

USE OF HIGH CAPACITY MICROPILES TO RESIST SEISMIC OVERTURNING OF COLUMNS

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ABSTRACT

As a result of California State Law enacted in 1994, Sharp Memorial Hospital in San Diego, CA required an extensive seismic retrofit in order to remain in service past January 1, 2015. When built in 1972, the structure was founded on spread footings below the core columns. While these footings remain in service to support static dead loads and live loads, high capacity micropiles were needed to resist overturning moments that would occur at the base of the columns in a seismic event. Rather than tying the micropiles into the existing footings, the micropiles were anchored directly to the retrofitted column base plates. Complicating the installation was the fact that the hospital needed to remain fully operational throughout the entire construction. Not only were the micropiles to be installed in severely limited access conditions, complex management of phase construction, dust control, and spoils management were required to comply with the hospital's infection control policy.

This paper will discuss the complex nature of this project in further detail. Additionally, it will highlight the benefits of how partnering between Contractor, Owner, Engineers, and manufacturers resulted in an efficient, safe, and cost effective solution to an extremely difficult foundation problem.

PAPER

HISTORY

It is well known that the state of California has experienced major catastrophic earthquakes in the past and will certainly experience more in the future. Earthquake related deaths are relatively rare considering only 363 have been recorded in California within the last 100 years. While this may seem insignificant, it is more than all of the other 49 states combined. The low death rate is largely due to laws and regulations passed subsequent to major earthquakes that implement stricter seismic building codes to protect life and property. As a result of this action, the state of California is considered to be the worldwide leader in earthquake resistant design.

One such law was passed in 1973. The Alfred E. Alquist Seismic Safety Act established a seismic safety building standards program under the jurisdiction of The Office of Statewide Health Planning and Development (OSHPD). The act was a result of the loss of life incurred due to the collapse of a hospital during the Sylmar earthquake of 1971, and emphasized that essential facilities should remain operational after an earthquake.

After the Northridge earthquake in January 1994, it was found that hospitals built in accordance with the Act performed well structurally, while those built prior to the Act experienced major structural damage that required evacuation. This led to the passage of Senate Bill 1953 later that same year. The Bill amended the 1973 Act to ensure that acute care hospitals are not only capable of remaining intact after a seismic event, but they can continue operation providing acute care after such an event. The Bill established requirements for hospitals to evaluate their seismic performance for placement into one of five specified Seismic Performance Categories (SPC), and required each acute care hospital facility to attain a specified SPC by specified timeframes.

THE PROBLEM

Sharp Memorial Hospital in San Diego, CA was first opened in 1955. Over the years, the hospital has undergone significant expansion. In 1972, a 9-story structure known as the Central Tower was completed. More recently, a major expansion project was completed in 2009. While the most recent expansion was done in accordance with the latest seismic requirements, the Central Tower was constructed just prior to the Alfred E. Alquist Seismic Safety Act, and was therefore severely deficient. Subsequent to analysis required by SB 1953, the Central Tower was categorized as having an SPC-1, the lowest rating and indicative of the greatest probability of collapse. To remain in service past January 1, 2015, the Central Tower would require significant seismic upgrades necessary for placement into SPC-2. Compliance with this provision would allow the Tower to remain in service until January of 2030.

The deficiency was that the tower would experience unacceptable story drift in a major earthquake. Interestingly, the lower floors of the tower were the problem, mainly due to the close proximity of the tower with adjacent structures. The original structure was founded on spread footings at each of the tower's 8 core columns. The spread footings were not able to resist the large overturning moments expected in a major seismic event. To remedy the problem would require establishing fixity to the columns at the foundation level.

The original design solution was to construct a mat foundation beneath the existing spread footings! When this solution was released for bid, it was difficult to even get a Contractor to agree to commit to pricing this high-risk solution, as it would require tunneling underneath the existing hospital lobby, presenting myriad problems with phasing, reinforcement placement, and safety, all of which would fall under heavy OSHPD Mining and Tunneling scrutiny.

It was clear that a solution utilizing micropiles would be much more feasible from a construction standpoint. Condon-Johnson & Associates, Inc. (CJA) was involved with the project very early in the process and proposed micropiles as a more economically feasible and significantly safer solution. After the General Contract was awarded to Swinerton Builders, the team agreed to explore the feasibility of the micropile solution under the premise that CJA would perform the work if the solution could be approved by OSHPD.

STRUCTURAL DESIGN

CJA and its Geotechnical Consultant, Leighton Consulting Group, worked closely with KPFF Consulting Engineers, the Structural Engineer for the Project, to advise and assist with the micropile design based on their installation and testing capabilities. The resulting preliminary concept design consisted of 76 high capacity micropiles with seismic compression and tension capacities of 2,738 kN (616 kips) and 1,507 kN (339 kips) respectively. The micropiles would support ten of the structure's core columns. Nine of the ten columns utilized 8 micropiles around the column, while the remaining column could only use 4 micropiles due to conflicts with existing utilities. The preliminary micropile section was an 8" diameter pile with casing in the upper 3 m (10 feet) of the pile, reinforced with 65mm (2-1/2") diameter 1034 MPa (150 ksi) all-thread bars.

One of the more unique aspects to the design was to anchor the micropiles directly to retrofitted column base plates rather than to the existing concrete footing or a new cast in place footing extension. The existing column base plates were too small and could not supply the required fixity to the base of the steel columns. The retrofitted base plates consisted of a 2-piece arrangement that allowed installation around the existing base plate after the micropiles were installed. One of the plates was "U" shaped, while the other was rectangular. To tie them into the existing column, gusset plates were welded to the base plates and the existing column. A sketch showing this arrangement can be seen in Figure 1, and a CAD rendering is shown in Figure 2. This solution resulted in very close spacing for the micropiles that were as little as 0.6 m (2 feet).

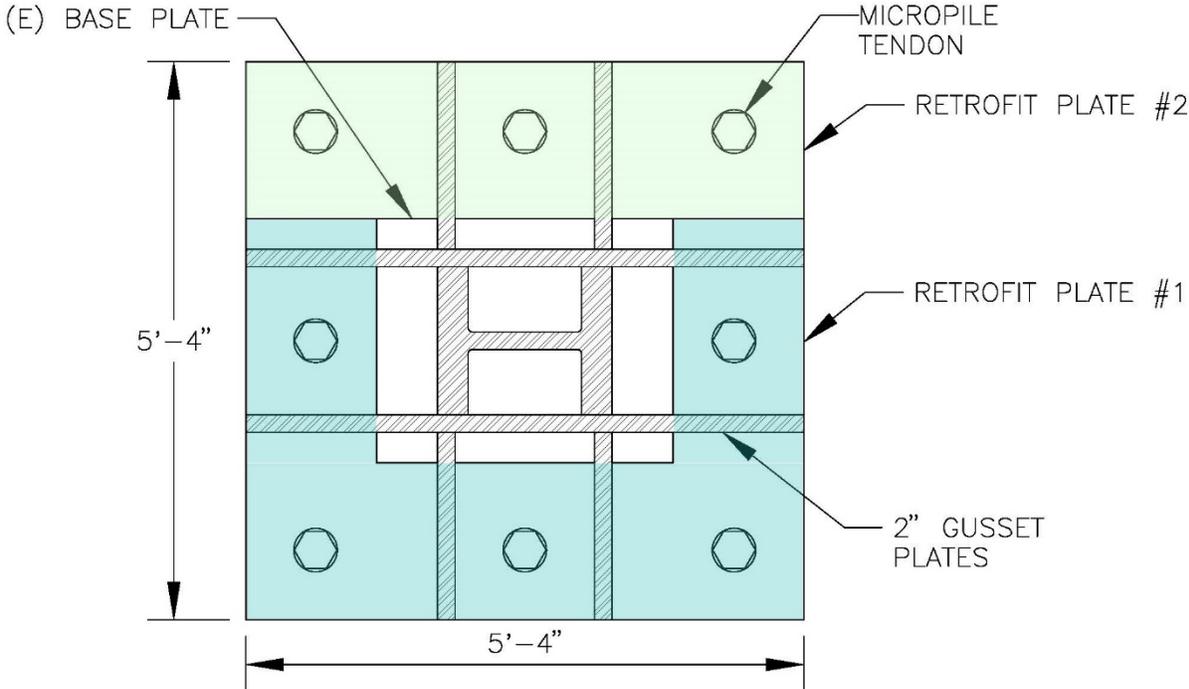


Figure 1: Typical Layout of Column and Retrofitted Base Plate

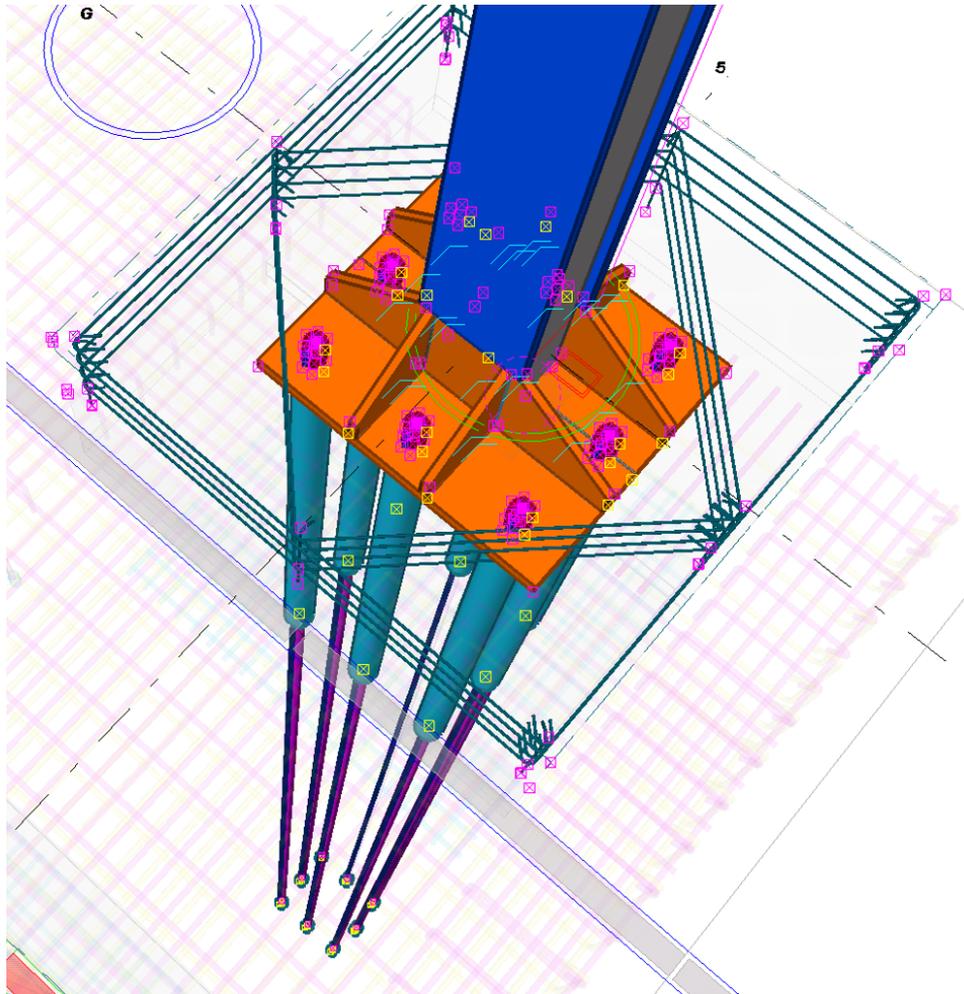


Figure 2: CAD rendering of retrofitted column

GEOTECHNICAL DESIGN AND PRE-PRODUCTION TESTING

Once the concept design was accepted, OSHPD required that all design assumptions be verified by testing prior to granting final approval of the solution. The verification required formal analysis and a report providing design recommendations for the micropiles stamped by a Geotechnical Engineer. CJA contracted directly with Leighton Consulting Group to observe the test pile installation and load testing.

The Sharp Hospital site is immediately underlain by what is known as the Linda Vista Formation, which is a dense silty sandstone extending to a depth of approximately 6-7.6 m (20-25 feet) below ground surface (bgs). Below this is the Stadium Conglomerate, a dense locally cemented conglomerate of sands, gravels, and cobbles. Both formations provide exceptional bond strengths to transfer the high loads. Groundwater elevation was approximately 21.3 m (70 feet) bgs.

Working with Leighton and KPFF, a pre-production test program was developed to load a sacrificial test pile to 3,444 kN (775 kips) in both tension and compression.

Additionally, strain gauges were installed on the test pile tendon that were used to calculate the stress in the tendon at various depths of the pile throughout the test. Reaction piles on each side of the test pile were installed for the compression testing. All three piles were 200 mm (8 inch) diameter and drilled to a depth of 25.9 m (85 feet). The test pile was bored out to 225 mm (9 inches) in the top 4.25 m (14 feet), and an 220 mm (8-5/8 inch) OD casing was set in the top portion of the pile. The piles were reinforced with 75mm (3 inch) diameter 1034 MPa (150 ksi) Williams Threadbar, and grouted with Portland Cement and water grout.

The test pile was loaded incrementally and deflection at the top of the pile were measured and recorded. Total Pile movements at the maximum test load were just over 25 mm (1 inch). The test pile easily met the acceptance criteria, which was consistent with recommendations in FHWA NHI-05-039 (2005), and required that the slope of the load deflection curve was less than 15 mm/kN (0.025 in/kip).

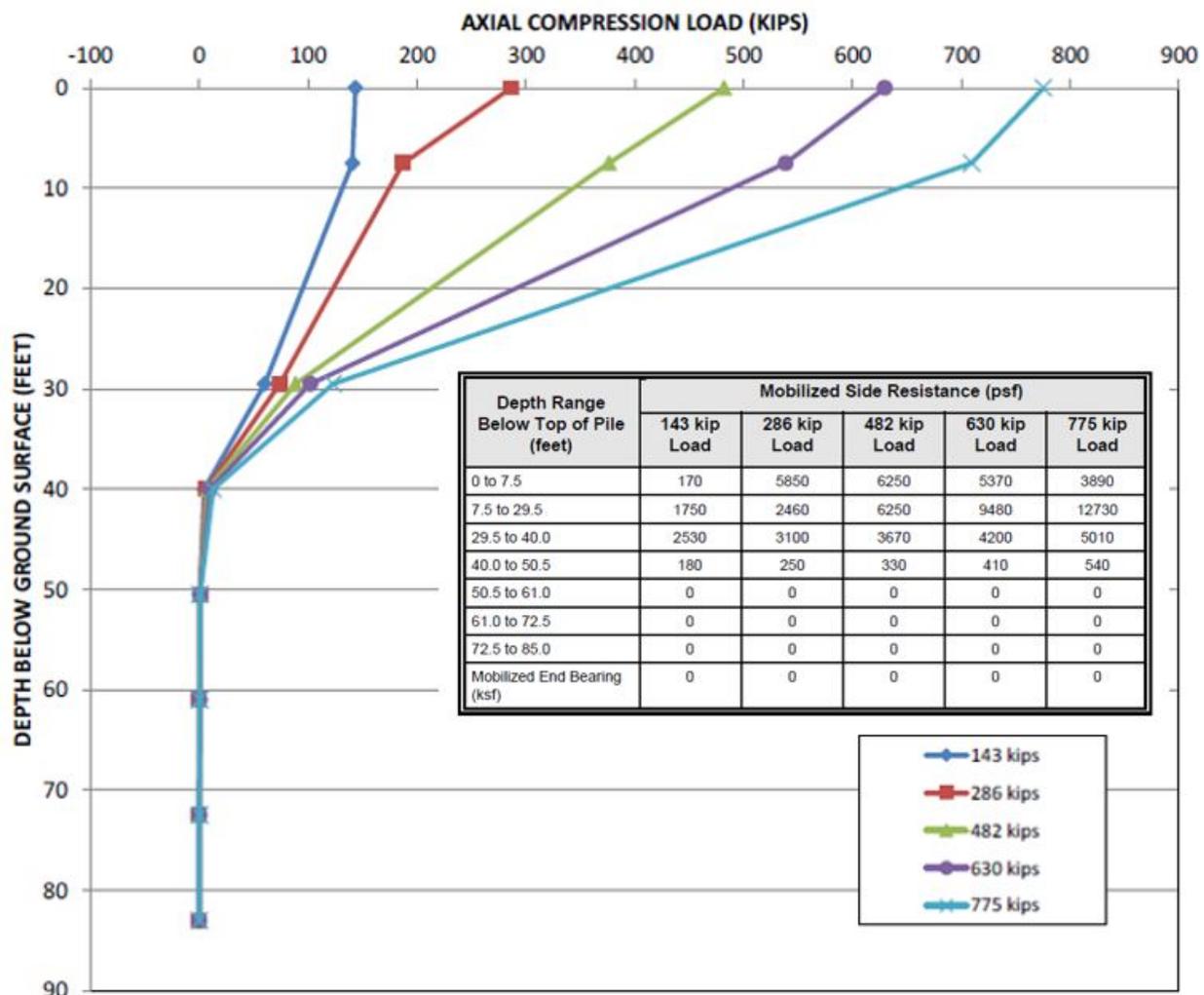


Figure 3a: Graphical Results of Strain Gauge Readings for Compression Loads with inset showing average bond stress within various depth ranges for specific load increments

The data obtained from the strain gauges (Figure 3a and 3b) showed that nearly the entire compression and tension test loads of 3,444 kN (775 kips) were transferred through the top 12.2 m (40 feet) of the pile. This data was used to economize the design by establishing bond stresses much higher than would have been assumed without instrumentation of the testing. The increased bond stresses allowed the production micropiles to be reduced to 18.3 m (60 feet), which put the pile tip well above the groundwater elevation. This simplified installation tremendously since all drilling was done from inside the existing hospital lobby. The final micropile design utilized 65 mm (2-1/2 inch) diameter 1034 MPa (150 ksi) Williams Multiple Corrosion Protected (MCP) Threadbar tendons as reinforcement.

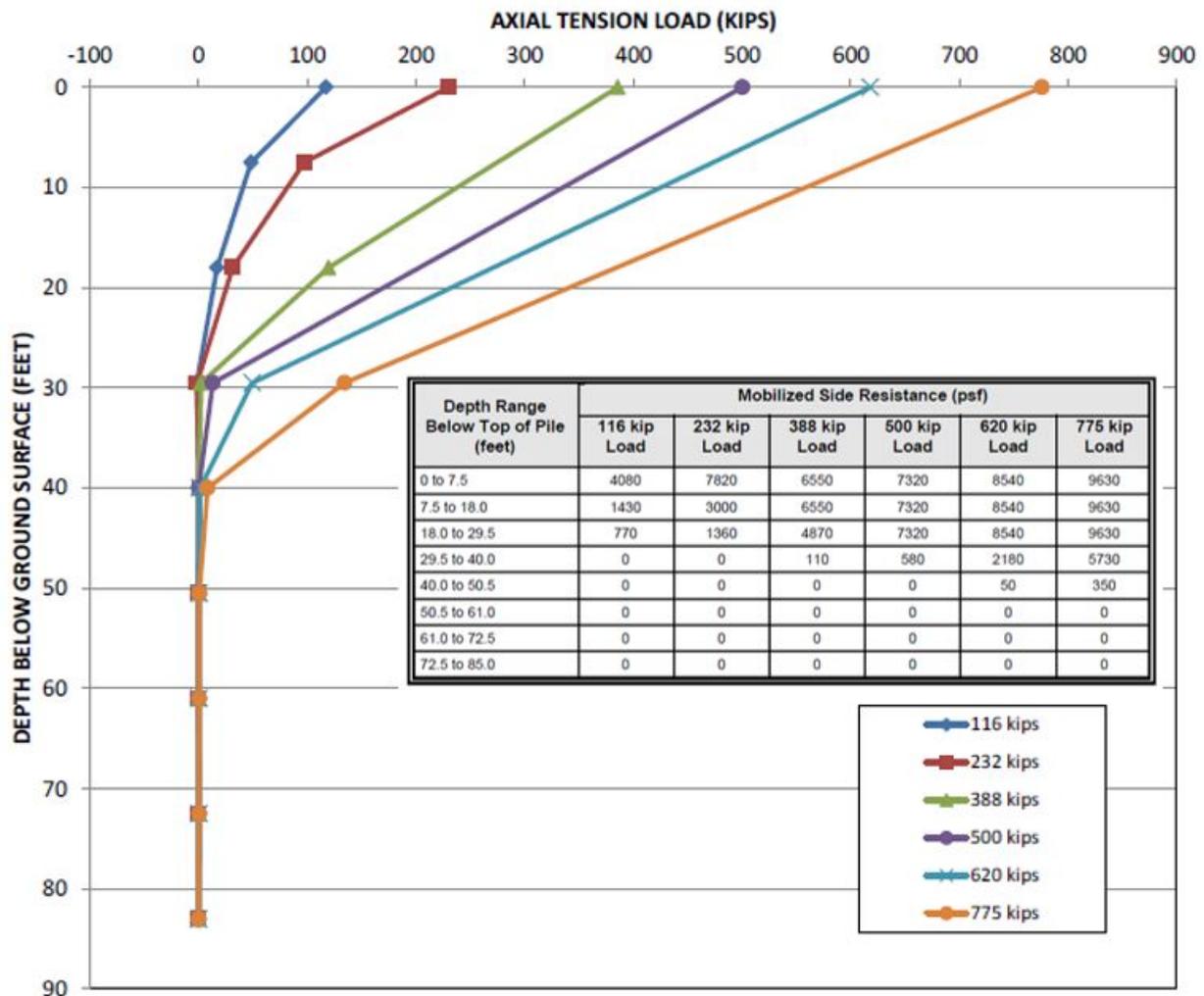


Figure 3b: Graphical Results of Strain Gauge Readings for Tension Loads with inset showing average bond stress within various depth ranges for specific load increments

CONSTRUCTION

Installation of micropiles inside an operational hospital requires extensive planning and specialized equipment to maintain a nearly dust free work area. To minimize the impact to the lobby and maintain required access, the micropiles were installed in four separate phases. Equipment within the work areas was electrically powered, and any diesel fueled equipment was located outside the hospital within a dedicated staging area nearly 91 m (300 feet) away.

A TEI TD75 drill with a single rotary and duplex setup was used to drill the micropiles. This compact rig was able to drill up to a 250 mm (10 inch) diameter hole, and track into the work area through a standard size doorway (Fig 4). The holes were advanced inside the casing using a 125 mm (5 inch) down-the-hole hammer. While casing was not needed to stabilize the drill holes, it was used to facilitate containment of the drill spoils. By fabricating a spoil swivel attached to the casing flushing bell, drill spoils were transported through a vacuum duct to a sealed separation tank, and removed from the work area when full.



Figure 4: Micropile Drill entering hospital

The shortest route between the staging area and the work areas ran through a quiet meditation area known as “The Healing Garden”. This area is adjacent to the

Cancer Treatment Center, and is used by patients and family. Support lines for grout, water, and compressed air, as well as vacuum duct lines had to discreetly run through this area.

The ceiling height within the work area was as low as 2.4 m (8 feet), so the micropile reinforcement had to be coupled with bar lengths of 2.25 m (7'-6"). Even with the short tendon length, each tendon still weighed 79 kg (175 lbs). CJA fabricated a steel tripod with an electric winch to hoist the tendons and suspend them over the hole while they were coupled together section by section.

To comply with infection control protocols, the work areas had to be completely contained to prevent dust and air within the work areas from entering the hospital. This was achieved by setting up temporary barriers and creating "negative air pressure". Negative air pressure is achieved by using vacuum pumps to keep the air pressure in the work area slightly below standard atmospheric air pressure. This way, any minor breaches in the temporary barriers will force air to flow from within the hospital into the work area rather than from the work area out.

Prior to pile installation, the slab was saw cut and the concrete from the area around the column was removed to the top of the footing. Then the existing footings were core drilled at each micropile location to facilitate the pile installation. After the holes were advanced to the correct elevation, the holes were grouted and the drill casing was withdrawn completely. Permanent casing was then set into the fluid grout and the tendon was lowered into the drill hole.

Because the micropiles were to be anchored to retrofitted base plates, location tolerance was extremely tight at only 1.6 mm (1/16 inch). To ensure proper placement of the tendon, template plates were used to hold the threadbar reinforcement in the correct position until the grout had set.

Four of the production micropiles were successfully load tested in both tension and compression to the seismic design capacity. To facilitate compression testing, adjacent production piles were used as reaction piles.

After all micropiles for a given column were complete, the retrofitted base plates were installed (See Fig 5). To facilitate transfer of both compression and tension loads, hex nuts were installed above and below the base plates. Finally, the slab cutout was poured back with concrete to cover the base plate, and micropile tendons to complete the work.



Figure 5: Completed retrofitted column

CONCLUSION

When Engineers are tasked with solving a difficult deep foundation solution, it is extremely beneficial to have the opportunity to consult with the Specialty Contractor that will be installing the work. Understanding the equipment capabilities and tooling to be used for the installation allows the Engineer the ability to optimize the design, resulting in the most cost effective solution possible.

The Owners of the Sharp Hospital Project not only facilitated collaboration, but encouraged further cost savings by approving additional costs to instrument the test pile; an investment that paid off by enabling shorter production pile lengths. The partnering between Owner, Contractor, Designer, and manufacturer on this project fostered excellent communication between the parties, and the final result was a difficult, yet very unique and highly successful Project allowing the hospital to remain open until at least 2030.