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INSIDE:
TOP 250 INTERNATIONAL CONTRACTORS
(P. 33)

EXTREME CONSTRUCTION

A RIVER RUNS ABOVE IT

ITALIAN CREWS BUILD AN UNDERPASS FOR THE 64-KM BRENNER BASE TUNNEL JUST METERS BELOW RACING WATERS
(P. 22)

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EXTREME CONSTRUCTION

PART THREE OF A SERIES

Tunnelers Conquer Peaks and Valleys

To create the world's longest rail tunnel, crews pierce beneath the Alps' rocky peaks and install a challenging underpass below an alpine river By Scott Blair

NARROW VALLEY
The Brenner Base Tunnel will pass just a few meters beneath the Isarco River. It will also pass underneath two major highways and a rail line crews cannot close during construction.

PHOTO COURTESY BBT SE

A logistics tangle decades in the unraveling, the Brenner Base Tunnel project is having a banner year. Twin tunnel boring machines in May were released on their relentless journey to mine the main tunnels underneath the Alps between Austria and Italy, while a multinational crew of 2,400 workers armed with a toolkit of just about every mining technique is swarming four major worksites, including a particularly challenging area where workers must undercut a river and pass through the fast-flowing aquifer below it.

"Basically, all that's happened until now was preparation to make things possible for what's happening right now," says Giorgio Malucelli, an operations manager at project owner BBT SE, a public entity established by Italy and Austria. The launch of the TBMs "is a turning point and a defining moment for us at BBT."

When it opens in 2028, the tunnel will form the world's longest underground rail route, serving high-speed rail passenger trains traveling up to 200 kilometers per hour, and cargo trains up to 120 km per hour, slashing the travel time over the existing overground Brenner Pass to 25 minutes from 80 minutes. An integral part of the Scandinavia-Mediterranean Rail Corridor, the tunnel flattens the transit incline from 2.6% on the existing pass to just 0.7% and reduces the travel distance by 20 km. The facilities are designed to be in service for 200 years.

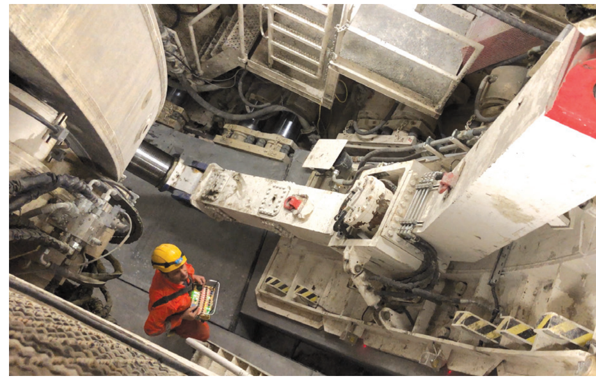
The feasibility studies stretch back to the 1970s and '80s, but planning began in earnest in 1994 when the European Union highlighted the route as a priority project. Ten years later, in 2004, Austria and Italy signed a treaty to build the tunnel and co-founded BBT SE to deliver the project.

Construction began in 2007, with the first exploratory bore launched in 2008 for the 55-km tunnel between Innsbruck, Austria, and Fortezza, Italy. With a link-up to the existing Innsbruck bypass, the travel length of the rail line will stretch a record-breaking 64 km, taking the mantle from the 57-km Gotthard Base Tunnel, opened in 2016 in Switzerland. But that's only a fraction of the story. All tunnels built as part of the €8.4 billion project—including HSR, emergency, ventilation, access and exploratory—add up to around 230 km. In April, the project team crossed the milestone of 100 km of completed tunnels.

Major Fault Line

Around 70% of the main rail tunnels are yet to be excavated and lined using two pairs of 10.7-meter-dia double shield TBMs. The first pair of Herrenknecht-built machines, nicknamed Flavia and Virginia and recently launched on the Italian (south) side, have bored 700 m and 300 m, respectively, towards their ultimate journey of approximately 12 km to the Austrian border. This TBM work comprises most of the €993-million Mules 2 and 3 lot, or contract, which was awarded in 2016 to a consortium of Astaldi, Ghella, Oberosler Cav Pietro, Cogeis and PAC.

Once lined, the parallel HSR tunnels will each have a diameter of 8.1 m and the distance between them will vary from 40 to 70 m. Side tunnels will connect the main tunnels every 333 m, to be used for maintenance access and emergencies. In between the main tunnels and about 12 m below them, a 6.8-m-dia TBM (Serena) paces about 500 m ahead of Flavia and Virginia, digging an exploratory tunnel. In addition to



STEADY PROGRESS Inside the TBM, a worker guides a precast concrete lining segment into place. Caverns and tunnel interchanges (right) provide much-needed logistical space along the 55-km worksite.

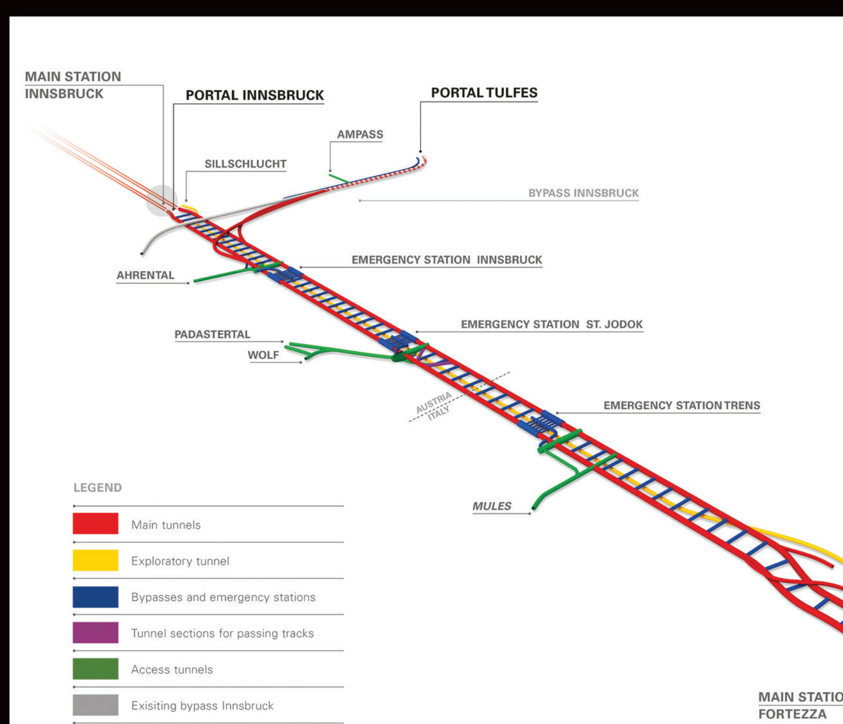
providing critical data regarding rock quality, the multipurpose pilot tunnel serves a central logistical role as a rail supply line for prefabricated tunnel lining segments to feed the advancing main TBMs. Upon completion, the exploratory tunnel will morph into a maintenance and drainage tunnel.

Almost a decade of prep work at the Mules site in previous contracts preceded the TBM launch, including a 10.5-km stretch of the exploratory tunnel which connects the TBMs to the concrete lining prefabrication plant.

"When dealing with a 64-km-long tunnel, logistics is the most important thing to look at before starting all the field activities," says Raffaele Zurlo, Italian CEO of BBT SE. "If

Creating the World's Longest Rail Tunnel Route

The project connects Fortezza on the Italian side with Innsbruck on the Austrian side and cuts through the Alps in a relatively straight line. An existing bypass connects the project to Tulfes. Cross tunnels every 333 m provide maintenance and emergency access. In addition, three emergency stations located approximately 20 km apart provide a safe haven for passengers in case of fire. In total, crews will bore 230 km of tunnels during the project.



the logistical aspects are not deeply analyzed and solved, you will have problems during the tendering phase and during the construction phase, and even the completion of the project could be at risk."

Other prep work included a 1.7-km access tunnel that descends from a staging area on the surface down about 200 m to meet the tunnel. For most of the project, this will be the only access point for workers, cars and trucks to the Mules tunnel site.

Previous phases also hollowed out 20-m-wide by 180-m-long caverns in the granite that serve various functions. For example, because the Mules design specs prohibited any surface concrete production, the batch plant is located in one of the enormous underground caverns, says Enrico Maria Pizzarotti, technical director for Pro Iter and general manager of design for Mules 2 and 3.

Early on, geotechnical engineers drilled 36,000 m of core samples to determine the rock composition throughout the Alps crossing. The work confirmed that the Brenner Base Tunnel would intersect the Periadriatic Seam, an area of heavily fractured rock with poor geomechanical properties created by the collision of the European plate and the Adriatic (African) plate.

"That major fault would've been too dangerous for us to drive a TBM through," says Malucelli. As a result, the contractor used mechanical demolition and drill and blast methods. Ground consolidation methods added additional stability and mitigated risk of rock burst due to the high overburden, which in some areas of the tunnel route is more than 1.5 km thick.

The fault ended up stretching more than 1 km wide instead of the expected 700 m, but Zurlo says the team was "lucky because even though this demanding zone proved to be longer than expected, the presence of water that was supposed to be found was not found. This meant we saved time and money and worked in safer conditions."

Once past the fault and into geologically stable rock, crews created two more large caverns and spent months assembling the 200-m-long TBMs inside.

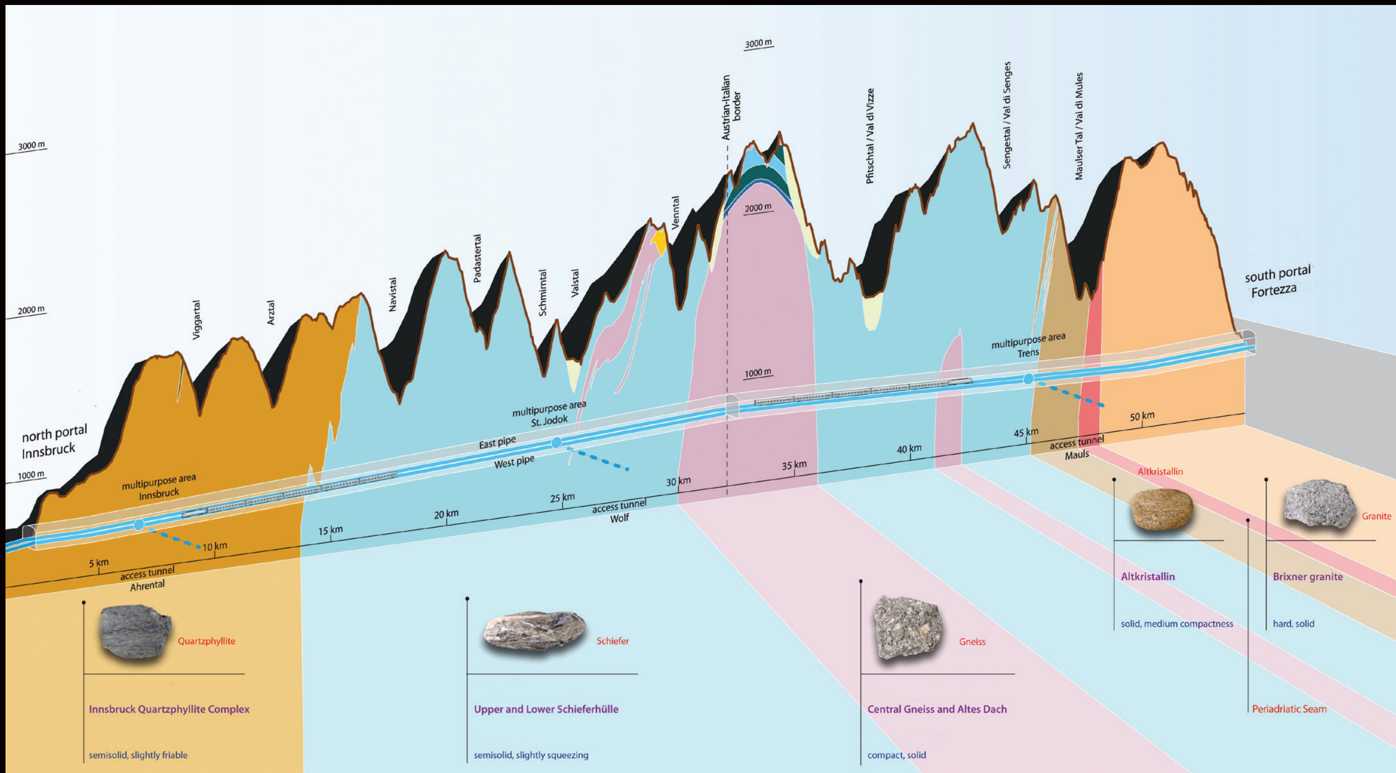
In total, 5.5 km of tunnels have been excavated at Mules using drill and blast or machinery, including a southbound segment which the contractor proceeded with during the lengthy TBM assembly period.

At the World Tunneling Congress (WTC) in Naples, held this May, Zurlo presented a detailed analysis of the cost per cubic meter of excavation compared to rock quality experienced so far at Mules, meant to provide useful information to tunnelers but also to encourage other large-scale infrastructure project teams to provide cost data with similar unit costs so the industry will "have a panorama of what's going on within other similar projects," he says.

He vows that the transparent cost monitoring and analysis will continue throughout the project. The goal should not only be building and operating a rail line, he says, it "should also be to discover something new, to better understand the behavior of the rock and upgrade and improve our construction methods and organization schemes."

Currently, the Italian side is on budget and schedule, whereas the Austrian side is pacing slightly behind schedule, Zurlo says. Flavia and Virginia should reach the border by early 2022. On the Austrian side, under a separate contract, crews prep for another pair of TBMs launching in the near future that will head south.

MAP DATA (LOWER LEFT): ©2019 GOOGLE, GEOBASIS-DE/BKG; PHOTO (TOP LEFT) BY SCOTT BLAIR FOR ENR; TUNNEL MAP (LOWER MIDDLE) AND PHOTO (UPPER RIGHT) COURTESY BBT SE



Four Fords at Isarco River

On the southernmost end of the Brenner Base Tunnel, crews face an even greater challenge: how to tunnel just a few meters below the rapids of an alpine river. The €303-million Isarco River Underpass lot was awarded in 2014 to a consortium of Salini Impregilo, Strabag, Consorzio Integra and Collini Lavori. Upon completion in 2022, the contract will link the tunnel with the existing Brenner line and the railway station in Fortezza.

Around 3 km of 6 km of tunneling has been completed at the site. "We have done the easiest part, which was through rock, and we were able to excavate up to 10 meters per day," says Maurizio Ferrero, geotechnical engineer with BBT SE. For the river underpassing, productivity will slow to just a half meter per day in the alluvial soil, he says.

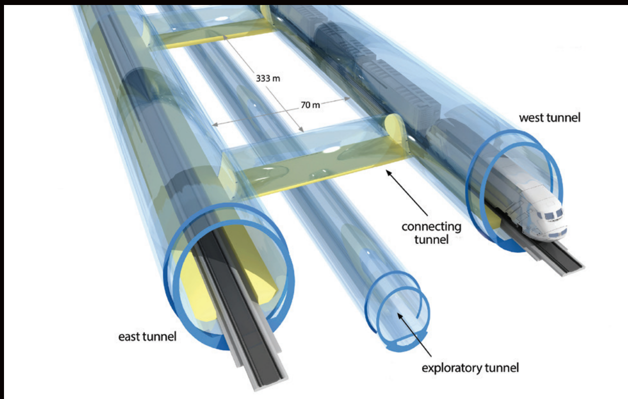
Just north of the river, the twin tunnels expand to their widest spaces at 275 sq m each to accommodate a bifurcation that splits off a rail interchange from the main HSR tunnels. As a result, crews must construct four tubes that will pass underneath the river as well as under two major roadways on one side of the river and an existing surface rail line on the other side.

Four enormous 25-m-deep shafts, elliptical in plan to accommodate the varying angles of the four tunnels, have been completed, two on either side of the river. They provide access for crews who will spend months preparing for large-scale ground freezing to safely construct the underpasses. The four tunnels will be between 56 m and 63 m long. Each will take four months to construct: two will be built in 2020 and the remaining two in 2021.

Originally, the design specified a cut-and-cover method of construction. But this would have required shifting the river twice and lowering the water table by 20 m. The contractor consortium proposed the ground-freezing alternative, which

PREFAB A plant fabricates and stores thousands of tunnel liner segments, which are shipped 10.5 km by rail to supply the TBM.

SCHEMATICS AND PHOTOS COURTESY BBT SE



Tunnelers Contend With Complex Geological Conditions
Brenner Base Tunnel passes through multiple geological zones and rock types, including hard granite and gneiss. The Periadriatic Seam (in red near the south portal of Fortezza) provided the biggest challenge to date on the project. The area of heavily fractured rock with poor geomechanical properties was too risky for TBM mining and had to be excavated using traditional methods. The twin high-speed rail tubes (image top right) enable trains to travel at up to 200 km/hour. A multipurpose exploratory tunnel in between the rail lines serves as a supply line during construction and transitions to a maintenance access and drainage line during operations.

eliminated the environmental impact to the riverbed and associated underground aquifer, Ferrero says.

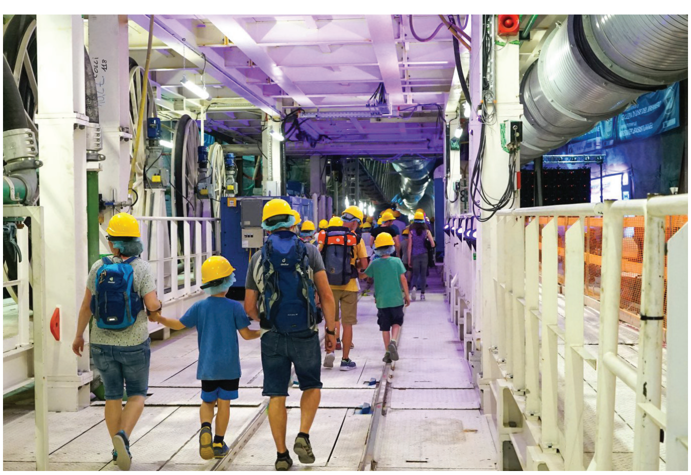
To enable ground freezing, the speed of the underground aquifer's 16 m-per-day water flows must be slowed. "It's a figure too high to perform the freezing treatment," says Giovanna Cassani, technical director for Isarco designer Rocksoil. Therefore, the team will use preliminary ground consolidation by cement injection to slow the aquifer to 1.5 m to 2 m per day, to enable proper freezing, she says.

Next, 66 pipes and 88 freezing probes up to 35 m in length will be installed around the perimeter. Liquid nitrogen will drop the soil temperature to -15° C and then a brine solution will maintain the temperature during excavation. "We are basically making a giant pipe of ice and then we're going to excavate inside," Ferrero says. The thickness of the "pipe" on the sides and bottom will be 1 m, but because the riverbed is just 5 m to 8 m above the excavation, the top will be twice as thick.

As challenging as the river transit will be, Ferrero says he's more concerned about tunneling under the roadways, scheduled for next year, They can't be closed due to their major economic importance for the region. Ground consolidation will be performed not only on the sides and ceiling of the advancing tunnel, but also on the front face, to prevent it from collapsing during excavation. Crews will cycle the consolidation and excavation in 7-m increments until the section wraps up.

The steep-sided valley poses additional risks. The entire valley is devoid of direct sunlight from November until March, creating brutally cold temperatures. Because of the ever-present aquifer and river water that must be constantly pumped out of the shafts, all piping has to be heavily insulated, and concrete casting has to be carefully scheduled. Additionally, barriers have been set up to mitigate rockfalls.

SCHEMATICS AND PHOTOS COURTESY BBT SE



FIELD TRIP
Once a year, the jobsite shuts down and the public can go deep underground to see what it's like to work on a TBM.

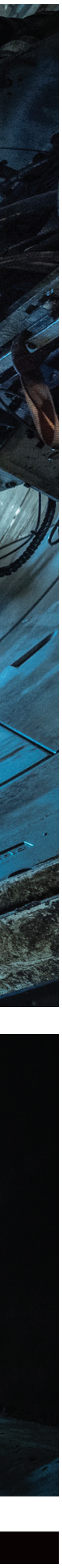
Local and International Outreach

With funding coming from the European Union, Italy and Austria, project executives recognize the importance of winning public favor and communicating the message that the new rail pass will improve the economy and mobility for all Europeans. Communication methods "have to be developed comprehensively and continuously in transnational, complex infrastructural projects," said Konrad Bergmeister, BBT SE's Austrian CEO, during a presentation at the WTC. Over the past 12 years, he said, BBT SE has honed its communication approach, cultivated contacts both with the media and local leaders and invited the local community to visit the worksites at various tours and annual Open Tunnel Days in both Austria and Italy.

As part of that effort, BBT SE has opened three visitors centers, including BBT Tunnel World, which has drawn around 50,000 people. The two-level museum includes a demonstration mine shaft and interactive exhibits.

During the most recent Open Tunnel Day in June, the entire Mules worksite was shut down, and hundreds of hard-hatted visitors were bused deep into the tunnels and escorted onto the TBM Virginia. "The organization of this event was a real challenge. It's not easy to open a construction site of this size to such a large audience and lead it to a TBM more than 4 km from the surface," says Zurlo. "But we're convinced that it is worth it, because I see a constantly growing interest in this project, which will be a reality in 10 years' time." ■

Workers erected tunnel lining segments at the rear shield while the front shield excavated at the face (top). Four TBMs drove the tunnels in two pairs side by side (above right). The first stretch of tunnels south of the Oslo cavern were in drill-and-blast (above left).



NORWAY'S HARD ROCK CONCERT

Two pairs of double-shield tunnel-boring machines break the mold in shaping Norway's new high-speed railroad between Oslo and Ski. By Peter Reina

To build a $3.4-billion underground high-speed railroad into Oslo, Norwegian engineers left their comfort zone of drill-blast rock excavation in favor of tunnel-boring machines. Hard, abrasive rock and more water than expected only hindered the project minimally; however, it fell victim to the weak finances of a main contractor.

A pair of hard-rock TBMs heading toward Oslo broke through their parallel drives side by side in September 2018, five months ahead of schedule, says Anne Kathrine Kalager, project manager on the bored sections with the state railroad infrastructure manager, Bane NOR. A second, southbound pair broke through in February.

But a corporate failure in the north section delayed the project's final holing through by months. Now running about a year behind schedule and 8% over budget, the project had been in good shape until the contractor drill-blasting the north stretch of caverns and tunnels went into court protection at home in Italy, says Bane NOR's project director, Per David Borenstein.

The 22-kilometer project will deliver a high-speed railroad from Oslo to Ski, augmenting the existing, slow Østfold line. From Oslo central station, the Follo tracks will run southwards through a 600-meter-long cut-and-cover tunnel before entering a 170-m-long rock cavern. They will continue southwards in drill-and-blast tunnels for about 1.5 km before entering around 18 km of twin tunnels driven by four 9.9-m-dia TBMs, surfacing near Ski. Set some 20 m apart, the tunnels are linked every 0.5 km with cross passages.

After reviewing European practices, Bane NOR's team saw that "in all long tunnels designed for high-speed and high-frequencies trains, they had chosen the concept of twin single-track tunnels with cross connections," says Kalager.

Having decided on twin single bores instead of a wide twin-track tunnel in 2010, Bane NOR again broke with tradition by choosing TBMs, rather than drill-and-blast, for environmental reasons, says Kalager. Instead of the seven access sites needed for D&B, a single location at Åsland, halfway along the route and close to the E6 highway, served the TBMs.

Since hard-rock tunnel TBMs had fallen out of favor in Norway, Bane NOR sought expertise from veterans of previous hydro projects. "We got in touch with a number of people. … They were in charge of making the specification for the TBMs," say Kalager.

No TBM tunnels had been built in Norway in the 20 years before 2013, according to Amund Bruland, a civil engineering professor at the Norwegian University of Science and Technology, Trondheim.

And no railroad tunnels were built with TBMs until Bane NOR's predecessor started the 7.7-km-long Ulriken twin drives into Bergen, where a 9.3-m-dia Herrenknecht Gripper broke through two years ago.

For the Follo tunnel contract, bidders were required to use double-shield TBMs because "we wanted (them) to focus only on one excavation method," says Kalager. Bane NOR's specification was "pretty much detailed," adds Matteo Ortu, then project manager with the bored tunnel's Spanish-Italian joint venture of Acciona Infraestructuras S.A. and Ghella S.p.A. (AGJV).

Kalager remembers scepticism in the supply chain about the size and weight of the TBMs. "Our experienced veterans told them, 'You are going to fight

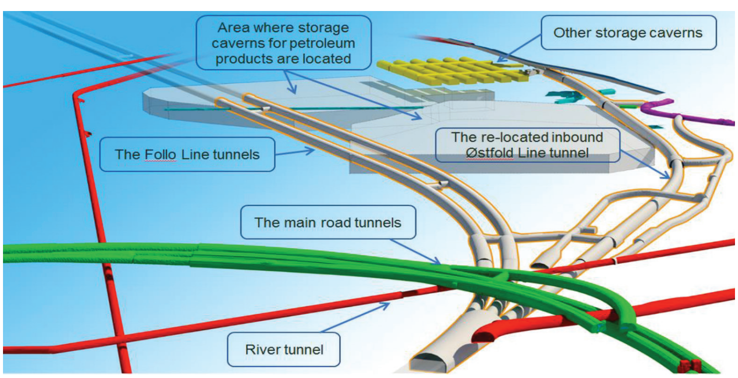
PHOTOS COURTESY HERRENKNECHT (TOP); TERJE SKÅRE (BOTTOM LEFT); NICOLAS TOURRENC/AGJV (BOTTOM RIGHT) against the hardest rock you have ever fought against,'" she says. With axial strengths of 150-300 megapascals, the generally abrasive gneiss rock along the tunnel includes bands of amphibolite and pegmatite. They also contain clay-filled valleys above known fracture zones.

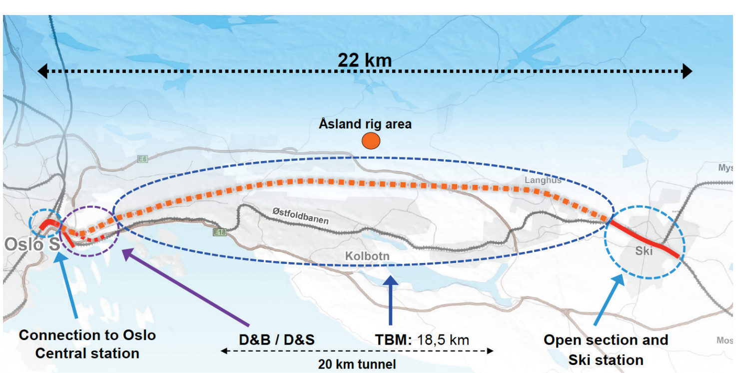
In such hard rock, "a lot of people were afraid the cutter head would not be able to complete the project," says Matthias Flora, product manager for hard-rock tunneling at the TBM's supplier, Herrenknecht A.G., based in Schwanau, Germany.

Weighing 265 tonnes, the cutter heads were about 25% heavier than those the company is supplying for work on the weaker Brenner tunnel rock between Italy and Switzerland, he says.

Bane NOR specified double-shield TBMs for maximum speed while protecting workers from rock falls by either the shield or following lining, says Kalager. By excavating the face while erecting the lining at the same time, such TBMs can be 30% faster than single-shield machines, says Flora.

In March 2016, AGJV won the TBM engineering,





The project includes parts of the existing Østfold line (top). TBMs drove most of the tunnels, while complicated northern sections were in drill-and-blast (bottom).

GRAPHICS COURTESY BANE NOR

"EVERYONE IS A FORMULA ONE DRIVER AT HEART"

—MATTEO ORTU, PROJECT MANAGER WITH ACCIONA/GHELLA JV

procurement and construction contract with the highest total technical and commercial evaluation score, though its $1 billion price was not the lowest, says Kalager. One of AGJV's first jobs was to excavated two large TBM launch caverns nearly 400 m apart along the tunnel route at Åsland.

The first TBM set off from Åsland in September 2016, followed some five weeks later by the second. They broke through simultaneously into the separate ends of drill-blast tunnels near Oslo central station last September.

The southbound TBMs began in November and December 2016, breaking through together into the open air late this February. "Healthy competition" between the parallel TBM crews probably boosted progress, says Ortu. "Everyone is a Formula One driver at heart," he adds.

The Follo tunnels are made permanently watertight by the segmental lining erected immediately behind the rear shield and grouted to fill voids in surrounding rock. But additional precautions were also needed. Because rock along the tunnel was known to contain clay-filled valleys above fracture zones, the TBMs were equipped to drill and grout 35 m ahead of the face. Otherwise, water draining from the clay, via the fracture zones, would cause pore pressure drops in the clay, resulting in surface ground settlement under built up areas, says Kalager.

The contract forecast 1,600 m of total pre-grouting, with provisions for time and budget compensation for more difficult conditions. "We did about 7,640 m," says Fabio Moizo, AGJV's technical manager. "In general, when water was not encountered, (the TBMs) performed very well," he says.

Covering excavation, track and other systems except signaling, AGJV's lump-sum contract includes a schedule of milestones. Falling behind schedule triggers penalties, says Ortu. However, "the contractor is protected in case the rock is harder and more demanding," he adds.

"Rock conditions encountered along the tunnel drives were resulting in lower penetration rates and higher cutter consumption," says Ortu.

In the contract, Bane NOR provided an assumed

Cutters on the TBMS endured more wear and tear than first expected; contractor's compensation is not yet agreed.

PHOTOS COURTESY HERRENKNECHT

baseline of rock and machine parameters. Predicted excavation rates were calculated at 16.22 m per day for the north tunnels and 15.86 m for the south, says Moizo. Real advance rates averaged 15 m per day northwards and 13.7 m in the south tunnels, he adds.

However, Bane NOR and the joint venture have yet to agree on an assessment of the actual geology, says Moizo. A four-month contract extension from the original April 2021 completion was caused by outside influences, says Kalager.

Back to Basics

While TBMs suited the Follo line's long straight drives, near Oslo the excavations were more traditional. The 600-m-long cut-and-cover section near the central station leads to a drill-and-blast cavern 170 m long to contain both Follo line tracks and one track of the existing Østfold line. The cavern size varies, reaching up to 32 m wide and 15 m high.

In a few sections, where the excavations passed slightly below large petroleum-storage caverns and the E6 highway tunnel, Bane NOR specified a drill-and-split approach, to avoid explosives. Instead, up to 500 narrow crews drilled holes 1.5 m long into the roughly 70-sq-m rock face.

Hydraulic wedges expanded in the holes split the rock with little vibration. It was slow work, advancing about 0.5 m a day, says Kalager. Altogether, 185 m of tunneling in the northern section was by drill and split while nearly 2.6 km involved blasting.

The 1.5 km set of twin tunnels from the cavern close to the station are also drill-and-blast, though Bane NOR had considered using TBMs. But because of nearby sensitive infrastructure, "it would not have been recommended to speed up in that area if the TBMs had been delayed," says Kalager.

To keep the last section of twin tunnels off the project's critical path, Bane NOR incorporated that work in an ill-fated drill-and-blast contract, setting it on a course to delay. Bane NOR procured all the drill-and-blast work and the cut-and-cover section in two EPC contracts worth $400 million, won by Società Italiana per Condotte d'Acqua S.p.A in 2015. In early 2018, the contracts were terminated with about half the required work completed, says Borenstein.

"The contractor had financial issues … they didn't have the money to pay the subcontractors [in Oslo]," says Borenstein. "So we divided the remaining work into four contracts and went out to the [local] market. It's worked very well," he says.

With the final contracts awarded last October, the project missed a six-week possession of existing tracks that it would otherwise have had for work needed last summer, says Borenstein. Preparations for systems installation are now taking over. And while the financial woes of one contractor pushed back the whole project's opening to December 2022, Kalager says neither the hard rock nor the face pre-grouting were "show-stoppers for using TBMs." ■