Pile Setup on Driven Friction Piles

Pile setup is an effect that can be encountered during driving of friction piles in specific soils. When piles are driven in certain soils (most often fine-grained saturated soils), the geotechnical pile capacity can be significantly lower than the design estimates during initial driving. These pile capacities tend to increase when given the appropriate amount of time, resulting in significant increase in capacity during pile redrive. This increase in capacity is termed pile setup.

Friction piles in fine-grained soils will often regain capacity with time; thus, the design capacity (with depth) is likely to be more representative of the redrive value rather than the capacity during the initial drive. If piles are driven in conditions prone to pile setup and the effects are ignored, the result can lead to significant increased costs for the owner. These costs are commonly derived from an excess number of piles, longer piles or larger piles in order to reach the desired capacity determined from the initial drive.

Our experience with driving friction piles in Northwestern Pennsylvania has helped to better understand and estimate locations in which pile setup is more prevalent. Identifying the potential for pile setup during design reduces the risk of unexpected pile driving results during construction (i.e., more and/or longer piles required).

Friction Piles in Northwestern Pennsylvania

Depending on the soil type and the expected pile loading, friction piles in Northwestern Pennsylvania are generally used where the depth to top of rock is greater than 50 ft (15 m). These piles typically consist of 50 ksi (345 MPa), 12 to 16 in (305 to 406 mm) diameter steel tapered tube pipe piles with a wall thickness between 0.375 and 0.5 in (9.5 and 12.7 mm).

The design of friction piles is commonly performed using both the DRIVEN and GRLWEAP computer programs. The DRIVEN program, which was developed by the Federal Highway Administration (FHWA), calculates pile capacities based on equations presented by Nordland (1963, 1979), Thurman (1964), Meyerhof (1976), Cheney and Chassie (1982), Tomlinson (1980, 1985) and Hannigan et al. (1997). The capacity from skin friction per unit length is calculated by the program using the Nordland Method (1963, 1979). The GRLWEAP program uses a one-dimensional wave equation analysis to model pile driving with various hammer types, and can be used to estimate driving stresses and hammer efficiency based on estimated bearing capacity.

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The drivability and feasibility for specific pile hammer types may be analyzed with GRLWEAP. Piles should be driven until their ultimate design geotechnical capacity is obtained without overstressing the pile itself. In Pennsylvania, the Pennsylvania Department of Transportation (PennDOT) *Design Manual 4* specifies that steel piles can be driven to a stress (at refusal) of 90% of its yield strength. Per *Design Manual 4,* refusal is defined as 20 hammer blows per inch of pile penetration. The criteria for pile refusal may vary from state to state, as outlined in the *FHWA Design and Construction of Driven Pile Foundations* reference manual (FHWA NHI-05-042).

Foundations for private and public projects in Pennsylvania are dictated through a number of design and construction publications. General design guidelines are outlined in the American Association of State Highway and Transportation Officials (AASHTO) *LRFD Bridge Design Specifications Manual,* PennDOT *Design Manual 4,* and *FHWA Design and Construction of Driven Pile Foundations* reference manual, just to mention a few.

determined using a Pile Driving Analyzer (PDA) and Case Pile Wave Analysis (CAPWAP). Sensors are mounted onto the walls of the pipe piles, and the piles driven until the proper capacities are obtained.

What is Pile Setup?

Pile setup (i.e., the increase in nominal axial resistance over time) is defined as the pile capacity at the beginning of restrike divided by the capacity at the end of initial drive. Pile setup commonly can be traced to specific soil types/deposits and groundwater conditions. It occurs over time following the end of pile driving. During pile driving, the soils (most commonly soft fine-grained soils, such as clays or silts) are weakened temporarily by a buildup of excess pore water pressure.

Excess pore pressure reduces the effective stress of the soil and reduces the pile capacity until the dissipation occurs. Based on experience, the capacity of piles after pile setup typically increases to the expected values used in design. Per AASHTO, the time for setup to occur can vary greatly depending on soil composition; clay soils commonly take 7 to 14 days to regain fully the peak soil capacity.

Taper tube pipe piles

Detailed knowledge of the surrounding geology and the results of the subsurface investigation at the project location give insight into what pile capacities may be encountered during initial pile driving. Initial capacities are unlikely to be comparable to DRIVEN results in areas where pile setup is known to occur.

Testing of friction piles typically consists of driving instrumented production piles to ensure the design capacities are satisfied at the design pile depths. Pile capacities are

A summary of the findings from a study of 99 test piles from 46 different sites to determine soil setup factors for different soil layers in contact with the pile shaft is shown in the table, which is reproduced from *FHWA NHI-05-042*. The results in the table reflect nationwide soil setup factors. As shown on the table, setup values for coarse-grained soils are fairly insignificant relative to fine-grained soils.

In addition to the pile setup factors provided by Rausche et al in *FHWA NHI-05-042,* AASHTO provides some guidance as to when pile restrike should be performed. It is important to note that these values are approximate; fine-grained soils and large pile groups can take up to several months for excess pore water pressure to dissipate fully.

If pile setup is expected, it should not come as a surprise that during initial driving the recorded capacity is significantly lower than the design value. Once the pile has been extended to its scheduled depth, pile driving should cease and the proper delay time should be allotted prior to redrive. Driving the pile beyond the estimated pile length (initial driving) will not necessarily result in a significant increase in capacity.

Geologic Background of Pile Setup Locations

The documented pile setup locations presented in this article are located predominately in Northwestern Pennsylvania within the Northwestern Glaciated Plateau Province. Per Pennsylvania Department of Conservation and Natural Resources (DCNR) Map 13, this region is commonly defined as having broad rounded to flat uplands with deep, steep-sided valleys

Sensors being installed on friction pile

Predominant Soil Type Along Pile Shaft	Range in Soil Set-up Factor	Recommended Soil Set-up Factors*	Number of Sites and (percentage of Data Base)
Clay	1.2 - 5.5	2.0	7 (15%)
Silt - Clay	1.0 - 2.0	1.0	10 (22%)
Silt	1.5 - 5.0	1.5	2 (4%)
Sand - Clay	1.0 - 6.0	1.5	13 (28%)
Sand - Silt	1.2 - 2.0	1.2	8 (18%)
Fine Sand	1.2 - 2.0	1.2	2 (4%)
Sand	0.8 - 2:0	1.0	3 (7%)
Sand - Gravel	1.2 - 2.0	1.0	1 (2%)

** Confirmation with Local Experience Recommended*

Soil setup factors (FHWA NHI-05-042)

partially filled with glacial deposits. The topography in this region has been shaped by glacial erosion and deposition. Valleys in this region commonly contain thick silt and clay deposits (stratified drift) in valleys that were formerly ice dammed during a previous glacial period.

Although the orientation of these stratified drift regions may appear random, they are in a roughly orthogonal pattern. The orthogonal pattern is due to fracturing of the rock during the formation of the Rome Trough, which is a regional geologic feature. These valleys were partially filled with comminution till, or subglacial crushed and powdered local bedrock. In general, comminution till consists of poorly sorted sediments skewed toward fine-grained sandy silts and fine sands. Due to the process by which it formed, glacial comminution till is prone to pile setup due to its relative density and low hydraulic conductivity.

Pile Setup in Northwestern Pennsylvania

Five general project areas with 12 test piles where pile setup was observed were analyzed. These areas are in Northwestern Pennsylvania within stratified drift regions. The test piles were driven by different contractors for different projects; however, A.G.E.S. was involved with each project during the design and construction phases. The general project areas are labeled 1 - 5 on the map. PDA instrumentation was used with each of the piles driven at these locations, and pile restrike was performed between 2 hours and 14 days after initial driving. Pile capacities were also determined using CAPWAP.

Soil Type	Typical Delay Time to Restrike
Clean Sands	1 day
Silty Sands	2 days
Sandy Silts	3-5 days
Silts and Clays	7-14 days*
Shales	7 days

** Longer times are sometimes required.*

Estimate for pile restrike (adapted from AASHTO Table C10.7.3.4.3)

For each test site, the pile capacities determined during initial pile driving and during redrive, and the computed pile setup are listed in the table. The data was collected over a period of nine years. In general, pile setup values computed for these locations ranged between 1.0 and 2.0, which are consistent with the factors documented in FHWA NHI-05-042.

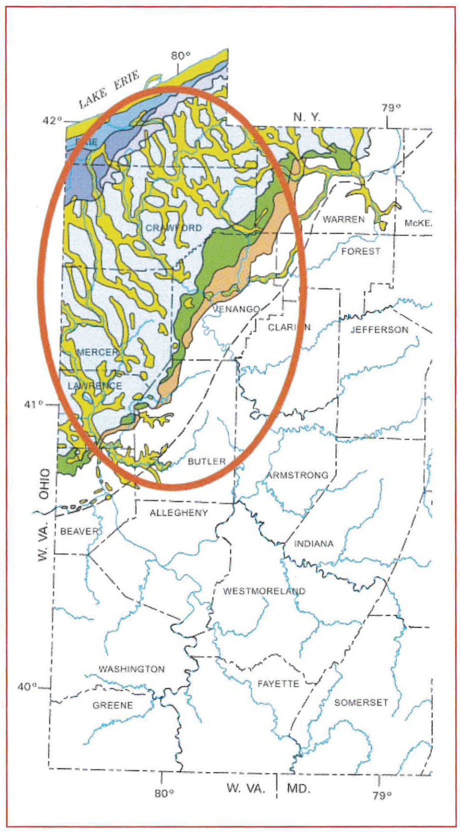
For these project sites, the findings indicate that pile driving in stratified drift deposits may result in significantly reduced pile capacities during initial driving. The pile capacity will re-establish itself once the excess pore water pressure fully dissipates. It is expected that allowing longer time to elapse prior to restrike will result in increased capacities and, therefore, larger pile setup factors. The setup values presented above only include the last restrike value at which point the design capacity was achieved. It is unknown what the final capacity would be if a longer wait time would have occurred prior to restrike.

Final Remarks

The potential for pile setup can be anticipated based on general location, geology and encountered conditions during the subsurface investigation. For Northwestern Pennsylvania, stratified drift (typically consisting of soft to stiff fine-grained soils, or loose to medium dense fine sands) provides the ideal environment for pile setup. These deposits have to be saturated or near saturated for pile setup to occur.

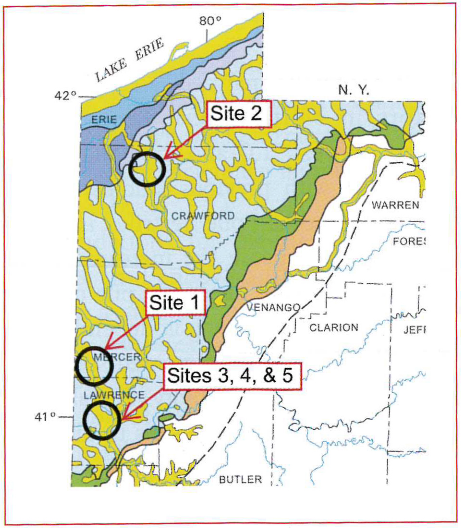
Based on the analyzed cases, pile setup factors in Northwestern Pennsylvania varied between 1.0 and 2.0, and are in agreement with previous studies. At the appropriate time, pile restrike is to be performed to ensure the increase in pile capacity following the initial pile driving. The timing for redriving is dependent on the soil type, and finer grained soils with lower hydraulic conductivity generally take more time than granular soils to dissipate any excess pore water pressure.

It is not uncommon for contractors, engineers and owners to become concerned when pile driving capacities during initial driving do not match the anticipated values.



Stratified drift shown in yellow (modified from DCNR Map 59)

It is important, particularly in regions with thick fine-grained deposits, to avoid the temptation to drive piles deeper (or increase the number of piles), and instead allow the proper wait time for redrive. As the results indicate within the stratified drift zones of Northwestern Pennsylvania, patience will likely result in significantly lower pile lengths (or number of piles) than attempting to reach capacity on initial drive.



Project locations (modified from DCNR Map 59)

Site	Pile	Depth at test (ft)	Capacity: End of Driving (kip)	Capacity: Restrike (kip)	Time	Pile Setup	Soil Type
1	TP1	45.0	110	200	2 hours	1.8	ML
1	TP2	49.0	285	413	14 days	1.4	ML/SM
2	TP1	79.0	54	253	3 days	4.7	ML
2	TP2	71.0	195	352	3 days	1.8	ML
3	TP1	96.5	405	625	6 days	1.5	ML
3	TP2	76.0	256	548	5 days	2.1	ML
4	PA2-1	39.8	458	534	6 days	1.2	SM
4	PA2-6	70.7	291	464	6 days	1.6	CL
5	TA1-3	71.0	310	411	11 days	1.3	ML/SM
5	TA2-4	65.0	317	405	7 days	1.3	ML/SM
5	PA1-1	70.0	245	368	7 days	1.5	SM
5	PA1-6	70.0	279	380	7 days	1.4	SM

Pile capacities at sites in Northwestern Pennsylvania

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