When Foundations Settle

Jacking of a Column in a 5-Story Concrete Building

By Dominic A. Webber, P.E., S.E.

Figure 1: Finished building corner and exposed column that experienced soil settlement.

Located in a boutique-shopping neighborhood of Portland, OR, 2121 Belmont is a 5-story residential building using Special Reinforced Concrete (RC) walls for the lateral load-resisting system and post-tensioned concrete for all elevated slabs. Spread footings support columns for the entire 42,000 square foot building footprint. Construction of the building progressed on schedule without unusual complication until placement of the concrete for the roof slab. Once the roof slab was poured, it became evident the foundation under a column in the Southeast corner of the building had settled approximately two inches. The settlement caused cracking in the slab-on-grade and the first-level elevated slab, and damage to exterior metal stud framing that was being installed at ground level. Excessive distortion of metal stud framing was the initial indicator that there was a problem in this corner of the building. While the cause of the foundation settlement has not been officially determined, it was clear that timely corrective measures were needed to avoid delays in the schedule and excessive costs to the project.

Upon being alerted by the contractor, the geotechnical and structural engineers arrived on site to assess safety concerns and to determine a course of action. One speculation on the cause of the problem was that heavy rains had created soil erosion of a utility trench adjacent to the footing, allowing soil below the footing to spread laterally. It was early winter in the Pacific Northwest, typically being the rainy season. It was therefore decided that, before any design solution was considered, soil stabilization was necessary to prevent further column settlement and hopefully mitigate continued damage to the building.

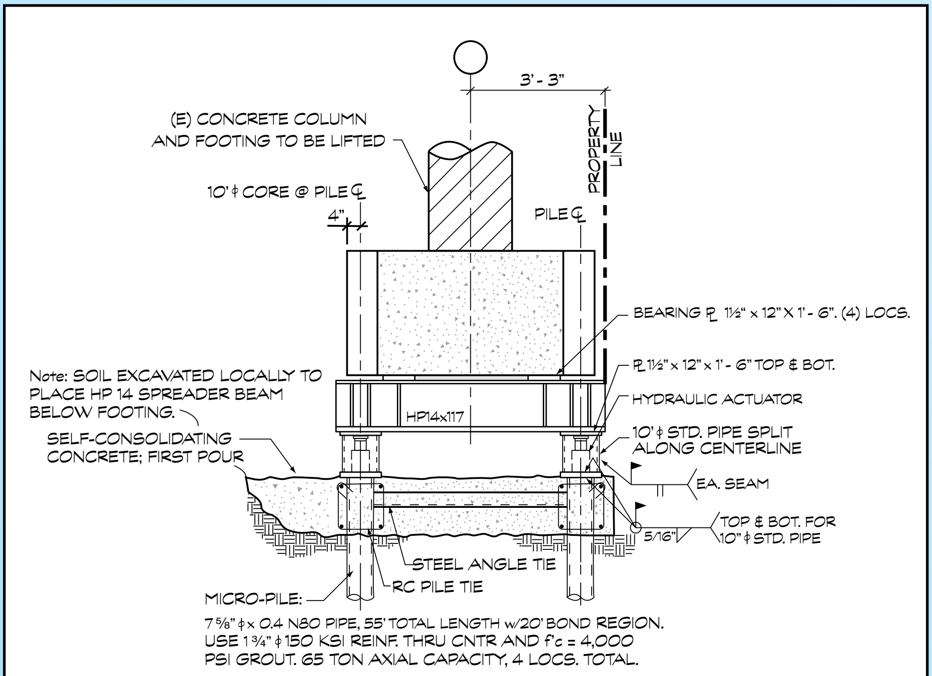

Figure 2: Schematic showing the overall concept of column jacking at the base of the footing. Sacrificial hydraulic actuators, supported by pin piles, raise the footing back into position and will ultimately be encased in steel pipe.

Soil Stabilization

The geotechnical engineer recommended that the apparent loose soil below the footing be pressure grouted with non-shrink or cement-bentonite grout as soon as possible. URETEK ICR, a deep injection process to control soil settlement was identified as the most suitable method. This process can inject polymer more than 30 feet into the soil where the polymer will expand to fill voids in the substrate, there-by minimizing future foundation settlement. To mitigate further settlement for the building, soil strengthening began within three days after soil remediation was recommended. Holes were drilled through the slab-on-grade and the exterior of the structure at an angle to access the soil below the foundation. The expanding polymer was pressure injected into the soil using six probes on each side of the foundation, approximately nine feet deep. Injections were applied at greater depths in the area of ground most affected by weak or unconsolidated soils. This application appeared to arrest settlement of the column, preventing further potential damage to the building and providing the time needed to correct the column settlement issue for the building.

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Constraints in Engineering a Solution

Ultimately, it was decided the column base needed to be raised back to its original level. To accomplish this, a contractor specializing in foundation construction, Scheffler Northwest, Inc., was hired. Engineering a solution for the column jacking required consideration of several items:

1) Since settlement occurred after the roof slab was placed, the spread footing was supporting an estimated 300 kips of structure self-weight.
2) Elevated slabs already constructed restricted headroom clearances for most hydraulic equipment needed for temporary column jacking and the permanent repair.
3) One edge of the settled footing was within inches of the property line. The City of Portland does not allow encroachment into the public right-of-way beyond the property line.

Figure 3: Reinforced concrete ties for the top of piles.

Figure 4: Concrete place to top of pile cap. Actuators are connected to the same hydraulic pump to ensure the lifting load is distributed to the footing equally.

Determining the most appropriate method to raise the footing proved to be the most difficult design task. The original concept proposed by the contractor was to install sacrificial micro-piles on either side of the footing, and span over the top of the footing with steel girders. Hydraulic actuators would be placed on the steel girders attached to a steel collar, which was in turn attached to the concrete column using post-installed anchors. This was considered the safest solution because the footing would not be undermined. The hope was to raise the footing and fill the void with grout. For this solution, the 300 kip column load required numerous large, post-installed anchors into the side of the column. Detailed for seismic considerations of a potential hinge region as required by code, the 24-inch diameter column had #4 spiral ties at a 2¼-inch pitch in the hinge region. Placing these anchors through the longitudinal and spiral confinement of the column was problematic. Also, the quantity needed would have extended the collar connection nearly 7 to 8 feet above the slab-on-grade. Further, the column finish was intended to be exposed concrete, and the visual impact after the removal of the anchors was undesirable architecturally.

Variations of this basic concept were also considered. To avoid scarring the concrete column surface, jacking to shoring in direct bearing below the slab was considered. Since a single floor slab did not have sufficient shear capacity to resist the expected gravity loads on the column, the shoring of each slab to the roof would have been needed. Ensuring adequate support of each upper floor slab from the shoring, to have each slab contribute equally to the resistance of the gravity load, also seemed problematic.

Simultaneous to the design of footing jacking, the geotechnical engineers were taking additional samples of soil around the footing. They found that the soil under the footing was extremely soft and, although strengthened with the expanding polymer, there was sufficient concern in relying on the soil to support the structure in the final condition. Consequently, it was decided that piles would be needed to permanently support the column in its final position.

In consideration of the need for permanent support, the preferred method proposed by the Contractor was to have steel girders span the footing (having the girder supported on either side of the footing by piles) and embed anchors into the footing from above. In this configuration, the post-installed anchors would be used in tension to lift the column and to support the column permanently. This raised numerous structural issues for the final configuration of the column, even if sufficient anchor capacity could be achieved without compromising the footing capacity. Further, this would have impacted the architectural function of the space at ground level.

Ultimately, the final solution was likely achieved only by meeting with the foundation contractor to work out a solution that was constructible, could allow the column to be lifted as needed, and eventually provide the permanent support needed for the column to be structurally competent. Since the footing had to be supported permanently by piles, the primary structural consideration was to place the footing in direct bearing on the piles. This would require placing girders below the footing, lifting the footing using hydraulic actuators to jack against the girders below the footing and tying it off for permanent use. One obstacle to the final solution was how to use the piles to lift the footing, presumably placing the hydraulic actuators directly on the piles, and to have the steel girder framework below the footing also bear directly on the piles for the permanent support. Eventually, it was concluded the only way to achieve this was to sacrifice the hydraulic actuator. Compression-only hydraulic actuators with sufficient capacity to lift approximately twice the estimated gravity loads were found. These actuators could jack the column footing to the needed elevation, and were small enough to be enclosed in a steel pipe for permanent support between the steel framework below the footing and the top of the pile.

Figure 5: Hydraulic actuators encased in structural steel pipe. Pipe is permanent support for the HP 14 spreader beam and footing.

The Final Design

Since most work was within the confines of the building envelope, it was decided that only micro-piles could be used to support the structure. Micro-piles may be installed in sections and only require approximately ten feet of clearance overhead. The micro-pile consisted of a nominal 7-inch diameter, N80 steel pipe casing, 4,000 psi grout and a 1¾-inch diameter high strength reinforcing bar. Having an allowable compressive capacity of 65-tons, the piles were 60 feet deep with a 35-foot bond zone for the high-strength rod. In total, four piles were used and placed symmetrically under the column.

Because the footing was at the property line, the outside micro-piles had to be installed within the footprint of the footing. To maintain symmetry, piles on the opposite edge were also placed within the footing footprint. This was accomplished by core-drilling 10-inch diameter holes through the footing at four locations. Coring the holes reduced the footing cross section, and also cut through longitudinal and transverse reinforcement on either edge. The piles were placed at locations so that the resulting shear and flexure imparted on the footing in bearing would not exceed the remaining strength of the footing.

With the micro-piles in place, a limited amount of soil below the footing was removed. Because it was a property line footing, the footing is relatively long and narrow, measuring 6 feet by 18 feet. Because of its length, calculations suggested that the soil bearing capacity could accommodate some soil removal for the loads currently on the column. A sufficient amount of soil was to be removed so that the steel girders could be placed below the footing and span to the piles on either side. The steel casing of the micro-pile was cut down to accommodate the steel girder depth, the height of the actuator and enough room to provide stability of the pile top. A cap plate was welded to the top of the pile to provide bearing for each hydraulic actuator and eventually support the weight of the column and footing.

With large forces expected at the pile top, it was felt the pile needed to be stabilized in each direction. Deformed bar reinforcement was used to create a grade beam along the length of the footing, and steel angle was used to tie transversely below the footing. Then, self-consolidating concrete was cast to the bearing plate level mitigating any slight out-of-alignment of the piles.

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Figure 6: Self-consolidating concrete cast throughout the excavation to top of footing. Slab-on-grade cast back with reinforcement to resist a lateral load of 10% of the expected maximum column load.

Two HP14 x 117 girders were placed below the footing to span to each pile. Primarily, the HP14 needed to have adequate shear capacity to support the total load computed for the 5-story column. To ensure proper bearing on the HP14, each end of the spanning girder had a bearing plate of sufficient area to accommodate its share of the total column load. Full depth stiffeners were added at each bearing location of the HP14 to prevent any possible web crippling. The bottom of the footing was scraped clean to provide uniform bearing, and the bearing plate was thick enough to avoid any other possible bearing location between the steel girder and the footing.

Four 100-ton compression-only hydraulic actuators were place between each pile cap and the HP14 girder ends. Hoses for each hydraulic actuator were linked to the same electric pump and fitted with quick release couplers. Linking the hoses to one pump was needed to ensure that all hydraulic actuators shared the column load equally. Quick releases were needed to remove the hoses from each hydraulic actuator while still pressurized, thereby maintaining their continued resistance of the gravity loads.

With the hydraulic actuator system in-place, the footing was easily raised back into position. Numerous indicators were used to monitor the lifting of the footing base, but the survey equipment positioned across the street to monitor targets placed on each floor dictated the final position. When the roof of the 5-story structure reached the desired elevation, the column jacking was stopped. Nearly as computed, of the 800 kip total actuator capacity, the demand needed to lift the footing was approximately 350 kips.

Once the footing was back in position, the hoses were removed from the actuators while pressure was maintained to sustain the column load, and each hydraulic actuator was encapsulated with steel pipe. Structural steel pipe had been delivered to the site in lengths longer than was needed. The final length of each hydraulic actuator was measured and the structural steel tube was cut to length. Each tube was split in two and a notch was provided at the base to accommodate the coupler for the hydraulic actuator. While each actuator sustained the needed pressure, the tubes were welded to the pile cap plate, the bottom of the HP14, and along each vertical tube seam. The entire assembly was then encased in concrete.

The final step was to finish the concrete slab-on-grade that was disrupted for construction. Since the new footing was effectively supported on a pile foundation, the footing was tied to the slab-on-grade sufficiently to resist laterally 10% of the expected column load in either direction.

Conclusion

Once it was determined the column footing needed to be raised back to its original configuration, engineering the final solution took approximately 1½ weeks, including several days to develop the solution with Scheffler Northwest, Inc. and several days to work out the details. Construction required approximately 3 weeks to be able to lift the column. The actual process of column jacking took less than an hour, and progressed without any complications. Final installation of steel tubing and refinishing the slab-on-grade took less than two working days.

Perhaps the most critical item of this design was working with the contractor to develop a solution to obtain actuators with enough capacity to lift the column yet small enough to eventually become encased in the steel tube. Once this solution became apparent, which placed the column jacking and the permanent resistance of the column in bearing, the complications of engineering a competent solution diminished.▪

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