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A Creative Solution to Problems with Foundation Construction in Karst

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A CREATIVE SOLUTION TO PROBLEMS WITH FOUNDATION CONSTRUCTION IN KARST

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ABSTRACT

Karst is a problematic geology located throughout the United States. It is problematic because it is very hard; however the mineral composition and the near vertical, pinnacled bedding of the bedrock (limestone) is vulnerable to the formation of solution cavities and sinkholes. The upper layers of the limestone are typically polluted with voids, massive clay seams and artesian conditions. The overburden soils above the limestone are typically silts and clays that are susceptible to large settlements when heavy foundation loads are placed on them. For heavily loaded structures or structures that are very sensitive to settlement, deep foundations are necessary.

Traditional deep foundations include drilled cast-in-place concrete caissons and driven piles. These foundation types typically transfer the foundation loads to competent rock at depth. However, in the karstic formations, "competent rock" may be underlain by voids and clay seams. Therefore, the actual load-carrying capacity of foundations bearing above these problem zones may be less than required.

A solution to avoiding these problems and installing foundation elements with adequate capacity would be to use micropiles as a deep foundation system. Micropiles are drilled and grouted piles typically ranging from 5 to 12 inches in diameter. Their capacity in both soil and rock is derived entirely from friction; nominal capacity derived from end bearing is conservatively neglected. In karst areas where several layers of bedrock must be penetrated, the micropiles are readily advanced through the hard strata and socketed into competent bedrock. However, the ultimate capacity of micropiles is entirely dependent on the development of an adequate bond between the pile and the rock socket with the bond zone. This paper concludes that not all micropile installation techniques are equally reliable. Recommendations are proposed to improve the quality of micropiles installed in karst topography and to lower the risk of capacity problems by the careful selection of appropriate installation techniques.

INTRODUCTION

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Many cases exist where it is not practical or economical to install more traditional deep foundation elements such as driven piles or drilled shafts. In these cases, such as in ground where obstructions, boulders and solution cavities are present, micropiles have been selected. Micropiles are drilled-in elements typically ranging from 5 to 12 inches in diameter, which consist of steel casing, steel reinforcement, and cement grout. They derive capacity in the ground from side friction and work equally well in both compression and tension.

These piles were developed in Europe in a simpler form, typically using only a central rebar core encased with cement grout placed into a small diameter drilled hole. These minipiles or micropiles were installed as individual elements or groups with cumulative benefit.

In the United States, particularly when considered for building applications, it was realized that traditional mini or micro piles were limited by their structural capacity. That is, the rebar core with virtually unconfined grout surrounding it was not very resistant to high compressive loads or any manner of lateral bending or eccentric loading.

Since these elements are most often installed using a steel drill casing, it was the innovation of the American contracting community to incorporate the steel casing into the pile designs. This ductile, steel-cased micropile, provides a high degree of structural resistance in the soft upper soils, and allows for the full optimization of the underlying competent geology. It is often the physical constraints that act as a catalyst for use of micropile technology. Such situations may be:

- subsurface obstructions or difficult ground,
- limited overhead clearance,
- vibration or noise sensitivity,
- settlement sensitivity,
- limited plan access,
- the need to install elements in close proximity to or through existing footings, columns, walls, or other structures.

Geotechnical complications may act as a single driving force for micropile selection, or may complement the already difficult physical limitations of a project. The geotechnical situations other than what might be called "conventional" which micropiles may be conveniently installed are:

- karstic limestone geology (see Figure 1) that includes voids or soil-filled solution cavities,
- bouldery ground or glacial till,
- variable and/or random fill,
- underlying existing foundations or man-made obstructions,
- rock formations with variable weathering,

- or soils under a high water table.

Figure 1 – Karst Uncovered

GEOTECHNICAL ASPECTS

Since the primary load carrying capacity in the ground is derived from frictional bond in soil or rock, the micropiles can develop high capacity in both compression and tension. In compression, micropiles typically range in working load from 50 to 200 tons. In tension, their capacity is nearly identical geotechnically, and is primarily limited by the amount and detailing of the core reinforcement and the configuration of casing joints used in the elements.

When subjected to lateral loadings, the micropiles derive resistance from the horizontal stiffness of the adjacent soils and can sustain significant lateral deflection within the available structural pile capacity. Seven-inch micropiles have been laterally tested in variable urban fills, with a free head condition, to up to 19 kips with 0.75 inch deflection. On a site with stiff alluvial soils, in a free head condition, a seven-inch micropile was tested to 24 kips with 0.3 inch deflection. Where significant bending capacity is desired due to lateral loads, a larger upper casing can be installed to provide a pile with a two-part cross-section, or the micropiles can be installed on a batter.

FOUNDATION PROBLEMS

A variety of techniques have historically been devised to install micropiles. The earliest, simplest, and least expensive method involves the so-called 'open hole' drilling technique. This method begins with the drilling of an uncased borehole through the use of drilling tools such as augers or casing with cutting teeth. Once the borehole is created, the drilling tools are withdrawn and casing is installed and grouted in place along with centralized reinforcing. This technique is perfectly acceptable in stable soils that do not cave when the drill tools are withdrawn. In karst, however, micropile installation usually encounters soft, wet soils. Using open hole techniques, between the time that the drill tools are withdrawn and the casing is inserted, these soft, wet soils may fall into uncased hole and contaminate the bond zone. An uncontaminated bond zone is required for load transfer from the grout to the rock (Taylor et al., 2002). Otherwise, micropile failure may result. There have been several noted cases where these types of failures have occurred.

THE SOLUTION

The ability to install micropiles in karst topography is a major advantage in their use as a foundation system. Since the performance of the pile is dependent on the bond between the grout and the competent rock, the integrity of the grouted bond zone in karst is of primary importance. Site specific installation techniques must be selected with this in mind. This capability is gained principally by the optimal selection of drilling and grouting techniques. Through proper selection and experienced execution, good results are obtained.

Micropiles are best installed in karst using rotary eccentric percussive duplex drilling. This method uses an inner rod and an outer casing, with the spoils flushed inside the casing. The bit on the inner drill rod is equipped with a down-the-hole hammer. The hammer bit is specially designed to open up during drilling to a diameter slightly larger than the outside diameter of the drill casing (see Figure 2). This bit provides a slightly oversized hole through obstructions or rock and thereby allows the casing to simultaneously follow it down. Compressed air is used to drive the hammer and also acts as the drilling fluid to lift the cuttings. This drilling method is used in soils containing large amounts of obstructions such as cobbles, boulders or demolition waste and is also very effective in advancing a drill casing through highly fractured rock zones in karst. Because near intimate contact between the casing and the surrounding soil and rock is constantly maintained, this method is highly effective for micropile installation in karst.

Figure 2 – Eccentric Hammer Inside the Casing

Tremie grouting is used to place grout in a wet hole. A grout tube is lowered to the bottom of the drill casing or rock socket. Grout is pumped through the tube as it is slowly removed from the hole. As the grout fills the drill casing or hole, it displaces the drilling fluid. Tremie grouting is primarily used where the Pin Pile bond zone is founded in rock. When working in highly broken or fractured rock or in voided, karstic situations, grout loss is possible and may warrant testing for a sealed bond zone. When this is done it is typical to perform water testing and seal grouting as required, then re-drill, and test again. This potentially repetitive process requires commercial compensation using unit prices for these variable and unpredictable quantities.

The response of the down the hole hammer indicates whether or not the rock of sufficient quality is penetrated Once a competent bond zone is established, the casing is withdrawn to the top of the bond zone and the pile is filled internally with grout. Once the grout level has stabilized in the bond zone, the centralized reinforcing steel is placed. A typical cross-section is shown below (Figure 3).

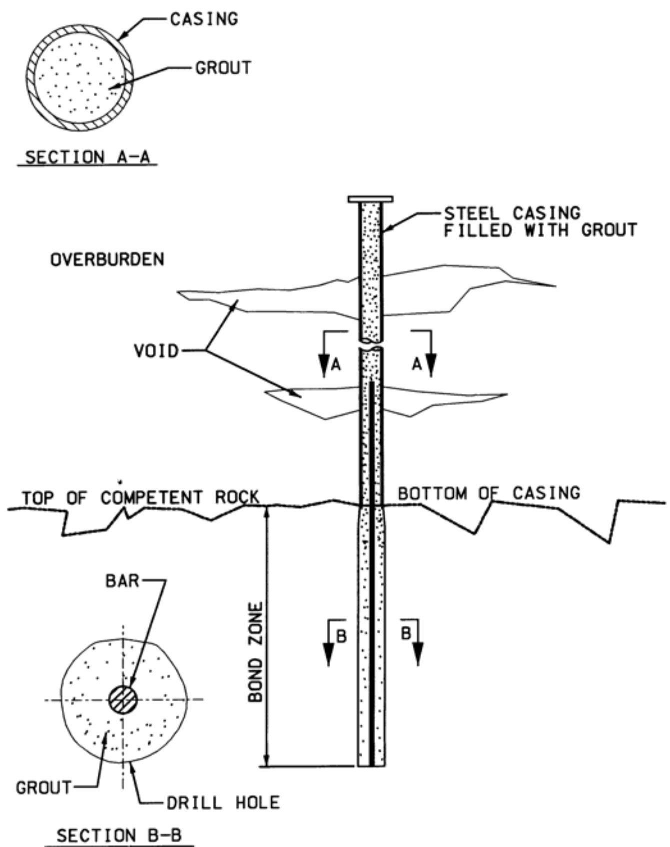

Figure 3 - Typical Cross-Section

ENGINEERING ISSUES

Because of their training and experience, engineers have been charged by various jurisdictions with statutory requirements to protect the health and welfare of the public and to adhere to a Standard of Care that is locale dependent. One definition of Standard of Care is: "That level or quality of service ordinarily provided by other normally competent practitioners of good standing in that field, contemporaneously providing similar services in the same locality and under the same circumstances." From a liability viewpoint, this is the reason that continuing education and discussion forums dealing with issues pertinent to a given area are so vital. Because technology changes rapidly, it is necessary that engineers adapt their practice to current trends in the industry.

Good design practice requires that engineers understand the systems that they design and specify and that these systems be appropriate for the particular environments where they will be employed and for the intended purposes. As has been seen, micropile installation using open-hole drilling techniques is perfectly acceptable in stable soils where the potential for contamination of the bond zone is minimal. Because of their experience, training, and contractual and statutory obligations to their employers, it is up to geotechnical engineers to determine which installation methods are appropriate for particular subsurface conditions.

In karst geology, open-hole drilling techniques rarely will be successful. The main limitation is the inablity to characterize the stability of soft, overlying soils and weathered broken rock layers through which micropiles are to be installed. Therefore, micropiles installed using open-hole techniques are generally not recommended.

CONCLUSIONS AND RECOMMENDATIONS

Micropile test pile failures have occurred in karst geology where micropiles were installed using open-hole drilling techniques. The apparent mechanism causing these failures is contamination of the bond zone resulting from the intrusion of overlying soft, wet soils into the bond zone between the time drill tools are withdrawn and casing in inserted. Rotary eccentric percussive drilling techniques have been successfully used in karst geology without testing failures primarily because this technique allows near intimate contact between the borehole and the surrounding ground throughout the installation process. Because the rotary eccentric percussive drilling technique is not proprietary and can be readily obtained by micropile contractors, Engineers and Owners can decrease project risk by requiring this installation technique instead of open-hole drilling.

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