Up-Down Construction Utilizing Steel Sheet Piles and Drilled Shaft Foundations

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Abstract
The use of steel sheet pile walls and drilled shaft foundation elements to enable up-down construction methods has been used successfully on recent high-rise structures with multi-story below grade parking. The John Ross Tower and The 3720 Tower in Portland, Oregon each make use of this system and are discussed in-depth. Up-Down construction involves the simultaneous construction of the building levels above and below grade instead of the standard construction technique of excavating and shoring the below grade construction before being able to build upward from the base of the excavation. Advantages of the up-down system include a shortened overall construction schedule, permanent basement walls that double as the temporary shoring walls, elimination of the typical continuous wall footing or grade beam at the building perimeter, increased use of recycled material (steel) while maintaining an overall decrease in total materials, elimination of wall forming costs, decreases in forming costs for slabs, decreases in waterproofing costs for walls and elimination of pile caps and/or footings for the building columns. Lessons learned during the construction of both buildings include the need for more extensive geotechnical boring information, descriptive sheet pile and drilled shaft specifications, a clear understanding from the design team on finished appearance of sheet pile and shafts, and careful consideration of the connection between both slabs and the sheet pile wall and slabs and drilled shafts.

Introduction
The use of driven steel sheet piles as permanent below grade perimeter wall systems combined with drilled shaft foundations has allowed for up-down construction to become a cost effective solution for building erection. Most commonly this type of construction is used for buildings that have multi-level subterranean basements or garages and high-rise towers above. KPFF Consulting Engineers has recently completed two such projects in Portland, Oregon that made use of the up-down construction technique. Both the John Ross and The 3720 are 31-story, 325-foot tall reinforced concrete condominium towers located above 3-story below grade garages.

As the name implies, up-down construction is a method by which a building can be erected in two directions simultaneously. There are numerous options for how an up-down construction project may be sequenced; however, the primary motivation for all of these methods is construction time savings. These savings are achieved by the removal of much of the below grade construction from the critical path of the overall project. In other words, construct the tower above while simultaneously constructing the basement or garage below.

Up-Down Construction
How can a building be constructed without first constructing the below grade supporting structure and the foundations? The answer to this question is that you cannot. The foundations must be in place prior to the erection of the structure above. But how are the foundations constructed if excavation to the foundation level has not first been completed? One answer to this question is the use of drilled shaft foundations constructed entirely from the surface or ground level of a site prior to any excavation work. Drilled shafts or drilled piers, as they also known, are high capacity reinforced concrete columns that are cast in-place inside of pre-drilled, cased or uncased holes. Typically each building column above is supported by a single drilled shaft. In Portland, we have been able to achieve very high tip bearing pressures using shafts embedded into dense cemented gavels that underlay the city. A 3-foot diameter drilled shaft can achieve an allowable compressive capacity of 3,500 kips in combined bearing and skin friction. This high capacity is
the key to being able to support a tall structure with relatively high column loads on individual shafts. The building’s foundation system is essentially complete once the shafts are in place.

The next question that may come to mind is, “How can the below grade structure be built from the top down without having perimeter retaining walls?” A quick and cost effective answer to this problem has been the use of heavy steel sheet piles that are driven from the surface simultaneously with the construction of the drilled shafts. Common sheet piles for use in building construction have a corrugated profile that is made up of rolled steel plate segments that are approximately 28 inches long and 20 inches deep. The segments have interlocking ends that allow them to be driven separately while maintaining good alignment with one another. These are not the relatively thin sheets of corrugated material commonly used as temporary shoring on construction sites. Instead the sections used on these projects have the strength and stiffness of structural steel shapes.

The selection of the sheet pile cross section is based on a number of factors; soil conditions, hydrostatic pressures, temporary and permanent clear spans and vertical loading all affect the size and shape chosen. First and foremost the soil type below the site must be compatible with the section thickness. Soft or sandy soils, clays and silts are easily penetrated by most sections. If cobbles or small boulders are encountered at the site the cross section thickness should be increased so that the objects can be penetrated or pushed aside by the driven pile. A heavy section similar to that shown in Figure 2 was used on both Portland projects for this reason.

Sheet piles do not require a separate foundation system to support them and their tributary floor loads. They are able to carry axial loads through skin friction on their sides and end bearing by embedding the tip of the piles a distance past the lowest below grade level. The AZ type sheet pile sections used at both the John Ross and The 3720 projects were supplied by the Arcelor Mittal subsidiary Skyline Steel of Parsippany, NJ.

The sheet piles and drilled shafts may be installed simultaneously as long as appropriate staging measures are maintained to keep the separate operations from interfering with one another. Once both are completed the ground floor level can be formed on grade and poured over the top of the drilled shafts and flush with the top of the sheet pile walls. The use of a temporary rat slab as a form base helps to assure that the underside of the permanent structural slab is flat. Either conventionally reinforced or post-tensioned slabs can be constructed in this manner. The completion of this slab signals the point at which the construction begins in earnest as a two-

Figure 1: The John Ross Tower (Courtesy of TVA Architects)

Figure 2: Typical sheet pile double section used for below grade building applications. Both projects use an earlier version of this shape. (Courtesy of Skyline Steel)
directional operation. The slab serves as both a work surface for the above grade erection as well as a protective barrier for the construction of the floors below. The above grade construction can progress in a conventional manner while the below grade construction can begin from the top down.

The excavation process associated with up-down construction may add considerable man hours to a project, but the hours are not on the critical path to completion of the above grade structure and can be offset by the savings gained in the simplification of the below grade structure. Although excavation methods vary based on the building geometry, access and layout of the site; a good rough estimate for the time it will take for the excavation to be completed is to double that of a conventional excavation.

**Construction Details**

The construction of the below grade floors can progress with each being formed at the level of the underlying soil below the ground floor slab can be removed once the slab has reached the cure time used with conventional shoring removal (typically 2 to 3 weeks for a conventional two-way slab). The excavation below the slab is similar to a mining process which takes more time and planning than a conventional excavation. Use of low overhead clearance equipment is a necessity during the initial weeks of the excavation. At times hand excavation with small tools is the only method that will remove soil from tight spaces where slab and wall or slab and drilled shaft meet. Openings must be left in the ground floor slab (and subsequent slabs below) for subsequent soil removal from the site. Only the portion of the below grade structure that directly supports the towers was constructed using the up-down technique on both the John Ross and The 3720. The remaining portion of each site was used for easy soil removal from the up-down portion. The photos in Figures 3 and 4 look across the conventionally excavated south half of the John Ross site to the up-down constructed north half.

*Figure 3: Excavation below the ground floor slab begins at the same time as the forming of the 2nd floor at the John Ross. The towers in the background are from a different project.*
excavation and the soil mined out from beneath and down to the next. In some cases it may be more cost-effective to mine out more than one floor at a time and then build back up, in a conventional manner, from below. This type of sequencing is restricted by the vertical span limitations of the perimeter sheet pile walls and the allowable unbraced length of the drilled shafts as they become exposed concrete columns. Both the shafts and the sheet pile walls are laterally braced by the completed slabs and the unexcavated soil below. Removal of up to three floors worth of excavation may be possible with a heavy enough sheet pile wall and large enough shafts. At the John Ross project, the 2nd and 3rd below grade levels were excavated at once below the completed 1st below grade level. This produced temporary clear heights of 20 to 22 feet. The 1st below grade level was the only suspended level poured on grade at The 3720 project. This level was then used as the interface between the tower construction above and the excavation below.

Below grade floors can be attached to and supported by the shafts using adhesive reinforcing dowels drilled into the perimeter of the roughened shaft. Some building owners and tenants object to the inherent roughness of a concrete shaft being poured against soil. The John Ross project made use of uncased shafts which took considerable time and expense to clean, shape, and paint before the below grade parking levels could be opened. This problem can be addressed by encasing the shafts in an architectural wrap or by leaving the steel pipe casing used to support the augured shaft holes as the permanent finish for the exposed height of the shaft. The 3720 project made use of the latter technique and although the cost of permanent casings was added to the project these costs were offset by the savings in time and materials required to clean uncased shafts. The floor slabs at The 3720 were also supported using adhesive dowels which were installed in a thin strip of exposed shaft concrete at each floor level (refer to Figure 6).

A similar welded dowel system or a more conventional ledger angle system can be employed to support the perimeter of the floor slabs where they meet the sheet pile walls. Prior to achieving a listed fire rating in 2005, sheet piles were required to be fireproofed if they were used to support gravity loads from the floors. At the John Ross project we avoided this costly requirement by designing the slabs to be supported entirely by the drilled shafts. The 3720 project was able to take advantage of the fire rating and the floor slabs were attached to the walls for both out-of-plane wall bracing and gravity support of the slabs using welded dowels. The sheet pile walls on both projects...
were cleaned and painted, which helps to give the garages a very bright and clean look.

**Time and Material Savings**

The amount of time saved off the end of a construction schedule using up-down construction depends almost entirely on the size of the below grade construction. The savings can amount to 4 months or more for a 3-story, below grade garage structure with post-tensioned flat slabs and a conventional slab-on-grade at the lowest level. In a world where time is money the shortened schedule has numerous benefits for the building’s owner. Not only does it decrease the overall cost of construction, but it also eliminates months of interest payments on construction loans, allows for building tenants to move into the building much earlier, and allows the owner to secure loans for other projects sooner.

The overall cost savings achieved in an up-down construction project comes not only from the shortened schedule but also from the overall simplification of the below grade structure itself.

Sheet pile seams are welded with a continuous, nonstructural, seal weld that, when completed, creates a solid waterproof steel wall. The seepage rates of sealed sheet pile walls are considerably lower than those of cast-in-place concrete walls. Sealed sheet pile walls are also a more reliable waterproofing system than conventional concrete walls with exterior waterproofing systems. These systems only carry limited warranties which are often voided by contractor installation errors. The elimination of this waterproofing also saves time during construction.

**Preconstruction Considerations**

Having very good geotechnical information at the building site is important for efficient installation of both sheet pile and drilled shafts.

On both of our recent up-down projects in Portland unforeseen below grade conditions caused delays in construction that would normally not affect a conventional construction process. Very large boulders or old building foundations can be impenetrable to sheet pile walls. In some instances pre-drilling ahead of the sheet pile installation may be required. Similarly, drilled shaft production can be slowed considerably in denser soils or where obstructions are encountered. Equipment failures during shaft production can also cause major delays and room should be left in the

![Figure 6: Adhesive reinforcing dowels embedded in drilled Shaft columns. The steel casing was removed for the depth of the slab. Note the difference between the cased shafts in this photo and the uncased shafts in Figure 5.](image)

![Figure 7: The 3720 tower (Courtesy of GBD Architects)](image)
schedule to account for such possibilities. On one recent drilled shaft project a clean-out bucket broke off at the bottom of an 85 foot deep 3 foot diameter drilled shaft hole. The bucket had to be removed since the drilled shafts depend on end bearing for a large percentage of their capacity and since the drilled shaft aligned with a tower column above, it could not be relocated. The process of removing the bucket was time consuming and dangerous.

Specifications that clearly state the tolerances and driving methods of both sheet pile and drilled shafts are essential. The tolerances of both systems can impact parking counts and usable floor areas and should be carefully considered. ACI tolerances for concrete building columns will allow up to 1 inch out of plan location. Drilled shafts are typically allowed up to 3 inches of tolerance. This means that the design team needs to be made aware of potential conflicts that may not exist with conventional construction techniques.

**Conclusions**
Up-down construction has become an extremely cost effective solution for tall building erection. The potential for very large cost savings from reduced time, labor, and materials makes this technique very appealing and should be considered anytime a project consists of a multiple level below grade structure that supports a high-rise structure above. The use of permanent steel sheet pile basement walls and drilled shaft column foundations has enabled the method to become more commonplace.

**References**