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Micropiles for Structural Support

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Abstract

This technical paper discusses the Micropiles brief history, Micropiles Classification, Drilling Techniques, Grouting, Reinforcement, Design Concept, Testing procedures and Guidelines of Micropiles. The paper provides a simplified step-by-step design approach. These include geotechnical strength limit states, other structural considerations, service limit states, corrosion protection and Micropiles testing procedures.

Keywords: Micropiles Classification, Drilling Techniques, Grouting, Reinforcement, Design Concept

Introduction

Micropiles are small diameter piles (less than 300 mm) can be installed in almost any type of ground where piles are required with design load (3 Tons to 500 Tons).

The first use of micropiles dates back to the early 1950's in Italy, where new methods of underpinning for existing structures were needed to restore structures and monuments damaged during World War II (Lizzi, 1982). Dr. Fernando Lizzi is commonly recognized as the inventor of micropiles in the form of the root or palo-radice.

Dr. Lizzi was a civil engineer and Technical Director with the Italian specialty foundation contractor Fondedile and obtained the first patents for root piles in Italy in 1952. This early form of micropile technology was used extensively in Europe for the restoration of various structures and monuments.

Fondedile introduced micropiles into North America in 1973 by performing a number of projects, mainly in the Northeastern United States. By the mid 1970's a number of US specialty foundation contractors previously engaged in drilled and grouted anchor work had developed their own variants of the technology. There was slow growth of the technology in the time period between the mid 1970's and the mid 1980's with Fondedile closing their North American venture for economic reasons. (Bruce and Juran, 1997)

There has been a rapid growth in the specification and use of micropiles in the United States since the mid 1980's to early 1990's partly as a result of FHWA research efforts, trade association promotion efforts and the development of various publications offering standardized design and specification guidelines.

In the early 1990's, the Intermodal Surface Transportation Efficiency Act (ISTEA) provided massive funding for the rehabilitation of highway infrastructure in the United States.

As part of this effort, the FHWA undertook a number of research and development projects associated with specialty geotechnical construction to encourage innovation in geotechnical applications and produced several design manuals including the first on micropiles. This was the beginning of the surge in micropile use in the United State.

In 2006 and 2007 respectively, the International Building Code and the AASHTO LRFD Bridge Design Specifications incorporated design code sections for micropiles thus making way for further expansion of applications in both building and highway construction. Micropiles currently are widely specified and used in all construction sectors worldwide.

Types of micropiles

Micropile classification

Micropiles are generally classified firstly according to design application and grouting method. The design application dictates the function of micropile while the grouting method defined the grout/ground bond capacity.

In the design application, there are two types of application. The first type is where the micropile is

directly loaded either axially or laterally and the pile reinforcement resists the majority of the applied load. Examples of such application are shown in figure (1). This type of pile is used to transfer structural loads to deeper, more competent or stable stratum and may be used to restrict the movement of the failure plane in slopes. The loads are primarily resisted by the steel reinforcement structurally and by the grout/ground bond zone geotechnically.

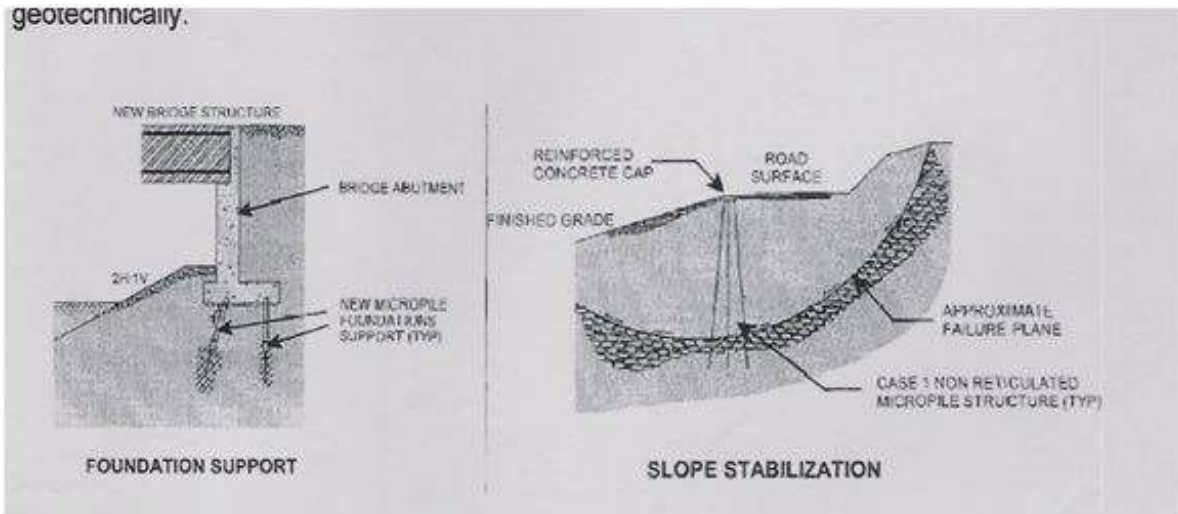


Figure (1): Directly Loaded Micropiles Example

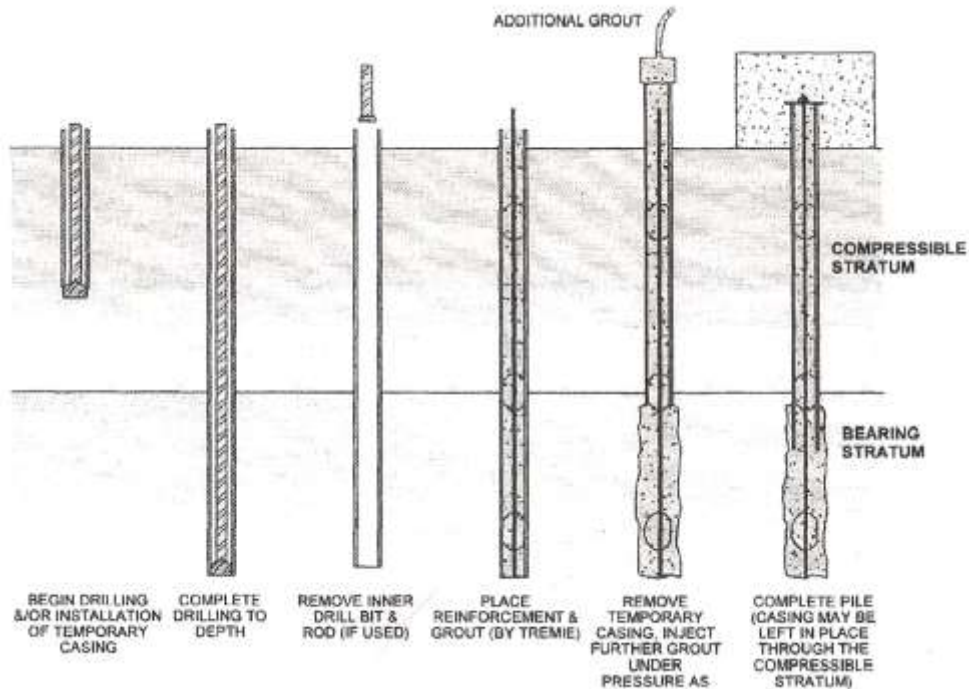


Figure (2). Micropile Construction Sequence (FHWA-SA-97-070).

Second type of design application is where the micropile reinforces the soil to make a reinforced soil composite that resist the applied load and known as reticulated pile net work. This application of micropile serves to circumscribe and internally strengthen the reinforced soil composite.

The method of grouting is generally the most sensitive construction control over grout/ground bond capacity and varies directly with the grouting method. The second part of the micropile classification is based primarily on the method of placement and pressure under which grouting is used during construction.

The classification is shown schematically in Figure (3).

Type A: Type A classification indicates that grout is placed under gravity head only. Sand-cement mortars, as well as neat cement grouts, can be used because the grout column is not pressurized.

Type B: Type B indicates that neat cement grout is placed into the hole under pressure as the temporary steel drill casing is withdrawn. Injection pressures typically range form 0.5 to 1 MPa, and are limited to avoid hydro-fracturing the surrounding ground or causing excessive grout takes, and to maintain a seal

around the casing during its withdrawal, where possible.

Type C: Type C indicates a two-step process of grouting: primary grout is placed under pressure 1.0 – 2.0 MPa, causing hydro fracturing of surrounding ground. Prior to the hardening of the primary grout (typically 15 to 25 minutes), secondary grout is injected usually via tube a manchette.

This method is sometimes referred to as IGU (Injection Globale et Unitaire)

Type D: Type D indicates a two-step process of grouting similar to Type C with modifications to the secondary grouting. Primary grout is placed under pressure and after hardening of the initially placed, additional grout is injected via tube a manchette at a pressure of 2 to 8 MPa. A packer may be so that specific levels can be treated several times, if required.

Type E: Drill and inject grout through continuously – threaded, hollow – core steel bar, initial grout has high w/c ratio, which is replaced with thicker structural grout (lower w/c ratio) near completion of drilling.

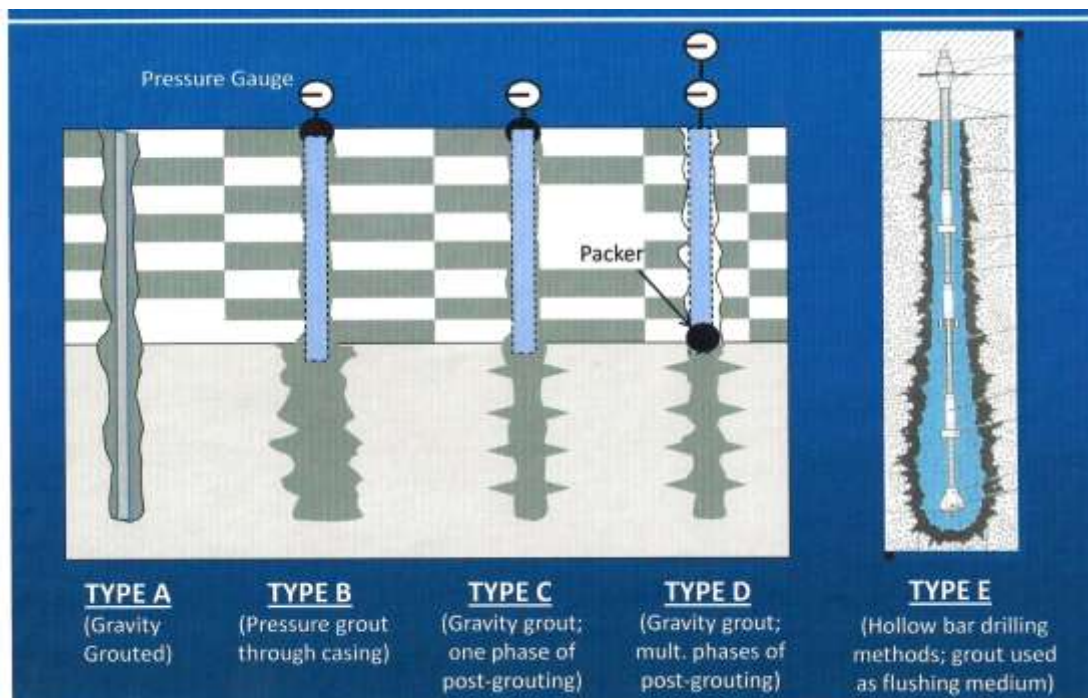


Figure (3). Micropiles Classification based on Grouting Method. The international Association of foundation Drilling (ADSC).

Drilling techniques

The drilling method is selected on the basis of causing minimal disturbance to the ground and nearby sensitive structures and able to achieve the required drilling performance. In all drilling methods, drilling fluid is used as a coolant for the drill bit and as a flushing medium to remove the drill cuttings. Water is the most common drilling fluid compared to other drilling fluid such as drill slurries, polymer, foam and bentonite. Another type of flushing medium is using compressed air.

Grouting:

Grouting operations have a major impact on the micropile carrying capacity and the details of the grouting vary somewhat throughout the world, depending on the origins of the practice and the quality of the local resources. In general, the grout mixture consists of cement, water and in certain cases additives such as sand and super plasticizers may be added to achieve the required working conditions.

Reinforcements

Generally, there are three types of reinforcement for micropiles and consist of single reinforced bar, reinforcement bars or steel pipe. Reinforcement bars is primarily deformed high-tensile strength steel bar and is typically placed in groups to increase structural capacity. They are available up to 40mm in diameter with yield strength of up to 460 MPa. Steel pipe is mainly used ex-oil API (American Petroleum Institution) pipe which are high tensile strength steel pipe. Available sizes ranges from 60mm to 300mm in diameter with typical yield strength 552 MPa for grade N80.

Design concept

Through the efforts of many authors it is now well established that micropiles have been used throughout the world since their development in Italy in 1952s. In North America, the use is somewhat more recent, and as is typical with a relatively new specialty geoconstruction technique, most of the technical knowledge has resided with the contractors. Not surprisingly therefore, and even given that such contractors have displayed admirable skill, knowledge, and zeal in their development, there still tends to be more certainty and consensus within the industry with respect to issues relating to construction and testing than to design.

There is no specific design standard for micropile design; however, relevant design standards for each design components can be referred to in the design.

These standards are BS 449, BS 8081, BS 8110, BS 8004, IBC (International Building Code), IWM (International Work Shop on Micropiles) and FHWA state of practice have been major efforts made in the quest of a “unified” design approach. Such efforts include micropile committees of both ADSC (International Association of Foundation Drilling) and DFI (The Deep Foundations Institute). However, working stress approach is still widely adopted for the pile design in view of the compatibility between the structural and the geotechnical designs.

Design steps for micropiles used for structural foundations:

- Step1.** Evaluate Feasibility of Micropile.
Step2. Review Available Information and Geotechnical Data.
Step3. Develop Applicable Loading Combinations.
Step4. Initial Design Constructions
 A) Micropile spacing
 B) Micropile length
 C) Micropile cross section
 D) Micropile Type (i.e., type A, B, C, D or E)
Step5. Final Design
 A) Geotechnical strength limits states:
 1) Bond length design
 2) End bearing
 3) Group effects for axially loaded micropiles
 4) Uplift resistance of single micropiles and micropile groups
 5) Downdrag
 B) Structural strength limit states
 1) Axial compression of cased length
 2) Combined axial compression and bending of cased length
 3) Axial tension of cased length
 4) Axial compression and tension of uncased length
 5) Lateral resistance of single micropiles
 6) Lateral resistance of micropile groups
 7) Buckling of micropiles
 C) Other structural considerations
 1) Grout to steel bond capacity
 2) Ultimate structural capacity
 3) Micropile to footing connection
 D) Service limit states
 1) Micropile settlements
 2) Micropile group settlement
 3) Lateral deflection of micropile groups
 E) Corrosion Protection
 F) Seismic Considerations
Step6. Develop Load Testing Program and Construction Monitoring Requirements

Step7. Prepare drawing and specifications**Micropile Structural Capacity:**

From FHWA Design Guide Line

Axial Compression of cased length. The allowable compression load for the cased (free) length is given as

$$Pc\text{-allowable} = [(f'c\text{-grout}/FSg\text{rout}) * Ag\text{rout} + (Fy\text{-steel}/FSg\text{rout}) * (Abar + Acasing)] * (Fa/Fy\text{steel}) / FSy\text{-steel} \dots\dots\dots \text{(Equation 1)}$$

Where,

 $f'c$ = uniaxial compressive strength of grout FSg = factor of safety on grout Ag = cross sectional area of grout $Fy\text{-steel}$ = minimum steel yield stress $FSy\text{-steel}$ = factor of safety on grout $Abar$ = cross sectional area of bar $Acasing$ = cross sectional area of casing Fa = allowable axial stress

Allowable Tension of cased length. The allowable tension load for the cased length is given as

$$Pt\text{-allowable} = 0.55Fy\text{-steel} * (Abar + Acasing) \dots\dots\dots \text{(Equation2)}$$

Axial Compression and Tension of Uncased Length. The allowable compression load for the uncased length of a micropile is given as:

$$Pc\text{-allowable} = [0.4f'c\text{-grout} * Ag\text{rout} + 0.47 * Fy\text{-bar} * Abar] \dots\dots \text{(Equation3)}$$

The allowable tension load for the uncased length of a micropile is given as:

$$Pt\text{-allowable} = 0.55Fy\text{-bar} * Abar \dots\dots\dots \text{(Equation4)}$$

Accordingly (IBC) International Building Code:

$$Pc\text{-allowable} = [0.33f'c\text{-grout} * Ag\text{rout} + 0.4 * Fy\text{-bar} * Abar] \dots\dots \text{(Equation5)}$$

$$Pt\text{-allowable} = 0.6Fy\text{-bar} * Abar \dots\dots\dots \text{(Equation6)}$$

For the uncased portion of the pile, the reinforcing bar yield stress used in the calculations in compression must not exceed 600 MPa.

Ultimate Structural Capacity.

Micropile load testing may be carried to loads up to and, in some cases, greater than two times the design load. For load testing, maximum test loads should not exceed 80 percent of the ultimate structural capacity of the micropile, which is given by:

$$Pult\text{-compression} = [0.85f'c\text{-grout} * Ag\text{rout} + fu\text{-casing} * Acasing + fy\text{-bar} * Abar] \dots\dots\dots \text{(Equation7)}$$

$$Pult\text{-tension} = [fy\text{-casing} * Acasing + fy\text{-bar} * Abar] \dots\dots\dots \text{(Equation8)}$$

Micropile Geotechnical Capacity:

Accordingly ASD (Allowable stress design-AASHTO 1998)

$$PG\text{-allowable} = (\partial bond/FS) * \pi * Db * Lb$$

Where:

 $\partial bond$ = grout to ground ultimate bond strength FS = factor of safety applied to the ultimate bond strength Db = diameter of drill hole Lb = bond length**Micropile testing procedures and guidelines**

The types of test loading:

- * Compression test
- * Up lift tension test
- * Lateral – load test
- * Torsion – load test

Test procedures of Ground Anchors:

- American Society for Testing and Materials (ASTM) D1143/D1143M-07. Standard test method for deep foundations under static axial compressive load.
- American Society for Testing and Materials (ASTM) D3689-07. Standard test method for deep foundations static axial tensile load.

Summary of typical δ bond values (grout to ground bond) for preliminary Micropile design and feasibility evaluation

SOIL / ROCK DESCRIPTION	GROUT-TO-GROUND BOND NOMINAL STRENGTHS (KPA)			
	TYPE A	TYPE B	TYPE C	TYPE D
Silt & Clay (some sand) (soft, medium plastic)	35-70	35-95	50-120	50-145
Silt & Clay (some sand) (stiff, dense to very dense)	50-120	70-190	95-190	95-190
Sand (some silt) (fine, loose-medium dense)	70-145	70-190	95-190	95-240
Sand (some silt, gravel) (fine-coarse, med.-very dense)	95-215	120-360	145-360	145-385
Gravel (some sand) (medium-very dense)	95-265	120-360	145-360	145-385
Glacial Till (silt, sand, gravel) (medium-very dense, cemented)	95-190	95-310	120-310	120-335
Soft Shales (fresh-moderate fracturing, little to no weathering)	205-550	N/A	N/A	N/A
Slates and Hard Shales (fresh-moderate fracturing, little to no weathering)	515-1,380	N/A	N/A	N/A
Limestone (fresh-moderate fracturing, little to no weathering)	1,035-2,070	N/A	N/A	N/A
Sandstone (fresh-moderate fracturing, little to no weathering)	520-1,725	N/A	N/A	N/A
Granite and Basalt (fresh-moderate fracturing, little to no weathering)	1,380-4,200	N/A	N/A	N/A

Type A: Gravity grout only

Type B: Pressure grouted through the casing during casing withdrawal

Type C: Primary grout placed under gravity head, then one phase of secondary "global" pressure grouting

Type D: Primary grout placed under gravity head, then one or more phases of secondary "global" pressure grouting

Conclusions and recommendations

- 1) Micropiles can be used as a normal foundation piles and compensation pile for remedial works, especially in area with site constraints.
- 2) Micropiles can be designed as either rock socketed or soil friction pile.
- 3) Micropile can be used easier than other foundation types in places far away from the sources of materials.
- 4) Factor of safety for both geotechnical and structural designs should be at least two.
- 5) Buckling load should be checked in soft overburden and very soft of loose infilled cavities.

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