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New WPI Parking Lot-Athletic Field: Deep and Shallow Foundation Design and Construction Planning

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New WPI Parking Lot-Athletic Field: Deep and Shallow Foundation Design and Construction Planning

A Major Qualifying Project
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the
Degree of Bachelor of Science
By

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Professor Guillermo F. Salazar, Advisor

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Abstract

This project proposes a combined shallow and deep foundation design for the construction of a new integrated parking garage and athletic field structure for Worcester Polytechnic Institute (WPI). It mainly focuses on the foundations design of the building and on the construction planning and Project Management, using of the traditional schedule with the Critical Path Method. The project also develops a Building Information Modeling (BIM) digital 3D model and extends it to a 5D model for integration of time and cost.

Capstone Design Experience.

The Capstone Design Experience is a requirement by the Civil and Environmental Engineering program at Worcester Polytechnic Institute (WPI), and all Major Qualifying Projects (MQPs) must include one.

In this Major qualifying Project, the students demonstrate their engineering and design ability, as well as Project Management and Building Information Modeling (BIM) knowledge.

Due to the lack of parking at WPI, the school board of trustees approved the construction of a new combined structure of a parking garage with an athletic field on top located in the north-west area of the campus along from Park Avenue, where the current softball field is located. This MQP mainly focuses in the foundation design of the building and on the construction planning and management using the critical path method. The project also develops Building Information Modeling digital 3D model and extends it to a 5D model for the integration of time and cost.

The foundation design used information provided by the design-build firm in charge of this project. The group also attended some of the weekly meetings and talk to the design-build firm staff. We received the soil report and carefully analyzed many important aspects of this soil. This allowed the group to estimate the values for live loads and dead loads from the structure acting on the foundations. We divided the foundation area into different zones according to the type of material and location of the bedrock. The team proposed the use of shallow foundations in some areas, where the soil bearing capacity allowed it and the bedrock was located closer to the surface. The team also proposed the use of drilled shaft foundations in the places where the bedrock was located deeper and soils conditions were poor. We analyzed different aspects of the foundation design, in terms of costs, materials, time to complete performance and compared our design with the Pressured Injected Footing (PIF) alternative proposed in the soil study. Project Management skills are used in this project, to come up with a suitable construction plan in terms of cost and performance, as well as to come up with the an efficient way to build the facility by organizing the necessary activities to complete the project, and creating a critical path. Using Revit Structure and Architecture software we created a 3D digital model of the facility and by the use of PRIMAVERA software we generated a construction schedule, listing all the activities with their corresponding duration and interrelationship. This allowed us to visually display the gradual construction of the garage and observe the expected progress over time. This is commonly known as the 4-Dimensional model. Finally, a cost analysis, organized under a break down structure of the work allowed us to add the cost dimension to the 4D model, to create what is known as a 5D

There were three major constrains in the development of this MQP. Our group didn't have a strong background in foundation design or geotechnical engineering. The early stages of the project were very challenging because of this; a lot of research was required. At first, the soil study was given to us; it was very challenging to understand most of the information, since our background was very limited. As we started understanding all the major concepts of foundations, soil mechanics and geotechnical engineering, everything stared making more sense for us, we were able to understand better the soil report and perform a good foundation design. Other major challenge we had, was the lack of information available about the project. The actual design of this building was in very early stages so we had to estimate some numbers to compute the superimpose loads that our foundation system needed to support. This loading estimation process was a little bit challenging, since there were many things that needed to be consider, wind loads, earthquake loads, and all the dead loads from drainage and precast. We didn't know much about precast members either, so we had to do research about this as well. The third major challenge was to come up with a 3-Dimensional digital drawing of the soil layers using Revit. A lot of research was done by the team in this matter; we didn't find any actual procedure about how to perform this 3-D design of the soil in any book since this is not a very common practice. We look for help around asking WPI students; however people with grad school background in Building Information Modeling didn't know how to perform this particular task, and some of them thought that is was not possible. Sergio Alvarez, a PHD student gave us some good ideas that were very helpful for our design of this soil layers.

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1. Introduction

In the last few years, Worcester Polytechnic Institute (WPI) has been going through an expansion process. This expansion has come by hand with an increase in the school population. Every year more faculty, staff and students are joining the Institution.

This fast growing process, which the school is going through, has brought more vehicles every year. There is a lack of parking and green spaces in the Worcester Polytechnic Institute campus area.

The WPI Board of trustees is considering many different alternatives to help solve this parking problem. One of the alternatives being considered consists of a parking garage with an athletic field on top of it. The parking garage will consist of a one floor garage with an approximated area of 174,400 ft^2 and capacity for 600 hundred vehicles.

The planned project site will be located at the northwestern corner of the Worcester Polytechnic Institute campus. The site chose for this project its bounded to the north with the First Baptist Church, the WPI football field and the Recreation Center to the south, to the east with the Higgins House and Harrington Auditorium, to the west by Park Avenue. The actual site it's a natural grass field and it's been used as a softball, soccer and baseball field, the site is around 6 to 7 feet lower than Park Avenue.

This Project has some design and construction challenges. Also due to the soil conditions of the site, this project will need a combined foundation design. The design need for this type of soil is a mix of Shallow Foundation for the strongest part of the site and a Deep Foundation for the weaker zone of the site.

Gilbane Construction Co. (Gilbane) has been studying many different alternatives, considering different possible designs looking for the best option that can be adjusted to WPI budget and desires. The school board of trustees has been working together with them, SMMA designer and Cardinal consultants in this project.

In this MQP project our main objective was to find the most effective way to satisfy the needs and requirements of the project with the most suitable design, in terms of cost and quality.

The construction industry is constantly changing in an effort to optimize the construction process, minimize material waste, decrease project cost, accelerate project completion, and very important, maximize communication between all parties involved. Also in this project analysis we are going to implement some of the most important and innovative project management's techniques using innovating software's like Autodesk Revit, which will allow us to design a three-dimensional model of the building. Then by introducing time, showing the progress of the work in each phase till competition, our 3D model becomes a 4D model. A 4D model can be very helpful to reduce timelines and make sure that the project is going on tract. BIM can also include money tracking in each phase of construction; this is very helpful for owners and manager because it allow them to have a better understanding of how money is being spent in the project.

These Major Qualifying Project tries to show the benefits BIM and it applications to many different areas of the project.

2 Project Background

2.1 The Parking Garage

Worcester Polytechnic Institute is going through a fast expansion process. School population (Students, Faculty and Staff) is growing very fast and there are needs for infrastructure updates.

This fast growing process caused a shortage for parking on campus, and every day it is harder to find spot to park without having to wait and drive around for a considerable amount of time.

This came to the attention of the board of trustees, who start analyzing many different alternatives and that when the idea of constructing of a new parking garage came.

Many alternative locations and designs were study for this new project. There were many things that needed to be considered, such as the location of the parking, the city permits, the access to the building, the soil conditions and so on.

Gilbane and WPI representatives carefully analyzed together many alternative possibilities, after many discussions about many different solutions, two main designs where selected as possible solutions, a one-story garage and a two-story garage, both of them to be constructed where the WPI softball field is located, by Park Avenue.

After Many meetings, they analyze the Pros and the Cons of the two alternatives, to determinate which of them was better and more convenient for the school purposes. They were discussing whether a two story garage was too much for what the school really needed or not, or whether a two-story alternative might be needed in the future, with a one-story built first and another story a few years later. So then a new alternative design came into play, if a one-story design was going to be built with intentions for a second story latter on, they would need to consider bigger loads in their design, and at the same time build bigger columns and foundations that would had increased the cost of the project by a considerable amount of money.

These three possible alternatives were brought to the board of trustees and where carefully study by them in several meetings.

In January 2012, the WPI board of trustees approved for the design of a new Parking Garage. They decided to go with a one-story design, they considered that it was cheaper, easier to construct and that the view of Park Avenue will be damage with a large building in that location.

Gilbane Construction Company is currently working in a new athletic and recreational center that is locate next to the site of the garage, WPI realized that for their convenience this new project should start now that Gilbane is at the site. This will reduce a lot the cost of mobilization, especially for labor and materials.

2.2 Soil Conditions (Soil Study):

This section of the project summarizes the soil conditions obtained from the soil report performed by McPHAIL Associates, Inc, Geotechnical Engineers (McPHAIL). It also gives some recommendations based on the results, to take into consideration in the design of the foundations.

Purpose of a Soil Analysis:

The subsurface exploration was performed to define the subsurface soil and ground water table conditions at the site as they relate to the foundation design. Base on this condition we were able to provide some recommendations for a foundation design.

Site Location:

Northwestern corner of the WPI campus, bounded to the west with Park Avenue, the existing WPI football field and the recreational center to the south, Harrington Auditorium and the ground of Higgins House estate to the east and the Baptist Church to the north.

Subject Site:

Natural grass soccer and softball field and former baseball field.

Site Surface:

The ground surface is relatively leveled. It varies from elevation +519 to elevation +522. The ground surface has an upward slope from the field level to the west of the subject site, then it meet the existing grade from Park Avenue, which is at an approximate elevation of +530. At the north, the surface slopes down moderately from field level to meet the elevation of the parking lot next to the Baptist church that is about +514.

Surface exploration program:

Surface exploration was performed in the site, within the footprint of the conceptual proposed parking structure. The soil exploration consisted of twenty-two test pits and fifteen soil borings. These tests were both performed between September 27 and October 10 2011.

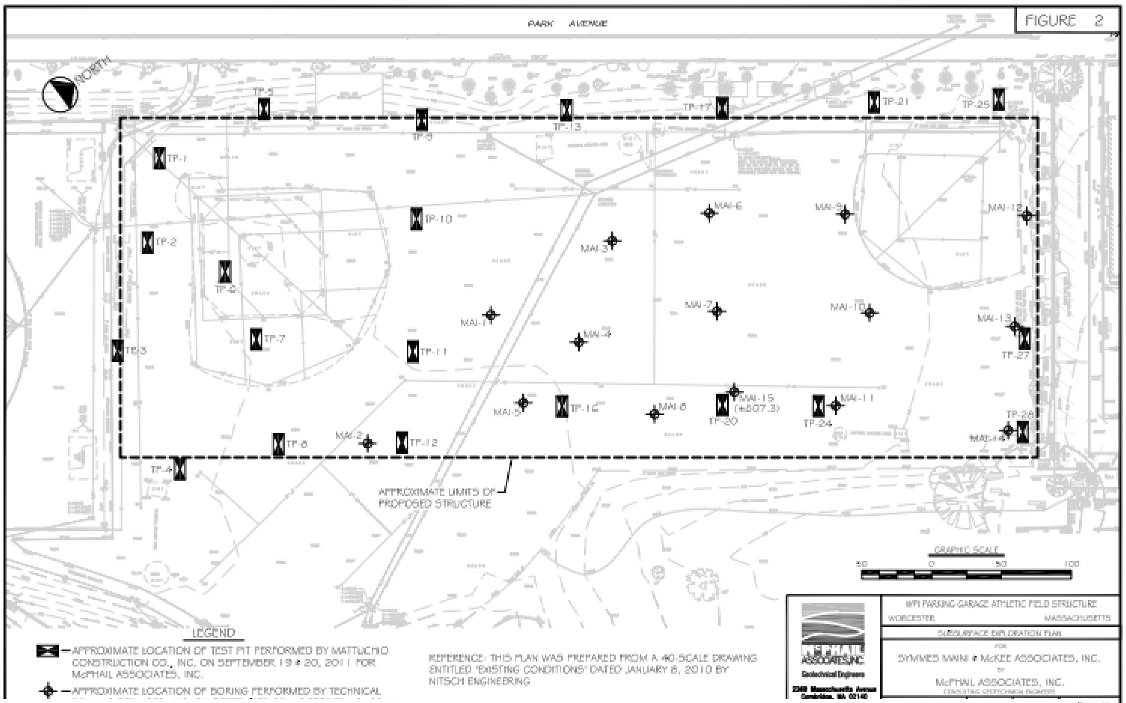


Figure 2-1 Location of the Boring tests and Log (MackPhail Engineering)

Figure2.1 shows the location of both, the pits test and the soil borings.

The borings logs performed in this soil study where executed by truck-mounted drill augers. The penetration testing was performed with standard procedures from ASTM D1586. Soil samples where obtained at minimum standard 5-foot intervals.

The number of blows required to drive the split-spoon for six inches was recommended during the sampling. The sum of the blows for the second and third interval is referred as “The N-value” . The N-value provides a measure of the density of the soil as well of the soil consistency. Borings were performed in depths between 8 and 22 feet below the surface.

Standard Penetration Test (STP):

The Standard Penetration Test is done by a thick-wall sample tube, that has an outside diameter of about 50 mm and an inside diameter of 35 mm. Its length is about 650 mm. This tube is driven into the ground as a hammer; its weight is 63.5 kg (140 lb.). It falls through a distance of 760 mm (30 in).

The number of blows needed for the tube to penetrate 150mm (6in) are accounted, up to a depth of 450 mm(18 in)

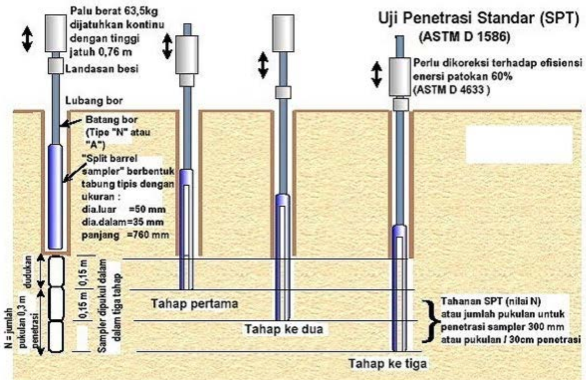


Figure 2-2 Steps followed in a SPT

source: http://3.bp.blogspot.com

The number of blows required for the second and third 6 in is sum up and are known as the "standard penetration resistance" or "N-Values".

N-Values are very important to determinate how strong a soil is.

Figure 2.2 shows in details how a Standard Penetration Test is performed.

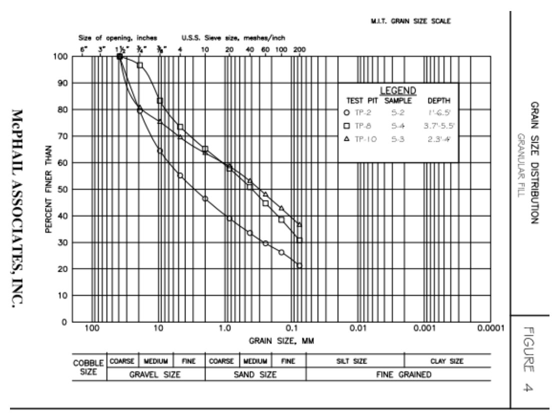


Table 2-1 result from sieve analysis 1
Source: McPhail Eng. Soil Report

Laboratory Testing:

After samples were collected, they were transported to McPHAIL's laboratories to obtain more information. The laboratory testing performed consisted on sieve analysis to determinate and average size for the soil particles. Laboratory test was performed following ASTM Standards.

From the information obtained from the sieve test (Tables 2.1, 2.2, 2.3), we can see how the soil particles are very evenly distributed, with grains that range from 50 MM to about 0.08 MM in size. The shapes of the distributions are similar in most points where the test was performed, except in TP-11 and TP-16 where the particles are much smaller in size.

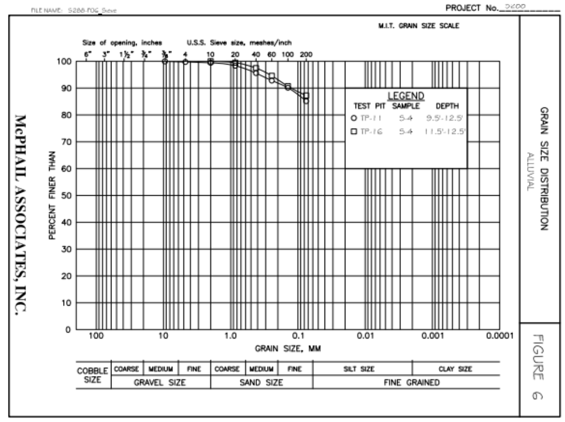


Table 2-2 result from sieve analysis 2 Source: McPhail Eng. Soil Report

Surface Conditions:

Generally composed by grass and untreated ground surface, the grass surface was underlain by a 0.5 to 2.7-foot soil. There was also encounter a discontinuous layer of topsoil with average thickness of about 1 foot, the topsoil deposit was observed to consist of loose compact silt sand with some gravel, the color was dark brown. There was also present come organic material and roots.

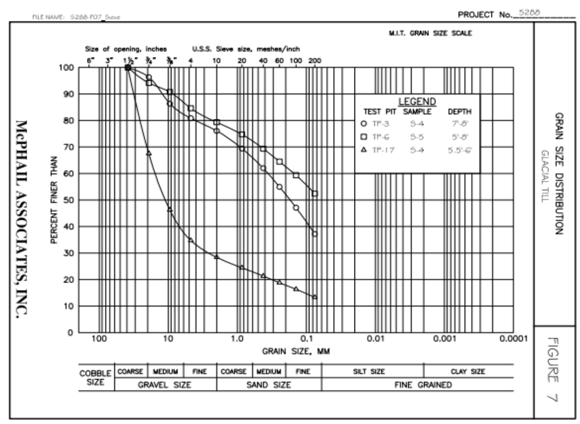


Table 2-3 result from sieve analysis 3 Source: McPhail Eng. Soil Report

Beneath the topsoil, with the boring and pits test, there was identify a fill deposit compose either by granular or urban fill. Granular fields contained cobbles.

The urban fills were observed on the eastern and northern portion of the site, and vary from brown or black gravel and some silt.

In test pit TP-16 an organic deposit was encounter beneath the field deposit. This organic deposit was mainly composed by some black soft organic silt and peat fiber. The thickness of this organic deposit was on average 3.5 feet.

It was observed in both, the fill and organic deposit that there was an alluvial deposit beneath them. This alluvial deposit was mainly composed by compact dense orange-brown gray silt with some sand and clay.

There was also found a glacial deposit beneath the alluvial soil and topsoil. It was found on a depth that varies from 5 feet to 14 feet below the ground surface. Groundwater was exanimated in each of the test pits and boring tests. Groundwater was observed in borehole MA1-1 and MAI-2, however the location of the ground water table is very deep, about 25 ft. beneath the surface.

Permeability analysis.

Soil permeability was estimated based on representative grain size analyses of the fill and glacial till deposits. It was recommended for design purpose to have permeability between $1x10^{-4}$ and $1x10^{-5}$ centimeters per second.

2.3 Foundations

One of the most important objective when it comes to structural design, is to make sure that the building has the proper bases so it can stand by itself, the loads received by the soil produced mainly by the structure's weight, are sometimes too big and if the soil strain exceeds the allowable amounts it can be very dangerous to the structure.

A foundation is the lowest and supporting layer of a structure; their main objective is to prevent the structure from any lateral, torsional or compressive movement. These movements may deteriorate the structure, and put people's life at danger.

Foundations are generally divided in two main categories, shallow foundations and deep foundations. Depending of the type of soil in which the construction will take place will be one of the key elements when determination the type of foundation that is needed to perform the task. The type of structure that is being built will be as well an important factor. Usually houses and small buildings will require smaller shallow foundations than big and heavy structures that will require bigger deep foundations.

Before designing a foundation, it is important determinate the soil conditions by the performance of a soil study. The types of material that compose that soil, whether it is clay, sand or something else will be a very important factor to determinate this. The percentage of water in the soil, the location of the ground water table, the seismic condition of the area are some other factors that need to be taken in consideration when foundation design.

The purpose of a foundation is to safely transmit all the structural loads into the ground. One of the main considerations to take into account during foundation design is the ability for the soil to support the applied load. Other than soil conditions there are many environmental and weather conditions, which must be taken under consideration.

For this project we divide foundation into two broad categories: Shallow foundations and Deep foundations.

2.3.1 Shallow Foundations

Shallow foundations are typically made of reinforced concrete and usually are built no deeper than 3m (7ft). This type of foundation transmits loads to the near-surface soils almost entirely vertically. Engineers prefer to use Shallow foundation wherever possible, because they are simple and inexpensive to build. However, we often encounter situations where spread footings are not the best choice. Shallow foundations can be divided into two categories: Spread Footing and Mat Foundation.

Spread footing

Spread Footings have an enlargement at the bottom of a column or a bearing wall that spreads the structural load over a certain area of the soil. They are nearly always made of reinforced concrete. There are different types of footings, square, rectangular, circular. The required footing size depends on the magnitude of the load, the engineering properties of the underlying soils, and other factors.

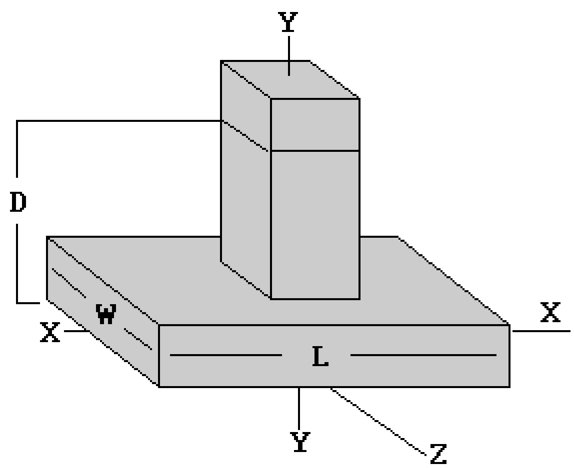


Figure 2-3 spread footing squared base sample source: soiltech.com

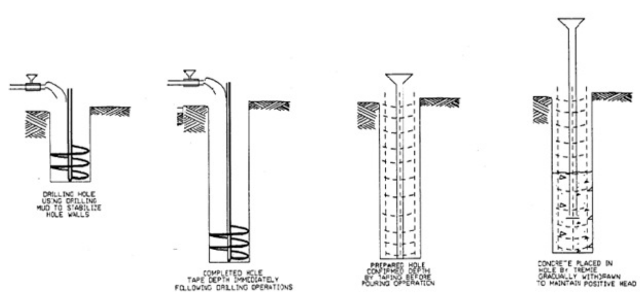
Mat Foundation

Mats are generally used on structures that are too heavy for spread footings, are essentially one large spread footing that encompasses the entire structure. They spread the weight of the structure across a larger area, thus reducing the induced stresses in the underlying soils. This footing also has the advantage of structural continuity and thus reduces the potential for differential settlements.

2.3.2 Deep Foundations

Engineers prefer to use spread footings wherever possible, because they are simple and inexpensive to build. However, we often encounter situations where spread footings are not the best choice. One of the main reasons to use deep foundations is when the upper soils are so weak and the structural loads so high that spread footings would be to large. The spread footing ceases to be economical when the total plan area of the footings exceeds about one-third of the building foot print area. Other reason is when a uplift capacity and large lateral load capacity is required. The uplift capacity of a spread footing is limited to its dead load.

Figure 2-4 step by step implementation of drilled shaft Source: soiltech.com



The different types of Deep foundation we are going to compare are the followings:

Drilled Shafts: Constructed by drilling a slender cylindrical hole into the ground, inserting reinforcing steel and filling it with concrete.

Advantages

-Cost of mobilizing and demobilizing a drill rig are much less than those for a pile driver. This is especially important on small projects.

-The construction process generates less noise and less vibration, both of which are especially important when working near existing buildings.

-Engineers can observe and classify the soils excavated during drilling and compare them with the anticipated soil conditions.

-Contractors can easily change the diameter or length of the shaft during construction.

-The foundation can penetrate through soils with cobbles or boulders. It’s also possible to penetrate many types of bedrock.

-It is usually possible to support each column with one large shaft instead of several piles, thus eliminating the need for a pile cap.

Disadvantages:

-Successful construction is very dependent on the contractor’s skill, much more so than with spread footings or even driven piles. Poor workmanship can produce weak foundations that may not be able to support the design load.

-Drilled Shafts removes soil from the ground, so the lateral stresses remain constant of decreases.

-Drilled Shafts does not increase the density of the soil beneath the tip. Therefore the unit end-bearing capacity in shafts may be lower.

-Full-scale load tests are very expensive, so the only practical way to predict the axial load capacity is to use semi empirical methods based on soil properties.

Pressure-injected footings: Cast in place concrete that is rammed into the soil using a drop hammer. A steel cage is placed in the soil after the drilling, and there it is poured with concrete.

Advantages

-The construction process compact the soil, increasing its strength and load-bearing capacity. This benefit is most pronounced in sandy or gravelly soils with less that about 15 percent passing the #200 sieve.

-When compacted shafts are used, the construction process produces a rough interface between the shaft and the soil. Further improving the side friction resistance.

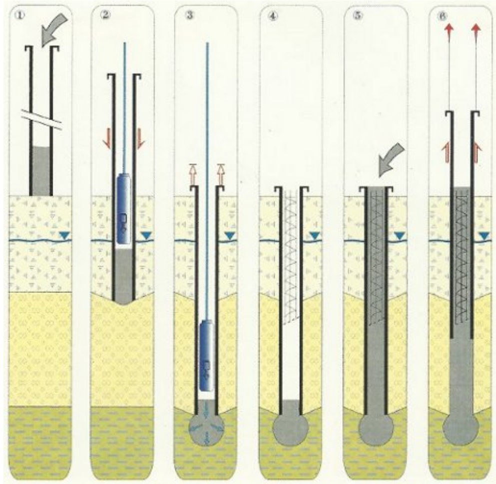


Figure 2-5 step by step implementation of PIF. Source: trevi.com

-It is possible to build PIFs with large base (gaining the additional end bearing area) in soils such as loose sands where belled drilled shafts would be difficult or impossible to build.

Disadvantages

-The side friction resistance for cased PIFs is unreliable because of the annular space between the casing and the soil.

-The construction process generates large ground vibrations and thus may not be possible near sensitive structures. These vibrations also can damage wet concrete in nearby PIFs.

-The construction equipment is bulky and cumbersome, also requires large work areas.

-Compacted shafts cannot include large amounts of reinforcing steel.

-PIFs will have a higher load capacity than pile or drilled shafts of comparable dimensions; it's also more expensive to build.

-They are generally economical only when the length is less that about 9m (30ft) for compacted PIFs.

Piles: Are constructed by prefabricating slender prefabricated members and driving or forcing them into the ground.

Advantages

-Piles push the soil aside, increasing the lateral stresses in the soil and generating more side friction capacity.

-Piles driving increase the density of the soil beneath the tip, therefore the unit end bearing capacity of a driven pile its greater.

-Less expensive than PIFs

-Many different alternatives of piles, Timber, Steel, H, Pipe, Concrete.

Disadvantages

-The cost of mobilizing and demobilizing a pile driver are higher than other deep foundation methods.

-The construction process generates noise and large ground vibrations because of the drop hammers. This could affect near buildings.

2.4 Loads:

In order for us to have the proper bases it is very important to compute all the loads that will act in the structure. Loads divide into two main sub categories, Dead Loads and Live Loads.

2.4.1 Live Loads (LL)

Live loads are loads that might change in position and magnitude. They are caused when a structure is occupied, used and maintain.

There are many types of live loads that need to be taken into account in structural design; some of them will be what we call environmental loads like Wind Loads (WL) or Snow Loads (SL) or Rain Load (RL).

The functionality of the building (whether it is a parking lot, a high school, a mall, a house) will change the size of the Live load and de need to consider this when performing our structure. These live loads are tabulated in tables from the Massachusetts Building Code MBC and the American Society of Civil Engineers ASCE.

2.4.2 Dead Loads (DL)

Dead loads are loads of constant magnitude that remain in one position; they consist of the structural frames own weight and other loads that are permanently attached to the frame.

For these parking garage, the main type of Dead Loads that need to be consider are those produced by the I beams, Double T, gravel, drainage system, and columns.

There will be two types of beams that need to be considered in our design:

Precast double tee beams:

Double Tee beams, also called double tee flooring units consist of two pre-stressed ribs that are connected in the top part. Depending on the span of the member, the ribs can vary in depth from 200 to 500 mm. The connecting slab is usually 2400 mm wide x 50 mm thick.

Double tee beams are very useful for large spanning floors and are currently used a lot in the construction of large parking garages. -

In figure 2.6, it is possible to visualize better some important characteristics of a double tee section.

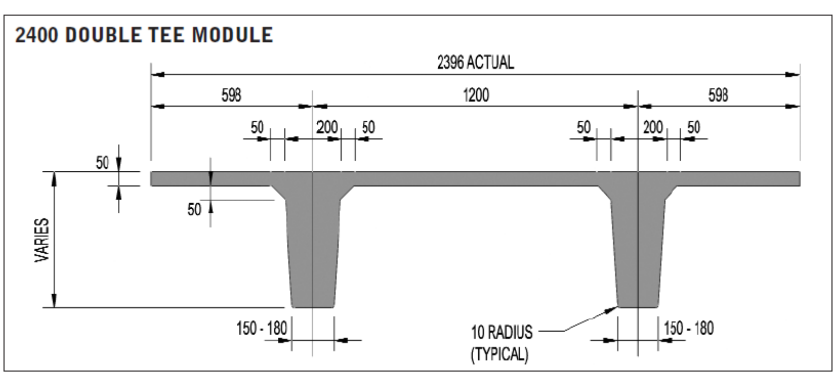


Figure 2-6 sample double tee section source: ACI Manual

2.5 Project Management

This section of the background will discuss some important concepts of project management that we are going to further develop and work in our project methodology.

2.5.1 Project Manager – Construction Manager at Risk – Gilbane

Project Management is "The art and science of coordinating workers, equipment, materials, money and project schedules, in order to successfully complete a project on time and within budget" (Oberlender, 2000). A project manager has the task to organize people, equipment and material to optimize the goal allocation. Project managers must be able to motivate. It is important for the project manager to be familiarized with many areas of the project so he is able to manage the project the proper way. The project manager will work closely with the owner till the project competition.

2.5.2 Contractual Agreement- Construction Management at Risk.

There are many different types of contractual agreements. However, for this project, WPI will implement Construction Management at Risk arrangement.

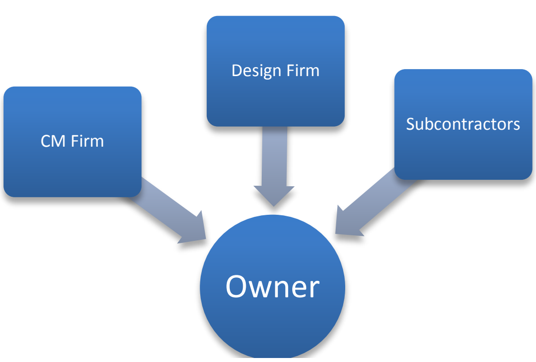


Figure 2-7 Owner: The center of the project

Construction Management at Risk is a four-party arrangement involving the owner, designer, CM firm and contractor. On Construction Management at Risk project, a design firm and a construction management firm work together and must report to the owner the status and progress in every phase of the project. The Construction

Management firm is usually responsible of hiring and organizes all subcontracted activities.

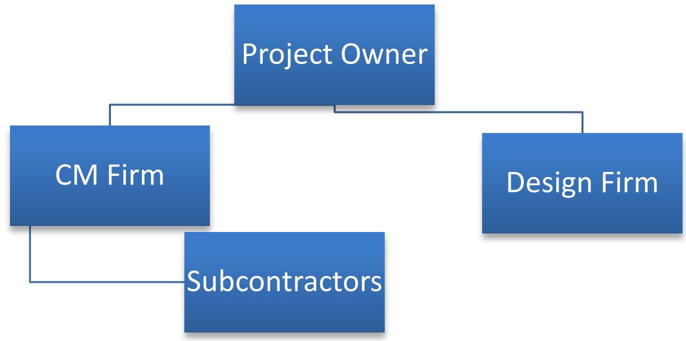


Figure 2-8 Typical Structure of Project organizational chart

Figures 2.7 and 2.8 above show in a more detail how a construction project is structured, and the relationships between the owner, deigned, construction manager and subcontractors. There are many other possible ways to structure a project, however this is the most common one, and is the one that will be implemented by WPI in the construction of our parking garage.

WPI’s CM at Risk agreement on the parking garage project includes a cost-plus compensation that has a Guaranteed Maximum Price. Part of Gilbane”s task as CM at Risk, they manage and hire most of sub-contractors throughout the project, besides several specialty packages which WPI takes direct responsibility. Because Gilbane is the one hiring subcontractors and setting a Guaranteed Maximum Price (GMP) they are the ones taking the greatest part of the risk.

A Guaranteed Maximum Price is beneficial to the owners (WPI) because the price is already set for them, any extra expense will be covered by the CM firm (Gilbane).

2.5.3 Designer- Symmes & McKee Associates

Symmes Maini & McKee Associates is an integrated design firm offering architecture, engineering, interior design, and planning services. Founded in 1955, SMMA is a company of 175 professionals with offices in Cambridge, Massachusetts, Chapel Hill, North Carolina, and Providence, Rhode Island.

Our mission is to lead clients to their goals through design excellence. We do this through our passion for talent, commitment to collaboration, dedication to client insight, and thirst for knowledge and exploration. (SMMA webpage, company mission)

2.5.4 WPI'S Agent- Cardinal Construction

WPI hired Cardinal Construction to be their representative throughout this project with an Owner/Agent agreement. This type of agreements is implemented not only in Construction Management at Risk projects, but also in different type of projects.

In this type of agreement, the owner gives the agent the authority to represent them in the meetings and to take important decisions acting in owner's best interest. Cardinal Construction has worked for WPI in many other projects in the past. Cardinal construction must work very close with Gilbane and Symmes to ensure WPI'S best interest.

2.5.5 Building Information Modeling.

There are usually many different parties involved in a construction project. The owner, the owner's representatives, the project management team, the designer's team, the sub-contractors and so on. Since there are so many different people with different backgrounds involved in a project, communication is a fundamental for the project to be successful.

In construction, must of communication is done through drawings. Generally these drawings are primarily performed two dimensional, using computer software such as AutoCAD. These 2D drawings work fine when all participants are familiar with this type of documents and understand how to read them and follow what they say. However they might cause problems when some details of the project are not represented accurately. Sometimes procedures are misunderstood and costly changes need to be performed because of this miscommunication.

A Building Information Model is a computer-driven representation of a facility for the purpose of design, analysis, construction and operation. A BIM model consists of geometric, 3D representations of the building elements plus additional information that needs to be captured and transferred in the AEC delivery process and in the operation process of the facility. (Reinhardt, 2010).

2.5.6 BIM History

BIM has been around since mid-1980's, however in recent years it has been raising its popularity, especially within architectures and engineers. Demand for its usage has impressively increased, and big construction companies are looking for individuals with BIM knowledge, capable to implement them in their big projects.

The First 3D modeling program was called SynthaVision, and first developed by MAGI (Mathematics Applications Group, Inc.), this software was released in 1972. It was mainly used to analyze nuclear radiation exposure. By that time, Solid Modeling was still too computer intensive as to perform 3D modeling use in the construction industry.

By the early-1980 since many improvements in technologies and better computers started to appear in the market. New more powerful UNIX workstations and 3D renderings were appearing, making it possible for CAD software to become 3 dimensional and for solid modeling. BIM has been improving since then and new powerful software like Revit was born.

For a very long time Building Information Modeling was not accepted by a considerable representation of the construction industry, but in the last few years, many of the big companies have adopted BIM. It is expected by market studies that in a few years BIM will be a standard tool used on most projects all around the world.

2.5.7 Bid Proposal, Project budgeting and Cost Estimate

From the beginning of the project, it is important to establish how the project is going to be financed. The budgeting of the project as well as the methods of payments is very important to set up from the beginning. There are many participants involved, Designer, CM, sub-contractors and so on, and it is essential to select an efficient and effective way of payment.

Before construction starts, it is necessary to create the bid. Once the bid is on the table, it is possible to come up with different alternative payment methods. In the case that a design is not finalized when the construction phase already started, it is possible to finance the project using a cost reimbursable method because there is not enough information to come up with a precise cost estimate. If the design is finished, then it is possible to come up with a fixed price method.

In the case of a fixed price contract, it is possible to perform a Lump sum payment method or a unit price method; these two methods allow the contractor to price out a project before any work has been performed. This price will have the total cost of the project, including equipment, labor, materials, subcontractors, overhead and profit. The only way this figures can be modified is if the owner decides to change something in the design after this price has been established. When making a lump sum, the Construction Specification institute (CSI) Master Format is used. This format divides all the activities in the project in 16 major divisions. (general requirements, site work, concrete, masonry, metals, woods and plastics, metals, thermal and moisture, doors and windows, finishes, special equipment, special construction, conveying, mechanical and electrical. All this divisions are also broken in subdivisions using Work Break Down Structure; this will facilitate the job a lot when it comes to the cost estimating.

2.5.8 Project Scheduling

In order to be efficient, reduce cost and get everything done in time, it is helpful to perform a scheduled agenda with all the activities that need to be done previous to the project completion. It is important for this agenda to be well-defined so all the parties understand the activities that need to be completed and those that are more critical, those that in case of dilate will extend the finishing time of the project.

Project Scheduling Divide the project in many faces, it sets timelines for the competition of each of these phases. With a start date and an end date for each of this activities. Some activities need to be performed sequentially and need a previous activity to be finalized prior to start the other. For example, before putting the slab of the second floor, it is necessary to foundations and columns in which this slab can stand. Some other activities are not 100% dependent in each other. For example, it is possible to start implementing foundations while site works and excavations are still going. It is important while scheduling to determine a logical sequential other in the activities and in order to save time it is also important to combine those activities that can be performed together. Now day, most project scheduling is done throughout software. Thanks to these technologies the process has been optimized a lot. Very powerful tools like PRIMAVERA that produces many different features of the project. Not only scheduling, but also lazy-S curve, cash flows, identification of the critical path, Gantt chart and so on.

2.5.9 The Critical Path Method (CPM)

The Critical Path Method (CPM) is a procedure done in project scheduling used to identify those tasks, which are on the critical path. A task that is in the critical path is a task that with any delay in completion will increase the project timescale, unless actions are taken. The CPM allows us to identify which tasks can be delayed and which tasks can't be. This allows us to relocate resources to catch up in any task that might be behind schedule.

It is important when creating a CPM to identify all activities before start scheduling. When using software, each activity has unique properties such as duration, dependency, star time, end time. Once all the properties are determinate, it is possible to produce a CPM network diagram. This Diagram will allow us to visualize the precedence among activities, and will include all the necessary information to determinate those activities that might be critical.

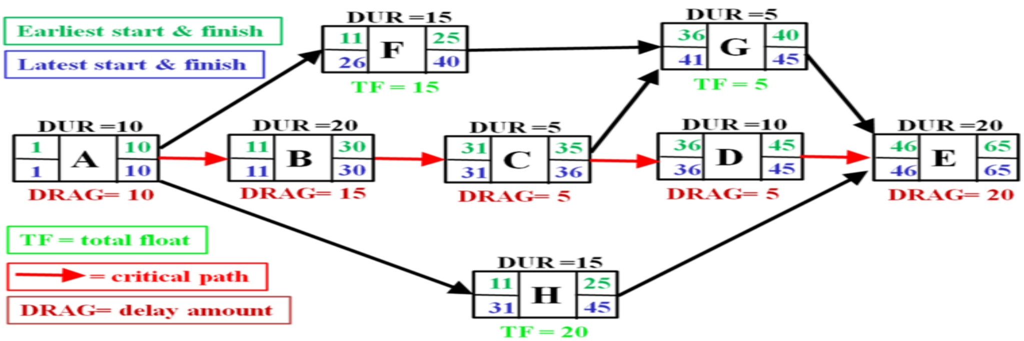


Figure 2-9 sample critical path method source: en.wikipedia.org/wiki/Critical_path_method

The CMP method is very effective to improve time to completion in a project, to determinate whether something is falling behind and to have a better communication between CM and subcontractors.

Figure 2.9 represents an example of the CPM method, having those activities that are in the critical path represented with red arrows.

2.5.10 Gantt Chart

A Gantt chart is a schedule type that shows all the activities in the form of bars chart. It also shows the critical activities and how all them are connected, but in an easier way to observe. A Gantt chart

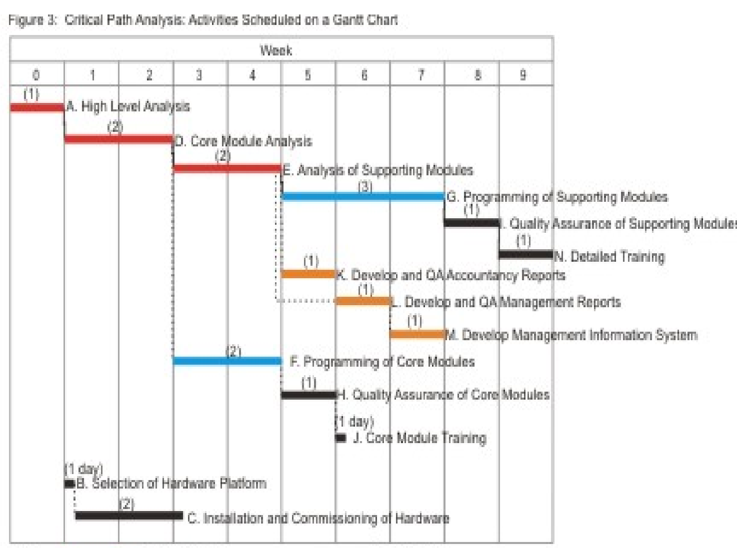


Figure 2-10 sample Gantt Chart Source: Primavera allow us to break each activity into subcategories, this is very helpful to determinate the amount of time that different contractors will need to be in a site. This is very helpful to make a more accurate cost estimate.

2.5.11 Lazy-S curve:

When plotted in a chart cost vs. time, Most Projects will generate an S shape curve, commonly known with the name of "Lazy S-curve". This is caused because most projects cost a smaller amount at the start (when the project is basically being started and the design is practically being performed), then cost increases in the middle part of the project when construction starts and cash flow is needed to pay subcontractors, materials, equipment's and most of the project expenses. And then cost a small amount at the end again (when the finishing touches are being put on the deliverables and the project is being wound down).

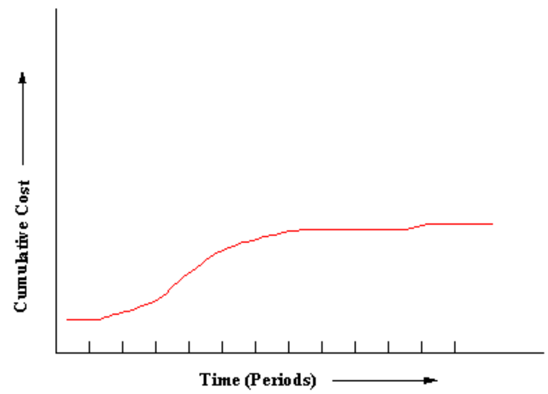


Figure 2-11 Sample Lazy-S curve Source: pmcomplete.com

2.5.12 Primavera

Oracle's Primavera is focused exclusively on helping project-intensive businesses manage their entire project portfolio lifecycle, including projects of all sizes. It is estimated that projects totaling more than $6 trillion in value have been managed with Primavera products. Companies turn to Primavera project portfolio management solutions to help them make better portfolio management decisions, evaluate the risks and rewards associated with projects, and determine whether there are sufficient resources with the right skills to accomplish the work. These best-in-class solutions provide the project execution and control capabilities needed to successfully deliver projects on time, within budget and with the intended quality and design (oracle.com).PRIMAVERA is the most important scheduling software that is currently being used by Gilbane. The used it to scheduled and organize the actives for the recreational center and they are using it again in the construction of the parking garage.

2.6 Weekly Meetings

In a construction project, the main goal of the project manager is to satisfy all the owners' needs and desires. In order to achieve this goal, communication is fundamental. Representatives of both, WPI and Gilbane held meetings every two weeks to discuss about this project, what important decisions need to be taken and what achievements where accomplished. Since not everybody in these meetings is familiarize with all aspects of construction. The use of Building Information Modeling is fundamental to improve communication between the parties.

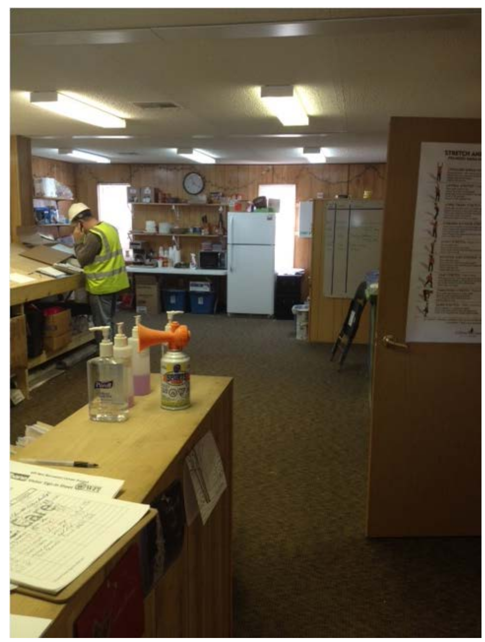


Figure 2-12 Inside the Gilbane trailer

WPI representatives in these meetings are Dana Harmon, the director of the Physical Education Department; Shawn McAvey, the physical Education Facilities Manager; Alfredo DiMauro, Assistant VP of facilities; Jeffery Solomon, Chief Financial Officer; Janet Richardson, the VP of Student Affairs; Sean O'Connor, Assistant Chief

Information Officer. Gilbane is represented by Neil Benner, the lead project manager, Bill Kearney, the project executive, Brent Flanders, Soil expert and Geotechnical Engineer.

The designing company, Symmes Maini McKee (SMMA) is in charge of MEP, landscape, architectural and structural engineering, They are working together with Vanasse Hangen Brustlin and JJA Sports, a sport consultant firm.

Cardinal Construction is an engineering consulting firm, which acts as WPI representative and Mirick O'Connell is WPI'S attorney.

2.7 Interviews to WPI staff.

In order to get a better idea and get more information about the project, our team interviewed to members of the WPI staff that was involved in the project. Dana Harmon, Director of the Physical education department and Janet Richardson, VP of Student Affairs & Campus Life.

Interview to Janet Richardson:

Q: What do you think about this project? Do you think it is a good initiative?

A: Yes, I think it is a very positive project for WPI. We have been lacking of parking forever. There are some things that need to be given up in the construction of this facility. For example we have to permanently give up the baseball field. However there are more gains than loses.

Q: Have you think in other alternative solutions to solve this parking problem?

A: They have thought about having parking in tennis courses in front of Park Avenue. There could be done something there too. However, that space is not that big, there are also other issues involved. Been Park Avenue a main street, there will be necessary to place light and it is very hard to get this kind of permits from the city.

Q: What do you think will be the biggest challenge in the construction process of the building for Gilbane?

A: The facility itself for the parking garage is simple, is a flat simple parking, only one level. However, putting the field on top is not done in a lot of places, is not a very common practice, and many things need to be consider, like for example the amount of gravel and the drainage system to avoid water to stay in the turf.

Q: What do you think will be the biggest challenge in the construction process of the building for the WPI community, staff, faculty and students?

A: Getting in and out of the parking lot, will be one of the biggest challenges, the entry will be by Salisbury street, however, the church parking lot is in the way and there have been some issues getting their approval.

Q: Do you think the school is financially strong enough to be executing four projects at the same time (The Rec center, the Biology building now this new Parking garage and the new upperclassman dorms)?

A: In the past few years, the school has been in a very strong financial process, every year there is money left on the table and is been invested in the best possible way. Building new dorms is not a hard project to cover, the bank usually gives the money, and then the school has many ways and facilities to pay it back.

Q: In terms of percentage, what chances do you think this project has to be approved by the board of trustees?

A: They did approve moving forward in the parking that was voted in the meeting last week, the only question right now is the problem with the entrances. So I would say that the chances of building this right now are close to 100 %.

Interview to Dana Harmon.

Q: How did this idea of having a building with a Field on top of a garage came about?

A: There has been an increasing demand for parking spots in school due to growing population, WPI is expanding, and every day is harder to have available places to park. About 6 years ago, and athletic master plan was done, they considered some ideas. Susaky construction, wanted to build dual a dual function garage and field.

Q: The design of the building is going on, how certain it is that it will be built?

A: I would say it is about 75% certain that it is going to be built, we won't know that till trustees review it, end decide to take a decision they will take decision in February.

Q: What are the main problems you think that need to be addressed during the construction of this Parking Garage?

A: The main problems for us, here in the athletic department are to find new places for relocation for all the club teams and clubs that use that place. We have been in de need to develop other fields in the city. Baseball will be permanently relocated to play off campus.

Q: Are there any perceive resistance for the construction of this project?

No, everybody is excited about it, the grass field in very bad shape, looking forward for replacement field turf. People will be happy to have a good field and a parking lot.

Q: Based on what has been discussed at the meetings, what do you think will be a better alternative, a two stories garage now, add a second story in the future, or just make a structure for a one story building?

A: Only the one story is the best alternative, we don't know what building code standard will be in the future. Might be a waste of money. Building a second floor in the future is construction nightmare. The university has also planned for other parking garages to help in the future. A two-story garage will be too high and the sensation of playing at that altitude will be very weird.

2.8 Massachusetts Building Code (MBC 406)

In our design, we follow standards and specifications from the Massachusetts Building Code MBC. We will briefly mention some of the most important things that need to be taken into account for the construction of parking lots and parking garages in the state of Massachusetts, according to the Massachusetts Building Code (MBC).

Specifications for educational use:

- Schools parking's should have at least 1 parking space per each 4 seats.
- There should be a total of one parking space for every three double or single bedroom.

Design Standards:

- Area used for parking or maneuvering should have a slope not greater than 5%. Driveways should have a slope not greater than 12%.

- No parking space shall be located within eight feet of a building wall.
- Parking areas shall be delineated and shall be provided with a permanent dust-free surface. Adequate drainage should be implemented.
- Compact parking places for small cars shall be no smaller than (8 ft. x 16 ft.) and shall be signalized.
- The curb radii, driveway width and other such dimensions shall comply with the "Street and site construction standard". Some standards are specified section 7.i of the MBC.
- Ramps between parings shall not exceed 12 percent slope.
- Lighting shall be provided for all parking areas of 10 places or more only if these places will have a night function.
- Entrances and exits size will depend on the size of the parking lot. For parking areas containing less than 5 spaces, the minimum width of entrance and exit is 10 feet wide for a one-way road and 18 feet for a two-way road.

Dimensions:

- Each parking space shall be at least 9 feet x 18 feet in size.
- Parking's shall have enough access for maneuvering areas
- Compacted parking spaces (8 x 16 feet) might be created, however they should be signalized with sign.
- Ramps between parking areas should different elevation should not exceed 12 % slope. (With a maximum of 5% transition slope in upper ad lowest section).
- Adequate lightening, especially if the parking will be used during night.
- The minimum width of entrance and exit shall be 10 feet for one-way using, and 18 feet for two-ways usage.

- The minimum curb radius shall be 15 feet.

Landscape Standards

- Parking areas of 10 or more spaces should provide a minimum of 10 % of the total area landscaped and open space.
- Parking areas with more than 25 parking spaces shall provide landscape islands.

Handicapped Parking:

- 10-20 spaces = 1 handicapped space.
- 21-30 spaces = 2 handicapped spaces
- 31-50 spaces = 3 handicapped spaces.
- 51-100 spaces = 4 handicapped spaces.
- 101 or more (refer to Rules and regulations of architectural barriers board).

2.9 Project Objectives

2.9.1 General Objective.

Our main objective is to satisfy the needs and requirements of the project with the most suitable design, in terms of cost and quality. In order to achieve this balance between cost and quality we compared two different alternative foundation designed (Shallow/Drilled Shaft) VS Pressure Injected footings/Shallow. Other important objective was to design a foundation that will allow and resist an additional parking floor for future development of the parking garage and compare the cost of doing it right now or adding reinforcement to a smaller and weaker foundation in the future.

Our main goal as project managers was to design a time efficient schedule taking into account the Critical Path and a Cost estimate using Primavera/Excel, also create a 5D BIM model with Revit Structural to visualize much better the final design of the Parking Garage.

2.9.2 Project Scope

The scope of the project is to design foundations for an approximately 172,000 ft^2 parking structure that will be located next to the existing football field, in front of Park Avenue. This Project will also cover Building Information Modeling, a 5D model of the structure, a CPM and a cost estimate.

2.9.3 General Steps to Follow

The following section will explain breathily all the steps taken by the team to complete the project design the foundations, schedule the projects activities, the CPM, the 3D model and the cost estimate.

First a soil study was performed. The soil study was analyzed by the team, to determine which type of soil we were dealing with, so we could determinate the type of foundations needed for our building. We analyzed all the results of the soil study that was given to us performed by McPhail Associates, a geotechnical engineering company that was hired to perform this job. There were 3 tests performed that were considered. There were performed 28 Test Pit Logs distributed all around the surface area of the site, 15 boring long tests and sieve analysis of the soil particles in all the points where these tests were performed.

The Pit test is performed to determinate the different layers of the soil, it helps geotechnical engineers to visualize what type of soil are they dealing with, and all the different layers that this soils may have.

A boring test is a test in which soils are nailed with a hammer. This type of test is performed to determinate the strength of the soils and the capability of the soil to resist loads. It measures the number of blows that a soil can take for every 6 inches of penetration.

A sieve Analysis is a test performed to determinate the size distribution of the particles, this is very important in foundation design to determinate whether a soil might be to determinate what type of soil it might be (whether it is a sandy soil or a clay one). It is also needed to get soil properties such as the internal friction angle.

After all this tests where analyzed, the team proceeded to subdivide the site in many subzones according to the soil conditions to perform the foundation design.

Soil profiles where drawn to have a better view of the homogeneity of these soils

Then, the next step was to calculate all the tributary loads of the entire structure. This was very important because we needed to know the amount of weight that each foundation was going to receive for completing the design.

In order for us to do this, first we needed to compute all the major loads that will be acting on the garage structure, factor them by equations (section 4.3) and then determinate which of this factored loads governed to use them in our design. The Massachusetts Building code was used to compute Snow Loads and Live Loads for a small vehicles parking lot (we can see this process with better details in section 4.3).

Once the tributary loads that act in each column were computed, it was possible to get an estimate size for our columns and get the column weight to take into our foundation design.

We made two types of foundations, Regular Square base shallow foundations, and drill shaft deep foundations, depending on the soil conditions on different areas. In the foundations section this procedure is detail explained.

Once the column spacing and the number of columns were selected, it was possible to start with a 3-dimendional model of the parking garage. To elaborate this 3-dimensional design we implemented the use of Autodesk software, Revit (Structural and Architectural).

With the used of Revit Structural, grid lines were first added. The intention of these lines is to be used as references for the location of the columns.

Columns, beams, girders, Joints and foundations were all added using Revit Structural, and then.

Once all the structural elements were in place, we were able to start working in the details and finishes of the project. Add the Nets for the softball field, as well as the grass material for the fields, the lights, cars and so on all this was done by using Revit Architectural.

Once all this was accomplish, it was possible to elaborate the 5D model of the building by creating a break down structure of the project. This is a motioned structure that starts assembling itself step by step, showing the order and the number of activities that need to be performed for completion.

Revit is also capable of calculating the amount of materials used in the drawing. Once the amounts of all these materials are computed by Revit, It was possible to migrate them to a

Microsoft Excel spreadsheet and then by the use of RSMeans Software costs for materials where obtained and it was possible to get a cost estimate for the building.

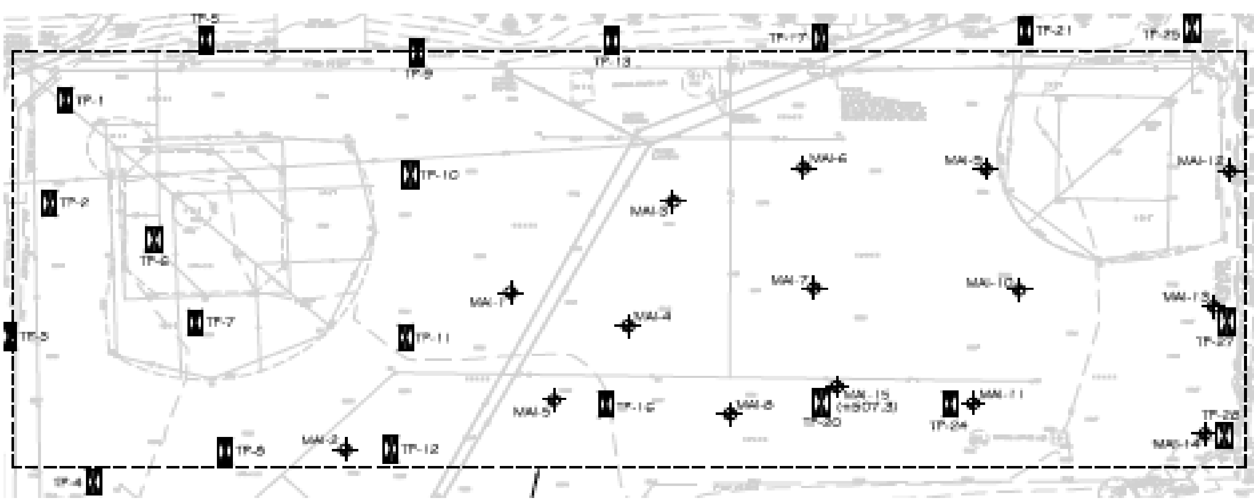
All the activities to completion were place in PRIMAVERA project scheduling software). In PRIMAVERA, we set the starting time and ending time of each of these activities, and organize them, linking activities in a sequential order. This software helped us to improve efficiency in time, reducing labor and overhead costs. It also helped us to produce a Lazy-S curve, showing how the cost changes as the project advances.

3 Shallow Foundation Design and Deep Foundation Design

This section explains in details all the steps that needed to be taken into account for the shallow foundation and deep foundation design, starting with the soil analysis, the calculations of settlements and bearing capacities and the actual footing and Shaft design.

3.1 Soil Analysis

In order to come up with our foundation designs, it was very important to analyze the soils where



the design was going to be implemented. A soil report performed by Mcphail Geotechnical

Figure 3-1 Location of the Boring and Log test Source: McPhail Engineers soil report

Engineers was given to us with some characteristics that we needed to account for our design. We analyzed the results from the boring logs and test pits that were performed in the site, and checked for the Standard Penetration Test, SPT and the Sieve analysis.

There is a good explanation of what Boring and Log Test are in section 2.2 of this report for a better understanding of their concepts and their importance in the foundation design process. Figure 3.1 was obtained from the soil report given to us by Mcphail Geotechnical Engineers. It represents the site where the construction is going to have place and the location of all the boring test and pit test performed along the site.

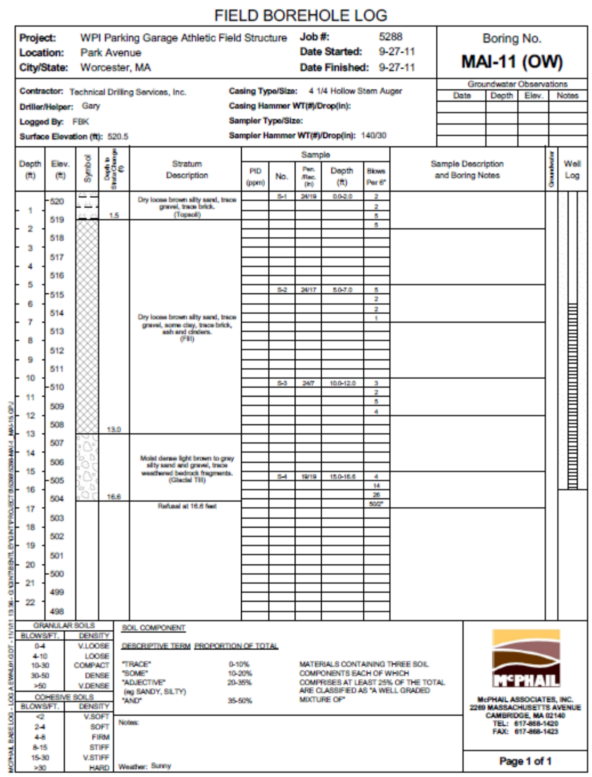


Figure 3-2 Sample Boring test performed by Mcphail Geotechnical Engineers

Figure 3.2 shows the result of one of the MAI tests that where performed on the site, (MAI-11 OW). MAI is a standard name that they use to refer to the boring tests. The main information we obtained from this tests to consider in our report is the deepness of the different soil layers, the number of blows for the 6 inches penetration used to calculate the "N-value" and the location of the ground water table. In the case of our soil, ground water was found in two of the tests; however the deepness of the ground water table was very deep, so we didn't worry about that in our

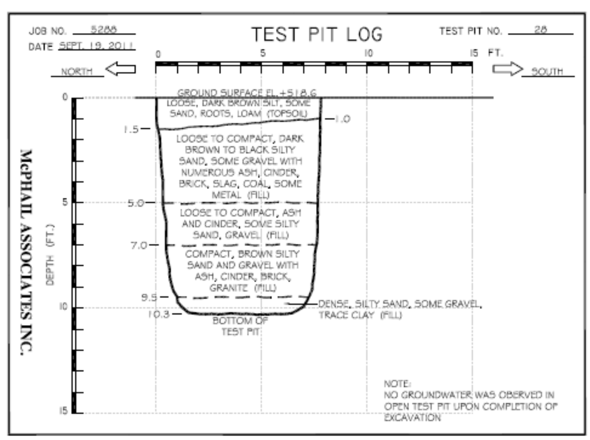


Figure 3-3 Sample Pit log test obtained by McPhail on the site

design.

The number of blows required for the second and third 6 in is sum up and are known as the “standard penetration resistance” or “N-Values”.

In appendix C, there is a summary of all the 16 MAI test that were performed all along the site, we computed an N-value in each of this points by adding the sum of the last two penetrations of each layer, for calculating the average N-values in the shallow foundation area, there were only three boring tests performed in this area (MAI-3, MAI-6, MAI-9).

For getting the N-values of the fill layer, we took the sum of the second and third 6 in. penetration number of blows. (See Appendix C)

$[(5+3)/2 + (5+15)/2 + (6+3)/2]=7$

So the N-value we used for our fill layer in the shallow foundation part was 7 blows. We did the same procedure to get the N-value in the glacial till obtaining 30 blows, and the N-value in the bedrock layer 45 blows.

For the part that would require deep foundation we did the same procedure, but computing the averages of (MAI-1,MAI-2,MAI-4,MAI-5,MAI-7,MAI-8,MAI-10,MAI-11,MAI-12,MAI-13,MAI-14,MAI-15,MAI-16). In appendix C there is a summary table with the results of all this average N-values. For the fill layer we obtained an average of N-value of 8, for the fill an average N-value of 34 and for the bed rock an average N-value of 51.

Figure 3.3 illustrate the results of pit log number 20 (PT-20), figure 3.1 shows the exact point in the site where this test was performed. From this test, we obtained the elevation of the top surface, as well as the deep of the different soil layers, a breath description of the layer properties. For simplification we grouped the soil in three different layers, the outer layer was a fill layer; mainly composed by dense and compacted sand, the middle layer was glacial till, mainly composed by compacted loose brown sand and silt, and the inner layer was composed by bedrock.

With the information obtained from the log pit test and boring tests, we created many cross-sectional soil profiles (See Appendix B for more details). To create these cross-sectional soil profiles, we had information about the elevation of the top soil and about the depth of each of the different soil layers, we drew the point that represent the start and end of each of this soil layers for one point, then with a scale that was given to us in the report, we were able to calculate the distance from one test point to another test point. We drew again the start and end of the different soil layers in the following point, then by the use of a ruler, we put together the points from the first test and the second test that represent the same layer. We did it again with the third point, the fourth point and so on. By putting together the points of the different depths in different soil layers, we were able to interpolate and anticipate how this soil layers where distributed all along the site. This

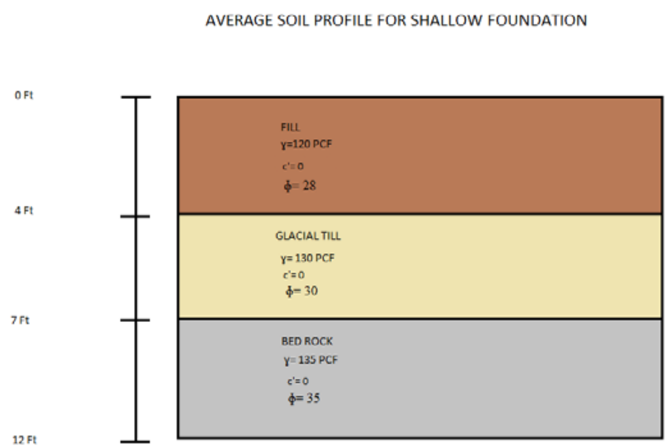


Figure 3-4 Average soil profile for shallow foundation

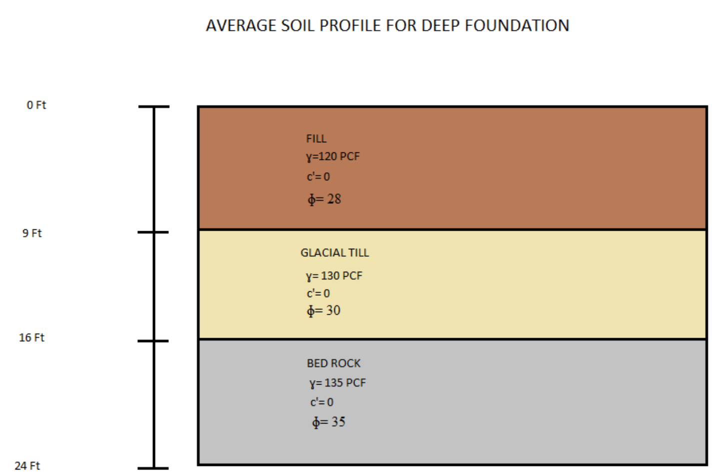


Figure 3-5 Average soil profile for deep foundations

helped us a lot have an anticipate overview of the underground conditions and the homogeneity of the soils.

By information given to us in the soil study (figure 3.6), we were able to anticipate the area of the soil that will require shallow foundations and the area that will require deep foundation, in this sketch, the light area at the left of the picture will be the area that will need to use shallow foundations, and the darker area at the right of the picture will be the area that will need to use deep foundations. The choice of whether to use a shallow or a deep foundation is governed by some important factors such as the nature of the structure, the loads exerted by the structure and the subsoil characteristics.

Once we had a possible area for shallow foundation and a possible area for deep foundation, we created an average soil profile for the shallow foundation area and an average soil profile for the deep foundation area. To create this average soil profiles, we took all the results of the test performed in each of them by separate, we added up all the depths for the fill layer, all the depths for the glacial till layer and all the depths of the bed rock layer and then take an average fill layer, and average glacial till layer and an average bed rock layer.

Therefore to decide about the type of foundation, we evaluate the subsoil characteristics in Figure 3.4 illustrate the average soil profile we obtained for shallow foundations, because we notice that the average fill layer was very thin 0 ft. to 4 ft. and it was followed by a layer of glacial till from 4 ft. to 7ft. that is stronger to support the foundations, as consequence we decided to use a shallow foundation for this side of the field. In the other hand we have Figure 3.5 that represents the average soil profile for deep foundations; we found from the soil profile that the soil was composed by a thicker fill layer between 0 ft. and 9 ft., followed by a glacial till between 9 ft. and 16 ft. and bedrock between 16 ft. and 24 ft. We decided to use deep foundations in this side of the site because the required bearing capacity of shallow foundation couldn't be obtained. Deep foundations transfer loads from structures to acceptable bearing strata at some distance below the ground surface. These figures are also available for better details in bigger size in Appendix B.

TABLE 3.2 TYPICAL UNIT WEIGHTS

Soil Type and Unified Soil Classification (See Figure 3.3)	Typical Unit Weight, γ			
	Above Groundwater Table		Below Groundwater Table	
	(lb/ft³)	(kN/m³)	(lb/ft³)	(kN/m³)
GP—Poorly-graded gravel	110–130	17.5–20.5	125–140	19.5–22.0
GW—Well-graded gravel	110–140	17.5–22.0	125–150	19.5–23.5
GM—Silty gravel	100–130	16.0–20.5	125–140	19.5–22.0
GC—Clayey gravel	100–130	16.0–20.5	125–140	19.5–22.0
SP—Poorly-graded sand	95–125	15.0–19.5	120–135	19.0–21.0
SW—Well-graded sand	95–135	15.0–21.0	120–145	19.0–23.0
SM—Silty sand	80–135	12.5–21.0	110–140	17.5–22.0
SC—Clayey sand	85–130	13.5–20.5	110–135	17.5–21.0
ML—Low plasticity silt	75–110	11.5–17.5	80–130	12.5–20.5
MH—High plasticity silt	75–110	11.5–17.5	75–130	11.5–20.5
CL—Low plasticity clay	80–110	12.5–17.5	75–130	11.5–20.5
CH—High plasticity clay	80–110	12.5–17.5	70–125	11.0–19.5

Table 3-1 typical unit Weight of soils Source: Coduto 2006

After the soil profiles where performed, it was possible to infer that all the soil components were very similar all along the site, urban fill deposits. In the left area of figure 3.6, the soil had a pretty homogeneous distribution of the layers, the depth of each of the layers was smaller and the glacial and bedrock were closer to the surface. In this area it was possible the use of conventional footing to transfer the loads from the surface to the underlying glacial till or bed rock.

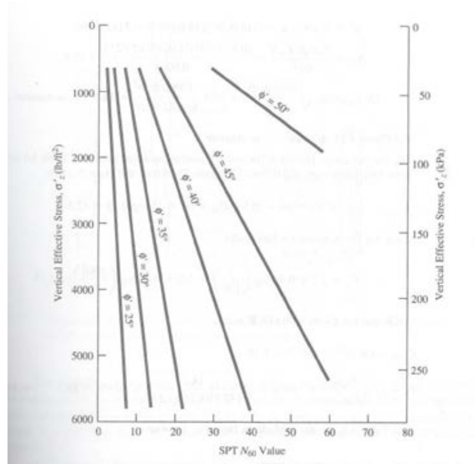


Figure 4.11 Empirical correlation between N_{60} and ϕ' for uncemented sands (Adapted from DeMello, 1971).

Table 3-2 Empirical correlation between N_{60} and effective friction (Coduto 2006)

In the area to the left of figure 3.6, represented in a darker color, the glacial till and bedrock deposits were deeper into the soil, as can be observe from the average soil profile from figure 3.5. In this area, the soil kept the homogeneous composition as in the area to the left; there was varying depth for the fill, glacial till and the bedrock deposit. For this area, the soil study given to us by McPhail Geotechnical Engineers recommended the implementation of Pressure Injected Footings (PIFs) for an economical support of the building. We decided to design a drilled shaft type of foundation and compare it with the PIFs alternative, to determinate the pros and cons of each of this system. Since the actual project was still in early stages of design, the foundation system design wasn't ready, so our team had to do some research about the PIFs system, to come up with a fair comparison between the two of them. Appendix A shows more details about the foundations recommendation.

Because of the lack of information obtained from the soil report we had to use tables and figures from Donald P. Coduto's book in order to estimate the soil properties. We used table 3-1 from Donald Coduto's book Foundation Engineering (Second edition) to determine the unit weight γ of the soil from the characteristics obtained from the average soil profiles. The average fill layer obtained from the soil profile was light sand, the glacial till layer was compacted dense sand, and for the fill we took an average unit weight of 120 lb. /ft3, for the glacial till 130lb /ft3 and for the bedrock 135 lb. /ft3

To determine the internal friction angle ϕ’ we first needed to calculate the vertical effective stress σ'_{ZD}, using the following formula $\sigma_{ZD} = \gamma . h$. Where h is the depth of the soil.

The second step after calculating the vertical effective stress in order to get the internal friction angle ϕ’ is to use the vertical stress together with the N-values obtained from the boring logs results of the soil report, and use Table 3-2 (from Donald Coduto’s book) to find the internal angle ϕ’ interpolating the vertical effective stress vs. the N-values. For the c’ value do to the soil composition, mainly sandy soils with silty sands we use a value of 0. Geotechnical engineers often use the term “cohesive soil” to describe clays.

It is important to mention that after a detailed analysis of the soil report and the boring logs results we notice that there was no water on most of the site test, just in two of them obtained from the boring logs water was notice (MAI-1 MAI-2) at a great depth that makes it irrelevant to account in our design.

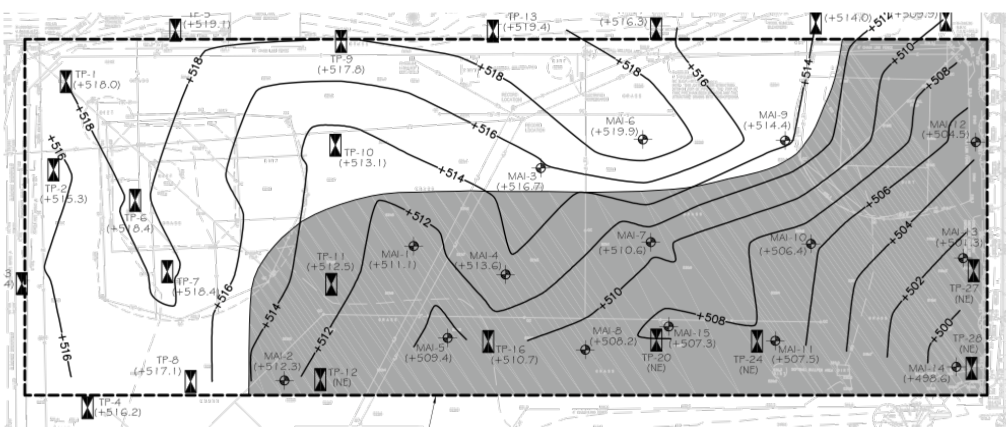


Figure 3-6 Soil Subdivisions: Shallow foundations (light area) deep foundations (dark area) Source: McPhaill Engineers Soil report

3.2 Load Calculations

To have an effective well designed foundation system it was necessary to account for all the structural loads that will be supported by the foundation system. Since the project of building the actual parking garage was just approved when we started our MQP. There was lack of information about the loads.

For the load calculations, we followed standard procedures from the Massachusetts Building Code (MBC) and the Precast Concrete Institute (PCI).

Fist Level:

The first floor of the building is going to a parking lot for passenger vehicles. The Live Load for a passenger vehicle parking structure was obtained from American Society of Civil Engineers Standard. Table ASCE/SEI 7.05.

LL= 40 psf (From American Society of Civil Engineers ASCE standard ASCE/SEI 7-05)

Dead load (DL) vary according to the usage that the pavement will receive, a pavement for truck loading for example would need to be thicker and have a greater strength concrete than a parking lot intended to be used for passenger vehicles.

According to the American Society of Testing Materials Standards (ASTM) section C1077, The weight of an average concrete is about 150 lb/ft^3.

An average concrete slab for a Small vehicles parking lot can vary its thickness from 4” to 6”. Do to the soil conditions and the amount of fill materials present in this soil; we used a conservative 6” design.

$$DL = 150\frac{lb}{ft^3}x6in\left|\frac{1ft}{12in}\right|$$

DL= 75 psf (for a 6" thick concrete slab, according to ASCE the normal weight of concrete is 150 lb. /ft3)

Second level:

In order to be able to compute the Dead Load (D) was necessary to determinate the size of the precast double tee beam sections that were going to be used to support the field. Once the beam size was determinate with the use of tables, it was possible to obtain the weight by the use of tables.

Table 3.3 gave us different sections based on the span and load of the double tee beams.

The Span of our beams is going to be between 55 and 60 ft. (between 16 and 18 meters), so we had to use the biggest possible beam section from the table below (2400x500TT mm)

LOAD/SPAN TABLE (kPa) (indicative only)

Safe superimposed live load in kilopascals (kPa) with 65mm thick concrete topping

SECTION	SPAN (m)													
	5	6	7	8	9	10	11	12	13	14	15	16	17	18
200TT	14.0	8.0	4.7	3.7	2.3									
250TT		12.5	7.5	6.1	4.4	3.0								
300TT			12.9	9.1	6.6	4.9	3.5	2.5						
350TT				11.7	9.5	7.1	5.1	3.8	2.8					
400TT					12.0	9.1	6.9	5.6	4.2	3.3	2.5			
450TT					13.0	10.5	9.2	7.4	5.8	4.3	3.8	2.4		
500TT						12.8	9.9	8.1	7.1	6.1	5.0	4.0	3.0	2.3

SDL= 0 kPa. Topping = 65mm. Simply supported, unpropped units.

Table 3-3 typical spam of double tee: PCI Manual

2400 DOUBLE TEE MODULE

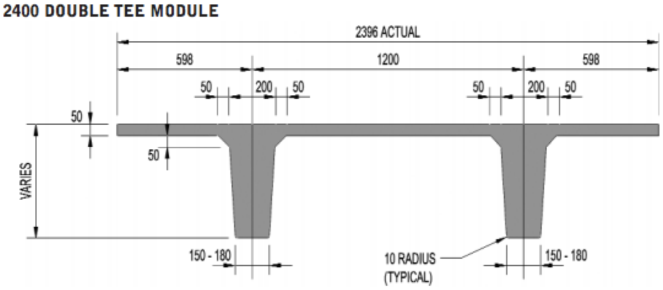


Figure 3-2 Typical double tee section; Source: PCI Manual

For the Dead load, the average weight of the double tee we used in the design is 62.62 psf, this was added to the weight of the gravel, drainage system, girder and columns. The thickness of the gravel fill varies from 6 in. (at the center) – 11 in. (Both edges of the field).

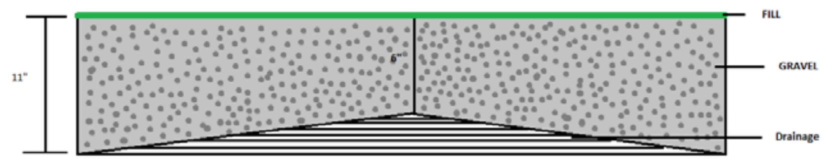


Figure 3-3 Representation of drainage slope in the top of the building

In Figure 3.3 the slope of the soil is illustrated to have a better understanding of how the gravel is distributed on the field. We calculated the weight of the gravel as:

$$GravelWeight = \frac{(6in+11in)}{2} X \frac{ft}{12in} * 105lb/ft^3 = 74.37lb/ft^2$$

The weight of the girders was obtained from the Precast Concrete Institute (PCI) Manual, section 2-52, (table 3-5) considering the needed span and the superimposed service loads on the girder.

Normal Weight Concrete

Section Properties

Designation	h (in.)	h_1/h_2 (in.)	A (in.^{2})	I (in.^{4})	y_b (in.)	Z_b (in.^{3})	Z_t (in.^{3})	wt (plf)
24IT20	20	12/8	336	10,981	8.29	1325	938	350
24IT24	24	12/12	432	19,008	10.00	1901	1358	450
24IT28	28	16/12	480	30,131	11.60	2598	1837	500
24IT32	32	20/12	528	44,969	13.27	3388	2401	550
24IT36	36	24/12	576	63,936	15.00	4262	3045	600
24IT40	40	24/16	672	87,845	16.57	5301	3749	700
24IT44	44	28/16	720	116,877	18.27	6397	4542	750
24IT48	48	32/16	768	151,552	20.00	7578	5413	800
24IT52	52	36/16	816	192,275	21.76	8836	6358	850
24IT56	56	40/16	864	239,445	23.56	10,163	7381	900
24IT60	60	44/16	912	293,460	25.37	11,567	8474	950

Table 3-4 average weight of I Beams: PCI Manual

These girders must hold the superimposed load of the gravel and the double tee beams as well as the Live Load. For this structure, we picked two beam sizes, one for the long span members and another one for the short span members, 24IT40

Designation	No. Strand	e	Span, ft.																	
			16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
24IT20	9	7.91	6888 0.3 0.1	5376 0.3 0.1	4294 0.4 0.1	3494 0.5 0.1	2886 0.6 0.1	2412 0.6 0.1	2033 0.7 0.1	1726 0.8 0.1	1474 0.8 0.0	1266 0.9 0.0								
24IT24	11	9.17	9759 0.2 0.1	7625 0.3 0.1	6099 0.3 0.1	4970 0.4 0.1	4111 0.5 0.1	3443 0.5 0.1	2913 0.6 0.1	2485 0.7 0.1	2135 0.7 0.0	1845 0.8 0.0	1601 0.8 0.0							
24IT28	13	10.84			8505 0.3 0.1	6951 0.4 0.1	5768 0.4 0.1	4848 0.5 0.1	4118 0.6 0.1	3529 0.6 0.1	3047 0.7 0.1	2648 0.7 0.1	2313 0.8 0.1	2030 0.8 0.0	1786 0.9 0.0					
24IT32	15	12.50				9248 0.3 0.1	7691 0.4 0.1	6480 0.5 0.1	5519 0.5 0.1	4744 0.6 0.1	4109 0.6 0.1	3583 0.7 0.1	3138 0.8 0.1	2760 0.8 0.1	2437 0.9 0.1	2159 0.9 0.1	1919 1.0 0.0	1709 1.0 0.0		
24IT36	16	14.50					9879 0.4 0.1	8337 0.4 0.1	7114 0.5 0.1	6127 0.5 0.1	5320 0.6 0.1	4644 0.6 0.1	4077 0.7 0.1	3598 0.7 0.1	3189 0.8 0.1	2836 0.9 0.1	2531 0.9 0.1	2265 0.9 0.0	2031 1.0 0.0	1825 1.0 0.0
24IT40	19	15.45							8675 0.4 0.1	7475 0.5 0.1	6494 0.5 0.1	5680 0.6 0.1	4998 0.6 0.1	4421 0.7 0.1	3928 0.7 0.1	3504 0.8 0.1	3137 0.8 0.1	2818 0.9 0.1	2535 0.9 0.0	2286 1.0 0.0
24IT44	20	17.46								9300 0.4 0.1	8083 0.5 0.1	7075 0.5 0.1	6230 0.6 0.1	5514 0.6 0.1	4903 0.7 0.1	4378 0.7 0.1	3922 0.8 0.1	3525 0.8 0.1	3176 0.9 0.1	2868 0.9 0.0
24IT48	22	19.08									9723 0.5 0.1	8522 0.5 0.1	7515 0.6 0.1	6663 0.6 0.1	5935 0.7 0.1	5309 0.7 0.1	4766 0.8 0.1	4293 0.8 0.1	3877 0.9 0.1	3510 0.9 0.1
24IT52	24	20.68											8917 0.5 0.1	7916 0.6 0.1	7061 0.6 0.1	6326 0.7 0.1	5688 0.7 0.1	5132 0.8 0.1	4644 0.8 0.1	4213 0.9 0.1
24IT56	26	22.26												9279 0.6 0.1	8287 0.6 0.1	7433 0.7 0.1	6692 0.7 0.1	6046 0.8 0.1	5480 0.8 0.1	4979 0.9 0.1
24IT60	28	23.81													9597 0.6 0.1	8616 0.6 0.1	7766 0.7 0.1	7025 0.7 0.1	6374 0.8 0.2	5800 0.8 0.1

Table 3-5 Sizes according to spams for I beams: from PCI Manual

girders will be used for the short span and 24IT48 girders for the long span.

From the table 3-5 from the PCI Manual, section 2-52 we obtained the weight of our girders (24IT40 and 24IT48) in linear foot. By multiplying the linear foots of each of the girder types by the total span, we obtained the total weight of each of this girders, then we added them up and divided them by the total area of the structure (172,604 ft^2) so we have the number in psf.

24IT48: Total span= 5210ft; weight= 800 plf

$$Weight_{24IT48} = (5510 ft)x(800 lb/ft)x\frac{1KIP}{1000lb} = 4168KIP$$

24IT40: Total span=3180ft; Linear weight= 700plf

$$Weight_{24IT40} = (3180 ft)x(700 lb/ft)x\frac{1KIP}{1000lb} = 2226KIP$$

$$Weigh_{total} = 4268KIP + 2226KIP = 6394KIP$$

$$\frac{(6394KIP)X\frac{1000lb}{1KIP}}{172604 ft^2} = 74.37 psf$$

Once obtained the weight of the beam, girder and gravel, we proceed to add them to have a dead load, and then by knowing the tributary area of each column, it is possible to obtain P_u and proceed with the column design.

DL = 62.62 psf + 37.04 +74.37 = 174.03 psf. (weight of double tee per ft2 + weight of gravel)

The values for the live load are very conservative, taking into consideration that this field will be used with massive concentrations and other activities different than sports. This value was obtained from the Massachusetts Building Code table 1601.1 (from theaters and fixed and fixed seats auditoriums)

LL= 100 psf

Snow Load (from MBC)

S= 33 psf (MBC 780 CMR table 5301.2)

Earthquake Load (MBC)

In order for us to calculate the earthquake load, we use the following equation.

$$E = Q_E + 0.2S_{DS}D \qquad \text{Equation 3-1}$$

Where:

E= Eeathquaque Load

S_{DS} = Design spectrum respond acceleration (equation shown in following step)

Q_E= the weigth os the structure times P which is a factor of safesty (Calculated in following step)

D= Sum of Dead loads (Columns, Girders, beams and gravel)

From table 1604.11 from the Massachusetts Building Code, for the area of Worcester:

Ss= The maximum considered earthquake spectral response

S_s= The Maximum considered earthquake spectral response at one second period.

S_s=0.24 and S_1= 0.067

From the Massachusetts Building Code, we classify this soil as type C since it is very dense, and have the presence of soft rocks.

The site coefficient adjustments factors (F_a and F_v) are obtained from type C soils from the Massachusetts Building Code Table 1613.5.3(1) and Table 1613.5.3(2) respectively.

Fa = 1.2

Fv = 1.7

The maximum considered earthquake spectral responses (S_{MS} and $S_{M1)}$ determinate as follow:

S_{MS} = F_aS_S = (1.2)*(0.24)= 1.44

S_{M1}= F_vS_1= (1.7)*(0.067)= 0.1139

The design spectrum response acceleration:

$$S_{DS} = \frac{2}{3}(S_{Ms}) = \frac{2}{3}(1.44) = 0.96 \qquad \text{Equation 3-2}$$

Determine reinforce modification factor R from ASCE 7 Table 12.2-1

R=2

Determine Pressure of Roof

W= (62.7 psf.)

Seismic importance factor I_E from IBC and Massachusetts Building code1604.5

$I_{E=}$ 1.25

Determine Seismic Base Shear "V":

$$p = 2 - \frac{20}{r_{\max}\sqrt{Ax}} = 2 - \frac{20}{2\sqrt{174000}} = 1.97$$ Equation 3-3

Using Equiation 3.1 we get:

$$E = Q_E + 0.2S_{DS}D$$ Equation 3.1

D= Sum of Dead loads (Columns, Girders, beams and gravel)

E= 1.97X (62.7 psf) +0.2 (0.96) (62.62 +37 + 74.4) = 157psf

Wind Load (W from MBC)

According to the Massachusetts Building Code, Worcester is a zone 2 exposure area for winds, with a V_{30}= 80 mph.

If we go to table 1611.4 from the Massachusetts Building code, we obtain that W= 11 psf.

In order to find the Ultimate load factor that governs the structure, we must plug the load values into the combination equations and find the greatest value.

Columns:

The column tributary area is defined as the effective loading areas that act in each of the columns. In a uniformly distributed load structure, the tributary area of each column will be taken as the middle distance of the space between that column and the neighbor columns, figure 3-8 show the tributary areas of the columns for our parking structure.

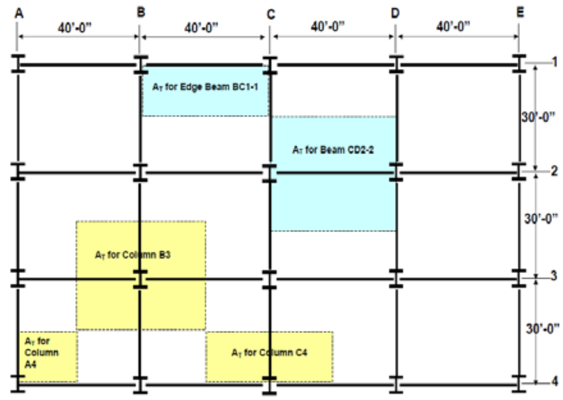


Figure 3-4 Example tributary areas source: Desing of Reinforce Concrete Nilson

From this image, we can infer that there are three different types of tributary areas, those for the corner columns, which are the smaller, those for the side columns and those for the middle columns, which is the greatest.

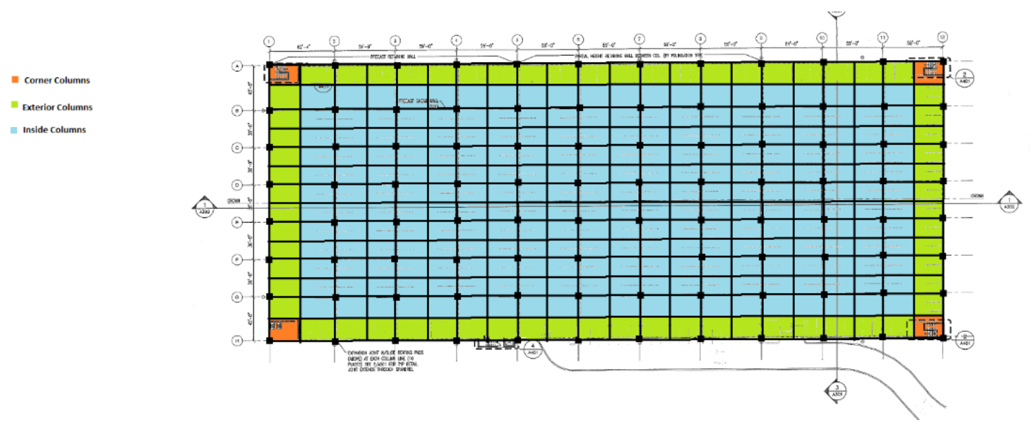


Figure 3-5 Column Tributary Area

Once we have the tributary areas and we check which of the load combination equations governs for all the live loads and dead loads that act above our columns. we are able to find the tributary loads Pu_{col}, by multiplying the tributary area in ft^2 of each column times the load per area in lb/ft^2 for convenience we convert it into kips to use smaller figures for our design. We

For the column size estimation, we proceeded as follow:

$$Pu_{Col} = \phi\,(0{,}85\,f'_C\ A_{Col}) \qquad \text{Equation 3-4}$$

Where:

Pu_{Col} is the load that is going to act in the column

f'c is the compressive strength of concrete (4000 psi for precast concrete)

A_{Col} is the area of the column

Φ is the minimization factor its value is 0.70

We computed Pu_{Col} by adding all the weight that will go above the column (gravel, double tee beams, girders and Snow and live load). Then we proceed to solve for $A_{Col\ \ in}$ equation 3.4 to estimate an area for our columns.

$$A_{col} = \frac{Pu_{Col}}{\phi(0.85f'c)} \qquad \text{Equation 3-5}$$

Once we had computed the area of the Colum, it was possible to estimate the weight of the column by multiplying weight of column times the area and the high.

$$Weight_{col} = (W_{concrete})x(A_{col})x(h_{col}) \qquad \text{Equation 3-6}$$

Where:

$W_{concrete}$= average weight of concrete (150 lb. /ft^2).

H_{col}=height of column (13 ft.).

The results for column weight and area can be observed in the following table:

Column	Pu_{col} (Kips)	Φ	f'c	A_{col} Ft^2	A_{col} in^2	h_{col} ft	$W_{concrete}$ lb	Colum Loa
A1	266.24	0.70	4000.00	1.00	24.00	11.00	150.00	27.28
A2	531.98	0.70	4000.00	1.00	24.00	11.00	150.00	53.11
A3A-10	517.33	0.70	4000.00	1.00	24.00	11.00	150.00	51.65
A11	512.95	0.70	4000.00	1.00	24.00	11.00	150.00	51.21
A12	254.28	0.70	4000.00	1.00	24.00	11.00	150.00	25.39
B1	502.07	0.70	4000.00	1.00	24.00	11.00	150.00	50.12
B2	977.35	0.70	4000.00	1.00	24.00	11.00	150.00	97.57
B3B-10	950.45	0.70	4000.00	1.00	24.00	11.00	150.00	94.89
B11	942.40	0.70	4000.00	1.00	24.00	11.00	150.00	94.08
B12	467.17	0.70	4000.00	1.00	24.00	11.00	150.00	46.64
C1	457.59	0.70	4000.00	1.00	24.00	11.00	150.00	45.68
C2	890.75	0.70	4000.00	1.00	24.00	11.00	150.00	88.93
C3-C10 ,D3-D-10,E3-E	866.23	0.70	4000.00	1.00	24.00	11.00	150.00	86.48
A7	821.26	0.70	4000.00	1.00	24.00	11.00	150.00	39.60
C12	425.78	0.70	4000.00	1.00	24.00	11.00	150.00	42.51
D1	457.59	0.70	4000.00	1.00	24.00	11.00	150.00	45.68
D2	890.75	0.70	4000.00	1.00	24.00	11.00	150.00	88.93
D11	858.89	0.70	4000.00	1.00	24.00	11.00	150.00	85.74
D12	425.78	0.70	4000.00	1.00	24.00	11.00	150.00	42.51
E1	457.59	0.70	4000.00	1.00	24.00	11.00	150.00	45.68
E2	890.75	0.70	4000.00	1.00	24.00	11.00	150.00	88.93
E11	858.89	0.70	4000.00	1.00	24.00	11.00	150.00	85.74
E12	425.78	0.70	4000.00	1.00	24.00	11.00	150.00	42.51
F1	457.59	0.70	4000.00	1.00	24.00	11.00	150.00	45.68
F2	890.75	0.70	4000.00	1.00	24.00	11.00	150.00	88.93
F3F10	866.23	0.70	4000.00	1.00	24.00	11.00	150.00	86.48
F11	858.89	0.70	4000.00	1.00	24.00	11.00	150.00	85.74
F12	425.78	0.70	4000.00	1.00	24.00	11.00	150.00	42.51
G1	495.72	0.70	4000.00	1.00	24.00	11.00	150.00	49.49
G2	964.98	0.70	4000.00	1.00	24.00	11.00	150.00	96.34
G3-G10	938.42	0.70	4000.00	1.00	24.00	11.00	150.00	93.68
G11	930.47	0.70	4000.00	1.00	24.00	11.00	150.00	92.89
G12	461.26	0.70	4000.00	1.00	24.00	11.00	150.00	46.05
H1	266.93	0.70	4000.00	1.00	24.00	11.00	150.00	26.65
H2	519.61	0.70	4000.00	1.00	24.00	11.00	150.00	51.87
H3-H10	505.30	0.70	4000.00	1.00	24.00	11.00	150.00	50.45
H11	501.02	0.70	4000.00	1.00	24.00	11.00	150.00	50.02
H12	248.37	0.70	4000.00	1.00	24.00	11.00	150.00	24.80

Table 3-6 column characteristics

We got several different areas of our columns since there were different tributary areas in the building, the outer columns, especially the ones in the corners had the smallest tributary area, therefore the smallest loads, however, for simplicity we used a standard 12 ft. by 12 ft. square column size which was an adequate size for all our columns.

The loads for the second floor and third floor were added, with the loads of the columns, and the sum of this was then factored, and the governing factored load was the one taken in the foundation design.

A Summary of the loads we calculated for this structure is located in Appendix A.

3.3 Foundations:

Section3.3 is divided in two sub sections, 3.3.1 deals with the methodology of designing shallow foundations and section 3.3.2 deals with the design of drilled shaft foundations.

3.3.1 Shallow Foundations

The following methodology for Shallow foundation design it's based on a trial and error method, it follows standards from the ACI 318-08, ACI 347.2R-05 codes and the Donald P. Coduto's book. For details on how the soil properties were obtained, see section 3.2

Step 1: Design of footing dimensions

a) Calculate required area of footing base: Footing dimensions, especially width are mainly governed by both the bearing capacity and the settlement. The bearing capacity and settlement of a footing are related both to the soil properties and the footing size and depth of embedment. Bearing capacity increase significant with increase in footing size and depth of embedment, settlement decreases with increase in the footing size. If the settlement exceeds the required allowable settlement which is usually less than 1 in. (depending on the structure and soil properties it might change), the footing is not adequate, if the actual bearing capacity is greater than the allowable, then the footing size is not adequate, and it is necessary to try a footing with different dimensions. In order to calculate the required footing area of the design we used the following area equation, A_{req} stands for the required area of the footing, P stands for the service load that is going to be acting on the footing, we got the load that governs from the structure factored load equation. Section 3.2 shows in detail the steps that were used to get the service loads. In Appendix A there are detail values for service loads in each of the columns of the building. $q_{allowable}$ is the soil bearing stress in Allowable Stress Design ASD, we get this by the Terzaghi's bearing capacity, we first we got a pre-dimension and in the following steps we checked whether this pre-dimension work or not. If it didn't work, it was required to repeat the whole process with a different footing size (trial-error method).

$$A_{req} = P / q_{allowable}$$ Equation 3-7

We carefully analyzed all constrains in the site, to determinate if there was need for rectangular footings in some areas due to lack of space or end of the property lines. We realized that were the building was located there was no need for rectangular base footings, so we only designed square base footings for simplicity and convenience. Because our design it's a Square footing (Bx=By), we have to make sure that

$$B \geq \sqrt{A_{req}}$$ Equation 3-8

b) Calculate an approximate footing thickness, "d": After having a required area we need to calculate the footing thickness of our design, this preliminary design should be checked for shear and flexural failure, for this approximation we are going to use the following equation

$$d \geq \sqrt{\frac{Mu}{\mu F'cB}}$$ Equation 3-9

$$Mu = q_{ult}(B(n^2)/2)$$ Equation 3-10

$\mu = 0.1448$ (Resistance factor)

Where:

P= DL+LL (ACI 9.2)

B = Spreads footing dimension in concrete design

d = effective depth from the top of a reinforced concrete member to the

q_{allow} = allowable soil bearing stress

F'c = Concrete design compressive stress (4000 psi in our design)

M_{μ} = Maximum momentum

μ = Resistance factor

A_{req} = Required area of footing

Step 2: Geotecnical design

a) Bearing capacity: In order to calculate the bearing capacity of the soil to satisfy $q \leq q_{allowable}$, we needed to calculate first the ultimate bearing capacity q_{ult} using the Terzaghi's bearing capacity for square foundations with the following formula

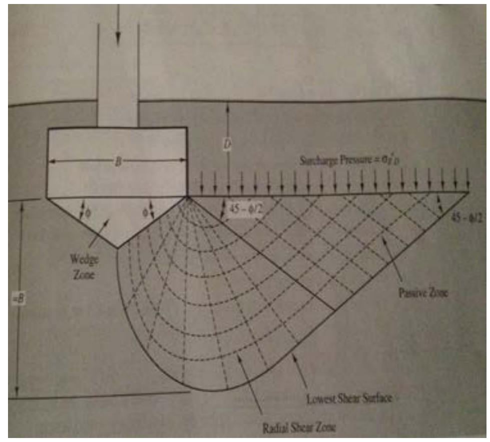


Figure 3-6 Terzaghi Bearing Capacity source (Coduto 2006)

$$q_{ult} = 1.3c' N_c + \sigma'_{ZD} N_q + 0.4\gamma' B N\gamma$$ Equation 3-11

$$N_q = \frac{a^2{}_\theta}{2\cos^2(45 + \phi'/2)}$$ Equation 3-12

$$N_c = \frac{N_q - 1}{\tan\phi}$$ Equation 3-13

$$N_\gamma = \frac{2(N_q + 1)\tan\phi'}{1 + 0.4\sin(4\phi')}$$ Equation 3-14

After the ultimate bearing capacity was calculated, we had to obtain the allowable bearing capacity and the bearing pressure to make sure that the bearing pressure, q , didn't exceed the allowable bearing pressure $q_{allowable}$ using the following formula

$$q_{allowable} = \frac{q_{ult}}{F_s}$$ Equation3-15

$$q = \frac{(P + Wf)}{B^2}$$ Equation 3-16

$$q \leq q_{allowable}$$ Equation3-17

where:

B = Spreads footing dimension in concrete design

c' = effective cohesion for soil beneath foundation

D = depth of foundation below ground surface

q_{allow} = allowable soil bearing stress

q_{ult} = ultimate soil bearing capacity

θ_{zD}' = vertical effective stress at depth D below the ground surface (γxh)

ϕ' = effective friction angle

γ_s = unit weight of soil (Section 3.1 has more details)

N_c , N_q, N_γ = Terzaghi's bearing capacity factors

Wf = Weight of the footing

P= DL+LL

F_S = Factor of safety 2.5. (fig 6.11 Donald Coduto's second Edition Foundation Engineering)

b) Check Settlements: We had to make sure that our settlement was acceptable, allowable settlements δ_a must be bigger than actual settlements. usually acceptable settlements are those that have values less than 1 in. (Coduto 2006). $\delta<\delta_a$

TABLE 2.1 TYPICAL ALLOWABLE TOTAL SETTLEMENTS FOR FOUNDATION DESIGN

Type of Structure	Typical Allowable Total Settlement, δ_a (in)	(mm)
Office buildings	0.5–2.0 (1.0 is the most common value)	12–50 (25 is the most common value)
Heavy industrial buildings	1.0–3.0	25–75
Bridges	2.0	50

Figure 3-7 Typical allowable settlement (Coduto 2006)

The table above, from (Donald 2006 Foundation Engineering) shows typical allowable settlement values according to the usage of the building. For our deign we attempted to be conservative, to use a $\delta_{allowable}$ no greater than 1 in.

In order to calculate the settlement was necessary to calculate different variables;

A1) Induced stress:

$$\Delta\sigma_z = [1 - (\frac{1}{1 + (\frac{B}{2Z_f})^2})^{1.76}](q - \sigma'_{ZD}) \quad \text{Equation 3-18}$$

where σ'_{ZD} is the vertical effective stress at a depth D below the ground surface, and Z_f is the considering depth for settlement purpose.

B2) Effective stress:

$$\sigma'_{zf} = \sigma'_{z0} + \Delta\sigma_z \quad \text{Equation 3-19}$$

Where σ'_{z0} is initial vertical effective stress at midpoint of soil layer.

$$\sigma'_{ZD} = \gamma H - Ud \quad \text{Equation 3-20}$$

Where H is the thickness of the soil layer in this project, based on the soil analysis and the cross sectional profile, the depth of the layer (Glacial till) changes in each zone. So was necessary to calculate the settlement for each of the 3 ranges of load 3 times because of different value of H.

C3) Settlement: For settlement calculations we used a spreadsheet created for Donald Coduto;s text book, we also computed the settlement by hand calculations. Since our soil was mostly normally consolidated, we used the following procedure:

$$\delta_c = \delta = (rCc/(1+e0))H \log(\sigma'_{Zf} / \sigma_{ZD}) \quad \text{Equation 3-21}$$

Where r is the rigidity factor which is taken from the table 7.1 (Donald P. Coduto). In this case r= 0.85

Cc is the compression index; e0 is the initial void ratio.

Since there was no relevant information in the soil report about the Cc/(1+e0) value, we assumed the values based on the table 3.5 and table 3.7 (Donald Coduto's second Edition).

At the end it should be satisfied that: $\delta<\delta_{a}$,, where δ_a in this case is taken to be 1 in.

Where:

δ = Settlement

δ_a = Allowable settlement

$\Delta\sigma_z$ = Induced vertical stress

r = Rigidity factor (Table 7.1 Donald Coduto's second Edition)

C_c= Compression index

e_0 = Initial void ratio

H = Thickness of soil layer

σ_{z0}' = Initial vertical effective stress at midpoint of soil layer

σ_{zf}' = Final vertical effective stress at midpoint of soil layer

The results obtained from the spreadsheet were very close to one's computed by hand. Its important to say that the settlement differential between each type of footing was very small, giving as a result a very similar settlement, neglecting any structural settlement problems.

3) Structural design

After the preliminary design was checked for geotechnical failures, it was also checked for flexural and shear failure.

a) Flexural failure and design reinforcement: Square footings may be designed for momentum in one direction and the same reinforcing used in the other direction. The footing thickness is generally established by the shear requirement, the shear is also known as punching shear, because the column tends to trespass through the footing.

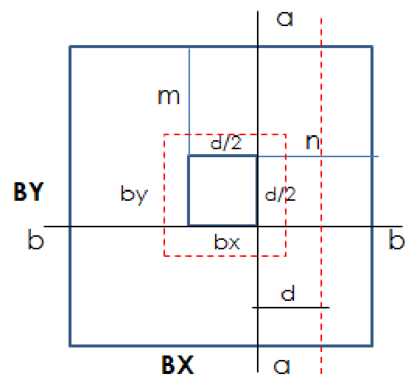


Figure 3-8 Representation of Footing dimensions from top

$$\upsilon_u \leq \upsilon_c$$

Where:

v_u= Nominal Shear stress

v_c= Nominal Shear of concrete

A1) Calculate projection of cantilever distance

$$n = \frac{(B_{footing} - B_{column})}{2}$$ Equation 3-22

B2) Find shear stress υ_U:

$$\upsilon_U = V_U / (\phi B d)$$ Equation 3-23

C3) Shear at “d” of the column V_u:

$$V_u = q_{ul} B (n - d)$$ Equation 3-24

D4) Find Nominal shear of concrete υ_c:

$$\upsilon_c = 0.53\sqrt{F'c}$$ Equation 3-25

E5) Calculate flexural stress M_{uc}:

$$M_{uc} = \frac{Pun^2}{2B}$$ Equation 3-26

F6) Calculate de area of steel:

$$A_S = (\frac{F'_C\, b}{1.176F_y}(d - \sqrt{d^2 - \frac{2.353M_u}{\phi F'_c\, b}})$$ Equation 3-27

b) Check for Two-way shear failure:

$$\upsilon_u \leq \upsilon_c$$

Where:

ν_u= factored shear force; ν_c= nominal two-way shear of concrete

A1) Find shear perimeter b_0:

Shear perimeter is located at a distance of d/2 outside boundaries of loaded area

$$b_0 = 4(b + d) \qquad \text{Equation 3-28}$$

B2) Find factored net soil pressure:

$$q_{ult} = \frac{Pu}{B^2} \qquad \text{Equation 3-29}$$

C3) Find factored shear force υ_U :

$$\upsilon_U = V_U /(\phi b_0 d) \qquad \text{Equation 3-30}$$

D4) Find maximum two-way shear V_u:

$$V_u = Pu - q_{ult}(b + d)^2 \qquad \text{Equation 3-31}$$

E5) Shear force capacity V_c

$$V_c = \phi 4\sqrt{f'c}\, b_{0d} \qquad \phi = 0.85 \qquad \text{Equation 3-32}$$

Note: (If it is not acceptable, increase thickness of the footing and repeat steps)

Where:

A_S = area of steel reinforcement in concrete design

F'_c= Strength of concrete after 28 days (3000 psi used in our design)

F_y= Steel strength (50000psi for A50 steel)

b_0 = perimeter length for two-way shear in concrete footing design

B = Spreads footing dimension in concrete design

d = height of a concrete Spreads footing

n = projected Length for bending in concrete footing design

M_u= maximum momentum from factored loads

P_u= factored axial force

q_{ult} = ultimate soil bearing capacity

TABLE 3.7 TYPICAL CONSOLIDATION PROPERTIES OF SATURATED NORMALLY CONSOLIDATED SANDY SOILS AT VARIOUS RELATIVE DENSITIES (Adapted from Burmister, 1962)

	$C_c/(1+e_0)$					
Soil Type	$D_r = 0\%$	$D_r = 20\%$	$D_r = 40\%$	$D_r = 60\%$	$D_r = 80\%$	$D_r = 100\%$
Medium to coarse sand, some fine gravel (SW)	—	—	0.005	—	—	—
Medium to coarse sand (SW/SP)	0.010	0.008	0.006	0.005	0.003	0.002
Fine to coarse sand (SW)	0.011	0.009	0.007	0.005	0.003	0.002
Fine to medium sand (SW/SP)	0.013	0.010	0.008	0.006	0.004	0.003
Fine sand (SP)	0.015	0.013	0.010	0.008	0.005	0.003
Fine sand with trace fine to coarse silt (SP-SM)	—	—	0.011	—	—	—
Find sand with little fine to coarse silt (SM)	0.017	0.014	0.012	0.009	0.006	0.003
Fine sand with some fine to coarse silt (SM)	—	—	0.014	—	—	—

Table 3-7 Typical Consolidation Properties of Saturated Sandy soils Source: Donald Coduto 2006

TABLE 3.5 CLASSIFICATION OF SOIL COMPRESSIBILITY

$\frac{C_c}{1+e_0}$ or $\frac{C_r}{1+e_0}$	Classification
0–0.05	Very slightly compressible
0.05–0.10	Slightly compressible
0.10–0.20	Moderately compressible
0.20–0.35	Highly compressible
> 0.35	Very highly compressible

Table 3-8 Classifications of soil compressibility Source: Donald Coduto 2006

V_c = shear force capacity in concrete

V_u= maximum two-way shear

ϕ = resistance factor

γ_c = unit weight of concrete

Note:

Footing Embedment: In order to safely resist vertical and horizontal loads, the footing must be embedded deep enough into the ground. Foundation embedment is usually measured below the undisturbed ground surface; the minimum required embedment depth for the footing is based on the number of floors supported and the soil condition. The rule of thumb (Soil Mechanics from Lambe & Whitman, 1969) states that for 1 story buildings the embedment must be at least 12 inches, 2 story buildings must be at least 18 inches and 3 story buildings must be at least 24 inches. In our design we decided to be conservatives and choose a value of 24 inches as embedment.

3.3.2 Calculations for Deep Foundations (Drilled Shaft)

The design methods for drilled shaft proposed in this MQP are largely based on values obtained from the soil boring tests, and the sum of all the structural loads. In general we tried to have a conservative design for this project.

Excavated Drill Shaft in Granular Soil (MEYERHOF METHOD)

Properties	Layer I (Fill)	Layer II (Glacial Till)	Layer III (Bed Rock)	Description
Prof. D =	3.00 ft	6.00 ft	13.00 ft	Depth
γ_s (Kip/ft^3)=	1.70	1.80	1.90	Soil Unit Weight
ϕ' =	26.00 °	32.00 °	34.00 °	Effective Friction Angle
%<#200	25.00	18.00	20.00	#Sieve analysis passing N200
D(fn)=	3.00 ft	-	-	Depth of the Fill subjected to negative)
Fn (Kip/ft^2)=	2.25	-	-	Negative friction factor
Pile Diameter, Security Factors and Materials Resistance				
Diam. B =	1.00 ft	Pile Diameter		
FSf:	1.25	security Factor Applied to friction		
FSp:	2.00	Security factor applied at toe		
fy= (lb/ft^2)	50,000	Resistance of steel		
f'c (lb/ft^2)	3,000	Concrete Strength at 28 Days		

Table 3-9 Sample view of inputs in spreadsheet

There are three different methods that have been used to calculate the loading capacity of a drill shaft foundation: a) the dynamic formulas; b) the static method; c) the loading probes.

In this project we used the static method for designing foundations proposed by George Gregory Meyerhof. Which is the most currently used in drill shaft calculations now days, it is also called the Meyerhof method, created by Geoffrey Meyerhof in 1963. We followed the design code standards from the American Concrete Institute (ACI) code, section 318, 336.R and 117.

In order to facilitate the calculation process, we calculated the drill shafts by the use of a spreadsheet we designed, this spreadsheet needs some input data and it will perform the work for us, you can have a better look of these spreadsheets by looking in Appendix C .

Step 1: Get the soil properties

The first step when using the Meyerhof method was to get the soil profiles and separate the different layers to get each layer specific characteristics, Usually the soil properties are obtained from the soil report, in the case of our soil report, some of the numbers were missing, however, the report gave us different soil classifications, we were able to get the soil values by using different sets of tables, this was a very challenging thing to do because we had to look for this tables in different books, since none of the books available had all the information by itself . In the case of our project, there were three mayor soil layers that we considered. The first and initial layer was mostly composed by fill; then the second layer that was present in most of the soils we analyzed is composed by glacial till, and the third layer is mainly composed by bedrock. More details of the procedure used to get the soil values are found in section 3.1 that refers to the soil analysis.

Once we had our layers Identified, the next step was to get the input values to place them in the spreadsheet. (Appendix E has the spreadsheets with the results) Most of these input values were taken from the soil properties. We toke from each of the soil layers the following characteristics (Depth, Soil Unit Weight, Effective Friction Angle, and the percentage of the sieve analysis passing the N200 sieve). For the first layer, that is fill, we also considered the depth of the fill, and a negative friction factor, that will be working on the shaft, only in the top part. In the image bellow we show how the input box from our spreadsheet looks like.

We can see in figure 3.9, how there is a negative friction factor that needs to be considered in the upper part of the shaft, due to the fill layer.

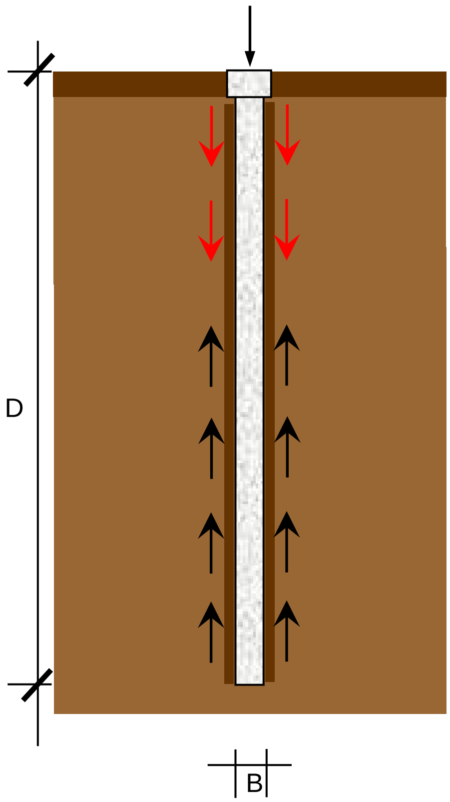


Figure 3-9 Possitive and Negative Friction in our shaft design

The other values we considered as input in our spreadsheet calculation where:

B= the pile Diameter in ft.

F_{Sf} = Factor of safety applied to friction

F_{SP}=Factor of safety applied at the toe (picked by designer, usually between 2 and 3)

fy= Resistance of steel for steel A588 Fy=50000 psf

f'c= concrete Strength at 28 days (3000 psi concrete was used in our design)

The factor of safety applied to friction F_{sp}, is obtained from the boring test using the following equation.

$F_{sp} = N/100$ Equation 3-33

Where N= "N" Value obtain from S (ACI 336.3 R-3)

Step 2: Corrections are done to the effective friction angle (Φ).

According with the percentage of the sieve analysis passing the #200 sieve, corrections need to be made to the correction friction angle in layer II (glacial till) and layer III (bed rock).

ϕ Correction According to % < #200	
% < #200	ϕ
0 - 20	$\phi' = \phi$
21 - 58	$\phi' = -1{,}05\phi + 121{,}05$
59 - 70	$\phi' = -2/3(\phi) + 98{,}66$
71 - 100	(Silt) $\phi' = -6{,}66 \times 10^{-2} (\phi) + 56{,}66$
72 - 100	(Clays) Cohesive Soils

Table 3-10 Friction Correction table, Meyerhoff 1961

In table 3.11 is shown how corrections are done to the effective friction angle depending on the amount of soil passing the N200 sieve.

Step 3: Get the unit friction resistance (Q_f) (Soil Mechanics Engineer 3 Edition, Karl Terzaghi)

Once we are done correcting the effective coefficient angle, the following step will be to compute the unit friction resistance, by the use of the following equation.

$Q_f = \text{Phx} \tan\delta$ Equation 3-34

Where:

Tan δ= Friction Coefficient between Soil and pile e = ⅔ φ

P_h= the lateral pressure along the column

P_h is computed with the equation shown below.

$$P_h = K x P_v \qquad \text{Equation 3-35}$$

K: is Coefficient for lateral pressure of soil. Is a function of soil's friction angle K=1-sinΦ

After we have the value for K, we need to get a value for our geotechnical pressure; we get this value by using the following equation:

P_v= Geostatic Pressure or effective vertical pressure.

$$P_v = \gamma x\ d \qquad \text{Equation 3-36}$$

Where:

d= the pile depth for constant vertical pressure

γ = the soil specific weight.

For the pile depth for constant vertical pressure we use the following equations;

d=5B for $\Phi \leq 33^0$ B= Pile Diameter Equation 3-36 A

d=10B for $\Phi > 33^0$ Φ= effective friction angel Equation 3-36 B

Once we get values for γ and d, we compute the geostatic pressure P_v and once we have P_v we are able to find Ph.

After obtaining Ph, we can compute the unit friction resistance just by inserting the value in the equation.

Step 4: Load determination due to negative friction (Q_{fn}):

$Q_{(fn)} = (F_n)x(As)$ Equation 3-37

F_n = Negative Friction Factor (Depends on quality and age of the fill)

As= Pile Surface Area in contact with fill.

$As = \pi x \ B \ x \ D_{(fn)}$ Equation 3-38

Where:

$D_{(fn)}$= Length of fill subjected to negative friction

B = Pile Diameter

Step 5: Determination of critical depth D_c

$D_c = 4xB \tan^{(45+\Phi/2)}$ Equation 3-39

Where:

B= Pile diameter

Φ= correction of the internal friction angle

Step 6: Check effective depth 'D' VS Critical depth 'Dc'

We have to compare the critical depth Dc that we calculated in the previous step with the effective depth of the pile D' to determinate the load factor Q_p.

If $D \geq DC$; $Q_p = P_V x N'_q$ Equation 3-40

If $D < DC$; $Q_p = P_V x N''_q$ Equation 3-41

N'_q and N''_q are both load capacity factors, and are calculated by the use of the following equations.

$N''_q = (N'q - N_q)x(D/D_C) + N_q$ Equation 3-42

$N_q' = 10^{12.7\tan\phi}$ Equation 3-43

We got the values for Nq from the following. This table comes from (G G Meyerhof 1973).

∅	Nq
0 ≤ ∅ < 32,6	0,31∅ + 15
32,6 ≤ ∅ < 35,5	3,45∅ - 87,41
35,5 ≤ ∅ < 38,2	5,55∅ - 162,22
38,2 ≤ ∅ < 40	7,22∅ - 225,88

Table 3-11 N_q with respect to effective friction

Them we calculate q_l which is the limit value of fail. $for\ \emptyset \leq 35^0$;

$q_l = 1.16(\phi - 28.3^0)$ Equation 3-44

$for\ \emptyset > 35^0$; $q_l = 1.92(\phi - 29.8^0)$ Equation 3-45

We compare the value we obtained for ql with Q_p, and then we proceed to use the smallest of this two value

s as our new Q_p.

Step7: Calculate the ultimate capacity load (QF) (ACI 336-03)

The ultimate capacity load QF is the load for friction between the soil and the pile; we compute this load by using the following equation.

$$QF = \sum Q_f xAs$$ Equation 3-46

Where:

As= Area in contact with fill

To calculate as, we use the following equation.

$$As = \pi Bx(D_2 - D_1)$$ Equation 3-47

Where:

D(fn)= Depth of the fill

D_2=Depth of bed Rock

P= Pile Diameter

Step 8: Calculate QP, the load for action in the pile toe (ACI 336-04)

To calculate Q_P, the load for action in the pile toe we use the following equation.

$$Q_p = Q_p xAP$$ Equation 3-48

Where:

Ap= The area of the pile toe.

$$Ap = \frac{\pi B^2}{4}$$ Equation 3-49

Where:

B= the pile Diameter.

Step 9: Allowable capacity considering negative friction (Q_{allow}).

When considering negative friction, it is important to consider allowable capacity. We use the following equation to compute Q_{allow}.

$$Q_{allaw} = (\frac{Q_f}{FSF} + \frac{Q_P}{FSF}) - Qfn$$ Equation 3-50

Step 10: Check for concrete resistance (ACI 318-08)

To determinate whether the concrete fails or not, we need to compute the maximum stress for the concrete that the pile can take in tension ($\sigma_{concrete}$).

$$\theta_{conctrete} \leq 0.25F'c$$ Equation 3-51

$$\sigma_{allow} = Q_{allaw}/Ap$$ Equation 3-52

Step 11: Calculate longitudinal transversal Steel (ACI SECTION 10.8.4 2004)

To calculate the amount of steel required, we followed standard norms established by the American Concrete Institute.

- The minimum longitudinal area of steel as is at least 0.5% the area of the pile.
- For lapped splices: The minimum longitudinal steel will be 40 times the diameter of the rebar.
- Minimum rebar diameter 3/8”
- The minimum separation of bars will be 3 times the diameter of the rebar and not less than 3 times the maximum size of the aggregates.
- Minimum Band separation = 3”
- Use spacer to keep the steel cage at least every 12 ft.

Settlement:

Most deep foundation designed using the methods described in chapter 12 to 17 will have total settlements of no more than 12 mm (0.5 in), which is acceptable for nearly all structures. Therefore, engineers often do not perform any settlement computations for deep foundation. (Donald Coduto 2006)

We analyzed the site and none of the conditions mentions for settlement calculation in (Coduto 2006) chapter 14.7 where present in our site.

The following procedure (adopted by Fellenious, 1999) is used to compute settlement of deep foundations.

$$\frac{(q'_t)_m}{q'_t} = (\frac{\delta}{\delta_u})^g$$ Equation 3-53

$$\frac{(f_s)_m}{f_s} = (\frac{\delta}{\delta_u})^h \leq 1$$ Equation 3-54

Where:

q_t = unit toe bearing resistance

$(q'_t)_m$= mobilized net unit toe-bearing resistance

f_s= unit side friction resistance

$(f_s)_m$=mobilized unit side-friction resistance

δ= Settlement

δ_u=settlement required to mobilize ultimate resistance= B/10 for toe bearing.

g= 0.5(clay)-1.0(sand)

h= 0.02-0.5

Drilled Shaft VS PIF

One of the major objectives of this project was to present an alternative foundation design of the Parking Garage, and compare it with the actual design. The actual design for the WPI Parking Garage is Pressure Injected Footings and the design we choose to compare it with is Drilled Shaft. After performing all the necessary investigation, soil analysis, design calculations and cost analysis of our design we realize that there are more advantages than disadvantages. From the soil point of view of the site, after reviewing the soil test and realize the quantity of fill and the hardness of the bed rock that exist on the site we could say that the use of PIF will have a bigger negative friction due to the waive body of the PIF, also because of the rock the bulb that is supposed to be formed at the bottom won't be able to develop its total size, decreasing the toe bearing capacity and wont calculations of the PIF. Another important fact from PIF is that the construction process generates much more vibration and noise than the regular drilled shaft, disturbing with the vibration the soils near the construction site as well other close buildings.

After design our foundations and review the design process of the PIF we realize that the PIF has a pre-establish maximum diameter that won't allow us to use one PIF per column because the allowable pressure won't be met, in this case more than one PIF will be required to support that load as well the need of a pile cap that will increase the amount of concrete.

From the point of view of cost and equipment after comparing the price of the implemented design (PIF) provided by Gilbane with the design of drilled shaft that we performed, the cost of PIF estimated by Gilbane was \$ 260,000 in total; the price computed by us for a drilled shaft design was \$ 400,230. There is a considerable difference in price between this two alternatives, but at the same time, the drilling trucks used to implement the shafts are easier to transport and faster to assemble (Soiltech Engineering).

3.4 Results Shallow and Deep Foundations

During the development of this project we analyze many important factors to take into account for the foundation design, we analyze all the soil properties as well the building loads to be supported by the foundations. As result we came up with two different methods of foundations due to the soil conditions, shallow and deep foundation. In the following figure we have a distribution of the different types of foundations used in the project.

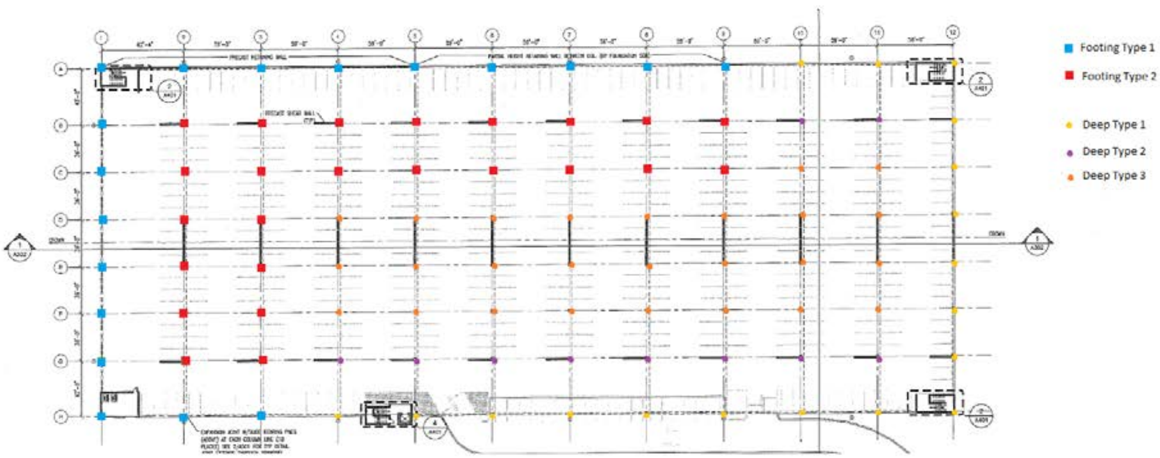


Figure 3-10 Location of Foundation Systems

3.4.1 Shallow Foundation

After analyzing all the loads to be supported by the footings and realize that were too many different loads, we separate them in two small groups with very similar loads, considering the greatest of the loads in each of the groups.

For a better organization execution of the project we design one footing for each group of load, obtaining two different types of footings:

Footing Results		
TYPE	SIZE in	Area of steel
1	101x101x26	6 # 8 bars
3	130x130x27	8 # 8bars

Table 3-12Footings summary table

GROUP	LOAD Kips
1	540
2	985

Table 3-13 Footings Loads

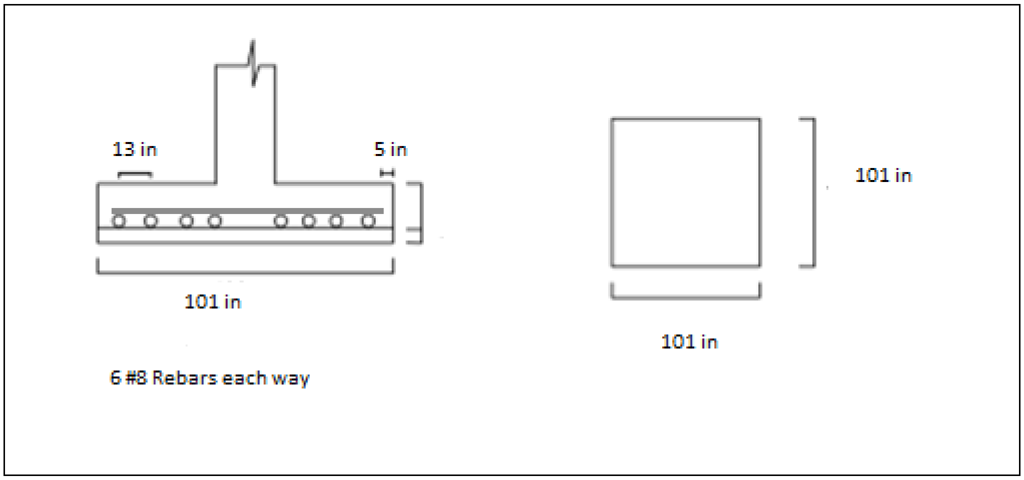


Figure 3-11 Dimensions of shallow type 1

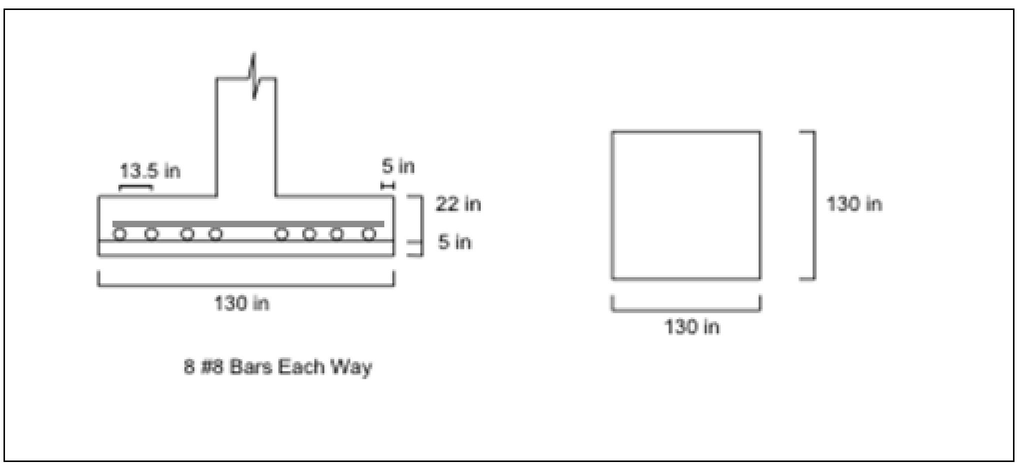


Figure 3-12 Dimensions of shallow type 2

3.4.2 Deep Foundations

For the deep foundation design we did the same procedure than shallow foundation, we analyze the loads to be supported by the shafts, and divided them in three small groups for simplicity.

GROUP	LOAD Kips
1	530
2	960
3	875

Table 3-14 Drilled Shafts Load summary

After having the loads separated into groups, we decided for a better organization and development of the project to design three types of shafts, one for each type of load.

Drilled Shaft Results			
TYPE	DIAMETER f	DEPTH ft	# Bars
1	3.5	17	23 bars 7/8
2	4.5	17	38 bars 7/8
3	4.15	17	32 bars 7/8

Table 3-15 Drilled shaft summary table

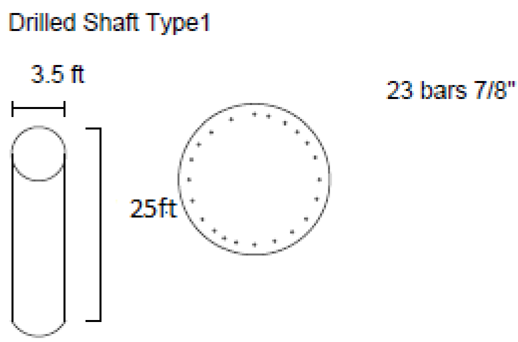


Figure 3-13 Drilled shaft Type 1

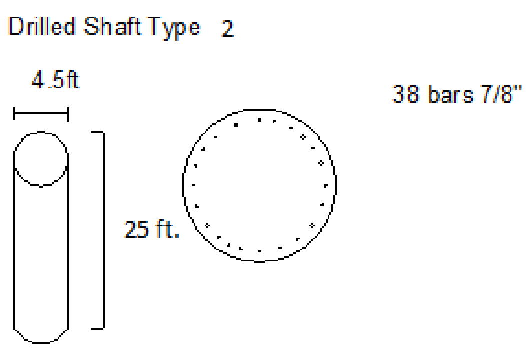


Figure 3-14 drilled shaft type 2

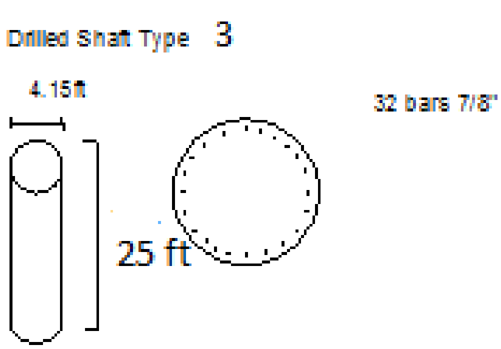


Figure 3-15 Drilled Shaft type 3

4 5D Modeling

4.1 Building Information Modeling (3-Dimensional Design)

We have been working in this model for the last three term, we have follow some specifications obtained from 2D drawings obtained from Gilbane and SMMA. Our team had some background in Revit and Building Information Modeling. However for the completion of our design, our previous background was not enough, and we had to research methods and techniques, we had first to refresh our knowledge and learn a lot of properties and commands we didn't know before.

A lot of important information was missing since there was not approval for the construction until recent days, there was no structural design at all, so we had to basically start everything from the beginning. We had a lot of constrains while performing this. In order for us to perform a good BIM design, is necessary to have the right members, the right sices and the right materials that were going to be implemented in the actual project.

4.2 Getting Started

We first had to open Revit. When we open Revit we saw how many options we have. This is really a challenge especially for people that might not be familiarizing with this type of software. (See Figure bellow to have an idea of how a Revit Menu Looks like)

Next to the tap, there are expandable views for different viewpoints, legends, sheets, families and other options

At the left hand side of a Revit window, we typically have expandable views from different viewpoints as well as legends, sheets, families, and other options.

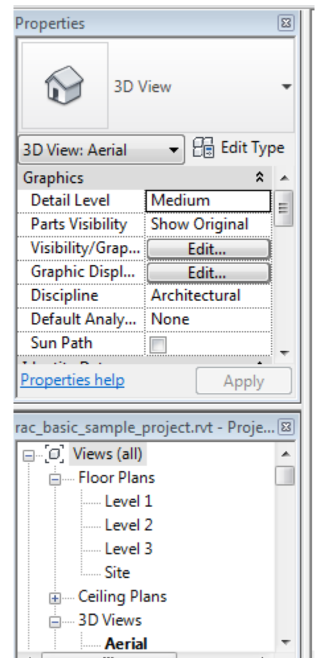


Figure 4-1 Left hand side menu Revit Source Revit

At the top of the screen there are a huge number of options ranging from walls, beams, and stairs to site plan and Toposurfaces.

Our model began using Revit Architecture, the first thing we did was to create gridlines that were used as references to place our columns, we created as well levels of the building. These levels start with the foundation and go all the way up to the top of the building.

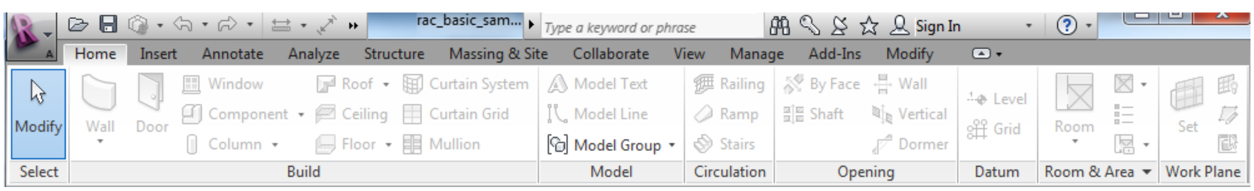


Figure 4-2 Revit Architectural top menu bar Source Revit

All levels are represented with dashed lines in the Building Elevation views (See 4.3). Our levels were oriented following some of the information we obtained from SMMA 2D drawings. Making the foundations of the first level, then the first and the second floor.

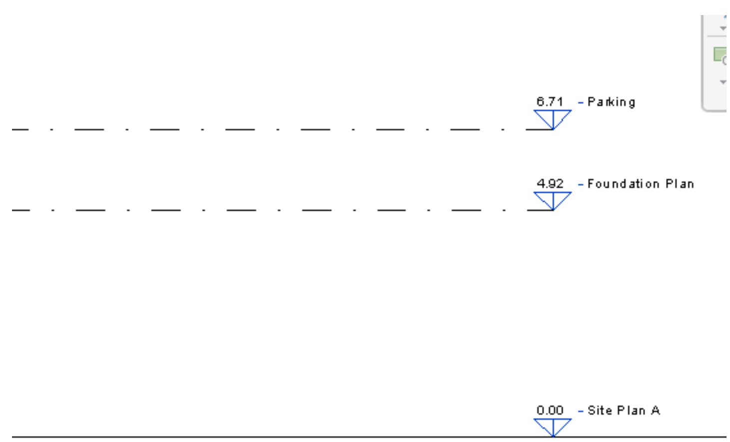


Figure 4-3 Revit: Elevations for the Parking Garage

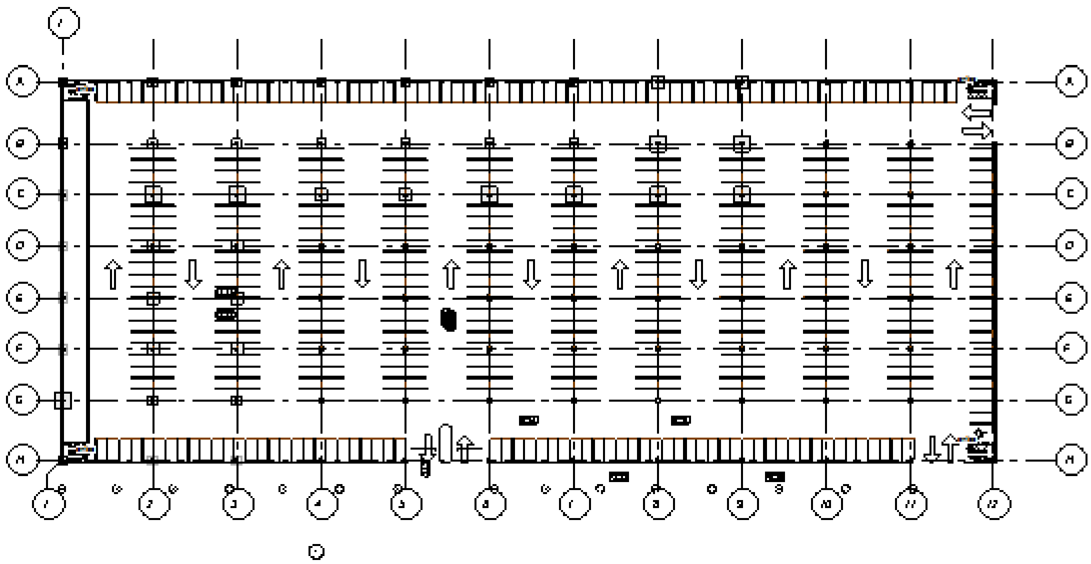


Figure 4-4 Revit: Gridlines parking garage Revit

The gridlines might look a little bit confusing at first but it was actually very helpful. They allowed us to locate all the important elements and we used them as references to place the columns and important elements of the structure.

To add gridlines in Revit, both, Structural and Architectural, we go to the tab “Structure”, located in the main menu above the screen, and then we go and click in the button that stands for grid line.

See figure 4.5

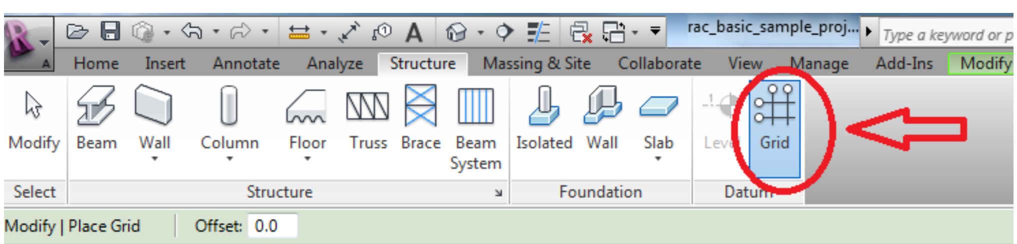


Figure 4-5 Revit: Main menu, Grid Line Source Revit

4.3 Creation of Top surfaces and Soil Layers

This part of the project was very challenged for us at first, we had to create a surface soil and then add all the different layers present in the soil profiles.

To create the soil surface and then all the soil layers, we got information obtained from the soil report given to us. We used information about the surface elevations. We started by creating the surface layer, adding the heights in the different points where the TP and MAI tests were performed. Once the soil Toposurface was created, did the same for all the other layers, subtracting the elevation of the topsoil to the deepness of each layer obtained from the TP and MAI tests. We created a Toposurface representing the fill layer, another Toposurface representing the glacial till layer, and another Toposurface representing the bedrock layer.

To Have a better view of what we were doing and make sure we were interpolating all the points the right way they supposed to be interpolated, we had to perform many hand drawings soil profiles in different parts of the building, a copy of this hand drawings of the soil profiles can be observe in Appendix B.

Create a three-dimensional soil profile using Revit is not a common practice and we weren't able to find any standard procedure for this in any book or in the internet. We had to create our own method by experimenting and trying different ideas, definitely one of the more challenging parts of the project.

To implement Toposurfaces, we went to the main menu, and in the top of the screen there is a tab labeled "Massing & site". After clicking in this tab, a button with the name Toposurface appears. When clicking at it, the following step will be to set the height from each point. This height was obtained from the soil report.

Once we were done setting the points of a Toposurface, we continue with the next layer and so on.

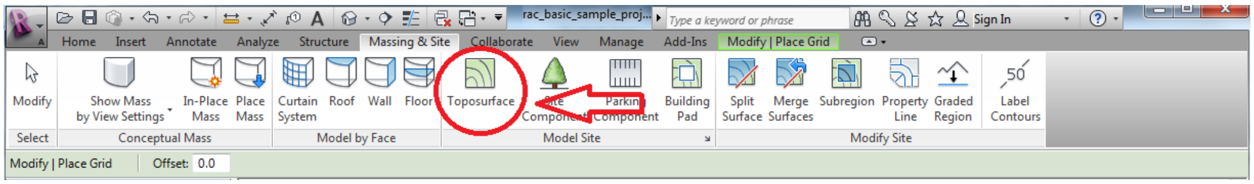


Figure 4-6 Revit: Main Menu, Toposurface, Source Revit

4.4 Foundations

The foundation design was one of the most extensive parts of our project; our foundation background wasn't strong enough at first, so it was the part that took the longest to finish from the entire project. Because of this, we decided not to worry very much at first and just insert any generic type of foundation that Revit has and then, once we had the right types that we were going to use, we changed them.

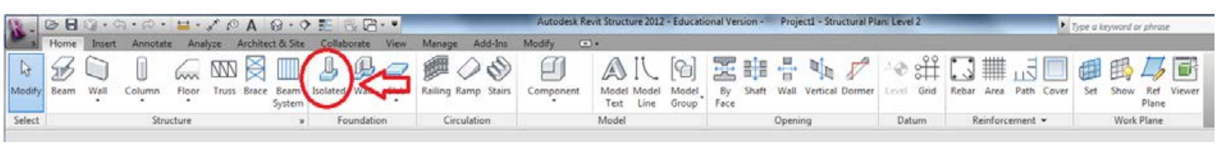


Figure 4-7 Revit: Main Menu, "Isolated" footing, Source: Revit

We used the gridlines we made as reference to put our foundations in place. Foundations might be inserted in both, Revit structure and architecture. We placed our foundations using Revit structure 2012. In the main menu of Revit Structural at the top, there is a button with the name “foundations”. By clicking where it says “isolated”, we were able to implement the footings in our design.

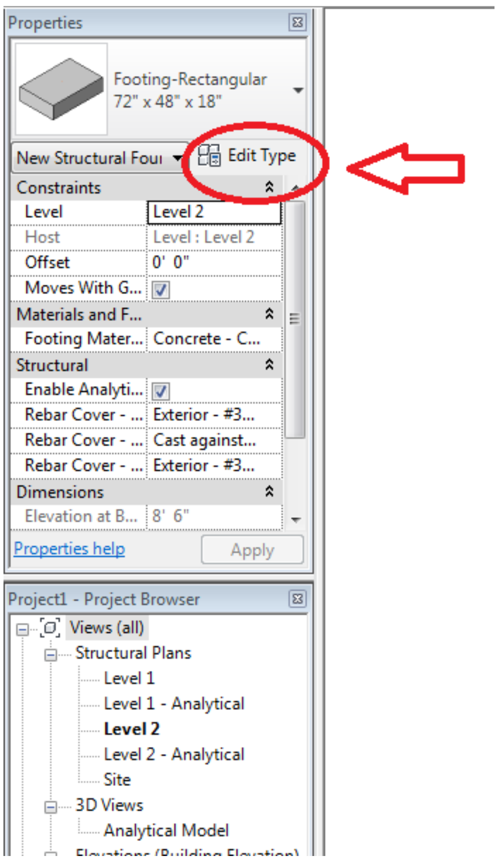


Figure 4-8 Revit: Main menu, Edit Type, Source: Revit

A footing size was already pre-established in Revit. Since our footing dimensions differed from the ones the program had, we had to edit different types of footings to get the proper ones in place.

We did this by clicking “edit type” in the left hand menu. Once we had the right size we were planning to use in our design, the next step was to place them in place. We elaborated a map with all the footing and drilled shaft locations (section 3.4). With the use of this map, and the gridlines as a reference, we were able to set the proper footings in the locations were we wanted them to be.

The drilled shaft footings weren't available in Revit, so we had to load them from the internet by clicking in the "Insert" tab in the main menu at the top of the screen and then getting a search bar. We used this same procedure of loading elements for other elements that were very specific and weren't found in the Revit object Library.

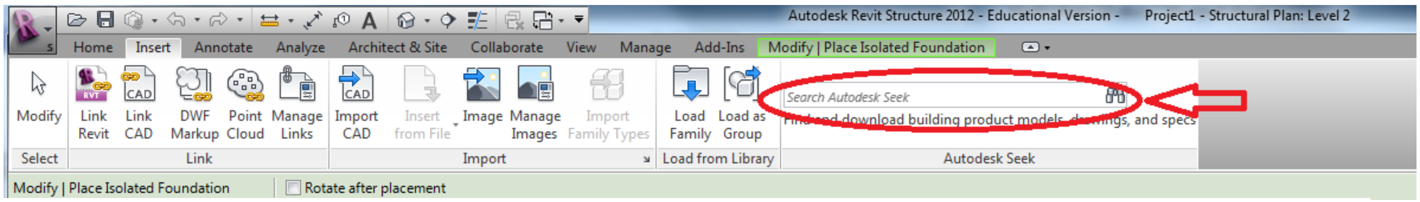


Figure 4-9 Revit: Main menue, Seach Elements on line, Source: Revit

This figure (4.10) shows in details the outcome of interpolation of the soil layer. We got this beautiful 3-dimensional soil profile in which we were able to see in details the soil component's, the lightest layer closer to the surface represents the fill component's, the middle layer represents the glacial till, and the inner layer represents the bed rock.

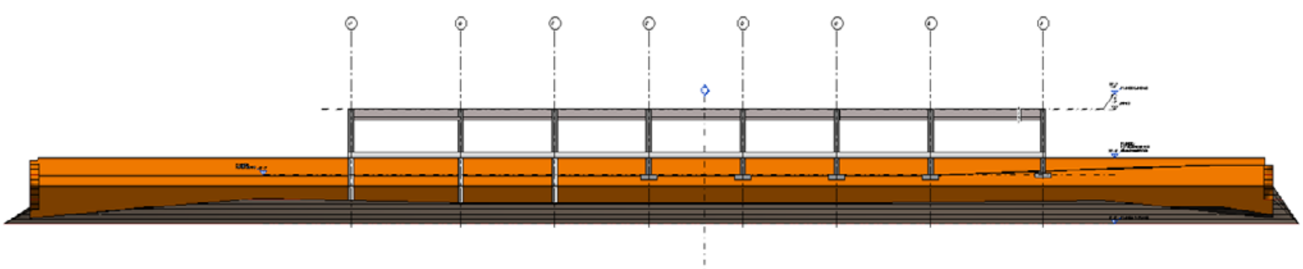


Figure 4-10 Revit: View of elevation with soil detail view, Source: Revit

4.5 Building up the Structure

After completing the foundation, it was possible to build up our model from there. We started by adding square size concrete columns (12”x12”) that we also had to estimate because of the lack of information about the structure (You can see section 3.2 for more details about the sizes pre-dimension).

These columns were precast, and they weren’t available in the Revit library. We imported these columns importing them from the web, using the procedure we previously showed for the drilled shafts. We used the gridlines as references for the location of our columns.

Then we also had to estimate sizes for I beams and double tee-precast concrete beams that would go on top of this girders (section 3.2 shows in detail how this sizes were estimated)

We imported the precast I beams from the Revit web data base, we placer between the columns (this beams were necessary, because are going to be supporting the double tee beams and the rest of the weight that will go on top of them.

Figure 4-11 Revit: Main menu, Beam System, Source Revit

To insert the precast double tee beams, we just went to the home tab, and in the main menu at the top of the screen there is a button with the name Beam system, by clicking at it, it was very simple to place the beams in a very fast way.

After creating the structural frame, the model progressed quickly. We already had the most challenging part done and the only thing we had left was to perform an architectural design.

For performing an architectural design, we exported the drawing we had created in Revit Structural to Revit Architectural and then add all the architectural details.

To export the model from one software to the other, we just saved it as usual and then, open it in Revit Architecture

We had some schematics and information about architectural details from the actual athletic field- parking garage structure, however the final architectural design wasn't ready and the ones given to us weren't very detailed, so we came up with an architectural design similar to the given one but with some modifications.

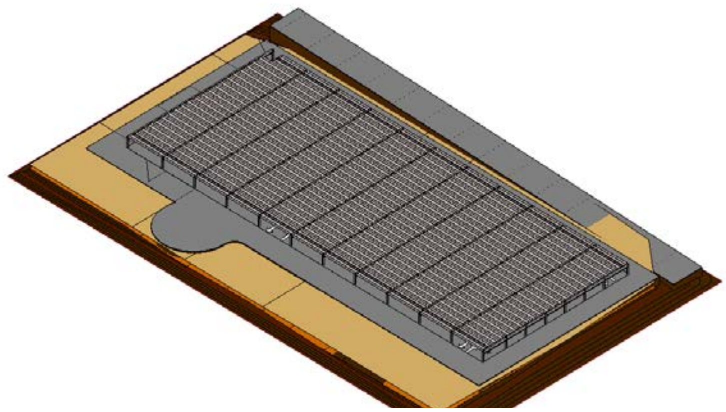


Figure 4.12 Structural elements , Source: Revit

Once we had the entire frame in place, we added a small 6 inches all around the perimeter of the parking lot except for the entrance, where we left open, to live some space to cars. We first select a wall from the basic tab and then set all the parameters of our wall. There are many different types of walls. For our model we choose a generic one, and the outside of it was brick. We also set the high of it to be 6 inches in the tab edit type.

The wall tab button was located in the home tab in the main menu.

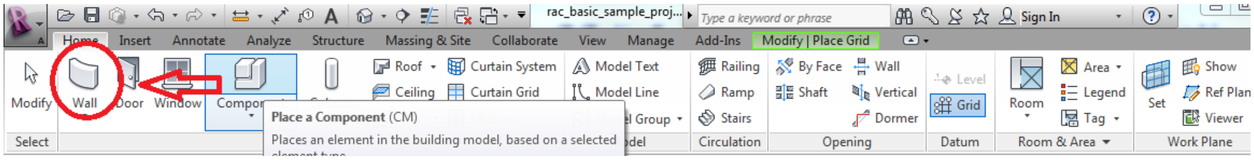


Figure 4-12 Revit: Main menu, Inserting Wall, Source Revit

The next part was to put on a slab. For doing this, we first go to the structural tab and look for the slab option. We poured the slab to the edge of the walls. Floors are available in the home tab in the main menu at the top of the screen.

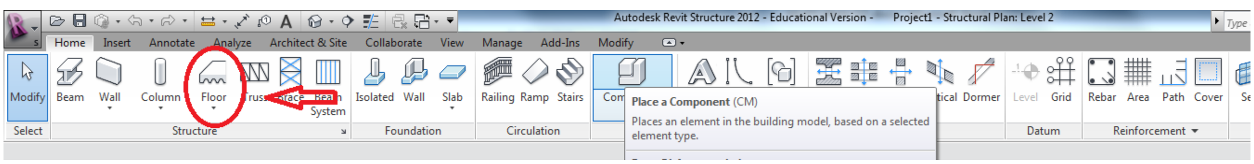


Figure 4-13 Revit: Main menu, Drawing floor, Source Revit

4.6 Finishes

Once the slabs were placed, windows and doors were put in place; we started working in the details. We had to import grass material for the Revit library online to make a turf Field. We also imported the lines of a field, Stadium Lights and Seats to make it look more realistic.

The parking spaces were put in place following a draft drawing performed by SMMA designers and following Massachusetts Building Code specifications for lines, parking space size and handicap spaces.

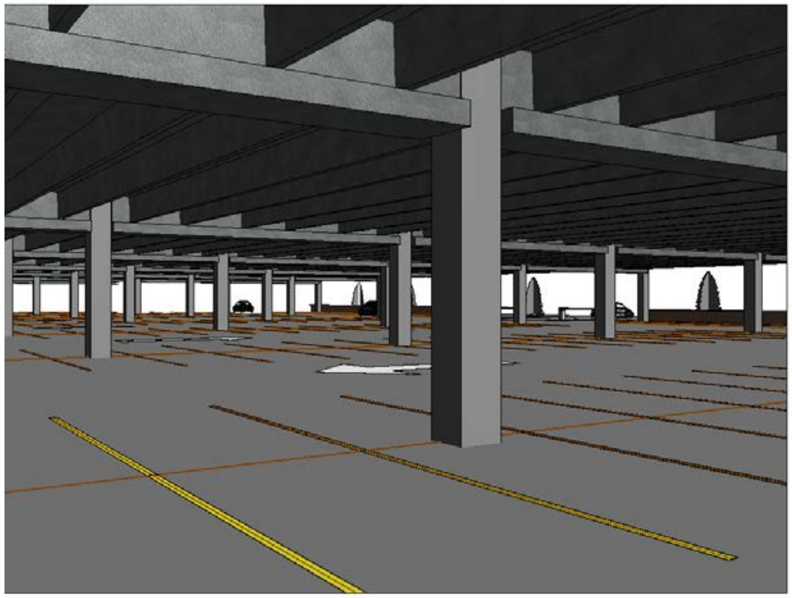


Figure 4-14 Revit: Internal view of the Parking Lot

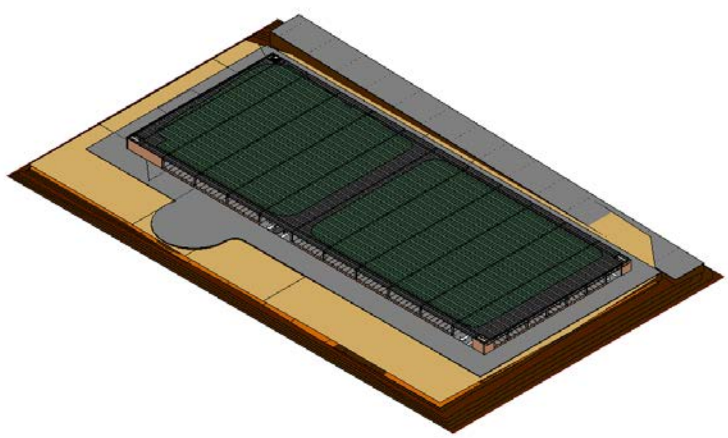


Figure 4-15 Revit: Structure With concrete and Turf

In figure 4.16 we can observe a picture of the Model finalized using Revit.

4.7 Summary of 3D Model

Using Revit for creating a 3D model of our design, was a great learning experience, it also helped us to understand better important aspects of this project. We were able to have a better view of the foundations and the soil layers.

This tool also helped us to account for the amount of materials needed, a very important part in the cost estimate of the project. The cost estimate shown in the methodology of this MQP was performed by hand calculations and by the used of spreadsheets, however, we also accounted for quantities of materials using Revit.

The design shown in figure 4.16 is the final outcome of our 3D model using Revit, we made a couple of adjustments to the actual model, adding small soccer courses, since we realized than varsity soccer already takes place in the big field in front of the new Athletic and Recreational Center.

We also added sand and some grass to the infield part of the softball field, in reality this won't look like this, since this is going to be turf (artificial grass).

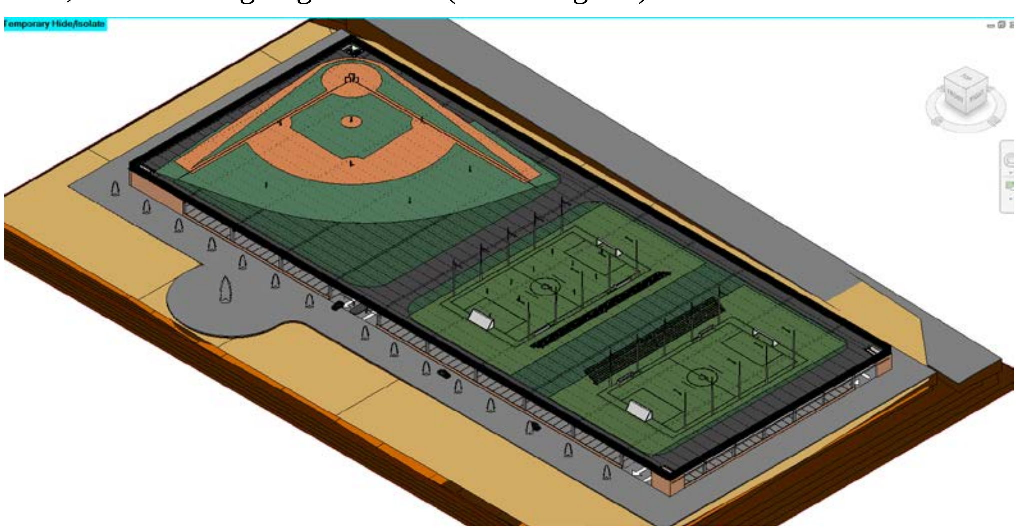


Figure 4-16 Revit: Finalized model

4.8 Work Break down Structure

A work Breakdown Structure helps a lot to organize the different activities than need to be done prior to the project completion; this is very useful to estimate the time for competition of a project.

When our MQP started, the actual project performed by Gilbane was only in its initial stages, Meetings were still going to discuss about the design and they were still waiting for final approvals by the WPI board of trustees in order to be able to continue.

Since the project wasn't approve, scheduling information was very general, they just had a draft with a list that only had 20 activities with the actual time and date.

For scheduling in or MQP project, we took the twenty activities given to us by Gilbane, and we put them together using PRIMAVERA. We had dates for these activities. All these activities given to us were activities about the initial stages of the project, meetings and permits. Activities about the actual construction project weren't given to us since must of the actual information was missing.

We divided the project in many other different activities and based on previous completion times in other projects that Gilbane performed in the past, we came up with some estimation about the time of completion of each of these activities.

Then we put the all together in PRIMAVEA, add all the information related to the dates and time for completion of each of them. In order to perform a schedule linking all the activities, we first created a hand draft design of the schedule, linking all those activities that where related, making sure that the schedule was going in a logical sequence and that none of the activities will start beforehand.

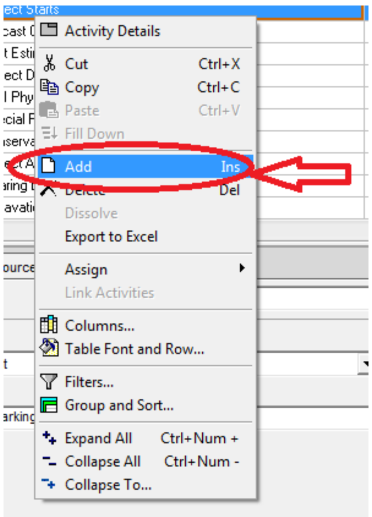


Figure 4-17 Primavera: Adding new Activity, Source Primavera

Activities are added to PRIMAVERA by right-clicking at the table located at the middle of the screen and by clicking “add activity”

We added all the activities one by one in the software, and the added the important information about them. Start time, end time, we could also add start times and durations for each of this activities and the software was able to compute the durations for us.

Since a lot of information was lacking, we had to come up with some estimations to place the duration for a lot of this activities.

Durations and starting times can be added just by clicking and tipping in the table

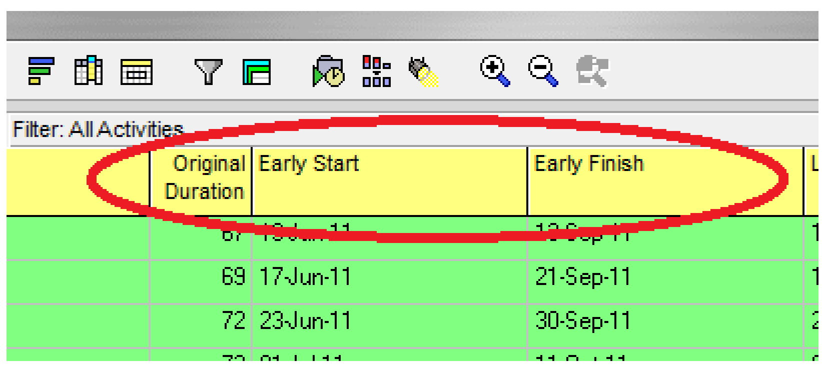


Figure 4-18 Primavera: Setting time, Source: Primavera

Once our draft design was completed, we were able to link al this activities in PRIMAVERA. After linking all this activities in PRIMAVERA, the software gave us two very important pieces of information for managing a construction project, a Gann chart and a Work breakdown structure of the activities showing the critical path method (results are located in section 4.2.10).

This two are very helpful for project managers to have a good visualization of the scheduling of the project and to make sure that everything is going on schedule.

PRIMAVERA also gave us the critical path, which is one of the most important pieces of information for manages when they don't want the project to have any dilate.

With the use of Microsoft Excel we produced a Lazy-S curve, doing a chart with two variables, money in the y-axis and time in the x-axis. This chart is very important for manager to visualize how money flows all along the project. Usually when a project starts it is very useful when comparing the actual money flow vs. the planned money flow, this helps to make sure that the money is flowing according to plan.

A better and more detail view of the Gann chart, the CPM and the Lazy-s curve can be visualize in our conclusions.

4.9 Cost Estimate

A cost estimate for the parking garage building was performed. Since the actual construction project hasn't started when we start performing our MQP, it was very hard to have an estimate for this building because most of the important information that we needed to estimate was missing. There was no information about the Size of all the members at first, so we had to calculate all the member sizes and characteristics by our self, in order to be able to perform this estimate.

Estimating was done two different ways, first the amount of materials where computed by hand, and they were also computed by the use of Building Information Modeling. Importing data from Revit to Microsoft Excel with all the quantities. Then Researched for market prices and proceed with the estimating process.

The main source we used to get our prices for the estimate was the Engineering software RS Means; we also obtained prices for some very specific details such as electricity and masonry from a table given to us by Gilbane. RS Means was really helpful for us because it gave us a huge list of prices; it is a database of prices so the searching process for each of these prices was relatively sheep.

In order to get a more accurate value for construction cost in Worcester, a City cost index was also applied to the prices. Since Worcester was not listed in this in the cost index list, we took Springfield, MA, which is a very close city so the costs will be very similar to those in Worcester.

4.9.1 Units of Quantity:

The quantity used to measure the concrete needed for construction is the Cubic Yard (CY).

In this project, all the steel we accounted for was rebar, the units we used in our cost estimate were linear inches. We first needed to have our design ready to compute the steel amounts we were going to need for the foundations.

The prices for double Tee beams were obtained in RS Means, in dollars per square feet; the prices for I beam were obtained in linear feet.

The prices for site works, landscape, turf, masonry, miscellaneous metals, waterproofing-rood, curtain all, painting, signage, Sports netting, elevators, plumbing, fire protection and electrical where were in dollars per square feet. Some of them obtained by RS Means and some others were given by Gilbane.

All these prices accounted not only the materials, but also an estimated labor and an estimated equipment cost to have a precise estimation.

4.9.2 Steel and Concrete Quantity Takeoff.

In order to perform a cost estimate, the first thing to do was to quantify all the materials needed for the Construction process.

In our Cost estimate, we first started by quantifying the amount of concrete. Since a great part of the concrete in our takeoff was precast, we divided the takeoff in two parts. We had precast concrete beams and Girders, and the remaining concrete (Foundations, columns, slab and walls) was a standard concrete with a compressive strength of 4000 psf.

We first calculated the concrete in the foundations. We had different sizes of shallow foundations as well as different sizes for deep foundations, we account first for the total volume of concrete in each of this foundations. To calculate the volume of concrete in each foundation, we calculated the general volume of the foundation, and the subtracted the volume of the steel. Then we add them all up we added a 10% more to the volume at the end, as a standard procedure to account for the waste material. The units for measuring the volume of concrete were Cubic yards (CY).

Once the volume of concrete was known for all the footings, all the volumes were added up, to get a total volume of concrete in foundations. To get the total volume of the shallow foundations, we calculated them as rectangular shapes, and to get the total volume of drilled shafts, we calculated them as cylindrical shapes. See Appendix D for more details about the concrete estimate.

Since we didn’t have initial information for the column size, we estimated a column size by the use of some equations and design parameters (you can see this with better details in the loads section). We came up with one column sizes, 12”x12” these columns were precast columns, and the price for them was obtained from RS means.

The slab dimensions were also estimated, so it was possible to calculate the volume easily, taking the slab as a rectangular volume we just multiply base times height.

For the precast double tee beams we calculated their quantity in Square Feet’s, since the prices for this elements where given in square feet by RS Means. This was very easy since we already knew the total area of the building.

The T beam inverted that were used as girders were quantify in linear ft.

A better and more detail explanation of the quantification of concrete can be obtained from Appendix E**.**

This structure is mainly a reinforced concrete structure. In the precast structural elements, the price wa already with the steel reinforcement accounted, so there was no need to account for it twice. For the slab and foundations we had to calculate the amount of rebar that was going to be needed for the reinforcement. The spreadsheets for the quantification of structural steel for the building can be found in Appendix E.

4.9.3 Takeoff for Other Activities.

It was a big challenge to find some of the values of our quantity takeoff. A lot of information about the project was missing and we weren't familiarized with RS Means at first. Gilbane gave us some information about the cost of some of this activities and the rest of them were obtained by us from the RS Means database. This search process took an extensive amount of time, since there were big lists of materials, a lot of them looked very similar and we needed to account for the most adequate ones to use the in our design. In section 4.10 we have the final outcome of all our takeoffs, and in Appendix E we have more detailed tables that will help to understand better the computations and steps followed to get the results.

4.10 Results Project Management (Cost Estimate, Scheduling and BIM)

Here we have a summary of the main outcomes we got by performing scheduling, cost estimate and the 3-dimensional model in Revit.

A 3-dimensional model with a schedule, a work break down structure and a cost estimate is what is known in Project Management as a 5-dimensional model.

4.10.1 Cost Estimate

One of the most important things inside the project management is the cost estimate, if it is not done properly, big amounts of money come into play and a bad estimate can bring bad consequences for the owner and for the construction management firm, making it possible to loose big amounts of money and ending with negative balances.

Deep Found	Concrete	Steel	Drilling	Total
Type1	$13,494.60	$27,945.00	$70,843.50	$112,283.10
Type2	$12,359.00	$25,650.00	$48,915.00	$86,924.00
Type3	$27,580.80	$56,160.00	$117,286.00	$201,026.80
Total Cost of Shafts	**$53,434.40**	**$109,755.00**	**$237,044.50**	**$400,233.90**

Quantity Takeoff Shallow

Shallow Foundation	Concrete	Steel	Excavation	Total
Type 1	$7,420.50	$9,266.40	$21,900.00	$38,586.90
Type 2	$9,622.00	$21,331.20	$21,763.00	$52,716.20
Total Cost of Shallow	**$19,429.30**	**$9,266.40**	**$43,663.00**	**$91,303.10**

Figure 4-19 Summary detail Price Shallow and drilled shaft

Description	Takeoff Quantity	Total Cost/Unit	Total $ amount
General Requirements/ Site Service	172,000 sqft	1.35 /sqft	$232,200
Sitework & Building Excavation	172,000 sqft	28.87 /sqft	$4,965,640
Landscape	172,000 sqft	0.79 /sqft	$135,880
Turf	172,000 sqft	3.75 /sqft	$645,000
Masonry	172,000 sqft	1.16 /sqft	$199,520
Misc Metals	172,000 sqft	0.65 /sqft	$111,800
General Trades	172,000 sqft	0.90 /sqft	$154,800
Waterproofing-Roof	172,000 sqft	1.25 /sqft	$215,000
Curtainvall	172,000 sqft	1.95 /sqft	$335,400
Painting	172,000 sqft	0.72 /sqft	$123,840
Signage	172,000 sqft	0.24 /sqft	$41,280
Sports Netting	172,000 sqft	0.72 /sqft	$123,840
Elevators	172,000 sqft	0.47 /sqft	$80,840
HVAC/Plumbing	172,000 sqft	5.85 /sqft	$1,006,200
Fire Protection	172,000 sqft	0.89 /sqft	$153,080
Electrical	172,000 sqft	8.41 /sqft	$1,446,520
TOTAL			**$9,970,840**

Figure 4-20 Summary Price Activities

Figure 4.19 shows you the cost estimate for the foundation design, divided in drill shaft and footings. It shows in details the three outcomes of the steel, concrete and drilling takeoff for the shafts, and steel, concrete and excavation for the shallow foundations. In the other hand figure 4.21 shows you the cost estimate to the rest of the main activities in the project.

Total Estimation Prices	
	Cost
Drilled Shafts	$400,233.90
Shallow Foundations	$91,303.10
Precast Concrete	$3,236,000.00
Slab	$89,185.19
General Requirements/ Site Service	$232,200.00
Sitework & Building Excavation	$4,965,640.00
Landscape	$135,880.00
Turf	$645,000.00
Masonry	$199,520.00
Misc Metals	$111,800.00
General Trades	$154,800.00
Waterproofing-Roof	$215,000.00
Curtainvall	$335,400.00
Painting	$123,840.00
Signage	$41,280.00
Sports Netting	$123,840.00
Elevators	$80,840.00
HVAC/Plumbing	$1,006,200.00
Fire Protection	$153,080.00
Electrical	$1,446,520.00
Total Estimation Of Project	**$13,787,562.19**

Figure 4-21 Summary Estimated Price of Project

In the following figures we can see the results obtained from the Primavera software. 6.8 Figure 4.22 shows the linked activities with the critical path, which will help to organize the schedule. Figure 4.24 shows all the activities in the project with the start date and finish date, original duration, remaining duration, and schedule % complete. Figure 4.24 shows the Gantt chart (bar chart) with the time that will take each activity. Those activities that correspond to the critical path are represented in the Gantt chart with red arrows. Lazy-S

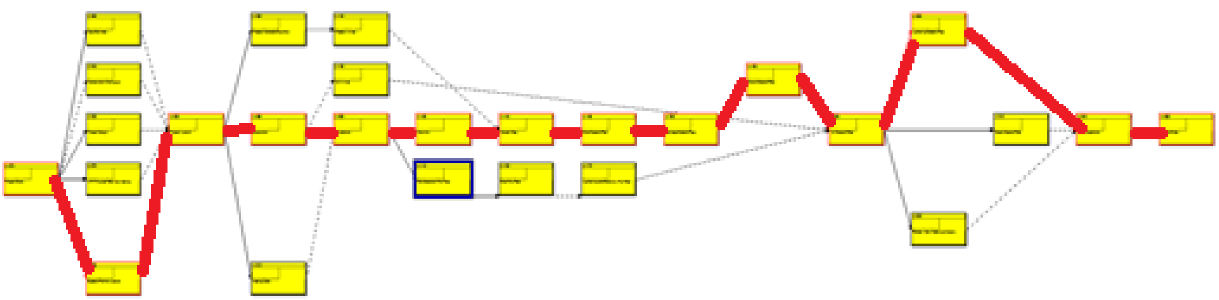


Figure 4-22 Primavera: Critical Path Method

(The activities that are part of the critical path were highlighted with red arrows)

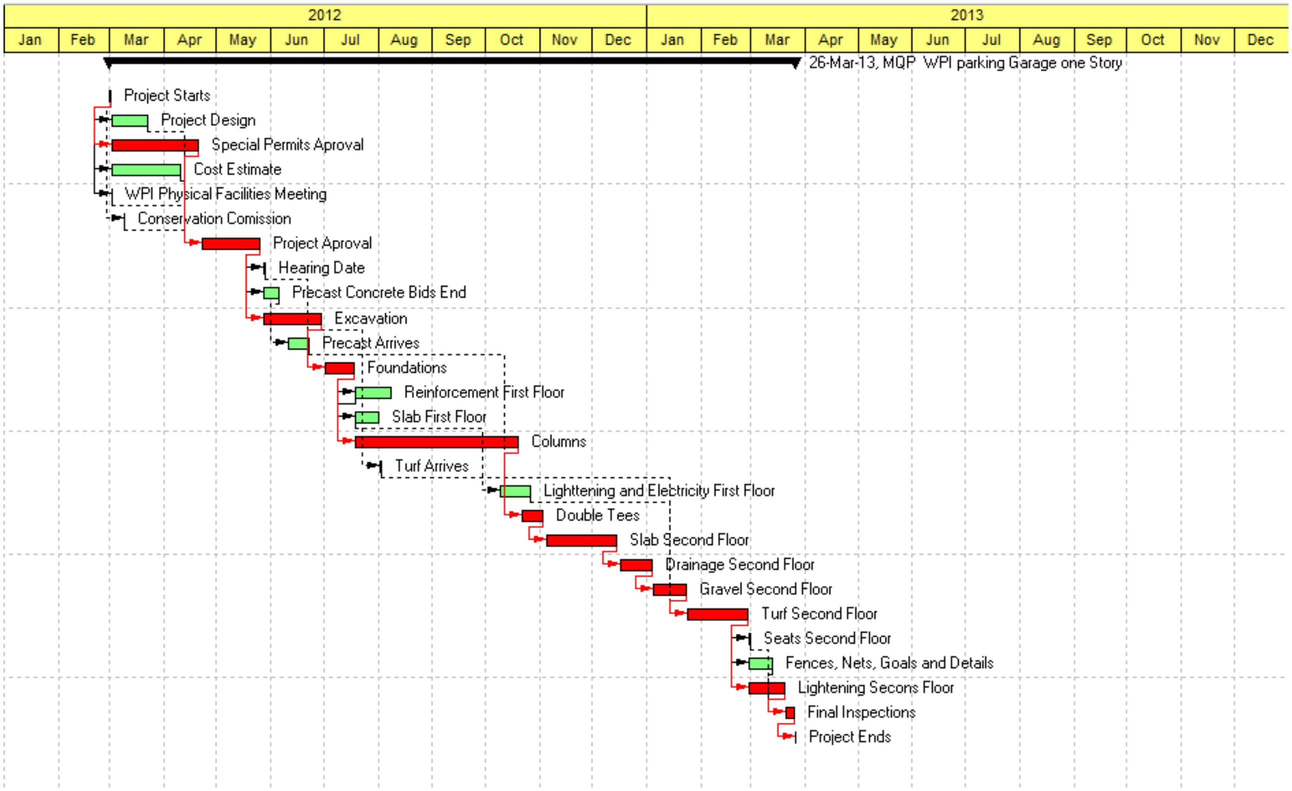


Figure 4-23 Primavera: Gantt Chart

This Gantt chart shows all the major activities we used in our schedule, in or scheduling we estimated March 26 2013 to be the time of completion of the project, Gilbane claims that the actual time of completion will be before January 2013, however we accounted in our estimate a long period of time for the placement in place of drilled shaft foundation system. Neither our estimate nor Gilbane's estimate aren't 100% acquired, since the project still under development. A lot of activities are to be determined and the bidding process hasn't finish.

Activity ID	Activity Name	Original Duration	Remaining Duration	Schedule % Complete	Start	Finish	Total Float
MQP WPI parking Garage oı		279	279	0%	01-Mar-12	26-Mar-13	0
A1270	Project Starts	1	1	0%	01-Mar-12*	01-Mar-12	0
A1020	Project Design	15	15	0%	02-Mar-12	22-Mar-12	21
A1030	Special Permits Aproval	36	36	0%	02-Mar-12*	20-Apr-12	0
A1060	Cost Estimate	28	28	0%	02-Mar-12*	10-Apr-12	8
A1070	WPI Physical Facilities Meet	1	1	0%	02-Mar-12	02-Mar-12	35
A1040	Conservation Comission	1	1	0%	09-Mar-12*	09-Mar-12	30
A1000	Project Aproval	25	25	0%	23-Apr-12*	25-May-12	0
A1010	Hearing Date	1	1	0%	28-May-12*	28-May-12	24
A1050	Precast Concrete Bids End	7	7	0%	28-May-12	05-Jun-12	88
A1080	Excavation	25	25	0%	28-May-12*	29-Jun-12	0
A1100	Precast Arrives	10	10	0%	11-Jun-12*	22-Jun-12	85
A1090	Foundations	13	13	0%	02-Jul-12*	18-Jul-12	0
A1110	Reinforcement First Floor	15	15	0%	19-Jul-12*	08-Aug-12	121
A1120	Slab First Floor	10	10	0%	19-Jul-12*	01-Aug-12	121
A1130	Columns	67	67	0%	19-Jul-12*	19-Oct-12	0
A1150	Turf Arrives	1	1	0%	02-Aug-12*	02-Aug-12	124
A1170	Lighttening and Electricity Fi	14	14	0%	09-Oct-12*	26-Oct-12	63
A1140	Double Tees	10	10	0%	22-Oct-12*	02-Nov-12	0
A1160	Slab Second Floor	30	30	0%	05-Nov-12*	14-Dec-12	0
A1180	Drainage Second Floor	14	14	0%	17-Dec-12*	03-Jan-13	0
A1190	Gravel Second Floor	14	14	0%	04-Jan-13*	23-Jan-13	0
A1200	Turf Second Floor	25	25	0%	24-Jan-13*	27-Feb-13	0
A1210	Seats Second Floor	1	1	0%	28-Feb-13*	28-Feb-13	14
A1220	Fences, Nets, Goals and De	10	10	0%	28-Feb-13*	13-Mar-13	5
A1230	Lightening Secons Floor	15	15	0%	28-Feb-13*	20-Mar-13	0
A1240	Final Inspections	3	3	0%	21-Mar-13*	25-Mar-13	0
A1250	Project Ends	1	1	0%	26-Mar-13*	26-Mar-13	0

Figure 4-24 Primavera: Lis of Activities with detailed times

With all the activities organized, we divided the project in phases; we used Revit, and performed the following 4-D model. In this model viewers have a better detail view of how the project is going to sequentially progress in different construction phases.

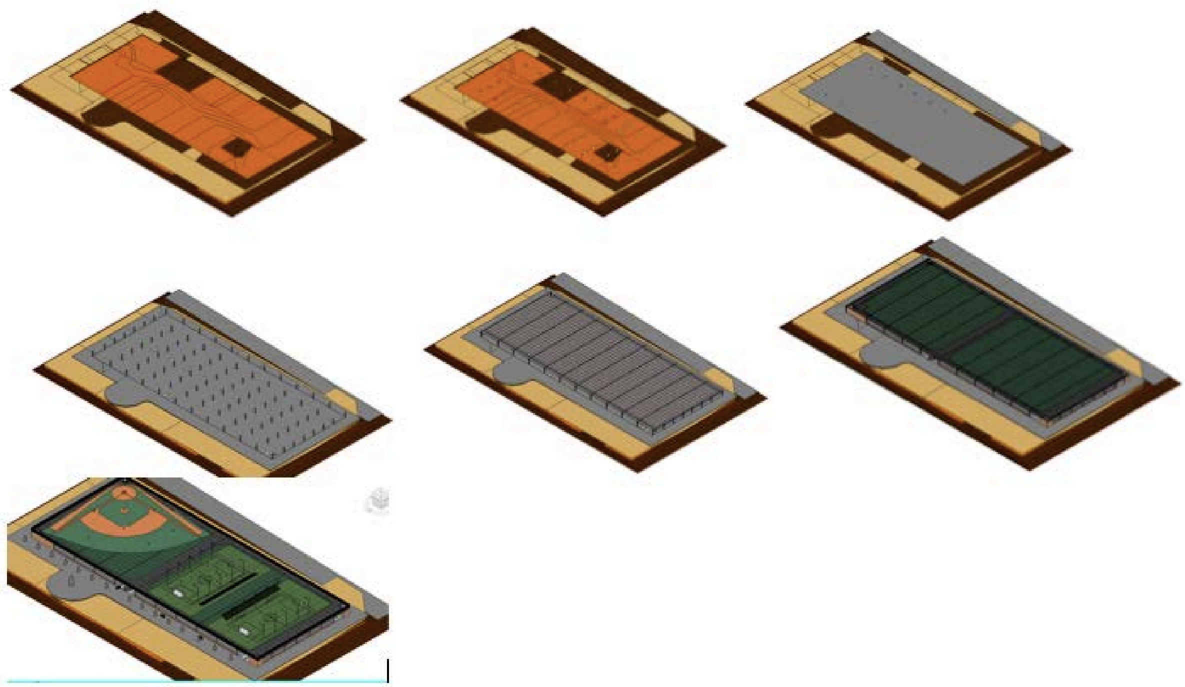


Figure 4-25 Work Breakdown Structure by phases (4D Model)

Figure 4.25 show how we performed a 4D model using Revit and the scheduling information. This is a very helpful method for project managers because it helps them visualize how activities are going to be taking place in a logical sequential order. A 4D model helps managers, owners and subcontractors to understand better how everything is assemble, it improves the communication, reduce mistakes saving money and time. When construction starts, it also helps to analyze and compare the actual vs. the planed schedule and determine whether the project is being performed on time or not.

4.10.2 Cost Analysis (Lazy-S Curve Discussion)

This section of the project will discuss the results obtained from the cost estimate.

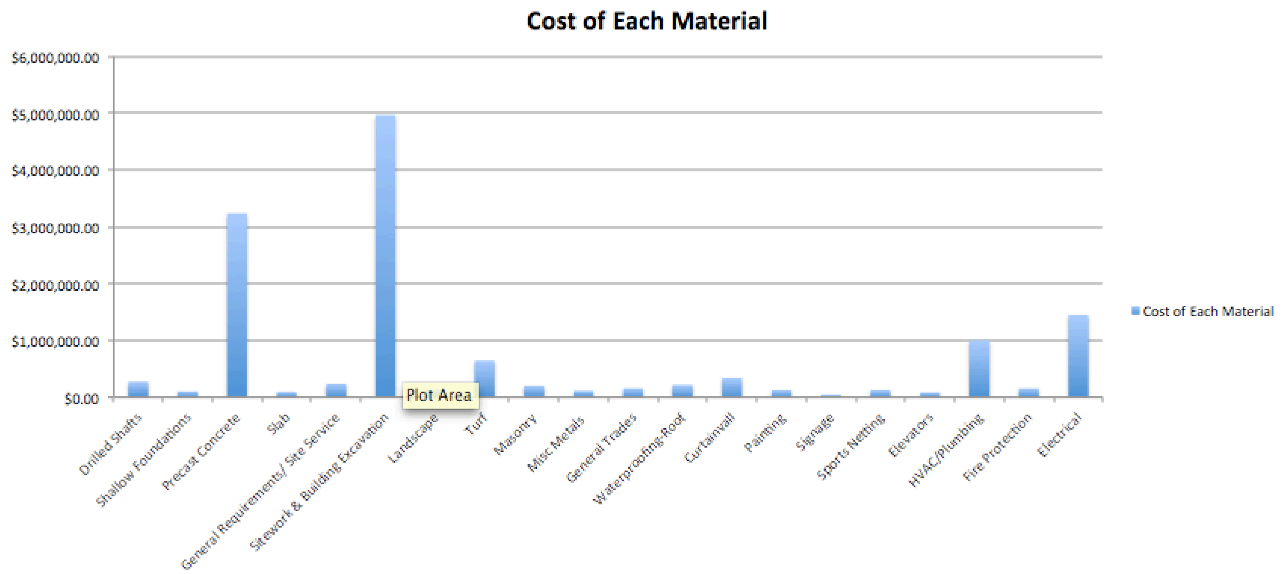


Figure 4-26 Chart Comparing Prices of Major Activities

Figure 4.26 shows the different activities that will be performed on the project, with the price of each activity, compared in bar chart form. This is very helpful, because it allows managers and owners to have a better idea of how the money is being spent. Which activities represent the biggest percentages in the planed budgets, and which budgets could be reduced for profit maximization in the case of managers.

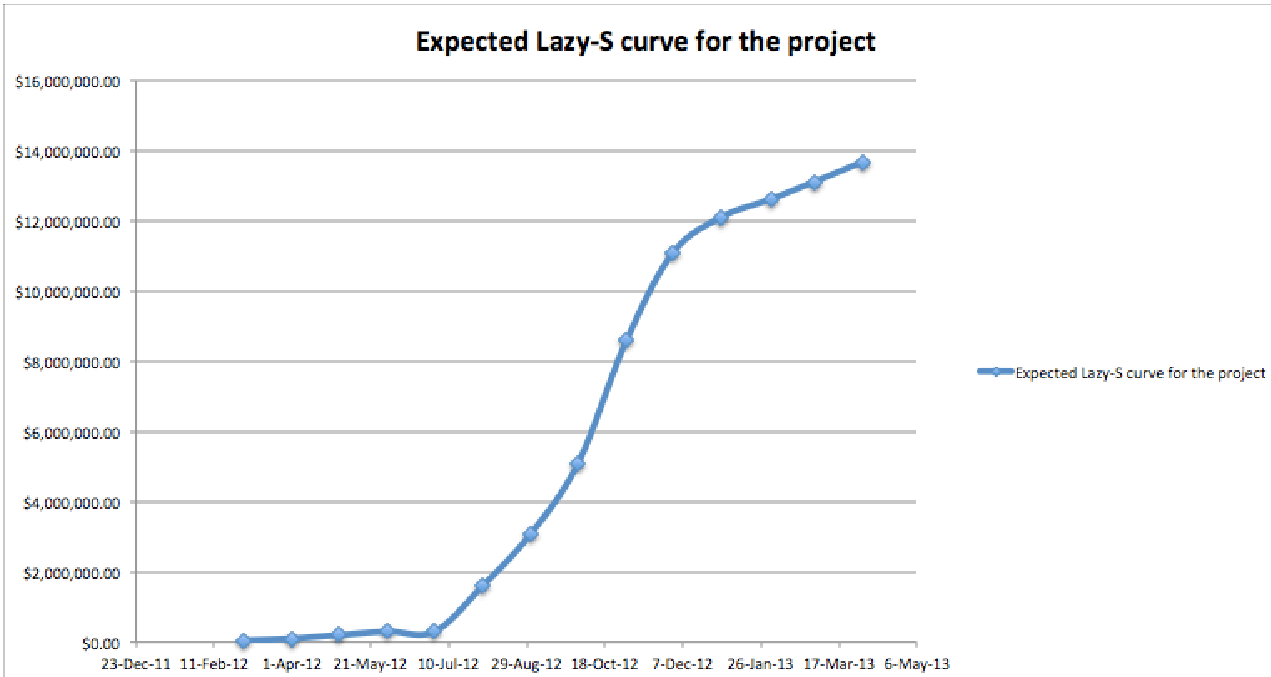


Figure 4-27 Projected Lazy-S Curve for Parking Garage

The lazy-S curves, helps to have a good estimation about how the project budget flow.It can be vizualise from figure 4.27 how most of the cash is injected to the project in the middle phase, this is very helpul as well for managers and owners, because it helps to vizualize how much money needs to be injected into the project in different time periods. It is also used to compared the actual vs the planed chash flow to prevent projects to go above or bellow the planed budget.

5 Conclusions and Recommendations

Since this project focus in two different areas of Civil Engineering, we divided the conclusions section in two parts, one part for soils, and foundations and another part for BIM scheduling and cost estimate.

Geotechnical conclusions (Soil Analysis and Foundations)

- ✓ Soil reports provide very important information that needs to be considered before starting a project.
- ✓ It is very important to account for settlement and bearing capacity in a foundation design, of them governs the size of the footing.
- ✓ Shallow foundations are used in stronger soils with more homogeneity.
- ✓ If soils are not homogenous, a lot of fill material is present and the bedrock deposits are very deep it is recommended to have deep foundation designs.
- ✓ A drilled shaft foundation system has a better performance than a PIFs system, however it account for more materials and is PIFs are more economical.
- ✓ Fill materials cause negative friction on drilled shaft foundations.
- ✓ From our research, we also concluded that is not recommended by most geotechnical engineers to preform dual foundation design. Deep foundations and shallow foundations tend to behave in different ways, especially with vibration and toil movements. If a dual foundation system is going to be implemented, the structure should be separated at some point so the different behaviors don't damage the building.
- ✓ Settlement in drilled shaft foundations is very small and is not significant most of the times.

BIM, Cost Estimate and Scheduling:

- ✓ Scheduling is very helpful to improve efficiency and organize a project development. PRIMAVERA is a very powerful tool that allows schedule in a very efficient and sophisticated way.
- ✓ A lazy-S curves, helps to have a good estimation about how the project budget flow.
- ✓ A lazy-S curve is very helpul to vizualize how much money needs to be injected into the project in different time periods.
- ✓ A Lazy-S curve is very helpful to compared the actual vs the planed chash flow to prevent projects to go above or bellow the planed budget.
- ✓ Critical Paths are important to consider making sure that the time of completion is not affected.
- ✓ BIM can be used as a project tracking tool. Allowing owners and manager to visualize progress in a project and compare the actual progress vs. the planned progress.
- ✓ BIM can be used to evaluate contractors and managers performance.
- ✓ BIM helps to reduce errors giving a better visualization and improving communication, this has save millions of dollars in the construction industry, especially in the last few years, since the usage of BIM has increasing exponentially.

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Appendix A-Proposal

Proposal

In the last few years, Worcester Polytechnic Institute (WPI) has been going through an expansion process. This expansion has come by hand with an increase in the school population. Every year more faculty, staff and students are joining the Institution.

This fast growing process, which the school is going through, has brought more vehicles every year. There is a lack of parking and green spaces in the Worcester Polytechnic Institute campus area.

The WPI Board of trustees is considering many different alternatives to help solve this parking problem. One of the alternatives being considered consists of a parking garage with an athletic field on top of it. The parking garage will consist of a one floor garage with an approximated area of 174,400 ft^2 and capacity for 600 hundred vehicles.

The planned project site will be located at the northwestern corner of the Worcester Polytechnic Institute campus. The site chose for this project its bounded to the north with the First Baptist Church, the WPI football field and the Recreation Center to the south, to the east with the Higgins House and Harrington Auditorium, to the west by Park Avenue. The actual site it's a natural grass field and its been used as a softball, soccer and baseball field, the site is around 6 to 7 feet lower than Park avenue.

This Project has some design and construction challenges. Also due to the soil conditions of the site, this project will need a combined foundation design. The design need for this type of soil is a mix of Shallow Foundation for the strongest part of the site and a Deep Foundation for the weaker zone of the site.

Gilbane Construction Co. (Gilbane) has been studying many different alternatives, considering different possible designs looking for the best option that can be adjusted to WPI budget and desires. The school board of trustees has been working together with them, SMMA designer and Cardinal consultants in this project.

In this MQP project our main objective is to find the most effective way to satisfy the needs and requirements of the project with the most suitable design, in terms of cost and quality.

The construction industry is constantly changing in an effort to optimize the construction process, minimize material waste, decrease project cost, accelerate project completion, and very important, maximize communication between all parties involved. Also in this project analysis we are going to implement some of the most important and innovative project management's techniques using innovating software's like Autodesk Revit, which will allow us to design a three-dimensional model of the building. Then by introducing time, showing the progress of the work in each phase till competition, our 3D model becomes a 4D model. A 4D model can be very helpful to reduce timelines and make sure that the project is going on tract. BIM can also include money tracking in each phase of construction; this is very helpful for owners and manager because it allow them to have a better understanding of how money is being spent in the project.

These Major Qualifying Project tries to show the benefits BIM and it applications to many different areas of the project.

Project Background

The Parking Garage

Worcester Polytechnic Institute is going through a fast expansion process. School population (Students, Faculty and Staff) is growing very fast and there are needs for infrastructure updates.

This fast growing process has cause a shortage for parking on campus, and every day it is harder to find spot to park without having to wait and drive around for a considerable amount of time.

This came to the attention of the board of trustees, who start analyzing many different alternatives and that when the idea of constructing of a new parking garage came.

Many alternative locations and designs were study for this new project. There were many things that needed to be considered, such as the location of the parking, the city permits, the access to the building, the soil conditions and so on.

Gilbane and WPI representatives carefully analyzed together many alternative possibilities, after many discussions about many different solutions, two main designs where selected as possible solutions, a one-story garage and a two-story garage, both of them to be constructed where the WPI softball field is located, by Park Avenue.

After Many meetings, they analyze the Pros and the Cons of the two alternatives, to determinate which of them was better and more convenient for the school purposes. They were discussing whether a two story garage was to much for what the school really needed or not, or whether a two-story alternative might be needed in the future, with a one-story built first and another story a few years later. So then a new alternative design came into play, if a one-story design was going to be built with intentions for a second story latter on, they would need to consider bigger loads in their design, and at the same time build bigger columns and foundations that would had increased the cost of the project by a considerable amount of money.

These three possible alternatives were brought to the board of trustees and where carefully study by them in several meetings.

In January 2012, the WPI board of trustees approved for the design of a new Parking Garage. They decided to go with a one-story design, they considered that it was cheaper, easier to construct and that the view of Park Avenue will be damage with a large building in that location.

Gilbane Construction Company is currently working in a new athletic and recreational center that is locate next to the site of the garage, WPI realized that for their convenience this new project should start now that Gilbane is at the site. This will reduce a lot the cost of mobilization, especially for labor and materials.

Appendix B- Load Calculations

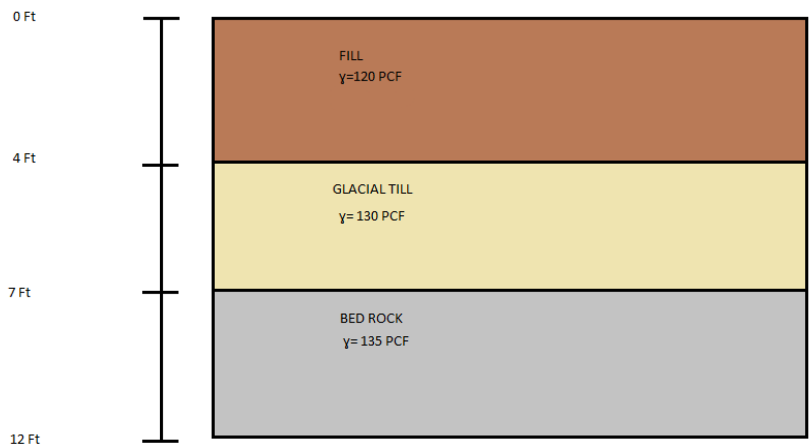
Column's Tributary Loads Summary Table (for one story Garage)																					
	First Level					Second Floor															
	Dimensions					Live Loads				Dead Loads					LOAD COMBINATIONS						
Columns	Side (X) Ft	Side (Y) Ft	Tributary Area (ft²)	Live Load (psf)	Dead Load (psf)	Live Load Second Foor (Psf)	Wind Load	Snow Load Second Floor (Psf)	Erthquacke Loads (psf)	Double Tee (psf)	Gravel (psf)	Girders psf	Columns Tributary Load (Kips)	Total Dead Load	U=1.4D	U= (1.2)Dl+(1.6)Ll+(0.5)Sl	U=1.2D+1.6W+0.5L+0.5S	U=1.2D + 1.6(S or R)+ (0.5 L or 0.8 W)	6. U= 0.9D ± (1.6W or 1.0E)	Governing Loads (psf)	**Total Load to Foundation (KIPS)**
A1	31.17	21.50	670.08	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**281.08**
A2	60.67	21.50	1304.41	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**539.78**
A3	59.00	21.50	1268.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**525.13**
A4	59.00	21.50	1268.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**525.13**
A5	59.00	21.50	1268.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**525.13**
A6	59.00	21.50	1268.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**525.13**
A7	59.00	21.50	1268.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**525.13**
A8	59.00	21.50	1268.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**525.13**
A9	59.00	21.50	1268.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**525.13**
A10	59.00	21.50	1268.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**525.13**
A11	58.50	21.50	1257.75	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**520.75**
A12	29.00	21.50	623.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**262.08**
B1	31.17	39.50	1231.08	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**509.87**
B2	60.67	39.50	2396.47	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**985.15**
B3	59.00	39.50	2330.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**958.25**
B4	59.00	39.50	2330.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**958.25**
B5	59.00	39.50	2330.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**958.25**
B6	59.00	39.50	2330.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**958.25**
B7	59.00	39.50	2330.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**958.25**
B8	59.00	39.50	2330.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**958.25**
B9	59.00	39.50	2330.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**958.25**
B10	59.00	39.50	2330.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**958.25**
B11	58.50	39.50	2310.75	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**950.20**
B12	29.00	39.50	1145.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**474.97**

Table continues in the next page

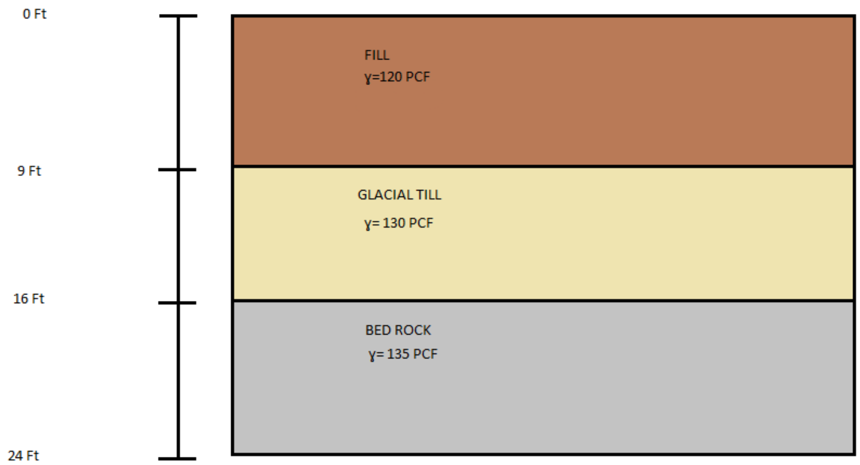
C1	31.17	36.00	1122.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**465.39**
C2	60.67	36.00	2184.12	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**898.55**
C3	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
C4	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
C5	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
C6	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
C7	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
C8	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
C9	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
C10	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
C11	58.50	36.00	2106.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**866.69**
C12	29.00	36.00	1044.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**433.58**
D1	31.17	36.00	1122.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**465.39**
D2	60.67	36.00	2184.12	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**898.55**
D3	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
D4	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
D5	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
D6	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
D7	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
D8	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
D9	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
D10	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
D11	58.50	36.00	2106.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**866.69**
D12	29.00	36.00	1044.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**433.58**
E1	31.17	36.00	1122.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**465.39**
E2	60.67	36.00	2184.12	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**898.55**
E3	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
E4	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
E5	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
E6	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
E7	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
E8	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
E9	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
E10	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
E11	58.50	36.00	2106.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**866.69**
E12	29.00	36.00	1044.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**433.58**
F1	31.17	36.00	1122.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**465.39**
F2	60.67	36.00	2184.12	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**898.55**
F3	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
F4	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
F5	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
F6	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
F7	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
F8	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
F9	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
F10	59.00	36.00	2124.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**874.03**
F11	58.50	36.00	2106.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**866.69**
F12	29.00	36.00	1044.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**433.58**
G1	31.17	39.00	1215.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**503.52**
G2	60.67	39.00	2366.13	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**972.78**
G3	59.00	39.00	2301.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**946.22**
G4	59.00	39.00	2301.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**946.22**
G5	59.00	39.00	2301.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**946.22**
G6	59.00	39.00	2301.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**946.22**
G7	59.00	39.00	2301.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**946.22**
G8	59.00	39.00	2301.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**946.22**
G9	59.00	39.00	2301.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**946.22**
G10	59.00	39.00	2301.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**946.22**
G11	58.50	39.00	2281.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**938.27**
G12	29.00	39.00	1131.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**469.06**
H1	31.17	21.00	654.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**274.73**
H2	60.67	21.00	1274.07	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**527.41**
H3	59.00	21.00	1239.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**513.10**
H4	59.00	21.00	1239.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**513.10**
H5	59.00	21.00	1239.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**513.10**
H6	59.00	21.00	1239.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**513.10**
H7	59.00	21.00	1239.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**513.10**
H8	59.00	21.00	1239.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**513.10**
H9	59.00	21.00	1239.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**513.10**
H10	59.00	21.00	1239.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**513.10**
H11	58.50	21.00	1228.50	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**508.82**
H12	29.00	21.00	609.00	40.00	75.00	100.00	11.00	33.00	157.00	62.62	74.37	37.04	7.80	174.03	243.65	385.34	276.44	311.64	407.83	**407.83**	**256.17**
Sum (Check)			**172604.22**																		

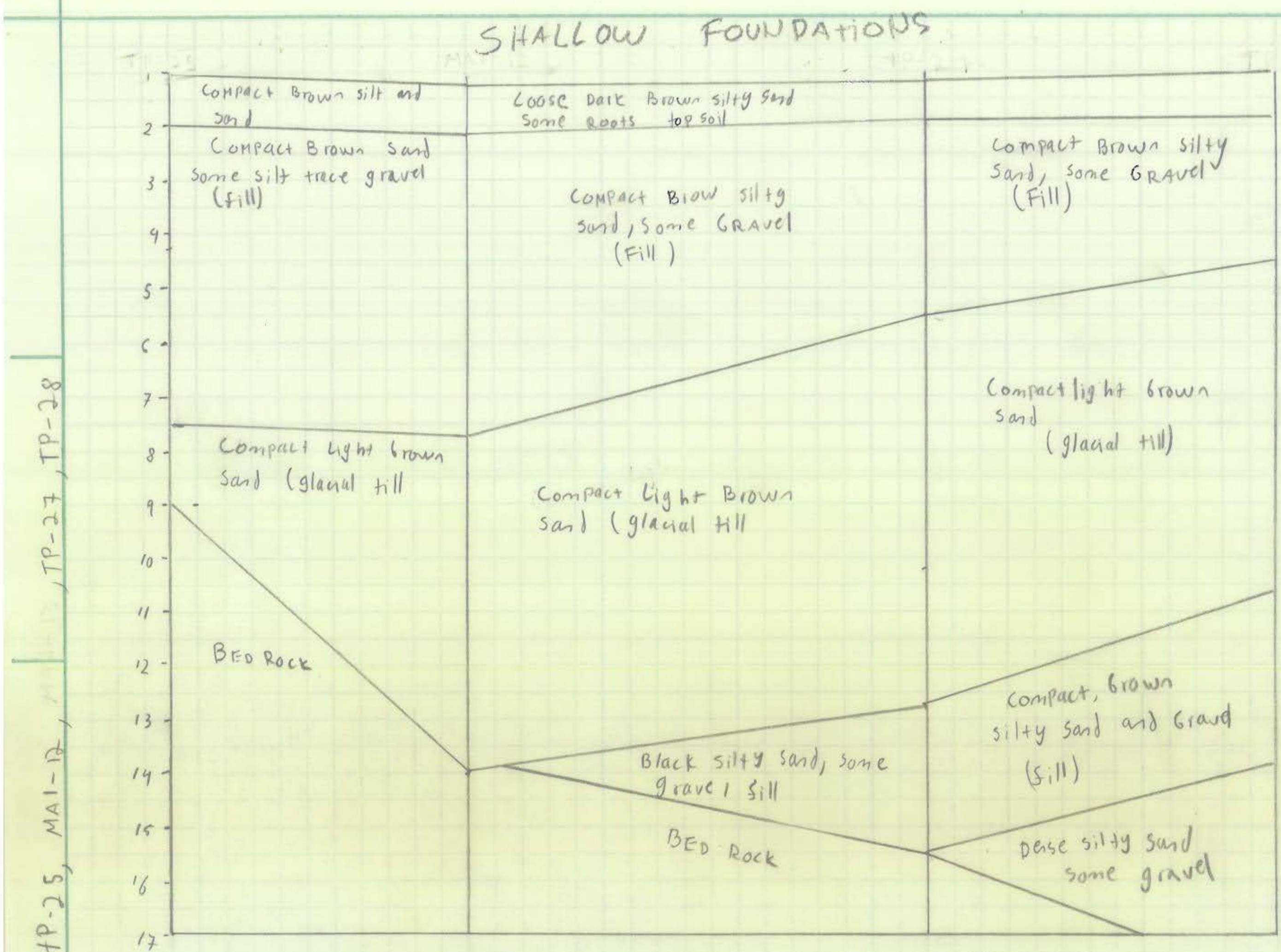
Appendix C-Soil Profiles

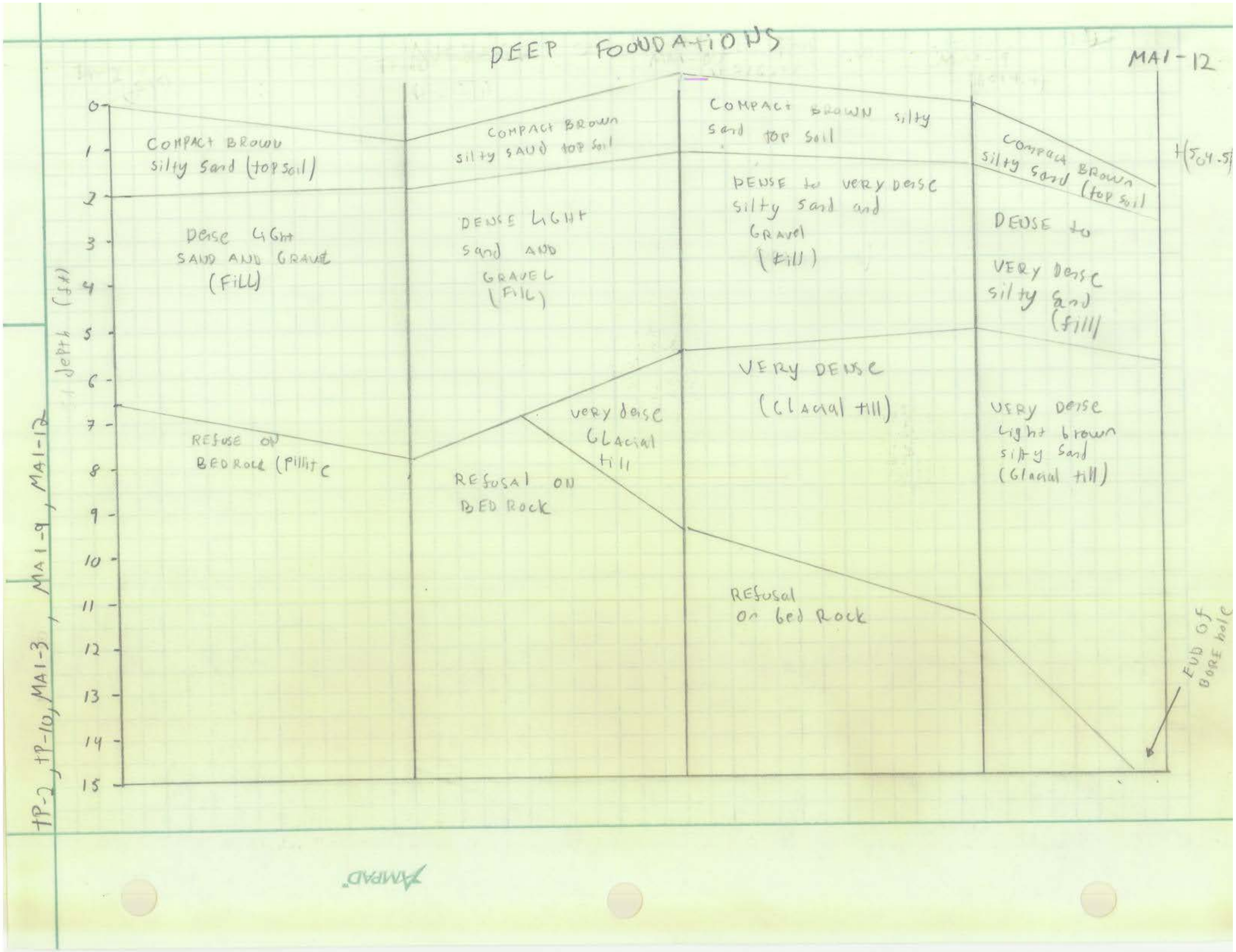
AVERAGE SOIL PROFILE FOR SHALLOW FOUNDATION

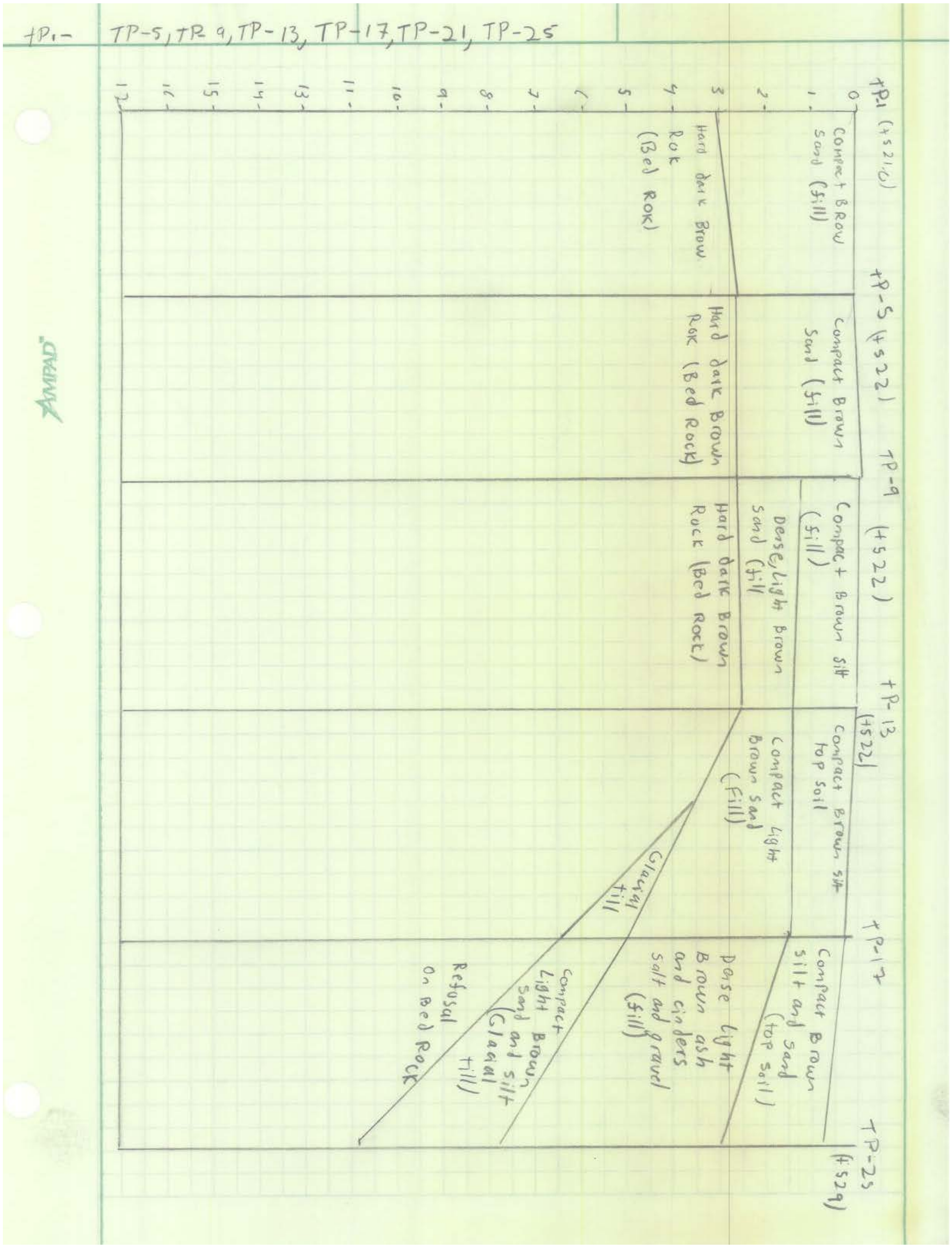


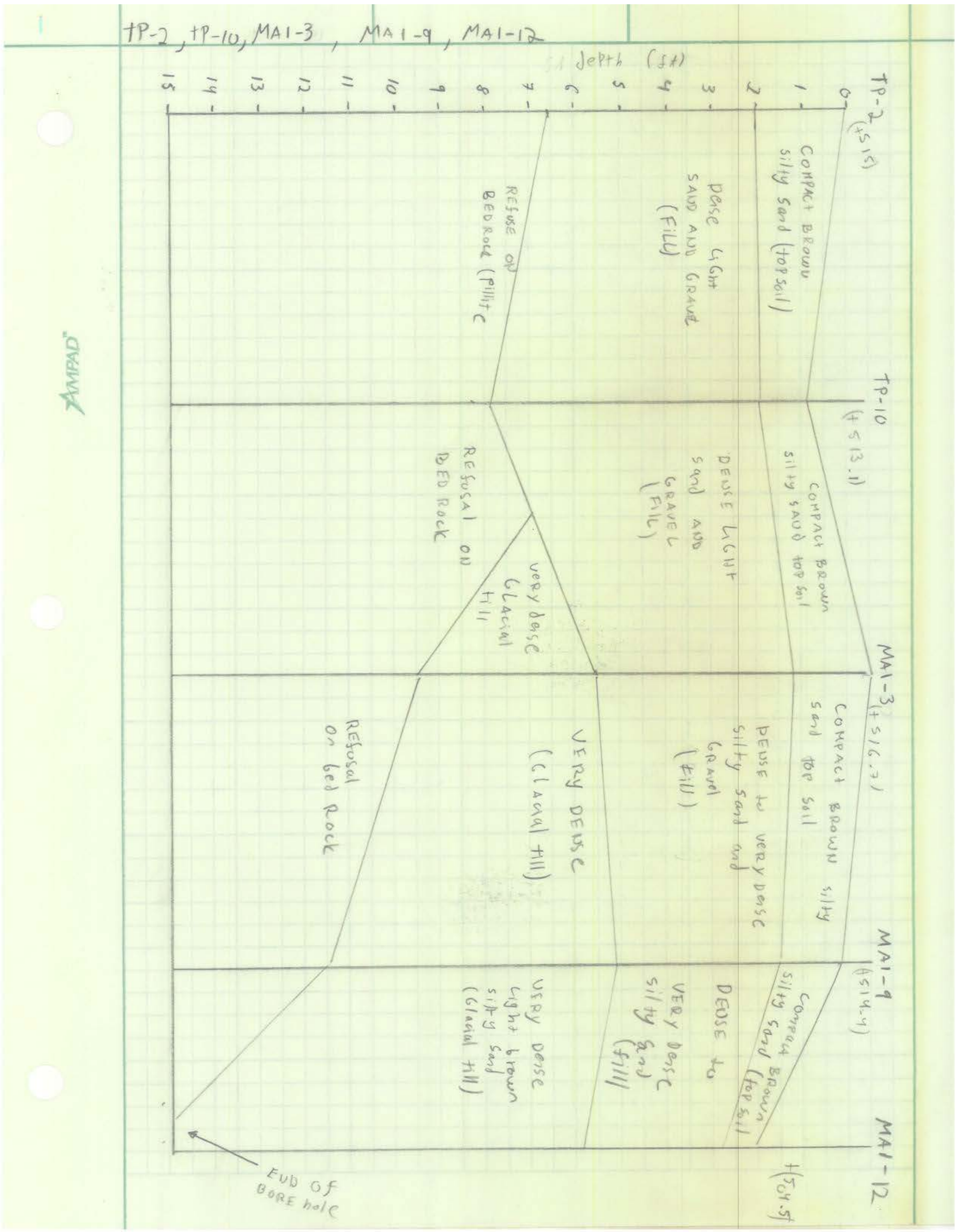
AVERAGE SOIL PROFILE FOR DEEP FOUNDATION



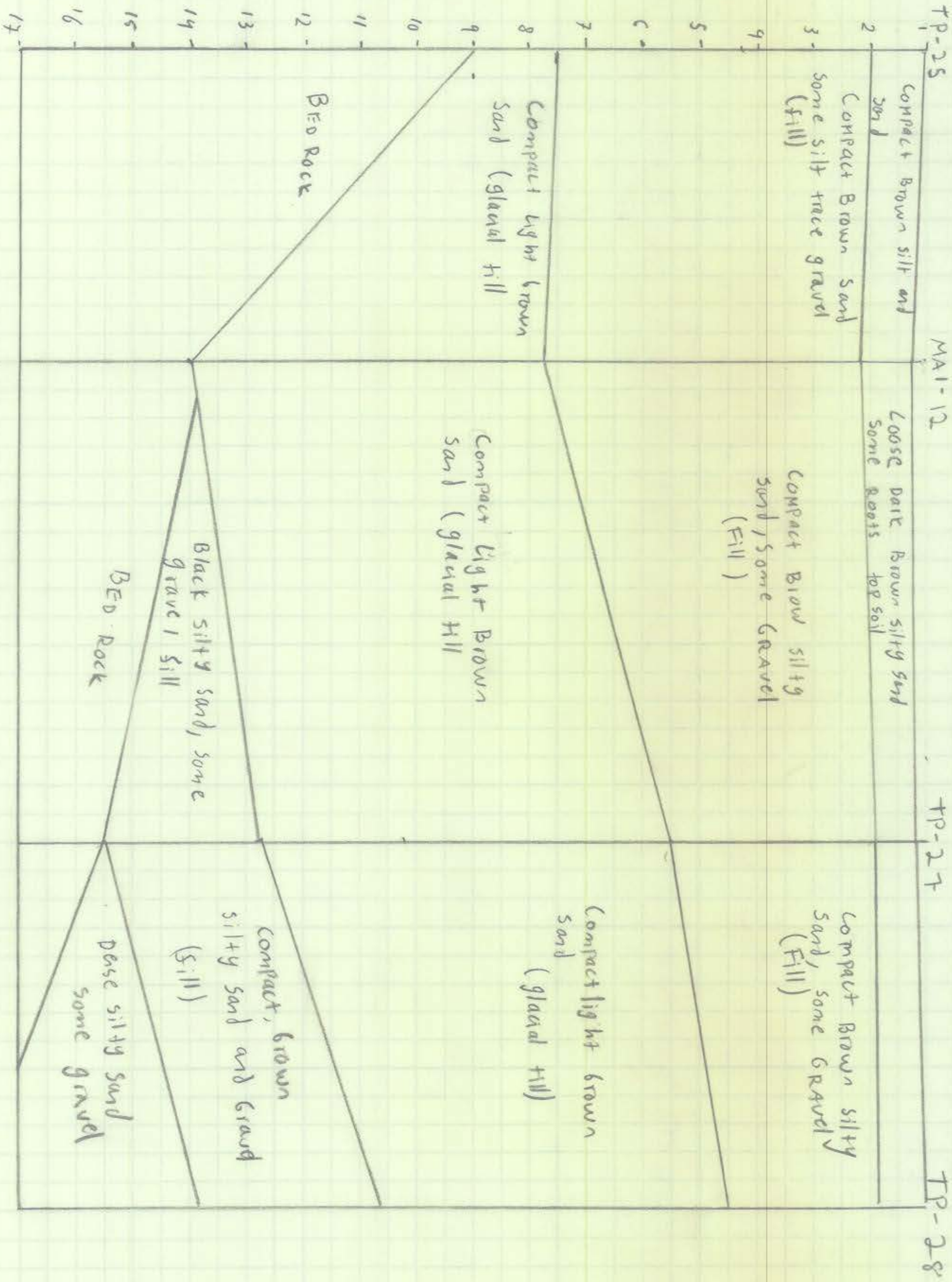

SHALLOW FOUNDATIONS
TP-25, MAI-12, TP-27, TP-28
Compact Brown silt and sand
Compact Brown Sand Some silt trace gravel (fill)
Compact Light brown Sand (glacial till
Bed Rock
Loose Dark Brown silty Sand Some Roots top soil
Compact Brow silty sand, Some Gravel (Fill)
Compact Light Brown sand (glacial till
Black silty sand, some gravel fill
Bed Rock
Compact Brown silty Sand, some Gravel (Fill)
Compact light brown sand (glacial till)
Compact, brown silty sand and Gravel (fill)
Dense silty sand some gravel


DEEP FOUNDATIONS
MA1-12
Depth (ft)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
COMPACT BROWN silty Sand (top soil)
Dense LIGHT SAND AND GRAVEL (FILL)
REFUSE ON BEDROCK (Pillit C
COMPACT BROWN silty SAND top Soil
DENSE LIGHT sand AND GRAVEL (FILL)
very dense GLAcial till
REFUSAL ON BED Rock
COMPACT BROWN silty Sand TOP Soil
DENSE to VERY DENSE silty Sand and GRAVEL (FILL)
VERY DENSE (GLAcial till)
REFUSAL On bed Rock
Compact Brown silty Sand (top soil
DENSE to VERY Dense silty Sand (fill)
VERY Dense Light brown silty Sand (Glacial till)
+(504.5)
END OF BORE hole
TP-2, TP-10, MA1-3, MA1-9, MA1-12
AMPAD

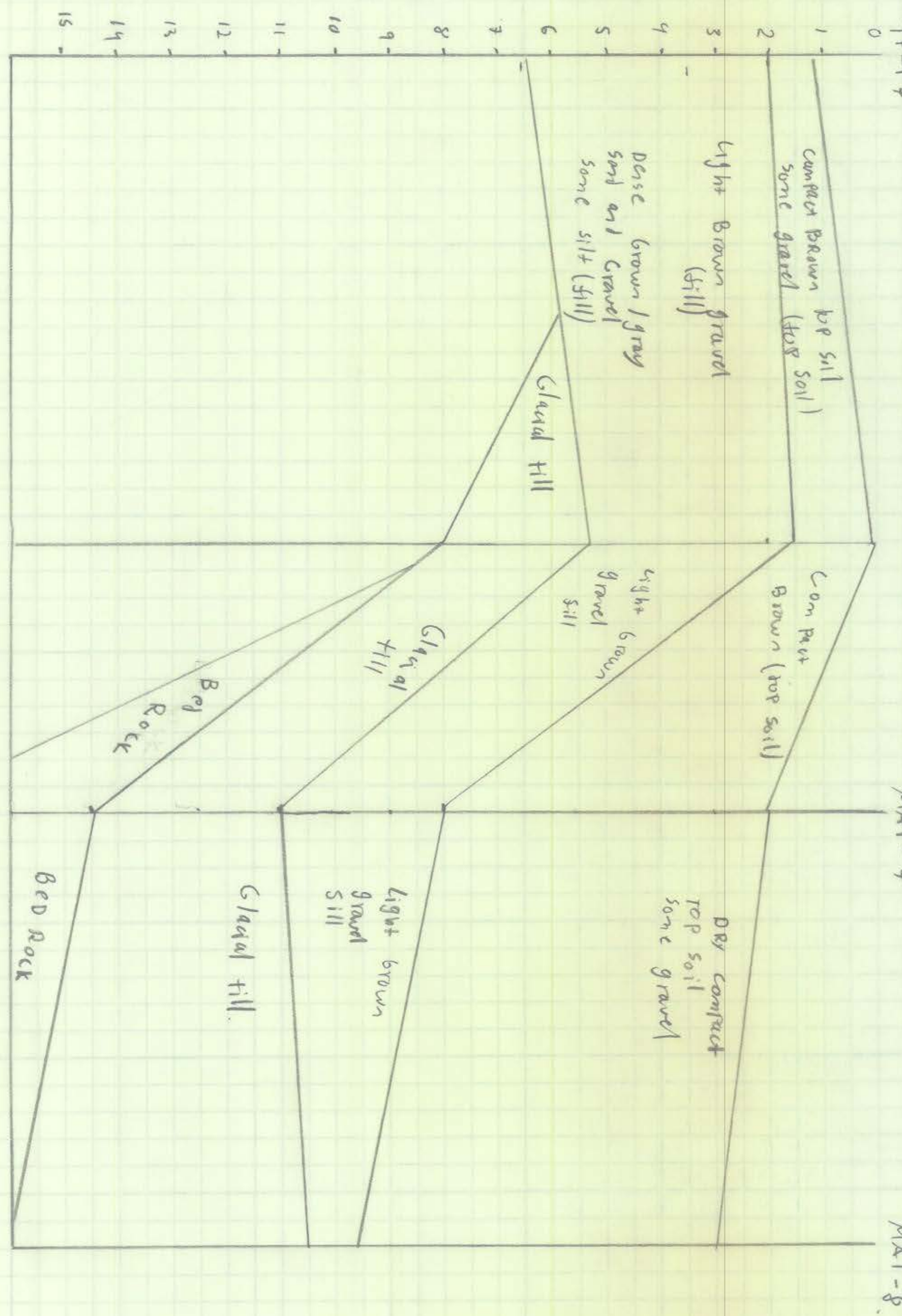

TP-1 TP-5, TP-9, TP-13, TP-17, TP-21, TP-25
TP-1 (+521.6)
Compact Brown sand (fill)
Hard dark Brown Rok (Bed Rok)
TP-5 (+522)
Compact Brown sand (fill)
Hard dark Brown Rok (Bed Rock)
TP-9 (+522)
Compact Brown silt (fill)
Dense, light brown sand (fill
Hard dark Brown Rock (Bed Rock)
TP-13 (+522)
Compact Brown silt top soil
Compact light Brown sand (fill)
Glacial till
TP-17
Compact Brown silt and sand (top soil)
Dense light Brown ash and cinders salt and gravel (fill)
Compact light Brown sand and silt (Glacial till)
Refusal on Bed Rock
TP-25 (+529)
AMPAD

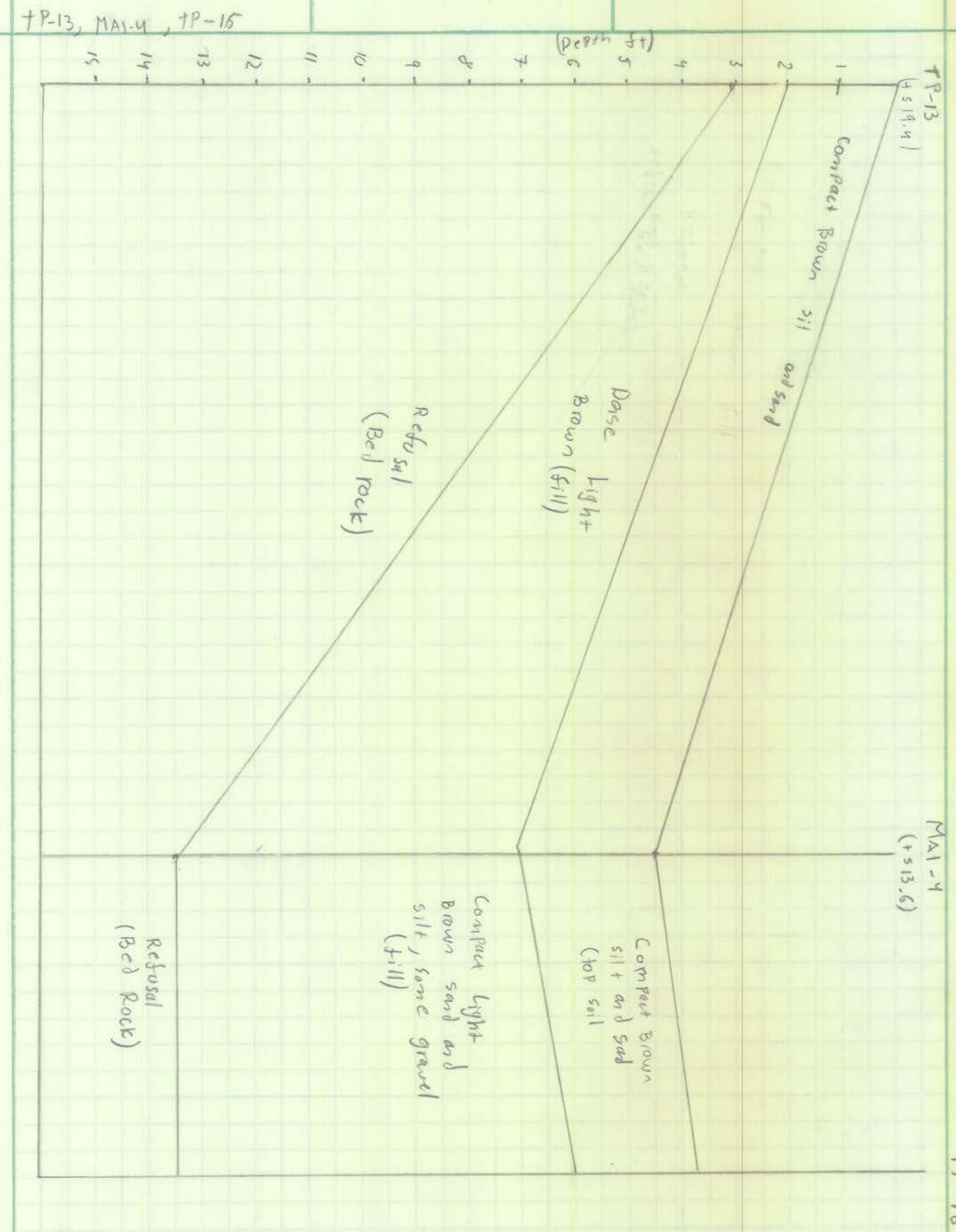

tP-2, tP-10, MA1-3, MA1-9, MA1-12
Depth (ft)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TP-2 (±515)
COMPACT BROWN silty sand (top soil)
DENSE LIGHT SAND AND GRAVEL (FILL)
REFUSE ON BEDROCK (PHILLITE
TP-10 (± 513.1)
COMPACT BROWN silty SAND top soil
DENSE LIGHT sand AND GRAVEL (FILL)
REFUSAL ON BED ROCK
very dense GLACIAL till
MA1-3 (± 516.7)
COMPACT BROWN silty sand top soil
DENSE to VERY DENSE silty sand and GRAVEL (Fill)
VERY DENSE (GLACIAL till)
REFUSAL on bed Rock
MA1-9 (± 514.9)
COMPACT BROWN silty sand (top soil)
DENSE to VERY DENSE silty sand (fill)
VERY DENSE light brown silty sand (GLACIAL till)
MA1-12 ±(504.5)
END OF BORE hole

tP-25, MA1-12, , TP-27, TP-28

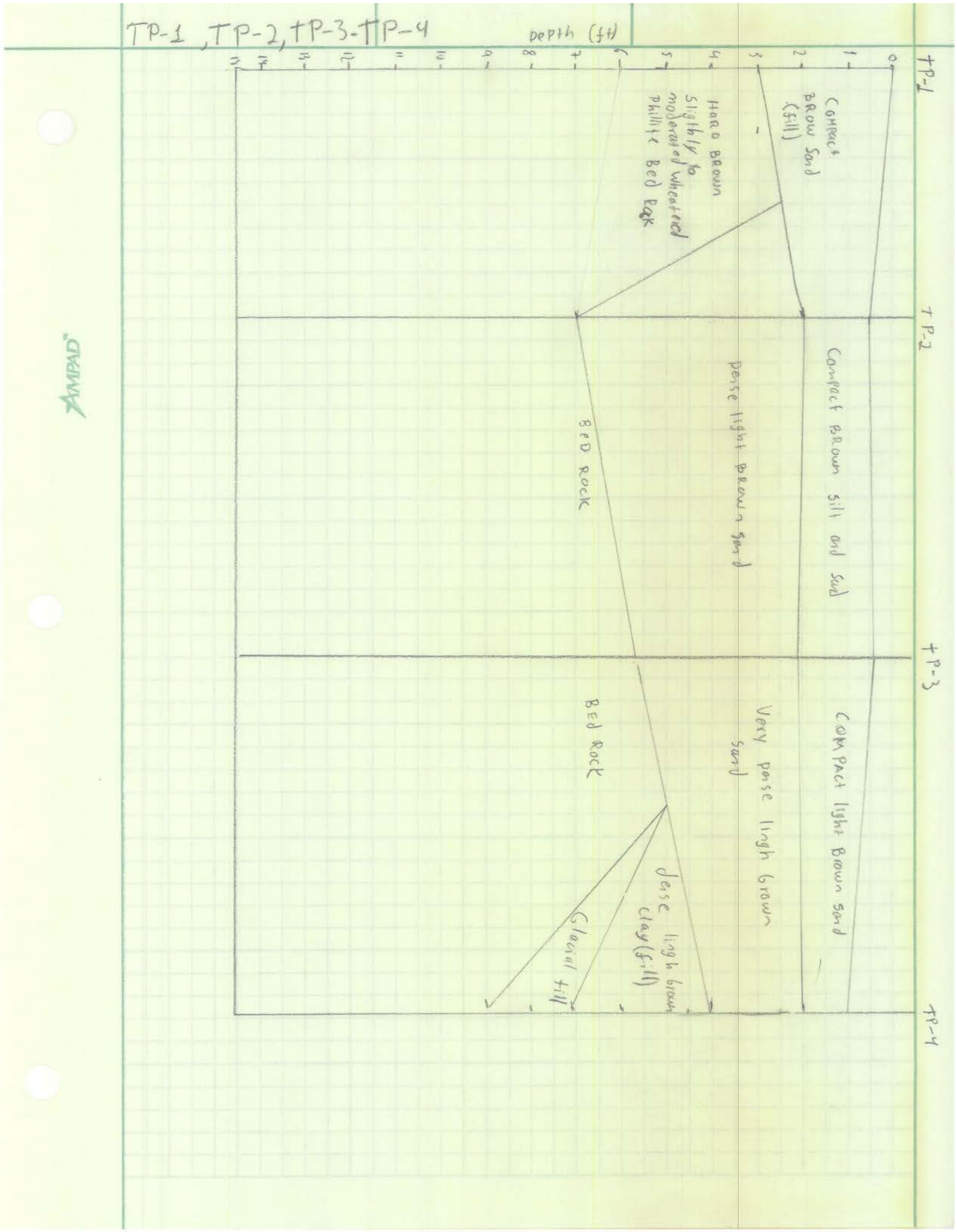


TP-17, MA1-6, MA1-7, MA1-8

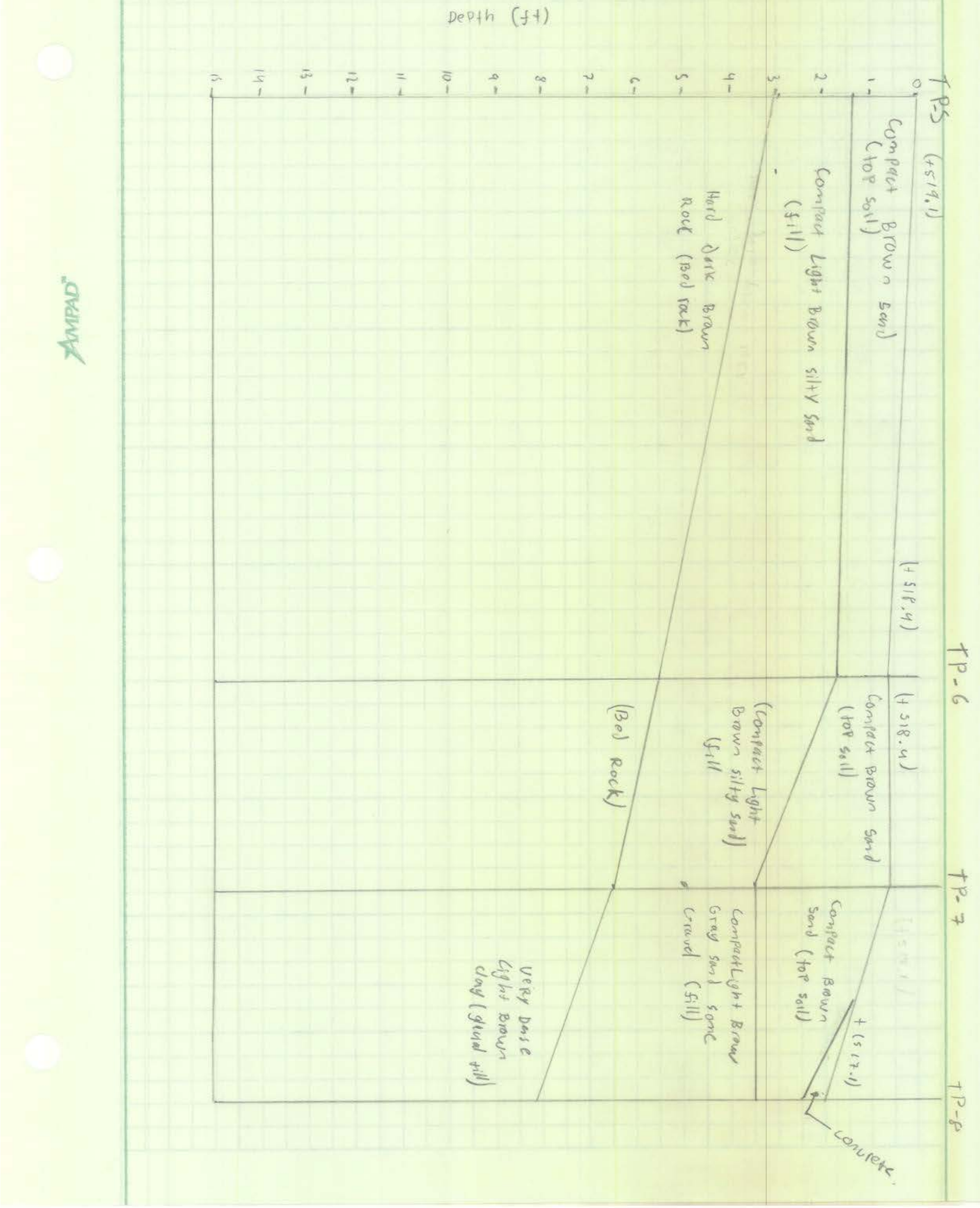


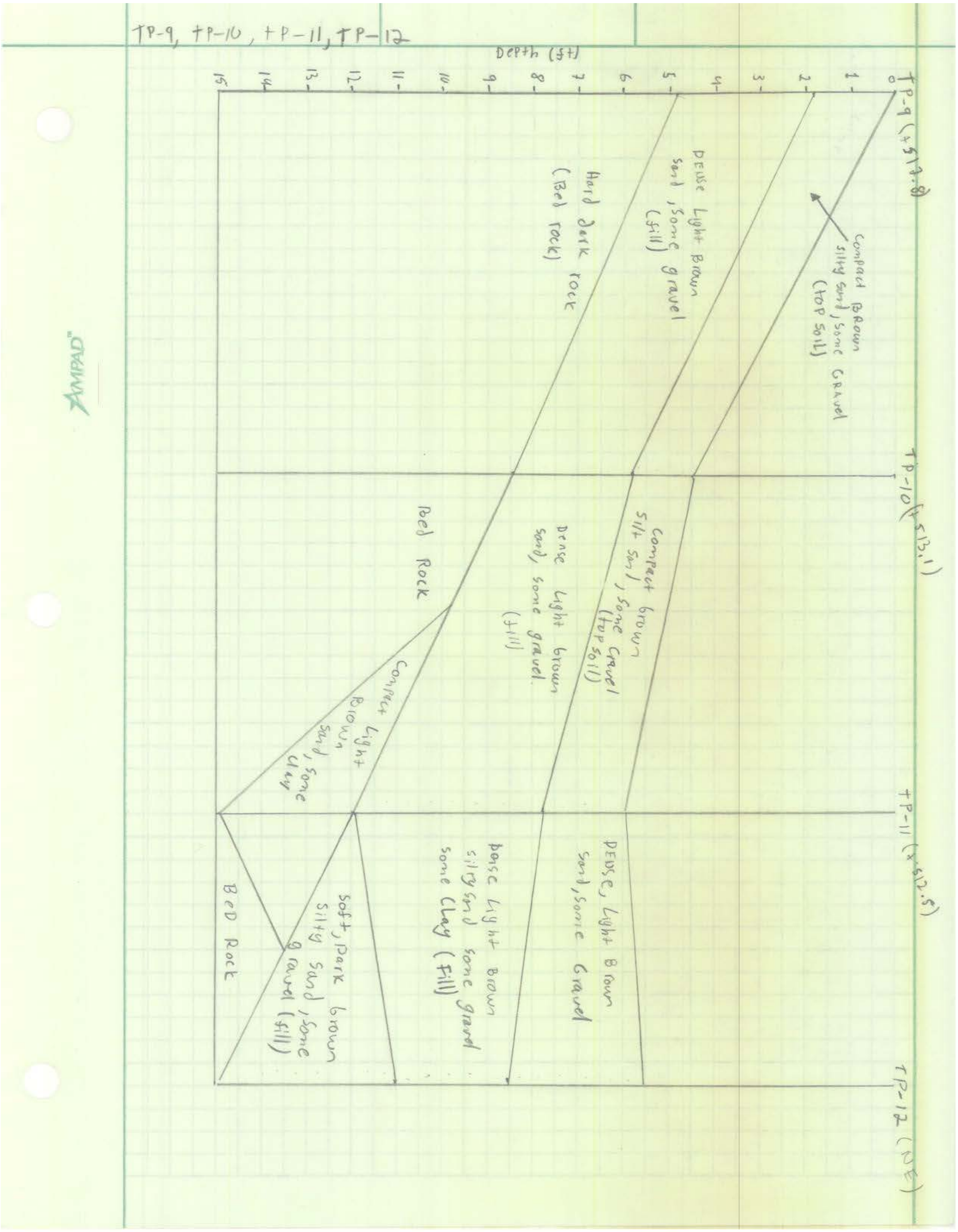


TP-13, MA1-4, TP-16
TP-13
(+519.4)
MA1-4
(+513.6)
TP-16
(Depth ft)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Compact Brown silt and sand
Dase Light Brown (fill)
Refusal (Bed rock)
Compact Brown silt and sand (top soil
Compact Light Brown sand and silt, some gravel (fill)
Refusal (Bed Rock)

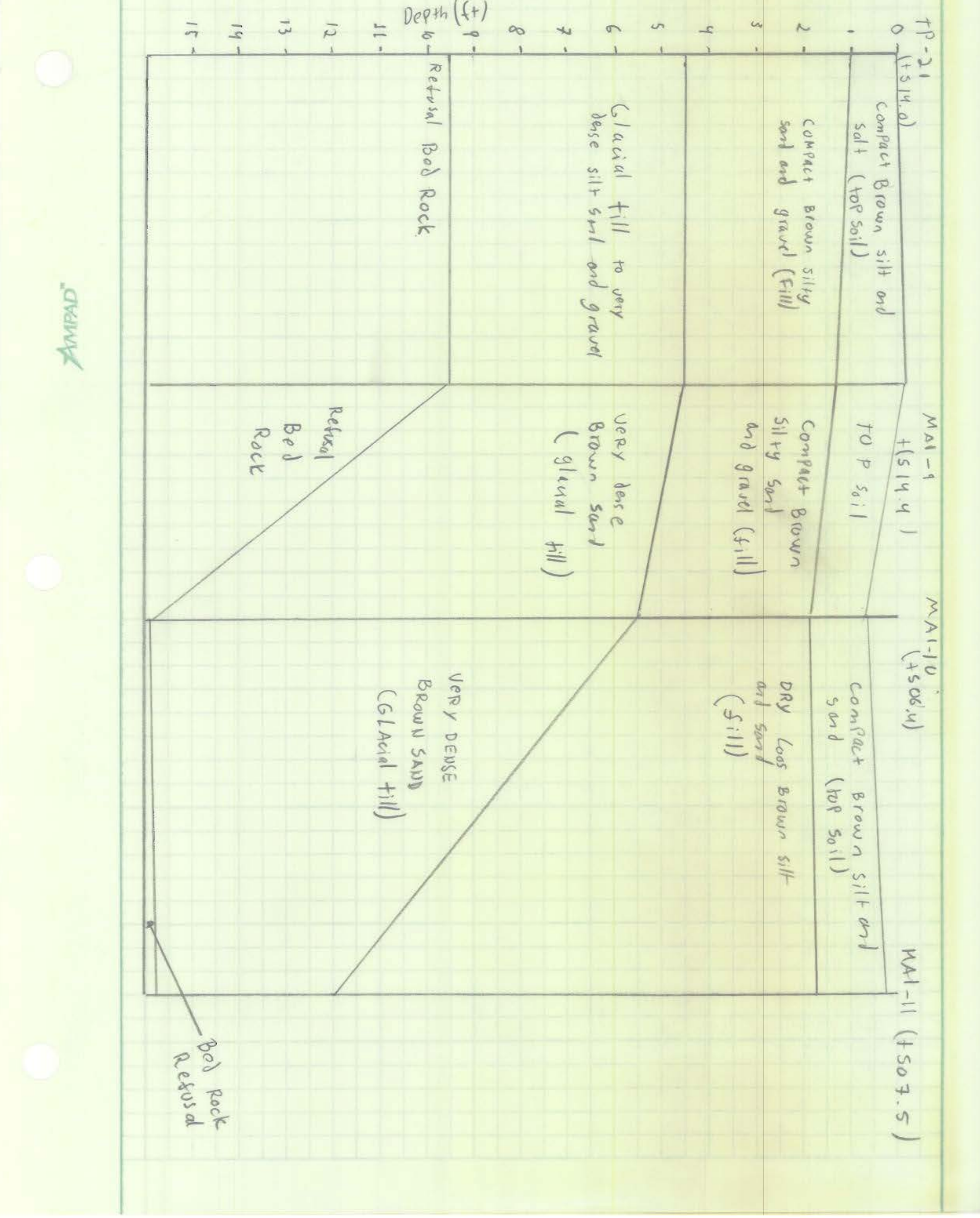

TP-1 ,TP-2, TP-3-TP-4
Depth (ft)
TP-1
TP-2
TP-3
TP-4
Compact Brow Sand (fill)
Hard Brown slightly to moderated weatered Phillite Bed Rock
Compact Brown silt and Sand
Dense light Brown sand
Bed Rock
COMPACT light Brown sand
Very dense ligh brown sand
Bed Rock
Dense ligh brown clay (fill)
Glacial till

TP-5, TP-6, TP-7, TP-8

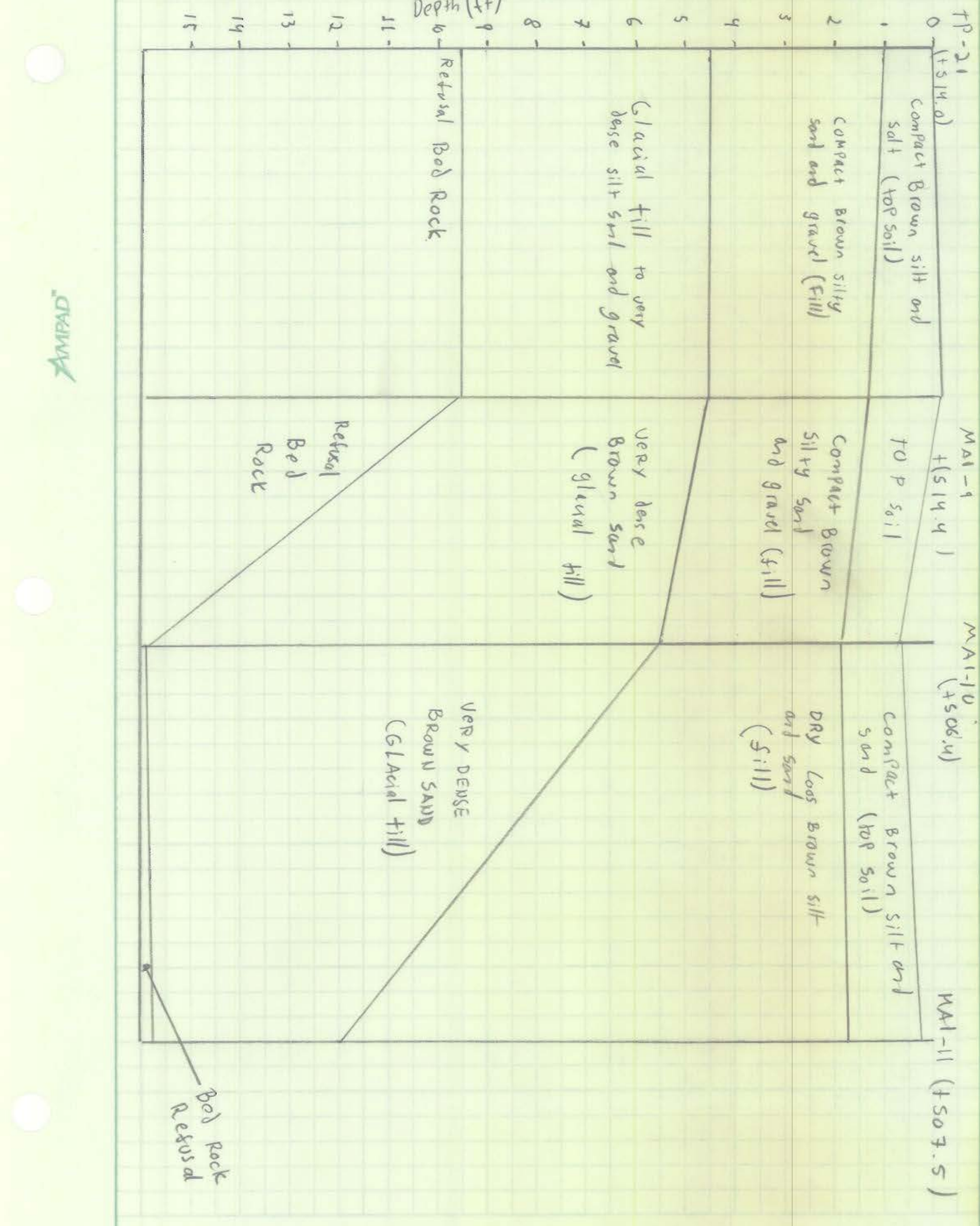



TP-9, TP-10, TP-11, TP-12
Depth (ft)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TP-9 (±517.8)
TP-10 (±513.1)
TP-11 (±512.5)
TP-12 (NE)
Compact Brown silty sand, some Gravel (top soil)
Dense Light Brown Sand, Some gravel (fill)
Hard dark rock (Bed rock)
Compact brown Silt Sand, Some Gravel (top soil)
Dense Light brown sand, some gravel. (fill)
Bed Rock
Compact Light Brown Sand, Some Clay
Dense, Light Brown Sand, Some Gravel
Dense Light Brown silty sand some gravel some Clay (Fill)
Soft, Dark brown Silty Sand, Some Gravel (fill)
Bed Rock

TP-21, MAI-9, MAI-10, MAI-11



TP-21, MAI-9, MAI-10, MAI-11



FIELD BOREHOLE LOG

Project:	WPI Parking Garage Athletic Field Structure	**Job #:**	5288
Location:	Park Avenue	**Date Started:**	9-27-11
City/State:	Worcester, MA	**Date Finished:**	9-27-11

Boring No.

MAI-1

Contractor:	Technical Drilling Services, Inc.	**Casing Type/Size:**	4 1/4 Hollow Stem Auger
Driller/Helper:	Gary	**Casing Hammer WT(#)/Drop(in):**	
Logged By:	FBK	**Sampler Type/Size:**	
Surface Elevation (ft):	521.6	**Sampler Hammer WT(#)/Drop(in):**	140/30

Groundwater Observations			
Date	Depth	Elev.	Notes
9-27-11	16.9	504.7	

Depth (ft)	Elev. (ft)	Depth to Strata Change (ft)	Stratum Description	PID (ppm)	No.	Pen./Rec. (in)	Sample Depth (ft)	Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
0–1.5	521	1.5	Dry compact brown silty sand and organic material, trace gravel. (Topsoil)		S-1	24/17	0.0-2.0	2, 5, 5, 5			
1.5–10.0	520–512	10.0	Dry loose brown to light brown silty sand, trace gravel, clay, and brick. (Fill)		S-2	24/11	5.0-7.0	4, 2, 4, 4			
10.0–10.5	511	10.5	Dry very loose light brown silt, some sand, trace gravel. (Topsoil)		S-3	24/16	10.0-12.0	1, 14, 18, 16			
10.5–17.0	511–505	17.0	Dry to moist dense light brown silty sand and gravel, some clay, trace weathered rock. (Glacial Till)		S-4	24/16	15.0-17.0	15, 18, 18, 36		▽	
17	504		End of borehole at 17 feet								

Depth scale (ft): 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22

Elev. scale (ft): 521, 520, 519, 518, 517, 516, 515, 514, 513, 512, 511, 510, 509, 508, 507, 506, 505, 504, 503, 502, 501, 500, 499

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE

COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

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MCPHAIL BASE LOG - LOG A EWMH1.GDT - 11/1/11 13:06 - G:\GINT\BENTLEY\GINT\PROJECTS\5288\5288-MAI-1_MAI-15.GPJ

FIELD BOREHOLE LOG

Project:	WPI Parking Garage Athletic Field Structure	**Job #:**	5288	Boring No. **MAI-2**
Location:	Park Avenue	**Date Started:**	9-27-11	
City/State:	Worcester, MA	**Date Finished:**	9-27-11	

Contractor: Technical Drilling Services, Inc.
Driller/Helper: Gary
Logged By: FBK
Surface Elevation (ft): 522.8

Casing Type/Size: 4 1/4 Hollow Stem Auger
Casing Hammer WT(#)/Drop(in):
Sampler Type/Size:
Sampler Hammer WT(#)/Drop(in): 140/30

Groundwater Observations

Date	Depth	Elev.	Notes
9-27-11	16.7	506.1	

Depth (ft)	Elev. (ft)	Symbol	Depth to Strata Change (ft)	Stratum Description	Sample PID (ppm)	Sample No.	Sample Pen./Rec. (in)	Sample Depth (ft)	Sample Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
						S-1	24/23	0.0-2.0	15			
									31			
1	522								30			
									34			
2	521											
3	520											
4	519											
5	518			Dry very dense to compact light brown sand, some silt, some gravel. (Fill)		S-2	24/19	5.0-7.0	7			
									4			
6	517								7			
									7			
7	516											
8	515											
9	514											
10	513		10.3			S-3	24/22	10.0-12.0	2			
			10.5	Dry loose dark brown to black organic silt, some sand, trace roots. (Topsoil)					12			
11	512								18			
12	511								23			
13	510											
14	509			Moist compact light brown silty sand, some gravel, some clay, trace to some weathered rock. (Glacial Till)								
15	508					S-4	24/23	15.0-17.0	10			
16	507								12			
									11		▽	
17	506		17.0						15			
				End of borehole at 17 feet								
18	505											
19	504											
20	503											
21	502											
22	501											
	500											

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE

COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

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MCPHAIL BASE LOG - LOG A EWNI01.GDT - 11/1/11 13:36 - G:\GINT\BENTLEY\GINT\PROJECTS\5288\5288-MAI-1_MAI-15.GPJ

FIELD BOREHOLE LOG

Project:	WPI Parking Garage Athletic Field Structure	**Job #:**	5288	Boring No.
Location:	Park Avenue	**Date Started:**	9-27-11	**MAI-3**
City/State:	Worcester, MA	**Date Finished:**	9-27-11	

Contractor: Technical Drilling Services, Inc.
Driller/Helper: Gary
Logged By: FBK
Surface Elevation (ft): 521.2

Casing Type/Size: 4 1/4 Hollow Stem Auger
Casing Hammer WT(#)/Drop(in):
Sampler Type/Size:
Sampler Hammer WT(#)/Drop(in): 140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth (ft)	Elev. (ft)	Symbol	Depth to Strata Change (ft)	Stratum Description	PID (ppm)	No.	Pen. /Rec. (in)	Depth (ft)	Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
	521			Dry compact brown silty sand, trace gravel, trace roots. (Topsoil)		S-1	24/17	0.0-2.0	3			
1	520		1.5						5			
									5			
2	519			Dry very loose to compact light brown to brown silty sand, trace gravel. (Fill)					3			
3	518											
4	517											
5	516		5.5			S-2	24/20	5.0-7.0	10			
6	515			Dry very dense light brown sand and gravel, some silt and weathered rock. (Glacial Till)					20			
									43			
7	514								24			
8	513											
9	512											
10	511		10.1	Auger and split spoon refusal at 10.1 feet		S-3	1/1	10.0-10.1	50/1"			
11	510											
12	509											
13	508											
14	507											
15	506											
16	505											
17	504											
18	503											
19	502											
20	501											
21	500											
22	499											

GRANULAR SOILS

BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE

COHESIVE SOILS

BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

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MCPHAIL BASE LOG - LOGA EWN(01.GDT - 11/1/11 13:36 - G:\GINT\BENTLEY\GINT\PROJECTS\5288\5288-MAI-1_MAI-15.GPJ

FIELD BOREHOLE LOG

Project:	WPI Parking Garage Athletic Field Structure	**Job #:**	5288	Boring No.
Location:	Park Avenue	**Date Started:**	9-27-11	**MAI-4**
City/State:	Worcester, MA	**Date Finished:**	9-27-11	

Contractor: Technical Drilling Services, Inc.
Driller/Helper: Gary
Logged By: FBK
Surface Elevation (ft): 521.6

Casing Type/Size: 4 1/4 Hollow Stem Auger
Casing Hammer WT(#)/Drop(in):
Sampler Type/Size:
Sampler Hammer WT(#)/Drop(in): 140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth (ft)	Elev. (ft)	Depth to Strata Change (ft)	Stratum Description
0.0–0.5	521	0.5	Dry very loose brown silty sand, trace gravel. (Topsoil)
0.5–8.0	520–514	8.0	Dry loose to very loose light brown to brown-grey sand, some gravel, some silt, trace to some ash and cinders. (Fill)
8.0–14.0	513–508	14.0	Moist very dense light brown to grey sand, some gravel, some silt and clay. (Glacial Till)
14.0	507		Auger refusal at 14 feet

Depth scale (ft): 1–22; Elev. scale (ft): 521–499

Sample

PID (ppm)	No.	Pen. /Rec. (in)	Depth (ft)	Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
	S-1	24/21	0.0-2.0	2, 9, 8, 7			
	S-2	24/16	5.0-7.0	1, 1, 1, 2			
	S-3	24/19	10.0-12.0	19, 29, 44, 32			

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE
COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

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2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

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FIELD BOREHOLE LOG

Project:	WPI Parking Garage Athletic Field Structure	**Job #:**	5288
Location:	Park Avenue	**Date Started:**	9-27-11
City/State:	Worcester, MA	**Date Finished:**	9-27-11

Boring No. **MAI-5**

Contractor:	Technical Drilling Services, Inc.	**Casing Type/Size:**	4 1/4 Hollow Stem Auger
Driller/Helper:	Gary	**Casing Hammer WT(#)/Drop(in):**	
Logged By:	FBK	**Sampler Type/Size:**	
Surface Elevation (ft):	522.4	**Sampler Hammer WT(#)/Drop(in):**	140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth (ft)	Elev. (ft)	Depth to Strata Change (ft)	Stratum Description	PID (ppm)	No.	Pen. /Rec. (in)	Depth (ft)	Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
0–1.5	522–521	1.5	Dry compact brown silty sand, trace gravel, roots. (Topsoil)		S-1	24/21	0.0-2.0	2, 3, 7, 16			
1.5–10.5	521–512	10.5	Dry to moist compact to loose light brown to brown silty sand, trace brick, trace ash and cinders. (Fill)		S-2	24/19	5.0-7.0	3, 2, 3, 2			
10.5–13.0	512–510	13.0	Moist compact grayish brown silt and fine sand, trace sand and gravel. (Alluvial Deposit)		S-3	24/22	10.0-12.0	4, 5, 6, 6			
13.0–16.5	509–506	16.5	Moist very dense grayish brown silty sand and gravel. (Glacial Till)		S-4	18/19	15.0-16.5	12, 27, 36, 50/1"			
16.5			Refusal at 16.5 feet								

Depth scale (ft): 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22

Elevation scale (ft): 522, 521, 520, 519, 518, 517, 516, 515, 514, 513, 512, 511, 510, 509, 508, 507, 506, 505, 504, 503, 502, 501, 500

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE

COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

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FIELD BOREHOLE LOG

Project: WPI Parking Garage Athletic Field Structure	**Job #:** 5288	Boring No. **MAI-6**	
Location: Park Avenue	**Date Started:** 10-10-11		
City/State: Worcester, MA	**Date Finished:** 10-10-11		

Contractor: Technical Drilling Services, Inc.
Driller/Helper: Bratt/Donnie
Logged By: FBK
Surface Elevation (ft): 520.9

Casing Type/Size: 4 1/4 Hollow Stem Auger
Casing Hammer WT(#)/Drop(in):
Sampler Type/Size:
Sampler Hammer WT(#)/Drop(in): 140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth (ft)	Elev. (ft)	Symbol	Depth to Strata Change (ft)	Stratum Description	PID (ppm)	Sample No.	Pen. /Rec. (in)	Sample Depth (ft)	Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
			1.0	Dry compact brown silty sand, some silt, trace gravel. (Topsoil)		S-1	24/18	0.0-2.0	5 / 15 / 18 / 11			
1	520											
2	519											
3	518											
4	517			Compact to very dense light brown silt and sand, some gravel. (Glacial Till)								
5	516					S-2	24/18	5.0-7.0	17 / 15 / 25 / 27			
6	515											
7	514											
8	513		8.0	End of borehole at 8 feet								
9	512											
10	511											
11	510											
12	509											
13	508											
14	507											
15	506											
16	505											
17	504											
18	503											
19	502											
20	501											
21	500											
22	499											

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE

COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

FIELD BOREHOLE LOG

Project: WPI Parking Garage Athletic Field Structure	**Job #:** 5288		Boring No.
Location: Park Avenue	**Date Started:** 10-10-11		**MAI-7**
City/State: Worcester, MA	**Date Finished:** 10-10-11		

Contractor: Technical Drilling Services, Inc.
Driller/Helper: Bratt/Donnie
Logged By: FBK
Surface Elevation (ft): 521.1

Casing Type/Size: 4 1/4 Hollow Stem Auger
Casing Hammer WT(#)/Drop(in):
Sampler Type/Size:
Sampler Hammer WT(#)/Drop(in): 140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth (ft)	Elev. (ft)	Depth to Strata Change (ft)	Stratum Description	PID (ppm)	Sample No.	Pen. /Rec. (in)	Sample Depth (ft)	Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
		1.0	Dry compact brown silty sand, some silt, trace gravel, trace roots. (Topsoil)		S-1	24/21	0.0-2.0	3 10 16 9			
1	520										
2	519										
3	518										
4	517										
5	516		Compact brown sand, some gravel, some silt, brick, ash, and cinders. (Fill)		S-2	24/7	5.0-7.0	5 5 6 6			
6	515										
7	514										
8	513										
9	512	10.0									
10	511	10.5	Loose light brown silt, some sand and gravel. (Fill)		S-3	24/18	10.0-12.0	4 10 15 17			
11	510										
12	509										
13	508		Compact to dense light brown silt and sand, trace to some gravel. (Alluvium)								
14	507										
15	506	16.0			S-4	19/18	15.0-16.6	7 23 71 50/1"			
16	505	16.6	(Bedrock)								
			End of borehole at 16.6 feet								
17	504										
18	503										
19	502										
20	501										
21	500										
22	499										

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE

COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

Page 1 of 1

MCPHAIL BASE LOG - LOG A EWMU1.GDT - 11/1/11 13:36 - G:\GINT\BENTLEY\GINT\PROJECTS\5288\5288-MAI-1_MAI-15.GPJ

FIELD BOREHOLE LOG

Project:	WPI Parking Garage Athletic Field Structure	**Job #:**	5288
Location:	Park Avenue	**Date Started:**	9-27-11
City/State:	Worcester, MA	**Date Finished:**	9-27-11

Boring No.
MAI-8

Contractor:	Technical Drilling Services, Inc.	**Casing Type/Size:**	4 1/4 Hollow Stem Auger
Driller/Helper:	Gary	**Casing Hammer WT(#)/Drop(in):**	
Logged By:	FBK	**Sampler Type/Size:**	
Surface Elevation (ft):	521.2	**Sampler Hammer WT(#)/Drop(in):**	140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth (ft)	Elev. (ft)	Symbol	Depth to Strata Change (ft)	Stratum Description	PID (ppm)	No.	Pen. /Rec. (in)	Depth (ft)	Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
	521			Dry compact brown silty sand, trace gravel, trace roots. (Topsoil)		S-1	24/22	0.0-2.0	3			
									5			
1	520		1.5						8			
2	519			Dry loose brown to olive silty sand, trace to some clay, gravel, brick, ash and cinders. (Fill)					7			
3	518											
4	517											
5	516					S-2	24/17	5.0-7.0	2			
6	515								2			
									4			
7	514								3			
8	513											
9	512		10.0									
10	511		10.5	Dry soft black organic silt. (Organics)		S-3	24/18	10.0-12.0	3			
				Moist loose light brown to olive silt and fine sand, trace fine gravel. (Alluvium)					3			
11	510								2			
12	509								5			
13	508		13.0	Moist very dense light brown silty sand and gravel, some clay. (Glacial Till)								
14	507											
15	506					S-4	21/17	15.0-16.8	15			
									42			
16	505								53			
			16.8						50/3"			
17	504			Refusal at 16.8 feet								
18	503											
19	502											
20	501											
21	500											
22	499											

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE

COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

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MCPHAIL BASE LOG - LOG A EWNUM GDT - 11/1/11 13:36 - G:\GINT\BENTLEY\GINT\PROJECTS\5288\5288-MAI-1_MAI-15.GPJ

FIELD BOREHOLE LOG

Project:	WPI Parking Garage Athletic Field Structure	**Job #:**	5288
Location:	Park Avenue	**Date Started:**	10-10-11
City/State:	Worcester, MA	**Date Finished:**	10-10-11

Boring No.
MAI-9

Contractor: Technical Drilling Services, Inc.
Driller/Helper: Bratt/Donnie
Logged By: FBK
Surface Elevation (ft): 520.4
Casing Type/Size: 4 1/4 Hollow Stem Auger
Casing Hammer WT(#)/Drop(in):
Sampler Type/Size:
Sampler Hammer WT(#)/Drop(in): 140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth (ft)	Elev. (ft)	Symbol	Depth to Strata Change (ft)	Stratum Description	PID (ppm)	No.	Pen. /Rec. (in)	Depth (ft)	Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
	520			Compact to dense brown silty sand, trace gravel and organic material. (Fill/Topsoil)		S-1	24/22	0.0-2.0	2			
1	519								10			
									6			
2	518								3			
3	517											
4	516											
5	515		6.0			S-2	24/15	5.0-7.0	15			
									18			
6	514			Dense to very dense brown-gray silty sand and gravel, trace clay. (Glacial Till)					15			
7	513								18			
8	512											
9	511											
10	510					S-3	24/17	10.0-12.0	13			
									24			
11	509								34			
									26			
12	508		13.0									
13	507			Auger refusal at 13 feet								
14	506											
15	505											
16	504											
17	503											
18	502											
19	501											
20	500											
21	499											
22	498											

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE
COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL
McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

MCPHAIL BASE LOG - LOGA EWM.GDT - 11/1/11 13:36 - G:\GINT\BENTLEY\GINT\PROJECTS\5288\5288-MAI-1_MAI-15.GPJ

FIELD BOREHOLE LOG

Project:	WPI Parking Garage Athletic Field Structure	**Job #:**	5288	Boring No. **MAI-10**
Location:	Park Avenue	**Date Started:**	10-10-11	
City/State:	Worcester, MA	**Date Finished:**	10-10-11	

Contractor: Technical Drilling Services, Inc.
Driller/Helper: Bratt/Donnie
Logged By: FBK
Surface Elevation (ft): 520.4

Casing Type/Size: 4 1/4 Hollow Stem Auger
Casing Hammer WT(#)/Drop(in):
Sampler Type/Size:
Sampler Hammer WT(#)/Drop(in): 140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth (ft)	Elev. (ft)	Depth to Strata Change (ft)	Stratum Description	Sample PID (ppm)	Sample No.	Pen. /Rec. (in)	Sample Depth (ft)	Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
0	520	0.5	Dry loose brown silty sand, some silt. (Topsoil)		S-1	24/22	0.0-2.0	4, 5, 7, 11			
0.5–12.0	519–509	12.0	Compact to loose silty sand, brick, ash, and cinders. (Fill)		S-2	24/15	5.0-7.0	2, 5, 9, 3			
					S-3	24/5	10.0-12.0	12, 11, 4, 4			
12.0–14.0	508–507	14.0	Loose to compact brown-black organic silt and sand. (Organics)								
14.0–17.0	506–504	17.0	Very dense brown silt, sand and gravel. (Glacial Till)		S-4	24/17	15.0-17.0	11, 32, 33, 40			
17	503		End of borehole at 17 feet								
18–22	502–498										

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE
COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

MCPHAIL BASE LOG - LOG A EWM.01.GDT - 11/1/11 13:26 - G:\GINT\BENTLEY\GINT\PROJECTS\5288\5288-MAI-1_MAI-15.GPJ

FIELD BOREHOLE LOG

Project: WPI Parking Garage Athletic Field Structure	**Job #:** 5288	Boring No.
Location: Park Avenue	**Date Started:** 9-27-11	**MAI-11 (OW)**
City/State: Worcester, MA	**Date Finished:** 9-27-11	

Contractor: Technical Drilling Services, Inc.
Driller/Helper: Gary
Logged By: FBK
Surface Elevation (ft): 520.5

Casing Type/Size: 4 1/4 Hollow Stem Auger
Casing Hammer WT(#)/Drop(in):
Sampler Type/Size:
Sampler Hammer WT(#)/Drop(in): 140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth to Strata Change (ft)	Stratum Description
1.5	Dry loose brown silty sand, trace gravel, trace brick. (Topsoil)
13.0	Dry loose brown silty sand, trace gravel, some clay, trace brick, ash and cinders. (Fill)
16.6	Moist dense light brown to gray silty sand and gravel, trace weathered bedrock fragments. (Glacial Till)
	Refusal at 16.6 feet

PID (ppm)	No.	Pen. /Rec. (in)	Depth (ft)	Blows Per 6"
	S-1	24/19	0.0-2.0	2, 2, 5, 5
	S-2	24/17	5.0-7.0	5, 2, 2, 1
	S-3	24/7	10.0-12.0	3, 2, 5, 4
	S-4	19/19	15.0-16.6	4, 14, 26, 50/2"

Depth (ft): 1–22; Elev. (ft): 520–498

Sample Description and Boring Notes

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE
COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

Page 1 of 1

FIELD BOREHOLE LOG

Project:	WPI Parking Garage Athletic Field Structure	**Job #:**	5288
Location:	Park Avenue	**Date Started:**	10-10-11
City/State:	Worcester, MA	**Date Finished:**	10-10-11

Boring No.

MAI-12

Contractor:	Technical Drilling Services, Inc.	**Casing Type/Size:**	4 1/4 Hollow Stem Auger
Driller/Helper:	Bratt/Donnie	**Casing Hammer WT(#)/Drop(in):**	
Logged By:	FBK	**Sampler Type/Size:**	
Surface Elevation (ft):	519.0	**Sampler Hammer WT(#)/Drop(in):**	140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth (ft)	Elev. (ft)	Symbol	Depth to Strata Change (ft)	Stratum Description	PID (ppm)	No.	Pen. /Rec. (in)	Depth (ft)	Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
						S-1	24/23	0.0-2.0	3			
1	518								9			
									7			
2	517								6			
3	516											
4	515											
5	514					S-2	24/12	5.0-7.0	1			
6	513								1			
									2			
7	512			Loose to compact brown silty sand, some gravel, ash and cinders. (Fill)					3			
8	511											
9	510											
10	509					S-3	24/6	10.0-12.0	1			
11	508								3			
									3			
12	507								2			
13	506											
14	505		14.5									
15	504					S-4	24/17	15.0-17.0	15			
16	503			Very dense light brown silt and silty sand, some gravel. (Glacial Till)					26			
									41			
17	502		17.0						52			
18	501			End of borehole at 17 feet								
19	500											
20	499											
21	498											
22	497											

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE

COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

Page 1 of 1

MCPHAIL BASE LOG - LOGA EWN01.GDT - 11/1/11 13:06 - G:\GINT\BENTLEY\GINT\PROJECTS\5288\5288-MAI-1_MAI-15.GPJ

FIELD BOREHOLE LOG

Project:	WPI Parking Garage Athletic Field Structure	**Job #:**	5288
Location:	Park Avenue	**Date Started:**	10-10-11
City/State:	Worcester, MA	**Date Finished:**	10-10-11

Boring No.

MAI-13

Contractor:	Technical Drilling Services, Inc.	**Casing Type/Size:**	4 1/4 Hollow Stem Auger
Driller/Helper:	Bratt/Donnie	**Casing Hammer WT(#)/Drop(in):**	
Logged By:	FBK	**Sampler Type/Size:**	
Surface Elevation (ft):	519.3	**Sampler Hammer WT(#)/Drop(in):**	140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth (ft)	Elev. (ft)	Symbol	Depth to Strata Change (ft)	Stratum Description	Sample PID (ppm)	Sample No.	Sample Pen. /Rec. (in)	Sample Depth (ft)	Sample Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
	519		1.0	Dry compact brown silty sand, some silt, trace gravel, trace roots. (Topsoil)		S-1	24/18	0.0-2.0	5, 6, 5, 7			
1	518											
2	517											
3	516			Very loose to compact brown silty sand, some gravel, brick, ash, and cinders. (Fill)								
4	515											
5	514					S-2	24/5	5.0-7.0	1, 1, 1, 1			
6	513		7.0									
7	512											
8	511			Very loose dark gray organic silt, some sand. (Organics)								
9	510		9.5									
10	509					S-3	24/13	10.0-12.0	2, 1, 3, 1			
11	508											
12	507			Loose dark gray sand, some silt and gravel, numerous ash and cinders. (Fill)								
13	506											
14	505											
15	504					S-4	24/9	15.0-17.0	3, 3, 3, 3			
16	503		16.5									
17	502		18.0	Very loose gray silty sand, trace gravel, organic material. (Topsoil)								
18	501											
19	500											
20	499			Dense light brown silt and gravel, some sand. (Glacial Till)		S-5	24/19	20.0-22.0	13, 25, 19, 15			
21	498		22.0									
22	497			End of borehole at 22 feet								

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE
COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

MCPHAIL BASE LOG - LOG A EWN101.GDT - 11/1/11 13:36 - G:\GINT BENTLEY\GINT\PROJECTS\5288\5288-MAI-1_MAI-15.GPJ

FIELD BOREHOLE LOG

Project: WPI Parking Garage Athletic Field Structure	**Job #:** 5288		Boring No.
Location: Park Avenue	**Date Started:** 9-27-11		**MAI-14**
City/State: Worcester, MA	**Date Finished:** 9-27-11		

Contractor: Technical Drilling Services, Inc.
Driller/Helper: Gary
Logged By: FBK
Surface Elevation (ft): 518.6

Casing Type/Size: 4 1/4 Hollow Stem Auger
Casing Hammer WT(#)/Drop(in):
Sampler Type/Size:
Sampler Hammer WT(#)/Drop(in): 140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth to Strata Change (ft)	Stratum Description	PID (ppm)	No.	Pen./Rec. (in)	Depth (ft)	Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
1.5	Dry loose brown, silty sand, trace gravel, trace brick, trace roots. (Topsoil)		S-1	24/18	0.0-2.0	2, 4, 5, 5			
20.0	Dry compact to dense light brown silty sand, some gravel, trace clay, trace brick, trace ash and cinders. (Fill)		S-2	24/15	5.0-7.0	4, 8, 9, 6			
			S-3	24/6	10.0-12.0	6, 20, 20, 13			
			S-4	24/7	15.0-17.0	3, 2, 8, 21			
22.0	Wet dense gray to brown silty sand and gravel, some clay. (Glacial Till)		S-5	24/14	20.0-22.0	17, 23, 25, 20			
	End of borehole at 22 feet								

GRANULAR SOILS	
BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE
COHESIVE SOILS	
BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

MCPHAIL BASE LOG - LOG A EWMI01.GDT - 11/1/11 13:36 - G:\GINT BENTLEY\GINT\PROJECTS\5288\5288-MW-1_MW-15.GPJ

FIELD BOREHOLE LOG

Project:	WPI Parking Garage Athletic Field Structure	**Job #:**	5288
Location:	Park Avenue	**Date Started:**	10-10-11
City/State:	Worcester, MA	**Date Finished:**	10-10-11

Boring No.

MAI-15

Contractor:	Technical Drilling Services, Inc.	**Casing Type/Size:**	4 1/4 Hollow Stem Auger
Driller/Helper:	Bratt/Donnie	**Casing Hammer WT(#)/Drop(in):**	
Logged By:	FBK	**Sampler Type/Size:**	
Surface Elevation (ft):	520.8	**Sampler Hammer WT(#)/Drop(in):**	140/30

Groundwater Observations

Date	Depth	Elev.	Notes

Depth (ft)	Elev. (ft)	Symbol	Depth to Strata Change (ft)	Stratum Description	PID (ppm)	No.	Pen. /Rec. (in)	Depth (ft)	Blows Per 6"	Sample Description and Boring Notes	Groundwater	Well Log
1	520											
2	519											
3	518											
4	517											
5	516			No samples taken. See test pit TP-20.								
6	515											
7	514											
8	513											
9	512											
10	511		10.0			S-1	24/7	10.0-12.0	3			
									11			
11	510								6			
12	509			Compact brown-black organic silt and sand, trace gravel. (Organics)					8			
						S-2	24/16	12.0-14.0	6			
13	508								5			
			13.5						5			
14	507								16			
				Very dense light brown silt, sand and gravel, some clay. (Glacial Till)		S-3	17/17	14.0-15.4	30			
15	506								48			
			15.4						100/5"			
16	505			End of borehole at 15.4 feet								
17	504											
18	503											
19	502											
20	501											
21	500											
22	499											
	498											

GRANULAR SOILS

BLOWS/FT.	DENSITY
0-4	V.LOOSE
4-10	LOOSE
10-30	COMPACT
30-50	DENSE
>50	V.DENSE

COHESIVE SOILS

BLOWS/FT.	DENSITY
<2	V.SOFT
2-4	SOFT
4-8	FIRM
8-15	STIFF
15-30	V.STIFF
>30	HARD

SOIL COMPONENT

DESCRIPTIVE TERM	PROPORTION OF TOTAL
"TRACE"	0-10%
"SOME"	10-20%
"ADJECTIVE" (eg SANDY, SILTY)	20-35%
"AND"	35-50%

MATERIALS CONTAINING THREE SOIL COMPONENTS EACH OF WHICH COMPRISES AT LEAST 25% OF THE TOTAL ARE CLASSIFIED AS "A WELL GRADED MIXTURE OF"

Notes:

Weather: Sunny

McPHAIL ASSOCIATES, INC.
2269 MASSACHUSETTS AVENUE
CAMBRIDGE, MA 02140
TEL: 617-868-1420
FAX: 617-868-1423

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Appendix D-Foundation Design

Spreadsheets For settlement obtained from Donald Codutos Book

SETTLEMENT ANALYSIS OF SHALLOW FOUNDATIONS
Classical Method

Date April 26, 2012
Identification Type 1

Input

Units	E	E or SI
Shape	SQ	SQ, CI, CO, or RE
B =	8.42	ft
L =	8.42	ft
D =	7	ft
P =	540	k
Dw =	20	ft
r =	0.85	

Results

q = 8667 lb/ft^2
delta = 0.35 in

Depth to Soil Layer Top (ft)	Bottom (ft)	Cc/(1+e)	Cr/(1+e)	sigma m' (lb/ft^2)	gamma (lb/ft^3)	zf (ft)	sigma c' (lb/ft^2)	sigma zo' (lb/ft^2)	delta sigma (lb/ft^2)	sigma zf (lb/ft^2)	strain (%)	delta (in)
0.0	7.0				130							
7.0	7.5	0.006	0.004	7000	130	0.25	7943	943	7756	8698	0.33	0.020
7.5	8.0	0.006	0.004	7000	130	0.75	8008	1008	7725	8733	0.33	0.020
8.0	8.5	0.006	0.004	7000	130	1.25	8073	1073	7620	8693	0.31	0.019
8.5	9.0	0.006	0.004	7000	130	1.75	8138	1138	7417	8554	0.30	0.018
9.0	9.5	0.006	0.004	7000	130	2.25	8203	1203	7116	8319	0.29	0.017
9.5	10.0	0.006	0.004	7000	130	2.75	8268	1268	6738	8006	0.27	0.016
10.0	10.5	0.006	0.004	7000	130	3.25	8333	1333	6309	7641	0.26	0.015
10.5	11.0	0.006	0.004	7000	130	3.75	8398	1398	5856	7253	0.24	0.015
11.0	11.5	0.006	0.004	7000	130	4.25	8463	1463	5401	6863	0.23	0.014
11.5	12.0	0.006	0.004	7000	130	4.75	8528	1528	4959	6487	0.21	0.013
12.0	12.5	0.006	0.004	7000	130	5.25	8593	1593	4542	6135	0.20	0.012
12.5	13.0	0.006	0.004	7000	130	5.75	8658	1658	4155	5812	0.19	0.011
13.0	13.5	0.006	0.004	7000	130	6.25	8723	1723	3799	5522	0.17	0.010
13.5	14.0	0.006	0.004	7000	130	6.75	8788	1788	3476	5264	0.16	0.010

SETTLEMENT ANALYSIS OF SHALLOW FOUNDATIONS

Classical Method

Date	April 26, 2012
Identification	Type 2

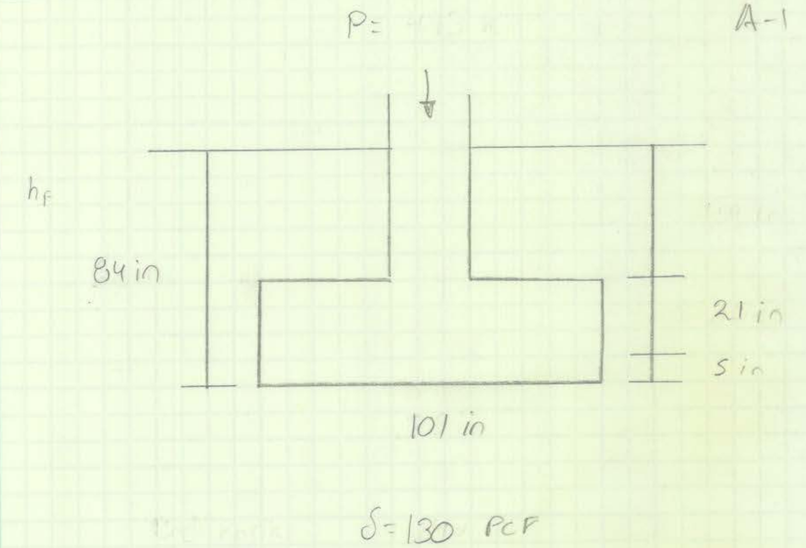
Input

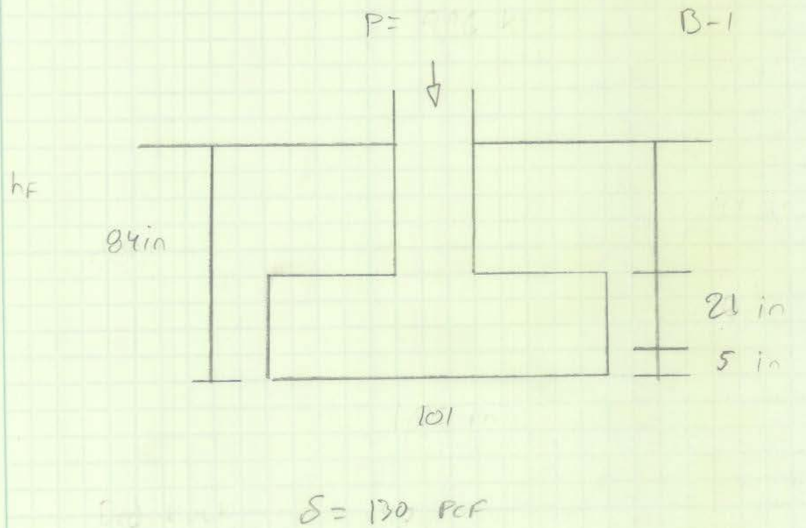
Units	E	E or SI
Shape	SQ	SQ, CI, CO, or RE
B =	10.83	ft
L =	10.83	ft
D =	7	ft
P =	985	k
Dw =	20	ft
r =	0.85	

Results

q =	9448	lb/ft^2
delta =	0.45	in

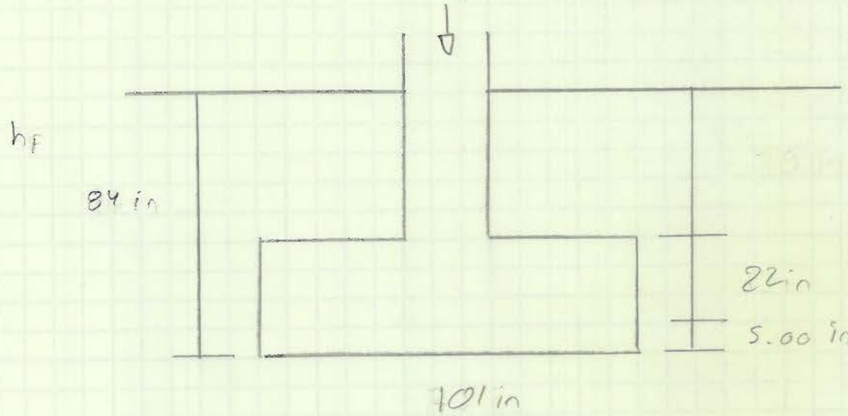
Depth to Soil Layer Top (ft)	Depth to Soil Layer Bottom (ft)	Cc/(1+e)	Cr/(1+e)	sigma m' (lb/ft^2)	gamma (lb/ft^3)	zf (ft)	sigma c' (lb/ft^2)	sigma zo' (lb/ft^2)	delta sigma (lb/ft^2)	sigma zf (lb/ft^2)	strain (%)	delta (in)
0.0	7.0				130							
7.0	7.5	0.006	0.004	7000	130	0.25	7943	943	8537	9480	0.35	0.021
7.5	8.0	0.006	0.004	7000	130	0.75	8008	1008	8521	9529	0.34	0.021
8.0	8.5	0.006	0.004	7000	130	1.25	8073	1073	8464	9537	0.33	0.020
8.5	9.0	0.006	0.004	7000	130	1.75	8138	1138	8348	9485	0.32	0.019
9.0	9.5	0.006	0.004	7000	130	2.25	8203	1203	8164	9367	0.31	0.019
9.5	10.0	0.006	0.004	7000	130	2.75	8268	1268	7916	9183	0.30	0.018
10.0	10.5	0.006	0.004	7000	130	3.25	8333	1333	7612	8944	0.29	0.017
10.5	11.0	0.006	0.004	7000	130	3.75	8398	1398	7265	8663	0.27	0.016
11.0	11.5	0.006	0.004	7000	130	4.25	8463	1463	6891	8354	0.26	0.015
11.5	12.0	0.006	0.004	7000	130	4.75	8528	1528	6503	8030	0.25	0.015
12.0	12.5	0.006	0.004	7000	130	5.25	8593	1593	6112	7705	0.23	0.014
12.5	13.0	0.006	0.004	7000	130	5.75	8658	1658	5728	7385	0.22	0.013
13.0	13.5	0.006	0.004	7000	130	6.25	8723	1723	5356	7079	0.21	0.013
13.5	14.0	0.006	0.004	7000	130	6.75	8788	1788	5002	6789	0.20	0.012
14.0	14.5	0.006	0.004	7000	130	7.25	8853	1853	4667	6519	0.19	0.011
14.5	15.0	0.006	0.004	7000	130	7.75	8918	1918	4353	6271	0.17	0.010
15.0	15.5	0.006	0.004	7000	130	8.25	8983	1983	4061	6044	0.16	0.010
15.5	16.0	0.006	0.004	7000	130	8.75	9048	2048	3791	5838	0.15	0.009


P=
A-1
hF
84 in
21 in
5 in
101 in
δ=130 PCF


P=
B-1
hF
84in
21 in
5 in
101
δ= 130 PCF

P=

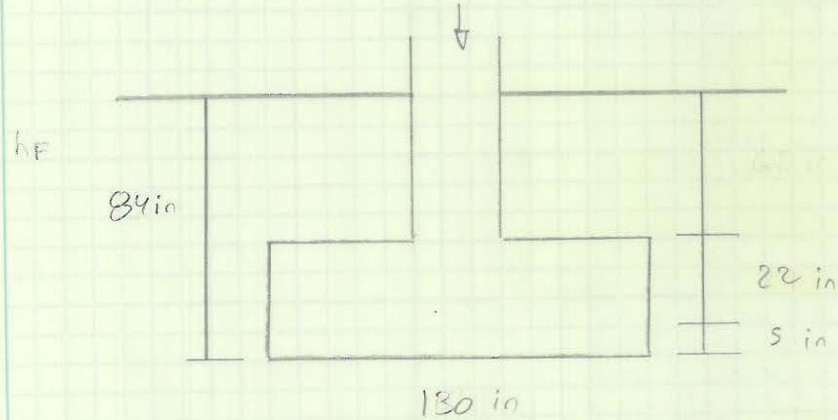
C1-D1-E1-F1



γ = 130 PCF

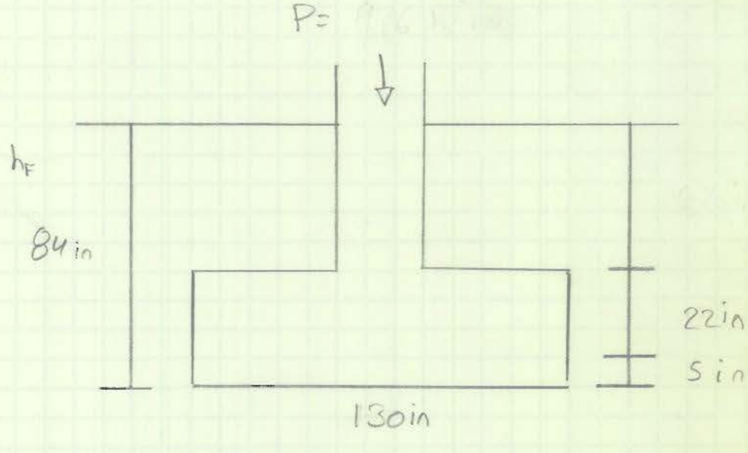
P=

C2,3-D23-E23-F23



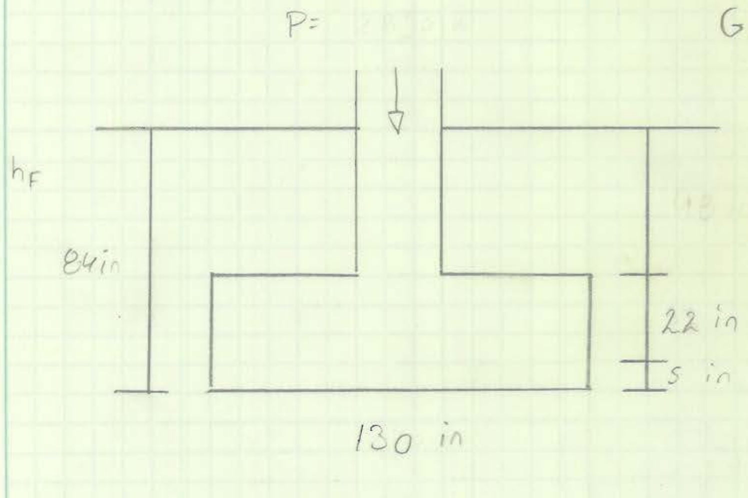
δ = 130 PCF

G1

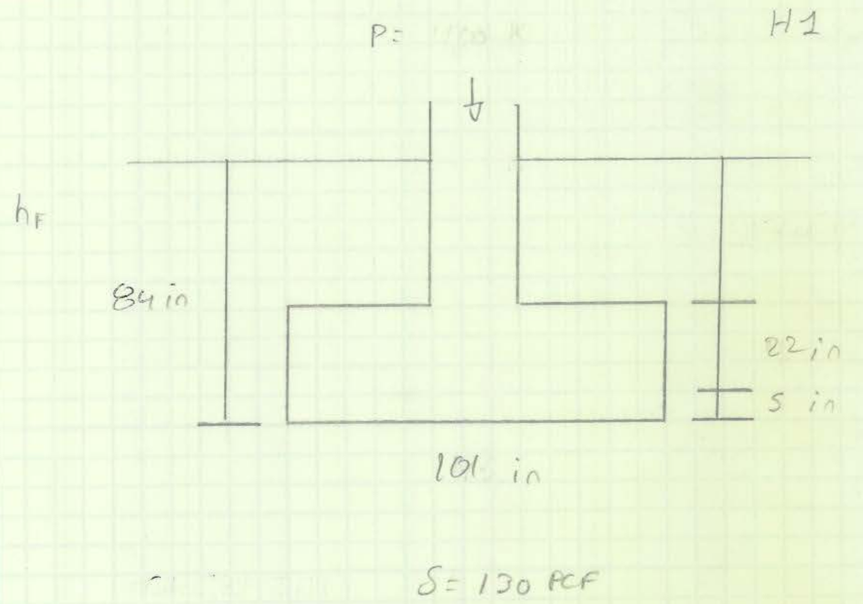


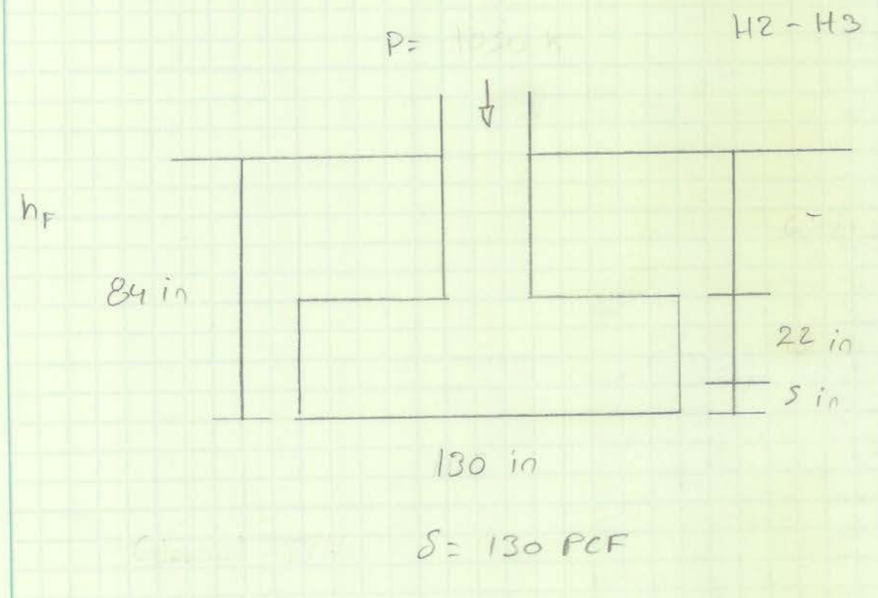
γ = 130 PCF

G2-G3

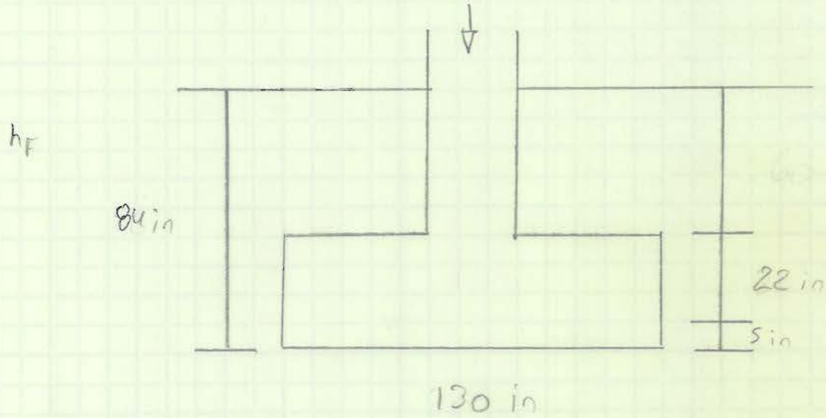


γ = 130 PCF


P=
H1
h_F
84 in
22 in
5 in
101 in
δ= 130 PCF

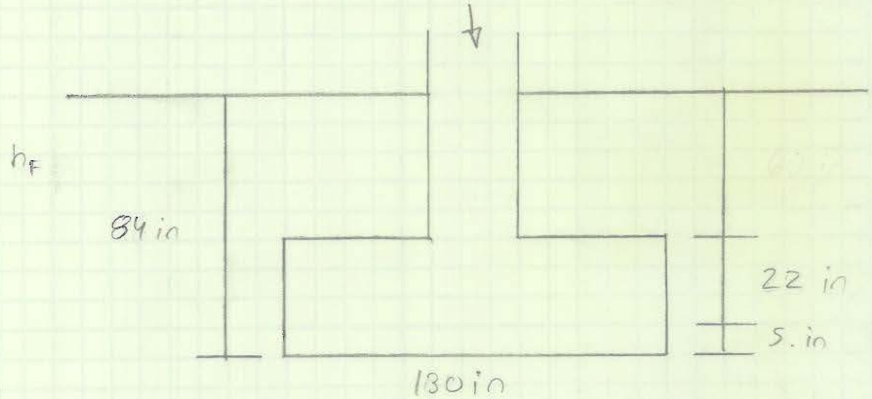

P=
H2 - H3
h_F
84 in
22 in
5 in
130 in
δ= 130 PCF

P=   C6-C7-C8-C9

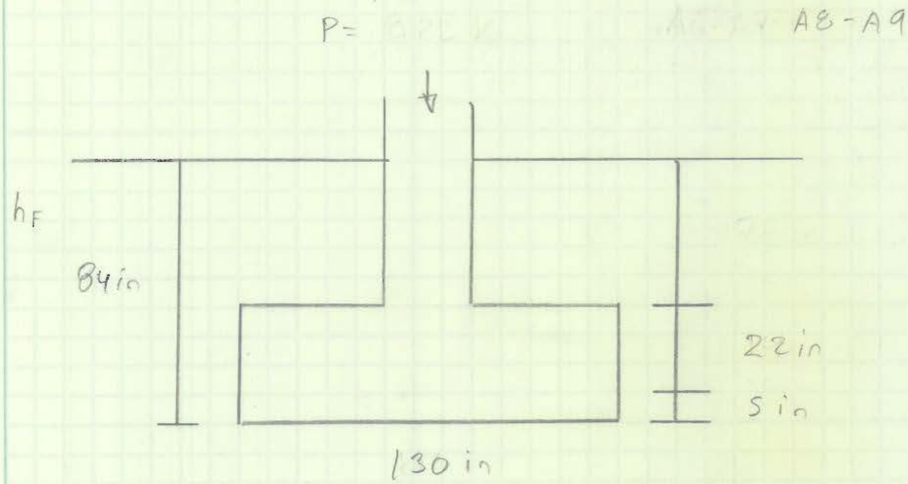


γ = 130 PCF

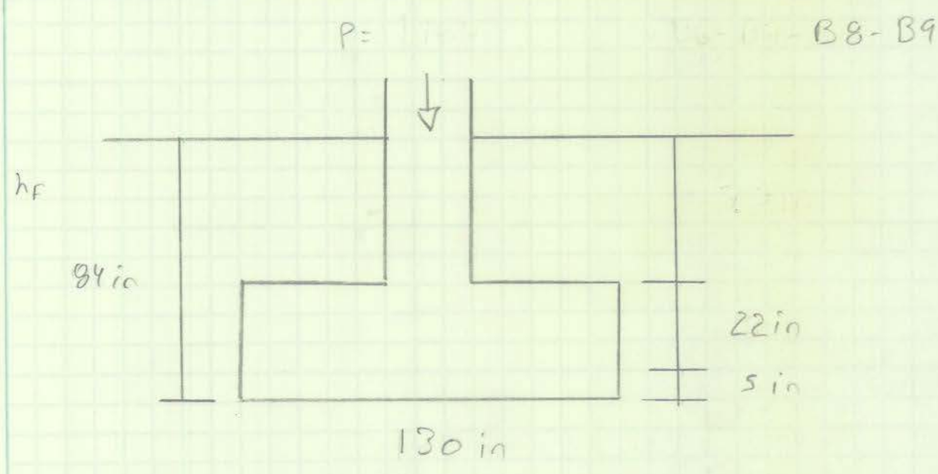
P=   C4-C5



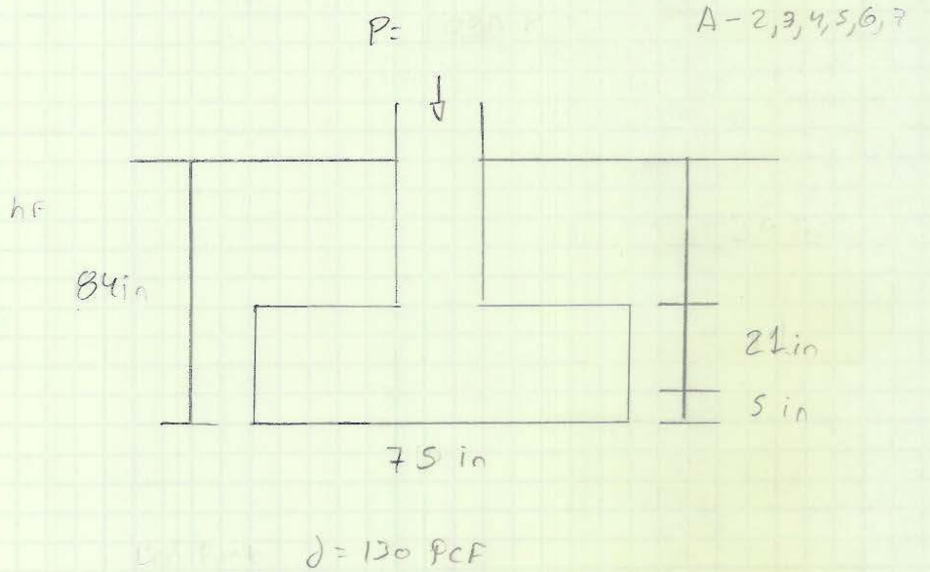
γ = 130 PCF

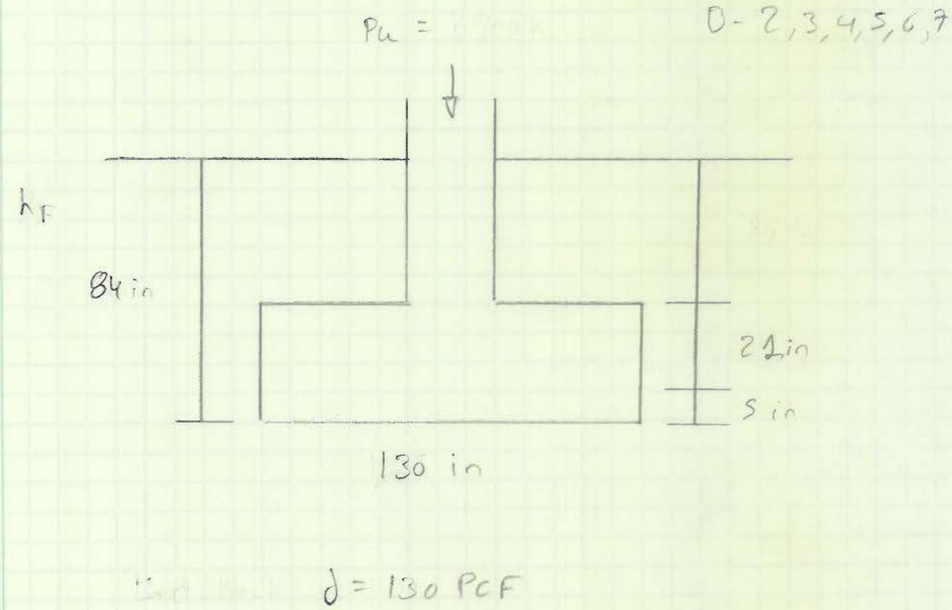


γ = 130 PCF



γ = 130 PCF


P=
A - 2,3,4,5,6,7
hF
84in
21in
5 in
75 in
ɣ = 130 PCF


Pu =
D- 2,3,4,5,6,7
hF
84in
21in
5 in
130 in
ɣ = 130 PCF

Geotecnical Design | Terzaghi | Type #1

- Terzaghi Ultimate bearing Capacity: (Calculated with excel)

$q_{ult} = 1.3c'N_c + \sigma'_{zD} N_q + 0.4\gamma' B N_\gamma$

$\gamma = 135$ PCF

$\phi = 32$

$q_{ult} = 43.54$ KSF

$q_{allowable} = \frac{q_{ult}}{2.5}$ → F.S = Fig 6.11 (Coduto)

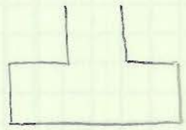
$q_{allowable} = \underline{17.41 \text{ KSF}}$

$q = \frac{P + W_F}{B^2} = \frac{(985 + 22.9)}{70.89} = \underline{14.21 \text{ KSF}}$

$q \leq q_{allowable}$

14.21 KSF ≤ 17.41 KSF ✓ OK

Settlement Calculations



Type #1 Load = 540 kips

(101 in x 101 in) x 26 in

(8.42 FT x 8.42 FT) x 2.16 FT

$\gamma = 140$ PCF

Depth = 8 FT

$\sigma_{zD} = \gamma \cdot h = 1120$ PCF

$$q = \frac{P + W_F}{B^2} = \frac{(540 + 22.9)}{70.89} = \underline{14.21 \text{ KSF}}$$

Induced Stress:

$$\Delta\sigma_z = \left[1 - \left(\frac{1}{1 + \left(\frac{B}{2z_F}\right)^2}\right)^{1.76}\right](q - \sigma'_{zD})$$

Assuming $z_F = 2'$

$$\Delta\sigma_z = \left[1 - \left(\frac{1}{1 + \left(\frac{8.42}{4}\right)^2}\right)^{1.76}\right](14.21 - 1.12)$$

$$= (0.94) \times (13.09) = \underline{12.42 \text{ KSF}}$$

Effective Stress:

$$\sigma'_{zF} = \sigma'_{z0} + \Delta\sigma_z$$

$$\sigma'_{z0} = \gamma H - \cancel{u^0} = (140)(9) = \underline{1.26 \text{ ksf}}$$

$$\sigma'_{zF} = (1.26) + (12.42) = \underline{13.68 \text{ ksf}}$$

$$\delta_c = r \sum \frac{C_c}{1+e_0} H \log\left(\frac{\sigma'_{zF}}{\sigma'_{z0}}\right)$$

$r = 0.85$ Table 7.1 Donald P. Coduto

$\frac{C_c}{1+e_0} = 0.006$ Table 3.5 3.7 Donald P. Coduto

$$\delta_c = 0.85(0.006)(8) \log\left(\frac{13.68}{1.26}\right)$$

$\delta_c = 0.35 = \delta$

$\delta_a = 1$ in $\rightarrow$ Table 2.1 Donald P. Coduto

$\delta \leq \delta_a$

0.35 in ≤ 1 in ok ✓

Flexural Stress	Type #1	

- Cantilever distance:

$$I = \frac{B - c}{2}$$

$$I = \frac{(101\,in - 12\,in)}{2} = 44.5\ in$$

Flexural stress:

$$M_{uc} = \frac{P_u\, I^2}{2B}$$

$$M_{uc} = \frac{(540) \times (44.5)^2}{2 \times 101} = 9656.16\ Lb/in$$

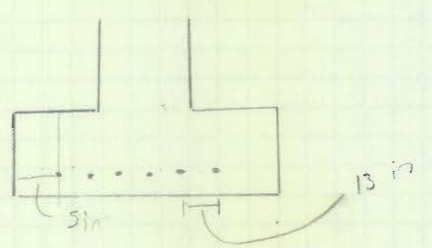
Area of Steel:

$$A_s = \left(\frac{F'_c\, b}{1.176\, F_y}\right) \cdot \left(d - \sqrt{d^2 - \frac{2.353\, M_{uc}}{\phi\, F'_c\, b}}\right)$$

$$A_s = \left(\frac{(4000)(35.5)}{(1.176)(60{,}000)}\right) \cdot \left(20.5 - \sqrt{\frac{20.5^2 - (2.353)(9656)}{(0.90)(4000)(35.5)}}\right)$$

$$A_s = 4.72\ in^2$$

6 # 8 bars at 13 in
each way.



AMPAD

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Geotecnical design	Terzaghi	Type #2

- Terzaghi ultimate bearing capacity: (calculated with excel)

$q_{ult} = 1.3c'N_c + \sigma'_{zD} N_q + 0.4\gamma' B N_\gamma$ $\gamma = 130$ PCF

$q_{ult} = \underline{24.41 \text{ KSF}}$ $\phi = 28$

$q_{allowable} = \frac{q_{ult}}{2.5}$ → F.S = Fig 6.11 (Coduto)

$q_{allowable} = \underline{9.76 \text{ KSF}}$

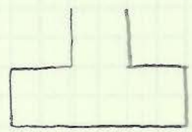
$q = \frac{P + W_F}{B^2} = \frac{(972 + 39.5)}{117.28} = \underline{8.62 \text{ KSF}}$

$q \leq q_{allowable}$

$8.62 \text{ KSF} \leq 9.76 \text{ KSF}$ ✓ OK

AMPAD

Settlement Calculation



Type # 2 Load = 972 kips

(130 in × 130 in) × 27 in

(10.83 ft × 10.83 ft) × 2.25 ft

$\gamma = 130$ PCF

Depth = 7 FT

$\sigma_{z0} = \gamma \cdot h = 910$ PCF

$$q = \frac{P + W_F}{B^2} = \frac{(972 + 39.5)}{117.28} = \underline{8.62 \text{ KSF}}$$

Induced Stress:

$$\Delta\sigma_z = \left[1 - \left(\frac{1}{1+\left(\frac{B}{2 \cdot z_f}\right)^2}\right)^{1.76}\right](q - \sigma'_{z0})$$

Assuming $z_F = 2'$

$$\Delta\sigma_z = \left[1 - \left(\frac{1}{1+\left(\frac{10.83}{4}\right)^2}\right)^{1.76}\right](8.62 - 0.91)$$

$$= (0.87) \times (7.71) = 6.78 \text{ KSF}$$

Effective Stress:

$$\sigma'_{zF} = \sigma'_{z0} + \Delta\sigma_z$$

$$\sigma'_{z0} = \gamma H - \cancel{u}^{D0} = (130)(8) = \underline{1.04 \text{ ksf}}$$

$$\sigma'_{zF} = (1.04) + (6.78) = \underline{7.82 \text{ ksf}}$$

$$\delta_c = r \sum \frac{C_c}{1+e_0} H \log\left(\frac{\sigma'_{zF}}{\sigma'_{z0}}\right)$$

$r = 0.85$ Table 7.1 Donald P. Coduto

$\frac{C_c}{1+e_0} = 0.006$ Table 3.5 / 3.7 Donald P. Coduto

$$\delta_c = 0.85(0.006)(7)\log\left(\frac{7.82}{1.04}\right)$$

$\delta_c = 0.42 = \delta$

$\delta_a = 1\,in \rightarrow$ Table 2.1 Donald P. Coduto

$\delta \leq \delta_a$

$0.42\,in \leq 1\,in$ ok ✓

Flexural Stress | Type #3

- Cantiliver distance:

$$I = \frac{B - C}{2}$$

$$I = \frac{(130 - 12)}{2} = 59 \text{ in}$$

Flexural Stress:

$$M_{uc} = \frac{P_u \, I^2}{2B}$$

$$M_{uc} = \frac{(972) \times (59)^2}{2 \times 130} = 13013 \text{ lb/in}$$

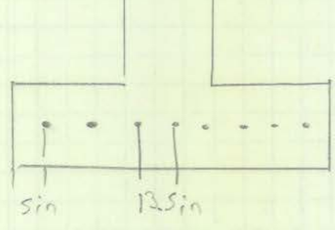
Area of Steel:

$$A_s = \left(\frac{F'_c \, b}{1.176 \, F_y}\right) \cdot \left(d - \sqrt{\frac{d^2 - (2.353)(9656)}{\phi \, F'_c \, b}}\right)$$

$$A_s = \left(\frac{(4000)(30.5)}{(1.176)(60000)}\right) \cdot \left(22 - \sqrt{\frac{22^2 - (2.353)(13013)}{(0.90)(4000)(22)}}\right)$$

$A_s = 6.318 \text{ in}^2$

8 #8 bars at 13.5 in

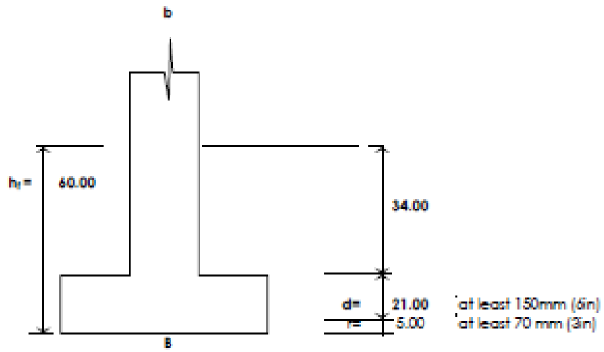


Design of Square Base shallow Foundation:

Parking Garage Project:

Mechanical characteristics of Materials			
σ_{adm} =	116.00	Psi	Allowable Stress Soil
γ_s =	140.00	lb/ft^3	Unit weight soil
γ_c =	150.00	lb/ft^3	Unit Weigt concrete
hf=	60.00	in	Deepness of foundation
bx colum.=	24.00	in	width of the column
by colum.=	24.00	in	length of the column
d asummed=	16.00	in	Effective height of foundation
Actual Loads			
Pu	985.00	Kips	Axial Load (Live Load)
M Ll x-x =	0.00	Kip-Feet	Moment of Live Load in X-X direccion
M cm x-x =	0.04	Kip-Feet	Moment of Dead Load in X-X direccion
P cs =	0.00	Kip	Axial Load (Earth quake)
M cs x-x	0.00	Kip-Feet	Moment seismic Load in X-X direccion
f'c =	4,000.00	lb/in^2	28-day compressive strength of concrete
fy=	0.00	lb/in2	Yield strength of steel
column Location=			Interior

Shallow Foundation type



Foundation Predimension

Predimension of 'Bx' = 'By'

AREA= (α x Pt)/σadm

α= 1.20

Pt= 985,000.00 Lb

Where: α: Resistance Factor: 1,15 si h <= 1,50 m / 1,20 si 1,5 < h <3 m / 1,30 si 3 < h <= 5 m

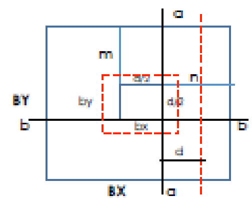
Pt: Axial Loads

σadm: Allowable Stress.

AREA= 10,189.66 in2 — Bx=By= 100.94 in Calculated — n= 38.5 in

Bx=By= 101.00 in Asumed — m= 38.5 in

A $_{Real}$= 10,201.00 in2



Foundation Design

Critical height Estimation 'd'

σult= Pu / Area

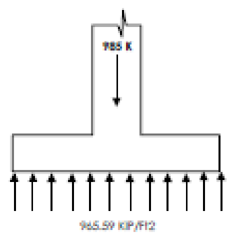
σult= 96.56 lb/in^2

where: Pu = 1.4CP + 1.7CV — Pu= 985.00 Kip

Mu_a= σult x By x (n^2)/2 — Mu_a= 7.228E+06 lb/in

$$d \geq \sqrt{\frac{Mu}{\mu\, F'c\, B}}$$

Where: μ= 0,1448 — d≥ 11.12 in Cálculo — **d= 21.00 Assumed**



CHECK FOR FLEXURAL FAILURE

Shear force on critical surface from "d" :

Uu≤ Uc — Where:

Shear stress	Uu= Vu / (ϕ B d)	Uu= 94.67	Lb/in2	
Shear at 'd' of the column	Vu= σult x By x (n-d)	Vu= 170,668	Lb	Ok Uu<Vc
Nominal Shear of concrete	Uc= 0,53 $\sqrt{F'c}$	Vc= 119.67	Lb/in2	
Resistance factor	0.85			

CHECK FOR TWO-WAY SHEAR FAILURE

Shear force on critical surface from "d/2" :

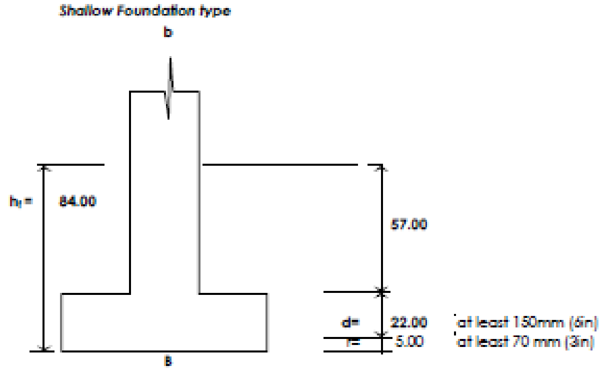
Uu≤ Uc — Where:

Factored Shear force	Uu= Vu / (ϕ b_0 d)	b_0= 180	in	
Applied shear load from b_0	Vu= Pu - σult x $(b+d)^2$	Uu= 246	Lb/in2	
Nominal Two-way Shear of concrete	Vc= 1,06 $\sqrt{F'c}$	Vu= 789,468	Lb	Ok Uu<Vc
Resistance factor	ϕ= 0.85	Vc= 256	Lb/in2	
Length of one face of inner block	b_0= 4(b+d)	b'_0= 324	Lb	
bx=by of Pedestal	b'= 60 in	U'u= 137	Lb/in2	Ok Uu<Vc
Height of Pedestal	h'= 10 in			

Design of Square Base shallow Foundation:

Parking Garage Project:

Mechanical characteristics of Materials			
σ_{adm} =	71.10	Psi	Allowable Stress Soil
γ_s =	130.00	lb/ft^3	Unit weight soil
γ_c =	150.00	lb/ft^3	Unit Weigt concrete
hf=	84.00	in	Deepness of foundation
bx colum.=	24.00	in	width of the column
by colum.=	24.00	in	length of the column
d asummed=	16.00	in	Effective height of foundation
Actual Loads			
Pu	972.00	Kips	Axial Load (Live Load)
M Ll x-x =	0.00	Kip-Feet	Moment of Live Load in X-X direccion
M cm x-x =	0.04	Kip-Feet	Moment of Dead Load in X-X direccion
P cs =	0.00	Kip	Axial Load (Earth quake)
M cs x-x	0.00	Kip-Feet	Moment seismic Load in X-X direccion
f'c =	4,000.00	lb/in^2	28-day compressive strength of concrete
fy=	0.00	lb/in2	Yield strength of steel
column Location=			Interior



Foundation Predimension

Predimension of 'Bx' = 'By'

AREA= (υ x Pt)/σadm

υ= 1.20

Pt= 972,000.00 Lb

Where: υ: Resistance Factor: 1,15 si h <= 1,50 m / 1,20 si 1,5 < h <3 m / 1,30 si 3 < h <= 5 m

Pt: Axial Loads

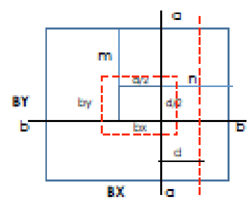
σadm: Allowable Stress.

AREA= 16,405.06 In2

Bx=By= 128.08 in Calculated n= 53 in

Bx=By= 130.00 in Asumed m= 53 in

A_{Real}= 16,900.00 in2



Foundation Design

Critical height Estimation 'd'

σult= Pu / Area

σult= 57.51 lb/in^2

where: Pu = 1.4CP + 1.7CV Pu= 972.00 Kip

Mu_c= σult x By x (n^2)/2

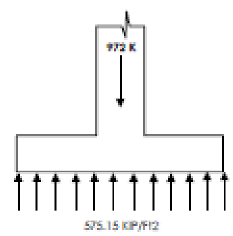
Mu_c= 1.050E+07 lb/in

$$d \geq \sqrt{\frac{Mu}{\mu\, F'c\, B}}$$

Where: μ= 0,1448

d≥ 11.81 in Cálculo

d= 22.00 Assumed



CHECK FOR FLEXURAL FAILURE

Shear force on critical surface from "d" :

υu≤ υc Where:

Shear stress	υu= Vu / (ϕ B d)	υu= 95.35	Lb/in2	
Shear at 'd' of the column	Vu= σult x By x (n-d)	Vu= 231,785	Lb	Ok υu<Vc
Nominal Shear of concrete	υc= 0,53 $\sqrt{F'c}$	Vc= 119.67	Lb/in2	
Resistance factor	0.85			

CHECK FOR TWO-WAY SHEAR FAILURE

Shear force on critical surface from "d/2" :

υu≤ υc Where:

Factored Shear force	υu= Vu / (ϕ b_0 d)	b_0= 184	in	
Applied shear load from b_o	Vu= Pu - σult x (b+d)^2	υu= 247	Lb/in2	
Nominal Two-way Shear of concrete	Vc= 1,06 $\sqrt{F'c}$	Vu= 850,299	Lb	Ok υu<Vc
Resistance factor	ϕ= 0.85	Vc= 256	Lb/in2	
Length of one face of inner block	b_0= 4(b+d)	b'_0= 328	Lb	
bx=by of Pedestal	b'= 60 in	υ'u= 139	Lb/in2	Ok υu<Vc
Height of Pedestal	h'= 10 in			

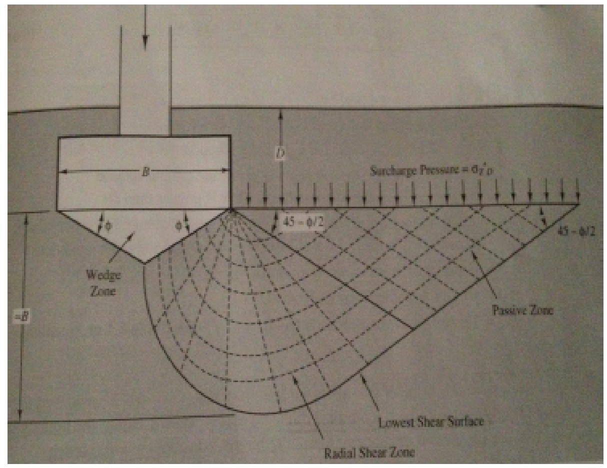
IMPUT VALUES

c' (Effective cohesion for soil)	**0**	lb/ft^2
B (width)	**8.42**	ft
Φ' (effective friction angle)	**32**	
D (depth of foundation)	**8**	
γ' (unit weight of soil)	**135**	lb/ft^2

VERTICAL EFFECTIVE STRESS

$$\boxed{\vartheta = (D)x(\gamma')}$$

σ (vertical effective stress) 1080 lb/ft^2



a_θ (FARCTOR IN N_q equation)

$$\boxed{a_\theta = e^{\pi(0.75 - \theta'/360)\tan\theta'}}$$

a_θ 4

N_q N_c N_γ (Bearing Capacity Factors)

$$\boxed{N_q = \frac{a_\theta^2}{2\cos^2(45 + \phi'/2)}}$$

Nq 28.51162092

$$\boxed{N_c = \frac{N_q - 1}{\tan\phi'}}$$ for Φ' >0

$$\boxed{N_c = 5.7}$$ for Φ' = 0

Nc 44.02779692

$$\boxed{N_\gamma = \frac{2(N_q + 1)\tan\phi'}{1 + 0.4\sin(4\phi')}}$$

Ny 28.04265074

Q_{ult} Soil bearing capacity

$$\boxed{q_{ult} = 1.3c' N_c + \sigma'_{zd} N_q + 0.4\gamma' B N_\gamma}$$

Qult(ultimate bearing capacity) 43542.98304 lb/ft^2

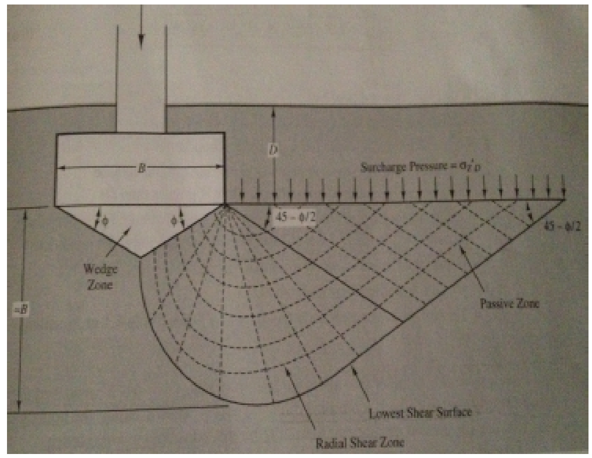
IMPUT VALUES

c' (Effective cohesion for soil)	**0**	lb/ft^2
B (width)	**10.83**	ft
Φ' (effective friction angle)	**28**	
D (depth of foundation)	**7**	
γ' (unit weight of soil)	**130**	lb/ft^2

VERTICAL EFFECTIVE STRESS

$$\boxed{\vartheta = (D)x(\gamma')}$$

σ (vertical effective stress) 910 lb/ft^2



a_θ (FARCTOR IN N_q equation)

$$\boxed{a_\theta = e^{\pi(0.75-\theta'/360)\tan\theta'}}$$

a_θ 3

N_q N_c N_γ (Bearing Capacity Factors)

$$\boxed{N_q = \frac{a_\theta^2}{2\cos^2(45+\phi'/2)}}$$

Nq 17.80556253

$$\boxed{N_c = \frac{N_q - 1}{\tan\phi'}}$$ for Φ' >0

$$\boxed{N_c = 5.7}$$ for Φ' = 0

Nc 31.60666621

$$\boxed{N_\gamma = \frac{2(N_q+1)\tan\phi'}{1+0.4\sin(4\phi')}}$$

Ny 14.58791735

Q_{ult} Soil bearing capacity

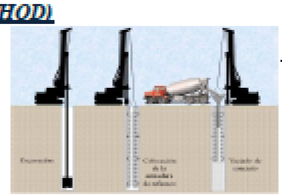
$$\boxed{q_{ult} = 1.3c'N_c + \sigma'_{zd}N_q + 0.4\gamma'BN_\gamma}$$

Qult(ultimate bearing capacity) 24418.39344 lb/ft^2

Excavated Drill Shaft in Granular Soil (MEYERHOF METHOD)

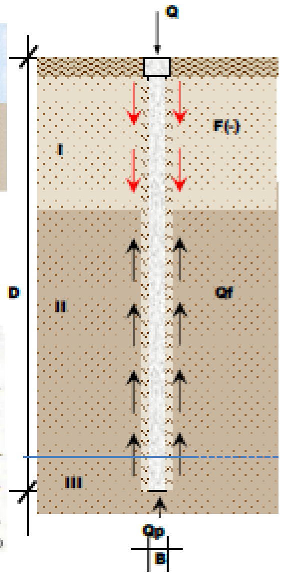
Properties	Layer I (fill)	Layer II (Glacial Till)	Layer III (Bed Rock)	Description
Prof. D =	7.50 ft	13.00 ft	17.00 ft	Depth
γ_s (KIP/ft^3)=	0.12	0.13	0.14	Soil Unit Weight
ϕ' =	27.00 °	29.00 °	32.00 °	Effective Friction Angle
%<#200	20.00	18.00	20.00	#Sieve analysis passing N200
D(fn)=	7.50 ft	-	-	Depth of the Fill
Fn (Kip/ft^2)=	2.25	-	-	Negative friction factor

Pile Diameter, Factors of safesty and Materials Resistance		
Diam. B =	4.50 ft	Pile Diameter
FSf:	1.25	Factor of safesty applied to friction
FSp:	2.00	Factor of safesty at the Toe
fy= psi	60,000	Steel yield Resistance
f'c psi	3,500	Concrete Strength at 28 Days



Construction Procedure

Pile type 1

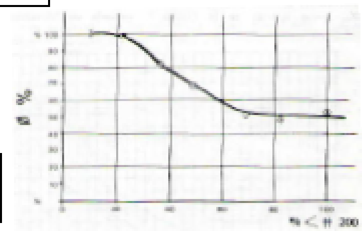


ϕ Correction According to % < #200

% < #200	ϕ
0 - 20	100% ϕ
21- 58	%ϕ= -1,05(%f)+121,05
59 - 70	%ϕ= -2/3(%f)+98,66
71 - 100	(Silt) %ϕ= -6,66x10^{-2} (%f)+56,66
72 - 100	(Clays) Cohesive Soils

Layer II	
% < #200	ϕ
18.00	29.00

Layer III	
% < #200	ϕ
20.00	32.00



Unit Friction Resistance

Q_f= Ph x Tg δ

Ph= K x Pv

Pv= γ x d

d= 14.00

Pv= 1.82 Kip/ft^2

Ph= 0.91 Kip/ft^2

Where: Ph: Lateral Preassure alon column

Tg δ: Friction Coefficient between Soil and pile e = % ϕ

ϕ= correction od the internal friction angle % #200

K: Coeficient for lateral preassure of soil = 0,5 for excavated piles

Pv: Geostatic preassure or effective vertical preassure

γ : Soil Specific Weight — B : Pile Diameter

D : Pile depth for constant Vertical pressure

D=10B for $\phi \le 33°$ — D=15B for $\phi \ge 33°$ — D= 45.00 ft

Layer II (Glacial Till)		
Q_f=	0.50	Kip/ft^2

Load Determination due to negative friction (Layer I)

Qfn= Fn x As

As= Pi x B x D(fn)

As= 106.03 ft^2

Qfn=	238.56	Kip	Layer I

Where Fn= Negative Friction Factor (Depends on quality and age of the fill)

As= Pile Surface Area in contact with fill

D(fn)= Length of fill subjected to negative friction

B : Pile Diameter

Resistance at toe

Determinate the critical depth 'Dc'

Dc= 4 x B x Tg (45+ϕ/2)

Dc=	30.56	ft

Where: ϕ=correction of the internal friction angle % #200

B : Pile Diameter

Check for efective depth'D' Vs critical depth'Dc'

Q_p= Pv x N'q $\le$ql

Pv= γ x d

d= 45.00

Pv= 6.08 Kip/ft^2

N'q= 10 $^{2.7 \, Tg\phi}$

N'q= 48.66

N"q= (N'q-Nq) x (D/Dc) + Nq

Nq= 24.92 — ϕ_{Corr}= 32.0

N"q= 30.75

Where: Pv: Effective Vertical Preassure

γ : Soil Specific Weight

D : Pile Depth — B : Pile Diameter

D=10B for $\phi \le 33°$

D=15B for $\phi \ge 33°$ — D= 45.00 m

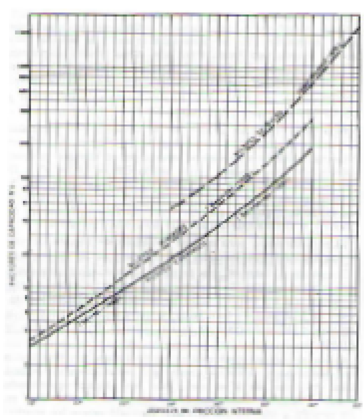
N'q= Load Capacity factor if D $\ge$ Dc

ql= Limit value of tall unit resistanc.

ql=1,16 (ϕ - 28,3°)^2 for $\phi \le 35°$ (in kip/ft2)

ql=1,92 (ϕ - 29,8°)^2 for $\phi > 35°$ (in kip/ft2)

N"q= Load capacity factor D < Dc



D<Dc we will N"q Correcting N'q

Q_p= 186.78 Kip/ft^2

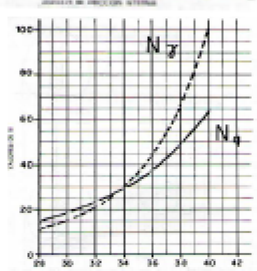
ql= 15.88 Kip/ft^2 — 1 Ton/ft2= 9,765 Ton/m2

ql= 155.07 Kip/ft^2

Q_p=	155.07	Kip/ft^2	We will use the limit q

Nq Factor for correccion of N'q

ϕ	Nq
0 $\le \phi <$ 32,6	0,31ϕ + 15
32,6 $\le \phi <$ 35,5	3,45ϕ - 87,41
35,5 $\le \phi <$ 38,2	5,55ϕ - 162,22
38,2 $\le \phi <$ 40	7,22ϕ - 225,88



Ultimate Capacity Loads

For Friction effect between soils and piles Where:

QF= Qf x As — As=Area in contact with fill.

As= 134.30 Ft^2 — Ap= Area in the pile Toe

QF=	67.75	KIP

For accion in the pile toe

QP= Qp x Ap

Ap= 15.90 ft^2

QP=	2,466.32	Kip

Admissible Capacity considering Negative Friction

Q_{allow}= (QF / FsF + QP / FSp) - Qfn

Qallow=	1,048.79	Kip

Check for Concrete Resistance

$\sigma_{Concreto} \le$ 0,25 F'c — 0,25F'C= 875.00 lb/ft2

σ_{allow} = Q_{allow} / Ap = 6.59 lb/ft2 — Check!!!

Longitudinal and Transversal Steel according to ASCE norms

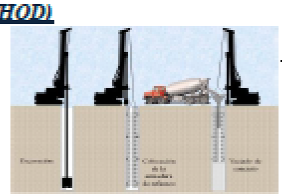
As $_{Min}$= 0,5% Area del Piloto — As $_{Min}$= 22.90 in2

ϕ Rebar	Quantity	Legth	Hooks ϕ 3/8" each 5 1m x 5 ϕP
7/8	38	17.00	Hooks ϕ 3/8"

Excavated Drill Shaft in Granular Soil (MEYERHOF METHOD)

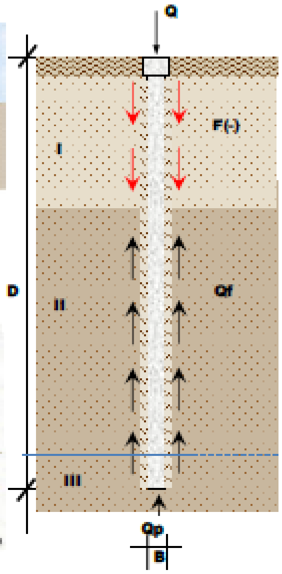
Properties	Layer I (fill)	Layer II (Glacial Till)	Layer III (Bed Rock)	Description
Prof. D =	7.50 ft	13.00 ft	17.00 ft	Depth
γ_s (KIP/ft^3)=	0.12	0.13	0.14	Soil Unit Weight
ϕ' =	27.00 °	29.00 °	32.00 °	Effective Friction Angle
%<#200	20.00	18.00	20.00	#Sieve analysis passing N200
D(fn)=	7.50 ft	-	-	Depth of the Fill
Fn (Kip/ft^2)=	2.25	-	-	Negative friction factor

Pile Diameter, Factors of safesty and Materials Resistance		
Diam. B =	4.15 ft	Pile Diameter
FSf:	1.25	Factor of safesty applied to friction
FSp:	2.00	Factor of safesty at the Toe
fy= psi	60,000	Steel yield Resistance
f'c psi	3,500	Concrete Strength at 28 Days



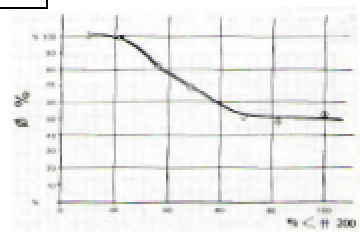
Construction Procedure

Pile type 1



ϕ Correction According to % < #200

% < #200	ϕ
0 - 20	100% ϕ
21- 58	%ϕ= -1,05(%f)+121,05
59 - 70	%ϕ= -2/3(%f)+98,66
71 - 100	(Silt) %ϕ= -6,66x10^{-3} (%f)+56,66
72 - 100	(Clays) Cohesive Soils



Layer II	
% < #200	ϕ
18.00	29.00

Layer III	
% < #200	ϕ
20.00	32.00

Unit Friction Resistance

Q_f= Ph x Tg δ — Where: Ph: Lateral Preassure alon column

Ph= K x Pv — Tg δ: Friction Coefficient between Soil and pile e = % ϕ

Pv= γ x d — ϕ= correction od the internal friction angle % #200

d= 14.00 — K: Coeficient for lateral preassure of soil = 0,5 for excavated piles

Pv= 1.82 Kip/ft^2 — Pv: Geostatic preassure or effective vertical preassure

Ph= 0.91 Kip/ft^2 — γ : Soil Specific Weight — B : Pile Diameter

D : Pile depth for constant Vertical pressure

D=10B for $\phi \le 33°$ — D=15B for $\phi \ge 33°$ — D= 41.50 ft

Layer II (Glacial Till)		
Q_f=	0.50	Kip/ft^2

Load Determination due to negative friction (Layer I)

Qfn= Fn x As — Where Fn= Negative Friction Factor (Depends on quality and age of the fill)

As= PI x B x D(fn) — As= Pile Surface Area in contact with fill

As= 97.78 ft^2 — D(fn)= Length of fill subjected to negative friction

Qfn=	220.01	Kip	Layer I

B : Pile Diameter

Resistance at toe

Determinate the critical depth 'Dc'

Dc= 4 x B x Tg (45+ϕ/2) — Where: ϕ=correction of the internal friction angle % #200

Dc=	28.18	ft

B : Pile Diameter

Check for efective depth'D' Vs critical depth'Dc'

Q_p= Pv x N'q ≤ql — Where: Pv: Effective Vertical Preassure

γ : Soil Specific Weight

Pv= γ x d — D : Pile Depth — B : Pile Diameter

d= 41.50 — D=10B for $\phi \le 33°$

Pv= 5.60 Kip/ft^2 — D=15B for $\phi \ge 33°$ — D= 41.50 m

N'q= Load Capacity factor if D ≥ Dc

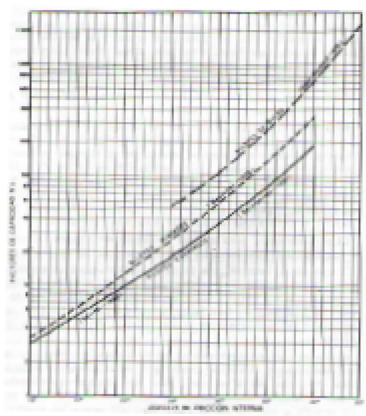
N'q= 10 $^{2.7\,Tg\phi}$ — ql= Limit value of fall unit resistanc.

N'q= 48.66 — ql=1,16 (ϕ - 28,3°)^2 for $\phi \le 35°$ (in kip/ft2)

N"q= (N'q-Nq) x (D/Dc) + Nq — ql=1,92 (ϕ - 29,8°)^2 for ϕ > 35° (in kip/ft2)

Nq= 24.92 — ϕ_{Corr}= 32.0 — N"q= Load capacity factor D < Dc

N"q= 31.24



D<Dc we will N"q Correcting N'q

Nq Factor for correccion of N'q

ϕ	Nq
0 ≤ ϕ < 32,6	0,31ϕ + 15
32,6 ≤ ϕ < 35,5	3,45ϕ - 87,41
35,5 ≤ ϕ < 38,2	5,55ϕ - 162,22
38,2 ≤ ϕ < 40	7,22ϕ - 225,88

Q_p= 175.01 Kip/ft^2

ql= 15.88 Kip/ft^2 — 1 Ton/ft2= 9,765 Ton/m2

ql= 155.07 Kip/ft^2

Q_p=	155.07	Kip/ft^2	We will use the limit q

Ultimate Capacity Loads

For Friction effect between soils and piles — Where:

QF= Qf x As — As=Area in contact with fill.

As= 123.86 Ft^2 — Ap= Area in the pile Toe

QF=	62.48	KIP

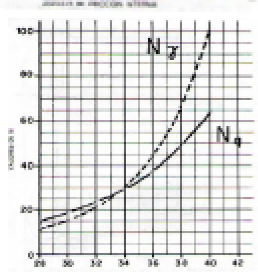
For accion in the pile toe

QP= Qp x Ap

Ap= 13.53 ft^2

QP=	2,097.59	Kip

Qallow=	878.76 Kip



Admissible Capacity considering Negative Friction

Q_{allow}= (QF / FsF + QP / FSp) - Qfn

Check for Concrete Resistance

$\sigma_{Concreto} \le$ 0,25 F'c — 0,25FC= 875.00 lb/ft2

σ_{allow} = Q_{allow} / Ap = 6.50 lb/ft2 — Check!!!

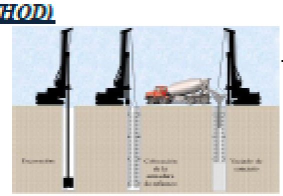
Longitudinal and Transversal Steel according to ASCE norms

As $_{Min}$= 0,5% Area del Pilote — As $_{Min}$= 19.48 in2

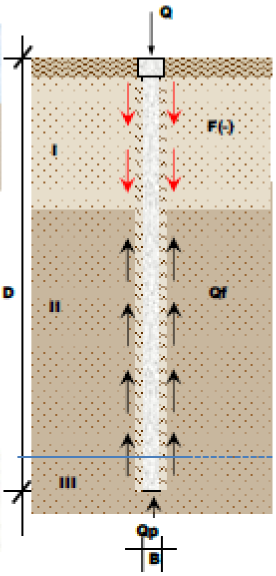
ϕ Rebar	Quantity	Legth	Hooks ϕ 3/8" each 5 1m x 5 ϕP
7/8	32	17.00	Hooks ϕ 3/8"

Excavated Drill Shaft in Granular Soil (MEYERHOF METHOD)

Properties	Layer I (Fill)	Layer II (Glacial Till)	Layer III (Bed Rock)	Description
Prof. D =	7.50 ft	13.00 ft	17.00 ft	Depth
γ_s (KIP/ft^3)=	0.12	0.13	0.14	Soil Unit Weight
ϕ' =	27.00 °	29.00 °	32.00 °	Effective Friction Angle
%<#200	20.00	18.00	20.00	#Sieve analysis passing N200
D(fn)=	7.50 ft	-	-	Depth of the Fill
Fn (Kip/ft^2)=	2.25	-	-	Negative friction factor
Pile Diameter, Factors of safesty and Materials Resistance				
Diam. B =	3.50 ft	Pile Diameter		
FSf:	1.25	Factor of safesty applied to friction		
FSp:	2.00	Factor of safesty at the Toe		
fy= psi	60,000	Steel yield Resistance		
f'c psi	3,500	Concrete Strength at 28 Days		

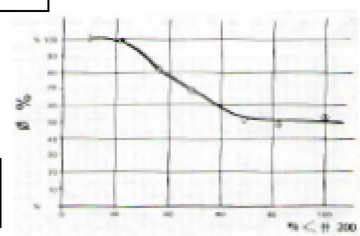


Pile type 1



ϕ Correction According to % < #200

% < #200	ϕ
0 - 20	100% ϕ
21- 58	%ϕ= -1,05(%f)+121,05
59 - 70	%ϕ= -2/3(%f)+98,66
71 - 100	(Silt) %ϕ= -6,66x10^{-2} (%f)+56,66
72 - 100	(Clays) Cohesive Soils



Layer II	
% < #200	ϕ
18.00	29.00

Layer III	
% < #200	ϕ
20.00	32.00

Unit Friction Resistance

Q_f= Ph x Tg δ — Where: Ph: Lateral Preassure alon column

Ph= K x Pv — Tg δ: Friction Coefficient between Soil and pile e = ¾ ϕ

Pv= γ x d — ϕ= correction od the internal friction angle % #200

d= 14.00 — K: Coeficient for lateral preassure of soil = 0,5 for excavated piles

Pv= 1.82 Kip/ft^2 — Pv: Geostatic preassure or effective vertical preassure

Ph= 0.91 Kip/ft^2 — γ : Soil Specific Weight — B : Pile Diameter

Layer II (Glacial Till)		
Q_f=	0.50	Kip/ft^2

D : Pile depth for constant Vertical pressure

D=10B for $\phi \le 33°$ — D=15B for $\phi \ge 33°$ — D= 35.00 ft

Load Determination due to negative friction (Layer I)

Qfn= Fn x As — Where Fn= Negative Friction Factor (Depends on quality and age of the fill)

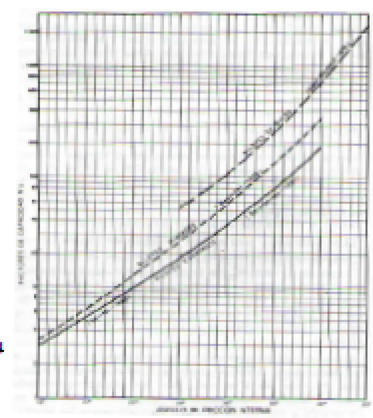
As= Pi x B x D(fn) — As= Pile Surface Area in contact with fill

As= 82.47 ft^2 — D(fn)= Length of fill subjected to negative friction

Qfn=	185.55	Kip	Layer I

B : Pile Diameter

Resistance at toe



Determinate the critical depth 'Dc'

Dc= 4 x B x Tg (45+ϕ/2) — Where: ϕ=correction of the internal friction angle % #200

Dc=	23.77	ft

B : Pile Diameter

Check for efective depth'D' Vs critical depth'Dc'

Q_p= Pv x N'q ≤ql — Where: Pv: Effective Vertical Preassure

γ : Soil Specific Weight

Pv= γ x d — D : Pile Depth — B : Pile Diameter

d= 35.00 — D=10B for $\phi \le 33°$

Pv= 4.73 Kip/ft^2 — D=15B for $\phi \ge 33°$ — D= 35.00 m

N'q= Load Capacity factor if D ≥ Dc

N'q= 10 $^{2.7 Tg\phi}$ — ql= Limit value of fall unit resistanc.

N'q= 48.66 — ql=1,16 (ϕ - 28,3°)^2 for $\phi \le 35°$ (in kip/ft2)

N"q= (N'q-Nq) x (D/Dc) + Nq — ql=1,92 (ϕ - 29,8°)^2 for $\phi > 35°$ (in kip/ft2)

Nq= 24.92 — ϕ_{Corr}= 32.0 — N"q= Load capacity factor D < Dc

N"q= 32.41

D<Dc we will N"q Correcting N'q

Q_p= 153.14 Kip/ft^2

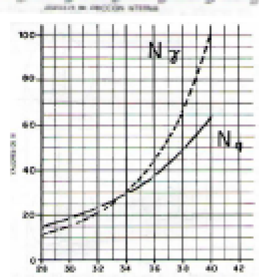
ql= 15.88 Kip/ft^2 — 1 Ton/ft2= 9,765 Ton/m2

ql= 155.07 Kip/ft^2

Q_p=	153.14	Kip/ft^2	Is less than ql: OK!

Nq Factor for correccion of N'q

ϕ	Nq
0 ≤ ϕ < 32,6	0,31ϕ + 15
32,6 ≤ ϕ < 35,5	3,45ϕ - 87,41
35,5 ≤ ϕ < 38,2	5,55ϕ - 162,22
38,2 ≤ ϕ < 40	7,22ϕ - 225,88



Ultimate Capacity Loads

For Friction effect between soils and piles — Where:

QF= Qf x As — As=Area in contact with fill.

As= 104.46 Ft^2 — Ap= Area in the pile Toe

QF=	52.69	KIP

For accion in the pile toe

QP= Qp x Ap

Ap= 9.62 ft^2

QP=	1,473.38	Kip

Admissible Capacity considering Negative Friction

Q_{allow}= (QF / FsF + QP / FSp) - Qfn

Qallow=	593.29 Kip

Check for Concrete Resistance

$\sigma_{Concreto} \le$ 0,25 Fc — 0,25FC= 875.00 lb/ft2

σ_{allow} = Q_{allow} / Ap = 6.17 lb/ft2 — Check!!!

Longitudinal and Transversal Steel according to ASCE norms

As $_{Min}$= 0,5% Area del Pilote — As $_{Min}$= 13.85 in2

ϕ Rebar	Quantity	Legth	Hooks ϕ 3/8" each 5 1m x 5 ϕP
7/8	23	17.00	Hooks ϕ 3/8"

Appendix E-Cost Estimate

Concrete Quantity takeoff				
Foundations	Units	# of units	Price/unit	Cost
Shallow Found Type 1	9.70CY	9	85	7420.5
Shallow Found Type 2	5.66CY	20	85	9622
Total Cost Concrete Shallow				**17042.5**
Deep Found				
Type1	8.82CY	18	85	13494.6
Type2	14.54CY	10	85	12359
Type3	12.48CY	26	85	27580.8
Total Cost Concrete Drilled Shaft				**53434.4**
Floor				
Slab on grade	1,274 CY	1	$70	$89,185.19
Precast Members				
Columns				
Double Tee Beams	172,000ft2		10.04	$1,726,880
Girder Type one	84		6200	$520,800
Girder Type 2	96		10300	$988,800
				$3,236,480

Steel Quantity Take-off Summary							
Rebar Shallow Foundation	Bar Type	# of bars	Length of bar (in)	Price ($/in)	Cost per Unit	Nomber of Units	Total Cost
Type1	#8 bars	12	130	0.66	1029.6	9	$9,266
Type2	#8 bars	16	101	0.66	1066.56	20	$21,331
Total Cost Shallow Foundations							**$9,266**
Rebar Drilled Shafts							
Type1	7/8"	23	300	0.225	1552.5	18	$27,945
Type2	7/8"	38	300	0.225	2565	10	$25,650
Type3	7/8"	32	300	0.225	2160	26	$56,160
Total Cost Drilled shaft Steel							**$109,755**

Drilling Drilled Shaft				
Deep Foundation	Deepness Of Drilling (17 ft)	Cost ($/ft)	Number of shafts	Total Cost
Type 1	17	157.43	18	$48,174
Type 2	17	195.66	10	$33,262
Type 3	17	180.44	26	$79,754
Total Drilling Cost				**$161,190**

Excavation Shallow Foundations		
Total volumen (CY)	price ($/CY)	Total Cost
786.72	55.50CY	**$43,663**

Deep Found	**Concrete**	**Steel**	**Drilling**	**Total**
Type1	$13,494.60	$27,945.00	$70,843.50	$112,283.10
Type2	$12,359.00	$25,650.00	$48,915.00	$86,924.00
Type3	$27,580.80	$56,160.00	$117,286.00	$201,026.80
Total Cost of Shafts	**$53,434.40**	**$109,755.00**	**$237,044.50**	**$400,233.90**

Quantity Takeoff Shallow				
Shallow Foundation	Concrete	Steel	Excavation	Total
Type 1	$7,420.50	$9,266.40	$21,900.00	$38,586.90
Type 2	$9,622.00	$21,331.20	$21,763.00	$52,716.20
Total Cost of Shallow	**$19,429.30**	**$9,266.40**	**$43,663.00**	**$91,303.10**

Descirption	Takeoff Quantity	Total Cost/Unit	Total $ amount
General Requirements/ Site Service	172,000 sqft	1.35 /sqft	$232,200
Sitework & Building Excavation	172,000 sqft	28.87 /sqft	$4,965,640
Landscape	172,000 sqft	0.79 /sqft	$135,880
Turf	172,000 sqft	3.75 /sqft	$645,000
Masonry	172,000 sqft	1.16 /sqft	$199,520
Misc Metals	172,000 sqft	0.65 /sqft	$111,800
General Trades	172,000 sqft	0.90 /sqft	$154,800
Waterproofing-Roof	172,000 sqft	1.25 /sqft	$215,000
Curtainvall	172,000 sqft	1.95 /sqft	$335,400
Painting	172,000 sqft	0.72 /sqft	$123,840
Signage	172,000 sqft	0.24 /sqft	$41,280
Sports Netting	172,000 sqft	0.72 /sqft	$123,840
Elevators	172,000 sqft	0.47 /sqft	$80,840
HVAC/Plumbing	172,000 sqft	5.85 /sqft	$1,006,200
Fire Protection	172,000 sqft	0.89 /sqft	$153,080
Electrical	172,000 sqft	8.41 /sqft	$1,446,520
TOTAL			**$9,970,840**

Total Estimation Prices	
	Cost
Drilled Shafts	$400,233.90
Shallow Foundations	$91,303.10
Precast Concrete	$3,236,000.00
Slab	$89,185.19
General Requirements/ Site Service	$232,200.00
Sitework & Building Excavation	$4,965,640.00
Landscape	$135,880.00
Turf	$645,000.00
Masonry	$199,520.00
Misc Metals	$111,800.00
General Trades	$154,800.00
Waterproofing-Roof	$215,000.00
Curtainvall	$335,400.00
Painting	$123,840.00
Signage	$41,280.00
Sports Netting	$123,840.00
Elevators	$80,840.00
HVAC/Plumbing	$1,006,200.00
Fire Protection	$153,080.00
Electrical	$1,446,520.00
Total Estimation Of Project	**$13,787,562.19**