Design of High Capacity Piles
Including Setup and Soil Tightening – A Case History

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ABSTRACT

One of the largest wastewater treatment facilities in the United States, located in Saint Paul, Minnesota, is being upgraded with a new solids processing plant, which is scheduled to go on-line in 2005. Dynamic pile testing was utilized during the foundation phase of the project to aid in evaluating pile capacities and to establish driving criteria. In the pursuit of a value engineering opportunity, the scope of dynamic pile testing was increased in order to evaluate the potential to achieve the design pile capacity at reduced driven lengths. The final pile testing program included dynamic testing of 39 of the 1,955 total pile driven for the project. Some of these pile were dynamically monitored during restrike as long as 60 days after initial drive. The results of the dynamic pile testing program are as follows: better coverage for evaluation of subsurface variability; the elimination of static pile load testing for the project; a reduction in time on the project schedule; the conservation of many tons of foundation materials; and a savings in excess of $1 million in foundation costs. This case history paper will describe how the Case-Goble pile driving analyzer was used and the results obtained.

INTRODUCTION

Facility

The Metropolitan Wastewater Treatment Plant (MWWTP), located in St. Paul, is the largest wastewater treatment plant in Minnesota. The facility is 65 years old and currently serves 62 communities and 800 industries. The new solids processing plant, currently under construction, will handle 400 dry tons of waste per day. The new plant is a much needed upgrade that will replace the existing solids incinerators, thus reducing air pollutant emissions and energy usage, as well as increasing capacity.

Site

The Metro Wastewater Treatment Plant, often referred to simply as Pigs Eye, is located southeast of downtown St. Paul, just northwest of Pigs Eye Lake (thus the nickname). The facility is located within the relatively flat area along the eastern banks of the Mississippi River, in what is termed the Mississippi Bottomland area. Site grades are relatively flat at about elevation 700 to 702. Surface grades rise sharply to the east of the site, where bedrock bluffs are exposed.

Geology of the Area

Bedrock in the Twin Cities area is predominantly marine sedimentary rock of the Early Paleozic age. In this time, a shallow sea covered southeastern Minnesota and the surrounding region, leading to the development of sandstone, shale, limestone, and dolostone.

Soils in St. Paul area were generally deposited by glacial ice and meltwater associated with the last (Wisconsian) glaciation period. Many of the soils which remain were deposited by either the Superior Lobe advance from the northeast, or by the Grantsburg Sublobe of the Des Moines Lobe, which originated in the northwest.

Site Geology

The geology of the Pigs Eye site was significantly influenced by river erosion and deposition before, during, and after the glaciations mentioned previously. A deep buried channel in the bedrock, called the Phalen Channel, passes through the area approximately north to south. Within this buried valley, a bedrock island is present, on top of which the Metro Plant site is located. Colluvial deposits are sometimes encountered along the margins of deep channels, such as the Phalen Channel. Colluvium can be defined as soil, rock fragments, or any combination of these materials which are transported by creep, slide, or local wash and then deposited at the base of a steep slope.

The upper bedrock on the "island" beneath the Metro Plant consists of St. Peter Sandstone, which varies from about 50' to 100' in depth. However, the sandstone "island" drops off rather quickly in all directions, to the underlying Prairie du Chien Dolostone at depths ranging from about 100' to over 500'. The boundary of this "island" is not well defined.

The overlying soils at the Metro plant site include alluvial (water deposited) soils. Typically, the Mississippi Bottomland alluvial deposits consist of waterbearing sand and gravel. However, there are many areas which include interbedded deposits and/or thick layers of finer sediments and organic material. In some areas, the layers of fine sediment act as a confining layer, producing artesian conditions within the lower sand and gravel layers.

PROJECT

New Solids Processing Plant

The Site Preparation Phase of the project included construction of the below-grade portion of the new solids processing plant. The footprint of the structure is about 180' by 422'. The bottom of the 4' thick slab for the structure is at elevation 680, about 20' below existing site grades. This corresponds to about 15' below the normal elevation of the adjacent Mississippi River. The project required installation of a large sheetpile retention system and extensive dewatering in order to create the excavation for the structure.

In general, the existing buildings and structures at the Metro Plant are supported on various diameter pipe pile extended to the St. Peter Sandstone. Installation and performance of these foundations has historically been satisfactory. Therefore, the owner, Metropolitan Council Environmental Services (MCES), had a preconceived notion that driven pipe pile would be the foundation for the new solids processing facility.

Subsurface Investigation

A subsurface exploration program was conducted for the project in December of 1999. The borings encountered a generalized soil profile consisting of fill soils over interbedded layers of alluvial and swamp deposits, which extended to depths of about 70' to 85' below existing site grades. Below these soft/loose soils, a layer of colluvium/coarse alluvium was encountered. This layer consisted of sand, gravel and fragments of limestone, with potential cobbles and boulders. Many of the samples recovered from this layer had limited recovery. The colluvium/coarse alluvium layer ranged from medium dense to very dense, based on the N-values. The upper several feet of this layer was often more dense than the lower portions. Bedrock may have been encountered in two of the borings, at depths of about 75' to 115' below grade. Groundwater was generally encountered at depths of about 4½' to 12' below the surface.

Colluvium

Colluvium is a subsurface deposit produced by the mass movement of soil and/or bedrock material which is shed downslope to an accumulation point. The driving force for this deposition is gravity. The specific mechanisms of colluvial deposition are rather variable, depending on site specific geology and topography; subsequently, they can be quite complex.

Colluvium in the St. Paul area is generally found along ancient or existing river channels. Most of these deposits were created when the underlying sandstone bedrock was eroded and undercut by water action. Erosion of the underlying sandstone removed support for the limestone bedrock above, which then fell and was deposited at the base of a rock bluff. Subsequent falls, as well as river flooding, lead to the infilling of the void spaces between the pieces of bedrock. Therefore, colluvial deposits in the St. Paul area generally contain a wide range of particle sizes, including clay, silt, sand, gravel, cobbles, boulders, and large slabs of bedrock. The resulting deposit is variable in regards to both composition and strength.

Foundation Recommendations

Based on the conditions encountered in the subsurface investigation, the soft and compressible organic swamp deposits within the upper alluvium were judged unsuitable for support of the proposed structure. The geotechnical consultant recommended the structure be supported on concrete filled steel pipe piles. Pipe with 12¾" outside diameter and a minimum wall thickness of ⅜" was recommended. Design working loads of 75 tons (150 kips) in compression and 30 tons (60 kips) for uplift could be achieved by driving the piles to bearing within the colluvium/coarse alluvium deposit. The geotechnical consultant recommended the pile be driven to an ultimate capacity of 250 tons (500 kips), thus providing a factor of safety of over 3. It was recommended that the pile toe be driven about 5' to 23' into the colluvial layer, resulting in estimated pile lengths of 56' to 73' below the bottom of the base slab (elevation 680).

Foundation Design

Based on the geotechnical information, the design engineer (CH2M Hill) designed the foundation of the structure. The pile were designed for an axial working load of 75 tons (150 kips) in compression and 30 tons (60 kips) in uplift. Negative load was not included in the pile design, due to the unloading effect of lowering the site by 20'. Including a factor of safety of 2.0, the desired ultimate capacities were 150 tons (300 kips) in compression and 60 tons (120 kips) for uplift.

A total of 1955 pile were called for, with a perimeter pile spacing of about 3' to 4' and an interior pile spacing of about 6' to 8'. The minimum pile penetration was set at 55', with an average estimated length of 85' (assumes the pile are driven from the base of the excavation at about elevation 680).

The test pile program specified 20 test pile to be dynamically monitored with the Pile Driving Analyzer™ (PDA) and four static load tests be performed, two each to verify both axial and uplift capacity. In addition, it was specified that the dewatering operations maintain a water level at about 2' below the bottom of the excavation. For the static load tests, maximum test loads of 225 tons (450 kips) in compression and 90 tons (180 kips) in uplift were specified.

Site Preparation Phase

The project schedule heavily influenced the actual sequence of events and the refinement of the test pile program. The general contractor was to have the base slab constructed within 230 days of notice to proceed. The pile contractor was to have all the pile, estimated at over 165,000 lineal feet, installed within 245 days of notice to proceed.

The planned construction sequence called for the installation of a sheetpile wall around the footprint of the structure. The sheets were extended down to a minimum elevation of 635 and included deadmen tiebacks. Following wall construction, dewatering of the site was performed in order to allow for excavation of the site down to elevation 678. At this point, a geotextile fabric and 2' rock layer were installed to provide a working platform for construction. The test pile installation and load tests were to be completed within about five weeks, at which point production pile installation would begin.

TEST PILE PROGRAM

Contractor Strategy

In an effort to save time, L.H. Bolduc Company, Inc., the pile driving contractor for the project, wanted to drive a portion of the specified test pile prior to excavation of the site. They believed the pile may achieve capacity with pile toe elevations near the top of the colluvial layer. They also anticipated considerable set-up would be achieved at this site. By installing several of the test pile early, they could determine what pile lengths to order and also allow for a more substantial time for set-up to occur and be verified by dynamic testing.

The pile contractor (Bolduc) requested that MCES consider installing six test pile prior to excavation and dewatering. Because of past successful projects, MCES had confidence in the contractor and they valued Bolduc's expertise. Consequently, permission was granted to install six test pile prior to other site activities.

These first six test pile were installed on December 3 and 4, 2001, and they were dynamically monitored with the PDA at the end of initial drive (EOID). These pile were extended to depths of 54' to 60' below the planned bottom of the excavation, corresponding to pile toe elevations within the top of the colluvial layer. The pile were driven inside the sheetpile area. They where subsequently cut-off and restruck as excavation work proceeded, with the intent of evaluating the effective stress changes caused by the excavating activities.

Initial Six Test Pile EOID Results

CAPWAP's were performed on the EOID data collected from the initial six test pile (TP-1 to TP-6). Because the site would be lowered by 20', the effective stress in the soil profile would be reduced, thus reducing the actual pile capacities from those recorded. Therefore, the CAPWAP capacities of these six test pile were reduced by factoring out the skin friction in the upper 20' of the profile. The results showed evidence that the pile may indeed achieve capacity with toe elevations within the top of colluvial layer.

Having this information in hand, the pile contractor placed his pile order. New rolled pipe in lengths of 55', 60', and 65' were railed to a location within one mile of the site. The pipe was stockpiled there and delivered to the site by truck as it was needed.

Initial Six Test Pile Restrike Results

Following excavation of the site to the planned elevation of 680, final restrikes of the initial six test pile were performed on January 29, 2002, allowing for 56 days of setup after EOID. CAPWAP's performed on the restrike data indicated ultimate capacities ranging from 176 tons to 236 tons (353 kips to 473 kips).

The design engineer was concerned that the initial test pile were within the zone of influence of the sheet pile walls; therefore, the CAPWAP capacities of these first six test pile may be higher than a pile located in the middle of the excavation. In addition, capacities and setup gains were not uniform across the site. Also, a Wave Equation analysis performed by the design engineer indicated a driving criteria that was more conservative than the penetrations observed for the first six test pile. Additional test pile would be needed before a final driving criterion could be established.

Second Ten Test Pile Results

Ten additional test pile were installed on January 29, 2002 (TP-7 to TP-16). These pile were initially extended to depths of about 54' to 57' below the excavation. The following day four of these test pile were extended to depths of 60' to 75', to better evaluate other bearing elevations within the colluvial layer. All of these test pile were dynamically monitored with the PDA at the EOID. Production pile installation commenced following the installation of these test pile.

Restrike testing performed seven days later indicated CAPWAP capacities of 113 to 233 tons (266 to 466 kips). The lower capacities gave credence to the designer's concern that the capacities of the first six test pile may be unrepresentative, due to their proximity to the sheet pile wall. Several of the lower capacity test pile were left at their current penetration, in order to evaluate further setup. In the end, five of these test pile achieved the desired capacity at depths of about 54' to 57'.

The remaining five test pile were extended to depths of 108' to 125'. The piles that were extended actually showed diminishing capacities after penetrating the very dense upper portion of the colluvium. These reduced capacities can be attributed to the density of the layer, as well as artesian effects within the underlying soils. Three of these deep pile where damaged at the end of the initial drive, on what is thought to be boulders and/or slabs present above the underlying bedrock.

Evolution of the Test Pile Program

The test pile results reinforced the idea that the very dense colluvial layer was of variable density and/or thickness across the site. Several of the construction team members requested that consideration be given to abandoning the static load tests, in an effort to perform more dynamic testing and thus provide better coverage over the large building footprint. After much discussion, the static load tests were eliminated and additional dynamic monitoring was approved. A supplemental standard penetration boring was also performed in the base of the excavation. In addition, a tentative driving criteria was established.

The Final Eight Test Pile

The final eight test pile (TP-17 to TP-24) were installed between February 12 and 14, 2002. The first half of these pile were initially driven to depths of about 61'. Restrikes performed the next day indicated the design capacity had not been achieved, so these pile were extended to depths of about 121' to 124'. Restrikes performed the next day showed CAPWAP capacities of 192 to 221 tons (384 to 442 kips) at the deeper penetrations.

The remaining four test pile were driven to depths of about 51' to 55', in order to investigate the possibility of achieving capacity at this general elevation. One of these shallower test pile had a CAPWAP capacity at the EOID of 174 tons (348 kips). The remaining three pile were restruck thirteen days later and indicated CAPWAP capacities of 172 to 194 tons (344 to 388 kips).

Production Pile Monitoring

During the time when the last eight test pile were being installed, personnel at the site indicated that several of the pile within a certain area of the structure were not meeting the tentative driving criteria. At this point, production pile installation was in full swing, with two cranes and crews operating about ten hours a day. Any delay in revising the criteria for this particular area would lead to logistic problems for the pile contractor, which would lead to cascading delays on down the line.

The pile contractor suggested that a few piles in this area be dynamically monitored. The owner agreed and three production pile were monitored at the EOID with the PDA. CAPWAP capacities of 150 to 245 tons (300 to 491 kips) were shown. Consequently, the design team decided to keep the tentative driving criteria. In addition, the "worst" pile in an area of piling not meeting the driving criteria would be monitored with the PDA during a 5 blow restrike after a waiting period of 4 to 5 days.

In the end, 12 additional production pile were monitored during restrike. CAPWAP's performed on the data collected indicated capacity had been achieved in all but one case. CAPWAP analysis of blows taken at EOID and then after installation of nearby pile shown significant gains in the resistance distribution along the pile shaft. These gains are attributed to both soil setup and soil tightening resulting from the installation of the adjacent displacement pile.

Conclusions

The Pile Driving Analyzer was a valuable tool utilized in an evolving project. Through the use of dynamic pile monitoring, the static load tests were eliminated, thus saving the time, material, and labor required to perform such tests. In addition, the PDA allowed evaluation of more test locations and better evaluation of subsurface variability at the site. The expansive coverage, both in terms of area covered and bearing layers tested, allowed the design team and owner to be more confident in the foundation system installed.

The cooperation of the construction team, as well as the experience and expertise of the pile contractor, also contributed to the success of this project. In the end, more than 7 miles of pipe was saved on this project. The result was a savings in excess of $1 million in foundation costs.