time will shrink to 15 minutes from 100 minutes.

Difficult Deals

The other significant hurdle was cobbling together the deal to make the project happen. Following a 2005 feasibility study, the Ministry of Transport, Maritime Affairs and Communications announced the tender for an 18-year BOT contract in 2008. A joint venture of Turkey's Yapi Markezi and South Korea's SK E&C won the tender in 2011. After two years, the joint-venture concessionaire, called ATAS, completed and secured the financing. "The time for the tender was very short, and the financial requirements were very heavy," says Basar Arioglu, chairman of Yapi Merkezi Construction Inc. "It was the first project in Turkey to be funded primarily by international banks," adds Naim Isli, project director with YMSK, the joint venture's contracting arm. The $1.25-billion financing came from European, Korean and Japanese institutions, including a $350-million loan from the European International Bank. The joint venture put up $290 million.

Along the way, four other Korean partners to Yapi Markezi had to drop out, with the 2008 recession playing a role. At the end of 2012, the concessionaire finally reached agreements with the government on debt-assumption clauses and project requirements, says Arioglu. "We signed on 12-12-12. We reached financial close in March 2013." By then, lenders were asking whether the construction time could be reduced to 48 from 55 months, he adds. While the contractual completion date for finishing construction is still July 31, 2017, the joint venture is now targeting December

PHOTOS COURTESY OF YMSK



2016 as a possibility, says Isli. Then, ATAS will operate and maintain the tolled tunnel for 24 years and five months.

The route is expected to meet international fire and safety standards and be able to function within days of a major seismic event, says Arioglu. With so much risk and investor scrutiny, the project linking Asia and Europe also features a slew of firms from throughout Europe, Asia and North America, including Arup doing due diligence for

PHOTOS COURTESY OF YMSK

PHOTOS COURTESY OF YMSK

DEEPER THAN MOST The TBM used for the Istanbul crossing is the world's sixth largest in diameter, digging in some of the most severe conditions.

the lenders, Parsons Brinckerhoff providing lead design, HNTB providing design verification, Fugro providing geotechnical studies of the fault-ridden alignment and Egis providing tunnel operations for the concessionaire.

Parsons Brinckerhoff and Japanese firms also worked on the design of the two seismic joints for the tunnel. And Germany's Herrenknecht supplied and customized the 13.7-m-dia mixed-shield slurry TBM that excavated, on average, 7 m a day, operating 24/7. Named "Yildirim Bayezid" for an Ottoman Empire-era sultan, the TBM excavated almost 500,000 cu m in less than two years. After emerging from the European side in August, it is being dismantled and returned to Germany. An on-site plant that de-silted the bentonite slurry used for excavation also is being dismantled.

COVER STORY
INFRASTRUCTURE

Tight and Tough

When a tunnel reaches a 5-bar level of water pressure, it presents a source of heightened concern, according to Gordon T. Clark, a vice president with PB. "At 11 bar of pressure, that gets our undivided attention," he says. While the highest water pressure ever encountered by a TBM is, at 17 bar, the Lake Mead Water Tunnel, that tunnel's diameter is about half the size of this one, says Sanja Zlatanic, chief tunneling engineer with HNTB.

The attention heightens when the tunnel is located in one of the world's most seismically active areas, through two different geological formations—either sandstones, mudstones and silts or clay, gravel, cobble and silts—and with

CUTTING-EDGE Advanced design of TBM includes replaceable cutterheads and a monitoring system that records data on wear and tear in real time.

PHOTOS COURTESY OF YMSK

IN FINE FORM
Specialized formwork system facilitated cast-in-place construction of upper roadway.

PHOTOS COURTESY OF YMSK

significant traffic issues on either end. The design of the double-gasketed, bolted and doweled precast-concrete tunnel lining, with each tunnel ring consisting of nine 600-mm-thick segments, "is to ensure that this tunnel stays safe and dry," Clarke says.

Herrenknecht engineers designed a cutting wheel that is accessible from the rear of the 120-m-long, 330-tonne TBM while under atmospheric pressure. During excavation, crews replaced the scrapers 85 times and the rock disc cutters 440 times, says Arioglu.

Divers performed four hyperbaric interventions in a specialized shuttle. They worked at pressures as high as 10.5 bar, after which the workers required two weeks of decompression. Herrenknecht's Disc Cutter Rotation Monitoring system included detectors in the 35 disc cutters, each 480 mm, providing real-time rotation and temperature data to the machine operator to optimize maintenance decisions.

The Italian manufacturer CAD 2000 Engineering provided a specialized formwork system to construct the cast-in-place upper roadway and the corbels that project from the tunnel walls to provide support for the cast-in-place slabs, says Bahriye Yaman, YMSK's TBM chief. The rolling double-decker gantry system's telescoping components and 20-ton capacity facilitated placing and drilling of the upper and lower corbels, the rebar and support of formwork for the delivery, and pouring of almost 10,000 m of roadway deck concrete.

Going with cast-in-place for the upper deck saved several months of work, says Arioglu. But the government wanted the lower roadway to consist of precast segments. A continuous walkway along the upper, Europe-bound deck has emergency stairway openings every 200 ft, providing evacuation access and safety chambers between the upper deck and the precast lower, Asian-bound road deck, says Yaman.

To optimize evacuation in a fire event, the team worked closely with the Istanbul highway department on new ramps and metering options so that motorists won't be trapped inside the tunnel due to congestion on either side, says Clark. The goal is to maintain a minimum of 20 km per hour—even if the tunnel is at capacity, with an anticipated 120,000 daily vehicles in each direction.

In addition to meeting U.S. fire safety standards, the tunnel has a 100-plus-year design life and is expected to meet functional standards in 500-year seismic events

PHOTOS COURTESY OF YMSK

ble-sealed, rubber-gasketed seismic joint rings, installed at strategic spots, to accommodate differential movements between tunnel areas located in soft versus hard rock. Each joint is surrounded on either side by three transition rings to avoid decompression and subsequent water leakage. The joints emulate "the flexible parts of an articulated bus," says Yaman.

and safety standards for 2,500-year seismic events. "In the event of a major earthquake, this tunnel will be operational within a few days," says Arioglu. That requirement meant procuring a seismic joint design with displacement limits of 50 mm for shear movement and 75 mm for expansion and contraction.

Japan's Seibu Polymer Corp. manufactured two dou-

Transition Tunnels

On the Asian side, the underwater tunnel ends at a 170-m by 80-m transition box, which is 37 m deep. On the European side, the tunnel ends at a 70-m by 30-m

PHOTOS COURTESY OF YMSK

transition box, which is 31 m deep. On the Asian side, the cast-in-place box structure sits in the Trakya Formation, a sedimentary rock composed of interlayered siltstones, mudstones and sandstones. Dikes composed of igneous rock intrude into the formation, on average, every 70 m, causing more cases of fractured and broken-down rock, according to Clark.

The box is supported by 800-mm-dia bored secant piles, with grouted-rock anchors up to 36 m long. It transitions into 950-m-long twin mined tunnels underneath a densely populated area; outside of the tunnels, crew also are widening 3.8 km of highway. Crews used the New Austrian Tunneling Method for the 11-m-wide, 8-m-high twin tunnels, 972 m and 925 m long. They were excavated, on average, at a rate of 1.4 m a day, says Arioglu.

On the European side, the box—with, on average, 1.2-m-thick concrete diaphragm walls anchored into rock—transitions to a 400-m-long cut-and-cover tunnel and 5.4 km of highway improvements. Crews spent $7 million on utility relocations along 3 km of alignment, says Ufuk Kukul, YMSK section chief manager.

Ersin Arioglu, chairman of Yapi Merkezi Holding Inc. and Basar's father, notes that 5 million-plus man-hours have been worked with no major incident. Considering the various aspects of the project, from the BOT agreement to engineering techniques, he adds, "This has been a most critical project for us." ■

EURASIAN COLLABORATION
Backed and aided by a slew of global firms, a Turkish-Korean team tackled the intercontinental link.