# *Inverted Drilled Pier Bells to Resist Uplift*

*By James Corsiglia, P.E., S.E., and Corey Switanowski, P.E., LEED AP*

Often, budget and schedule are the two deciding factors in new building design and construction. For the North Pavilion addition to the existing St. John Hospital in Detroit, Michigan, it was no different. The fast-track construction schedule placed the structural engineering requirements well ahead of the designs of architects and mechanical and electrical engineers. Thus, it was imperative to control project design and construction costs from the beginning.

The steel-framed, seven-story building, which has a full basement, is approximately 285,000 square feet. The building was designed to support the future construction of two additional floors. The main lateral-force-resisting system is composed of steel braced frames (R = 3) supplemented by moment frames, drag struts and collectors. The building has a unique geometry, with the long and narrow bed tower resting on the lower three levels of "pancake" structure. The new building was "tucked" in between existing buildings on three sides, and tied into a fourth building on the remaining side.

During schematic design, the most logical locations for braces were determined to be adjacent to stair, mechanical and elevator shaft openings. Unfortunately, these locations were not the most efficient from a structural standpoint. The logical positioning of the bracing resulted in larger than normal secondary torsional lateral loads. In some locations, the eccentricity between the center of rigidity and the center of load could be greater than 40 feet, rather than the conventional or recommended value of 10-15% of the building footprint.

Adding to the complexity of the project was the task of transferring and resisting extremely high uplift forces, a consequence of designing such a tall and narrow building configuration to resist seismic loading. The braces in some locations generated about one million pounds of net uplift. Explaining a million-pound uplift force to owners and construction mangers is exhausting, to say the least.

The project geotechnical engineer proposed three types of foundation systems for this project – a mat, drilled piers and auger-cast piles. During the due diligence phase, the authors schematically designed all three systems and worked closely with the construction managers to assess which system was most cost-effective, and determine any associated construction restraints. The project team proposed rock anchors and socketed drilled piers as additional alternatives, but these options were priced and deemed not to be feasible.

Drilled piers were ultimately selected as the most appropriate foundation system for the project for two reasons – cost and the fact that the deep foundation system, when compared to the mat foundation system, would not require underpinning of the existing building foundations. The drilled piers for this project were constructed as approximately 80-foot-long foundation elements bearing on competent limestone bedrock.

The typical soil profile at the site consisted primarily of silty clay, which extended about 100 feet below grade to the top of limestone bedrock. A discontinuous layer of hardpan soil, having a thickness ranging from 3.5 to 7 feet, was encountered below the silty clay soils and above the limestone bedrock.

A significant portion of the soil profile consisted of medium to very soft silty clay soils, having unconfined compressive strengths as low as 400 psf. Given the decreasing clay soil strength with depth, the deeper soil layers provided little skin friction. Therefore, the initial design of conventional drilled piers resulted in unrealistic diameters for this type of project. In some cases, preliminary design calculations indicated pier diameters of 11 feet would be required to resist the calculated uplift forces. Immediately, the geotechnical and structural engineers were concerned about constructability. The biggest uncertainties were how to keep the holes open (sleeve the hole or use slurry), how long the holes would be open, and what the effects on adjacent piers would be.

*Clean off.*

*Machine being lowered in open shaft.*

Like most firms, the authors have strong relationships with the industry experts. Working jointly with the construction manager and the local drilled foundation companies, the project team held a pre-construction meeting to discuss constructability and explore any potential ideas for cost savings. Changing the structural system – specifically, relocating the braces – was reevaluated but determined not to be feasible due to schedule implications, so the focus shifted to the foundation system. The contractor proposed intermediate bells along the length of the pier to provide additional resistance.

Unfortunately, the usual belled-shaft piers could not be reliably constructed within the anticipated site soil profile. One of the borings performed during the recent subsurface investigation, and several borings drilled previously at the site, encountered water-bearing silt or sand layers just above the top of bedrock. The presence of saturated granular soils within the profile of the bell increases the likelihood of bell collapse. This posed too great a risk. Therefore, the geotechnical engineer recommended against construction of conventional belled piers.

At this point, the advising drilled pier contractor suggested inverting the bell.

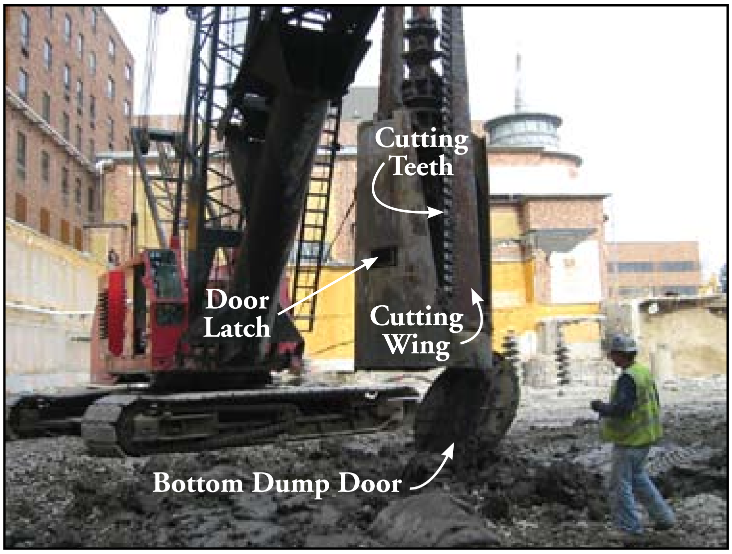

*Diagram 1.*

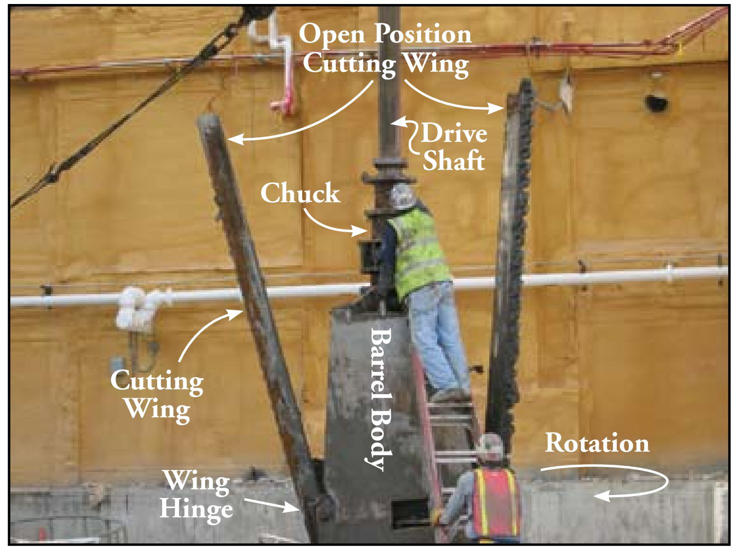

*Diagram 2.*

From a geotechnical standpoint, designing the pier with multiple inverted bells made sense. With a conventional bell, there was potential that the existing soft clay soils situated above the bell would "flow" around the bell when the drilled pier was subjected to uplift force. By inverting the bells, the risk of this occurring was greatly reduced. The inverted configuration logically provided more resistance than a typical bell with an arrowhead-type profile, having the narrowest point aimed upward through the soft clay.

The geotechnical engineer re-evaluated the soil conditions and determined the modes of failure that could occur with multiple inverted bell piers. Certain soil characteristics required further examination, such as skin friction, bearing pressure, and soil unit weight including buoyancy effects. Failure of the soil column situated above a single bell was compared with the failure of the soil column that would be created between multiple bells. The placement of the inverted bells in relation to the soil profile became critical. The geotechnical engineering analysis provided revised soil and design parameters for the structural engineer to review. The inverted bells were designed as unreinforced concrete cone sections. Therefore, the balance between the shaft diameter and bell diameter was factored into the geotechnical and structural analyses.

Once the design parameters for upward bearing capacity, skin friction, and soil weight were established, the foundations were reevaluated. The massive piers of 11 feet in diameter were reduced to 6 feet in diameter by utilizing two inverted bells. The lateral capacity of the soil became the controlling factor in pier diameter. The design limit for head deflection was set to a maximum lateral movement of ¼-inch. The reduction in size for just one pier saved about 200 cubic yards of concrete, not to mention the reduction in slurry, labor and spoil haul off. In addition, although this project is not certified by the U.S. Green Building Council, the reduction in materials and spoil disposal achieved by the re-design would have certainly earned the project an innovation point or two under the Leadership in Energy and Environmental Design (LEED®) program.

The contractor envisioned the use of the inverted pier cutting tool, and was able to design and fabricate the machine. The inverted bell machine works very similar to conventional equipment. However, cutting the inverted bell actually required less time than a conventional bell. The shaft must be over drilled prior to the cutting of the bell to allow the spoils to fall to the bottom and later be excavated.

In the end, being innovative and working with all of the team players saved the owner money. This project demonstrates that approaching challenges as a unified design and construction team, and evaluating the opinions and suggestions of all players, can lead to greater success for all stakeholders.▪


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