RISK MITIGATION FOR MICROPILE FOUNDATIONS IN KARSTIC TERRAIN

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ABSTRACT

Micropiles are typically recommended by the Geotechnical Engineer and designed by the Structural Engineer as they complete the foundation layout and pile cap designs. This leads to conservatism on both ends as neither the Geotechnical Engineer nor the Structural Engineer has a full understanding of both the ground conditions and building needs. This conservatism gets amplified when the site has difficult ground conditions, as a perception of greater risk drives more caution in the design expressed both as a higher design factor of safety and more redundancy through an increase in the number of piles.

The current practice for micropile foundations in karstic terrain is to install long, relatively lightly loaded micropiles extending through encountered and possible voids and fractured rock. Where voids and fractures are encountered, grout loss often occurs, which is resolved by the specialty contractor pumping dramatic volumes of high mobility micropile grout in an attempt to fill the hole. Additionally, fractures and soil seams throughout the rock strata are often disregarded and the bond zone started below the fractures and soil seams to get “good rock.” These practices can lead to excessively long piles, an excessive number of piles, high quantities of cement use, larger than necessary pile caps, increased potential for pile conflicts, and unnecessary delays and cost to the owner.

It is time for these designs to be completed by the Foundation Engineer who understands the ground conditions, how micropiles are constructed, how they perform, and the demands of the structure. Only when the Foundation Engineer understands the entire project and has influence during construction, including quality control and treatment of anomalies encountered, are the risks of construction in difficult ground mitigated. This paper will demonstrate the value of such an approach and describe how real savings can be obtained.

CURRENT INDUSTRY PRACTICE

Current practice within the industry typically limits the involvement of the Geotechnical Engineer to the site exploratory phase, development of design recommendations, and inspection of earthwork and foundation element installation. After the exploratory phase, the Geotechnical Engineer issues a report recommending various foundation types that are applicable to the preliminary loading and building footprint.

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Recommendations typically include allowable bearing pressures for footing, estimated total and differential settlement, or a recommended deep foundation system and capacity.

Typically, when micropiles are the recommended foundation, a geotechnical capacity and structural capacity for various sizes of micropiles are provided in the report. These recommendations are often conservative as they are meant to be a starting point for the design team to lay out the piles based on the loading and to estimate the cost of construction. Furthermore, they are often based on guidance manual design rules and have little site specific and constructability considerations factored in. This stage of the project warrants conservatism as there are many unknowns associated with the project during initial concept and pricing phases.

Unfortunately, once the Geotechnical Engineer provides the recommendations, they are often left out of the subsequent refinements and revisions. After the design footprint and loading are finalized, the Structural Engineer applies the conservative micropile recommendations to the project and lays out the piles. Micropiles are often new and unfamiliar to the design team and since the Structural Engineer did not develop the geotechnical capacity, this value is considered an absolute limit. Thus, most piles are usually under loaded. This practice leads to costly risk mitigation through the use of many lightly loaded piles.

Karstic Terrain

Karst is a highly irregular subsurface condition formed by the solutioning of carbonate rock strata. Additional complications arise during design and construction when such difficult ground conditions exist at the site. Karstic terrain is a particularly problematic formation and often an example of risk mitigation through ignorance and excess. During the investigation and design phases, the Geotechnical and Structural Engineers are even more conservative than usual as the site variability and perceived risk of unforeseen conditions are greater. The design bond zone is typically lengthened in an effort to reduce the impact of the rock formation unknowns. Additionally, more piles are often added to the footprint as the Structural Engineer is also wary of potential voids. This is similar to practices for driven piles where redundant piles are installed in case a pile refused on floating boulders or unstable pinnacles in the karst matrix.

A typical construction method is to define the bond zone as suitable continuous rock: "good rock." Complications result from chasing this "good rock" when soils seams and small voids are found within the anticipated bonded zone. The result is that the top of the rock formation is disregarded and the final suitable bond zone is started well below the surface of the encountered rock. This problem gets compounded if the micropile designer does not observe the construction of the micropiles, which often happens as many owners choose to have the pile installation "inspected" by a low cost service provider instead of the specialized micropile designer with experienced micropile inspection personnel. When this happens (or is likely to happen), the designer will protect their interests and increase factors of safety and provide more restrictive specifications to assure an adequate micropile is constructed, thus negating the risk of variability from voids and soil seams in the bond zone. This practice further leads to excessive pile lengths.

During construction, even the "good rock" will encounter some voids or seams that may result in a loss of grout. Unless carefully controlled, the standard practice is for the specialty contractors to pump more, high mobility micropile grout (often much more grout) in an attempt to fill the pile. This practice leads to excessive grout takes.

Consequences of Conservatism

Increased factors of safety, longer bond zones, and lightly loaded piles may seem like a reasonable approach when faced with difficult ground conditions, particularly to the engineers with whom the potential failure may weigh heavily. However, this conservatism comes at a price and more risk. More piles mean more holes drilled, which increase the potential for ground damage and conflicts with utilities, existing structures, and other micropiles. Additionally, more piles require larger pile caps, thus larger excavations exposed to the elements and possible standing water that could induce a sinkhole formation. Larger pile caps also increase the amount of concrete and reinforcing bars required, as well as more time required to install the piles. Longer piles mean more challenges during drilling, more flushing and greater risk of tooling failures in the hole.

Excessive grout takes from grouting voids and seams with high mobility grout and attempting to fill all cracks and crevices can lead to very high cement costs. Furthermore, injection of grout can cause ground heave, risk filling nearby utilities, or change groundwater flow patterns, increasing risk of subsurface erosion in other areas.

More piles, more time required to drill and install the foundation elements, high grout takes, and larger pile caps all increase the cost to the owner and do little to mitigate risk. Foundation base costs are a part of this, but the schedule costs and added risk of unforeseen problems also increase and may be much more significant.

PROPER RISK MITIGATION

The Foundation Engineer, the professional engineer who has the knowledge and skill set to address the specific geotechnical and structural aspects of the project, is the only one who has the ability to assimilate all of the information and knowledge to properly mitigate risk through an understanding of both the superstructure requirements and the ground conditions. This person must be involved as a key member of the project team from the initial design phase through the completion of foundation construction. A Foundation Engineer responsible for the design, layout, and quality assurance of the installation has a unique position to manage and mitigate risks and costs to the owner through a variety of techniques.

Design

The first step in mitigating risk and reducing costs is to reduce the required number and length of micropiles through efficient design and specifications. The Foundation Engineer, knowing they will have the opportunity to confirm assumptions and remediate difficult ground conditions, has the ability to manage risk and uncertainty and thus be less conservative in the foundation design. The bond length can be established based on site data and experience and less controlled by concern about unknowns that might be encountered during construction. With an efficient design, the piles can be loaded closer to their geotechnical and structural capacity, and configured in a manner to minimize the pile cap footprint. Furthermore, the guidance of the project documents can be more relevant for the project and less of a catch all that tends to create adversarial situations between the owner and contractor or specialty contractor.

An example of a more efficient design developed by an engineer integrating the challenges of complicated geotechnical and significant structural loading conditions is demonstrated in the following real world case history of a micropile foundation to support a multilevel structure in karstic limestone. Figure 1 shows the initial pile layout done the traditional way with a Geotechnical Engineer providing foundation recommendations (micropile capacity and bond length) and the Structural Engineer placing many lightly loaded piles to support the structural load.

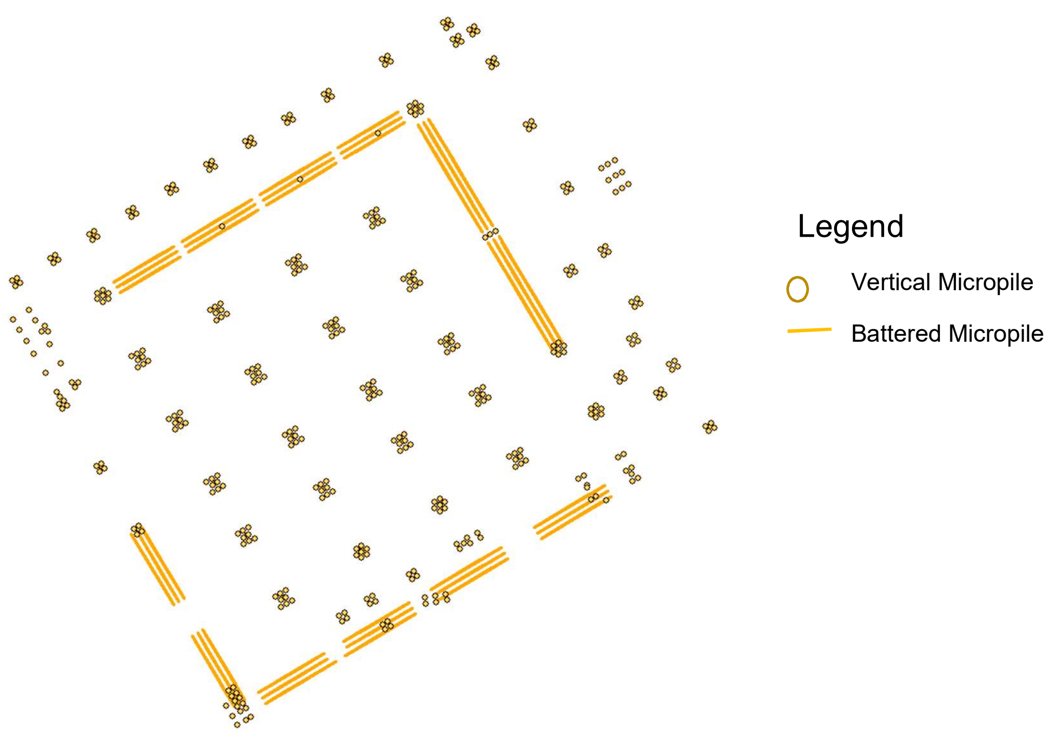

Figure 1. Initial pile layout with many lightly loaded piles.

The revised layout (Figure 2) shows the more efficient design achieved when a Foundation Engineer has a seat at the table during the design phase. Note that approximately 1 to 2 micropiles were removed from each pile cap supporting the vertical loads by utilizing the piles more efficiently. This represents about a 30% reduction in piles for the same loading conditions and, considering a cost of about $100 per foot, translated to an instant savings to the owner on the order of $500,000 in piles that were not constructed. The average pile length in this case was about 15m with the longest piles reaching upwards of 40m. This reduction in the number of required micropiles quickly reduces the overall foundation cost, but possibly more importantly, it reduced the construction schedule and risk exposure. Additional savings are realized due to the reduction in pile cap size, which reduces concrete and rebar costs, labor costs, and the time required to construct the pile caps.

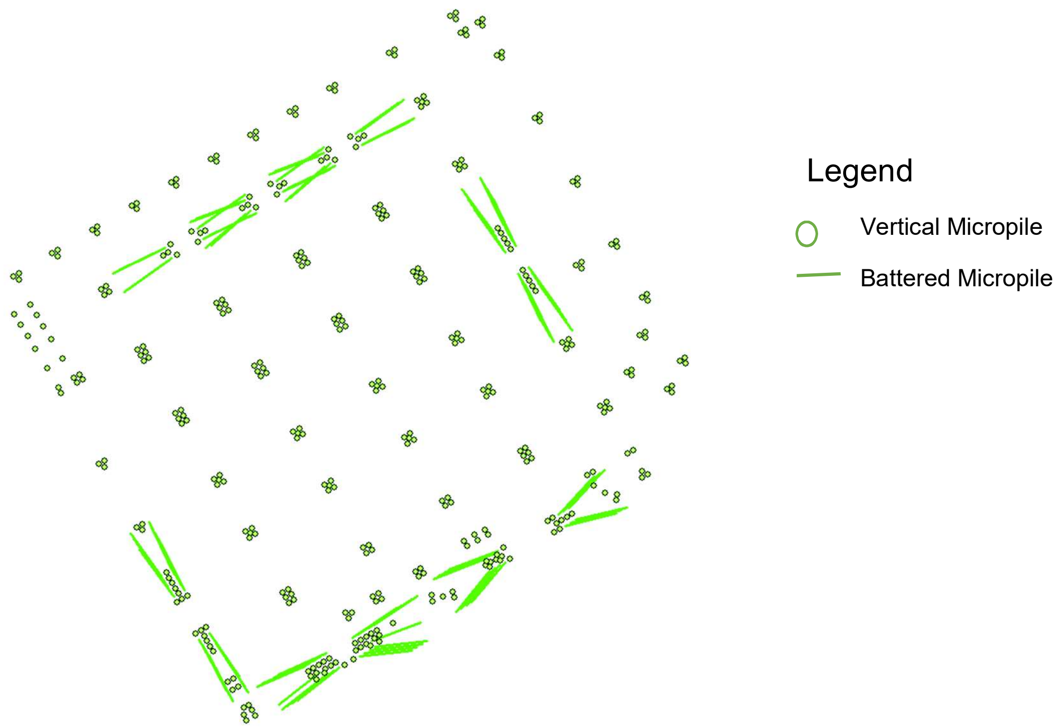

Figure 2. Revised pile layout with 1 to 2 piles removed per pile cap.

A further challenge posed by the initial design is depicted in Figure 3, which shows the potential conflicts of the battered piles in the original configuration. The initial pile layout would have risked striking previously installed piles as they attempted to reach "good rock." The layout is reliant on rock being shallow and predictable, which was not the case at this site.

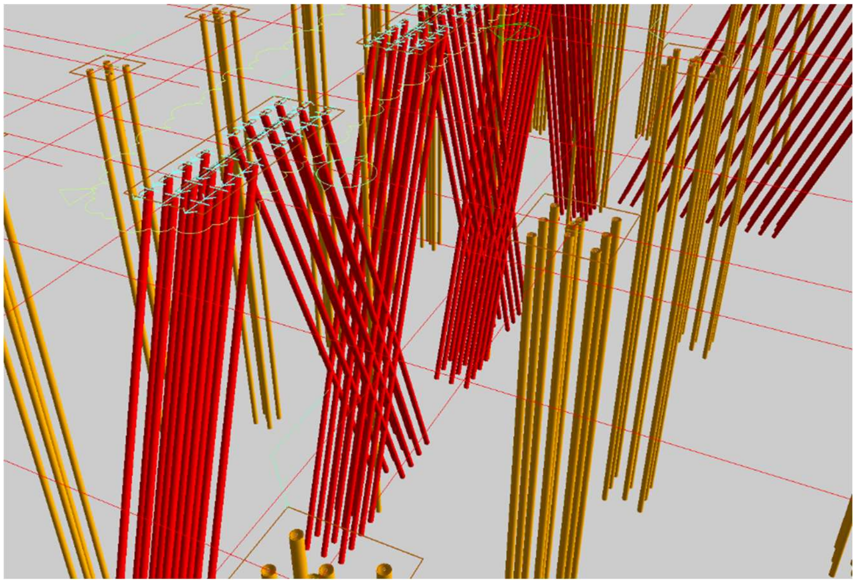

Figure 3. Original battered pile conflicts.

Figure 4 depicts the revised micropile layout for the shear walls utilizing a combination of vertical and battered piles to resist the lateral forces and minimize potential pile conflicts while drilling. This layout was able to accommodate varying depth to rock while not risking the striking of a previously drilled pile.

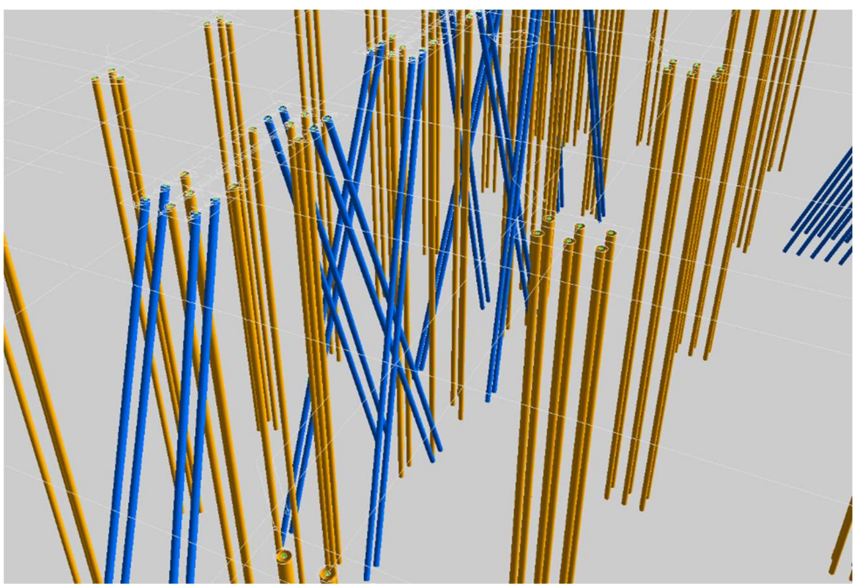

Figure 4. Revised battered and vertical shear key minimizing conflicts.

Specifications

Specifications are contract documents and must be specific to define expectations of the contractor to meet the client's needs. These documents help ensure qualifications of the construction personnel, expectations of the installation equipment and materials, quality control and quality assurance, and may define measurement and payment methods. These are all key elements of good construction documents. However, they cannot become a crutch to replace sound engineering judgement and the ability to modify means and methods to accommodate variable site conditions.

In the world of micropile construction, it is imperative that the Foundation Engineer utilize the entire installation method as a tool to improve the design. Furthermore, ground conditions dictate the correct construction method to build the pile. Only by understanding and utilizing the tools available can the project be considered a success. The specification needs to allow the Foundation Engineer to collect information during drilling, determine the top and bottom of the bond zone based on that information, determine the best grouting process to ensure a stable hole, and ensure the reinforcement is placed correctly. It must be recognized that each pile record is not a stand-alone document; combined they provide significant insight into the subsurface condition that must be considered as a whole. Additionally, the specification must make the contractor aware of the role of the Foundation Engineer and the contractor's role to work together to build reliable piles.

Grouting of the holes is a critical element. Unfortunately, little flexibility is typically included in the specification so that the contractor is aware that the foundation engineer may require staged grouting, redrilling and regrouting, use of variable high mobility mixes, or even low mobility grouting to achieve a sound pile. Furthermore, little guidance is typically provided regarding how the specialty contractor will be compensated if such challenging grouting methods are deemed necessary.

Construction Observation

There are several advantages to the owner and project team to having the Foundation Engineer observe construction that may not be apparent at first glance. As noted above, the Foundation Engineering is a package deal from initial design through final construction. The goal is to reduce cost, schedule, and risk, which can only be accomplished through consistency in the foundation philosophy. That philosophy is realized during construction through confirmation. Once an efficient foundation system reaches construction, the savings (or losses) are not yet realized. Delivering on the efficiency requires coordinated delivery of the foundation construction.

Often (or typically) getting the project out of the ground is on the critical path. It is also the phase most often fraught with unforeseen conditions that can impact the schedule. As a result, the focus is how many piles can be drilled in a day and how many crews can be provided to accelerate this schedule. This message trumps all concerns discussed in the design team meetings with the owner. Unfortunately, this leads to short cuts. You see this in the form of drilling multiple piles too close together and connection between piles, leaving numerous pile ungrouted for extended periods of time, excessive grouting volumes rather than managed grout placement and possible redrilling. Furthermore, the tendency to drill to “good rock” actually provides relief to the specialty contractor since this gives them a basis for some schedule delays as it is an “unforeseen” condition. Keeping the Foundation Engineer involved allows cooperative adaptation to site conditions while maintaining the design intent and allowing for quick responses by the design team.

Several decisions by the field personnel have the ability to significantly impact both cost and schedule. Some of these include:

- Establishing the bond zone. Rather than seeking "good rock," the entire borehole should be evaluated and considered for load transfer. There is a trade off in cost and time for drilling, casing, and grout for a long hole that must be compared to the benefit of shorter casing, easier reinforcement installation, yet possible grout loss and the need for additional regrouting or redrilling.
- Grouting of a hole. A defined volume of grout should be established for placement on initial grouting (within reason). This can be tied to a multiple of the theoretical volume of the bore hole and is typically 1.5 to 2 times; although actual site geology and designer experience should determine the specified volume. If this volume is exceeded, considerations of alternative grouting methods should be considered. These may include mix modification, waiting for grout set and regrouting, allowing grout to harden and redrilling, or electing to use other methods such as low mobility grouting.
- Allowing multiple holes to be drilled before grout placement. Many factors impact this including the ground conditions and quality of the bond zone material. Although attempted in many cases, and occasionally unavoidable, there are many down sides to this that go unnoticed and can be difficult to reliably correct.

The often overlooked benefit is the time factor involved when dealing with deep foundations in difficult terrain. Time is of the essence during micropile installation, and delays can not only increase the time and cost of the foundation, but can slow the progress of a typically critical path item, preventing the next phase of construction from beginning. A conflict between a proposed micropile and an existing utility or a problematic void, as examples, can take days to resolve if the Foundation Engineer does not have a presence on the site. The typical process is for the micropile contractor and/or inspector to notify the general contractor of the conflict. The general contractor will then submit an RFI to either the Structural Engineer or the Architect who forwards the RFI to the micropile designer. The designer must then review the information, which can be lacking and may not provide what the designer wants to see, and either request more information from the team (drill logs, record drawings, etc.) or issue an RFI response. This process will be repeated for each conflict, encountered void, broken casing in the hole, lost piece of drill string, etc.

The presence of the Foundation Engineer on site during construction means conflicts can be remediated more quickly as information is conveyed in real time, the Foundation Engineer has firsthand knowledge of the issues, and they can modify the micropile layout in a few minutes instead of days or weeks. This may be the biggest cost savings to the owner and it is often overlooked.

CONCLUSION

The profession is doing the owner a disservice by attempting to reduce risk by using excessive conservatism. It is time for us to make it clear to the owners that proper risk mitigation and cost savings can only be attained through involvement of the Foundation Engineer from the beginning to end of the project.

The entire project team wins when the Foundation Engineer is involved from design through construction. When the Foundation Engineer understands the entire project and has intimate involvement during construction, including quality control and treatment of anomalies encountered during construction, the risks of construction in difficult ground are mitigated and the owners save money (and time, which is money). We must communicate this message to owners and design teams so they recognize the benefits and cost savings of this approach.

Often an owner compares the cost of the Foundation Engineer to that of a typical construction inspector and does not see the need to pay a premium for what is seen as a commodity. With a little effort on our part, it will become clear that the owner will not only save on the cost of micropiles installed, but also on the cap size and associated rebar and concrete. More significantly, they will save time and schedule. We must be tireless in our efforts to educate the owners to show them what not involving the Foundation Engineer truly costs.