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Malcolm Installs Excavation Support for Miami Tunnel

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MALCOLM

Provides Excavation Support for Miami Tunnel

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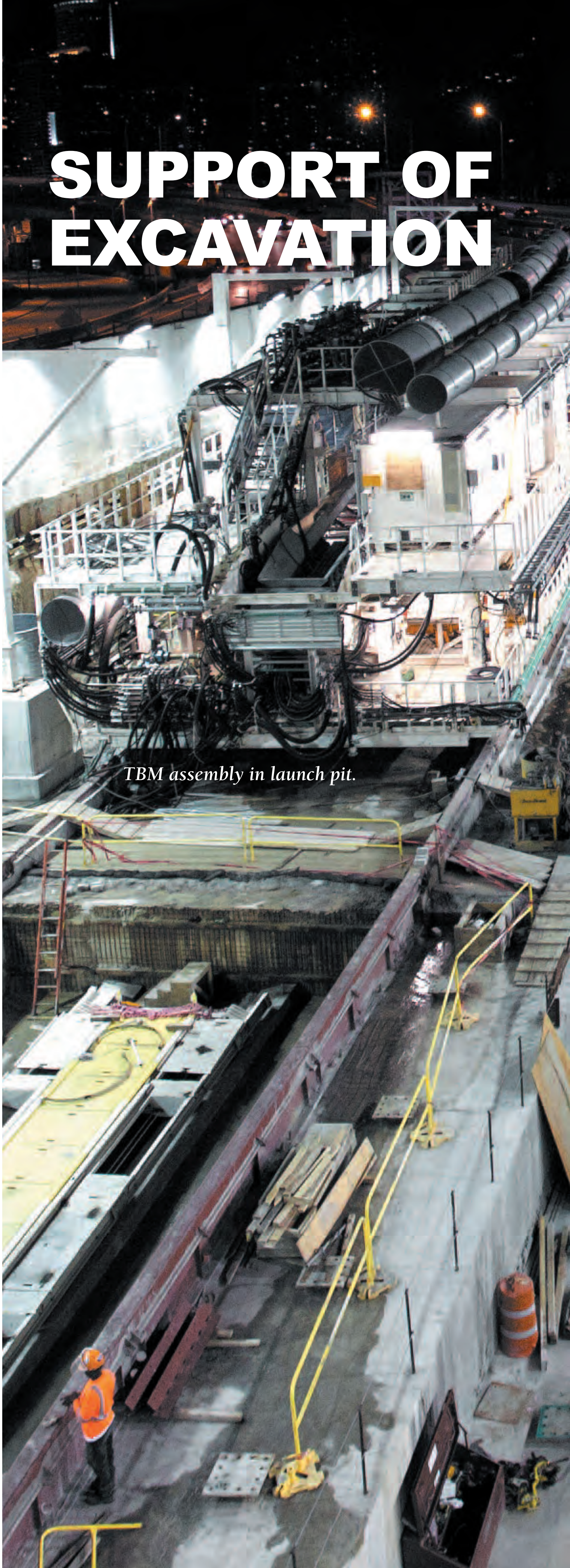
Introduction

The Florida Department of Transportation (FDOT) contracted with the Miami Access Tunnel (MAT) concessionaire group to construct two 42 ft outside diameter, 4,000 ft long tunnels with two lanes of traffic each way between Watson and Dodge Islands to alleviate commercial traffic congestion in downtown Miami. ADSC Contractor Member Malcolm Drilling Co. Inc. was selected by the Design-Builder, Bouygues Civil Works Florida (BCWF), to perform specialty foundation work for the two excavation support systems (SOEs) for the Tunnel Boring Machine (TBM) access as well as various ground improvement work to support the launch and reception of the TBM on each island. The design and construction teams worked closely together to fast-track the preparation of the design documents and drawings, incorporate the contractor's cost-efficient and preferred systems, implement the test program and construct the support of excavation elements in an expeditious manner. The TBM launched from the Watson Island SOE on November 11, 2011. It emerged on Dodge Island on July 31, 2012 where it was disassembled, turned and reassembled for its return trip to Watson Island. Mining began on October 29, 2012 and should be completed by Spring 2013.

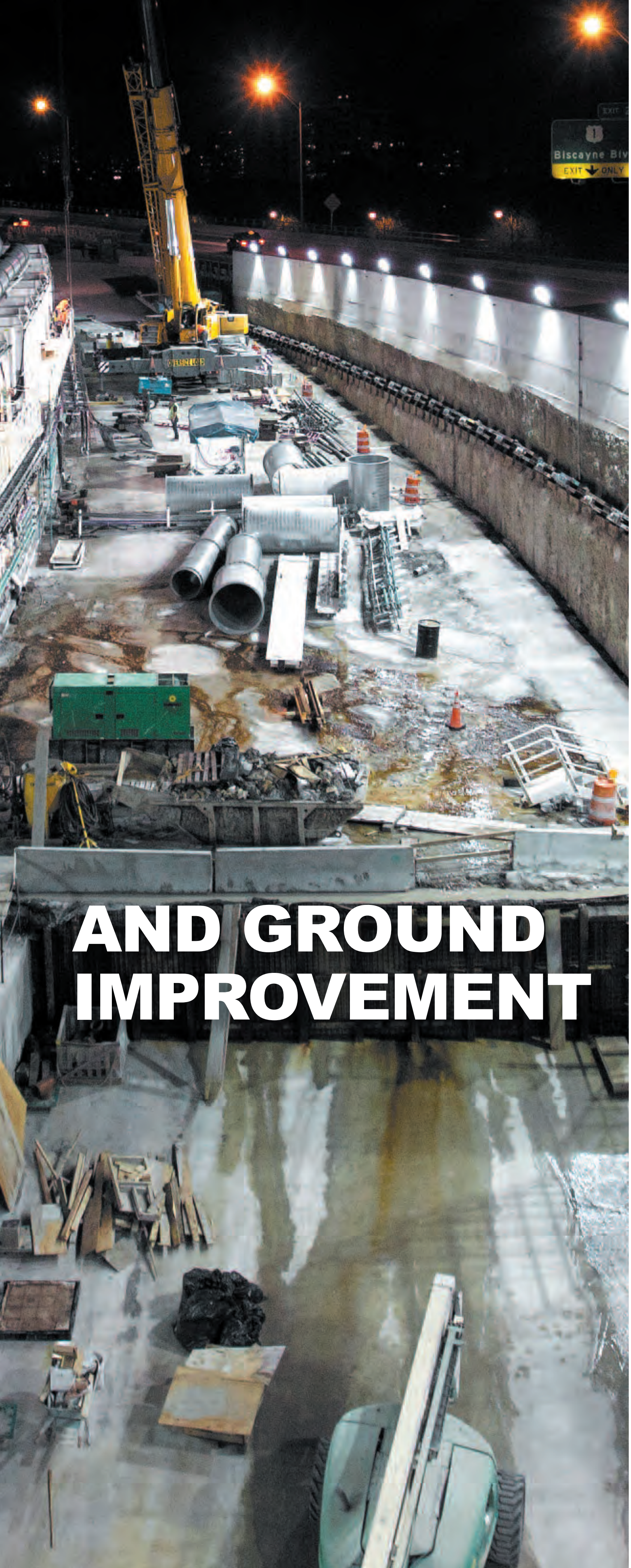
ADSC Contractor Member Malcolm Drilling Co., Inc. was selected by the Design-Builder, Bouygues Civil Works Florida (BCWF), to perform specialty foundation work for the two excavation support systems (SOEs) for the Tunnel Boring Machine (TBM) access...

To facilitate bored tunneling operations a temporary excavation support system was required to launch the TBM and allow construction of the permanent works including a U-Wall and Cut and Cover Tunnel system. This temporary excavation support system, which reaches maximum depths of 50 ft below grade and up to 40 ft below the natural groundwater level, is currently the deepest excavation to date in Miami. The excavation support system consisted of a Cutter-Soil-Mix (CSM) wall reinforced with structural steel sections, designed to serve as a lateral structural Support of Excavation (SOE) and groundwater cut-off in combination with an anchored, bottom concrete tremie seal. Additional lateral support at the top of the CSM wall was provided via pre-stressed, 5 to 9 strand, 6-in diameter

SUPPORT OF EXCAVATION



TBM assembly in launch pit.



AND GROUND IMPROVEMENT

tiebacks structurally connected to the face of the CSM panels through a system of double channel walers. Bottom tremie concrete seals anchored with a combination of H-pile reinforced 36 in diameter Cast-In-Drilled-Hole (CIDH) elements and 8.5 in diameter minipiles reinforced with 3 in diameter high-strength threaded bars were utilized to provide a bottom groundwater cut-off during construction, provide lateral support to the SOE walls at the base of the excavation, and uplift resistance in the temporary condition.

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At the break-in/break-out location for the TBM, a solid plug incorporating CSM panels and 12 ft diameter unreinforced secant piles configured in an overlapping and integral pattern was constructed immediately adjacent to the SOE system on each island as an alternate to a sheet pile and mass excavation. The TBM break in/out plug allowed the earth pressure balance (EPB) TBM to construct the sealed concrete ring segments. CSM in combination with single-axis soil mixing was used to solidify non-cohesive soils and develop a self-supporting arch above the TBM until its crown was under the first rock layer. CSM was also used in combination with single-axis soil mixing to install a maintenance chamber for work on the TBM cutter head prior to its passing below Government Cut channel. Design and construction challenges included difficult sedimentary geologic/geotechnical conditions, the associated high permeability of the subsurface materials and the high static groundwater levels, a fast-track design-build schedule and access restrictions while existing roadways were relocated. Measurements taken with inclinometers as well as periodic surveys have confirmed minimal wall and tremie seal movement well within the design criteria.

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Soil Investigation

The geologic profile on Watson Island presented a formidable challenge for the installation of the various foundation elements. Fill material with rubble overlies the native sand. Underneath the native sand, several layers of very porous, vuggy limestone serve as the bearing layer for the various foundation elements. Loss of material into the highly voided lower limestone layers was a primary concern during the design and execution of the work.

Installation Sequence

A compressed schedule required that multiple types of SOE elements be installed concurrently as the work progressed. Ini-

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Drilling of 12 ft secant piles.

tial work on the Watson Island SOE west wall was started in the 39 ft wide existing median of MacArthur Causeway in September 2010 following the test program for the CSM and CIDH elements. The narrow median necessitated close coordination between the general contractor and the specialty foundation subcontractor to allow for removal and relocation of existing utilities and the relocation of the eastbound lanes of MacArthur Causeway while work progressed on the SOE west wall, CIDH tie-down elements and the TBM plug. Installation of the Watson Island SOE East wall commenced following the relocation of MacArthur Causeway.

After completion of the SOE walls and the excavation face of the TBM plug, a dry excavation to Elev. 3 ft was performed to allow for installation of the tieback anchors. Following completion of the TBM plug, a wet excavation, was performed to the bottom of the 5 ft thick tremie seal slab. The top portion of the wet excavation was ramped at an approximately 5.2 percent grade from the bottom of tremie seal at Elev. 1 ft to Elev. 16.1 ft In order to allow for the erection of the TBM within the excavation, an 11.4 ft step was excavated prior to resuming the 5.2 percent grade to the bottom of the excavation at Elev. 35.4 ft. Minipile tie-downs were installed from a sectional barge platform following completion of the wet excavation. The tremie seal slab was then poured after careful cleaning of the SOE walls and floor of the excavation. After the tremie seal cured, the excavation was dewatered in July 2011.

Work on the Dodge Island SOE began in May 2011 and was completed by December 2011. The SOE work area on Dodge Island also was split in two halves to allow for the relocation of roads while SOE work was being performed. The sequence for Dodge Island SOE followed the same pattern as performed for Watson Island except for the elimination of the minipile tie-downs in favor of CIDH tie-downs.

Cutter Soil Mixed Wall

The SOE walls were originally designed as a combination of sheet piles in the shallow excavation and secant piles in the deeper section of the excavation. The design was revised to a cutter soil mixed (CSM) wall to reduce the number of joints and provide a smoother surface for the tremie seal thus minimizing the potential for infiltration of water. The CSM SOE wall was designed using several software programs, including Shoring Suite, FLAC and L-Pile. The design of the CSM/soldier pile wall allowed for a movement on the order of 4 in wideflanged W36 (soldier piles placed every four ft in the freshly mixed soil serve as the lateral support while the cement-soil mix serves as low permeability lagging between the soldier piles. The performance criteria for the CSM wall required a permeability of less than 1 x 10-5 centimeters per second, no more than 3 gallons of seepage per 1000 square ft of exposed wall and no flowing water. A minimum strength of 250 psi for the cement-soil was required to provide arching between the soldier piles.

BCM 10 tool for cutter soil mixing.

A 4 ft continuous flight auger (CFA) was used to process the overburden and underlying limestone layers to increase production and assist in maintaining the verticality of the CSM panels. It also confirmed the relative hardness and elevation of the limestone layer used as the primary lateral restraint. Preconstruction borings indicated that the top of the limestone layer along the SOE East Wall may have a dip in a portion of the wall. The planned tips for CSM panels were originally extended deeper to accommodate the expected dip in the bearing layer. Electronic data from the drill rig documenting the relative resistance of the soil and rock was used to confirm the limestone layer did not dip in the deep section of the SOE wall. The design team was able to quickly respond and reduce the depth of the CSM panels thus saving time and cost of construction.

Because of the expected time to penetrate through the limestone and its high permeability, a two phase technique was used for construction of the CSM panels. Low-concentration bentonite slurry was used to lubricate the cutter wheels during penetration. Based on ground losses of up to 10 ft observed during the pre-drilling, there was concern that a loss of cement slurry might occur in the highly voided limestone. The bentonite slurry effectively plugged small voids prior to the injection of cement slurry during withdrawal of the CSM unit thus assuring the cement slurry did not migrate away from the panel. No significant slurry loss was observed. The quantity of cement per cubic meter of mixed soil and volume of cement slurry were determined based on a pre-production laboratory mix design and field trial program. Only minor adjustments to the quantity of cement slurry injected during work were made based on a pre-production decision matrix.

Bauer BG50 – the largest drill rig in the world.

Tieback Anchors

Tiebacks were designed to resist an unfactored anchor load of 30 to 60 kips per linear ft of wall. Tiebacks were spaced between soldier piles from 4 to 8 ft on center. The tiebacks have free

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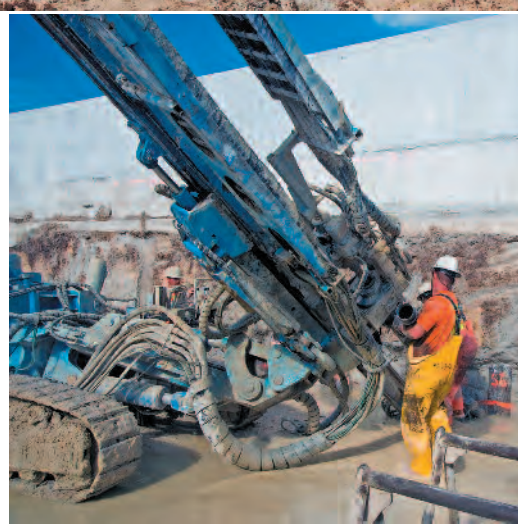
Tieback installation using dual rotary drilling.



stress lengths on the order of 100 ft through the upper four soil strata and a bonded length within the lower limestone rock layers for tieback anchorage. Based on results of initial sacrificial load test, the maximum allowable shear resistance of 8.5 ksf in the limestone layers was used to design the tieback bonded length. All performance and proof testing was in accordance with FDOT specifications. The placement of the anchor heads above the water table at Elev. 4 ft eased the construction process while maximizing the performance of the tieback. Walers connected to the tiebacks transfer the load to the soldier piles in the CSM wall to provide lateral restraint for the top of the wall.

After excavation of a 30 ft wide bench at Elev. 3 ft on each side of the SOE, (122) 6 in diameter, 5 to 9 strand, tiebacks with lengths of 110 to 140 ft were installed using a dual rotary drill rig. A down-hole hammer (DHH) was used to remove the drill cuttings while

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casing was twisted into place with the lower rotary unit. Even though geotextile socks and a thixotropic grout additive were used to minimize the amount of grout which would migrate into the highly porous limestone, grout overage averaged 400% over theoretical volume.

Tie-Down Elements

Two types of tension elements were installed to resist the hydrostatic uplift on the tremie seal and provide axial support of the TBM during its assembly. The shallow tremie seal was anchored utilizing a combination of 52, 36 in diameter Cast-In-Drilled-Hole (CIDH) elements reinforced with HP14 x 102 sections and the lower tremie seal was anchored with 8.5 in diameter minipiles reinforced with 3 in diameter high-strength threaded bars. The larger diameter CIDH elements were selectively utilized in the permanent structure as well to provide resistance to uplift for the permanent U-Wall and Cut & Cover Tunnel sections. Tension element embedment length was determined based on the side shear resistance of the limestone rock of the individual element capacity as well as for group effects. The most stringent resulting embedment governed the design. Two sacrificial load tests were required for each type of element. A test load (TL) of 820 kips and 1200 kips was specified for the minipile and CIDH, respectively, and a maximum vertical movement set at 1.25 in under the design load. Load test performed satisfied the specified criteria.

CIDH tension elements with the top of concrete and bearing plates ranging from 15 to 25 ft below grade were installed prior to excavation of the tieback bench. Temporary 48 in casing was initially installed and excavated to approximately 4 ft below the planned concrete cutoff to provide support of excavation after removal of an inner 39 in sectional casing that was extended to the top of limestone bearing layer. A conical concrete dipping bucket was used to clean the concrete surface and remove excess concrete to the cutoff elevation. A multi-positional follower beam of the same size as the pile reinforcement with a connection plate with drilled holes to match the bearing plate of the production pile was used to place the H-pile bearing plate at the proper elevation. Styrofoam block outs placed at the top of the H-pile kept a clean bonding surface for the subsequent tremie seal.

The minipiles were installed from sectional barges using a dual-rotary drill rig after excavation to the tremie slab subgrade level to minimize the potential for damage to these elements during excavation. A DHH was used to remove drill cutting within the casing while the casing was twisted into place with the lower rotary unit. A 3 in diameter Grade 150 high-strength threaded bar was placed in the cased excavation prior to tremie placement of grout. The

The TBM cutting head assembly.

minipiles extended through competent limestone into the highly porous Key Largo formation. Installation of the test piles confirmed suspicions that the grout overage would be excessive even with the use of geotextile socks due to the high head of grout within the pile. The original specification required that grout be visible at the top of the casing 40 ft above top of pile. After discussion between the design and construction teams it was decided to install three levels of thermocouples within the pile profile to confirm the presence of grout as the casing was withdrawn so that grout could be confirmed at the top of pile and necking of the pile would not occur. In addition to reducing head pressure, a high-strength ballistic-cloth grout sock was used to minimize grout overage. Divers later attached the shear plate connection on the top of the threaded bar prior to pouring the tremie seal.

TBM Break In/Out Plug

The purpose of the TBM break in/out plug is to provide the TBM a water tight entry point for the start of the tunneling process. After the TBM penetrates approximately 36 ft into the plug, the sealing system between the tunnel shield and the pre-cast 2 ft thick concrete segments that comprise the tunnel lining can be installed to prevent water seepage into the completed tunnel. The TBM plug also provides the excavation support along this face of the excavation and is designed to be a self-supporting retaining structure capable of resisting all superimposed lateral loads. Lateral resistance was achieved from side and base shear as well as shear keys at the base as required to provide adequate factor of safety against sliding and overturning.

The TBM Plug was originally designed as a mass excavation supported by sheet piles. The idea for the re-design of the 114 ft wide by 59 ft long by 50 ft deep TBM plug was developed as a cost saving alternative by Malcolm during the pre-construction phase. The design team quickly confirmed the feasibility of the alternate design and provided construction drawings. The TBM plug is comprised of a square lattice of overlapping cutter soil mix (CSM) panels with an inside face-to-face of approximately 7 ft. After completion of the CSM panels the unmixed soil within the lattice was excavated in a secant pile pattern in both directions and replaced with a minimum 750 psi controlled density fill. The lattice work of CSM panels served as the support of excavation for the 12 ft diameter secant piles as well as low permeable material in the unexcavated material between the secant piles.

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TBM Arch Support

The top 20 to 25 ft of the subsurface profile consists of non-cohesive fill and natural sand. As the TBM leaves the confines of the break in/out plug it travels approximately 420 ft through this loose material until its crown dives below the top of the first rock layer, the Miami Limestone formation. If left untreated this non-cohesive material would unravel into the cutter head as the TBM advanced.

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TBM break in/out plug made of 12 ft secant piles.

Originally designed as a jet grouting application, the specialty foundation contractor worked with the design-builder during the pre-construction phase to revise the design to a more economical scheme consisting of single-axis soil-cement mix (SCM) columns and CSM panels. The design team confirmed the feasibility of the alternate design and provided construction drawings.

CSM panels installed along the center line between the tunnels serve as the wall to support an arch over each tunnel alignment consisting of overlapping 9 ft diameter soil-cement mixed columns. The depth of each column was customized to its location within the tunnel alignment to minimize the treated volume while forming an arch over each tunnel. Deeper columns were used along the edges of each tunnel while the depth of the columns decreased towards the crown of each tunnel thus minimizing the treated soil that would be mined by the TBM. CSM panels were tipped into a deeper more competent limestone layer within the Fort Thompson formation to provide bearing support for the arch. The CSM panels also provided a barrier between the closely spaced tunnels to prevent ground loss during the construction of the adjacent tunnels.

TBM Inspection Plug

After commencement of the work the design-builder requested a proposal from the specialty foundation contractor to construct a TBM Inspection Plug to allow for inspection and maintenance of the TBM's cutter head prior to its initial pass underneath Government Cut Channel. After penetrating into the Inspection Plug the TBM's cutter head chamber will be pressurized with approximately 60 psi of air to remove water up to approximately the mid-point of the TBM. Workers can then enter the cutter head chamber to inspect and replace the cutting teeth and rollers as necessary.

Tie backs of the SOE.

In order to construct the TBM Inspection Plug, a "roof" was first constructed using 32, 15 ft deep overlapping 9 ft diameter soil-cement mixed (SCM) columns. The SCM columns were spaced to prevent untreated soil within the 34 by 56 ft plug area. After construction of the roof, 22 CSM panels were installed to approximately 103 ft below existing grade along the perimeter of the plug. The CSM panels cut through the previously installed SCM columns to provide a tight connection and prevent the upward release of air during the pressurization of the TBM cutter head chamber.

SOE walls made of CSM panels and 12ft secant piles

Cross Passages

Cross passages between the tunnels are required approximately every 650 ft to allow for emergency services to be provided from one tunnel to the other tunnel in the event of a tunnel shut-down. Cross passages No. 1 and 2 are located at each end of the tunnels approximately 35 to 70 ft below grade in a weak to very hard, porous limestone. Malcolm used 36 overlapping CSM panels to construct a 35 ft thick, 34 ft by 28 ft block of low permeability treated soil for Cross Passage No. 1 and 5. Cross Passage 4 is located 70 to 110 ft below existing grade approximately 1,300 ft from the eastern end of the tunnels. Because the distance between the tunnels increases as the tunnels move away from the break in/out plug, 76 overlapping panels were required to construct the 40 ft thick, 34 ft by 60 ft treated area required for Cross Passage No. 5. After completion of the tunnels, BCWF will use conventional excavation techniques and a reinforced shotcrete liner to construct the cross passages.

Performance

The SOE wall is fully instrumented for performance monitoring including inclinometers, tieback load cells, piezometers, deformation monitoring points and survey target points. The TBM

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Arch area is also instrumented with survey target points to measure changes in the working grade as the TBM advances underneath them. To date no instrumentation reading has exceeded the threshold values set for the project. Verification boreholes with rising head permeability test values of less than 1 x 10^{-6} cm/sec as well as laboratory permeability test values confirmed the maximum permeability of 1 x 10^{-5} cm/sec requirement was met. No flowing water through the CSM wall has been observed since dewatering of the Watson Island SOE was completed in July 12, 2011. No appreciable vertical movement has been observed to date in the tremie seal.

Conclusions

To the author's best knowledge the Watson and Dodge Island SOEs are the deepest and largest excavations in South Florida. The CSM/soldier pile system performed remarkably well in very challenging ground conditions. Wall movements and water infiltration were well within limiting values established in the design criteria. Laboratory results and field observations have validated CSM as an effective water-resistant barrier. The anchored tremie seal has also been proven an effective water resistant barrier including the construction joint between the CSM wall and the tremie seal. The TBM break in/out plug performed as planned during the launch. The TBM arch support system has also worked to stabilize the loose surface soils adjacent to each SOE.

Acknowledgements

The authors would like to thank the many people from the design and construction teams that participated in the project. The authors also thank the entire team at Bouygues Civil Works Florida for the privilege and opportunity to work on a project of this magnitude.

Project Team

Owner:	Florida Department of Transportation
Concessionaire:	MAT Concessionaire, LLC
General Contractor:	Bouygues Civil Works Florida, Inc.
Structural Engineer:	Jacobs Engineering Group, Inc.
Geotechnical Engineer:	Langan Engineering & Environmental
Specialty Foundation Contractor:	Malcolm Drilling Company, Inc.

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Look to the Blue

TBM Plug on Watson Island
Port of Miami Tunnel
Miami, FL

SECANT PILES WITHIN A CONFINING MATRIX OF CUTTER SOIL MIXED WALLS. 12FT IN DIAMETER PILES TO 70FT DEPTH

Malcolm Drilling has been providing support for our clients for over 50 years. Our innovative technology and extensive equipment fleet uniquely positions Malcolm as a national leader in the deep foundation industry. Find out more about what we can do for you at **Malcolmdrilling.com.**