Effective Use of Steel Piles for a Large Transportation Project in Central Florida

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ABSTRACT: A major transportation improvement project in the heart of downtown Orlando, Florida involved twelve structures at the busy junction of Interstate 4 and the East-West Expressway. The deep foundations consisted of 60,000 meters of driven piles, with a distinguishing feature being the extensive use of steel H-piles on such a large scale transportation project in Florida. This paper describes the inherent advantages of steel pile that were used to ensure the success of the foundation work. Special features characteristic of driven steel piles include the ability to bring production pile sections of various lengths to the site prior to driving test piles, ease of transportation and handling, quick welding and cutoff procedures, low ground vibration, partial installation by vibro-hammers, rapid installation for efficient production, compatibility for low-headroom constraints, and drivability characteristics. The paper presents data and discussions on interesting findings from the dynamic pile testing performed, including the demonstration of high load bearing capacity, subsurface variability and soil setup effects, timeliness of field testing and turnaround for production purposes, procedures to expedite construction, and a comparison between the drivability of an H-pile and a prestressed concrete pile in high rebound soil conditions.

INTRODUCTION

The junction of Interstate 4 (I-4) and the East-West Expressway (SR 408) in the heart of downtown Orlando is the most heavily traveled interchange in Central Florida. Through establishment of a joint partnership between the Florida Department of Transportation and the Orlando Orange County Expressway Authority, a $120 million, 900-day, construction project was undertaken to enhance the safety and flow of the increasingly demanding traffic volume that is an inevitable by-product of the area's rapid population growth. The extensive improvements involved twelve structures including the widening of existing, and construction of new bridges, flyover ramps, viaducts and overpasses. Figure 1 shows a general overview of the project and its location in the congested urban setting of downtown Orlando. All construction was done while maintaining the current number of traffic lanes and capacity during the day on both highways. The twelve structures were supported on a total of 138 foundation units (i.e., bents or piers) consisting of pile groups ranging between 3 and 56 piles per unit. Figure 2 shows a typical driving setup for a large group of bridge pier foundation piles.

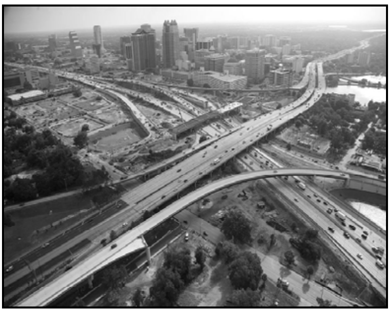


Figure 1: General project overview.

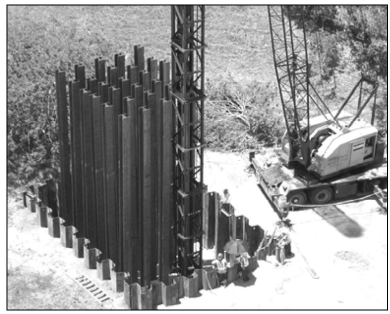


Figure 2: Pile driving at a bridge pier.

Local geologic and geotechnical conditions, structural loading requirements, project and site-specific constraints dictated the use of deep foundations for support of all the structures. A total of 60,000 meters of driven piles were employed, almost all of which were steel piles with minor use of prestressed concrete piles. A distinguishing feature of this project is the extensive use of steel H-piles for a large transportation project in Central Florida. Two steel H-pile sizes were used: HP 12x53 and HP14x89. The inherent advantages of steel piles were utilized to the benefit of the project. This paper describes the engineering, construction and testing practices used that resulted in the effective installation of the driven steel piles, which ensured the success of the foundation work. It also includes data and discussions on interesting findings from the dynamic testing results. Aspects such as high load bearing capacity, soil setup, subsurface variability, timeliness of field testing and related data analysis turnaround for production, effective use of testing to expedite construction, and a comparison between the drivability of an H-pile and a prestressed concrete pile in high rebound soil conditions are demonstrated by examples.

PILING WORK PRACTICES IN FLORIDA

Piling work for transportation projects in Florida typically follows the FDOT Standard Specifications for Road and Bridge Construction (Florida Department of Transportation, 2007). The process in general includes three phases: preliminary evaluation, field testing and data analysis; and recommendations for production pile driving. Initially, information provided by the contractor in the Pile Installation Plan, along with specific project requirements, are used for a preliminary assessment of general adequacy of proposed equipment and methods to install the piles within specifications. This evaluation phase includes Wave Equation Analysis for assessment of the general suitability of the proposed hammer for pile drivability based on the site geotechnical conditions and project structural requirements.

Pile driving activities typically commence with the installation and dynamic testing of a number of test piles at designated production pile locations. Dynamic pile testing is based on the measurement of pile force and velocity records under hammer impacts during initial pile driving and/or restrike. Utilizing Pile Driving Analyzer® (PDA) field equipment, testing results available in-real time on site include information for the assessment of hammer system performance, pile driving stresses and structural integrity, soil/rock resistance and pile static load bearing capacity (Hussein and Likins, 1995). Testing during restrike some time after initial installation is performed to evaluate the time-dependent changes in pile load bearing capacity. Following the field test, representative PDA data is further analyzed with the CAPWAP™ computer program to obtain soil parameters including resistance distribution, damping, and quake for shaft resistance and end bearing. The analysis results also include a simulated static load test relating pile top and tip load-movement relationships.

Results of the dynamic pile testing and related data analyses, including refined Wave Equation Analyses, along with information recorded by the pile driving inspector's installation log, as well as specifics related to the geotechnical conditions in the relevant boring(s), required minimum pile tip elevation, pile top cutoff elevation and other available data are used to issue engineering recommendations regarding production pile lengths and driving criteria. This is done as a cooperative effort between the dynamic pile testing consultant and the project geotechnical design engineer, with input from the FDOT geotechnical engineer. The contractor proceeds by ordering the production piles. For concrete piles, the casting and delivery to the site requires at least one week before production pile driving can start. In the case of steel piles, the contractor typically has the production piles delivered to site in sections of various lengths during, or even before, the Test Pile driving program.

A total of 105 Test Piles and an additional 25 instrumented production piles were dynamically tested for this project. Test Pile data was used for issuing production piles lengths and driving criteria. Production piles were tested for assessment of their static load bearing capacity and structural integrity in cases where the driving criteria was not met or where pile driving exhibited unusual characteristics.

BENIFICIAL FEATURES OF STEEL PILES

The success of the foundation work on this large project depended on the effective use of the beneficial features offered by steel H-piles. The inherent advantages of steel piles were incorporated into a well-planned and coordinated process between the test pile driving, data collection and analysis, and production pile driving. The following presents examples demonstrating the effective use of steel piles on this project.

The ability to bring production piles to the site prior to or at the same time as driving the Test Piles and the ease of splicing by conventional welding made it possible to immediately proceed into production work following driving of the Test

Pile at each pier. The piles were brought to the site in sections with lengths of 9, 12, 15, and 18 m, which allowed for combinations meeting the required production pile lengths. The entire stock of piles needed for the job was stored on site in advance of construction. This feature eliminates construction delays by making it possible to use off-the-shelf pile sections rather than having to wait for custom-made-to-order piles. Production pile driving typically commenced on the same day the Test Pile was driven at a given foundation unit location, and in some cases, the Test Pile and instrumented production piles were installed concurrently.

The relatively light weight and short lengths of the pile sections allowed for ease of transportation to the project and handling on site in the crowded conditions of the urban setting. There was no need for tedious permits or expensive escorts for transporting the piles. Relatively small equipment was adequate for handling and installing the piles at all project locations. The Test Pile for Pier 3 of the Anderson Street over I-4 Bridge was originally designed to be a 610-mm square prestressed concrete pile with a length of 32 m. The location of this pier in a very limited area in the middle of I-4 made it very difficult to mobilize large equipment and safely handle long, heavy piles within extremely close proximity to highway traffic. Using steel H-piles at this pier provided an effective alternative by minimizing the risk that is always present in working close to the traveling public.

A significant portion of the work on this project entailed driving piles within close proximity of in-service bridge foundations. Eighteen residential and commercial high rise buildings were also identified for monitoring. Use of steel H-piles is very suitable for such conditions due to the low level of ground vibration produced by their installation. The project specifications included the standard FDOT requirement of limiting vibration levels to below 12.5 mm/sec. Vibration monitoring was performed using a Safeguard Seismic Unit 2000DK. The monitoring was performed during the driving of over 630 HP 14x89 and HP 12x53 steel H-piles varying in length from 32-40 m at pre-identified locations. The measured vibration levels at all locations were well below the specified Peak Particle Velocity (PPV). No adverse effects were observed on the existing structures due to the nearby pile driving.

Pauses and delays in construction activity normally experienced between the installation of Test Piles and production pile driving were minimized, and in many cases eliminated by the use of steel piles. The construction schedule was expedited by implementing a dynamic pile testing program that was well coordinated with the pile driving activities. In most cases, the piles consisted of two pile sections. The bottom pile sections, mostly 18.3 m long, were installed with a vibro-hammer before splicing on the top sections with the appropriate length for the required pile penetration. For foundation units made up of a few piles, the bottom sections were vibrated and the top sections spliced on and tested during driving. This process typically lasted a total of two days to complete the pile driving for the foundation unit. For large pile groups, the following procedure was typically followed: Test Pile was installed by vibrating the bottom section and impact driving, with PDA testing, of the top section; this process typically took about three hours. While the PDA data was being analyzed and recommendations for production pile lengths and driving criteria were being developed, the contractor vibrated the bottom sections of the production piles. These concurrent activities typically took a day or two depending on the size of the pile group. By the time the engineering recommendations were issued, the contractor was ready to splice on the top pile sections with lengths that meet the required pile penetrations. The concurrent engineering analysis of Test Pile data and partial installation of production piles contributed to the success of the foundation work on this project. In many cases, the work for very large groups was completed in less than a week, including Test Pile and production pile driving.

The Florida Central Railroad Pier 5 crashwall under the I-4 Robinson Street Bridge presented the usual challenges associated with deep foundation construction in low-headroom conditions. Employing short H-pile sections, welding for quick splicing, and relatively small installation equipment was an effective pile driving solution. HP 14x89 sections with multiple spliced 2 m lengths were installed with a vibro-hammer then dynamically tested under a few blows of an impact hammer for verification of load bearing capacity and structural integrity.

The relative ease in which steel H-piles can be installed by vibro and impact hammers, and the absence of constructability issues typically associated with other pile types contributed significantly to the success of the foundation work. Installation of each steel pile typically took less than an hour, including vibrating the bottom section, splicing, impact driving of the top section, and cutoff. Impact pile driving blow counts were generally less than 40 blows/300 mm. Serious difficulties encountered during the driving of 610-mm square prestressed concrete piles were eliminated with the use of steel H-piles. High elastic rebound experienced by the concrete piles at Ramp E and the Anderson Street Bridge prevented the piles from being driven to desired penetration depths, despite the employment of various means and methods. By comparison, steel H-piles drove to the desired penetration depth and load bearing capacity without any difficulty. More details on the comparison of driving concrete and steel H-piles are presented later in the paper.

The geology of Central Florida often dictates the use of varying length piles for a given project, or even within the same foundation unit. Cases have been documented in the technical literature where the use of steel piles was advantageous due to the ease of adjusting pile lengths to accommodate the varied subsurface conditions (Kuhns et al., 2003). On this project, two neighboring steel piles (HP 12x53, 36 m long) at the Church Street Viaduct East Bound Pier 2 foundation unit drove very differently from each other. Pile 1 had a blow count of 240 blows for 150 mm with a hammer stroke of 2.2 m at a pile tip elevation of –1.2 m. Pile 4, located within 2 m of Pile 1, had a blow count of 33 blows for 300 mm with a hammer stroke of 2.2 m and at pile tip elevation of –1.2 m. Pile 4 was driven 2 m deeper and still did not show marked increase in driving resistance; it was subsequently tested during restrike and showed significant setup effects. In this case, one pile was an end bearing foundation while the one next to it was a friction pile. At other locations, the pile length was conveniently adjusted to accommodate the driving resistance effects and load bearing requirements. The use of steel piles in varying subsurface conditions is advantageous to any other type of deep foundations.

H-PILE CAPACITY INCREASE DUE TO SOIL SETUP

This project presented an opportunity for evaluation of soil setup effects on the low-displacement H-piles used. There were occasions where dynamic tests were performed during initial driving and restrike to investigate the change in pile capacity over time for further understanding of the long-term pile behavior and comparison with analytical models used in foundation design. Restrike testing was performed to evaluate the in-place condition of production piles that may not have met the driving criteria or experienced unexpected driving behavior. At Ramp D1, Pier 12 the soils from the surface down consist of 11 m of fine sands (SPT N-values 2 to 12); 17 m of layered clayey & silty fine sands (N-values 4 to 30); 4 m of silty & sandy clays (N-values 20 to 30); and highly over-consolidated clay (N-values > 50) extending to depths of 40 m. At this Pier, a 33.5 m long, HP14x89, pile was driven with an ICE I-30 open-ended diesel hammer (29.4 kN ram weight) to a depth of 30 m and a blow count of 41 blows/300 mm at a hammer stroke of 2.5 m. A 30-minute setcheck indicated a blow count of 8 blows/25 mm at a hammer stroke of 2.6 m. Figure 3 presents plots of PDA measured pile top force and velocity records obtained under hammer blows from the end of driving and restrike tests. Also included are plots of CAPWAP simulated static loads tests results. The results indicate an end of driving pile load bearing capacity of 1800 kN, which increased to 2500 kN after 30 minutes. The data confirmed the development of soil setup effects and the marked increase in pile capacity to a high value in a short period of time.

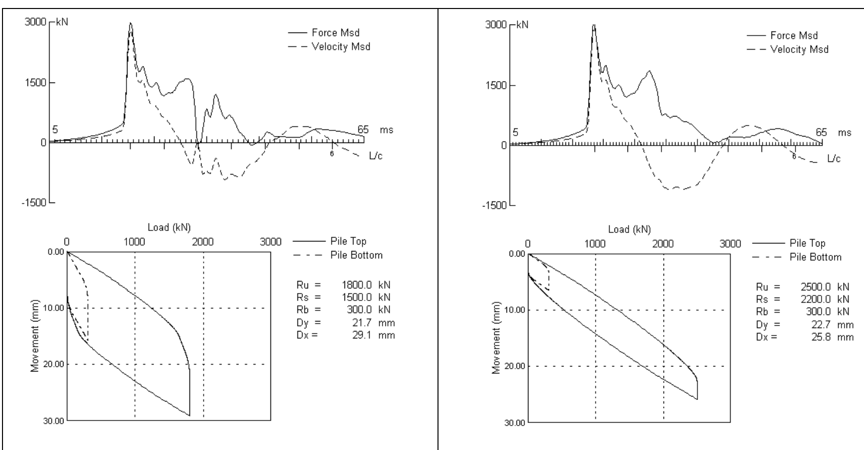


Figure 3: PDA Dynamic pile measurements of pile force and velocity records and CAPWAP analysis generated load-movement relationships for a 33.5 m long HP14x89 pile, from the end of initial driving (left) and beginning of restrike (right).

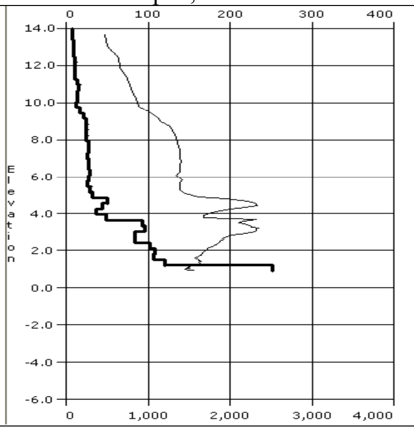
DRIVEABILITY COMPARISON OF CONCRETE AND STEEL PILES

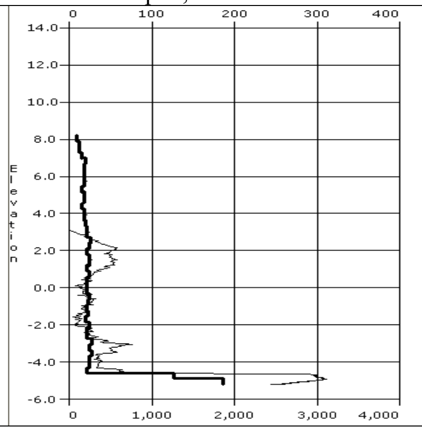
Deep foundations for the Anderson Street Overpass were originally designed using 610-mm square prestressed concrete piles for an ultimate pile capacity of 2800 kN. From the surface down (elevation at +32 m), the soils consist of 15 m of fine sands (SPT N-values 3 to 27); 12 m of sandy/silty clays & silty/clayey fine sands (N-values 2 to 19); and highly over-consolidated clays & clayey fine sands (N-values > 50) to depth of 42 m. The first concrete Test Pile was 38 m long consisting of two 19 m long sections utilizing a mechanical splice. A Delmag D62 diesel hammer (ram weight of 61 kN) was used to drive the pile. Driving was relatively easy with blow counts between 10 and 20 blows/300 mm to an elevation of +5 m where the blow counts steadily increased to a value of 254 blows/280 mm with a stroke of 2.1 m at an elevation of +2.4 m. At the end of driving, the dynamic pile tension stresses were 6 MPa (exceeding the allowable limit for a spliced concrete pile), ultimate pile capacity was 1600 kN, and elastic pile rebound of 30 mm. Several attempts using redrives over time and changes in driving system failed to advance the pile due to the detrimental high rebound effects on pile driveability.

A renewed attempt to drive a concrete Test Pile was undertaken using a 34 m long, one-piece pile. The pile driving blow counts and capacity for this pile are presented versus elevation in Figure 4. The pile met refusal blow counts at elevation +1 m with an end of driving capacity of 1500 kN; the pile elastic rebound was 25 mm and the dynamic tension stresses reached the limit of allowable value of 8 MPa. The high elastic pile rebound and its detrimental effects on pile driveability (e.g., refusal pile driving blow counts with low pile static bearing capacity, high dynamic driving tension stresses, etc.) frustrated all attempts to drive concrete piles at this location. Means and methods to overcome the difficulties included changes to the pile makeup (one piece instead of splices), changes to the driving system (hammer change, cushion changes, etc.), and pile redrive sequences.

An HP 14x89 steel pile, 40 m long, was driven with an ICE I-30 diesel hammer (ram weight of 29 kN) to assess its driveability characteristics at this pier location and compare it to the nearby concrete piles. The driving blow counts and pile capacity for the ending portion of driving the steel pile are presented in Figure 4. Pile driving was easy for the entire pile penetration depth until the design bearing layer was reached where the blow counts reached 189 blows/300 mm with hammer stroke height of 2.9 m and the pile capacity reached 3000 kN. The difficulties experienced with installation of the concrete piles at this location were not encountered during the driving of the steel piles. The deep foundation for this pier, and others, were redesigned to allow for the use of steel H-piles.

Concrete pile, blows/300 mm	Steel pile, blows/300 mm





Ultimate pile capacity, kN	Ultimate pile capacity, kN

Figure 4: Pile driving blow counts and ultimate capacity for 610 mm square concrete pile driven with Delmag D62 hammer (left), and HP14x89 steel pile driven with an ICE I-30 hammer (right).

CONCLUSIONS

Improvements to the heavily traveled junction of Interstate 4 (I-4) and the East-West Expressway (SR 408) in downtown Orlando, Florida involved twelve structures supported on 60,000 meters of deep foundations. A distinguishing feature of this project was the extensive use of steel H-piles for a large transportation project in Central Florida. Utilizing the many beneficial features of steel H-piles in a well planned and executed construction process allowed for a successful project. The paper contains dynamic pile testing data and discussions highlighting the many advantages of steel H-piles and their effective use on this large project. Some of the practical findings and lessons learned were the high load bearing capacity of H-piles, and the relative ease of their driveability in high-rebound soils.

REFERENCES

Florida Department of Transportation (2007). "*Standard Specifications for Road and Bridge Construction"*, FDOT, Tallahassee, Florida,www.dot.state.fl.us: 490-562.

Hussein, M. and Likins, G. (1995). "Dynamic Testing of Pile Foundations During Construction." Proceedings of the ASCE Structures Congress XIII, held in Boston, Massachusetts, www.asce.org: 1349-1364.

Kuhns, G., Hussein, M, and Gray, K. (2003). "Deep Foundations in the Challenging Geology of Central Florida." Deep Foundations Institute's 28th Annual Conference held in Miami Beach, Florida, www.dfi.org: 33-43.