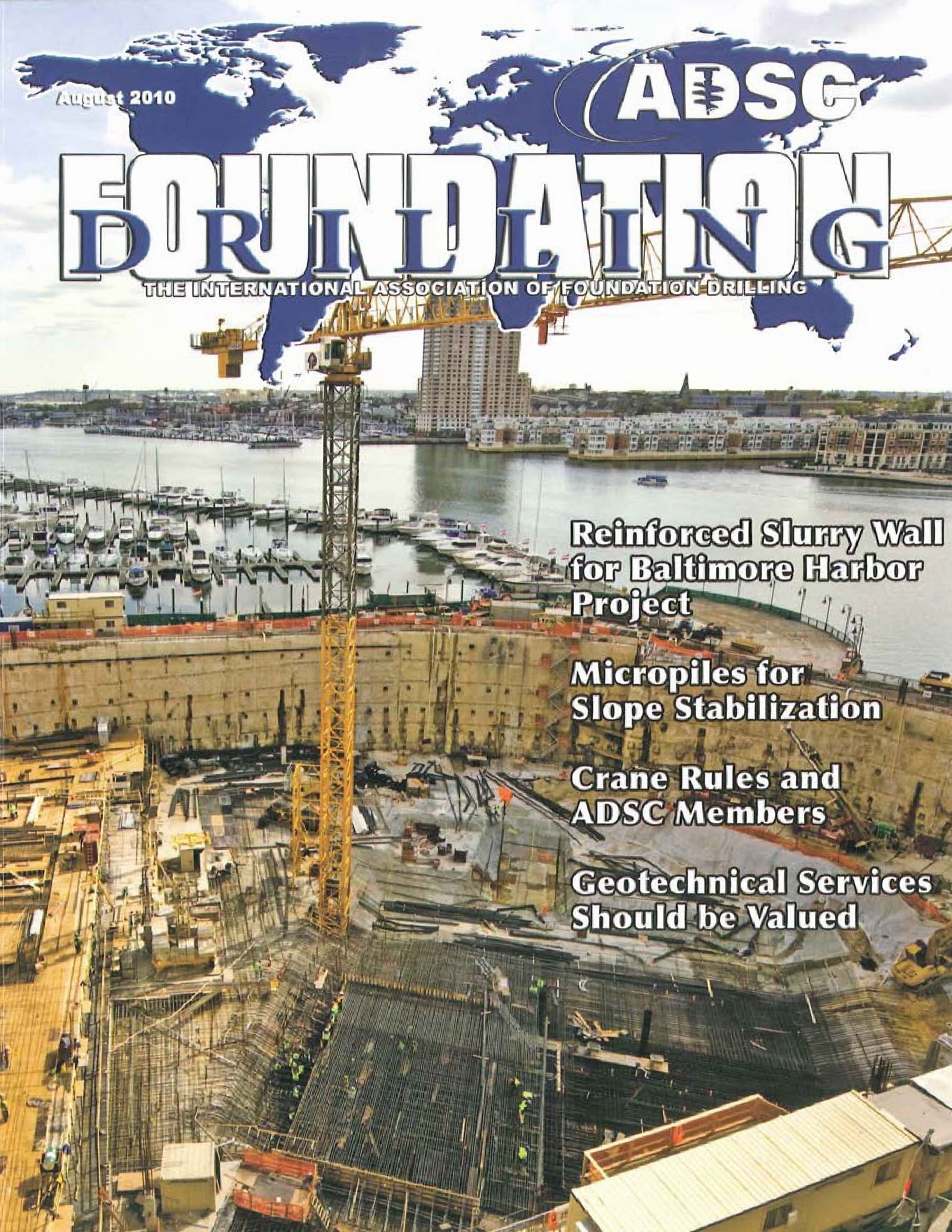
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ADSC
FOUNDATION DRILLING
THE INTERNATIONAL ASSOCIATION OF FOUNDATION DRILLING
Reinforced Slurry Wall for Baltimore Harbor Project
Micropiles for Slope Stabilization
Crane Rules and ADSC Members
Geotechnical Services Should be Valued

Nicholson Construction Installs Foundations for a Waterfront Property at Harbor East in Baltimore

by Brian O'Gara, Nicholson Construction Company

Project Site

The Inner Harbor is a historic seaport, tourist attraction, and iconic landmark of the city of Baltimore. The area was a working port from the 17th century up to the mid 20th century. In the 1970s, the harbor area was rediscovered as an economic and cultural center of the city, and new buildings were constructed in the area. Since then, an increasing number of museums, shops, residential buildings, restaurants and hotels have emerged in Baltimore's Inner Harbor. Construction activities continue to be strong – especially so in Harbor East, a new mixed-use development featuring commercial properties and residences.

One of the most notable projects in the Harbor East area is development of the site that contains the Four Seasons Hotel and Residences and the Legg Mason Tower. The site is a waterfront property located directly opposite the Inner Harbor East marina. The 2.3 acre site has two high-rise towers with five levels of below ground parking being built.

During the last 100 years, the site was occupied by various industrial structures and warehouses. Before the recent development began, the site was a paved parking lot.

Design

The project site is only 20 feet from the water. To provide for the five-story parking garage below the water table, the design called for an anchored diaphragm wall for both excavation support and protection from seawater infiltration. The Engineer of Record for the diaphragm wall, Mueser Rutledge Consulting Engineers, ADSC Technical Affiliate Members, completed the design.

The unique shape of the site, combined with the presence of known structures and bulkheads along the southern property line, posed a challenge during diaphragm wall design and tieback anchor layout.

The anchors along the south diaphragm wall, which extended beyond the bulkhead, had to be anchored into the bedrock beneath the East Harbor active marina. The layout of the diaphragm wall panels and tieback anchors was dictated by the location of piles supporting the existing bulkhead. The tieback anchors were placed between the existing structure's piles and beneath the deadman anchors.

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Along the North wall directly opposite the Baltimore Civil War Memorial monument where the Northeasterly diaphragm wall curves until it decidedly turns westerly for a straight run,

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tieback anchors had to be positioned using a 3D CAD model to avoid potential conflicts during installation. Diaphragm wall panels along the curve were adjusted based on tieback anchor locations.

The diaphragm wall was designed as a fast track project and the design could not wait until borings were made along the proposed wall alignment. For the design of the diaphragm wall, typical soil properties were selected for the Fill, Silty Organics, Cretaceous Sediments and varying depth of Decomposed Rock.

Diaphragm Wall Construction

The diaphragm wall contract was completed by a joint venture between Nicholson Construction Company (doing business as Soletanche Inc.) and Inquip. The JV met with the designers after contract award and suggested the panel layout be slightly adjusted to accommodate their equipment and the panel sequence in which they would follow in prosecuting the work. Based on their input, the layout of the diaphragm wall was revised.

The construction schedule required the diaphragm wall contractor to complete the construction of the approximately 90,000 square ft wall and installation of over 600 tiebacks in 10 months. To meet the schedule, the contractor decided to use two rigs in a 10 hour day shift to excavate the panel and cast the diaphragm wall. The construction of the diaphragm wall was completed, as scheduled, in five months including time for mobilization and the set up of the slurry mixing and desanding plant. The slurry mixing and desanding plant required approximately 4,000 square ft of space and included seven tanks with a holding capacity of 20,000 gallons of bentonite slurry each. Caviem desander pumps and slurry distribution systems were set up on site and used for the construction of the wall.

The slurry filled panel excavation through the various soil strata and weathered rock was performed using a KS3000 crawler crane fitted with a hydraulic clamshell bucket and a Liebherr HS855* crawler crane fitted with a mechanical bucket. A 7 ton chisel was used to aid the excavation in instances when the vertical alignment was difficult to achieve due to the presence of an obstruction or hard weathered rock was encountered.

The diaphragm wall reinforcing cages were fabricated on site. The width and length of the reinforcing cages varied slightly, most were 22 ft wide and 78 ft long. Two cages were fabricated at a time and three or four completed cages were ready for placement. Once excavation was completed, the bottom of the panel was cleaned and desanded followed by rapid placement of the cage.

The typical 21 ton reinforcing cage was lifted using a 100 ton Liebherr LR1100* crane and lowered into position. It was set at the correct elevation using steel beams to hang the cage from the guide walls. 4000 psi concrete was then placed by the tremie method using two 11 inch pipes and two concrete trucks in tandem displacing the slurry, which was pumped to the desanding unit for reuse.

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The approximately 1300 linear ft of perimeter diaphragm wall consisted of 56 panels each averaging 23 ft long with the exception of the primary panels which were 18 to 23 ft long. The average height of panels was 78 ft and the tip of the panels extended into the weathered rock stratum except for superstructure load bearing panels that were carried down to competent bedrock. Load bearing panels support the high-rise tower's columns that carry approximately 5000 kips. These panels were

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founded on bedrock with an RQD of 80% or better to provide the required bearing capacity.

The depth of excavation varied from 60 ft along the diaphragm wall to 68 ft towards the middle of the site. The minimum standoff distance between the deeper excavation and the diaphragm wall was 17 ft. Based on the depth of excavation, the high groundwater table and the nature of soils at the site, a 30-inch thick wall was used for economy, to keep anticipated wall displacements to a minimum and to provide efficient panel reinforcing.

Tieback Anchor Construction

Four tiers of high capacity tieback anchors were used to support the 30 inch thick diaphragm wall all around the site except at the southeast double re-entrant corner where a unique top-down construction was implemented. The capacity of tieback anchors varied from 125 tons at the first tier to 450 tons at the fourth tier. The total length of tiebacks varied from 120 ft to 95 ft respectively.

Tieback anchors for the first tier were anchored in the weathered rock whereas the rest of the tiebacks were anchored in competent rock with bond lengths varying from 30 ft to 40 ft.

Tiebacks were installed from a 6 ft high berm, which served two purposes. The berm with an average width of 40 ft and at a distance of 5 ft from the face of the wall, helped reduce the tieback anchor forces by an average of 5 to 15 percent for the top three tiers and also reduced the movement of the wall by providing an added temporary passive resistance prior to the tieback anchors being locked off.

Four tiers of high capacity tieback anchors were used to support the 30 inch thick diaphragm wall all around the site except at the Southeast double re-entrant corner where a unique top-down construction was implemented.

Over 600 high capacity tiebacks were drilled and installed in five months using three drills. Eight inch diameter cased holes were made using the rotary duplex method with water flush. The holes were cased through the overburden and to the top of rock. Once the hole was drilled to the appropriate length, it was cleaned and the tieback tendons placed and grouted. After the grout achieved a minimum of 3,000 psi, a performance test or a proof test was performed and the anchor was locked off at 80% of the design load as specified.

At the southeast double re-entrant corner, the contract drawings initially required four tiers of corner bracing. The bracing was necessary to avoid installing anchors that would cross each others path and because of the presence of an existing underground structure that had to remain.

Over 600 high capacity tiebacks were drilled and installed in five months using three drills.

During construction, it was determined that the steel sections for the corner bracing would not be readily available. Furthermore, the cost and time required to fabricate the corner bracings were not acceptable. The general contractor requested that the design engineer propose an alternate to the corner bracing. A top-down construction method was implemented by the engineer utilizing a portion of the permanent slab as corner bracing. Temporary high capacity micropiles were used to support the slab.

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Groundwater

Groundwater was reported to be at Elev. -1 to +4. One goal of the diaphragm wall was to cut off groundwater flow into the site, to permit the installation of an under-drainage system. The permeability of the rock below the bottom of the diaphragm wall was not known at the start of design, therefore inflows were estimated based on assumed permeability values.

Packer tests were performed during the supplemental subsurface investigation, at selected boreholes to estimate rock permeability. Preliminary data indicate that flow through the rock below the wall would be within the range estimated during design.

Joints Between Panels

Joints between slurry wall panels are usually formed with pipes or structural members inserted at the ends of primary panels. These forms are removed by either the crane or using an extraction device operated by a hydraulic jack.

An optional water stop within a panel joint is sometimes used in the United States but is usually avoided because of the high labor cost associated with the careful preparation and the removal of the end stop device.

The project's perimeter wall along the southern property line is within 40 ft of the bulkhead and in close proximity to the brine seawater of Baltimore Harbor. Hence, a watertight joint was one of the requirements of the project. An H-pile joint was shown on the contract drawings as the connector and joint between panels to ensure a reliable method of keying the panel joints, minimizing the differential movement and providing the required water-stop. However, the tight construction schedule did not allow sufficient time to obtain the H-piles. Therefore, the contractor proposed to use the proprietary CWS (Coffrage avec Waterstop) joint developed by Soletanche Bachy in France. The CWS forms a watertight joint between the panels of the slurry wall while providing the required shear key to prevent relative movement between adjacent panels. The Owner, Con-

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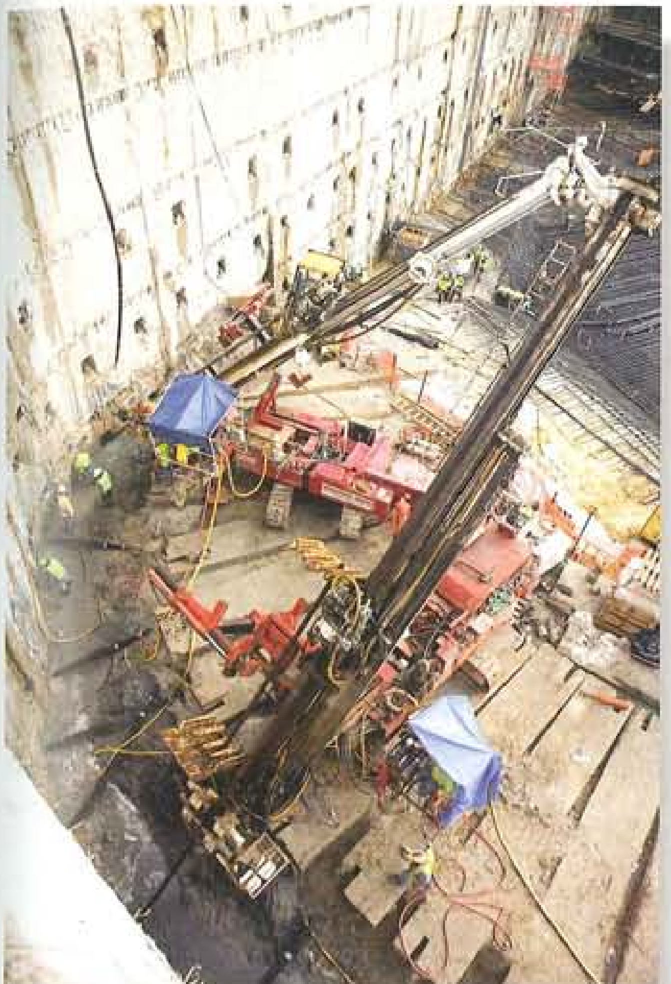

tractor, and Engineer evaluated the value engineering proposal and concluded that the CWS joint would not only produce a tight joint but also save cost by eliminating the need for the H-piles.

The CWS system provides for an end stop made from steel tubular shapes welded to a continuous plate. The pair of tubes is designed to hold one half of the PVC waterstop in place and protect it during adjacent panel excavation. The device is tightly

The Owner, Contractor, and Engineer evaluated the value engineering proposal and concluded that the CWS joint would not only produce a tight joint but also save cost by eliminating the need for the H-piles.

secured to the reinforcing cage with the other half of the PVC water stop projecting into the reinforcing cage where it will engage the concrete once the tremie concrete hardens. After the tremie concrete has set and the adjacent panel is excavated, the CWS joint is removed by pulling laterally on the plate portion of the end stop. Later when the adjacent panel is cast, the other half of the water-stop remains within the follow-up or secondary panel forming a barrier to water ingress through the joint.

The CWS end stop is usually placed approximately 9-12 ft above the bottom of the excavated panel to provide the required connection with the clamshell during the excavation of the follow-up or secondary panels.

The successful use of the joint was achieved by careful setting and centering of the CWS end stop. The panel's end verticality was evaluated prior to setting each CWS joint and the required adjustment was made using the clamshell bucket or the chisel so that the end stop could be placed fairly perpendicular to the end of the excavated panel.

One of the advantages of this type of end stop is that a continuous water barrier is cast within the concrete and provides a positive water barrier at the joint. The other benefit is that the end stop is removable and can be pulled and re-used for successive panel construction. The disadvantage is that in some instances the end stop binds to the insitu concrete and its removal becomes difficult. In such cases, the use of a chisel would be required where once the end stop is removed, a portion of the PVC water-stop might be torn or compromised. On this project, the CWS joint performed well with minor exceptions where the use of a chisel was required to remove the end stop.

References

This article is adapted from a paper titled *Diaphragm Wall for Deep Basement Provides Efficient Use of Waterfront Property at Harbor East in Baltimore* by S.Y. Fantaye; D. Iliadelis; R. J. Poletto; D. W. Christie of Mueser Rutledge Consulting Engineers, New York, NY.

Project Team

Owner:	Harbor East Parcel D, LLC
General Contractor:	Armada Hoffler Construction Company
Diaphragm Wall Contractor:	Soletanche Inquip JV
Anchor Contractor:	Nicholson Construction Company
Diaphragm Wall Engineer:	Mueser Rutledge Consulting Engineers

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