



SOLUTIONS FOR SOFT SOILS

Because of poor soils, high water tables, and high wind and hurricane loads, deep foundations and basements in southeast Florida have been virtually impossible, limiting the heights of towers in cities like Miami. But thanks to contractor innovations—including cutter soil mixing, deep soil mixing, and continuous flight auger megapiles—robust underground support is now possible, and towers in and near Miami are rising.

BY ALEC BLOEM AND NICK TURUS, P.E.

DESIGN ENGINEERS often take the lead in developing innovative building solutions to accommodate nature's forces. However, advances in construction techniques can also open up new design possibilities. A design alternative that might have been

impractical a decade ago may now be the optimal choice because contractors have perfected new construction methodologies.

Such is the case for foundation construction in southeast Florida, a region plagued by high groundwater and high hurricane-force wind loads. Heavier and more specialized equipment, operated by experienced constructors, enables cost-effective strategies to deal with Mother Nature's forces and difficult site conditions.

From 1990 to today, Florida's population has grown by 8 million, making it the third-most populous state in the nation. Miami's skyline has grown dramatically taller over that period as well, providing housing and workspace for half a million people, not to mention million-dollar views. Real estate is at a premium.

Tall buildings have always required robust foundation systems designed to support very heavy compressive loads and resist uplift and lateral forces caused by wind and seismic forces.

Deep soil mixing techniques enabled a multistory below-grade parking structure to be built for Brickell City Centre—a first in Miami.

Furthermore, foundations and below-grade construction can represent a significant percentage of the overall building cost. New construction techniques are now bringing down the cost of such foundation systems and enabling below-grade real estate to be cost-effectively utilized like never before.

THE FLORIDA PLATFORM

Miami is perched on the eastern edge of the Florida Platform, a regional geologic feature with an escarpment that plunges deep into the Gulf of Mexico on the west. The platform's deep bedrocks are predominantly igneous, sedimentary, and volcanic. On top of those ancient formations sits a porous plateau of karst limestone, and on top of that is sandy soil.

The subsurface soil profile for a foundation for a typical tall building in Miami shows sand with occasional silt, clay, and peat layers overlying or interbedded into the underlying limestone formation. The limestone varies from very weathered to fractured to relatively solid and competent.

Additionally, as anyone who has ever visited Florida knows, there is water everywhere: in the ocean, gulf, bays, lakes, ponds, lagoons, canals, ditches, and swales—and also in the ground itself. The groundwater table is typically just a few feet below the ground surface and water flows easily through the permeable sands, voids, and cracks in the karst limestone.

Florida's beachgoers and sand castle builders experience firsthand the same challenges that contractors face when contemplating building a deep excavation. Shovels-full of wet sand are tossed to one side, while water and saturated sand flows, or caves, right back into the hole. Water rises to create a puddle. The digging begins again, much to the hole digger's delight.

To contractors, on the other hand, high groundwater is more serious. In the past, to handle excavations in high-groundwater conditions, contractors have typically launched a two-pronged approach. First, build a wall or barrier, such as a sheet pile or slurry wall, to stabilize the excavation and slow the flow of groundwater. Second, install and operate a dewatering well network around the excavation to draw down the groundwater levels.

Pumping groundwater is not only costly but also is sometimes unpredictable and potentially has unintended consequences. During initial planning stages contractors and engineers must estimate not only how much water must be pumped from the excavation but also how much water can be disposed into discharge wells on-site. If these rates are underestimated, there will be delays in the project schedule as contractors adjust their construction plans on the fly. If dewatering is successful on the initial drawdown, pumps must be maintained around the clock to prevent the excavation from being flooded, which could potentially damage waterproofing before concrete is placed. Dewatering may also cause the surrounding soil to shift

and settle, potentially causing damage to nearby buildings, roads, utilities, and infrastructure.

For these reasons, many southeast Florida developers and designers simply avoid deep excavations altogether. In other parts of the country, parking or other useable spaces are routinely built below buildings, but in southeast Florida, basements are scarce, and aboveground parking garages are installed on nearby real estate. Elsewhere, underpasses can be built for roads and grade separations—not so in southeast Florida.

But there are solutions that are making basement levels possible under such conditions, even in southeast Florida.

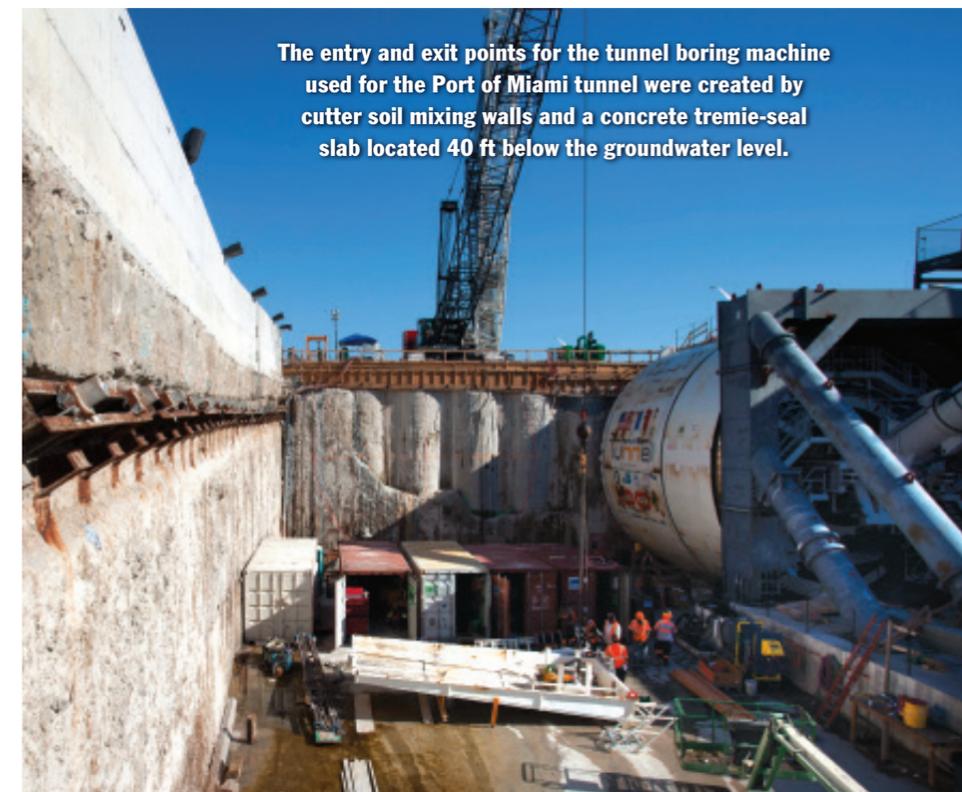
PORT OF MIAMI TUNNEL

One example comes from the Port of Miami twin tunnels completed in 2014. Most of the Port of Miami's facilities are on Dodge Island, located in Biscayne Bay between downtown Miami and Miami Beach. Nearly 16,000 vehicles—about a third of them trucks—travel to and from the port each weekday.

Before the tunnel project, that traffic traveled local streets. To reduce congestion, improve safety, and keep the port economically competitive, the Florida Department of Transportation (FDOT) commissioned two 42 ft diameter tunnels, each carrying two lanes of traffic, between Dodge Island and nearby Watson Island. The tunnels provide a direct connection from the port, via the MacArthur Causeway on Watson Island, to Interstate 395 on the mainland. (Read "Progress for PortMiami" in *Civil Engineering*, November 2014, pages 50–57.)

Tunnels are routinely built below the groundwater table and are installed to be relatively watertight. The tunnel boring machine (TBM) starts and ends its work from launch and retrieval pits, which must also be dry. For the Port of Miami tunnels, the launch pit walls could not be built with slurry walls because of the weak and permeable sand layers. Sheet pile walls were out of the question because it would be difficult to drive them through the strong limestone layers. Therefore, the contractors—Malcolm Drilling, headquartered in San Francisco—opted to use a combination of cutter soil mixing (CSM) and deep soil mixing

The entry and exit points for the tunnel boring machine used for the Port of Miami tunnel were created by cutter soil mixing walls and a concrete tremie-seal slab located 40 ft below the groundwater level.



(DSM) techniques to build a temporary excavation support system of steel-reinforced CSM walls.

CSM uses large counter-rotating cutter wheels to advance vertically into the underlying soil and rock, while concurrently injecting cement through the cutter wheels. DSM typically uses a single large-diameter mixing tool that rotates as it penetrates the underlying materials, also injecting cement through the mixing tool. The native material and cement are blended to form a low-strength, mortar-like column (DSM) or rectangular panel (CSM).

Malcolm Drilling elected to build the excavation side-walls (parallel to the tunnel alignment) using CSM. The bulkheads (perpendicular to the tunnel alignment) were installed using a combination of CSM and drilled shafts. More than 400 CSM panels, each 39 in. wide and 9 ft long, were constructed for the walls to an average depth of approximately 50 ft. Sequential panels were overlapped to form an impervious, continuous wall around the perimeter of the excavation. Steel soldier piles were embedded at regular intervals into the wet mortar before it cured to provide lateral structural excavation support. Tiebacks were installed at the top of the wall to provide additional lateral support.

The bottom seal of the excavation was created using a conventional tremie seal. The tremie seal was constructed using a combination of large excavators, long-reach excavators, and clamshell buckets to excavate to the underside of the tremie slab. After excavation to the appropriate depth, divers prepared hold-down piles for embedment into the tremie slab and cleaned the excavation edges and the bottom of the excavation. Finally, an extended, continuous concrete placement was made to form the base and join the CSM walls with an impermeable bottom seal.

Groundwater is within a few feet of the ground surface at this location; the deepest excavation was 50 ft, and the lower 40 ft of excavation was below the water table. Together, the walls and floor held back the groundwater until a permanent concrete wall and hydrostatic slab could be placed.

BRICKELL'S BASEMENT

Over the past decade, downtown Miami has undergone a stunning transformation, from blight to beauty. Brickell City Centre, a 4.9 million sq ft, mixed-use development, was at the vanguard of a redevelopment wave that continues today.

Brickell City Centre spans 9 acres along South Miami Avenue between SE Eighth and Sixth Streets, in the Brickell District of greater downtown Miami. The complex contains residential condominiums, offices, high-end shops and restaurants, a hotel, cinema, and other amenities. The tower portion is 500 ft tall.

While the aboveground construction is remarkable, the underground construction represents a phenomenal industry advancement, opening up a huge untapped resource: valuable below-grade real estate. Two levels of below-grade parking were installed at the project, representing the first two-level commercial basement in southeast Florida.

Malcolm installed Brickell City Centre's perimeter wall using almost 800 overlapping 6 ft diameter DSM columns spaced 4 ft apart on center, extending to an average depth of

roughly 30 ft. Steel sheets were inserted into the columns to support the excavation and provide a watertight barrier.

The base of the excavation was sealed off across three large city blocks by installing nearly 8,000 overlapping 9 ft diameter DSM columns spaced 7 ft apart on center to create a plug. Together, the walls and plug created a "bathtub" structure, one of the first ever to be built this way in North America and perhaps the largest ever built, spread out over a five-city-block footprint. In total, more than 125,000 cu yds of DSM were installed for the plug.

The parking structure was then built within the dry bathtub; this represented a completely new approach to building in southeast Florida. Additionally, 2,406 continuous flight auger (CFA) piles, ranging in diameter from 18 to 36 in., were installed for the building foundations. These also resist uplift pressures on the DSM plug.

START OF A TREND

Many new buildings are now built in southeast Florida using these techniques, including Jade Signature, a 57-story residential tower in Miami, which has three levels of below-grade parking. For Jade Signature, the excavation was 43 ft deep, but the DSM columns extended another 14 ft beneath the bottom elevation to withstand groundwater uplift pressures. Deep CFA foundations for the building itself were drilled directly through the plug to depths of up to 100 ft into southeast Florida's limestone bedrock.

More than 1,600 CFA piles with diameters of 18 and 36 in. were installed. The 18 in. piles were used to support the structure and provide additional uplift resistance to the water pressure below the plug.

Partly as a result of these new techniques, tall buildings are getting taller in Miami, placing even more demand on the foundation systems. Structures up to 900 ft tall are becoming common; SkyRise Miami, planned to reach 1,000 ft, is currently under construction, and more of this height are planned.

Historically, driven precast concrete piles were one of the preferred methods of pile installation in this region. This technique is still typically what FDOT, for example, specifies for its projects. CFA technology has been around since the 1970s; however, more powerful and sophisticated drilling equipment, coupled with the development of higher-strength concrete and grout mixes, has enabled piles to be constructed at larger sizes and to greater depths than ever before. CFA techniques are now being adopted for tall buildings across Florida and North America.

These CFA megapiles, as they are called, vary from 24 to 48 in. in diameter and can be installed to depths of 180 ft. To install a CFA megapile, a continuous auger drills to the desired depth. As the auger is extracted, very high-strength grout (up to 9,000 psi) is injected under pressure through the auger's hollow shaft. A reinforcing steel rebar cage is then inserted into the wet grout after the auger is removed. This creates a continuous pile without ever leaving an open hole.

The CFA megapile system is extremely fast and efficient, leading to substantial decreases in the cost and schedule for deep foundations. Installing CFA megapiles generates little or no vibration and is relatively quiet compared with

For Jade Signature, a 57-floor condominium tower adjacent to Biscayne Bay, excavation reached a depth of 43 ft. Deep soil mixing columns extend 14 ft beneath the bottom elevation, and continuous flight auger piles were driven to depths of up to 100 ft.



driven piles, a definite plus when constructing in urban environments.

Malcolm has built CFA megapile foundations for several high-profile high-rise buildings in southeast Florida, including Elysee Miami, X-Las Olas, Miami Worldcenter, Park Grove, and Brickell Flatiron.

Elysee Miami, a new 57-story, 650 ft tall, luxury condominium built on the waterfront in the East Edgewater section of Miami, has only 100 apartments—two large and luxurious units per floor. Each unit has a magnificent view of Biscayne Bay.

Still under construction, Elysee Miami will rest on 261 CFA megapiles, each typically 36 in. in diameter and installed to depths of 121 ft. The piles were heavily reinforced with up to 24 #11, grade 75, vertical rebars and 8,500 psi grout to support compression loads of 1,430 tons and tension loads of 515 tons. These high capacities were possible because of load-transfer values of up to 14 ksf in the limestone.

The CFA megapile drilling system can readily accommodate southeast Florida's stratigraphy—silt and sand—that would otherwise have a tendency to collapse into any holes. And southeast Florida's limestone is riddled with joints and holes. With traditional drilled-shaft construction using support fluid to hold the hole open, the fluid could be lost if it flows into a large hole or crevice. CFA eliminates this issue.

Purpose-built CFA installation equipment and 300-ton cranes with special lead attachments built for southeast Flor-

ida's difficult and deep geotechnical conditions are used to create these megapiles. The equipment can install CFA piles up to 4 ft in diameter, and 36 in. diameter piles can be installed to depths of up to 175 ft, a depth unheard of just a few years ago.

Many new buildings in southeast Florida are now being designed with multilevel basements, primarily for parking, because the DSM technique makes it possible. General contractors are very supportive of this type of construction because it allows them more certainty in their construction schedules, obviates pump breakdowns, and enables them to work in a dry pit and complete their work more quickly.

Because no external dewatering is required, budgets for this portion of a project are fixed, which reduces the risks of unforeseen project costs. And there is far less concern about damage to adjacent structures or utilities.

Of course, the risks and rewards need to be explained to owners and developers. New construction techniques may appear more expensive at first glance, but when factoring in the time and cost savings, not to mention risk reduction, overall savings in construction time, and the benefit of underground real estate utilization, there is immense benefit to using these techniques to construct belowground in southeast Florida. **CE**

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