

Port Of Miami Tunnel Project Features Big Challenges

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[By Aileen Cho and Scott Judy in Miami](#)



Photo by Daniel Azoulay/Courtesy of Bouygues

Harriet's cutting face is positioned for west-bound excavation of the second tunnel as workers prepared to re-attach its trailing equipment, which still sat in the newly excavated east-bound tunnel in Miami.

When the 2,000-ton cutterhead of a tunnel-boring machine named Harriet made a U-turn last summer in Miami, the event marked a major turning point for the Port of Miami tunnel project.

After Harriet broke through the end of one 4,200-ft-long, 42.3-ft-dia tunnel under Biscayne Bay last July, crews with the design-build team, led by Bouygues Civil Works Florida, used a giant Teflon turntable to rotate the TBM's cutterhead and shield in preparation for boring a twin tunnel in the opposite direction.

The feat is one of many milestones and firsts for the \$663-million construction portion of the \$1-billion project, now more than halfway complete. When done, the tunnels will provide new access to Miami's port and ease congestion in the region.

Complex geology and a congested urban setting continue to challenge the design-build team as it constructs cross passages and completes tunneling through eight different layers of earth using both the earth-pressure-balance method (EPBM) and water-controlled pressure, also called hydraulic mucking.

"This is the first time that a large-diameter tunnel has been bored through coralline limestone," says Louis P. Brais, project executive with Bouygues, whose French parent company has an equity stake in the public-private partnership (P3) financing. The limestone—found in the seventh layer, approximately 80 ft to 110 ft deep—is extremely porous and unstable.

The concrete for the tunnel, which, when completed, will allow some 16,000 daily trucks to bypass local streets and directly access Port of Miami from Interstate 395 and I-95, is expected to last 150 years. It is the first tunnel in the U.S. with a passive fire protection system: concrete panels specially treated for fireproofing, says Trevor Jackson, chief executive officer with MAT Concessionaire LLC. MAT will maintain the untolled tunnel and receive performance-based availability payments—as much as \$32.5 million annually—until it hands the operations back to the Florida Dept. of Transportation in October 2044.

Meanwhile, the concessionaire stands to earn as much as \$450 million for completing five construction milestones, with the final one to come in August 2014 upon final acceptance, says Mark Croft, Florida Dept. of Transportation construction program manager.

Mystery Layer

Wedge between Miami's downtown and the famous Miami Beach area, the project squeezes in between the MacArthur Causeway and two man-made islands, Dodge Island and Watson Island, which also serve as its portals. Before beginning the east-bound launch from Watson Island, the design-build team embarked, in 2010, on an extensive supplementary geotechnical investigation that lasted 22 months, says Bouygues' geotechnical director, Roger B. Storry.

"It was difficult for us to get samples of this [seventh] layer," Storry says, referring to the worrisome coralline limestone. The investigation was so extensive, "there was a hole approximately every 32 feet," he says. "It took that much to understand the nature of this layer." The team performed a variety of tests, including ultrasonic, cone penetration, rock coring, permeability and water flow, and camera log surveys. In addition, crews sank five 8-ft-dia shafts to the lowest point of the tunnels, at 120 ft.

The team not only investigated all the permutations of the eight layers at various locations in its on-site lab but also sent to European labs the soil samples, Biscayne Bay seawater and the grout mix it developed, says Storry.

Nicholson Construction Co. won the approximately \$40-million contract in 2011 to fill voids in the seventh layer with the bentonite-rich, weak-strength grout, says Storry. "The grout is like a toothpaste—thick, to prevent it from flowing away," he adds. At Watson Island and on a flotilla of barges that had to work around the schedules of ships entering the port, crews drilled 1,000 holes as deep as 120 ft and injected 65,000 cu yards of grout to stabilize the layer.

In her journey, Harriet—named by Miami-Dade County Girl Scouts for Harriet Tubman, the Underground Railroad heroine—had less than 22 ft of buffer above her and below the highway. She had to travel down, at most, a 5% grade—at one point mere feet from the bottoms of port facilities and ships. The route's only flat, straight section is at the very bottom and runs for about

eight feet, says Brais. Bouygues decided to lengthen the tunnel alignment by an extra 150 ft at each end, so that Harriet could avoid the hard-rock layers. Bouygues also value-engineered the tunnels' two launch boxes into one.

Of the need for lengthening, Brais says, "We could not excavate layer five [a hard limestone] under water, and we had no lateral access to the box on Watson Island—there are highway lanes on each side." Thus, at the start of tunneling, the TBM's topside would be above ground. To provide sufficient cover for Harriet, crews built a 17-ft-high overburden of roller-compacted concrete pad combined with a geogrid for the first 400 ft.

Due to the longer alignment, the two tunnels come within 15 ft of each other at the ends. Launch shafts could not have slurry walls due to the weak and permeable layers, nor sheet piles due to the strong layers. So, the team opted for cutter soil mixing (CSM), in which paddles rotate to mix cement and soil.

San Francisco-based Malcolm Drilling Co. won an approximately \$40-million contract to build a temporary excavation support system of steel-reinforced CSM walls, combined with a 5-ft-thick tremie seal slab reinforced with 160-ft-long tiebacks. The 9-ft-long, 4-ft-wide CSM panels create a 3D tic-tac-toe-like grid, says Joe Folco, Bouygues commercial manager. The holes within the grid are filled with 12-ft-dia unreinforced secant piles. Monolithic, watertight walls resulted. Down to 120 ft, it is the deepest-ever application of CSM, officials say.

In a compressed-air chamber—necessary when working deep under water—crews periodically inspect the cutterhead for wear and tear. Because of the extremely porous ground conditions, the "hyperbaric interventions were very challenging," says Brais. "Early on in the east-bound launch, we attempted it 16 times. We could not develop the confinement area for the compressed air we needed, so we looked at the CSM technique again." Harriet's cutter face is submerged in CSM "refuge" blocks at about 700-ft intervals, so crews can safely conduct inspections without water intrusion and water pressure.

In EBPM tunneling, a screw conveyor ingests the excavated material and excretes it onto a conveyor system, which takes it out of the tunnel. However, when digging through the infamous coralline-limestone layer, the material is discharged into a 12-in.-dia pipe, then impelled out of the tunnel by the pipe's water pressure, says Folco. Outside, machines separate the coarser materials from the finer sands, remove the silts and produce dried-out cakes of the coralline limestone. Expected to total 400,000 cu yd, the muck is trucked away at night, for use in parks and landfills.

About a third of the construction consists of above-ground work, says Brais. To make room for the plant area, which includes concrete batch mixing for the 12,100 precast tunnel-lining segments, the team rebuilt a MacArthur Causeway bridge span 100 feet out. Furthermore, the team is building lanes to take dedicated port traffic directly to and from the interstate highways.

Durability Debate

From the beginning, the main design requirement for the concrete was durability, not strength. But since no design standard existed for the 150-year life span mandated by the contract, Bouygues and FDOT had to figure one out. "The issue is, how do you prove 150 years?" says Mark Scott, Bouygues quality and environmental manager. "There's nothing in the codes."

Victor Ortiz, an FDOT consultant from CSA Group, says FDOT relied heavily on a model sponsored by the American Concrete Institute that assumes corrosion of reinforcing steel from chloride ingress as the main cause of degradation. Ultimately, the Bouygues team based its design on the DuraCrete/DARTS system, which considers a wide range of factors related to items such as chloride ingress, depth of concrete covering the reinforcing steel, curing, temperature and age. Scott says this system uses the Monte Carlo method of running thousands of repeated calculations.

"In Europe, I guess they're more aggressive on their designs," says Ortiz. "But we were able to come to an agreement by sharing our experience on the current environment with their innovative design." The resulting mix includes cementitious substitutes fly ash and slag to aid durability, says Scott. For strength, FDOT required 6,000 psi at 28 days; the contractor says it is achieving roughly 9,000 psi.

Depth of concrete cover was another debate. FDOT wanted each 2-ft-thick panel to have three inches of cover over the reinforcing steel—about twice the depth Bouygues thought necessary. The 3-in. cover is "more than what we're accustomed to doing, and it brings an uncertainty into the segment erection process," says Scott. "Three-inch cover on segments is not common." Scott says Miami was the first time but adds that other owners have since asked for the 3-in. cover.

Bouygues and FDOT also debated whether to tie or weld the rebar cages. "We typically weld the reinforcing steel to get very tight tolerances," says Brais. "In the contract, FDOT said no welding—tie them. We tried to convince them, but ultimately we tied them. We've gotten very good results."

In placing the 13-ton concrete panels, Bouygues has to account for the varying patterns within each tunnel ring. Each ring has five standard segments, one key segment and two counterkeys. "Our software is constantly predicting how the ring should be aligned," says Scott. A vacuum-equipped segment erector picks up each panel and rotates it into place. In all, it takes about one hour to erect one ring. Scott says the contractor is averaging about eight rings a day.

It took two months of preparation to turn Harriet after she finished east-bound excavation. Crews scrambled to complete a 32-ft-dia, 5-ft-high, 120-ton Teflon disc to carry the 2,000-ton shield, which was detached from its 361 ft of trailing gear, on its 9-day, 180° spin. Then, crews reattached her gear for west-bound excavation, which took another two months, according to Falco.

In the meantime, CSM is being used to pre-treat three of five cross passages. The other two could not receive CSM panel reinforcements due to their locations in the water. For those two,

Bouygues is using artificial ground freezing. The risk is that, "after freezing, when it thaws out, collapse is possible," says Brais. "Then, you would have concentrated, irregular loads on the tunnel lining. So, the object is to freeze a ring around the perimeter, not a solid block. We create a six-foot-thick ring and mine inside it."

For each passage, 44 pipes are installed to inject the earth with freezing brine. Steel support frames protect the two main tunnels' segmental lining from potential deformation due to the pressure of the frozen ground in the cross-passage area. It takes about a month to freeze the ground enough to begin mining the cross passage. After about two months of excavation, the ground will be thawed out over several weeks.

A temporary lining of steel arch ribs and shotcrete supports the passage during construction, then is replaced by permanent cast-in-place concrete. A steel door is installed so that, if something goes wrong, workers can seal off the cross passage and keep water from entering the main tunnels.

Mechanical-electrical work began in March. Brais expects to add another 150 workers on-site in June for more than 600 total. Tunnel tests begin in December. So far, all has gone well. For example, the team boasts good community relations and no major injuries through almost three million man-hours.

"Right now, what wakes me up in the morning is the schedule," Brais says. After Harriet's work is done, "there's a lot left to do."

A GIGANTIC TURNAROUND FOR A GIANT TUNNELING MACHINE



Crews slid Harriet's "head" off the body of trailing gear and onto a Teflon turntable that slowly rotated it around to face the opposite direction. Then, the trailing gear was re-attached, and tunneling began again.

