Retrofitting of Existing Foundation Using Micropile

Civil and Environmental Engineering

By

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An undergraduate thesis submitted to the Department of Civil & Environmental Engineering of Islamic University of Technology, Board Bazar, Gazipur in partial fulfillment of the requirements for the degree

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DECLARATION

We hereby declare that the undergraduate project work reported in this thesis has been performed by us and this work has not been submitted elsewhere for any purpose (except for publication).

October, 2013

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Dedicated

To

Our Beloved Parents

Acknowledgement

Firstly we are going to thank almighty Allah for giving us opportunity to conduct this thesis work and helping us in solving difficulties during our project work.

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Islamic University of Technology, 2013

Abstract

Recently in overpopulated countries building construction is become a problem due to scarcity of land. Day by day this problem is increasing as demand of future construction also increasing. By vertical extension of existing building the demand can be fulfilled. Due to this vertical extension strengthening of existing foundation is required. Micropile technology is one of the best and suitable solutions in this kind of underpinning work. Though the technology is not familiar in Bangladesh, successful implementation of this method will come with a very good result. Various advantages over other underpinning work make it applicable in all type of structural and soil condition. This study has proposed different installation process of micropile technology and its detail design procedure. It also discusses advantages of using this technology for underpinning work. This study is mainly focused on using micropile technology in case of vertical extension of existing structure. Installation of piles through existing foundation and thus strengthening of it also discussed over here. a case study is also shown here analyzing present condition of IUT new academic building and condition after vertical extension. Adequate no of micropiles also calculated with their suitable installation and design process. By this analysis future building construction problem can be minimized and also a different technology about strengthening of existing foundation is introduced.

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Notation

BNBC	: Bangladesh National Building code.
FHWA	: Federal Highway Administration.
COF	: Continuous Footing.
CF	: Combined Footing.
SMF	: Stair Mat foundation.
LMF	: Lift Mat Foundation.
F	: Single Footing.

Chapter 1 Introduction

1.1. General

In a densely populated country like Bangladesh, scarcity of land is increasing day by day. Adequate space is not available for future construction. However, if the existing structures can be extended vertically, this problem may be reduced to some extent. Retrofitting of structure can be a solution for accomplishing this type of project which requires retrofitting of existing foundation and strengthening of columns. Limited head room, confined work spaces are the major obstacles in retrofitting of foundation. There are different methods involved in retrofitting of foundation like soil improvement, micropile installation, base isolation etc. Micropiles have shown significant advantages among them. Micropiles are small diameter (less than 300 mm or 12") reinforced piles that are drilled and grouted in to place. Designers and micropile contractors have exploited the various drilling methods and relatively light-weight, small size equipment available for micropile installation in providing solutions to challenging foundation retrofitting projects (FHWA 2000). Besides retrofitting of foundation, strengthening of building column is also necessary for vertical extension. Strengthening of column can be achieved by column jacketing. It consists of added concrete with longitudinal and transverse reinforcement around the columns that improves the axial and shear strength of existing column. This paper discusses about design of micropile, different drilling methods and column jacketing.

1.2. Literature Review

As the concept of retrofitting of existing columns and foundation to support vertical extension of existing structures is somewhat new to our country, the literature review presented in this section mostly discusses projects from other countries – where micropile and column jacketing have been used successfully applied to retrofit existing structures.

1.2.1. Definitions

According to Fleming et al. (1985), micropiles are small diameter subset of cast-in-situ replacement piles. Drilled piles are composed of injected grout and some sort of steel reinforcement to resist a good amount of the design load.

Micropile is constructed by drilling a borehole (FHWA, 2000). Micropiles are able to carry axial and lateral loads. In micropile installation special drilling and grouting methods are used for high grout- ground values along the grout –ground interface.

Karpe et al. (2011) stated that micopile has small diameter as a result it can be casted in any limiting condition. They are used in various application of ground improvement in order to increase bearing capacity and reduced settlement specially in retrofitting of existing foundation.

1.2.3. Micropiles for underpinning

All soil types and ground conditions are suitable for the installation of micropiles. Same type of equipment used for ground anchor and grouting projects can also be used for installation of micropiles at any angle below the horizontal plane. Generally, end bearing contribution is neglected due to small diameter of micropile.

Nasim et al (2008) presents a case history that demonstrates the application of retrofitting of existing foundation to facilitate vertical extension of the surgical wing of Washington DC Children's National Medical Centre. Portions of the hospital extended five stories above grade and three levels below-grade as parking garage. Aim of the project was to expand the surgical wing up to the current build out (five stories) above the remaining portion of the existing parking garage. Micropiles were used to enhance the capacity of the foundation. New loading on the foundations required each of the original piles to be capable of supporting 150 tons. The paper presents the base line design approach of micropile, connections of micropiles to existing foundation, and innovative solutions to typical challenges faced during construction. It also stated that high groundwater table, micropile installation under limited head room and keeping the parking garage fully operational for the entire duration of construction needed to be carefully considered during design and construction phase of this project. These challenges were overcome through use of various types of light weight and small equipments.

Martin et al. (2008) presents the refurbishment of the Department of Justice, Colmstock House, Dublin that we reviewed as another example of retrofitting of existing foundation. The addition of an extra storey was required to upgrade this prime real estate into a high quality office. The existing columns and ground bearing concrete pads were unable to accommodate additional loadings. As the bearing capacity of the soil beneath the bearing pads was not adequate to support the vertical extension, a foundation retrofitting scheme was developed using high capacity minipiles. Vertical and inclined piles with head plates were used to reduce the risk of punching shear failure of the existing foundation. Installation of vertical minipiles can increase the bearing capacity of existing foundation. As the minipiles are vertical they can be installed in foundation close to columns carrying the additional loading and fewer minipiles are required then in existing systems.

Wolosick et al (2007) presents a case history on a historic structure at the University of Puerto Rico, which was damaged during Hurricane George in 1998. The entire roof of the structure was completely torn off by the hurricane, leading to total destruction contents of the building. The renovation design required new support for the new roof structure because of the inability of the original walls to support the proposed loadings. Micropile installation was selected due to confined access and low headroom condition.

From Liew and Fong (2003), we observed that micropile can be used as normal foundation and compensation pile for remedial work where site constraints are present. Micropiles can also be designed as rock socketed pile and soil friction pile. A disadvantage of micropile is that it is a costly option in case of supporting lateral load and huge bending moment. For both geotechnical and structural design of micropile, minimum factor of safety is two.

Fitzgerald and Lewis (2004) presents paper on Grand Rapid Convention Centre Project, West Michigan. The renovation work consists of 160,000 sq ft column free exhibit hall with a 54,000 sq ft grand gallery and a 50,000 sq ft of ballroom area. The site geology consisted of sand, gravel and clay layers. Cobbles and boulders were also present throughout the site. The underlying bedrock consisted of alternating layers of moderately weathered shale, limestone and gypsum. Voids were evident in most of the exploratory borings within the limestone and gypsum layers. Low mobility grout was chosen to solve this problem. Designers used friction caissons, end bearing caissons and group of piled micropiles for the renovation work. The most important factor for selection of micropile was the ability to penetrate the various manmade and natural obstructions using drilling techniques. In the project, a total of 22 micropiles were installed at locations adjacent to existing structures with limited access where caissons could not be installed.

Traylor et al. (2005) presents a paper on micropile installation on karstic limestone terrain. This paper describes two projects of retrofitting using micropile. One of them is about U.S. Post Office and Courthouse building which was built on driven steel and timber piles in 1940. This structure is retrofitted to resist affects of liquefaction of the underlined sands below the foundation. This project includes installation of 217 micropiles, each with a working load of 40 tons tension, 60 tons compression and 5 tons in lateral capacity at a maximum allowable deflection of 0.5 inch. The second project represents a major expansion of an existing and fully operating shopping mall named Exton Square Mall including two parking garages. This project was executed on a karstic dolomitic bedrock. The existing structure needed 405 micropiles and the garages needed 355 micropiles.

1.3. Observation from literature review

For retrofitting of existing building foundation, micropile can be used in different soil conditions. It can increase the bearing capacity of existing foundation. Simple equipments as used for ground anchor and grouting projects can also be used for installation of micropiles. These minipiles can be used at any angle below the horizontal plane. The overall process cause minimal disturbance to the existing soil and structure. Installation of micropiles will not cause any hindrance in the regular use of the operational building. All these work can be executed under limited headroom. Half of the whole volume of the micropile should be occupied by high capacity steel elements. However, micropile is not a good solution for restraining lateral movement and access bending moment.

1.4. Objective

Our project vicinity is the new academic building of IUT, Board Bazar. The objectives of our work are as follows:

a) To study the suitability of using micropile in case of retrofitting or strengthening of existing buildings in respect of Bangladesh.
b) To find out the appropriate design and installation procedure for micropiles.
c) To conduct a case study involving vertical extenstion of the New Academic Building of IUT. It involves calculation of extra load and design of micropile in case of expansion of the existing building by two stories.

1.5. Scope of the Work

As micropile has not been introduced in Bangladesh yet, the scope of the work will be to organize a suitable design procedure of micropile. Determination of plausible installation procedure is another consideration of this research. The thesis will include a case study to prove the suitability of use of micropile. The case study will be based on the Academic Building of IUT. The design and possible installation procedure of micropile required for vertical extension of the structure will be shown in the case study section.

1.6. Organisation of the Thesis

Outline of the thesis paper is thesis paper is described in this section.

Details of micropile is discussed in chapter two. Chapter three contains the installation procedure of micropile. Design procedure of micropile is described in chapter four. Details about the case study is discussed in chapter five.

Chapter 2 Micropile

2.1. General

Though micropile is not yet extensively used, it has high potential for underpinning works. The major difference between conventional pile and micropile is that micropiles can be installed in limiting conditions, since diameter of micropile is much smaller. Another advantage of micropile is it can be installed with minimum disturbance to the surrounding soil and structures.

2.2. Definition

There are generally two types of pile; displacement pile and replacement pile. Displacement piles are driven into the ground displacing the surrounding soil laterally. Replacement piles are constructed within a previously drilled borehole. Micropile is one type of replacement pile composed of grout and steel reinforcement. It is a small diameter pile (generally less than 12 inch). It can be installed in any type of ground condition. Micropile design loads range from 3 tons to 500+ tons.

2.3. Advantages of Micropile

Generally conventional piles require large staging area and heavy equipments whereas micropiles can be installed using light weight equipments that provide good accessibility. Micropile causes minimal disturbance to surrounding structures and it has high carrying capacity. As micropiles are grouted with high pressure, they can immediately manage the soil resistance. This property helps to make quick response to any type of settlement.

2.4. Structural Design of Micropile

A micropile generally consists of a cased upper length and an uncased lower length. The upper length includes a permanent steel casing and a central reinforcing bar. The lower portion is a pressure grouted bond length reinforced with central bar. Transition zone of upper and lower portion is termed as plunge length. The steel casing is inserted into the grout throughout the plunge length. This zone has significant role in the design of micropile.

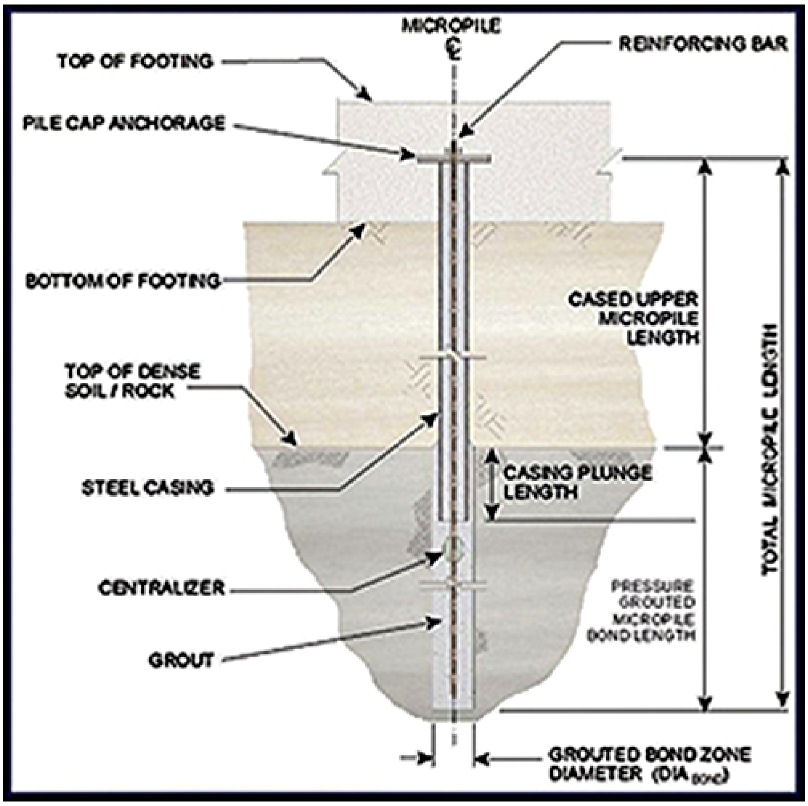


Figure 2.1: Detail of a composite micropile (FHWA 2000)

2.5. Composition of Micropile

For permanent casing, high grade steel pipes are used with yield strength of 80,000 psi. Outside diameter of the steel pipe ranges from 5.5 to 12 inches. Wall thickness ranges from 0.4 to 0.6 inches. One or more bars may be used as the central reinforcement bar. 75, 95 or 150 grade steels can be used for the reinforcement bar with diameter of 0.5 to

3.5 inches. Grout consists of water and cement with a ratio ranging from 0.4 to 0.5 by weight. Sand may be used to increase strength and to lower the cost. Water reducers and plasticizers can also be used for other additives. (Brengola, 2005)

2.6. Types of Micropile

Based on grouting process micropiles can be classified into four processes.

Type A: According to this category grout is placed under gravity head and no external pressure is required. Normal sand cement mortar or neat cement grout is used here.

Type B: Pressure is required for the placement of neat cement grout during the withdrawal of temporary casing. Pressure is maintained between 0.5 to 1 MPa. This typical value of pressure should be maintained to avoid hydra fracturing as well as excessive grout injection.

Type C: This is a two step process. The first one is placement of grout under gravity head and approximately after 15 to 25 minutes similar type of grout is injected by grout pipe at pressure ranged from 1 to 2 MPa.

Type D: This is also a two step process like the previous one. The difference is in the second stage additional grout may be injected under gravity head or by applying pressure like type B. This excessive grouting takes place after hardening of the primary grout.

2.7. Application of Micropile

Now a day micropiles are widely used for rehabilitation projects. It can also be applied for new constructions for recovering physical constraints. Micropiles can be installed through existing shallow foundation and difficult ground condition that’s why application of micropile is very important for new foundation and also for underpinning of existing structure.

2.7.1. Vertical Extension of Existing Structure

The price and scarcity of land is increasing day by day. That's why builders are aimed to build their future structure towards vertical direction. To cope with the huge scarcity of lands in densely populated areas heavy loaded high raised buildings are constructed by builders. These types of jobs demands lots of challenges like piling work without disturbing adjacent old structure and conversion of low rise building to high rise building. These challenges can be overcome by applying micropile installation technology.

2.7.2. Underpinning of Existing Foundation

Underpinning is necessary to overcome deterioration of existing foundation and also to increase load bearing capacity. For executing these works micropile is used.

2.7.3. Miscellaneous Application

Micropile is also applicable for seismic retrofitting of highway bridges, slope stabilization and also for earth retention.

2.8. Conclusion

There are many methods like soil improvement, base isolation, fibre reinforced polymer etc for retrofitting of foundation of existing structure. Some of them require a very high cost. Micropile is much suitable than other methods in comparison with the cost. Design and installation of micropile are much less complicated than those methods.

Chapter 3 Installation

3.1. General

The typical installation sequence of micropile involves drilling the pile shaft to the required depth, placing the steel reinforcement and grouting. There are a large number of drilling systems for installation of micropile. Standard procedure is also available for placement of reinforcement though different grade size and configurations are used for different countries. Installation procedure also includes various methods of mixing and placing of grout. Connection between new pile and existing foundation is also very important for installation procedure.

3.2. Drilling

Drilling method involves forming a stable hole of the required dimension that should not be harmful to the surrounding structures. Though the drilling action creates disturbance to the surrounding conditions, unacceptable level of disturbance should be avoided. Drilling process should also be cost effective. Water flushing is a common method for increasing the drilling rates as well as incorporating ground penetration and pile capacity. But it may create voids in soil or may cause settlement of soil. Duration between drilling and placement of reinforcement and grouting should be minimum to avoid the harmful consequences of surrounding soil. Large quantities of water are required to conduct water flushing procedure. There are a number of processes of drilling and different site conditions affect the selection of these drilling methods.

3.2.1. Drill Rigs

A drill rig is a machine which creates bore holes or shafts in the ground. Drilling rigs can be massive structures used to drill water wells oil wells or natural gas extraction wells or they can be small enough to be moved manually by one person. Drilling rigs can be mobile equipment mounted on trucks, tracks or trailers or marine based structures.

Drill rigs that can be used for micropile installation are basically hydraulic rotary power units. Two types of drill rigs may be used. One is track mounted used in hard and sloped surface. It has larger drill contained long section of drill roads and casing in high , overhead condition and smaller drill works in lower overhead and congested locations . Drill mast can be used in very limited access with low over head condition. On the other hand a frame mounted drill is contained with a separate hydraulic power unit and a long hose pipe. Thus we can apply it in smaller areas decreasing noise in the work area. A fork lift is used for operating the drill frame. Successful installation can be produced by using this kind of drilling equipment. Micropile centerline can be installed within 0.3 m from its adjacent wall

With overhead less than three meter. Small frame mounted rotary hydraulic drill rig is also very cost effective comparing with other drilling machines.

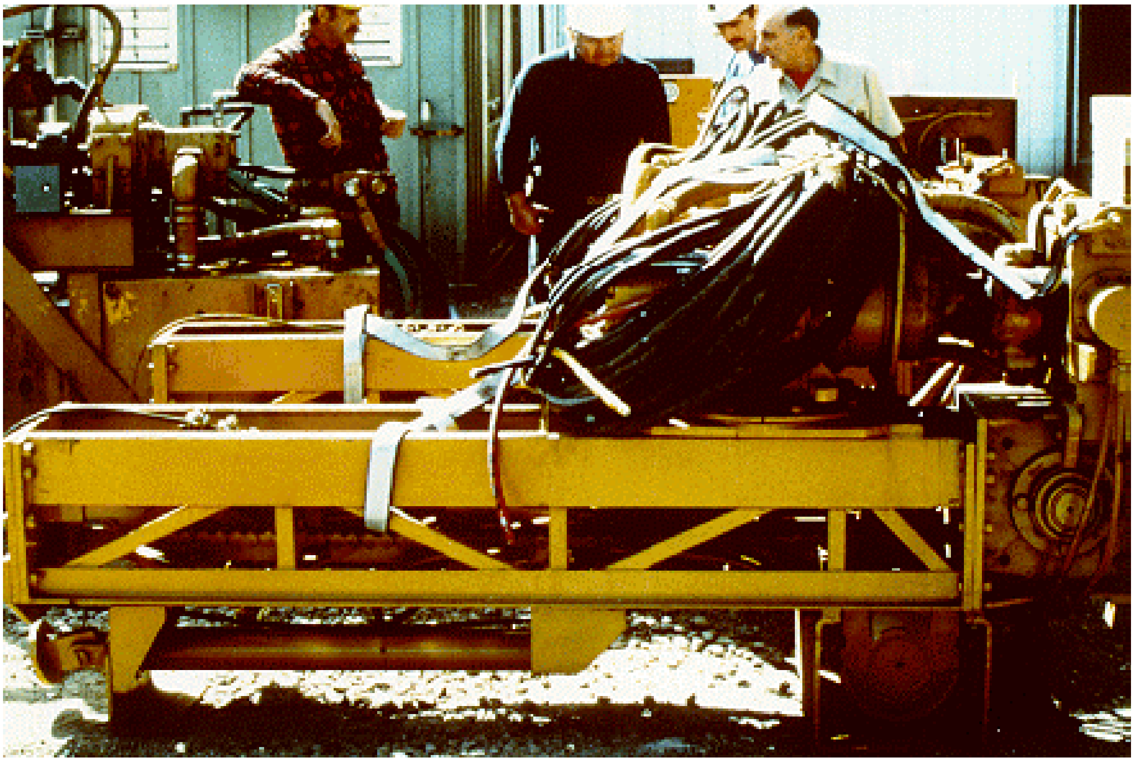


Figure 3.1: Small frame hydraulic drill rig

3.2.2. Drilling Techniques

Selection of drilling method depends on the site condition. Micropile may be required to be drilled through weak soil to reach high capacity bearing stratum. Drilling process may also face self supporting or cohesive type soil. Existing foundation may also have to be drilled for installing micropile.

Cleansing and flushing is required during the drilling process. Water, air, drill slurries and foam are used for this purpose. Among them water is the most common and cost effective medium. Precaution should be taken in case of using air flushing so that air does not penetrate into surrounding soil. Bentonide slurry may be used for stabilizing and flushing holes but sometime it reduces bond capacity by forming skin of clay at the inter face. To avoid this problem polymer drilling mud is used which can apply in all types of ground. It provides the facility of easier cleanup and disposal.

There are mainly two types of drilling techniques such as overburden and open hole. Soil condition affects the types of the drilling techniques.

A. Overburden Drilling Technique

Weak and unconsolidated soil which has low bearing capacity requires temporary casing during drilling to sold the soil around the hole. This type of soil is suitable for using overburden drilling technique. If the bearing stratum is not self supporting soil, the drill hole will need temporary support for its full length. Temporary casing can be used for the support. There are six types of overburden drilling method.

- **Single Tube Advancement**

A bit is used for fitting the toe of the drill casing. Then the casing is penetrated into the ground by rotation of the drill head. Water flushing is used through the casing for removal of debris away from the crown. The water born debris is transferred to the surface around the outside of the casing. Precaution should be taken to sensitive structures in order to prevent cavitations created by uncontrolled washing. In this method air flush is not used to avoid ground disturbance.

- **Rotary Duplex**

This technique involves using of a drill bit for placing the drill rod inside the casing. Like other processes water is used for the flushing purpose which is pumped through the central drill rod. The flush borne debris then escapes to the surface along the annulus between the drill rod and the casing. In this technique, air flush can be used with caution.

- **Rotary Percussive Duplex (Concentric)**

This technique is a modified form of rotary duplex method. In this technique, percussion, rotation and penetration of drill rods and casings are done simultaneously.

- **Rotary Percussive Duplex (Eccentric)**

The rotary percussive drilling combined with an under reaming bit is used in this method. A drill casing undercuts by the eccentric bit, and then it is pushed into the oversized drill hole. It requires less rotational energy or thrust than concentric method. The diameter option more than 127 mm requires down the hole hammer acting on a drive shoe at the toe of the casing. As a result, casing is properly pulled into the bore hole.

- **Double Head Duplex**

In this technique, the rods and casings are rotated by separate drill heads mounted one above the other on the same carriage. This drill heads provide high torque but it causes low rotational speed. The lower head rotating the outer casing and the upper head rotating the inner drill string turn in opposite directions. The aggressive cutting and shearing action at the bits permits high penetration rates.

- **Hollow Stem Auger**

It is a continuous flight auger system. The hollow core is attached with the drill bit by a cap during drilling down. Later the cap is blown off by grout pressure permitting the pile to be formed as the auger is withdrawn. Such types of augers are used to drill cohesive material or very soft rocks.

B. Open Hole Drilling Technique

Open hole drilling technique is used in case of drilling through high bearing capacity and self supporting soil. This technique does not require any temporary hole support. Therefore, open hole drilling technique is applicable in stable and free standing conditions. Open hole technique is less costly then the overburden technique. This technique may be classified as follows:

- **Rotary Percussive Drilling**

This method is suitable for rocks of high compressive strength. Both top drive and down the hole hammers are involved in this method. Down the hole techniques are the most economical and common for small hole diameters like micropiles. Air, air/water mist or foam is used as the flush.

Top drive methods has limited diameter and depth capacities. They are relatively noisy and may cause damage to the structure because of excessive vibration.

- **Solid Core Continuous Flight Auger**

Continuous flight auger may be used in stiff to hard clays without boulders and in some weak rocks. These techniques do not require flushing medium to remove the debris. It may cause lateral decompression or wall remolding, both of which adversely affect grout to soil bond.

- **Underreaming**

Various devices are available to enlarge or under ream open holes in cohesive soil. This is more suitable when piles act in tension. This is a time consuming process. Effectiveness of this process cannot be verified. Cleaning of the under reams is difficult. Although water is the best cleaning medium, it may cause softening of the ground. Therefore this method is not suitable for micropile installation

.

3.3. Grouting

Micropile load capacity mostly relies on grouting procedure. The most significant objective of grout is that it transfers the imposed loads from the reinforcement to the surrounding ground. It also protects the steel reinforcement from corrosion. The grout must achieve adequate properties of fluidity, strength, stability and durability to serve these objectives. Strength, fluidity and stability of grout depend on the water cement ratio which should be within the range of 0.4 to 0.5. Potable water is used for grouting to reduce the danger of corrosion of the reinforcement. Sometimes, sand or bentonite is used as additives. But using bentonite may reduce strength of grout.

Grout mixing is similar to normal concrete mixing procedure. Predetermined volume of water is added into the mixture with cement. The mixing process generally takes approximately two minutes. It is prepared for use by agitating in a holding tank. The grout must be injected within a certain time to achieve safe workability. This time limit is affected by many factors and it should be determined on the basis of site test.

3.3.1. Grout Placement Method

Four grouting methods are available for micropile installation. Depending on these methods there are four types of micropile (type A, type B, type C, type D). These methods are discussed below.

- **Gravity Fill Techniques (Type A)**

Micropiles which are installed in this technique is denoted as type A micropile. In this method grout is filled up to the certain depth and a tremie pipe is used for grouting. The pipe exits at the end of the hole and after. The injection of grouts is stopped after achieving free extraction of same of same quality grout from the mouth of the hole.

Then the reinforcement is placed at the center of the hole. The main advantage of this type of grouting process is no requirement of external pressure. The grout quality should be equal all through the length of the bore hole. Water cement ratio is maintained between 0.45 and 0.5. For rocky or cohesive type soil this technique is applicable. As this soil have self supporting properties so no external pressure is required for placement of grouts.

- **Pressure Grouting (Type B)**

Grout ground bond capacity can be enhanced by pressurizing grouts through the casing. This is the main objective of this technique where micropiles are termed as type B micropile. After finishing initial grouting, excessive pressure is required for the placement of additional grout. This work is executed under control pressure by attaching a pressure cap at the mouth of the drill casing. Now a day's air compression method is used for this purpose. Loss of grout, drilling system, pile depth, bond capacity is some factor that should be considered in determining the value of pressure. This process is suitable for cohesion less soil for achieving the ultimate load carrying capacity. Grout ground skin friction can also be improved by this technique. Pressure grouting involves enhancing diameter in the bond zone area which improves grout soil contact.

- **Post Grouting (Type C and Type D)**

In some cases high grouting during the removal of the casing causes fracture on the ground surface and leakage around the casing wall. So pressure grouting of the type B method is not applicable where temporary casing is not necessary. In such cases post grouting is applicable where grout is inserted through tubes after a certain time of initial grouting. Water content is usually higher than the primary grout, ranges from 0.5 to 0.75. Type C and type D are in this post grouting technique.

In case of type C micropile additional grout is inserted as same method using in type A micropile. This additional grouting is inserted after 15 to 25 min of initial grouting. On the other hand additional grout is placed under gravity head or under pressurized condition like type B micropile. Pressure ranges from 2 to 4 MPa.

3.4. Reinforcement

A single reinforcing bar, steel casing or group of reinforcement can be used as reinforced steel part of micropile. In most of the cases single reinforcing bar is used. Reinforcement can be placed before or after placement of grouting. Centralizers can be used for connection of the bar threads. Reinforcement should not be corrosive and should free from deteriorated materials. Normal reinforcement using for construction purpose can be used for micropile installation.

3.5. Micropile – Superstructure Connections

Connection between micropile and superstructure is relatively a complex task. If two or more micropiles are used in a group, a new pile cap is required attached to the existing foundation. Connection between new pile cap and existing foundation may be achieved through the use of dowel (Figure 3.3). Doweled connections should be carefully designed and checked against shear. If only one micropile on each side of the column is used, it can be connected to the superstructure through the existing foundation (Figure 3.2).

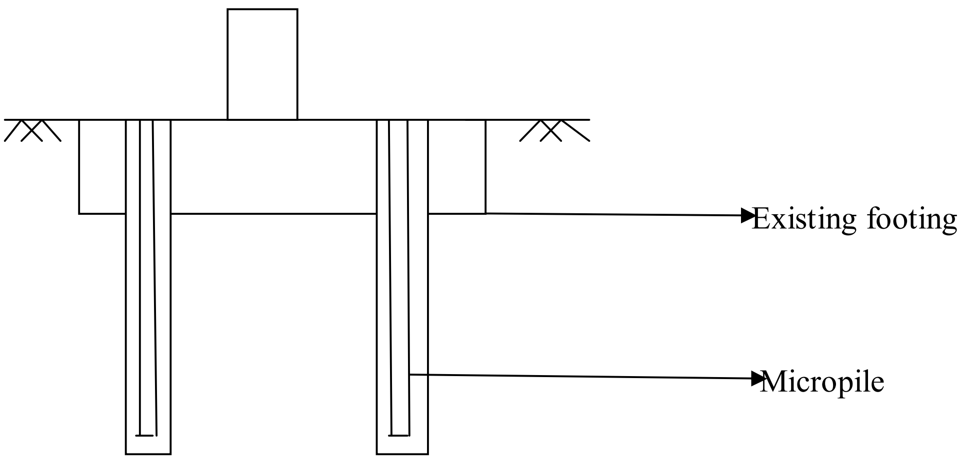


Figure 3.2: Micropile through existing foundation.

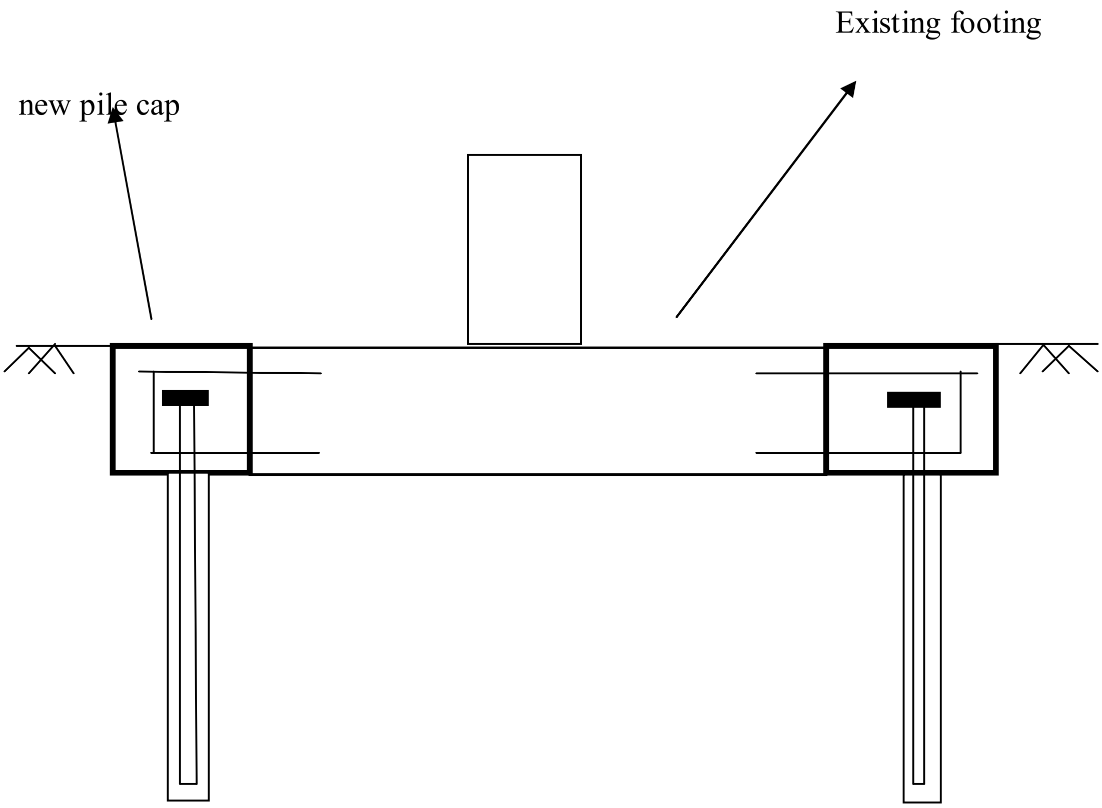


Figure 3.3: Micropile through new pile cap.

There are different ways of connecting micropile with the existing foundation. These methods are being discussed in the following sections.

A. Connection through new pile cap

Connection of micropile using a new pile cap can be achieved in various methods. Figure 3.4 shows a reinforced pile connected to the new footing. Tension and compression loads are transferred to the pile through the top plate. Here, stiffener plates are used to provide bending strength to the plate. These can be eliminated if the top plate does not require any additional support. Load capacity of the bearing plate can be reduced by utilizing the bond between pile casing and the footing concrete.

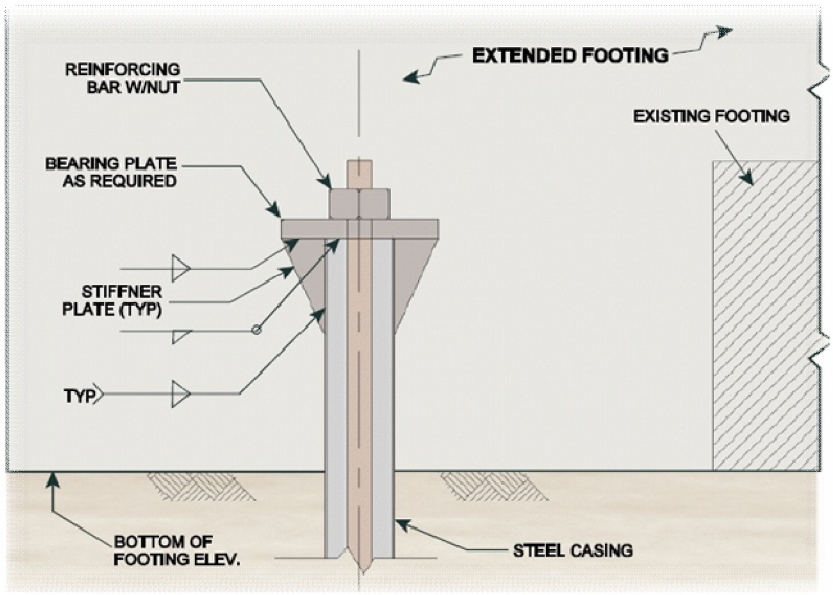


Figure 3.4: Pile to footing connection

Another method for installation through a new pile cap is shown in Figure 3.5 .

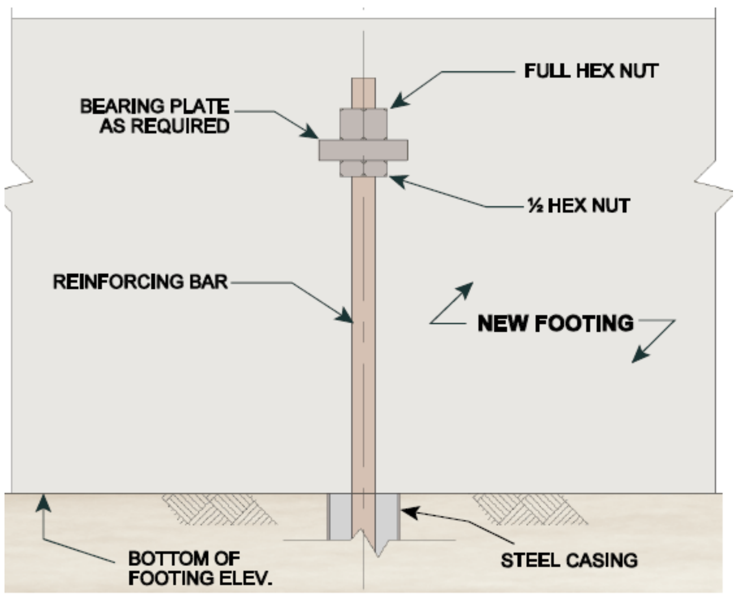


Figure 3.5: Pile to footing connection

In this case, the footing's compression and tension load is transferred to the pile through bearing on the bar plate, and through bond between the footing concrete and the reinforcing bar. Quality of construction joint between the pile grout and footing concrete should be considered for this type of connection. (Figure 3.5).

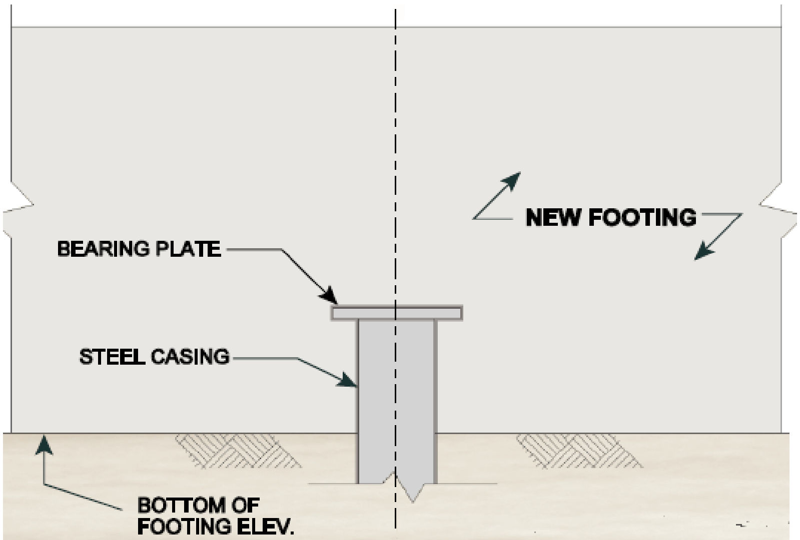


Figure 3.6: Pile to new footing connection.

In Figure 3.6, a different method for connection of micropile with new pile cap is shown. This connection is applicable for only compression load. It cannot take any tension. The bearing capacity is required for high load. If load is moderate, it can be eliminated.

B. Connection through existing foundation

Various methods are also available for connection of micropile through existing foundation. In the first case (Figure 3.7), an oversized hole is cored through the existing foundation to install the pile. The hole is cleaned and filled with non-shrink cement grout after the installation. Before the installation, steel rings are welded in the top section of the casing to transfer the load from the footing through the grout to the pile.

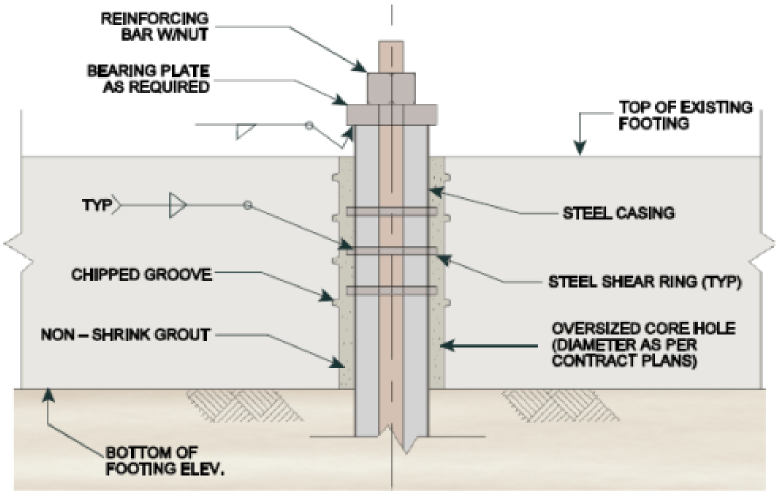


Figure 3.7: Connection through existing footing.

Vertical reinforcing bars may be drilled and epoxies into the existing concrete around the exterior of the connection to increase the punching shear capacity.

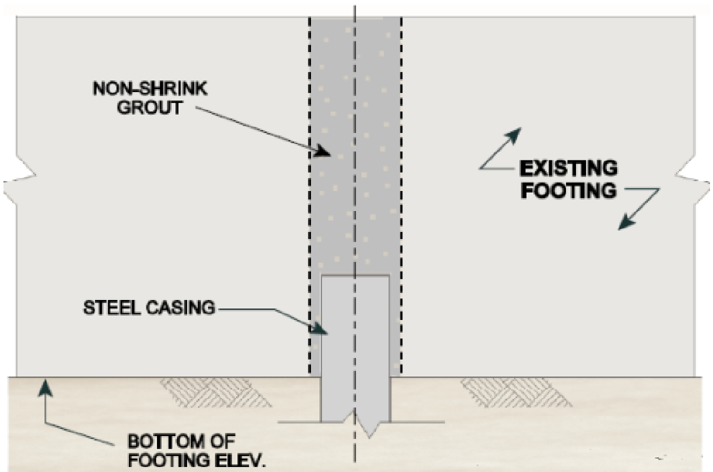


Figure 3.8: Connection through existing footing

Another method of micropile connection through existing footing is shown in figure 3.8. This method is applicable only for compression load. Like the previous method, an oversized hole is cored which is filled with non-shrink grout.

3.6. Conclusion:

Depending upon the ground and surrounding condition proper installation process should be choosen. Appropriate selection of the procedures discussed in this chapter make the installation procedure much easier. Micropile installation process is almost similar with conventional pile installation process. During connection through existing footing safety of existing foundation and its surrounding structures should be taken in consideration.

Chapter 4 Design of Micropile

4.1. General

Design of micropile includes geotechnical and structural design considerations for micropiles. Micropile design principle is almost similar to the design of any other conventional piles. The pile components should work at a safe stress level withstanding the predetermined loading condition. The displacements of the structure should be within acceptable limits. Evaluations of geotechnical as well as structural load capacity are the two basic considerations for micropile design. Geotechnical design requires estimation of grout to ground bond capacity of micropiles. Structural design section includes methods for determination of structural strengths of pile components.

There are generally two types of design method i.e. load factor design (LFD) and service load design(SLD). In Bangladesh, service load design method (SLD) is the most common approach to design foundation of R.C.C structures. According to this method, allowable load have to be greater than design load.

4.2. Geotechnical design

4.2.1. Geotechnical bond capacity

Micropiles transfer loads from structure to the ground through grout-ground skin friction without any contribution from end bearing. The effect of end bearing is negligible because area available for skin friction is much greater than that of end bearing. Besides, high grout to ground bond capacity can be attained through micropile installation methods.

4.2.2. Grout to ground bond values

Tension and compression axial design values for both SLD and LFD methods can be determined using grout to ground bond values. These values depend upon drilling, grouting, installation of micropile and also the existing ground condition. Table 4.1 can be used to determine grout to ground bond values for four types of micropile design.

Table 4.1: Typical grout to ground bond values for preliminary micropile design (FHWA Micropile Design, 2000).

Soil / Rock Description	**Typical Range of 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	515-1380	N/A	N/A	N/A

weathering)				
Limestone (fresh-moderate fracturing, little to no weathering)	1035-2070	N/A	N/A	N/A
Sandstone (fresh-moderate fracturing, little to no weathering)	520-1725	N/A	N/A	N/A
Granite and Basalt (fresh-moderate fracturing, little to no weathering)	1380-4200	N/A	N/A	N/A

4.3. Structural design

The structural design of micropile consists of upper cased length with a center reinforcing bar and an uncased length. Design of plunge length is also included in this section.

4.3.1. Pile cased length structural capacity

Cased length is the upper section of a micropile to be located in a weak upper soil. Laterally unsupported length should be considered in the determination of compression capacity. Capacity of upper cased length of transferring load to the bond length can be determined by the following equation.

$$P_a = 0.4 f'_{c-grout} A_{gc} + 0.47 f_y [A_B + A_C] \quad \text{..... ....} \ (4.1)$$

Here,

P_a = Allowable load

$f'_{c-grout}$ = Compression strength of grout

A_{gc} = Area of grout concrete

F_y= Yield strength of concrete

A_B= Area of reinforcement bar

A_C= Area of steel casing

4.3.2. Pile uncased length:

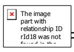
The lower uncased portion of the bond length is the weakest component of the micropile. Since the upper uncased portion or the plunge length can transfer a small portion of the load to the soil, an allowance is made for the geotechnical grout to ground capacity developed along the plunge length. This capacity adds to the structural capacity of the uncased pile for resisting the design load.

Plunge length is typically assumed and later verified.

$$P_{transfer} = [\frac{\alpha_{bond}}{FS}] * 3.14 * D_u * l_p \quad \text{… ….. ….. ….. (4.2)}$$

Here,

$P_{transfer}$ = Plunge length allowable load

= grout to ground bond strength

FS= Factor of Safety

D_u= Diameter of bond length

L_p=Plunge length

Allowable load of the bond length can be determined by the following equation.

$$P_a = 0.4 f'_{c-grout} A_{gu} + 0.47 f_y A_B + P_{transfer} \quad \text{…. …. ….(4.3)}$$

Here,

$A_{gu=}$ Uncased area of grout

Length of the uncased portion can be determined from the previous relationship of bond length and grout to ground bond strength.

$$P_a = \frac{\alpha_{bond}}{FS} * 3.14 * D_u * L_b \quad \text{….. ….. …. ….} \; (4.4)$$

Here,

P_a = Actual load on micropile

L_b =Bond length

By following the described design procedure, micropile can be designed to support excessive loading condition.

4.4. Conclusion

Though micropile design is not mentioned in Bangladesh National Building Code (BNBC), it's geotechnical and structural strength design calculation is much reasonable. Adequate micropile length for any type of ground condition can easily be calculated using these design procedure.

Chapter 5 Case Study

5.1. General

Micropile is an innovative solution for underpinning and retrofitting type of work. Unfortunately this has not yet been introduced in Bangladesh. The vision of this study is to show the application of micropile installation and its suitability in case of vertical extension of an existing structure through a case study. The case study is performed on the new academic building of Islamic University of Technology (IUT). This chapter includes the design and installation of micropiles required for vertical extension of this academic building.

5.2. Present Condition of Existing Structure

Soil and structural properties of the building are discussed in the following sections.

5.2.1. Soil Condition

The available geotechnical information included a report prepared by M/S ENGINEERING & PLANNING CONSULTANTS LTD. The report indicates that the sub-soil formation encountered at the site is homogeneous. The soil condition mainly consists of clay, silt and little amount of sand. There is 60-68% silt, 29-38% clay and 5-9% sand. So it can be concluded that the soil is clayey silt. It was also depicted in the report that soil is medium stiff up to the depth of 3.5 m and then stiffness increases with depth. The bearing capacity of soil at the site is 1.09 tsf or 2.18 ksf.

5.2.2. Sub-Structural Condition

The subsurface condition of site is suitable for shallow foundation. The foundation of Building is provided at a depth of 10 feet from existing ground level. The footings are concentric with column load. The foundation consists of single footings, combined footings, continuous footings and mat foundations.

5.2.3. Super-Structural Condition

The academic building was a five storied structure with a foundation for six stories. The sixth story has been constructed recently and thus is not included in the case study.

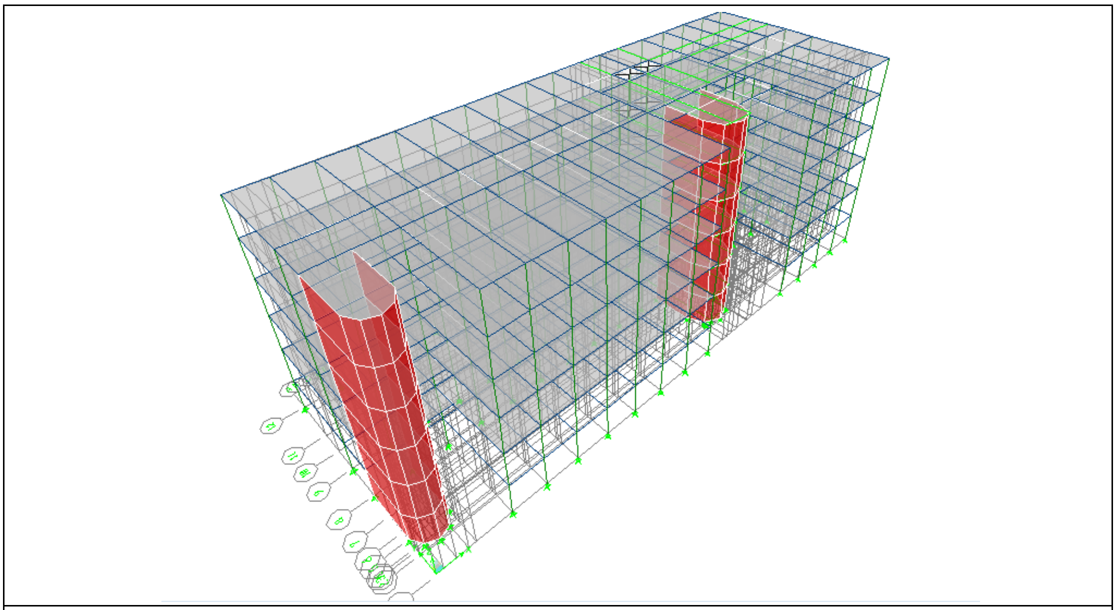


Figure 5.1: Model of new academic building.

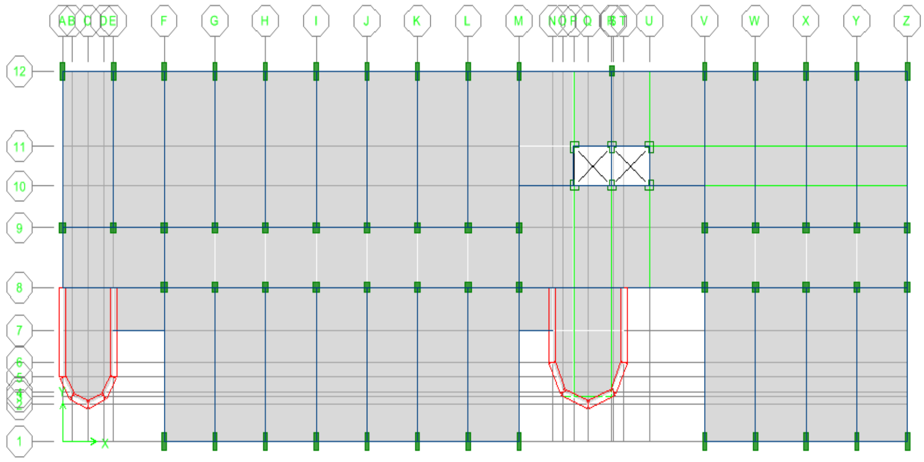


Figure 5.2: Plan view of academic building

5.3. Structural Analysis of Existing Structure

A model of five stories of the building was created in ETABS. Expected loads on each footing were determined from the model. This also helped to check the capability of the footings to support the existing columns. Loads and net pressure of the footings are shown in Table 5.1 and 5.2.

5.4. Discussion on the Result

It's observed from the soil reports that the bearing capacity of the soil at the site is 2.18 ksf. Information from Table 5.1 and 5.2 ensures that all the net pressures are within bearing capacity. It can be concluded from the information's that the foundation is capable of withstanding the loads for five stories.

5.5. Analysis for Vertical Extension

If the academic building is constructed up to seven stories, the foundation is required to be retrofitted and micropile may be used for that purpose. The model of the building in ETABS has been extended up to seventh floor to determine an approximate loading condition on the foundation. These loading conditions are shown in the tables 5.3 and 5.4.

In case of constructing seven stories, net pressure under four continuous footings, five single footings and ten combined footings exceeds the capacity. Table 5.5 and 5.6 depict the extra load on the footings beyond the capacity.

Table 5.1: Loads on continuous footing (COF1-4), single footing(F1-11) and mat foundation (SMF1-2, LMF) for five stories.

Properties	COF 1	COF 2	COF3	COF4	SMF 1	SMF2	LMF	F5	F6	F7	F8	F9	F10	F11
soil unit wt (kcf)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
conc unit wt (kcf)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Footing depth (ft)	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Footing Thickness (ft)	2	2	2	2	2	2	1.5	1.5	1.5	2	2	2	1.5	1.5
soil thickness (ft)	7.5	7.5	7.5	7.5	7.5	7.5	8	8	8	7.5	7.5	7.5	8	8
Column load	18	16	16	14	325	290	588	166	102	186	165	165	139	112
Footing width (ft)	9.5	9	8	8	20	16	15	9.5	7	9.5	9.5	9.5	7	7
Length(ft)	1	1	1	1	24	24	22	9.5	7	13	12	12	9.5	8
pressure from column load (ksf)	1.89	1.77	2	1.75	0.67	0.76	1.78	1.84	2.08	1.50	1.45	1.45	2.09	2
Pressure from soil (ksf)	0.68	0.68	0.68	0.68	0.68	0.68	0.72	0.72	0.72	0.68	0.68	0.68	0.72	0.72
Pressure from conc (ksf)	0.3	0.3	0.3	0.3	0.3	0.3	0.23	0.23	0.23	0.3	0.3	0.3	0.23	0.23
gross pressure (ksf)	2.86	2.75	2.98	2.73	1.65	1.73	2.73	2.78	3.02	2.48	2.42	2.42	3.04	2.9
Surcharg(ksf)	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
net pressure (ksf)	2.01	1.89	2.12	1.87	0.79	0.88	1.87	1.92	2.17	1.62	1.56	1.56	2.18	2.09

Table 5.2: Loads on combined footings(CF 1-11) for five stories.

Properties	CF1	CF2	CF3	CF4	CF5	CF6	CF7	CF8	CF9	CF10	CF11
Soil unit wt (kcf)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Conc unit wt (kcf)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Footing depth (ft)	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Footing thickness (ft)	2	2	2	2	2	2	2	2	2	2	2
Soil thickness	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Length (ft)	25	25	25	25	25	25	25	25	25	25	25
Width (ft)	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Column load 1 (k)	215	209	209	209	215	214	191	191	207	189	109
Column load 2 (k)	148	189	207	208	208	207	188	188	206	190	98
from column load (ksf)	1.52	1.68	1.75	1.76	1.78	1.77	1.59	1.59	1.73	1.59	0.87
from soil (ksf)	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
From conc (ksf).	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Gross pressure (ksf)	2.5	2.65	2.726	2.73	2.756	2.74	2.57	2.57	2.713	2.57	1.84
Surcharge (ksf)	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Net pressure (ksf)	1.64	1.79	1.87	1.87	1.90	1.89	1.71	1.71	1.85	1.71	0.99

Table 5.3: Loads for 7 stories on single (F 5-11), continuous footing (COF 1-4) and mat foundation (SMF 1-2, LMF).

Properties	COF1	COF2	COF3	COF4	SMF1	SMF2	LMF	F5	F6	F7	F8	F9	F10	F11
soil unit wt (kcf)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
conc unit wt (kcf)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Footing depth(ft)	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Footing Thickness(ft)	2	2	2	2	2	2	1.5	1.5	1.5	2	2	2	1.5	1.5
soil thickness (ft)	7.5	7.5	7.5	7.5	7.5	7.5	8	8	8	7.5	7.5	7.5	8	8
Column load(k)	25	22	23	20	468	401	688	234	140	260	229	229	210	155
Footing width(ft)	9.5	9	8	8	20	16	15	9.5	7	9.5	9.5	9.5	9.5	7
Length(ft)	1	1	1	1	24	24	22	9.5	7	13	12	12	9.5	8
Pressure from column load(ksf)	2.63	2.44	2.87	2.5	0.98	1.04	2.08	2.59	2.85	2.10	2.0	2.0	2.32	2.76
Pressure from soil(ksf)	0.68	0.68	0.68	0.68	0.68	0.68	0.72	0.72	0.72	0.68	0.68	0.68	0.72	0.72
Pressure from conc(ksf)	0.3	0.3	0.3	0.3	0.3	0.3	0.23	0.23	0.23	0.3	0.3	0.3	0.23	0.23
gross pressure	3.60	3.41	3.85	3.475	1.95	2.01	3.02	3.53	3.80	3.08	2.98	2.98	3.27	3.71
Surcharge	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Net pressure (ksf)	2.75	2.56	2.99	2.62	1.09	1.16	2.17	2.68	2.94	2.22	2.12	2.12	2.41	2.85

Table 5.4: Loads on combined footings for seven stories.

Properties	CF1	CF2	CF3	CF4	CF5	CF6	CF7	CF8	CF9	CF10	CF11
Soil unit wt (kcf)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Conc unit wt (kcf)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Depth of footing (ft)	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Footing thickness (ft)	2	2	2	2	2	2	2	2	2	2	2
Soil thickness (ft)	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Length (ft)	25	25	25	25	25	25	25	25	25	25	25
Width (ft)	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Column load 1(k)	298	297	297	297	297	295	269	270	292	263	170
Column load 2 (k)	222	268	295	297	297	295	264	266	292	265	156
Total column load (k)	520	565	592	594	594	590	533	536	584	528	326
Pressure from column load (ksf)	2.18	2.37	2.49	2.50	2.50	2.48	2.24	2.25	2.45	2.22	1.37
Pressure from soil (ksf)	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Pressure from conc(ksf)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Gross pressure(ksf)	3.16	3.35	3.46	3.47	3.47	3.45	3.21	3.23	3.43	3.19	2.34
Surcharge(ksf)	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Net pressure (ksf)	2.30	2.49	2.61	2.62	2.62	2.60	2.36	2.37	2.57	2.34	1.49

Table 5.5: Extra load on single and continuous footing.

Properties	COF1	COF2	COF3	COF4	F5	F6	F10	F11
Soil unit wt (kcf)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Con unit wt (kcf)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Length (ft)	98	77	49	47	9.5	7	9.5	8
Width(ft)	9.5	9	8	8	9.5	7	9.5	7
Allowable bearing capacity	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18
Gross load(k)	20.71	19.62	17.44	17.44	196.745	106.82	196.745	122.08
Footing depth(ft)	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Footing thickness(ft)	2	2	2	2	1.5	1.5	1.5	1.5
Soil thickness (ft)	7.5	7.5	7.5	7.5	8	8	8	8
Load from conc (k/ft)	2.85	2.7	2.4	2.4	20.30	11.02	20.30	12.6
Load from soil (k/ft)	6.4125	6.075	5.4	5.4	64.98	35.28	64.98	40.32
Load from surcharge(k/ft)	8.1225	7.695	6.84	6.84	77.163	41.895	77.16375	47.88
Footing capacity(k/ft)	19.57	18.54	16.48	16.48	188.62	102.41	188.62	117.04
Actual load(k/ft)	25	22	23	20	234	140	210	155
Extra load (k)	532.14	266.42	319.48	165.44	45.37	37.59	21.37	37.96

Table 5.6: Extra load on combined footing.

Properties	CF1	CF2	CF3	CF4	CF5	CF6	CF7	CF8	CF9	CF10
Soil unit wt (kcf)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Con unit wt (kcf)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Length (ft)	25	25	25	25	25	25	25	25	25	25
Width (ft)	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Allowable bearing capacity	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18
Gross load (k)	517.75	517.75	517.75	517.75	517.75	517.75	517.75	517.75	517.75	517.75
Footing depth (ft)	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Footing thickness (ft)	2	2	2	2	2	2	2	2	2	2
Soil thickness (ft)	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Load from conc (k)	71.25	71.25	71.25	71.25	71.25	71.25	71.25	71.25	71.25	71.25
Load from soil (k)	160.31	160.31	160.31	160.31	160.31	160.31	160.31	160.31	160.31	160.31
Load from surcharge (k)	203.06	203.06	203.06	203.06	203.06	203.06	203.06	203.06	203.06	203.06
Footing capacity (k)	489.25	489.25	489.25	489.25	489.25	489.25	489.25	489.25	489.25	489.25
Actual load (k)	520	565	592	594	594	590	533	536	584	528
Extra load (k)	30.75	75.75	102.75	104.75	104.75	100.75	43.75	46.75	94.75	38.75

1.1. Design of micropile

Table 5.5 and 5.6 show the excessive loads on each footing for vertical extension of the academic building. Micropile is required to support the additional load. The design and number of micropiles for the corresponding footings is described in this section.

Design for the single footing, F5 is going to be shown as an example. The single footing has a dimension of 9.5 feet by 9.5 feet. It is shown in the table 5.5 that due to vertical extension, F5 will carry an additional load of 46 kips. Equal number of micropiles should be provided on both sides of the footing considering eccentricity. If two micropiles are used at opposite sides of the footing, each one will have to carry approximately 25 kips load. For steel reinforcement, #7 bar can be used as the reinforcement. Since the soil at the site is not weak, permanent casing is not required.

The properties required for the design are given below.

Diameter of bar, D_b =0.875 in

Area of bar, A_b = 0.6 in^2

Grout to ground bond nominal strength, α_{bond} = 0.017 [From table 4.1]

Diameter of micropile, D_p = 7in

Compressive strength of grout, $f'_{c\text{-}g}$ = 3 ksi

Yield stress, f_y = 60 ksi

Factor of safety, FS = 2.5

Design load = 25 kips

Area of grout, $A_g = (D_p{}^2 * \frac{\pi}{4}) - A_b$

=37.89 in^2

Allowable load on micropile, $P_a = (0.4 f'_{c-g} A_g) + 0.47 f_y A_b$

$= 62.38$ kips > design load

So, the design is OK.

Length of the micropile, $l_p = \dfrac{P_d * FS}{\pi * \alpha * D_p}$

$= 14$ feet

So, with the installation of two micropiles with a length of 14 feet and diameter of 7 in at opposite sides of the footing, F5, the additional load can be supported. Dimension and number of micropiles required for other footings are shown in the Table 5.7 and 5.8.

Table 5.7: Design of micropile for single and combined footings.

Properties	F5	F6	F10	F11	CF1	CF2	CF3	CF4	CF5	CF6
Design load (k)	25	20	13	20	17	18	25	26	26	25
compressive strength of grout (ksi)	3	3	3	3	3	3	3	3	3	3
Dia of bond length (in)	7	7	7	7	7	7	7	7	7	7
Area of reinforcement bar (sq. in)	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Grout area (sq. in)	37.88	37.88	37.88	37.88	37.88	37.88	37.88	37.88	37.88	37.88
Yield stress (ksi)	60	60	60	60	60	60	60	60	60	60
Grout to ground bond strength	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
Factor of safety	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Allowable laod on micropile (k)	62.38	62.38	62.38	62.38	62.38	62.38	62.38	62.38	62.38	62.38
Micropile Length (ft)	13.93	11.14	7.24	11.14	9.47	10.03	13.93	14.48	14.48	13.93
No of micropiles	2	2	2	2	2	4	4	4	4	4

Table 5.8: Design of micropiles for combined and continuous footings.

Properties	CF7	CF8	CF9	CF10	ConF1	ConF2	ConF3	ConF4
Design load (k)	22	25	25	20	53	34	53	28
compressive strength of grout (ksi)	3	3	3	3	3	3	3	3
Dia of bond length (in)	7	7	7	7	7	7	7	7
Area of reinforcement bar (sq. in)	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Grout area (sq. in)	37.88	37.88	37.88	37.88	37.88	37.88	37.88	37.88
Yield stress (ksi)	60	60	60	60	60	60	60	60
Grout to ground bond strength	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
Factor of safety	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Allowable laod on micropile (k)	62.38	62.38	62.38	62.38	62.38	62.38	62.38	62.38
Micropile Length (ft)	12.25	13.93	13.93	11.14	29.53	18.94	29.53	15.60
No of micropiles	2	2	4	2	10	8	6	6

1.2. Installation process for the project

Selection of suitable installation process is required for the successful implementation of the project. Installation process should be selected on the surrounding condition of the project vicinity. This process is directly related to ground condition and soil type. Installation process should be executed under low head room condition and it should be ensured that the site remain operational under low head room condition.

Easily accessible equipment is necessary for excavation purpose. Soil should be excavated 10 ft below from the existing ground level. Excavation work should be executed in such a way that the building remains operational during excavation. That’s why excavation work should be done in part wise process.

Drilling method should be selected in such a way that it is cost effective and it causes minimum disturbance to surrounding structures. There are generally two types of drilling techniques such as overburden and open hole drilling technique. Overburden technique is usually used for weak and unconsolidated soil. On the other hand, open hole technique is applicable for rock and cohesive soil. As soil condition of the project site is clayey silt, open hole drilling technique is applicable for the project. Open hole drilling may be classified into two types. Rotary percussive drilling and solid core continuous flight auger. Rotary percussive drilling is suitable for the project.

Top drive or down the hole hammers are used for rotary percussive drilling. For small diameters like micropile, down the hole techniques are most economical. Steel casing is used for drilling up to a certain depth but as the soil is cohesive so casing is not required. Soil inside the hole is cleared out by water flashing. In this method tricone bit is useful for drilling purpose.

There are different types of drill rigs. Small frame mounted rotary hydraulic drill rig is the most suitable for installation of micropile. It allows placement of power unit outside the area of work and reduces the space requirement. The drill frame can be moved and supported with a fork lift, or moved by hand with winches and supported by bolting to a concrete floor, footing or bracing from a ceiling. It allows installation of less than 3m of overhead. The pile centerline can be located within 0.3m of the face of an adjacent wall.

Micropiles are of four types based on grouting method. Because of cohesive soil condition of our project we choose type A micropile. First the whole has been drilled to design depth , then he whole is filled with grout and the reinforcement is placed . Tremie pipe is used to introduce grout into the drill hole and grout is pumped into the bottom of the hole until it flows freely from the mouth of the bore hole. Grout is injected by gravity pull that's why no excess pressure is applied. The water cement ratio of grout ranges from 0.45 to 0.50. Same quality of grout must be ensured for the full length of the bore hole.

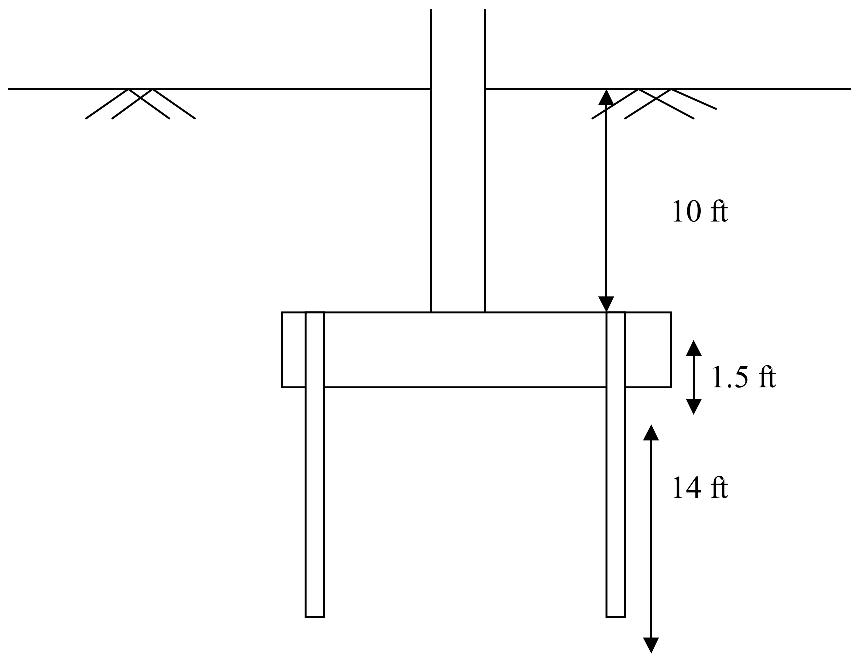


Figure 5.3: Installation of micropile for single footing, F5.

Some micropiles have to be installed through existing footing whereas some micropiles needs to be attached with footing by pile cap. For more than one micropile doweled connection is used to link between existing footing and new pile cap. For installation through existing footing an oversized hole is cored and then it is filled with non shrink grout (Figure 3.8). As these piles are designed for compressive load this method is suitable for installation process.

5.8. Conclusion

Lower diameter should be considered for design purpose because it causes minimal vibration during installation. Overall the installation process should be economical and cause fewer disturbances to the surrounding structures**.** Total 68 micropiles are required to execute the underpinng of the building. Also equipments needed for conducting installation of piles is available in Bangladesh.

Chapter 6 Conclusion

2.1. Review on Completed Works

The purpose of this paper is to introduce micropile technology in Bangladesh. Case history of this paper demonstrates the unique application of micropile to increase the capability of existing foundation for future vertical extension of new academic building of IUT. As this is a new technology in Bangladesh so load testing was not possible during project analyzation phase. Installation of micropile with local technology is the most challenging part for the execution of the project. Considering the academic purpose of the building , it is required to be operational during the installation and excavation work. Producing minimum vibration during drilling and successful installation through existing footing are the main criterias that should be considered to finish this work within schedule time.

2.2. Summary and Conclusion

In a densely populated country like Bangladesh, space and resources both are limited and this fact causes hindrance for future construction. Vertical extension of structure and underpinning of existing foundation is a very promising solution to overcome this situation. Micropile is widely used for underpinning as well as extension of existing structure. The most notable advantage of micropile is that it can be installed in low head room condition without disturbing surrounding structures. Also drilling technique and installation is almost same as conventional pile installation. Considering these advantages micropile technology can be effectively used in Bangladesh.

In the case study of the paper total seventy micropiles are required for the vertical extension of two story. The length of the micropile ranges from 7 to 29 ft. If two or more pile requires in each side of the micropile , then pile cap is required for the connection between micropile and existing foundation. Soil should be excavated 10 ft below the existing ground level. Dia of micropile is 7 inch and #7 bar is used for reinforcement.

Soil type is clayey silt and the nature of the soil is cohesive. Considering the soil condition open hole drilling technique can be used. Also here micropile categorized under type A where gravity grouting can be used. Temporary drill casing is not required for self supporting condition of the soil. Excavation work can be done part wise maintaining the operational condition of the building.

2.3. Recommendation for Future Studies

Apart from the study that have been carried out, there are scope for further studies especially on the following area:

- An analysis of cost is required for the implementation of the micropile.The analysis may include the cost of excavation, drill rigs , reinforcement, cement, labour etc.

- If installation of micropile is not possible in both side, then micropile will have to be installed in one side of the footing. center of gravity will be moved and it will cause eccentricity. Further study can be carried out on this fact.

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