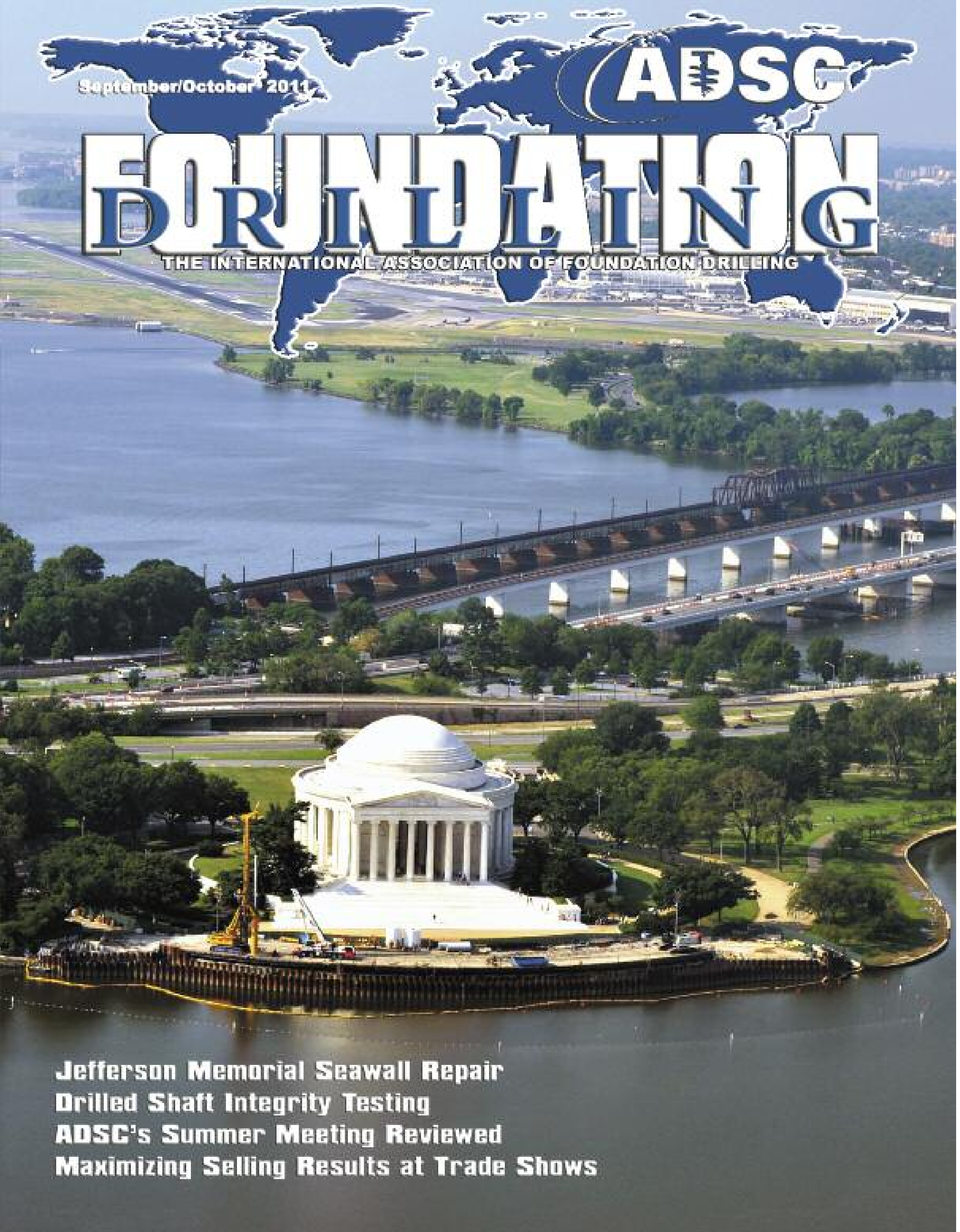

September/October 2011
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Jefferson Memorial Seawall Repair
Drilled Shaft Integrity Testing
ADSC's Summer Meeting Reviewed
Maximizing Selling Results at Trade Shows

Restoring Value to a National Monument:

Emergency Repair of Jefferson Memorial Seawall and North Plaza

Construction activities on the North Plaza and Seawall at the Jefferson Memorial.

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Introduction

The Summer of 2011 will mark the completion of emergency repairs to the Jefferson Memorial North Plaza and Seawall. These repairs were necessitated by settlement and lateral movement of the seawall and North Plaza, which prompted the National Park Service (NPS) to initiate an investigation as to the possible causes of the movement and commission a design for its mitigation.

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Information gathered from extensive instrumentation onsite led to the design of a movement mitigation scheme that included demolition and reconstruction of the seawall without compromising the historic Ashlar facing.

demolition and reconstruction of the seawall without compromising the historic Ashlar facing. The new seawall foundation consists of vertical caissons and battered piles connected through the seawall itself to provide resistance to future vertical and lateral movement of the North Plaza and the new Seawall. Repair to the seawall and plaza began in December 2009. This article is a follow-up to an initial article that appeared in the Spring 2010 issue of the *Deep Foundations* DFI magazine and discusses the mechanisms believed to be responsible for settlement and lateral movement, summarizes the procedure followed for design of the mitigation, and describes the construction methods and some challenges faced during the repair.

Events of 2005

In late 2005, a Park Police officer jogging along the scenic trails in this part of our Nation's capital noticed that the seawall had moved. Upon further investigation, it was apparent that there was differential settlement between the wall and the North Plaza, rotation of the seawall, and differential settlement between areas supported on piles and areas on grade. As this differential settlement continued, frequent asphalt patching became necessary to prevent tripping hazards. As a result, NPS was forced to restrict access to the edge of the North Plaza at the Seawall and several surrounding areas.

This prompted NPS to commission a study on the potential causes of the movement and to develop possible repair alternatives. This study was carried out by the ADSC Technical Affiliate Member Firm Schnabel Engineering* and it included geotechnical exploration of the site, installation and monitoring of instrumentation, periodic optical surveys, a review of historical information, and interviews with retired NPS engineers. Instrumentation devices included inclinometers, open stand pipe wells, vibrating wire piezometers, and tiltmeters.

Subsequently, NPS also commissioned Schnabel Engineering to development the final design documents following the results of an extensive Value Analysis.

Subsurface Conditions

The geologic stratigraphy consists of Pleistocene Age terrace soils that were extensively eroded by the Potomac River down to bedrock, and were replaced with recent alluvial deposits. Significant filling of this area took place early in the 20th Century during reclamation of the West Potomac Park. Overall, fills up to 30 to 40 feet deep were placed for reclamation and grading for the

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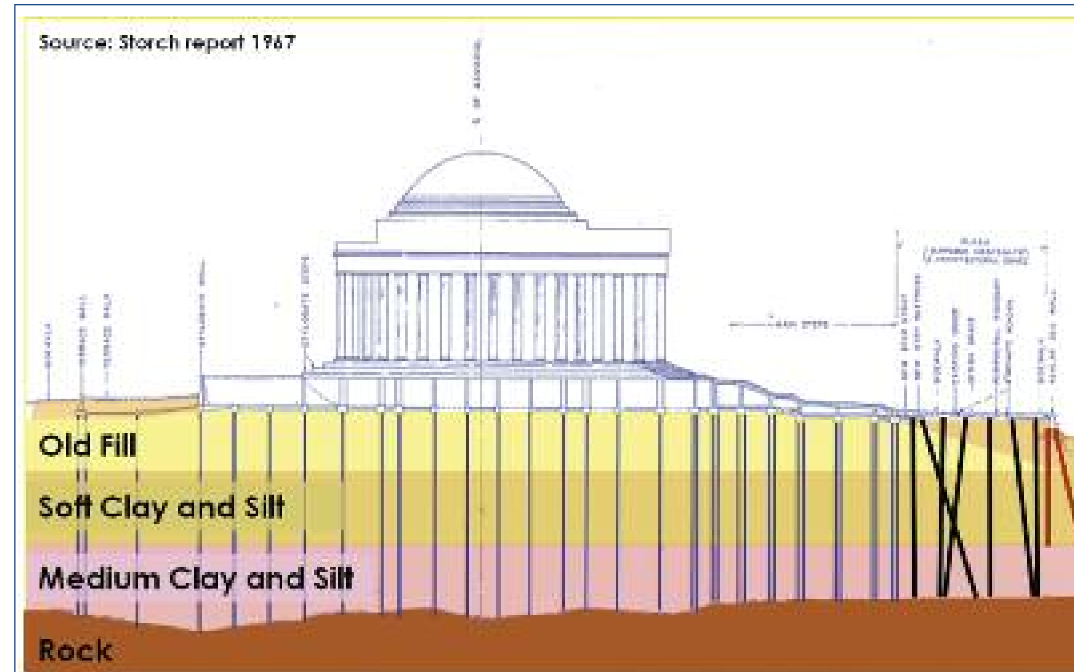
Memorial site. These fills were placed over the soft, highly compressible alluvial soils extending down to a depth of about 90 to 100 feet below the North Plaza, where bedrock is encountered. The present day fill thickness under the North Plaza ranges between about 10 and 25 feet.



Memorial Foundation Types and Stratigraphy. Adapted from Storch Report (1967).

Since its construction, the Jefferson Memorial grounds have sustained noticeable ground settlement. The main structure of the Memorial, however, has not sustained significant damage because it is supported on deep foundations carried to bedrock. The main Memorial structure, the Stylobate Wall, and the Terrace Wall are supported on a system of 443 Raymond Piles and 191 concrete caissons. Through the years, several repairs were made to the appurtenant structures of the Memorial. In addition, minor repair operations were conducted to ensure public safety and aesthetics.

The length of the timber piles supporting the seawall was established based on the metrics of historic photos at 70 to 75 feet.

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This range of length was insufficient to reach rock. The piles, however, may have reached the somewhat stiffer alluvium overlying rock.

The North Plaza of the Jefferson Memorial was originally an asphalt road on grade bordered by concrete sidewalks. The plaza settled and showed considerable damage in the years following the Memorial's construction. The plaza was reconstructed in 1969-1970 as a structural slab on grade beams and HP piles. Based on construction records, the piles were extended into bedrock. This was confirmed through interviews with engineers involved with reconstruction of the North Plaza at the time.

Mechanism of Movement

The data collected from the inclinometers, piezometers and optical surveys suggest that the primary cause for the recently observed vertical movements is compression of the alluvial soils due to a substantial drop in the piezometric head near the rock interface. Because the North Plaza and the Memorial structure are supported on piles extending to bedrock, there is little, if any, vertical movement in these areas. Conversely, the surrounding areas on grade located within the area of influence of the piezometric head drop also underwent settlement. The Ashlar seawall underwent settlement primarily because the tips of the timber piles are located above the elevation where most of the compression of the soils took place.

The lateral movement of the seawall is due to the effect of the proximity to the edge of the embankment. Typically, embankments placed over soft soils that undergo settlement, also undergo lateral movement near their edges. As the seawall is at the edge of the embankment, lateral movement of the subsurface soils caused the slender timber piles supporting the seawall to move laterally as well.

There were no significant movements observed at the eastern half of the North Plaza and seawall. This area was reclaimed much earlier than the west side of the North Plaza and was excavated during construction of the Memorial as part of the shoreline realignment. Compression of the alluvial soils in this area could be expected to be less and take place initially at a slower rate than in the west half upon reduction of the boundary piezometric head. However, it is anticipated that if the magnitude of piezometric head drop is sustained over time, the soils under the eastern half of the North Plaza will also undergo compression and lateral movements.

Remediation

The design team considered various options for mitigation of

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the movements. They included micropiles to underpin the existing wall and tiebacks to restrain lateral movement, Deep Soil Mixing (DSM) with either micropile underpinning of the existing seawall or reconstruction of the seawall on deep foundations, a tied-back diaphragm wall with reconstruction of the seawall atop the diaphragm wall, or reconstruction of the seawall on an A-Wall consisting of vertical caissons and battered pipe piles.

The caisson and pipe pile A-Wall was selected after an extensive Value Analysis. Tiebacks were discarded, among other reasons, because they would need to be "woven" among the numerous piles existing under the North Plaza.

The caisson and pipe pile A-Wall was selected after an extensive Value Analysis.

West end of Memorial Stairs. By the 1950s, the North Plaza on grade had experienced significant settlement (the Memorial steps are supported on piles). Source: National Park Service Archives.

In addition, they would be very long and would provide limited lateral stiffness should the thrust force be under predicted. One important factor in the selection of the stabilization solution was "visitors' experience." Some of the options considered would limit or deteriorate the visitors' experience more than others and thus were impacted negatively during the Value Analysis.

In the adopted solution, the existing wall would be demolished after carefully removing, cataloguing and storing the Ashlar facing blocks. Caissons with a diameter of 4 feet would then be drilled and socketed into rock. Battered, 18-inch, pipe piles would be installed toward the Tidal Basin, thus avoiding conflicts with the existing North Plaza piles. The wall would be rebuilt over the caissons and piles, and would be designed as a structural connection between the foundation elements and to support the earth pressures behind, as well as the lateral force transmitted by the North Plaza. The new seawall would maintain the exact same exterior geometry as the original wall to support the same original

The selected alternative would make it possible to avoid demolition or substantial damage to the existing North Plaza structure and to maintain a suitable "visitors' experience" throughout the process.

Ashlar facing blocks. The selected alternative would make it possible to avoid demolition or substantial damage to the existing North Plaza structure and to maintain a suitable "visitors' experience" throughout the process.

The battered piles are splayed with respect to the wall in order to limit the tendency for out-of-plane movements of the system. In addition, the inclination of the piles alternated as either 25° or 35° to prevent conflicts during installation.

Because it is expected that settlement of the areas on grade will continue developing over time, it was necessary to devise a way to mitigate differential settlements between these areas on grade and the North Plaza on piles. A transition zone on each end of the North Plaza was designed, which consisted of a structural slab supported on a grade beam on piles at its interface with the North Plaza. At the other end, the transition slab was supported on grade. The design magnitude of settlement adopted was 12 inches, which required a span of about 40 feet to meet the maximum slope of 5% dictated by wheelchair accessibility requirements. The slab is designed to support the expected

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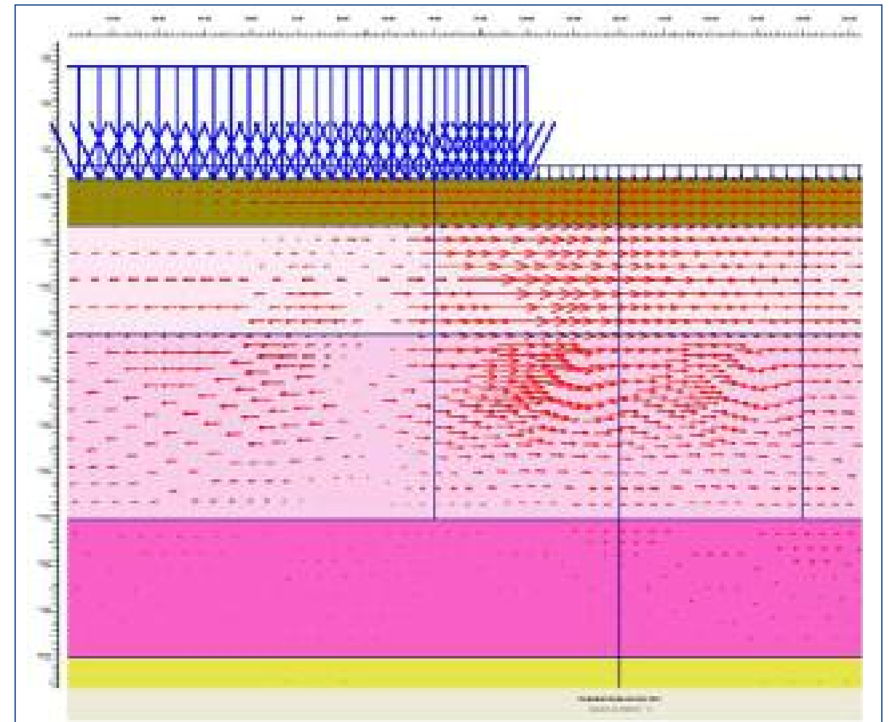
Timber Pile driving for original Seawall. What type and how long were the piles used for the Ashlar Seawall? Historic photo that answered this most important question. Notice start of pile driving in background.

vehicular traffic loads over this span.

Immediately after construction, the A-Wall system will be only subject to the weight of the seawall, which will be absorbed by the vertical caissons. Over time, lateral and vertical movement of the surrounding soils will develop and will generate downdrag as well as lateral thrust on the caissons and battered piles. Due to the presence of the caissons, it is anticipated that the lateral loads on the piles would be relatively small.

The lateral loads on the system will induce bending of the caissons as well as axial loads in the caissons and piles. It is estimated that, over time, if the tendency for lateral soil movement continues, significant tension will develop in the caissons and compression in the battered pipe piles.

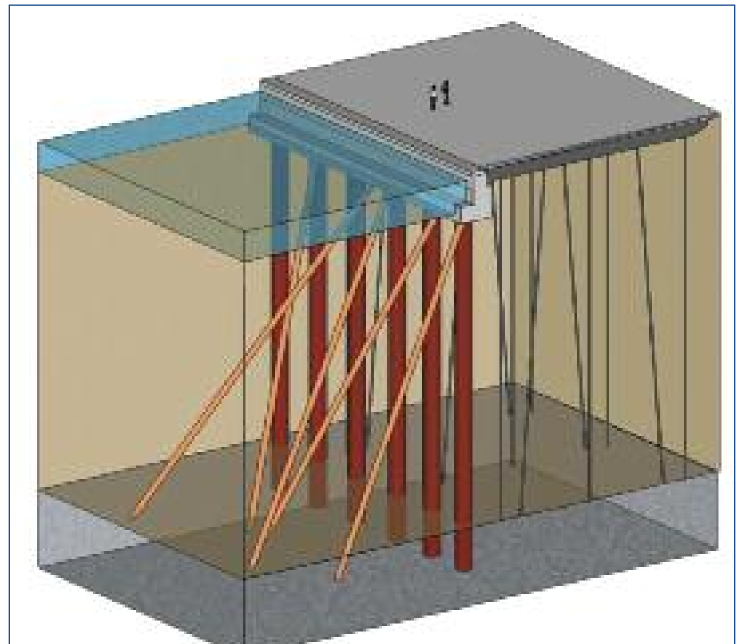
The existing North Plaza piles are subjected to lateral loads and downdrag as well. The lateral loads will be transferred through the North Plaza to the new seawall and generate additional axial loads on the caisson and pipe piles without significant bending. Earth pressures from the backfill of the seawall would also develop and generate additional bending and axial loads that are relatively minor.



Soil Movement Vector Plot. Settlement and lateral movement occur simultaneously at the edge of an embankment on soft soils undergoing consolidation.

Estimation of vertical loads due to the weight of the wall and downdrag is a relatively simple matter. However, estimation of the loads induced by the tendency for lateral movement of the soils required relatively complex soil structure interaction analyses that involved determination of lateral pressures on caissons for various magnitudes of soil lateral movement and calculation of deformations of the A-Wall. The force exerted on the North Plaza piles by the lateral soil movement and transferred to the new seawall through compression of the North Plaza grade beams was also considered in the analysis. The analyses involved an iterative procedure until equilibrium of forces and moments and compatibility of displacements within the A-Wall was achieved at any level of soil displacement. It is anticipated that the A-Wall would be stable even though lateral soil movements may continue to develop past the caissons.

The final design considered a maximum deflection at the top of the piles and caissons of 1 inch, which resulted in 525 kips of tension in the caissons, and 354 kips of compression in each pipe pile.



Artist's rendering of A-Wall solution.

Construction

Clark Construction Group, LLC, of Bethesda, Maryland was selected by NPS to perform the emergency repairs under a competitive, best-value acquisition. The notice to proceed was issued in December 2009 and is expected to be completed by Summer 2011.

In order to protect the North Plaza structural slab from damage during the project, a loading limit of 240 psf was put in place for any construction traffic. Clark designed and constructed a temporary work platform that spanned the entire North Plaza allowing access for heavy-duty cranes and drill rigs that ultimately were required to construct the new foundation elements. The decking system included additional steel H-piles driven to bedrock and utilized the existing bearing piles installed as part of the Plaza grade beams in the 1970's. The steel structure was

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Removal of historic Ashlar facing from Seawall.

designed similar to a bridge deck and finally topped with hardwood timber mats to support the 360,000 lb work load of the caisson drill rig, the largest piece of equipment required on the project. During installation of the new bearing piles, records of the final tip elevations were maintained. These records provided the preliminary information of where caisson and bearing pile would ultimately reach beneath the Tidal Basin.

During the deck construction, the cofferdam structure was installed by utilizing a 110 ton crawler crane and a vibratory hammer. The 288 pairs of steel sheets were installed over fourteen weeks and provided a dewatered area in which to demolish the historic seawall, install the new foundations elements and reconstruct the new seawall. Workers utilized small floating working platforms, or flexi-floats, to facilitate installation within the Basin. During removal of the Ashlar facing stones, it was discovered that the facing stones were originally used as concrete formwork for the seawall. In a desire to maintain the historic integrity of the new construction, National Park Service requested that the new seawall be built in the same fashion.

Caissons

After demolition of the historic seawall within the dewatered area, caisson installation began in June of 2010. ADSC Contractor Member, Raito, Inc.*, of Woburn, Massachusetts was contracted by Clark Construction to construct the caissons lining the tidal basin on the North Plaza. A work trestle was constructed by Clark to support drilling equipment on the North Plaza, and Raito mobilized drilling and support equipment in June, 2010. The final design consisted of 39 each, 48-inch diameter drilled shafts installed to depths of up to 120 feet below work trestle elevation.

Three distinct challenges were identified in the design prepared by Schnabel Engineering and drilling methods were developed to counteract these possible obstacles. The primary challenge consisted of timber piles that supported the original seawall, along with debris and organic matter in the upper 50 feet of the drilled shaft profile. Raito used 54-inch diameter, jointed bolt-together casing with a cutting shoe to cut through the timber piles and advance the shafts through debris. Jointed casing was advanced in fifteen-foot sections from the deck elevation of +13 feet to an elevation of approximately -47 feet.

The second challenging soil profile extended from the bottom of the jointed casing to the top of rock. This zone consisted of sand and silt with low SPT blowcount values. To counteract the loose soil conditions, the SlurryPro CDP polymer slurry system from ADSC Associate Member, KB Technologies* was utilized. Polymer slurry was batched onsite using Tidal Basin water. Following the installation of the jointed casing, the shaft was flooded with polymer slurry in preparation for excavation to the top of rock. Additional slurry was added to

> ***The final design consisted of 39 each, 48-inch diameter drilled shafts installed to depths of up to 120 feet below work trestle elevation.***

the shaft as the drill advanced through the sand and silt layers to the rock at elevation-90 feet. The base slurry was fortified with admixtures to control flowing sands, and designed so that no pH adjustment would be required. The polymer slurry system performed very well stabilizing the sidewalls of the drilled shaft with very little fluid loss, even in zero blow count material. The polymer slurry proved to be an effective alternative to extending jointed casing to the top of rock in a limited space environment.

The final challenge consisted of moderately weathered green and black schist. Drilled shafts were socketed up to fifteen feet into rock using an ADSC Associate Member, Bauer BG40* and various

> ***The polymer slurry proved to be an effective alternative to extending jointed casing to the top of rock in a limited space environment.***

rock augers and buckets. Most shafts were allowed to sit overnight before pouring concrete the following morning. A cleanout bucket was used prior to the placement of the reinforcing cage to assure a clean shaft tip. During placement of concrete, polymer slurry

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was returned to batching tanks to be reconditioned and used at the next shaft location.

Careful attention to drilled shaft construction sequencing was crucial to the schedule of the project, as drilling, reinforcing steel tying, and concrete placement occurred simultaneously on the trestle in close proximity. Space was further constricted towards the completion of the drilled shafts when an additional pile driving rig was added to install and test the battered 18-inch pipe piles. Twenty-five of the reinforcing steel cages were fitted with Crosshole Sonic Loging (CSL) tubes, and CSL was ultimately performed on seven drilled shafts. Two CSL tests yielded questionable data, but subsequent concrete coring verified that concrete exceeded specified strengths.

Pipe Piles

As caisson installation was nearing completion, battered pipe pile installation began. The 18 inch diameter pipe piles were installed with 25 or 35 degree batter and driven to refusal at bedrock. The pipe piles were prefabricated in two sections with a conical tip installed at the end schedule to bear at the bottom of the Tidal Basin and the top section with a splice collar to adjoin the two pieces. Due to the batter requirement, the piles were installed using a specialized ADSC Associate Member, Junttan* driving rig that could accommodate the unique requirement. After the piles were driven to refusal, the piles were filled with a concrete mix, placed from the bottom. Finally a reinforcing steel and steel plate assembly was wet stabbed in place to create a connection to the seawall structure above. Before piles were installed, a load test program was completed to verify actual bearing capacity achievable. Two vertical piles were installed within the west transition zone area with arc weldable gauges installed at four locations along the length of the pile. The test piles were driven in two pieces to accommodate the length to bedrock, and spliced with a full penetration weld. After completion of the driving activities, the gauges did provide usable data for the load test. The two load tests were run in the ASTM D1143 Quick Method to determine the amount of settlement recorded with loads applied at 866 kips. After the instrumentation malfunctions, thought to be from the hard driving, a third load test was installed with both arc weldable gauges and sister bars installed with a center bar to provide a "belts and suspenders" approach to ensure multiple sources of data were collected in the last load test. In addition, the pile was driven to a shallower depth to collect the skin friction capacities required to verify and complete pile design. All gauges functioned correctly and adequate data was collected to verify the pipe piles would meet the design load.


Caisson construction using the Bauer BG 40 (background) and caisson concrete tremie placement (foreground).


Load test setup.

Seawall

In the efforts to recreate the construction

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Pile driving rig reaches over to install battered pipe piles.

methodology, the seawall was broken into three concrete pours, the bottom footing portion that was constructed in typical cast-in-place methods. The stem of the seawall was poured in an upper and lower pour to align with the two courses of Ashlar facing stones. After the footing was poured, "A" frame style steel brackets were bolted to the horizontal surface of the seawall and vertically supported the Ashlar facing stones and secured the top of the stone to withstand the hydrostatic pressure of the concrete as it was placed from above. The stones were methodically placed in their original position and poured in sections of up to 70 linear feet long after the reinforcing steel was installed. After the bottom section had cured, the upper course of stone was set in the same method. The ultimate result was a monolithic structure where the historic stone is firmly attached to the concrete structure.

Transition Zones

In the spring of 2011, concrete work at the east and west transition zones began to rehabilitate the grounds that had been subjected to settlement, particularly on the west side of the project. The new footings and slabs were poured to tie-in to new and existing bearing piles, and included different expansion joints to allow for future settlement as the soils are expected to continue to move. After structural concrete was complete, the exposed aggregate topping slab was placed to complete the aesthetic finishes deserving of the Memorial's grounds. The North Plaza center portion of exposed aggregate was scheduled to be colored in a dark asphalt color in contrast to the widely used brown and grey color common on the Memorial grounds. This dark asphalt color was selected to honor its historic use as a driveway after the Memorial's completion in the 1940's.

Summary/Acknowledgements

Since October 2006 fencing and guide rails have stood between Jefferson Memorial guests and the rippling Tidal Basin. Now visitors may once again walk up to the edge of the North Plaza and dangle their legs over the seawall, enjoying the view of the encircling cherry blossoms or turning to admire the majestic Jefferson Memorial behind them for years to come.

The authors thank Schnabel Engineering, Clark Construction Group, and Raito, Inc. for providing support and resources during preparation of this article. We would also like to thank Kevin Waldron, Steven Sims, Steve Lorenzetti from the National Park Service. We especially want to acknowledge Doug Denk, Patrick MacDonald, Margaret Lemke and Eric Weisman of the National Park Service Denver Service Center for tirelessly guiding this project and seeing it from

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Original Ashlar facing stone re-positioned before pour of bottom section of the new wall stem.

infancy to fruition. We also thank Phil Sheridan, Caroline Norton and Matt Cerritelli from Clark Construction and Andreas Chrysostomou and Rudy Achiri from Alpha Corporation for their support during the construction of the project. Finally, the authors thank George Aristorenas of the Geostructural Group of Schnabel Engineering who was responsible for numerical modeling and Allen Cadden for his technical input in the project.

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PROJECT TEAM

Owner:	National Park Service
Engineer:	Schnabel Engineering*
Architect:	HNTB
Construction Management:	Alpha Corporation
General Contractor:	Clark Construction Group, LLC
Drilled Shaft Foundation Contractor:	Raito, Inc.*

**Indicates ADSC members.*

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