6-9-2016

Foundation Design for Multistory Building in Oakland

Sean Cain
Santa Clara Univeristy

Santa Clara Univeristy

SANTA CLARA UNIVERSITY

Department of Civil Engineering

I hereby recommend that the

SENIOR DESIGN PROJECT REPORT

Prepared under my supervision by

SEAN CAIN

entitled

FOUNDATION DEISGN FOR MULTISTORY BUILDING IN OAKLAND

be accepted in partial fulfillment of the requirements for

the degree of

BACHELOR OF SCIENCE IN CIVIL ENGINEERING

Sukhmander Singh — June 8, 2016

Advisor — Date

6/9/16

Chairman of Department — Date

FOUNDATION DESIGN FOR MULTISTORY BUILDING IN OAKLAND

by

Sean Cain

SENIOR DESIGN PROJECT REPORT

submitted to
The Department of Civil Engineering

of

SANTA CLARA UNIVERSITY

in partial fulfillment of the requirements
for the degree of
Bachelor of Science in Civil Engineering

Santa Clara, California
Spring 2016

Abstract

This project focuses on the design of a foundation and garage-level retaining walls for a 25 story building in Oakland, California. The design was completed through the use of data from a 1988 soil investigation and provided structural loads. The site is composed of a thin sand layer above a clay layer about 400 feet thick. Analysis included soil and groundwater conditions and exploration of spread footings, mat footings, and pile foundations. The final selected foundation type is driven piles with the other options discarded due to lack of data and an unsuitability for the structure requirements. Piles are suitable for the deep, strong soils underlying the work site and the massive loads of the structure. Pile capacity and settlement of the final foundation design, as well as the strength of the designed retaining walls, safely met all project requirements. Additional recommendations were made in order to ensure accurate foundation construction.

Acknowledgements

I would like to thank my project advisor, Dr. Sukhmander Singh, for the time he spent with me discussing various parts of geotechnical engineering. This project was personally challenging, but he was always available for guidance when I needed it.

Table of Contents

Introduction

One of the most important considerations in ensuring the long life and safety of a building is the foundation it rests upon. Stated in the 2013 California Building Code in section 1803.1.1.1, "Each city, county, or city and county shall enact an ordinance which requires a preliminary soil report, prepared by a civil engineer who is registered by the state" (California Building Standards Commission, §1803.1.1.1). The building code further states in section 1803.5.5 that "where deep foundations will be used, a geotechnical investigation shall be conducted" (California Building Standards Commission, §1803.5.5). This geotechnical investigation includes a detailed analysis of the underlying soil conditions and recommendations as to the foundation type and capacity, settlement, and construction methods.

Figure 1: The Leaning Tower of Pisa, a popular case study in foundation settlement

Regardless of whether an investigation is required, proper foundation design is required by common sense and the duty of engineer to safeguard the public. Due to the size, use, and location of the structure in this project, a 25-story tall office building in downtown Oakland, its structural integrity is of the utmost importance. An improperly designed or deficient foundation could lead to dangerous structural failure of the building, negative impact on adjacent structures, and costly and constant repairs. The role of foundation design is to make sure that the structure, its inhabitants, and its surroundings are safe.

The goal of this project is to come up with an effective and smart foundation design for the given structure. The end result will be safe recommendations for the foundation, as well as the garage-level retaining walls that take into account the subsurface conditions and site location. This project does not delve into seismic design and remains focused on the effect of gravity loads.

Design Criteria

All data used in the calculations for this project were provided in a data package, attached to this report as Appendix A. The data package used in the foundation design included column loads, a geologic report including logs of five borings, data from a small number of additional tests such as consolidation, liquid and plastic limit, and grain-size distribution tests, as well as site profiles and layout drawings. Also included are details about the garage levels for use in retaining wall design.

The gravity loads on the columns were provided based on the location of the column. Columns were given different max loading values depending on whether they were located in the interior of the tower, exterior of the tower, or in the garage. This way of providing data did not give any information as to the number of each column in the structure, where exactly the column was located in the building layout, and the exact loading on each column.

Because there was such a range in loads, the max load had to be used in the design, which made it excessively conservative and resulted in a more expensive design.

Column Location	Dead Load (kips)	Live Load (kips)	Dead + Max Live (kips)
Tower Interior	2,200 to 4,000	1,400 to 2,700	3,600 to 6,700
Tower Exterior	600 to 2,600	400 to 1,800	1,000 to 4,400
Garages	200 to 300	120 to 200	320 to 520

Table 1: Column loads provided in data package

Groundwater levels were supplied in the boring logs, but an additional note was added to state that in this area the groundwater level fluctuates between about 6 to 15 feet in elevation over the year. In this design, the worst case of groundwater at 15 feet elevation was used in calculations. The initial data was entered into an Excel spreadsheet (charts shown in Appendix B) in order to quickly process information and easily complete calculations.

The data described so far was enough to begin the analysis process; further assumptions and values used in the design will be explained as they appear in this report.

Soil Analysis

Using the boring logs and geologic profile in the supplied data package (Appendix A), the underlying soil was characterized in order to better understand what was going on below the site. This understanding was then used in order to make judgments regarding which foundation type was most appropriate for this site. The first step in this process was looking at the geologic profile and report to get a basic understanding of the depth and composition of the underlying soil.

The site's underlying soil is composed of a Merritt Sand layer (~30 ft. thick) composed of slightly cemented, fine-grained to clayey sands above the San Antonio formation, which is composed of very stiff to hard silty clays with occasional dense gravel lenses. Under the San Antonio Formation is the Alameda formation, which consists of hard marine clay in the upper half and sandy oxidized clay in the lower half. These three layers rest on Franciscan bedrock, which did not come into use in this design. Essentially, there is a relatively thin sand layer on top of a very thick clay layer, although a dense gravelly sand lens in the San Antonio Formation was an essential part of the final design.

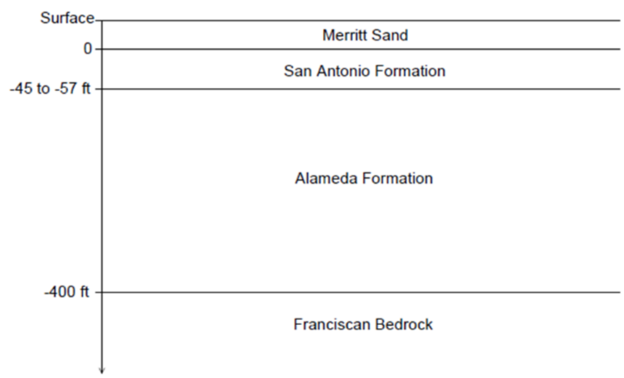

Figure 1: Basic diagram of the underlying soil composition

After understanding the overall trends in site conditions with the general soil profile above, more specific details were required. Using data provided for three borings (Borings 1, 3, and 5 in Appendix A), the specific soil profile was constructed. The specific soil profile showed that this site conformed to the general geologic trends. As can be seen on Figure 3, the site is composed of a sand layer above a thick clay layer. The boring data also showed the presence of a gravelly sand layer at an approximate elevation of -40 feet that extended an unknown distance through the site. After the underlying soil conditions and their strength were known, the analysis proceeded to the exploration of different foundation types.

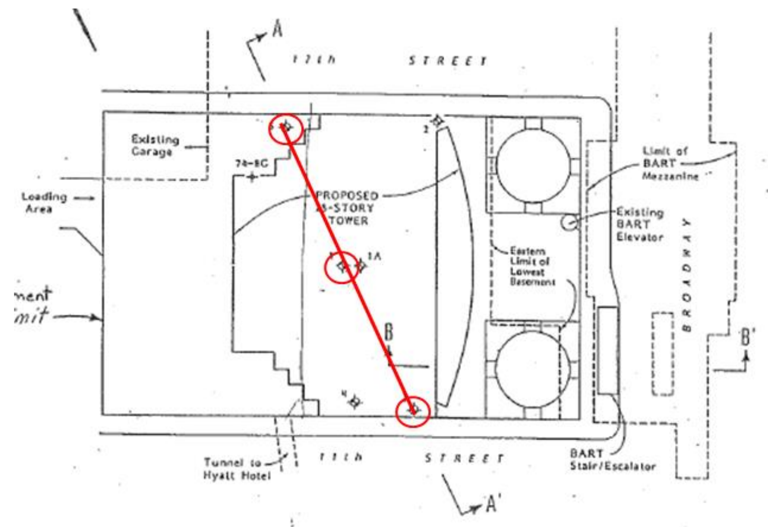

Figure 2: Site layout showing the cross-section used in construction of the specific soil profile

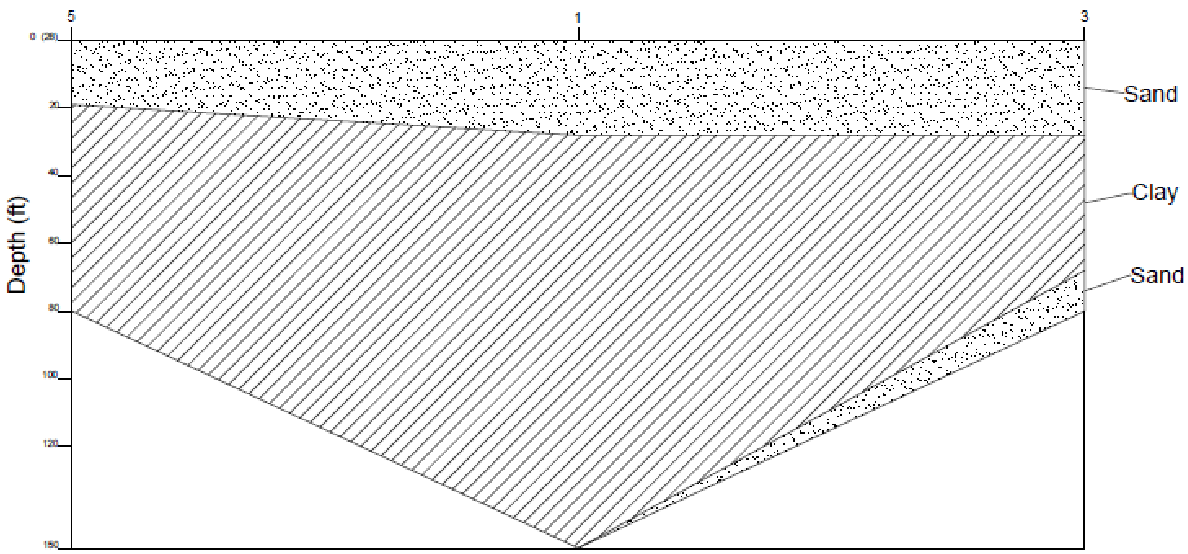

Figure 3: Specific soil profile of the site

Analysis of Alternatives

The analysis of which foundation type was most appropriate started with shallow foundations and then moved to deep foundations. The reason for this is the lower cost of materials and installation for shallow foundations. If a shallow foundation could meet the demands of the column loading, then it would be a better option than a deep foundation.

The first shallow foundation investigated was the spread footing. Values for the effective angle of internal friction for sands were conservatively estimated using the density of the layer which was estimated from soil type and blow count values during boring. Excavation of the site prior to foundation installation would drop the top of the spread footings to below the maximum water table level. Although dewatering during construction would lower it further, after the dewatering systems are removed, the water level would again be at or above the spread footing, so the depth to water was taken to be 0 feet. As can be seen in Figure C1, the size of a spread footing would need to be about 26 square feet to satisfy the loading on the heaviest column. This is excessively large for a spread footing, especially considering the spacing of the columns is approximately 30 feet in the tower section. Furthermore, after excavation the spread footing would be dangerously close to the very thick clay layer. The consolidation of the clay layer due to the large spread footing would cause excessive settlement and damage to the structure. Additionally, the way the footings spread their load would adversely impact the foundations of nearby structures. Due to the excessive size and settlement issues, the spread footing was discarded as a solution.

The next foundation type explored was the mat footing. The immediate problem with designing a mat footing is the lack of data provided on the columns. The columns are only divided into three groups and assigned a load range based on their group. However, in order to properly design a mat footing, far more specific data would be needed. Because large mat foundations cannot be perfectly rigid, an analysis using a non-rigid method would have to be performed to design the thickness of the mat. This analysis would need specific data on the location of each column and the load it is receiving in order to calculate bending moments. Because this data was not provided, the proper analysis for the mat footing cannot be performed, so it was discarded as a solution. Also, because the water table exists at an elevation higher than the bottom of the mat footing, dewatering operations during the pouring of the concrete would pose a challenge.

The analysis then proceeded to the deep foundations, between driven piles and cast-in-place piles. Driven piles were selected over cast-in-place piles because of the reduction of soil strength that comes with drilling a shaft before pouring. Cast-in-place piles disturb the in-situ soil strengths due to the installation method, resulting in unchanged or decreased lateral pressure and side friction, as well as decreased end bearing capacities. Driving piles densifies both the soil surrounding the pile and the soil beneath the tip, resulting in increased side friction and end bearing capacity. The driven piles used in this project were assumed to be round, pretensioned, reinforced concrete piles. The combination of the clay-dominated site conditions and the heavy column loading required getting as much strength out of the soil as possible, so the cast-in-place piles were discarded in favor of the driven piles.

Pile Capacities

After driven piles were selected as the optimal solution, calculations began to determine the capacities of the piles. After review of the soil profile, the decision was made to split the piles into two groups: friction piles and friction plus end bearing piles. Because of the presence of the dense gravelly sand layer, it could be utilized to support shorter end bearing piles with capacities near to those of the friction piles with less than half the length. The other piles would be entirely dependent on the friction of the clay layers to resist the gravity loads. Data from Boring 1 was used for friction pile calculations and data from Boring 3 was used for the end bearing piles.

For analysis of piles in clay, the methods used to calculate the end bearing capacity and the side friction capacity were the O'Neill and Reese Method and the α-Method, respectively. The supporting calculations are given in Appendix C. Calculations were performed with the aid of the spreadsheet shown in Appendix B.

For analysis of piles in sands, the methods used to calculate the end bearing capacity and the side friction capacity were the Vesic-Kulhawy Method and the β-Method, respectively. The supporting calculations are located in Appendix C. Calculations were performed with the aid of the spreadsheet shown in Appendix B.

A factor of safety of 2.5 was applied to both the friction and end bearing piles. This value was decided to be conservative enough for the piles in sand and clay. After calculating the capacities of the individual piles, the basic design of the pile caps was performed. Using the size, spacing, and number of piles, the approximate sizes of the pile caps were determined. The group efficiency of the piles was calculated and applied to the allowable capacity of the pile groups. Additionally, the contributions of the piles caps as spread footings were added to the capacity of the pile groups.

The result of the pile design was a group of end bearing piles driven down to the gravelly sand layer, and friction piles driven down as far as the data would allow. With the addition of the factor of safety of 2.5, the number of friction piles required to support the columns rose dramatically, and the piles needed to be sunk to great depth in order to reduce the number required. Although very deep, the embedment depth is not unreasonable and should not introduce any great difficulties. The majority of pile diameters were 18 inches in diameter, which was in the upper bounds of what is reasonable in a driven pile, but was necessary in order to recruit as much side friction as possible. Both friction and end bearing groups were split into interior and exterior tower column groups, and all garage columns were supported on friction piles. The garage columns were so lightly loaded that they did not need to be driven as deep as the sandy layer, allowing a much cheaper, shallower pile group to be utilized.

Type	Column Location	Pile Diameter	Embedment Depth (ft)	Piles per Column	Pile Cap Size (ft)
Friction	Tower Interior	18”	127	17	13 X 11.5
	Tower Exterior	18”	127	10	14 X 9.5
	Garages	16”	42	5	5 X 5
End Bearing	Tower Interior	18”	57	19	16 X 13.5
	Tower Exterior	18”	57	13	12.5 X 8.5

Table 2: Final design of driven piles

Settlement

Settlement for the selected design was determined to be negligible due to a variety of factors. Foremost is the historical tendency of piles to have undergone very minor settlement. According to Donald Coduto, “Most deep foundations… will have total settlements of no more than about 12mm (0.5 in), which is acceptable for nearly all structures” (*Foundation*

Design, 543). He additionally states that engineers often do not even perform any settlement computations for deep foundations. The next most important factor in the decision to disregard settlement was the very high strength of the deep soils. Although they are clays, the soils below this site have very high compressive strength generally ranging from 3,000 psf to 4,000 psf and even up to 5,500 psf (as seen in Boring 1 in Appendix A). These assumptions were brought to the advising faculty member and it was advised that settlement be regarded as negligible. Therefore, no calculations were performed for settlement of the driven piles because it was assumed to be within safe bounds for the project structure.

Construction Recommendations

During completion of the foundation design, there were some concerns that arose that should be mentioned as final construction recommendations. First, the effect of down drag on the piles, which will create an additional force on the pile in the downward direction. This is caused by the densification of upper layer soils, which in turn compress the soil below them, leading to compressing layers which “pull” down on the pile. This is often caused by dewatering systems or pile driving, where water is driven from the soil as the pore pressure increases. The down drag effect should not have a large impact on this site as the top layer is sand, in which pore pressure equalizes relatively quickly, and below that is already very compact and hard soils. Because of the in-situ strength of the soils and what should be a minor dewatering system, down drag should not be a problem.

The next consideration is the care required in handling, transporting, and driving the piles. As the piles are rather thin and long, there must be great care taken to not destroy them as they are being moved and transported. Lifting piles from the middle or ends will result in broken piles. Although the construction crew should know this, it is something worth a reminder, as broken piles could lead to costly delays and replacement. Furthermore, proper methods in driving should be followed to prevent the destruction of the tops of the pile.

Finally, additional borings should be performed in order to properly determine where the gravelly sand layer ends under the site. Because the pile design is split into end bearing and friction piles, it is very important that the end bearing piles end on the sand layer. Because the amount of boring data is limited, there should be additional borings conducted prior to construction so that the piles are driven in the proper place. Thus it is recommended that further investigation be done between the initial Borings 1 and 3.

Retaining Walls

The final design component of this project was the garage-level retaining walls. In performing the calculations for the retaining walls, the only data needed from the data package in Appendix A was the height of the retaining walls and the soil the wall footing would be resting upon. Because the garage is composed of two levels across the western half of the site and three levels across the eastern half, there were two walls designed. The retaining walls were to be embedded in the present soil, a clayey sand, but it was decided that in order to remove the expansive effects of the clays additional excavation would be carried out. The backfill would be replaced with a well-graded, clean gravel-sand mix in order to facilitate proper drainage, increase the uniformity of the walls, and help ensure the accuracy of the calculations. Values for pressure caused by this backfill were sourced from the 2012 International Building Code and can be seen in Appendix C. Because the basement floors are tied into the retaining walls, there needs to be some nominal reinforcement of the walls. The floors also act to prevent overturning and sliding of the wall. However, when in construction, there will be no floors to support the wall so calculations were performed using free standing retaining walls. Calculations were performed with the aid of the “Bearing” and “Retaining Wall” excel spreadsheets and can be seen in Appendix C.

Design Values	Western Garage	Eastern Garage
Stem Height (ft)	30	31
Footing Thickness (ft)	3	3
Footing Embedment (ft)	1.5	1.5
Stem Thickness – Top (ft)	3	3
Stem Thickness – Bottom (ft)	3	3
Toe Extension (ft)	7	7
Heel Extension (ft)	13	13
Sliding FS	1.94	1.88
Overturning FS	5.35	5.04
Bearing Pressure OK?	Yes	Yes

Table 3: Dimensions and safety factors of retaining walls

Non-Technical Issues

With the construction of a large office building, the foundation it rests upon will be partly responsible for ensuring the safety of its inhabitants. When the building has a proper foundation, workers can be safely housed inside and bring the economic advantage of the structure to full use. In this way, this foundation is essential to a structure that would bring jobs to the local populace, economically benefit the area, and thereby improve the lives of people in the Oakland area. Throughout the design, the goal was to provide an effective solution that is as affordable as possible. Although conservatism is very important in the design of foundations because of the amount of uncertainties and estimation in the process, it was also important to make sure it wasn't too conservative. By putting a great deal of thought into the judgment calls made in this project, the overall efficiency of the design is maximized. As far as environmental impact, the main factor is simply the cradle to grave cost of the materials. Concrete is an incredibly long lasting material, and for a structure of this size, a lot of concrete is needed for the foundation. There are not any great alternatives to concrete when used for this purpose as its strength is essential, but by making a foundation that will stand the test of time and remain functional as long as needed, the environmental impact can be lessened.

Conclusion

In summary, driven piles were chosen as the design solution due to the overwhelming presence of clay under the site and because of the massive column loading. All required capacities modified by a conservative factor of safety were met and settlement was determined to be negligible. Retaining wall design was completed and met the safety requirements for sliding, overturning, and bearing capacity failure. Although this project did not include any seismic design or in-depth detailing, it demonstrated a diligent design attitude and creative thinking. Ultimately, this project is a practical and effective foundation design for the data provided and reflects the hard work and thoroughness that went into the design process.

References

California Building Standards Commission. (2013). *2013 California Building Standards Code*, International Code Council, Washington, D.C.

Coduto, Donald P. (2001). *Foundation Design: Principles and Practices,* 2^{nd} Ed., Prentice-Hall, New Jersey.

Coduto, D. P. (n.d.). "Bearing.xls." *Software Download for Geotechnical Engineering: Principles and Practices*, program documentation, Prentice Hall.

Coduto, D. P. (n.d.). "Retaining Wall.xls." *Software Download for Geotechnical Engineering: Principles and Practices*, program documentation, Prentice Hall.

International Code Council. (2011). *2012 International Building Code*, ICC. Country Club Hill, Ill.