SUBSURFACE COMPONENT DESIGN AND CONSTRUCTION FOR A HIGH-RISE IN A DENSE URBAN ENVIRONMENT: A CASE HISTORY OF THE 181 FREMONT TOWER

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ABSTRACT

The 181 Fremont Tower will be an 800-foot high-rise with a 60-foot deep basement located in a dense urban part of downtown San Francisco. The design and construction methods of the subsurface elements navigated a variety of site constraints such as loose fill and soft estuarine soils, shallow groundwater, contaminants, historic obstructions, small work area, proximity of adjacent buildings, and the on-going excavation and build-out of the adjacent Transbay Transit Center (TTC) train box. Design of the approximately 260-foot-deep drilled shafts (some of the deepest foundations ever constructed in San Francisco) was proven by a full-scale load test that provided unique data on the frictional capacity of the deep soil and Franciscan Complex bedrock in the region. Design and construction of the shoring system for the 5-story basement excavation was exceptionally challenging because of the on-going construction for the TTC. To allow for flexibility during construction, hydraulic rams were placed in a transfer waler along the shared TTC shoring wall that could adjust the forces transferred through to the TTC excavation if required. Open and steady communication between the shoring engineer, the geotechnical engineer, and the shoring/foundation contractor was crucial in order to satisfy the complex constraints of this site.

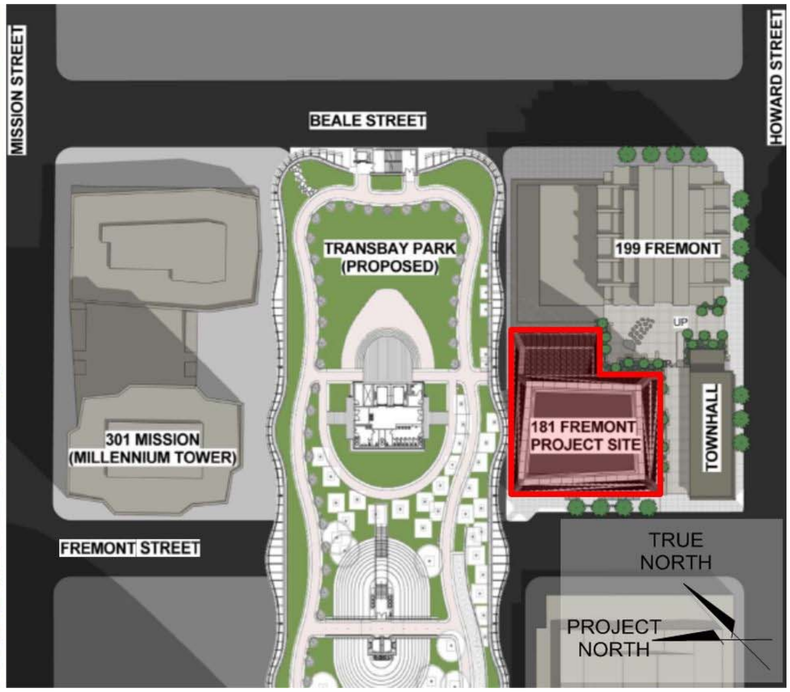
Keywords: Deep Foundations, Drilled Shafts, Excavation Shoring, Osterberg Bi-directional Pile Loadtest, Franciscan Complex Bedrock

INTRODUCTION

The 181 Fremont Tower is a new build mixed-use tower, currently under construction in the dense urban core of the South of Market District of San Francisco, California. This high-rise will consist of 54 above ground floors with the roof level 700 feet high. Atop the roof will be some architectural features including a spire that will top out at just over 800 feet, which will make it the second tallest building in San Francisco upon completion.

The tower is being developed by Jay Paul Company and the architectural design is by Heller Manus. The structural engineer and geotechnical engineer for the project is Arup North America Ltd (Arup). The shoring designer is Brierley Associates (Brierley). The general contractor is Level 10 Construction (Level 10) and the specialty foundation contractor and excavation contractor is Malcolm Drilling Co., Inc (Malcolm).

The tower boasts a unique architectural and structural approach, using exterior mega-cross-braces which provide the lateral stability of the tower during seismic and wind loading. The mega-cross-braces can be seen in the architectural rendering in Fig. 1(a). This approach allows for a more open floor plate as compared to the more common reinforced concrete core approach, which is critical for this building because of the small and narrow site. However, this structural approach creates a challenge for the foundations because the seismic loads are concentrated in the corners. To resist these seismic forces, deep drilled shafts embedded into the Franciscan Complex bedrock were framed into a ring beam pile cap that encompasses the entire perimeter of the building.



(a) (b)

Fig. 1. Architectural renderings of the 181 Fremont Tower site: (a) side view, and (b) plan view (used with permission from Heller Manus Architects)

Below the tower will be a 5-level basement, extending 60 feet below existing grade, which houses a loading dock facility and underground parking. A watertight, stiff temporary shoring system was required to allow the excavation to be performed without adversely affecting adjacent improvements, including a 27-floor tower to the east and a three-story masonry building to the south. The shoring wall along the north side of the excavation is shared with another deep excavation under construction simultaneously for the Transbay Transit Center.

This paper discusses the various challenges and solutions which were navigated by the engineers working on both the design and construction of the subsurface elements. Many of the challenges were created by the dense urban setting which is becoming more of the norm instead of the exception in downtown San Francisco.

SITE CONSTRAINTS

As shown on Fig. 1(b), the site sits directly south of the Transbay Transit Center (TTC), which is also currently under construction. This new transportation facility requires a 60-foot-deep excavation for an underground train box extending over 4 entire city blocks. The TTC excavation was constructed using soldier piles in a Cement-Deep-Soil-Mix (CDSM) cut-off wall and cross lot braces. The excavation for the 181 Fremont basement was designed to share the TTC shoring wall to the north. At the time of excavation, this shoring wall was supported on both sides using temporary walers and temporary struts. Special care was made to design the 181 Fremont shoring support system so that it would not transfer forces in the plane of the shoring wall from the diagonal braces.

To the east of the site lies the 199 Fremont tower. This building holds 27 above ground floors, rising 364 feet in height. It has 4 basement levels which extend to about 50 feet below the ground surface. This building is so close to the site that the 181 Fremont shoring wall was placed directly adjacent to the shoring wall installed for the 199 Fremont basement. 199 Fremont bears on a mat slab foundation.

Just to the south of the site is a small plaza and walkway for the 199 Fremont building. South of the walkway is a small building, 342 Howard Street, also referred to as the “Marine Electric” or “Town Hall” building. It is a three-story masonry building which has a modern seismic upgrade. It has a one level basement and rests on wall footings which frame into driven timber piles through the Bay Mud.

Fremont Street lies to the west of the site. This one-way street provides the main accesses from I-80/CA-101 Bay Bridge into downtown San Francisco. Every morning it is completely saturated, reducing the amount of available traffic lanes which can be procured for temporary construction access. The parking lane and sidewalk have been appropriated for the construction of the tower and is used for deliveries. Other than this narrow strip along Fremont Street and some of the 199 Fremont plaza that is occupied under a temporary easement, the entire site was excavated to a depth of 60 feet below the ground surface (bgs).

SITE SOILS AND ROCK

The site lies near the eastern margin of the San Francisco Bay. In fact, the site was part of the historic Yerba Buena Cove prior to its reclamation in 1853. Consequently, the site soils are sequences of sands and clays which correspond to the fluctuating depositional changes of the bay margin. Fig. 2 shows a typical cone penetration test (CPT) result and an in-situ shear wave velocity test (suspension logging method) juxtaposed with the simplified site stratigraphy. While the thicknesses of soil units varied, because the site was so small, the soil profile presented in Fig. 2 represents the site fairly well.

Fill is found at the ground surface which is underlain by a seemingly random sequence of Holocene marine clays and sands. The marine clay is referred to locally as Bay Mud. Below these interbedded marine deposits lies a stiff, late Pleistocene marine clay referred to locally as Old Bay Clay. Sloan (1992) refers to this clay as Yerba Buena Mud. This clay, deposited during the Sangamon stage when the valley between the Santa Cruz Mountains and the East Bay Hills most likely resembled today’s San Francisco Bay, is relatively homogeneous and slightly overconsolidated. Beneath the Old Bay Clay is a very stiff clay with interbedded sands and gravels that are terrestrial, colluvial, fluvial, and possibly estuarine in origin referred to locally as Valley Deposits. This material has been found to have cobbles and large pieces of wood which would indicate debris flows that filled a valley that once existed between Rincon Hill (to the south) and Telegraph Hill (to the north). Contour of bedrock maps (Schlocker, 1974) indicate that this deep valley would have drained the entire Mission hills watershed.

The bedrock underlying the site soils is the Franciscan Complex. The site sits in the Alcatraz Terrane which consists of mainly sandstones, siltstones, and shale based rock types. The bedrock has a block-in-matrix structure, which is referred to as bimrock (Medley, 2001). Blocks of more competent material are floating in a heavily sheared matrix. These harder blocks and softer matrix are chaotically arranged which adds complexity to the design and construction of the drilled shafts which were embedded in this material.

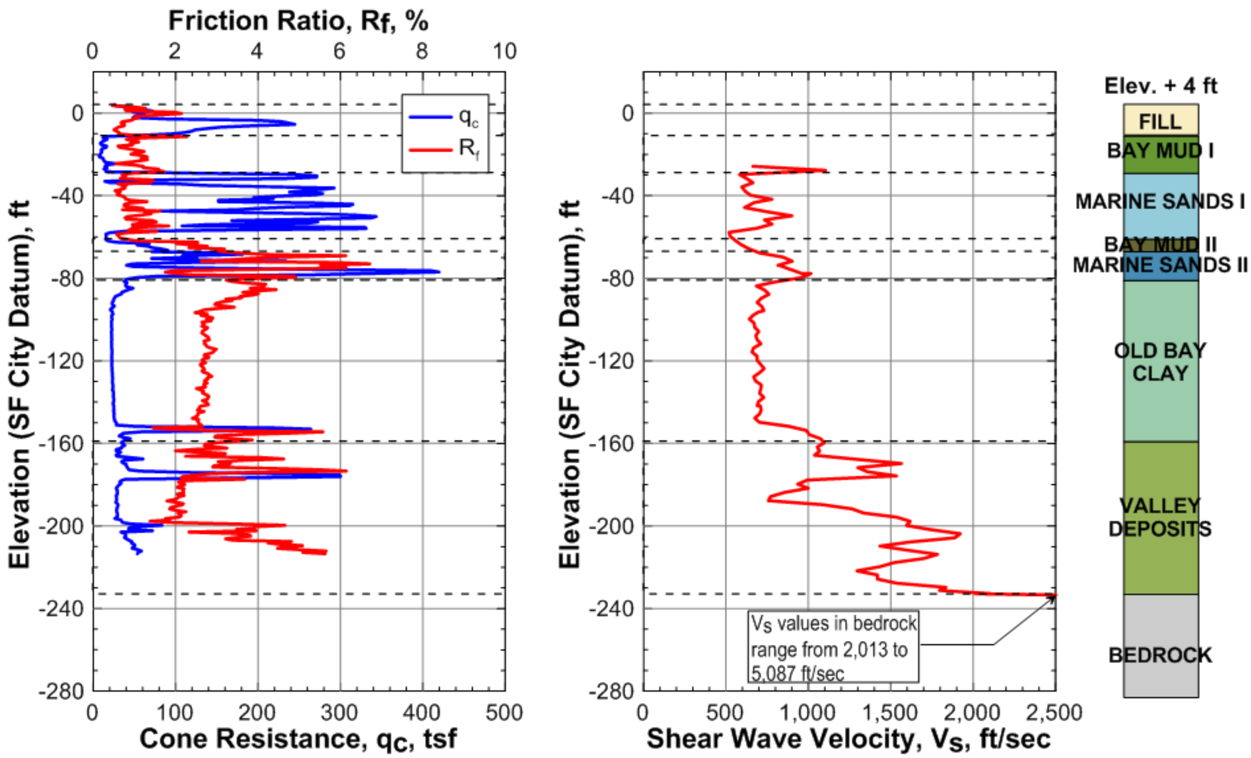


Fig. 2. Sample cone penetration test and suspension velocity test results from the 181 Fremont site.

FOUNDATIONS

Design of the foundation system

The foundation system for the 181 Fremont Tower consists of drilled shafts socketed into Franciscan Complex bedrock. This foundation system was selected at an early stage for the following reasons: 1) net unloading due to the excavation and build-out of the adjacent transit center could enable the formation of a slip surface extending from the southern edge of the tower to the northern edge of the transit center while passing through the bottom of the Valley Deposits, 2) case studies from nearby sites indicate that shallower pile systems can mobilize creep settlement of the Old Bay Clay under heavy loading, and 3) large seismic forces will be mobilized at the corners of the building as a result of the external megabrace system.

Under gravity, most of the vertical building load is resisted by 34 drilled shafts located along the perimeter of the building. Some of the vertical load is also resisted by hydrostatic uplift on the 3-foot-thick base mat and through columns framing into nine drilled shafts in the middle of the building. The design does not rely on forces transferred directly to the medium stiff Bay Mud underlying the base mat.

During wind or seismic loading, most of the lateral forces of the superstructure are resisted by the diagonal megabraces which then must be resisted by columns which land in the six corners of the basement. The maximum axial force that falls on one of these columns in the Maximum Considered Earthquake (MCE) event is too large to be resisted by a single foundation element. The structural engineer first considered using conventional pile caps in the corners of the building to transfer the load between several shafts; however, the loading on these caps would be highly eccentric due to the proximity of the property boundary. Furthermore, each additional shaft would need to be located further away from the location of the corner loads, making these additional shafts less efficient. The solution was to tie all of the perimeter shafts together through a 12-foot-deep by 8-foot-wide ring beam pile cap as indicated in Fig. 3.

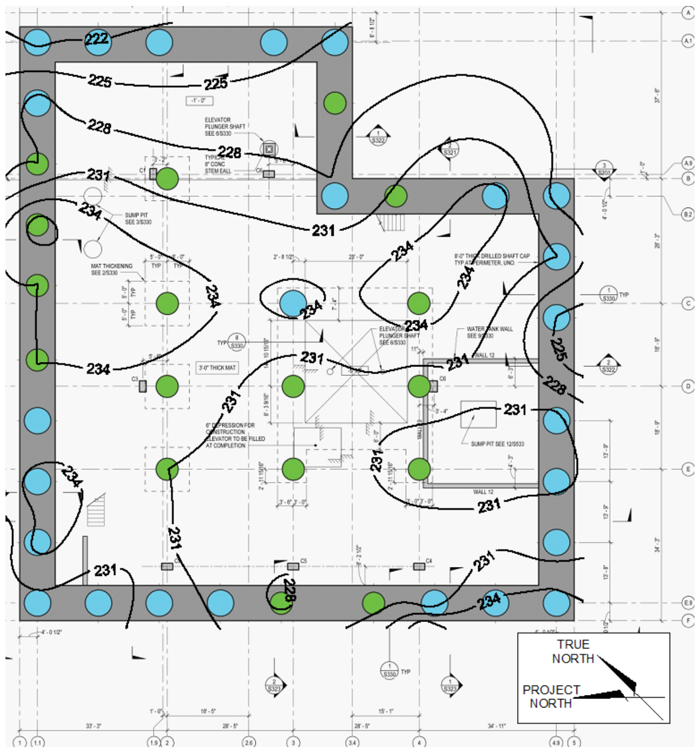


Fig. 3. Plan view of deep foundation system and depth to bedrock contours in feet

Design of the drilled shafts

The deep foundation consists of 17 5-foot-diameter shafts and 25 6-foot-diameter shafts. The tip depth of each shaft was selected to achieve the required ultimate capacity based on the stratigraphy local to the shaft. Although the plan area of the site is small, the depth to bedrock shown in Fig. 3 varies by as much as 14 feet between the east and west ends of the site. The deepest shaft drilled was slightly over 260 feet from the ground surface. The longest rock socket is over 25 feet in length.

Not only do the bedrock contours vary widely across the site, but the composition and therefore the capacity of the Franciscan Complex is very chaotic. This is a reflection of the violent geological activity of the past and (unfortunately) the present in and around the city of San Francisco. Little was known about the load carrying capacity of this chaotic formation since only few full-scale load tests have ever been performed in this material. Unfortunately, all of these tests were on drilled shafts installed with different drilling methods. The project team therefore decided to install one Osterberg bi-directional load cell (O-cell) in a test shaft to assist in the foundation design.

The test shaft was designed to be incorporated into the final foundation system to reduce overall cost. The 6-foot-diameter shaft was socketed 30 feet into the bedrock with the O-cells located 20 feet above the shaft base. Using three 24-inch O-cells on a single plane, an equivalent top down load of 14,000 kips was applied by Loadtest. The shaft displacements, strain gage and load data were analyzed to obtain q-z curves for the shaft bottom and t-z curves in 16 zones along the sides. The t-z curves within the Franciscan Complex reveal more than 20 ksf mobilized unit side shear. These high values were unexpected and are attributed to the selected construction technique with extreme focus on shaft cleanness during the drilling and concreting process. They allowed for an optimized shaft-by-shaft design based on rock conditions and actual load demand.

Construction of the drilled shafts

The deep foundation design required drilling to depths beyond the reach of conventional large diameter rotary drilling equipment. Malcolm's Bauer BG46 rig with an 80-meter-long Kelly bar was used to drill each shaft from existing site grade using drilling buckets and augers. Since the overburden soil layers consisted of loose man-made fill, including old wooden piles, and several sand lenses to depths around 80 feet, Malcolm elected to install temporary steel casing to stabilize these layers. Drilling beyond the casing in the mostly stiff clay layers proceeded under polymer slurry support. The Valley Deposits were believed to pose a significant borehole stability risk due to their loose matrix of gravel and cobble components; therefore, Malcolm decided to use the higher grade KB polymer product family which allows for immediate slurry enhancement with stabilizing additives when loose soil layers are encountered. Upon completion of the excavation of the shafts, airlifting was used to clean the tip.

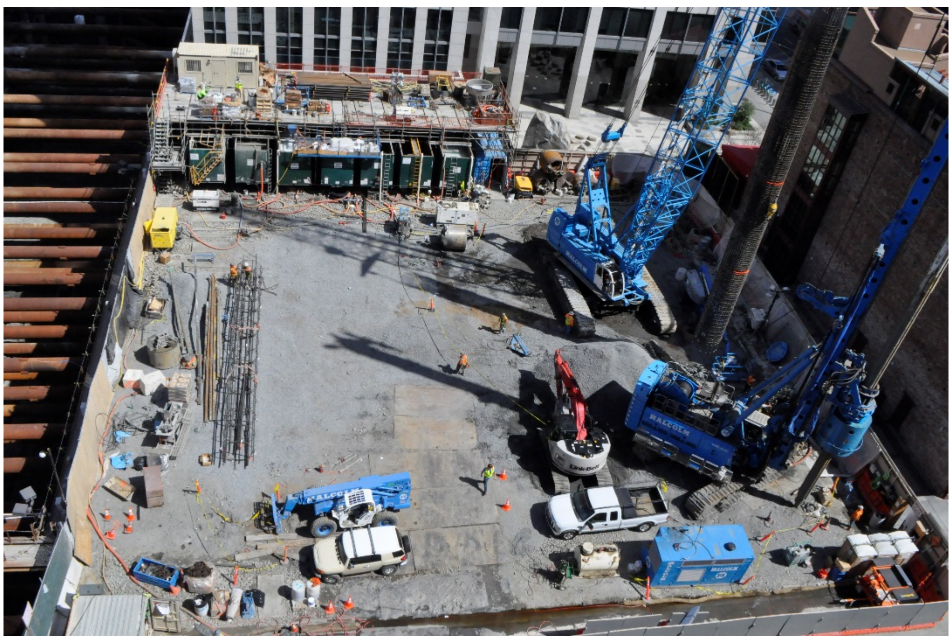


Fig. 4. Overhead view of the 140- by 130-foot 181 Fremont site

Since the 140- by 130-foot site shown in Fig. 4 was located in San Francisco's financial district and adjacent to at least two other major construction projects, traffic and required site logistics were a major driver of all construction activities, for example:

- The rebar cages had to be spliced multiple times over the borehole since delivery of long cages was not possible;

- Slurry tanks had to be moved during production and covered to provide some storage capacity;

- Large deliveries were limited to narrow night time windows and unscheduled events posed a significant time delay risk; and

- Malcolm worked in two shifts (almost around the clock) in close collaboration with Level 10.

The shafts were completed ahead of schedule and no anomalies were revealed by the integrity testing via crosshole sonic logging (CSL). The success of the drilled shaft installation at 181 Fremont is attributable to the close collaboration between the engineers, the general contractor, and specialty foundation contractor as well as the focus on shaft cleanliness until shortly before the concrete pour.

SHORING AND EXCAVATION

Design and construction of the excavation support system

Fig. 5 shows the as-built shoring system with the excavation at full depth. The 60-foot-deep excavation is supported by soil mix shoring walls and an internal bracing system comprised of four bracing levels. Fig. 6 presents a plan view of bracing system. As discussed below, design and construction of the shoring system successfully navigated several site constraints in order to ensure the constructability of the bracing system and the ability to perform the excavation in an efficient manner.

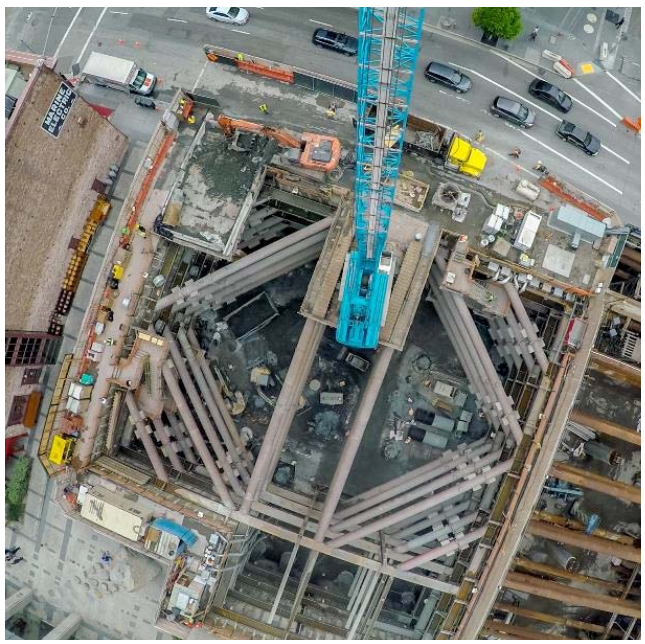


Fig. 5. Shored excavation at full depth

As noted above, the north side of the basement excavation utilized the CDSM wall with embedded soldier piles constructed for the TTC excavation. New 3.3-foot-thick cutter soil mix (CSM) shoring walls reinforced with W30 steel piles were used to shore the west, east and south sides of the excavation. CSM differs from CDSM in that it employs two sets of counter-rotating, vertically mounted cutter wheels to form rectangular soil-cement panels (as opposed to circular secant shafts). The soil mix shoring walls were designed to act as both a stiff structural wall as well as to provide groundwater cutoff. Mixing extended to a depth of 95 feet below existing grade in order to penetrate into the low permeability Old Bay Clay for bottom cutoff.

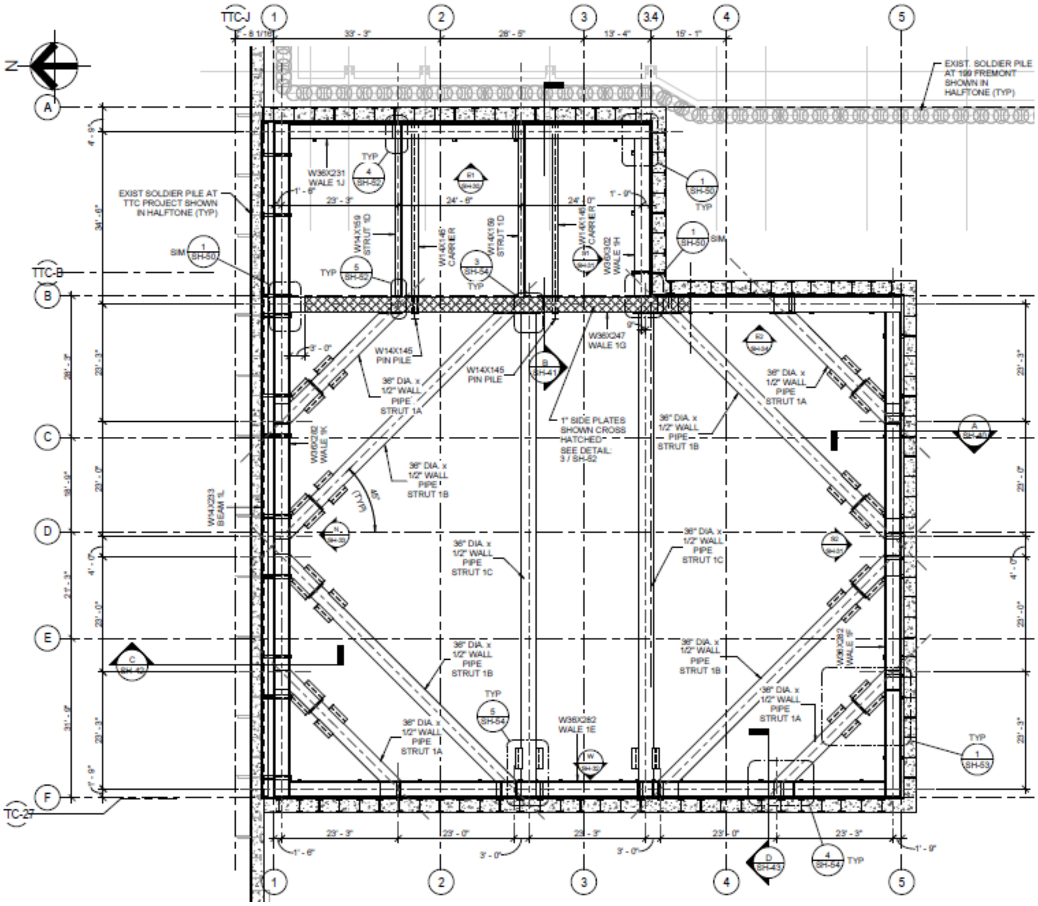


Fig. 6. Plan view of shoring system

The design loads for the internal bracing varied from approximately 23 kips/ft at Level 1 to 71 kips/ft at Level 4. The typical bracing consisted of heavy W36 wales (stacked double wales at Level 4) and 36-inch-diameter pipe struts. In order to ensure a continuity of load transfer across the TTC site to the north, the elevations of the bracing levels were coordinated with the elevations of the internal bracing levels at the TTC project, which were already in place when the 181 Fremont excavation commenced. The bracing elevations also had to consider the planned construction sequence for the new 181 Fremont basement level slabs.

The shoring system was designed to be sufficiently stiff to minimize movement of the adjacent TTC shoring system and to protect the 199 Fremont and Marine Electric buildings against excessive movement. Special bracing details were employed at the shared TTC shoring wall to have a means of controlling the response of the TTC shoring to the 181 Fremont excavation. At this location a pair of wales with spacers were used to provide a gap where jacks could be installed to locally adjust the loads in the bracing system. This detail is shown in Fig. 7. This detail also reduced the potential for longitudinal load transfer between the bracing system and the TTC shoring wall.

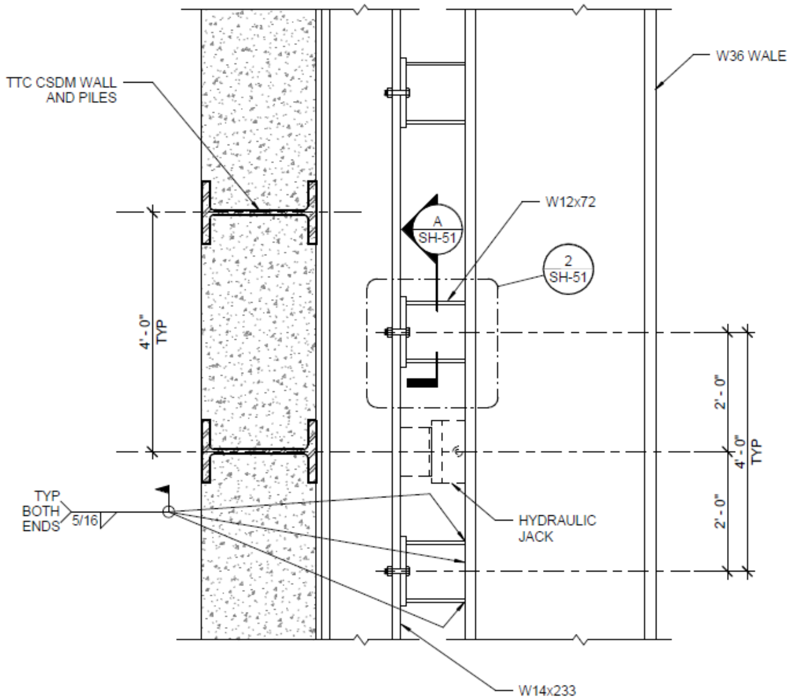


Fig. 7. Plan view of spaced wale pair detail for bracing load adjustment at shared TTC shoring wall

Performance criteria and monitoring

The design criteria limited horizontal deflections of the CDSM wall to 1.0 inches above the top level of bracing and 1.5 inches below the top level of bracing. Compliance with these criteria were assessed by Arup via monitoring of approximately 40 glass prism survey monuments mounted to the tops of the soldier piles in the soil mix walls and 6 inclinometers embedded in the soil mix walls and extending to bedrock. Monitoring of the survey monuments was performed in two-hour increments by extending an automated total station (AMTS) network for the TTC that was installed and maintained by GEO-Instruments. This survey data was made accessible to the contractors, engineers, adjacent property owners and other stakeholders through an online portal managed by Arup known as the *Global Analyzer*. The inclinometers were read manually at roughly two week intervals and interpretation of the data was calibrated against deflections measured at the nearby survey monuments.

The design criteria also required that dewatering within the excavation footprint not lower the groundwater more than 5 feet outside the excavation. Compliance with this criterion was assessed via manual reading of piezometers installed in 2 boreholes: one adjacent to the soil mix wall along Fremont Street and the other adjacent to the soil mix walls near the truncated southeast corner. Two nested piezometers were installed in each borehole that were slotted within the fill and marine sand layers.

The soil mix walls were specified to have a minimum unconfined compressive strength of 200 psi at 28 days. Wet grab samples were obtained for UCS testing from both preproduction and production CSM panels to confirm that the shoring contractor's mix design was achieving this minimum strength. One significant leak (about 3 to 5 gallons per minute) was exposed at a depth of 15 feet below ground surface during the excavation near the truncated corner.

At the time of preparation of this paper, build-out of the basement was underway and lateral deflections had been limited to approximately 1.0 inches or less. The nested piezometers along Fremont Street indicated a reduction in piezometric head of approximately 4 feet; however, as a result of the nearby leak in the CSM wall, the piezometric head of the piezometers near the truncated corner stabilized approximately 11 feet below the original readings.

COLLABORATION OF THE TEAM

The subsurface elements designed and constructed for this project benefitted from positive collaboration between the various teams involved in this project. The collaborative environment was established by Level 10 Construction, the general contractor for the project. They directly hired Brierley Associates, the shoring designer who designed a shoring system that could meet the performance criteria as developed by Arup, the geotechnical engineer for the project. Malcolm Drilling supplied constructability advice which was used by the foundation designer and the shoring designer to optimize the delivered product.

SUMMARY AND CONCLUSIONS

Design and construction of the subsurface elements for the 181 Fremont Tower were completed successfully despite complex site constraints.

While challenging, this project demonstrates that approximately 260-foot-deep drilled shafts can be constructed on a small site in downtown San Francisco if there are inadequate bearing units at shallower depths. In addition, results from a full-scale load test, using the Osterberg-cell method, provided unique data on the frictional capacity of the deep soil and Franciscan Complex bedrock in the region.

Design and construction of the shoring system was complicated by the adjacent Transbay Transit Center excavation as well as the busy roadway and the adjacent buildings, 199 Fremont and the Marine Electric building. To allow for flexibility during construction, hydraulic rams were placed in a transfer waler along the shared TTC shoring wall that could adjust the forces transferred through to the TTC excavation if required.

Such a tight and complex project site requires very close collaboration between the owner, designer, general contractor, and specialty foundation and shoring subcontractor to make it successful. Detailed planning and extra effort up-front (soil investigation, obstruction removal, work sequence, contingency plans) benefits the construction schedule and overall cost. Furthermore, this project demonstrates that the specialty foundation and shoring subcontractor can play a vital role in the decision about the most time and cost-effective construction techniques when consulted ahead of time and not only after things go wrong.

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