Efficient Concrete Pile Design in D.C.

Changing the Face of Deep Foundations in our Nation's Capital

By Karl A. Higgins, III, P.E.

The Washington, D.C., metro area enjoys one of the healthiest building and infrastructure development markets in the United States, particularly in the early 21st century. The region is home to some of the nation's largest building developments. Notable recent projects include the National Harbor Development and the redevelopment of southeast D.C., spearheaded by the recent construction and opening of the new Washington National's baseball stadium.

Until recently, preferred deep foundation alternatives in the Washington, D.C., metro area often included drilled shafts (caissons) and augered, cast-in-place piles. Notable and recent Washington developments are supported on driven precast concrete piles, prompting some building industry leaders to ask, "Why the change?"

Introduction

Building in our nation's capital is expensive. Real estate, labor and materials are all major cost considerations. Having worked on hundreds of D.C. metro building and infrastructure projects, our collective experience indicates that owners want a reliable and less costly foundation, with emphasis on less costly. Let's face it - a building's foundation is "unseen" post-construction (typically). Many decision-makers would prefer to spend a building's cost budget on upgraded interior or exterior features versus a more costly foundation. As such, unless driven concrete piles are the least costly alternative, they are highly unlikely to be selected. So, why the recent trend toward the use of driven concrete piles in the Washington metro area? We believe the reason is price.

Efficient Designs

The Gaylord National Harbor Hotel and Convention Center project was the largest East Coast building project in 2006-2007 and the world's fourth largest building project during the same period. The project is situated on the bank of the Potomac River in Prince George's County, Md., just east of the newly constructed Woodrow Wilson Bridge connecting Maryland to Virginia. The project is a visible component of Washington, D.C.'s skyline and the hotel has views of our nation's capital. The hotel's grand opening was in April 2008.

The Gaylord National Hotel and Convention Center was the catalyst for the Washington Region's overall National Harbor project, the region's largest construction project, described by some media as a city in itself. The construction

Gaylord National appears in the right foreground while National Harbor appears to the left.

value of Gaylord's project is reported to be near $900 million, with the adjoining National Harbor Development, launched by D.C. metro developer The Peterson Companies, at nearly the same value. Gaylord Entertainment of Nashville, the project owner, required a tight construction schedule and a firm opening date in spring 2008. The first project task was installing the foundations for the new 18-storey hotel containing 2,000 guestrooms.

The preliminary geotechnical designs suggested that both auger cast-in-place piles and drilled shafts (caissons) be used. Driven precast concrete piles were considered an "alternative," but one that was believed to be more expensive than auger cast-in-place piles or caissons. Engineering Consulting Services, Ltd. (ECS), the Washington metro area's largest geotechnical consultant, believed that driven, precast concrete piles would be the least costly deep foundation alternative if the geotechnical design capacities could be increased from the preliminary assessments derived by others. ECS was hired by Gaylord Entertainment to demonstrate that driven precast concrete piles were more cost efficient and less risky than other deep foundations previously considered. Fourteen-inch square, prestressed, precast concrete piles with compression capacities of up to 150 tons each were ultimately chosen to support the hotel. Superior cost and schedule considerations, coupled with a high degree of design certainty — every driven pile is a tested pile — resulted in the choice of driven precast concrete piles for the hotel project.

Preliminary precast concrete pile capacities were determined to be on the order of 100 tons per pile. To make driven, precast piles more attractive from a cost perspective, the capacities needed to be increased toward the upper levels of allowable stress limits permitted by the International Building Code (IBC). For the same sized piles originally considered, 14-inch square precast concrete, the capacity estimates were increased to 150 tons per pile, a 50 percent increase from the original estimates. Even higher capacities were feasible, but pile driving times and lengths were limiting factors. Pile capacities in this range were previously thought to be too aggressive in the D.C. metro area considering the variability of the underlying soil deposits. However, a comprehensive test pile program confirmed that individual pile capacities in excess of 150 tons were possible with reasonable embedments into the bearing soils. Proving the higher range of capacities was key to the decision to utilize driven, precast concrete piles for this project.

Schedule was also an important consideration. Because higher capacity piles were considered, fewer were needed as compared to say auger, cast-in-place piles. Fewer piles resulted in smaller pile caps, which also improved the schedule. Overall, preconstruction assessments determined that driven, precast concrete piles would be faster to construct than other deep foundation types, including drilled shafts. The positive schedule impacts of driven piles were a definitive cost-savings measure.

Regional Influence

The positive impacts of efficiently designed, driven, precast concrete piles for Gaylord National spilled over onto the neighboring National Harbor Development, which began construction about one year after the start of Gaylord National, by regional developer The Peterson Companies. The entire National Harbor development cost is estimated at $2 billion. Several of the adjoining larger hotel or mixed-use structures (the Westin or Wyndham Resorts, for example), were also supported on driven, precast concrete piles, designed as efficiently as the project schedule would permit. Considering the construction dollars involved, all serious deep foundation alternatives were considered for the entire National Harbor development. Cost and predictability were key reasons precast concrete piles were chosen and why other deep foundation alternatives were not selected.

National Harbor Development shown on the left, and Gaylord National (not pictured) is to the right.

Undoubtedly, the regional successes of National Harbor have influenced the designers, contractors and owners of new projects planned in the Washington, D.C., metro area, particularly plans for redeveloping southwest and southeast D.C., where soil conditions are similar to National Harbor. The new Washington National's stadium is supported on driven precast concrete piles, and planned building developments in Washington's old "Navy Yard" will also be supported on driven precast concrete piles. Neighboring Arlington's "Potomac Yard" re-development, under construction since 2004, has several buildings supported by higher capacity, precast concrete piles.

ECS began a new building project in 2008, termed "Waterfront" located in southwest D.C. which is supported on 150-ton, relatively short (lengths on the order of 45 feet), 14-inch square precast concrete piles.

Vice-President and project representative, Herb Faling of Vornado said, "I have built buildings supported on drilled shafts (caissons), driven steel piles and auger cast-in-place piles, but never driven concrete piles."

In 10 more years, as the pile driving industry continues to flourish alongside Washington's building boom, we don't expect to hear these sentiments repeated.

Updating Pile Capacity Assumptions for the 21st century

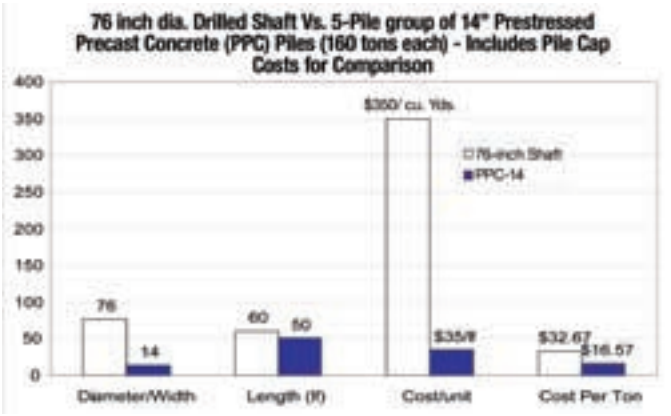
The success of National Harbor was born out of the idea of matching the structural pile capacity with the geotechnical capacity, for an efficient design. This approach has been repeated successfully since. Section 1809.2.3.3 of IBC 2003 states that the maximum allowable pile stress for prestressed piles is f'c = 0.33 f'c-0.27 fpc (f'c is the 28-day concrete compressive strength, fpc is effective prestress). For example, for a concrete compressive strength, f'c, of 5,000 psi and 6,000 psi, the maximum allowable piles stresses are 1,461 psi and 1,797 psi, respectively (assuming fpc is 700 psi). As such, allowable compression working loads for 14-inch precast concrete piles could range from 140 to 175 tons (approximately). The author recalls seeing many late 20th century geotechnical reports, industry training guides, or text book examples with suggested working loads for 14-inch piles in the 75- to 90-ton range.

Increasing the geotechnical design capacities, nearer to the code derived structural limits will produce a more efficient design. A more efficient design is likely to be more cost competitive with other deep foundation alternatives. This strategy is why the author believes precast concrete piles have seen a rise in popularity in Washington, D.C., over the past several years.

Improved Capacities' Impacts on Cost

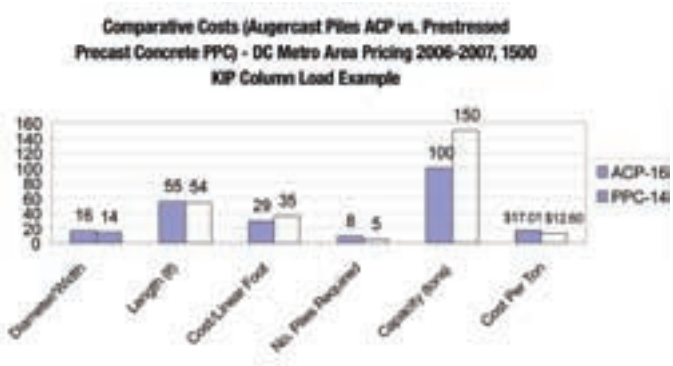
Utilizing higher capacity precast concrete piles makes them more attractive financially. Beginning about 2004, when higher capacity piles in the DC metro area were first considered, proving their cost effectiveness to owners and structural engineers was important. The Potomac Yard redevelopment project in Arlington presented a great opportunity to establish our anticipation of precast concrete piles' cost advantage.

Potomac Yard developers initially expected drilled shafts (caissons) to be the least costly foundation. Our initial assessment was similar; however, once higher capacity concrete piles were considered, their cost advantage became evident. Below



is an example cost evaluation that was prepared for Potomac Yard in 2004-5. Precast concrete piles only became the less expensive alternative (on a cost per ton basis) after their capacities were increased, and the pile group sizes diminished.

During the same 2005-06 time frame, ECS made several other similar cost evaluations for buildings supported on Auger Cast-in-Place (ACP) Piles. Like drilled shafts, ACP piles did possess price superiority, but only when late 20th century PPC pile capacities were applied. Once higher PPC pile capacities were applied, they became the less expensive alternative. Below is an example cost evaluation utilizing the higher range of PPC pile capacities.



Impacts to the Industry

Driving similarly sized piles to higher capacities does impact the pile contractors. Larger ram weights of 1.5 to 2 percent of the test load may be needed to establish minimum pile tip elevations, suitable terminating blowcount criteria, or "prove" the higher capacities during a dynamic testing program. For the 150-ton (300-kip) example mentioned several times above, the required ultimate test load would be about 600 kips (F.S.=2.0). The suggested ram weight may need to be in the 9.0- to 12.0-kip range and larger hammers require larger cranes. In some cases, deeper pile embedments require longer drive times and more total blows, which impact hammer and pile cushions. Hydraulic and air hammers are best suited due to larger ram weights and stroke height control. Large diesel hammers can be utilized if stroke height control can be ensured.

Superior cost and schedule considerations, coupled with a high degree of design certainty (every driven pile is a tested pile) resulted in the choice of driven precast concrete piles for the hotel project.

Closing

We believe that more efficiently designed piles will help the pile driving industry flourish; however, we designers also acknowledge the cost impacts to the contractors in achieving this goal. At least in the Washington, D.C. metro area, there is no one preferred or consistently less expensive deep foundation type. As such, most major building developments explore deep foundation alternatives and the least costly is often chosen.

If the pile driving industry wants to ensure its active participation in today's building market, cost needs to be a part of the equation and efficient pile designs help this endeavor. We encourage more dialogue on this topic within the industry to ensure broad support of driven piles between geotechnical designers and contractors.

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ECS, Ltd. (ECS) is a geotechnical, environmental, and construction materials engineering firm headquartered in Chantilly, Va. ECS' subsidiaries operate 30 offices in the Midwest, Southeast, and Eastern states and employ approximately 1200 people, including registered professional engineers and geologists, certified technicians, technicians, field engineers, and support staff. ECS was established in 1988.

ECS' staff is dedicated to providing responsive and reliable engineering and monitoring service to the construction industry. Experienced personnel support design and construction phases and provide practical guidance on constructability issues. We are also fully committed to providing innovative engineering services.

ECS was recently ranked as the nation's 96th largest engineering firm by Engineering News Record (ENR, April 2007). Additionally, ECS was the only geotechnical firm ranked among the Top 100 Pure Design Firms by ENR. ▼