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AFTER THE BLAST

Jacobs forces Conagra to honor indemnification and pay $109 million (P. 6)

EXTREME CONSTRUCTION FIRST OF A SERIES

POWERING THROUGH

JOINT VENTURE WORKS IN -35º C WINTER TO MAKE UP FOR LOST TIME (P. 14)

A bnp media PUBLICATION

EXTREME CONSTRUCTION FIRST OF A SERIES

COURSE CORRECT

October in northern Manitoba means daily dips into subzero temperatures and frequent dustings of snow. For most construction jobsites, it also might mean it's time to start sending workers home until temperatures rise again in the late spring.

But here, at Keeyask Generating Station work camp, 725 kilometers from Winnipeg and 10º south of the Arctic Circle, workers will stay through the winter, placing concrete and continuing construction of a powerhouse, dams, dikes and a tailrace for Manitoba Hydro's latest hydroelectric facility on the Nelson River, in temperatures that will likely reach as low as -40º C with wind chill as low as -70º C (-94º F).

It will be the second year in a row that the joint venture of Bechtel Barnard and EllisDon (BBE) will work through the frigid weather. "It's not common to work through the winter," says Bechtel's Jacob Mumm, a BBE project manager. "Talking to other construction managers, it's sacrilegious."

But the alternative is losing established work teams and likely falling behind on the work schedule.

The decision to work during the 2017-18 season paid off for BBE. Managers say with con-

SPILLWAY SUNSET
Construction of the 119-m-long, 42-m-wide and 28-m-high spillway was completed ahead of schedule last summer. The powerhouse is in the background.

tinued innovative placements and a second season of winter work, they expect to have most of the concrete placed by 2019, and the job complete by its target date in 2021. Manitoba Hydro, a crown corporation owned by the province of Manitoba, has expressed confidence that the cost will remain at 8.7 billion Canadian dollars ($6.63 billion). That's about CA$2 billion ($1.56 billion) over the original budget, but not rising to the CA$10 billion ($7.6 billion) that consultants had warned.

"We made hay," says Mumm of the winter work. "We did really well and improved on milestones for the schedule. We're ahead of schedule for the in-service date for the first unit."

Home Grown

The 695-MW Keeyask hydroelectric plant will be Manitoba Hydro's sixth hydro project on the Nelson River, which flows north, draining Lake Winnipeg into the Hudson Bay.

Manitoba Hydro's first project on the river, the 287-MW Kelsey Generating Station, was completed

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The Keeyask Hydroelectric project fell behind schedule, but BBE is making up time.

By Pam Radtke Russell, in Northern Manitoba, Canada

PHOTO COURTESY OF BBE

RAPID PROGRESS The Keeyask hydro project is on the Nelson River between a lake and a downriver reservoir on Gull Rapids, which has a 23-m drop.

PHOTO COURTESY BBE

in 1957. The most recent, the 1,330-MW Limestone Generating Station, was completed in 1990 by Bechtel.

Keeyask is a relatively low-head dam that will use 18 meters of the 27-m drop known as Gull Rapids. While the elevation drop at the site makes it good for hydroelectricity, the width of the river and the remoteness of the site make the job challenging. At the site of the dam, the Nelson River is about 2 km wide.

Because of the width, Hatch consulting engineers designed the seven-unit powerhouse separate from a seven-gate spillway. It's an unusual configuration for hydro facilities, which typically have adjacent spillways and powerhouses. At Keeyask, the two structures are connected by earthen dams that also connect them to the riverbank and to a 23-km dike that will surround what will become a 93-sq-km reservoir with an operating level of 139.2 m.

All the material to build the dams comes from on-site borrow pits that were identified by Manitoba Hydro decades ago as it looked to develop the Nelson River for hydroelectricity. As of Sept. 12, the pits had supplied 3.5 million cu m of material for the permanent embankments. In fact, all sand, rock and clay needed for the job are mined on site, including for the 370,000 cu m of concrete needed to complete the spillway and powerhouse. "It's home grown," says Bechtel's James "J.Q." Hicks, BBE project manager.

Since construction started in 2014, almost 20 million cu m of material has been moved around site using Caterpillar 777 and 773 haul trucks. Without the on-site borrow pits, construction of the site "probably wouldn't have been feasible," says Barnard's Mike Fuller, BBE construction manager.

As it is, everything else, from the roughly 2,000 laborers and support staff and 237 pieces of equipment—including 17 cranes—to the steel, and down to the toilet paper, must be hauled in on a 180-km-long dirt road from the city of Thompson. Getting to the site is a daylong affair. For many BBE workers, it begins with a chartered flight from Winnipeg to Thompson and then continues with a two- to three-hour bus ride on the dirt road. Most employees have a 21-days-on, seven-days-off work schedule.

BBE is handling all of the civil work at Keeyask, self-performing about 90%. The site operates 24/7 and is

averaging 22 concrete placements a week. The fourth and fifth unit of the powerhouse should be enclosed in early 2019. The last structure to be completed will be the tailrace, to funnel water out of the powerhouse. Voith Hydro will separately provide and install the seven vertical propeller turbine generator units. The Keeyask Hydropower Limited Partnership has contracts for housing, food and other services—including for falconers who use their raptors to keep gulls off the worksite.

To compete for labor with other work camps, including at oil and gas projects in Alberta and two other hydro projects being built in Canada, the camp has hotel-like amenities, including a full-sized gym, movie theatres, arcade and other gaming systems, and pool tables. Each worker has his or her own room and bathroom. An onsite cafeteria provides food around the clock.

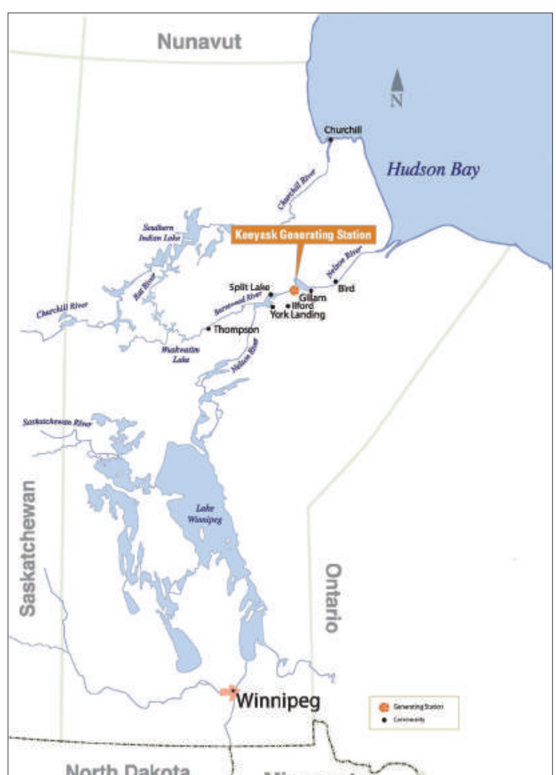
A second camp, on the south side of the river, is much more basic. With the completion of the last dam across the river, though, workers on the south side will be able to quickly access the northern camp that previously took three hours to reach.

Keeyask also has something that's not commonly found on a jobsite: a sweat lodge. That's because to build Keeyask, Manitoba Hydro partnered with the four aboriginal communities—the Tataskweyak, War Lake, York Factory and Fox Lake Cree—that have lived in the region for generations. The Cree people have had a voice in the design, construction and operation of the hydro project, and have 10% ownership.

The First Nation heritage is honored in regular ceremonies, such as an Aug. 31 event to commemorate the diversion of the river through the recently completed spillway. Notably, in 2015, workers were excavating a portion of the Nelson River bottom to create the powerhouse when one of the blasts revealed a grandfatherly face

PHOTO COURTESY BBE

WINTER HOARDING
Contractors modified the existing powerhouse and used tarps, insulation and heaters to raise the temperature enough to work and place concrete.

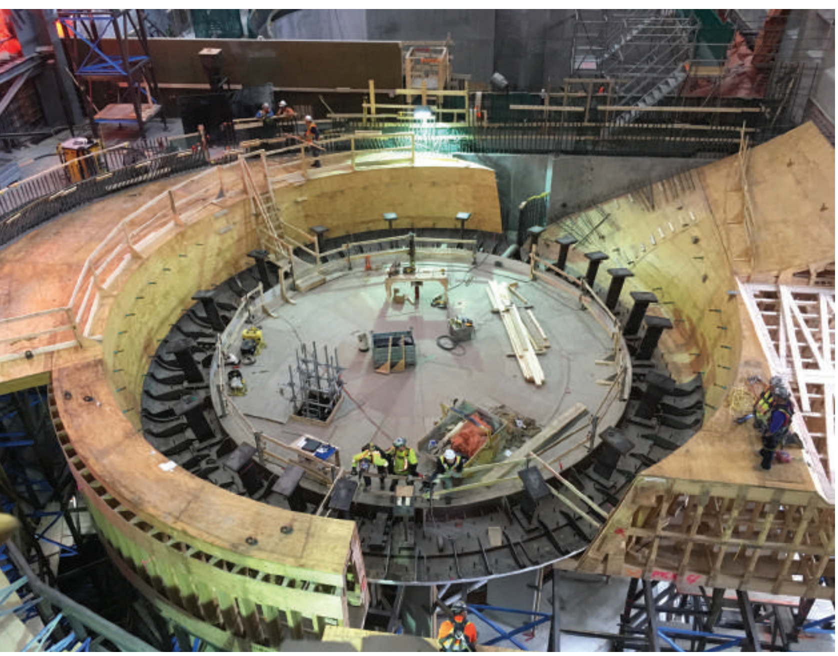


in the rock. A subsequent blast uncovered the likeness of a thunderbird nearby. As word spread throughout the camp in the boreal forest just south of the Arctic tundra, workers came to see the images, considered symbols of the Cree peoples.

"It was a very special time for a lot of the indigenous people," says Fuller. "It really struck them, it was so visible," says Fuller, who added that non-indigenous people were also moved by the images. Out of respect for the Cree, work on that section of the powerhouse temporarily stopped so workers could view the images. Several months later, a ceremony was held to honor the images.

According to a year-in-review report released in March by the owners, about 5,600 of the total 13,700 hires have been indigenous people. More than half of those were hired as laborers, carpenters or caterers. About 100 have been hired on the site to apprentice to a trade, Mumm says.

FINE FORMED Workers set forms for the spiral-like enclosure for one of the seven Voith turbines in the powerhouse.



Yet a report released earlier this year says Manitoba Hydro and its contractors are not doing enough in their hiring of the indigenous people. The report, commissioned by Keeyask Hydro Limited Partnership, found that the contractors, including BBE, discriminated in their hiring of indigenous people.

"Workers felt that contractors were able to manipulate the [job referral system] and screen in preferred workers while being able to screen out others such that in particular job areas there was a disproportionate number of workers from a particular company or in some instances close friends and relatives," the report states

Since the report was completed, the Keeyask partnership and BBE have improved their efforts to hire more First Nations workers and reduce harassment at the campsite. The Keeyask partnership says it has implemented or is implementing all of the report's 64 recommendations.

In response to the report, a BBE spokesperson said, "We have been responsive by strengthening our commitment to providing a positive, respectful and safe workplace for all our people, and firmly embedding fair treatment and equal opportunity in Keeyask's culture."

BBE has a mandate to hire indigenous workers first, Manitoba workers second and workers from other provinces third. Because Manitoba has a relatively small population, many of the workers are from outside the province, Mumm says. Bringing together workers from throughout the country required some finesse because each province has different laws and requirements, but overall, Mumm says, the workforce is "phenomenal."

"They are some of the best craftspeople I've seen in 30 years," agreed Fuller.

Winter Solution

But because of the short work season—from about June to October—BBE was losing a chunk of those workers every year when the site closed down. By the time teams had gelled, it was time to send them home for the winter. When hiring began for the next season, many of the workers had moved on to other jobs. "The learning curve is pretty steep," says Fuller. But he and others noticed that once teams came together and productivity hit a high, it was maintained, even as temperatures began dropping. The benefit of keeping those teams together factored into the decision to keep working through last winter. The site shut down for just a few weeks from December 2017 to February 2018.

BBE took a lean approach to winter hoarding to keep the costs low. Crews placed lightweight temporary steel columns on top of three powerhouse units that were partially completed, and double tarps were used to enclose the structures. Insulation and hundreds of diesel heaters kept interior temperatures at about 10º C.

Still, the work was challenging. "Almost nothing cooperates in -40 degrees," says Mumm. Freezing temperatures are really hard on equipment, he added.

During the cold season, about 900 workers worked in the powerhouse, while another about 700 worked elsewhere around the site. The crew placed more than 20,000 cu m of concrete in temperatures as low as -35º C. The winter work has helped BBE recover from a critical consultant's report compiled by MGF Project Services for the Manitoba Public Utilities Board. That report, released in December, criticized BBE's slow pace of work and the cost-reimbursable nature of the contract, which MGF said provided BBE "little incentive to actually per-

PHOTO BY PAM RADTKE RUSSELL FOR ENR

CANADIAN HYDROPOWER BOOM HITS ROADBLOCKS

Keeyask is one of three major hydropower projects under construction in Canada—a country that gets 59% of its electricity from hydropower. Judging by the problems faced at all three sites, they could be the last three built in the country for decades.

The most problematic of the hydro plants is Nalcor Energy's Muskrat Falls. On Oct. 18, it ordered contractor Astaldi Canada to stop work on the project because of its "inability to pay its workers" after its Italian-based parent company filed for bankruptcy earlier this month.

As of Oct. 22, all but 25 of Astaldi's 500 workers on the job had been sent home, and Nalcor, a crown corporation—meaning it is owned by the state—said it was working on a contingency plan to complete the 5% of work remaining on the powerhouse, intake and spillway, according to Nalcor spokeswoman Karen O'Neil. "The remaining work is not on the critical path and therefore won't hold us up for achieving first power next year as planned," she says.

Astaldi did not respond to a request for comment. SNC-Lavalin, the engineering, procurement and construction management contractor for the 824-MW plant job, referred all questions to Nalcor. The project, located on the Churchill River in Labrador, is the second hydro facility in what is considered the Lower Churchill complex. A separate joint venture of Barnard-Pennecon is building the north and south dams at the facility.

The Astaldi problems at Muskrat Falls come on top of a yearlong formal inquiry into the Muskrat project, which has doubled in price to almost CA$13 billion ($9.9 billion) and could be a burden and boondoggle to the province's population of 530,000 if the power isn't sold elsewhere.

Cost overruns are a worldwide problem with hydro projects, according to a report completed for the Muskrat Falls inquiry by Bent Flyvbjerg, an Oxford University professor who studies megaprojects. Flyvbjerg notes that hydro projects, on average, have cost overruns of 96% and schedule overruns of 42%. "The cost and schedule risks of dams is only exceeded by nuclear power projects," the report states. "Often cost and schedule overruns are explained by unforeseen conditions and adverse events, e.g., unforeseen geology, project complexity, scope changes, bad weather. However, these are not root causes. The root causes … can be found in optimism and political bias in estimates of geology, complexity, scope, weather, etc., which translate into underestimates of cost and schedule, which later turn into cost and schedule overruns."

PARALLEL DEVELOPMENTS BC Hydro is building the Site C dam on the Peace River in British Columbia, above, while Nalcor Energy is building Muskrat Falls on the Churchill River in Labrador.

Muskrat Falls, and a third Canadian hydro project under construction—BC Hydro's Site C in the Peace River Valley of British Columbia, are opposed by indigenous people and others because of their environmental impact. Muskrat Falls is opposed, among other reasons, because of the potential methylmercury poisoning that could occur downstream. Site C faces resistance because the reservoir will flood 100 sq km of land that is still occupied and farmed by First Nations people who live in the Peace River Valley.

Still, the three crown corporations that have implemented the projects have the same rationale: "Once complete … the project will provide clean, reliable and cost-effective electricity for more than 100 years," says BC Hydro of its 1,100-MW, Site C dam. New provincial leadership threatened to cancel the project, which has grown in cost by CA$2 billion ($1.5 billion) to CA$10.7 billion ($8.2 billion). But the new government decided that the project, which began in 2015, was too far along to cancel. ACCIONA, Petrowest and Samsung are the main civil works contractors for the project, which is expected to be complete in 2024. ■

By Pam Radtke Russell

LAYERS OF PROBLEMS A yearlong formal inquiry began in September on the multitude of problems and cost overruns at the Muskrat Falls hydro project, shown here in December 2016.

IMAGE (TOP) COURTESY BC HYDRO; PHOTO (LOWER) COURTESY ASTALDI CANADA

POWERHOUSE Much of the winter work occurred last year within the powerhouse units because they can be temporarily enclosed using tarps on the partially completed structures.

form the work." It recommended that Manitoba Hydro increase its oversight over BBE.

While the original contract with BBE was for CA$1.4 billion ($1 billion), a more realistic price would have been CA$1.8 billion to CA$2.2 billion ($1.4 billion to $1.7 billion), MGF said. The original contract has been amended but still uses the same cost-reimbursement formula, according to MGF:

"In our opinion the most significant issue for the project is the almost 100% decoupling of work performance from payment by paying actual costs instead of quantities-times-unit-prices for actual work done."

Manitoba Hydro spokesman Bruce Owen said "we continue to make improvements to oversight and productivity with BBE."

BBE also points to improvements, including completing the spillway 45 days ahead of schedule.

Mumm and Fuller say the geology of the riverbed is largely to blame for the cost overruns and schedule slippage. After cofferdams were built and water was drained out of the river, there was a moonscape surface that required months of labor to remove the infirm rock—often with jackhammers and hand tools—to create a smooth surface to build upon. BBE started instream work in July 2014. The crew was still "licking the rock," as the work is called, into the second quarter of 2018.

One crater was so deep, the footprint of the central dam had to be moved. "The design contemplated this [river bed] being nice and smooth," says Mumm. That massive amount of earthwork "increased quantities drastically," he says.

Other surprises added to the work, including having to raise the height of cofferdam embankments after ice booms broke during the first winter of construction and 15-ft-thick sheets of ice flowed downstream and onto the worksite. "These are the kind of things that cost," Mumm says. "We lost time."

Keeyask isn't the only project facing scrutiny. In July, Manitoba Hydro completed work on a 1,384-km, high-voltage, direct-current transmission line that will move Keeyask's power from nearby Gillam to Winnipeg. Rokstad, formerly partially owned by Carillion, was the primary contractor on the line, called Bipole III. Originally expected to cost about CA$2.25 billion ($1.72 billion), the line was completed at a cost of CA$5 billion ($3.8 billion). Manitoba Premier Brian Pallister has called for a review of Hydro's operations because of the cost overruns, but none has begun.

The projects were approved when a then-growing industrial sector in neighboring provinces, as well as CA$4.5 billion ($3.4 billion) in export contracts, supported the rationale for the projects. But since then, development of projects in the Canadian oil sands has contracted, and U.S. utilities, like Minnesota-based Xcel, which is contracted to purchase hydropower from Manitoba Hydro through 2025, have begun developing solar and wind power.

Manitoba Hydro says Keeyask still will be necessary to serve its customers by 2033 and will allow wholesale customers to integrate wind into their system. "That, coupled with the long life of hydroelectric facilities (over 100 years), means we still see tremendous value in these hydropower projects moving forward," says Owen.

Arctic Foxes

Work aside, Mumm, Hicks and Fuller—who have worked around the world—like to talk about the uniqueness of the Keeyask site. The bitter cold is countered by northern lights that glow in the winter and arctic foxes that steal leather gloves out of workers' hands. Many workers have bear or moose encounters—and pictures—to share. Wolves have been spotted, and wolverine tracks have been seen.

Hugo Mejias, BBE's environmental manager, drives around the site showing where bears have been spotted, and highlighting the efforts his team is making to keep the site in compliance with the law and with the spirit of the Cree nation. Evidence of fur trading from 300 years ago, including muskets and tea cups from England, has been found on the site.

"It's very special up here," says Mumm. "It just feels different." ■

PHOTO COURTESY BBE

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EXTREME CONSTRUCTION

ISLAND HOPPER

Chinese crews navigate typhoons and deep seas to build record-busting bridge network (P. 24)

A bnp media PUBLICATION

EXTREME CONSTRUCTION SEA

Part Two of a Series

OPEN WATER
Pile-driving ships install 109-meter-long premanufactured steel foundation piles in seas as deep as 36 m.

PHOTO COURTESY ROAD & BRIDGE EAST CHINA ENGINEERING CO.

CHANGE

Chinese contractors take the plunge into prefab and BIM for island-hopping roadway

By Scott Blair in Zhoushan, China

Winter typhoons and summer monsoons regularly pummel workers and equipment. Strong tides churn in a sea crisscrossed by submerged pipelines and some of the busiest shipping channels in the world. Working platforms across the open ocean disappear into the horizon. These are just some of the extreme challenges that contractors must mitigate using prefabrication, technology and logistical prowess in their effort to construct the largest network of island-connecting bridges in the world.

The conditions are “the worst” that veteran offshore bridge builder Jiang Junbo has seen. “Our construction area is located in the open sea, without any shelter,” says the vice president with Road & Bridge East China Engineering Co.

Located in the East China Sea southeast of Shanghai, the Zhoushan archipelago consists of thousands of small islands, about 100 of which are inhabited. Until recently, the only access was by sea or air. But in 2010, China completed a string of five cross-sea bridges to connect the mainland to tourism mecca Zhoushan Island, which also serves as an important fishery and industrial hotbed.

Multiple contractors, including Road & Bridge, are working concurrently under separate contracts to extend the expressway another 30 kilometers to reach Daishan Island, with a spur reaching

MULTIPLE CONTRACTORS
The $2.74-billion, 28-km Ningbo-Zhoushan Port Main Channel Road is divided into four primary contracts: (1) Zhejiang Communications Construction Group Co., (2) China State Construction Bridge Corp., (3) Road & Bridge East China Engineering Co. and (4) CCCC Second Navigation Engineering Bureau Co. Fuchimen Bridge and Yushan Bridge are separate contracts.

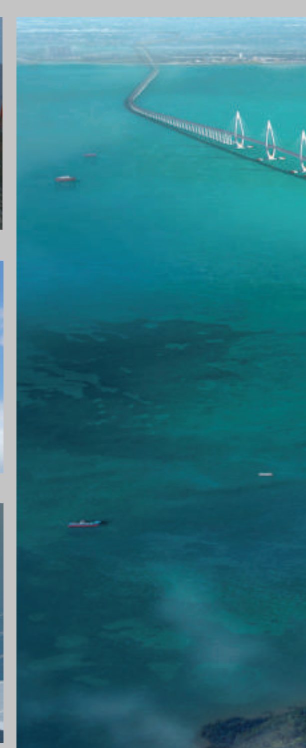
Changbai Island. Meanwhile, the 8.8-km Yushan Bridge is being built to connect Yushan and Daishan islands. Together with the 2010 bridges, the roadway will stretch 86.68 km, the majority of it over water. Future sections will complete a giant circular route through the Yangtze River Delta area, creating an economic and physical beltway linking Shanghai, Ningbo and Zhoushan.

Multiple Worksites on Land and Sea

Under a $239-million contract, Guangdong Changda Highway Engineering Co. and CCCC Second Harbour Engineering Co. are constructing the Fuchimen Bridge, which connects the 2010 bridge to a new route that will travel north on Zhoushan Island. While the 1,493-meter-long connector bridge "may seem a little small" compared to the extreme spans found elsewhere in China, "it is still innovative in design," says a project spokesperson. Inverted Y-diamond main towers support a steel and concrete composite bridge deck, used for the first time in the area.

When it wraps up this year, Fuchimen Bridge will connect to the $2.74-billion Ningbo-Zhoushan Port Main Channel Road, which began in 2016 and is scheduled for completion in 2022. The almost 28-km project consists of three bridges, two land tunnels and five interchanges and is divided into four contracts. The southwesternmost section that begins where Fuchimen Bridge leaves off is being built by Zhejiang Communications Construction Group Co. The route traverses a mountainous region of the island and includes two land-based tunnels and half of a cable-stayed bridge and its southernmost 152-m tower.

MAP (TOP LEFT) COURTESY CCCC SECOND HARBOUR/GUANGDONG CHANGDA; ORIGINAL MAP (TOP RIGHT) GOOGLE MAPS © 2019 SK TELECOM; SCHEMATIC SEQUENCE (BOTTOM LEFT) COURTESY CHINA STATE CONSTRUCTION BRIDGE CORP.



From there, China State Construction Bridge Corp. picks up with its section, employing dozens of ships and temporary platforms to construct the longest over-water segment of the main channel road. It includes 5.3 km of main roadway and a 4.5-km interchange and spur road that will connect to the small but important port island of Changbai. "The construction of this section is complex in form and structure, including a cable-stayed bridge and a maritime interchange with the highest degree of assembly," says Cao Haiqing, project manager with China State.

To add even more complexity to what's already an unusual high-wire act of engineering, Haiqing's team will build the northern half of the cable-stayed bridge and tower and will be responsible for installing the final deck section to connect its half with the one built by Zhejiang. "It is very unusual [to have two contractors build either half], but we have a monitoring system between the contractors and the design is very precise," Haiqing says.

The bridge foundations for the piers and towers feature some of the longest steel pipe piles used in the world, according to China State. The 1,384 obliquely inserted 2-m-dia steel pipe piles extend 109 m through 36 m of ocean and a thick layer of seabed muck before reaching bedrock.

China State contracted with consultant Tianjin Tianhe-Cloud Building Engineering Technology Co. to provide modeling and analysis on the job. By combining seabed elevation models and borehole measurement data with the pile and foundation BIM model, Tianjin Tianhe optimized the insertion sequence for the multiple steel pipes needed for each foundation to prevent each subsequently installed pile from damaging or distorting the previous piles, says Jin Yangshuo, BIM senior engineer.

Hostile Environment

At 1,643 m, segment three (see map), being built by Road & Bridge East China Engineering Co. over the main navigable channel, will provide the port road's visual centerpiece. Two main cable-stayed spans—each 550 m long—will allow 100,000-ton oil tankers to navigate below in either direction at full tide. Twin 187-m secondary spans and 78-m side spans form the approaches connecting to two other segments.

Crews are currently installing the seven piers required for the bridge foundation. Because of the time-consuming boat rides required to access the mid-ocean jobsites, the contractor constructed living quarters on temporary work platforms at each pier where crews live and work for two-week shifts. When conditions are unsafe, such as during the six typhoons that hit the area last year, "personnel and machinery are evacuated from the con-

10

THE SEQUENCE, STEP BY STEP
While techniques vary from segment to segment, each contracting team follows a similar sequence. (1) Pile-driving ships install steel piles deep into the ocean floor. (2) A ship-based crane hoists a prefabricated anticollision steel box into place. (3) Workers then install a preassembled rebar cage into the steel box. A BIM model precisely guides workers to assemble the cage in a factory setting. (4) Once pier cap concrete is placed, workers begin to build up the pylon. (5) A tower crane is fixed to the pylon, and hydraulic climbing formwork begins to form the vertical shape. (6) Curvature of the pylon is attained from adjustable curved templates. (7) The upper steel box beam is installed on the pylon via a floating crane. (8) Subsequent steel box beams are installed using cantilever hoists. (9) Final closure will be achieved by lifting the final middle-span section. (10) The completed Ningbo-Zhoushan Port Main Channel Road will include two navigable channels and a mid-ocean interchange.

RENDERING (BOTTOM) COURTESY ROAD & BRIDGE EAST CHINA ENGINEERING CO.

REACHING CLOSURE
The Fuchimen Bridge, set to wrap up construction this year, features a 340-m-long center span high enough to allow ship navigation below.

MITIGATING STORM RISK Because worksites in the open sea get walloped by typhoons (top), contractors must keep workers safe. A simulation room (middle), with a motion platform, heavy-duty fans, mist, strobe lights and a 3D movie shows a worst-case typhoon, to give workers a taste of what could happen if they didn't seek safety. Extensive prefab factories (bottom) allow workers to pre-assemble most of the bridge's superstructure.

PHOTOS: (LEFT, CENTER RIGHT AND LOWER RIGHT) BY SCOTT BLAIR FOR ENR; (TOP RIGHT) COURTESY ROAD & BRIDGE EAST CHINA ENGINEERING CO.

struction site to a designated safe place," Junbo says. Because of the hostile environment, "the effective operation time of the project is very short. For example, only 13 days in January 2017 could be used for work," he says. Only about 190 days per year offer weather clear enough for work. In addition, tides swing up to 3.67 m and wave heights can reach 4.5 m. Currents are strong, flowing up to 2.8 m per second.

To date, there have been zero incidents or injuries on the road's over-water sections, according to Junbo and China State's Haiqing.

Factory-Based Assembly

The hazardous conditions led contractors to collectively build extensive on-land prefabrication factories that produce much of the superstructure, with modules then shipped to the work platforms for final assembly.

At the upper end of the size scale, workers prefabricated 42-m-long, 10-m-thick anticollision steel boxes to create the frames for mass-concrete platforms at the bridge pylons. Each box weighs 2,200 tons and has two rings. Fully preassembled inner rings are transported to the jobsite by boat and hoisted into place by a 2,600-ton floating crane (see cover). After the outer box ring is assembled on site, workers install a fully assembled rebar cage that fits around the tops of the foundation piles. To verify the feasibility of such a precise installation, BIM technicians at Tianjin Tianhe created a refined steel bar model and found 21 collision points. As a result of the BIM analysis, the team was able to correct 120 drawing faults and 624 collision points, which shaved off 50 days on pile construction work, according to Tianjin Tianhe's Yangshuo.

Workers place 6,135 cu m of concrete into each box around the rebar cage to create a pier cap. Locations of temperature sensors embedded in the concrete are synced with the BIM model and alerts are sent to managers' cellphones when temperatures rise too high. Computer controls can also automatically open condensing system valves to cool the concrete interior.

QR codes assist with tracking assembled components. Workers can also use their cellphones to scan QR codes via WeChat (China's popular social media app) and watch animations of how to perform the day's work.

Grand Scale

The scale of work being performed simultaneously pushes the limits. On its segment, Road & Bridge crews drill concrete piles up to 3.5 m in diameter and 134.5 m deep for the three tower foundations. Assembled rebar cages are lowered into the holes and 1,200 cu m of concrete forms each pile. Once the cap and anticollision steel boxes are installed, work will begin on the elegantly curved 180-m-tall pylons, designed to mimic two hands held with palms together in honor of the area's Buddhist history. Hydraulic climbing formwork creates the curve via a patented "integral adjustable curved surface template."

Where the main channel road terminates, Zhejiang Communications Construction Group Co. holds a separate contract for the Yushan Island project to construct an 8-km-long spur to Yushan Island. The contractor says this project is the first in the world to use segmental erection on steel-concrete hybrid girders and to use supersized 5-m-dia, 148-m-long steel-tube composite piles, instead of multiple-pile groupings, to help reduce construction time by 40% and cost by 30%. Crews spent three months building a modular 7.8-km continuous trestle system to ease transport of construction equipment, personnel and material in the harsh marine environment and increase the number of viable work days. Together, these steps reduced the construction schedule to just 27 months.

With the Ningbo-Zhoushan Port now the busiest in the world in terms of cargo tonnage, the fast-track effort to build the bridge network and, in the future, connect the roadway north to Shanghai forms a critical backbone for economic growth in the region. ■

Reported with the assistance of Construction Times, Shanghai

COVER STORY
EXTREME CONSTRUCTION
PART TWO OF A SERIES

THE CONSTRUCTION RESOURCE

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Engineering News-Record

AUGUST 19/26, 2019 ▪ enr.com

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)

A bnp media PUBLICATION

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.

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 a maximum of 26% on the existing pass to just 6.7% 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

PHOTO COURTESY BBT SE

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.

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.

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.

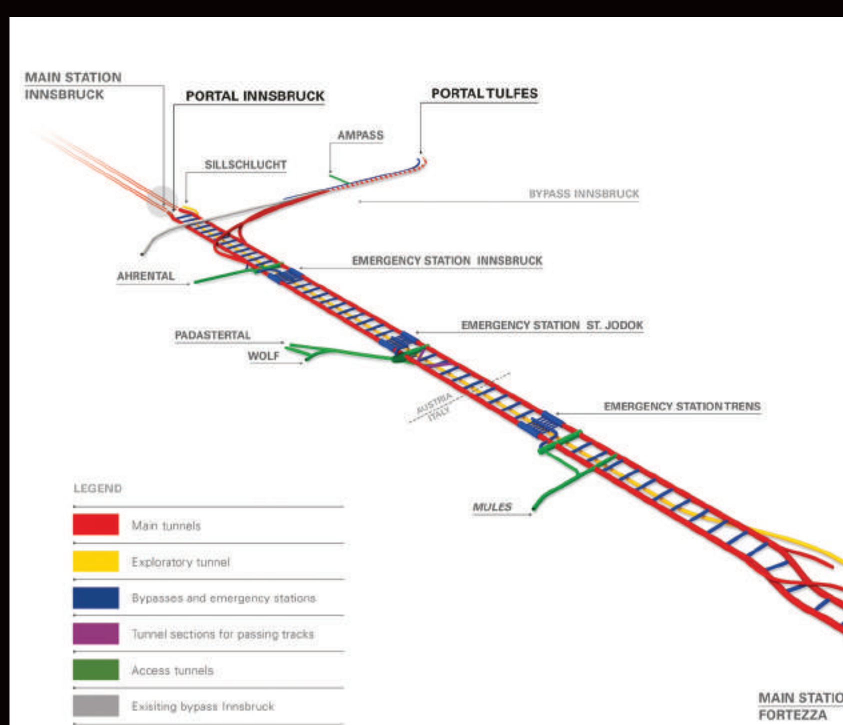
Once lined, the parallel HSR tunnels will each have a diameter of 8.1 m and the distance between them will vary from 40 to 70 m. Side tunnels will connect the main tunnels every 333 m, to be used for maintenance access and emergencies. In between the main tunnels and about 12 m below them, a 6.8-m-dia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

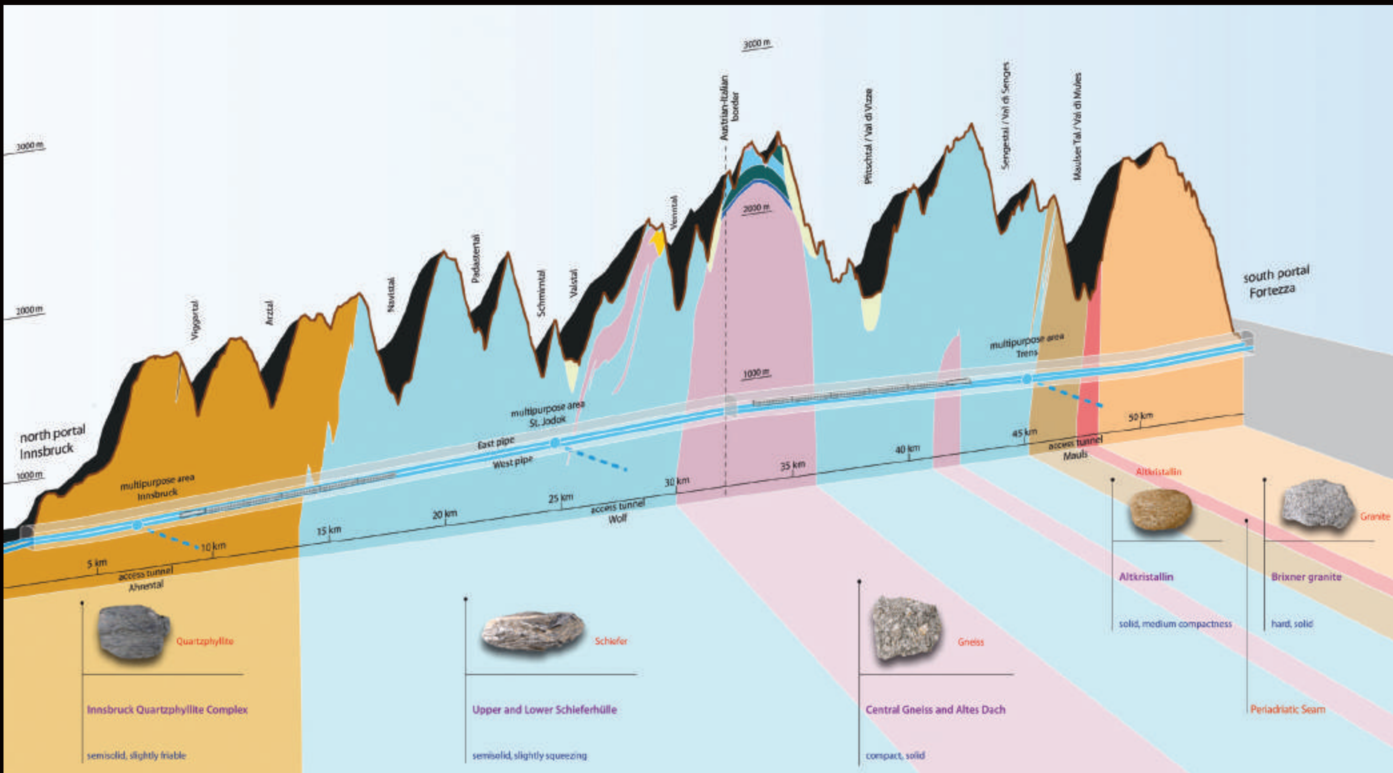
In total, 5.5 km of tunnels have been excavated at Mules using drill and blast or machinery, including a southbound segment which the contractor proceeded with during the lengthy TBM assembly period.

At the World Tunneling Congress (WTC) in Naples, held this May, Zurko 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, Zurko 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.

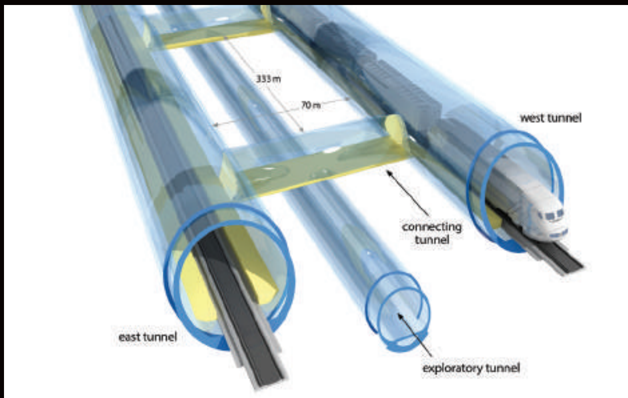
Just north of the river, the twin tunnels expand to their widest spaces at 275 sq m each to accommodate a bifurcation that splits off a rail interchange from the main HSR tunnels. As a result, crews must construct four tubes that will pass underneath the river as well as under two major roadways on one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

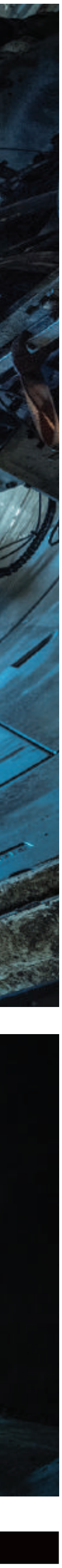
Local and International Outreach

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)

"EVERYONE IS A FORMULA ONE DRIVER AT HEART"

—MATTEO ORTU, PROJECT MANAGER WITH ACCIONA/GHELLA JV

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, 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.

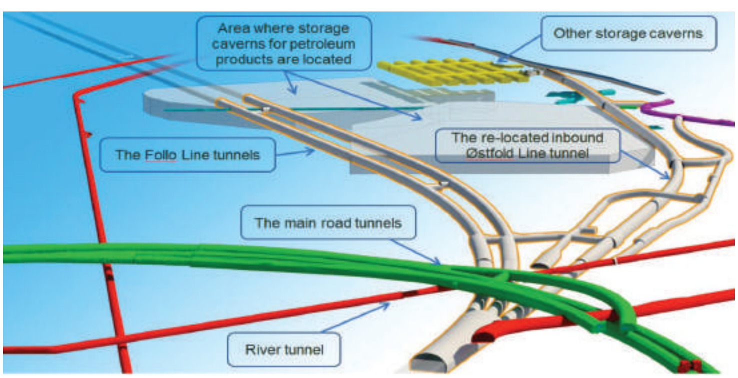
The Follo tunnels are made permanently watertight by the segmental lining erected immediately behind the rear shield and grouted to fill voids in surrounding rock. But additional precautions were also needed. Because rock along the tunnel was known to contain clay-filled valleys above fracture zones, 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.

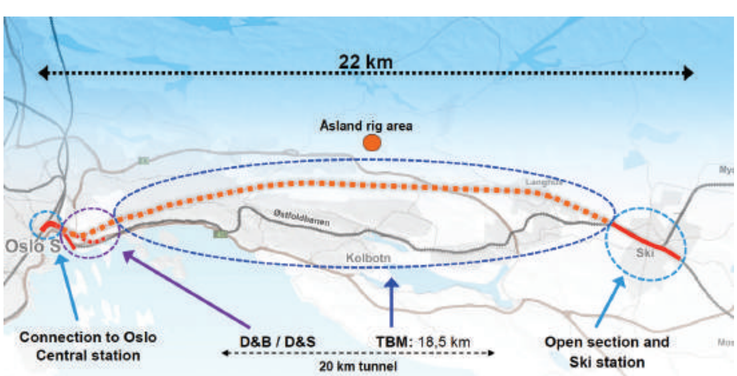
The contract forecast 1,600 m of total pre-grouting, with provisions for time and budget compensation for more difficult conditions. "We did about 7,640 m," says Fabio Moizo, AGJV's technical manager. "In general, when water was not encountered, (the TBMs) performed very well," he says.

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





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

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." ■

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

PHOTOS COURTESY HERRENKNECHT