FACTORS CONTRIBUTING TO COST-EFFECTIVE DRIVEN-PILE DESIGN

Driven-pile design is not a commodity service. It requires years of experience and focused study to truly serve the construction and development industries. Wagner Komurka Geotechnical Group, Inc. ("WKG²") has that experience and knowledge. WKG² is a recognized national leader in cost-effective, driven-pile design. This document describes a few of the "tools" in the WKG² "toolbox", which when utilized, can potentially save millions in construction costs and significantly reduce construction time.

Matching Allowable Pile Loads to Structural Load Requirements – Conventional pile design often involves a "one-size-fits-all" approach, such as where one pile section and/or allowable-pile load is used for a project having a wide range of structural loads. This usually results in an inefficient design, where a large quantity of low-allowable-load piles are installed to support large structural loads, or high-allowable-load piles are installed to support small structural loads. Both types of pile/structural load mismatching will result in higher foundation costs.

Piles are below-grade extensions of a structure, and their design should be integrated with the above-grade structure and its load-support requirements. At each pile-supported structure location where load is to be resisted, (e.g., at each column, along load-bearing walls, beneath structural slabs or mats, etc.), structural support requirements consist of two basic components: the design load to be resisted, and the minimum number of piles required to satisfy structural stability. WKG² works closely with the structural engineer to judiciously select allowable pile load(s) based on a project-wide review of these two components, at each structure support location, which promotes cost-effectiveness. Depending on structural support requirements, it may be beneficial to use multiple allowable pile loads/types/sections on a single project.

Higher Allowable Pile Loads – In general, higher allowable loads can result in more-cost-effective foundations for a number of reasons:

- If low-strength soils must be penetrated, a certain length of pile is required, or "invested," just to reach more-competent soils. The higher the allowable load, the greater the return on each pile's "investment."
- While installed pile cost increases linearly with depth (practically speaking), soil strength/pile resistance often increases at a greater rate (e.g., driving a pile 25 percent deeper often results in greater than a 25 percent capacity increase). Hence, pile support cost generally decreases with increasing depth and associated higher allowable load.
- Higher-allowable-load piles result in smaller pile caps, reducing pile-cap costs. Potentially required increased pile-cap thicknesses are more than offset by decreased pile-cap footprints. Increased savings result if pile-cap excavation costs are affected by shoring or dewatering requirements, disposal of contaminated material, etc.

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- Fewer, higher-allowable-load piles result in lower construction control costs (inspection time, dynamic monitoring or restriking a minimum percentage of production piles, etc.)
- Fewer, higher-allowable-load piles result in a shortened driving schedule.

Soil/Pile Set-Up – Soil/pile set-up is a time-dependent increase in driven-pile capacity. Set-up is primarily related to increased shaft capacity, and can provide a significant contribution to long-term capacity. WKG^2 has documented as much as 80 percent of a pile's long-term capacity being attributable to set-up (e.g., a pile with an initial capacity of 150 tons exhibited a capacity of 750 tons on the order of a month later). Incorporating set-up into design and installation can increase cost-effectiveness and reduce construction schedules by:

- Achieving higher allowable pile loads
- Using smaller pile sections
- Terminating piles shallower
- Using smaller installation equipment (cranes and hammers)

Set-up can be characterized and incorporated by:

- Using presumptive values
- Performing dynamic monitoring, including signal-matching analyses, during installation and restrike testing
- Delaying load testing

A properly designed, implemented, and interpreted project-specific testing program can characterize set-up as a function of depth, to produce depth-variable installation criteria (as a pile is driven deeper, more set-up occurs, and less end-of-drive capacity is required) for multiple allowable loads. Such criteria results in piles being driven no deeper than required.

Balancing Allowable Geotechnical and Allowable Structural Loads – Pile design must take into account both an allowable geotechnical load, and an allowable structural load; one of which will govern design. If a pile installation has significantly more allowable geotechnical load than allowable structural load, available soil resistance is wasted, potentially manifested as unnecessary pile length. If a pile installation has significantly more allowable structural load than allowable geotechnical load, available additional structural support is wasted, potentially manifested as unnecessary pile size or material strength. Relatively balanced allowable geotechnical and structural loads may result in a more-economical design.

Pile Type – Pile type selection based on the desired allowable load(s), and subsurface conditions contributes to cost-effectiveness. For example, tapered piles are well-suited for granular soils; timber piles may be considered for relatively low allowable loads, steel Monotube or Tapertube™ piles may be considered for relative high allowable loads; H-piles are well-suited for predominately end-bearing conditions; displacement piles are well-suited for predominately shaft-resistance conditions and/or soils exhibiting

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significant set-up (closed-end steel pipe, and pre-stressed concrete, are examples of this pile type).

Pile Material – The material of which a pile is constructed may affect cost-effectiveness. Steel is more expensive than concrete, both of which are more expensive than timber. Strictly from a material-cost standpoint, and all other things (granted, a lot of things) being equal, a timber pile is less-expensive than a pre-stressed concrete pile, which is in turn less-expensive than a concrete-filled pipe pile, which is in turn less-expensive than an all-steel pile.

Design Stresses – The material stress resulting from design loads to which piles are designed may affect cost-effectiveness. For example, higher permissible material stresses may be permitted in conjunction with increased field testing, resulting in smaller required section areas for a given allowable load.

Driving Criteria – The driving criteria to which piles are installed may affect cost. For example, codes, agencies, or designers may require that different safety factors be applied to different dynamic formulas, or to wave equation analysis. Additionally, various criteria (e.g., one dynamic formula vs. another, dynamic formula vs. wave equation) may have different inherent biases, accuracy, conservatism, etc., which may result in different installed lengths for a given required capacity.

Field Testing – In this context, field testing related to pile design refers to subsurface exploration, driving probe/indicator piles, dynamic load testing, rapid load testing, and static load testing. All these testing options can contribute to cost-effectiveness by permitting the use of a lower safety factor, with respect to both geotechnical and structural allowable load. Deeper borings are commensurate with designing for higher allowable loads. Driving probe/indicator piles can confirm drivability and capacity, and refine bid-quantity estimates. In addition, load testing can characterize set-up, determine driving stresses (potentially justifying a smaller section), more-accurately estimate dragload, provide parameters to refine driving criteria, and assess suspected damage.

Support Cost – To evaluate the cost-effectiveness of various foundation alternatives, WKG² utilizes the concept of support cost. Support cost is defined as the cost of a foundation component divided by its allowable load (expressed in dollars per allowable ton). For example, pile support cost is the cost of an installed pile divided by its allowable load. Other examples include pile-cap support cost (pile-cap cost divided by the cap's allowable load), and construction-control support cost (the cost of a construction control method divided by the total allowable tons of support to which it applies).

For pile-supported structural slab or mat foundations, higher allowable-pile loads could increase pile spacing, which may result in a thicker, more-heavily reinforced, more-expensive slab or mat. In these cases, using support cost, WKG² works closely with the slab or mat designer to determine the combination of allowable pile load and associated slab or mat thickness which results in the lowest combined cost.