Table of Contents

Abstract

On December 17, 2010 the historic Provo Tabernacle was almost completely destroyed by fire; the only structural aspect remaining was its outer walls. To the great delight of Provo's citizens, The Church of Jesus Christ of Latter-day Saints later announced that they were going to restore the Provo Tabernacle into a temple. Thus an opportunity for a senior design project was created.

The ultimate goal of our project is to design a constructible, lasting, and cost efficient foundation for the restoration of the Provo Tabernacle Temple. With our project, however, comes a large list of constraints. The exterior walls need to be supported while two floors of basement are to be added underneath. Two other imposing constraints are the high water table and the lack of space for construction.

With our limited experience, we were unsure how to first tackle this problem. As a group, we decided to research as many possible solutions as we could. By talking to professors, local engineers, and searching through books and the web, we spent the first half of the semester looking at ways we could accomplish our project goal. We studied soldier walls, micropiles, underpinning, jet grouting, slurry walls, and more. From our research we determined none of the ideas individually would work for a variety of reasons. However, by talking to some experienced engineers, we were able to combine the ideas we researched into one plausible, constructible, and lasting design.

Our final design combines many of the ideas we researched in order to optimize the benefits. The design uses an underpinning system (after removing the old foundation) that will support the existing wall during construction. In this underpinning design, micropiles would be the main component so vibration would be avoided. The design calls for walers, mesh netting, anchors, and soil nails along with the micropiles as a soil retention system during excavation. Previous to excavation, however, a system of deep wells and pumps would be installed in order to draw down the water table enough to clear the future excavation site. After excavation, our design requires waterproofing membranes to be installed as well as a system of pipes and a pump under the foundation. Next would be the mat foundation which consists of anchoring micropiles and then the foundation walls designed to withstand the high lateral earth and water pressures.

We feel our design is very reasonable, meets all the constraints, and would be a very constructible design. However, we do not claim our design is the absolute best design out there. We simply do not have such experience or knowledge to claim such an idea. Overall, this project was very beneficial to us as a team. We learned about engineering and the process of design through our research and design process. It has been an immense learning experience that will be carried with us throughout our careers.

Objective

Design a constructible, lasting, and cost efficient foundation for the restoration of the Provo Tabernacle Temple.

Rehak MSA

Background

The Provo Tabernacle was first completed in 1898 as a conference center for The Church of Jesus Christ of Latter-day Saints. Since that time, the Provo Tabernacle has not only played an important role in the Church's history but it has also become an integral part of Provo's history. For years, the Provo Tabernacle has stood sentinel of downtown Provo. Its walls have housed many musical concerts and church meetings. The historical nature and beauty of the building has always touched the people of Provo (especially the university students).

Then, on December 17, 2010 the Provo Tabernacle was almost completely destroyed by fire, the only remnants consisted of the outer walls. The people of Provo were distraught, many came out to watch and mourn the loss of this historical monument. However, to the excitement of the members, The Church of Jesus Christ of Latter-day Saints announced in October of the following year that the structure would not only be restored, but also transformed into a temple.

Temples are held as very sacred buildings to members of The Church of Jesus Christ of Latter-day Saints. Therefore, their construction is held to the highest of standards. The historical significance of the tabernacle's makes it essential that the Provo Tabernacle Temple maintain its previous appearance. With these two factors each playing an important role in the tabernacle's restoration it is necessary that the greatest care and attention to detail be placed in its design.

During fall semester 2011, there was a request for proposal given to our class requesting a qualified team to design the foundation of this important structure. As a team we felt we had the qualifications and the determination needed for this project. We presented our proposal and were awarded the project. This project came as an even greater problem with more constraints than we first expected.

Constraints

The problem requires designing a foundation for two floors of added basement underneath the existing building. The sponsor of this project has asked us to come up with a design, wondering if it will be similar to the design the team of engineers working with Reaveley Engineers on the project prepared. This problem seems simple enough; however, the difficulty comes with the constraints on the project.

The design of a foundation for the Provo Tabernacle Temple comes with many constraints. First, because of the limiting space between the building and the current roadway, all the construction for the basement and foundation will need to be done inside of the existing structure. Second, The Church would like to preserve the as much space as possible for the basement. Third, the foundation needs to be built underneath the existing, unstable walls. This will require the design to support the existing wall during the excavation of the basement and the construction of the permanent foundation. Fourth, there is currently a 5 foot foundation under the existing walls that is unstable, un-moldable, and deteriorating. The design will need to consider this obstacle and either reinforce the existing foundation or take it out before constructing the final foundation. Fifth, the water table is at 15 feet and our excavation will be dig down 40 feet. Thus, the final design will require a dewatering system in place during the entire construction as well as a permanent dewatering system for the life span of the building.

Even with all the constraints and our team's lack of experience, with have approached this problem with enthusiasm and confidence. Through hours of research and talking to local professionals, we have studied multiple designs, rejected multiple designs, and finally combined our ideas and knowledge into one suitable design.

Preliminary Designs

Throughout our hours of research, we seriously considered five different types of foundations and soil retention methods. Each method fist seemed plausible, had many positive aspects, and catered to our design constraints. In the end, we decided against using any single idea as the final solution. These ideas included underpinning, soldier walls, jet grouting, slurry walls, and micropiles.

Under-pinning

Defined

Under-pinning supports can provide a temporary or a permanent support system to an existing wall. Under-pinning is the process of strengthening and stabilizing the foundation of an existing building or other structure. Most commonly, an under-pinning support system is used to provide stability for an existing structure while repairing or replacing an unsatisfying foundation. As can be seen in Figure 1, under-pinning systems are off-set and do not sit directly beneath the existing structure. A support column (11) is used as the transfer column which eventually carries the load into the underlying soil.

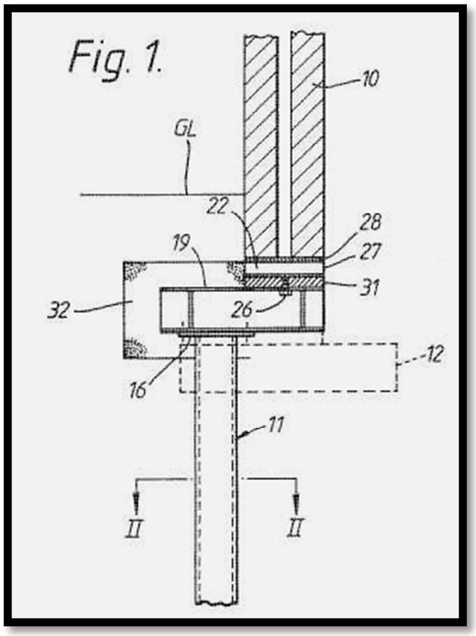


Fig. 1.

A cantilever is used in the system as the transfer column connects to the beam (19). In so doing, the loads from an existing building are held by the beam that has been pinned in the system. As mentioned previously, an under-pinning method used to provide structural support can be a temporary fix for some of the foundation concerns, or it can be left in place as part of the permanent foundation. In the case with the Provo Tabernacle, the process of under-pinning would be done with the intent of constructing a basement in the existing building.

Positives

There are many positive characteristics of using an under-pinning solution. Under-pinning methods are relatively less expensive than other options that we explored. It is a very competitive model when comparing the cost against others. Because of the cantilever, an under-pinning support system frees up the soil under the existing walls. By excavating directly under the exterior walls, a basement wall can be placed directly under any existing walls. This allows basement foundation and footings that directly support the existing walls. Under-pinning allows for more area available for the basements and foundations.

Negatives

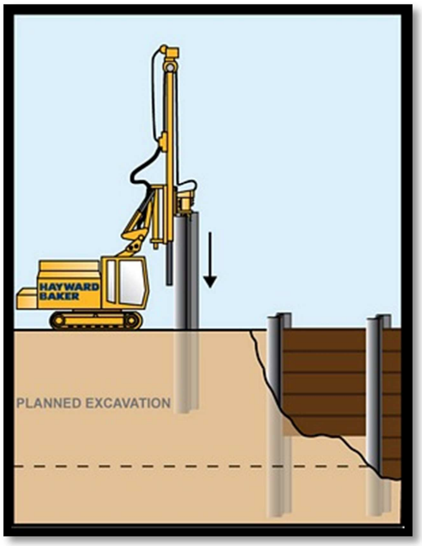
While an under-pinning plan would provide structural support for the vertical loads in the existing structure, it does not account for the lateral soil pressure during the construction process. Simply using the transfer columns in the design shown in Figure 1 would mean that there is nothing to hold back neighboring soil that is exposed during the excavation process. In order to use an effective under-pinning process, more consideration would be necessary to account for the lateral soil pressure from the exterior of the existing walls. Under-pinning method would not directly facilitate water movement during construction. Using vibrations or a brute force to pound the column into place could disturb the existing structure.

Why we decided not to use it

Because of the necessity to excavate two stories under the tabernacle, under-pinning alone could not be used alone. Under-pinning alone does not withstand the lateral pressures in the soil. The vibrations caused in the process could be detrimental to the existing structure of the tabernacle.

Soldier Wall

Defined

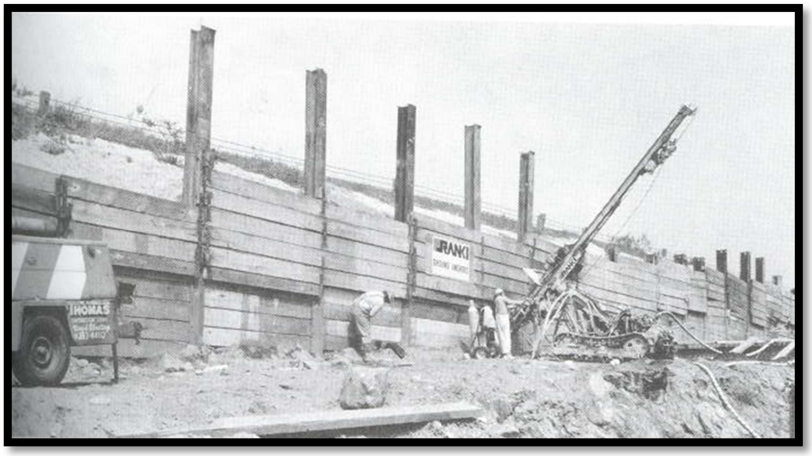


A soldier wall is a widely used soil retention system mainly used in situations where deep excavations are required with limited access. This type of soil retention is especially helpful when the construction site is adjacent to existing buildings or structures. In such situations, the soldier wall not only retains the soil but also has enough strength to support the existing foundations during excavation and construction.

The process of building a soldier wall is simple. Steel I-beams (called soldier piles) are pounded into to ground at regular intervals surrounding the construction site. As the soil is excavated wooden planks (called lagging) are placed horizontally between the I-beams. The lagging transfers the soil load to the soldier piles, successfully retaining the soil and loads behind the retention wall. Behind the lagging, compacted fill is added in order to avoid settling of the surrounding soil which could adversely affect neighboring foundations. If more strength is required, anchors are added to the structure. Anchors use tension and friction to tie back the walls into the surrounding soil giving added strength.

Positives

There are many advantages to using a soldier wall. Their greatest advantages are being fast, easy, and cheap. Soldier walls are also very strong and can be used for very deep excavation projects. Soldier walls can also be temporary; they are relatively easy to take out when they are no longer required. On the other hand, they can also be retained as a permanent feature of the foundation. Because of these characteristics soldier walls are often used for a wide range of projects.

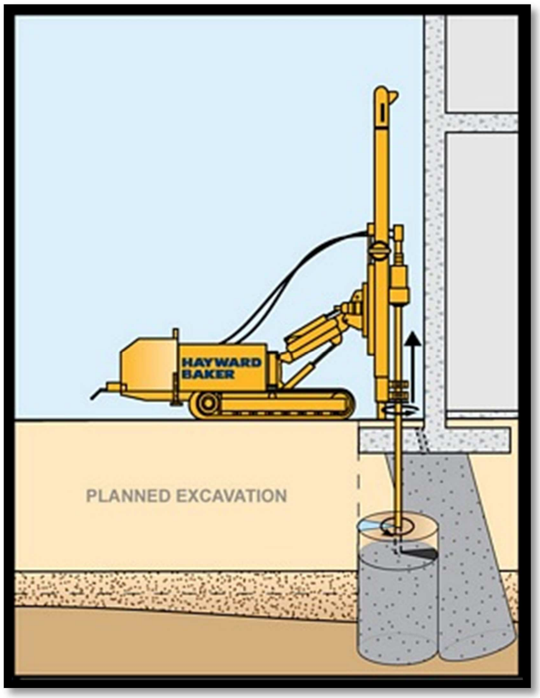


Negatives

Besides positives, there are also a few negative aspects of soldier walls that need to be considered. Although soldier walls can be permanent it is better if they are taken out to conserve space as well as to prevent the possibility of the lagging rotting. Also, the drilling of the soldier piles can cause high vibrations that could negatively affect surrounding buildings. In such cases a lower frequency driller would need to be used at a higher cost and in other situations even this lower frequency will not be acceptable. If the water table is high, major dewatering will need to be used because soldier walls are not impermeable.

Why we decided not to use it

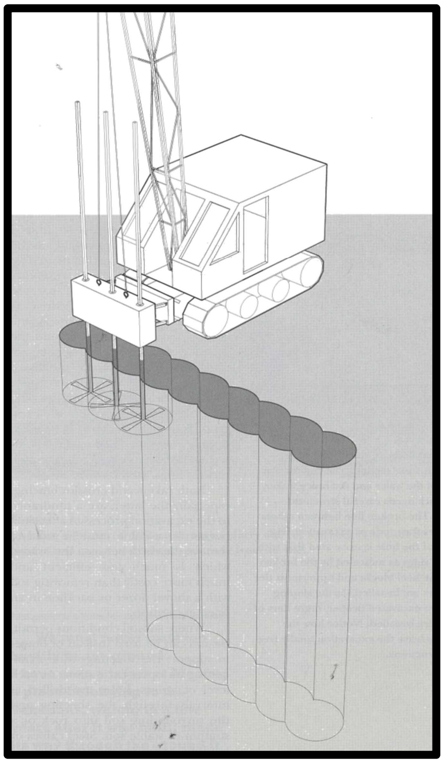
We really like the idea of how easy, fast, and cheap soldier walls are to install. Most importantly though, we were interested in the ability that soldier walls have at supporting existing foundations during deep excavation. We were hoping to be able to build the soldier wall right up against the existing walls of the Provo Tabernacle Temple. This would take up space from the basement, but we figured giving up a few feet of space for easy construction would have been worth it. Then we found out that we could not build the wall within three feet of the Tabernacle's existing walls because of the hazardous effect the vibrations would have on the unstable wall.



Jet Grouting

Defined

Jet grouting is a process that inserts a grouting monitor into the ground, and mixes grout at high velocities into the in situ soil. As the grout and soil mixes, the grouting monitor is raised creating a thick concrete column in the soil. These columns can be placed very close together creating a thick concrete wall.



Positives

Jet grouting works very well in gravel and sand. The thick concrete wall is very strong and resists the lateral loads produced by the soil very effectively. Construction crews can excavate right up to the jet grout wall. This process is also good for rehabilitating existing foundations. The walls are so thick that it can also be used for groundwater control and slope stabilization. Jet grouting can be used as an underpinning method and is great for tight spaces.

Negatives

Jet grouting produces very thick walls. It is also an extremely expensive method even compared to the other alternatives we have come up with.

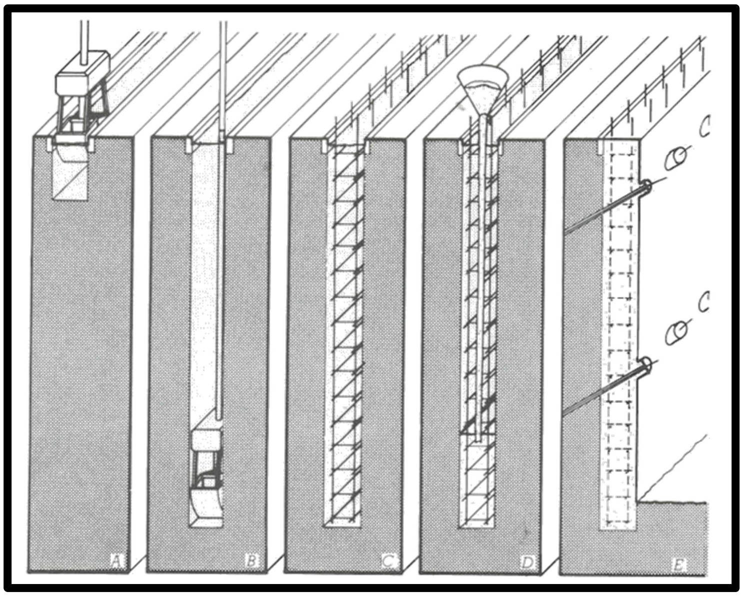
Why We Decided Not to Use it

The reason we chose not to use jet grouting is because the basement needs to conserve space. In order for the jet grout walls to properly support the existing walls, the grouting would need to be done on either side of the walls, making a wall possibly four feet thick. This method would also limit extending the basement beyond the walls of the tabernacle. Jet grouting is also one of the most expensive methods available. Although any method for this project will be difficult, this would be extremely expensive.

Slurry Wall

Define

A slurry wall digs a narrow trench and then fills the trench with a slurry. The slurry allows for the excavation of the trench while keeping the soil back; the hydrostatic pressure is enough to hold the soil back during excavation. After the trench is excavated, a pre-assembled reinforcement cage is dropped down. Concrete is then pumped into the bottom of the trench and the slurry (which is lighter than the concrete) rises to the top and is then removed. The concrete in the trench cures forming a wall that will allow soil to be excavated right up to the wall.



Positives

Slurry walls can be very used for very deep foundations. They can be built at least seven stories deep. They are very effective in that they retain soil during construction and continue to resist the lateral loads after the concrete has cured. They are used as permanent foundations. Slurry walls are built with low vibration.

Negatives

Slurry walls seem very messy. Because of the slurry, construction workers are digging up slurry along with each bucketful of excavated soil. The machinery is large and would have difficulty getting very close to an existing wall.

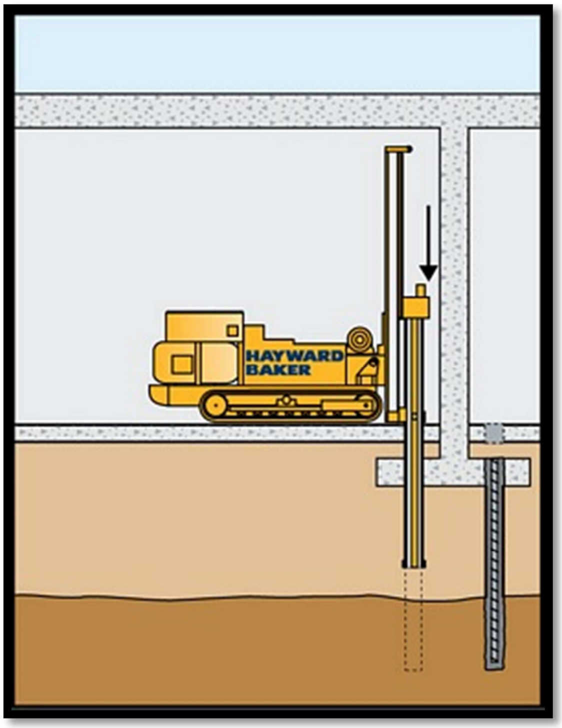
Why We Chose Not to Use it

We chose not to use the slurry wall because it would be difficult to get close enough to the existing wall, thus taking up too much space inside the basement. Also, the slurry wall cannot be built underneath the existing wall.

Micropiles

Defined

Micropiling is a type of deep foundation element. The hole for the micropile is drilled into the ground. A casing is placed in the hole during the drilling process to hold back the soil. After the desired hole length is achieved, the micropile is inserted into the casing. The casing is then filled with high strength grout.



Positives

Because the micropiles are drilled into the ground, the process does not involve vibrations. Due to the fact that micro piles are small, anywhere between 3 to 10 inches when they are driven into the ground they cause little to no disturbance to the surrounding soil. Also because of their size they are much easier to penetrate rocky ground conditions, caving, or raveling soil. The machinery for drilling micropiles is small and allows for micropiling to be done in tight spaces. The piles can be placed either vertical or at any angles. Micropiles have a capacity to about 1000 tons.

Negatives

This is a deep foundation element; therefore micropiles cannot hold back the soil during excavation.

Why we chose not to use it

This method is not viable on its own. It cannot hold the soil back sufficiently during the excavation of the walls.

Final Design

After discovering all of our preliminary designs would not work alone, we were a little deflated. We did not know any other methods, or a good way to combine these methods to a plausible design. Then a local professional name Todd Ross gave us the idea of combining all of our ideas into one design. Thus, our final design contains the best aspects from each of our earliest designs. The order of implementation and construction of our design is as follows:

Construction Dewatering

Previous to any construction, some type of temporary dewatering system will need to be put into place. As a team we have decided to use a system of deep wells to draw down the water table an extra 2 feet below the lowest excavation depth. A system of 8 deep wells will be place around the construction site (see Construction Dewatering in the Appendix). Each well will be connected to one of three pumps that will need to pumped at a rate of approximately 2200 gal/min in order to draw down the water table from 15 feet to 35 feet below excavation. After the excavation and construction process is completed, these wells can be taken out in order to allow the restoration of the original water table.

Removing the Old Foundation

Before any type of foundation can be built, the problems that arise from the presence of the previous foundation needed to be solved. We decided to completely remove the weak, rubble foundation. This will be done by removing the old foundation 6 foot sections at a time until the entire foundation is removed (see Development Length of Existing Wall in the Appendix). The removal of the foundation needs to be done in sections so the walls and their framed support will be able to support themselves while the sectional excavations take place. While excavating a six foot section, we will also be connecting steel channels in order to keep the brick from separating from the wall. After removing a section we would then replace them with a concrete beam. This beam would extend not only under the existing walls but also have a 8ft x 2ft x 1ft section protruding beyond the wall towards the outside of the building. With this protruding section we will be forming our underpinning system.

Underpinning System

Through our research the benefits of an underpinning system outweighed all other options. With an underpinning system we will be able to support the walls while eventually placing the final foundation directly under the existing walls. However, instead of the common support columns that require vibrating to install, we have chosen to use micropiles. Micropiles can be placed with very little vibrations while still withstanding large loads. The a set of 2 micropiles will be placed 4 feet apart from each other, 75 and 55 feet deep, and will completely circumference the building at 6 foot intervals (see Underpinning Design in the Appendix for more detailed dimensions). Thus, our underpinning system will encompass the entire existing structure.

Excavation/Soil Retention

As the actual excavation takes place, there needs to be a system in place to retain the soil. We have decided to use a soldier wall type approach. This “soldier wall” system will be built using a metal lagging, called a whaler, which can be welded onto the micropiles. These whalers will allow for a soil retaining meshing to be applied between the micropiles. Also, anchors will be placed through the whalers while a grid of soil nails will be placed within the mesh (see Final Design images in the Appendix). With this design, the soil load will be transferred successfully to the micropiles in order to support the underpinning system and ultimately the existing walls.

Waterproofing

When the foundation has been completed and construction is over, the dewatering system will be taken out, resulting in a rising water table. This high water table will adversely affect our foundation unless certain measures are taken. As a first defense, we will be building our foundation like a boat. This will be done by water proofing the entire outside of our foundation using bentonite sheets as well as anchoring our foundation with a grid of 24 micropiles. Our second defense will include a gravel layer with perforated drains under the mat foundation.

Connected to the perforated drain grid will be a pump. This pump will allow for either routine draining or in emergency situations could complete the drainage if the waterproof membrane were to fail. Ideally we would have liked to let gravity drain the water from under our foundation to a storm drain by running pipes south of the construction location; the natural lay of the land drops off dramatically. However, because of the large depth of our foundation (35 feet below the ground surface), this option is not possible. Thus, we have determined to be content with the original two lines of defense.

Mat Foundation

Once excavation and waterproofing is complete the mat foundation can be built. As a team we have decided to use a simple mat foundation. With a 2 foot thick reinforced concrete mat and 24 micropiles, our foundation will be able to withstand both the loads of the building and the upward force of the high water table (see Mat Foundation Design in the Appendix).

Foundation Walls

The placement of our foundation walls, though simple in design, is important. In order to prevent the foundation wall from shearing away from the mat foundation, due to the load of the building and the uplift, the foundation walls will be built on top of the mat foundation. In order for the bentonite sheets to be an effective waterproofing tool, the foundation wall needs to be built right up against the soil retention system. After analyzing the lateral earth pressures that will be present, we determined a 2.75 foot thick reinforced concrete wall will be necessary (see Foundation Wall Design in the Appendix). We have chosen to use 2.75 feet the entire length of the foundation wall to provide the necessary conditions of the bentonite sheets previously discussed.

Cost

Along with the other constraints for this project, the cost of the project was taken into account for our final design. We calculated the final cost to be around 1.5 million dollars. These cost estimates were given to us from local professionals, professors and online research. The cost of the micropiles is determined based on the linear length of the micropile. We have 82 micropiles at 75 feet, 82 at 55 feet and 24 micropiles at 15 feet. Price for micropiles also depends on head room and capacity. Head room is not a constraint in this project, so the prices are relatively low. The concrete was estimated to be $200 per cubic yard. This price includes the labor and the reinforcement. We are not sure if this estimate includes the required forms. The concrete price includes the concrete required for the foundation, the walls and the cantilever beams. We estimated the price of the benotonite sheets based on the price for bentonite clay, and the price for other types of membrane sheets. The exterior walls and the foundation were included in the amount of required waterproofing membrane. The wells estimated $2000 per well with an additional $30 per foot of well drilled. We are using eight wells drilled at 50 feet each. A summary of the costs can be found in the table below:

Micropiles	$50-$70 (per linear foot)	$ 551,000-$826500
Concrete	$200 (per cubic yard)	$ 508,807
Bentonite Sheets	$3 (per square foot)	$ 90,000
Wells/Pumping	$2000 (per well)+$30 (per linear foot)	$ 28,000
	Max Estimated Total	$ 1,453,307

Positives

The placing of micropiles produces very little vibrations and can be done in confined spaces, which is important for the preservation of the existing walls. With an underpinning system, we can build the foundation wall underneath the existing walls which maximizes the amount of basement space. Our design will also effectively solve the problem of the existing foundation, retain the soil during excavation, and alleviate the water table concerns both short term and long term. Plus, our design does not need to be taken out after the foundation is built and most of the construction process can be completed inside the existing walls.

Negatives

The negative aspects of our design include the cost, the difficulty of implementation, and the time it will take to construct. We feel, however, that these negatives are outweighed by the positive facets of our design.

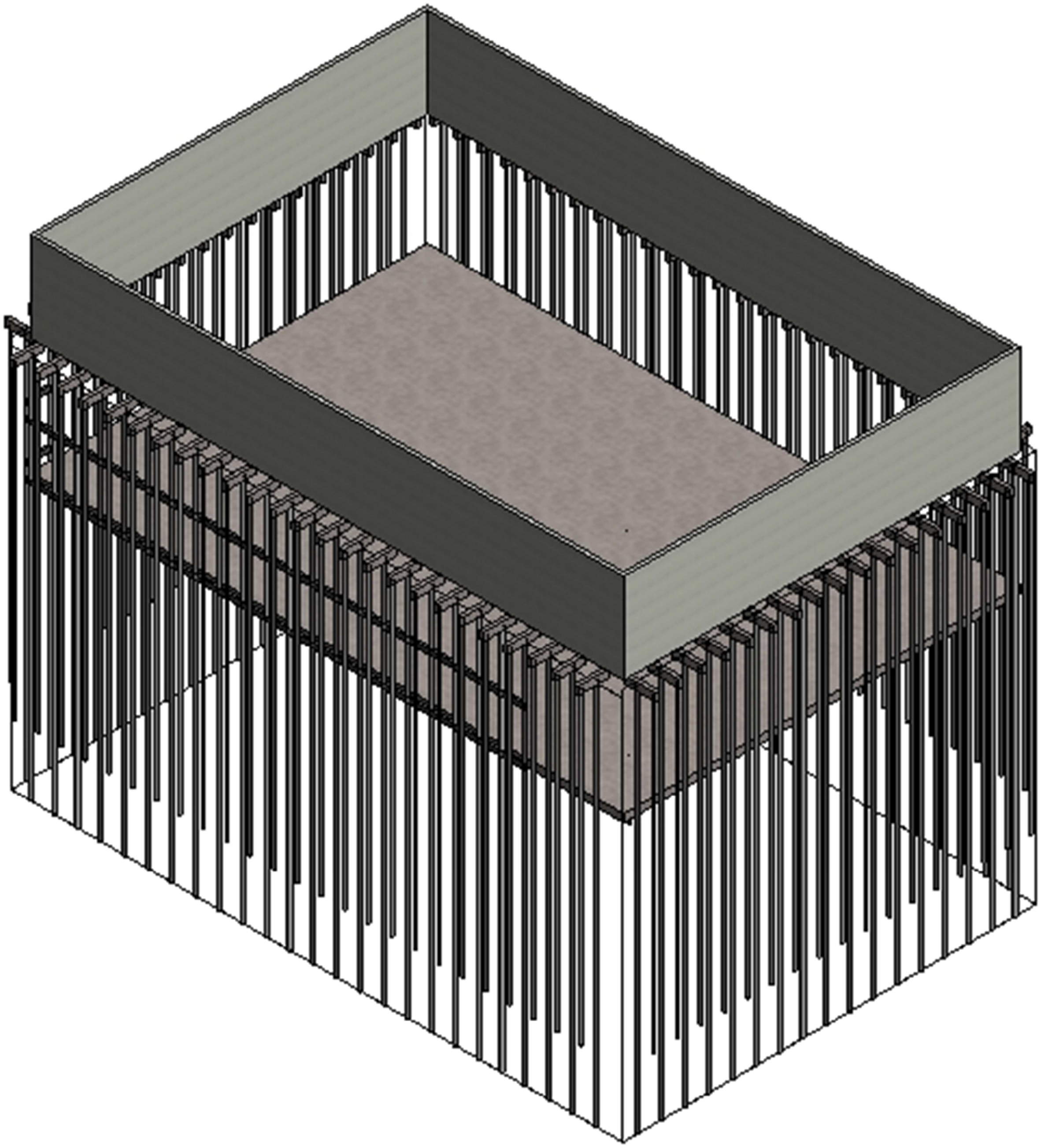
Why We Decided To Use It

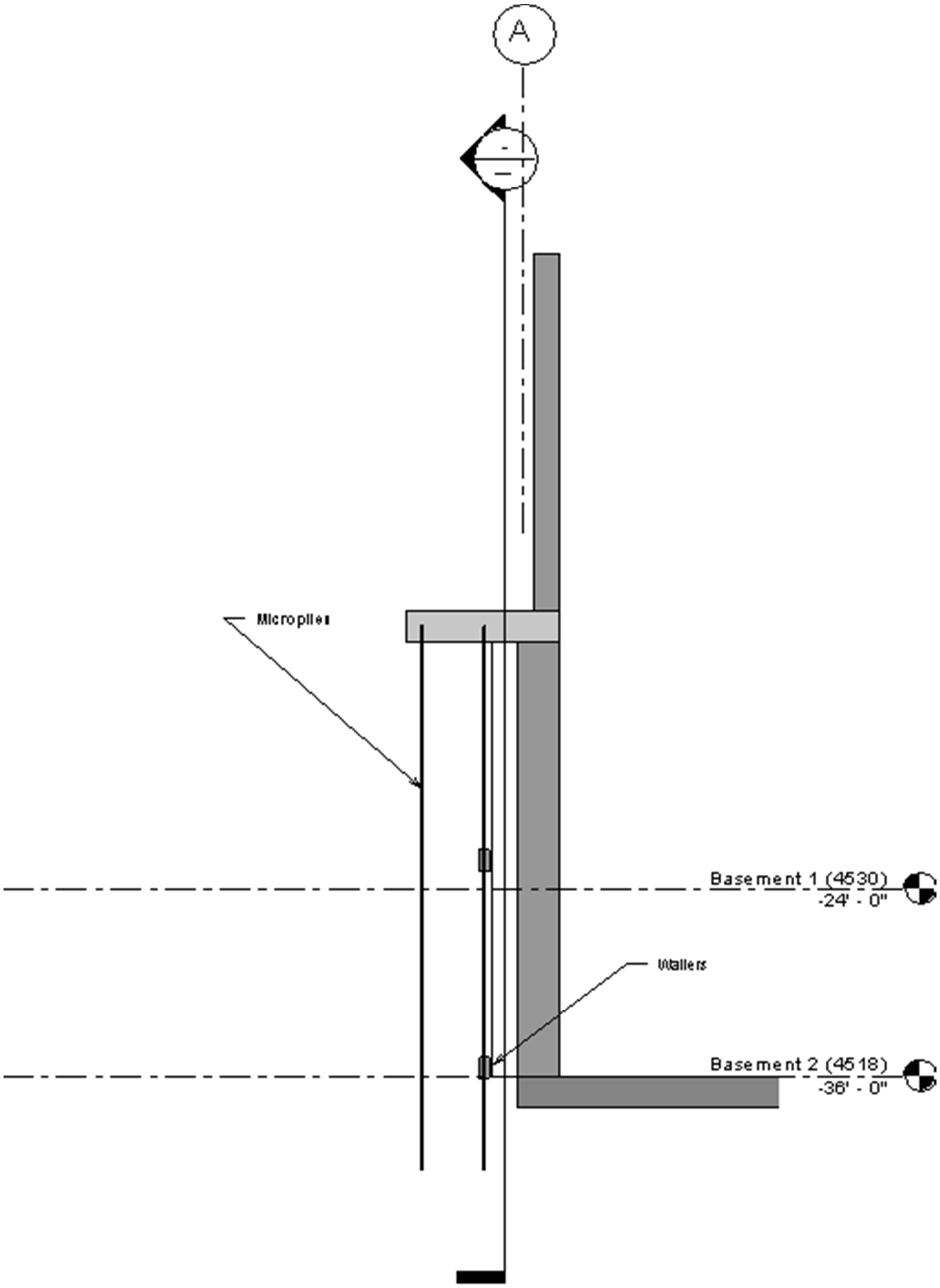
Overall, our final design forms a plausible, creative, and efficient design for the construction of the Provo Tabernacle Temple foundation. It incorporates all the positive aspects of our preliminary designs as well as new aspects we found necessary during the analysis process.

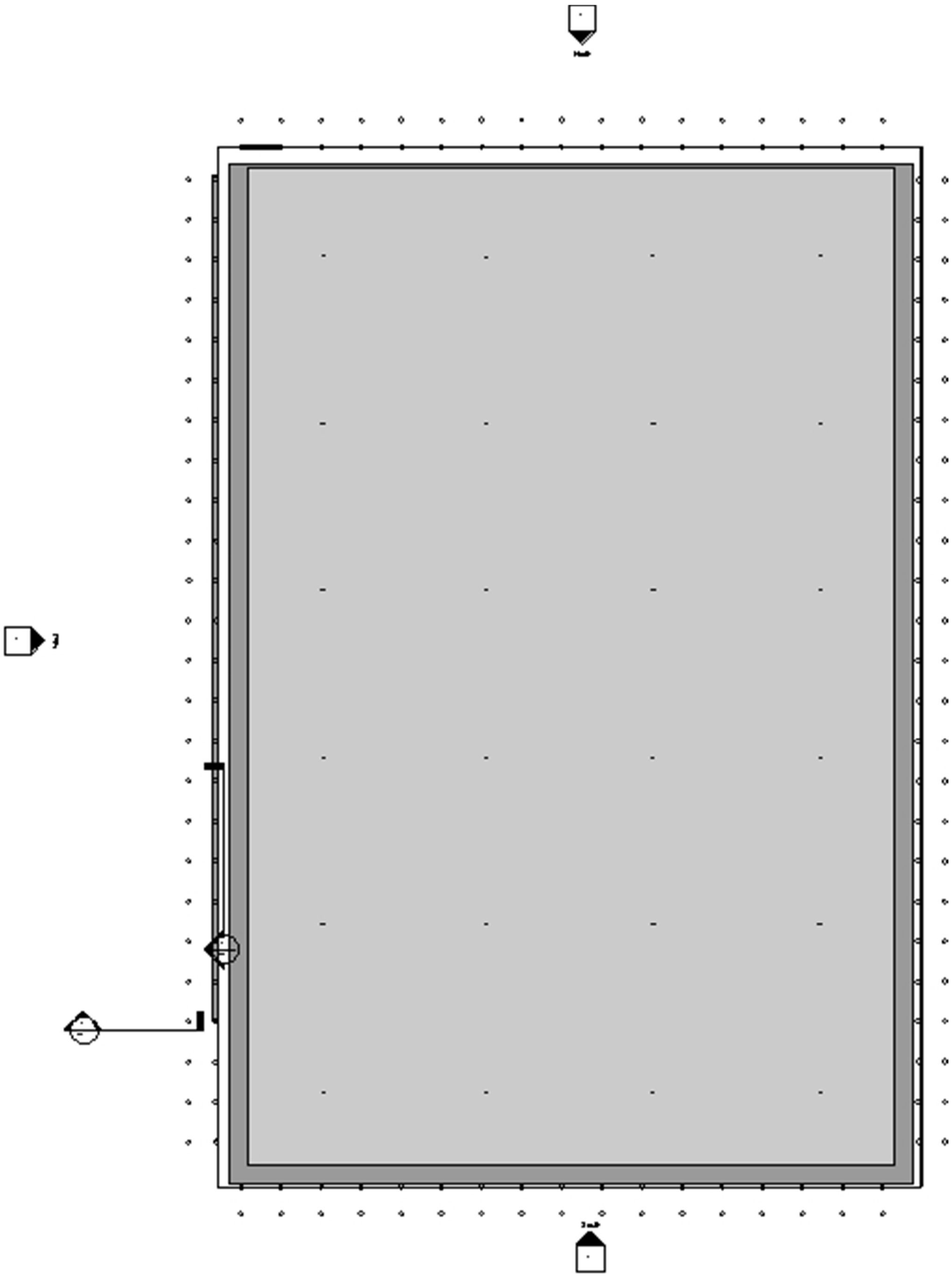
Through our research and discussions with current professionals, we feel this is the best design with the given constraints.

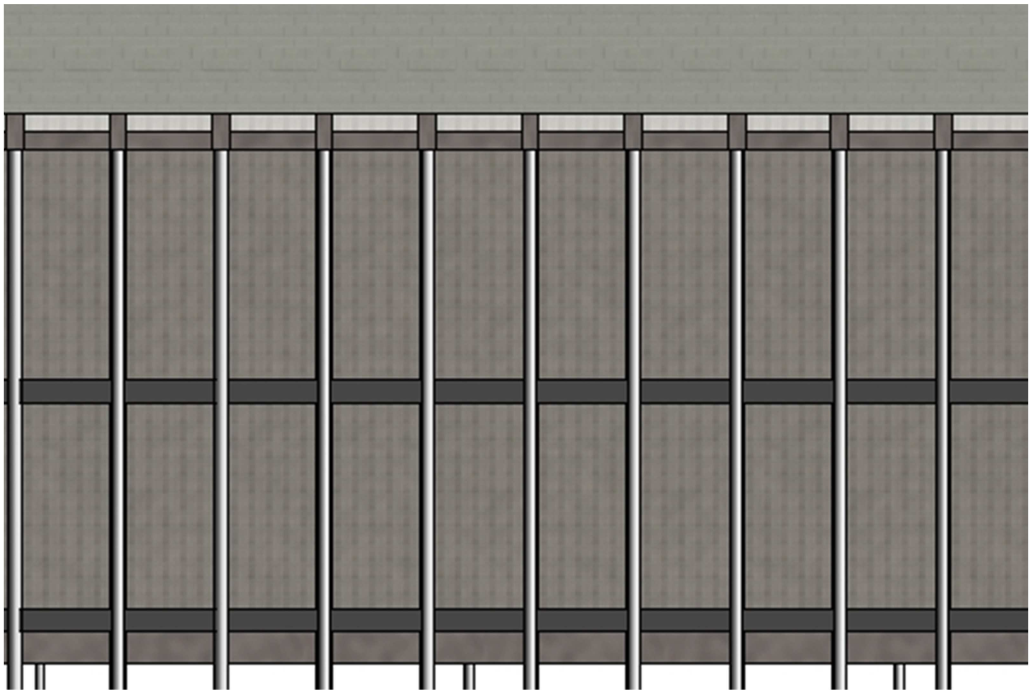
APPENDIX

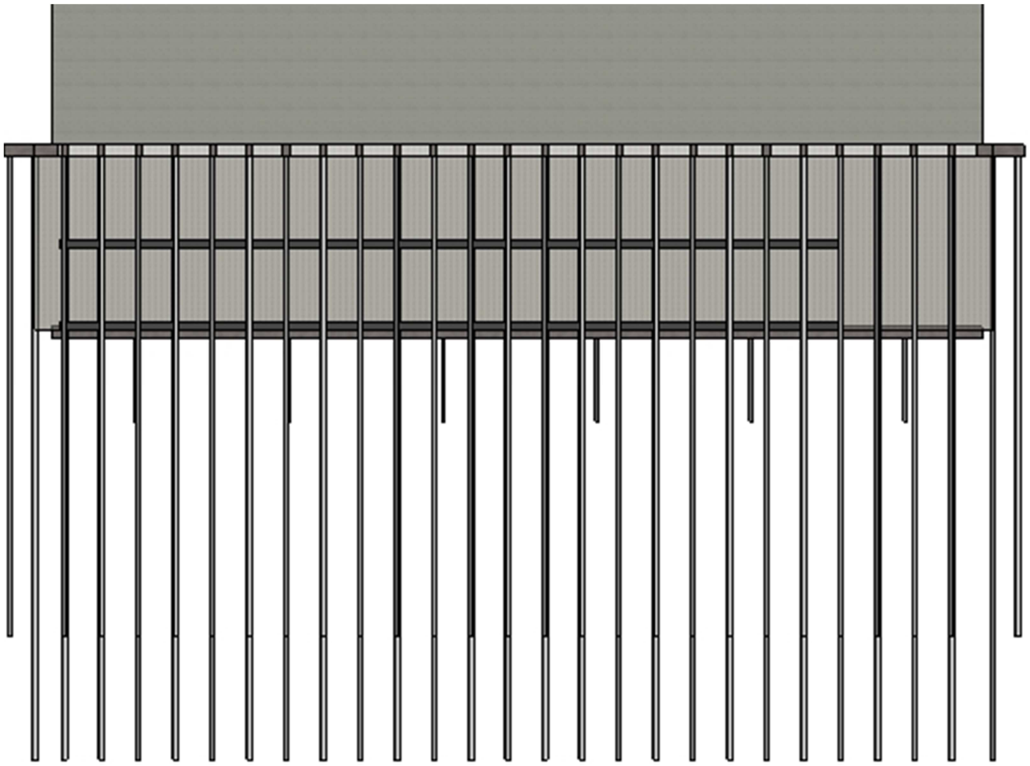
FINAL DESIGN




A
Micropiles
Basement 1 (4530)
-24' - 0"
Wallers
Basement 2 (4518)
-36' - 0"

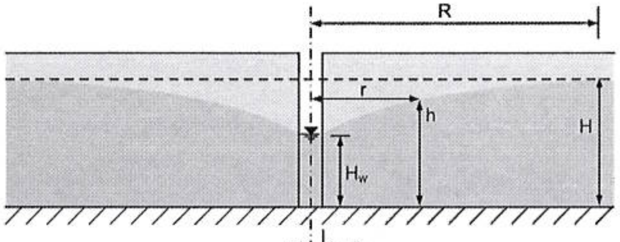






Construction Dewatering - Unconfined Aquifer

Brigham Young University - CE En 594R



This winter was very dry so we are assuming the water table has stayed near 18 ft. If this is a bad assumption, the water table should be assumed to be at 15 ft.

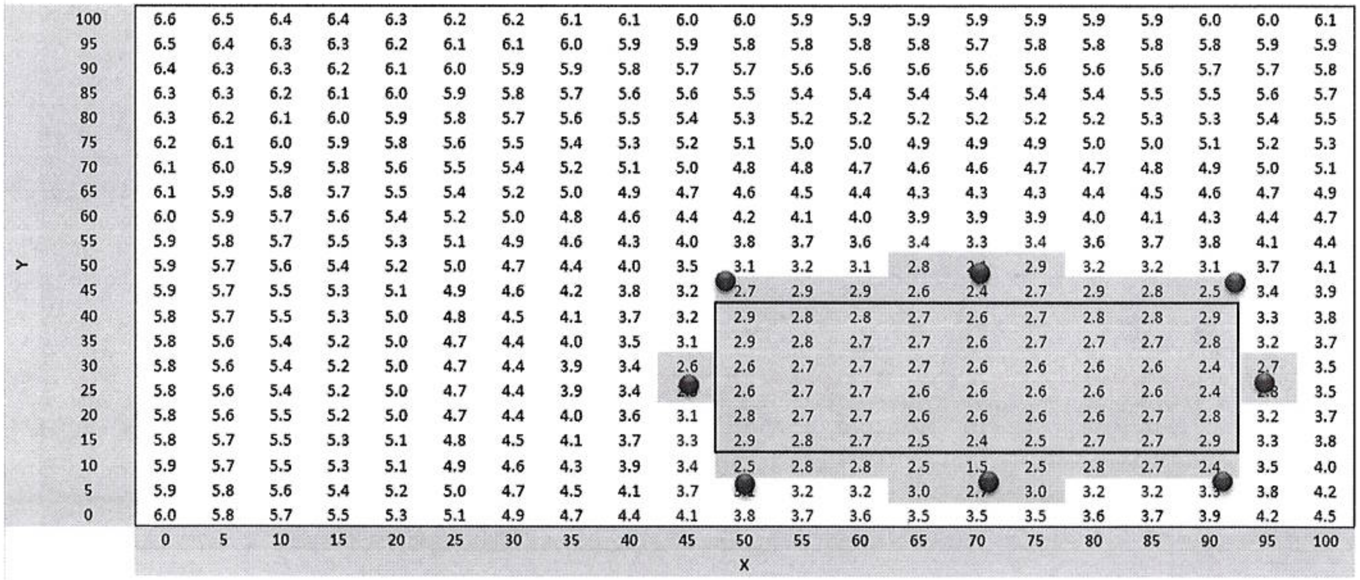
k:	0.505	[cm/s]	xmin:	0	[m]	Design h:	3.0488	[m]		
k:	0.00505	[m/s]	xmax:	100	[m]	Max h:	2.9	[m]		
H:	9.756	[m]	ymin:	0	[m]	Total Q:	0.41	[m^3/s]		
R:	750	[m]	ymax:	100	[m]		6493.2	[gal/min]		

Build Wells

$$h = \sqrt{H^2 - \frac{1}{\pi k}\sum_{i=1}^{n} q_i \ln(R/r_i)}$$

This analysis is based off the following assumptions:

- H goes down from the water table (at 15ft) to the clay layer (at 50ft)
- We are designing for the water table to drop below 40ft - the bottom of the excavation

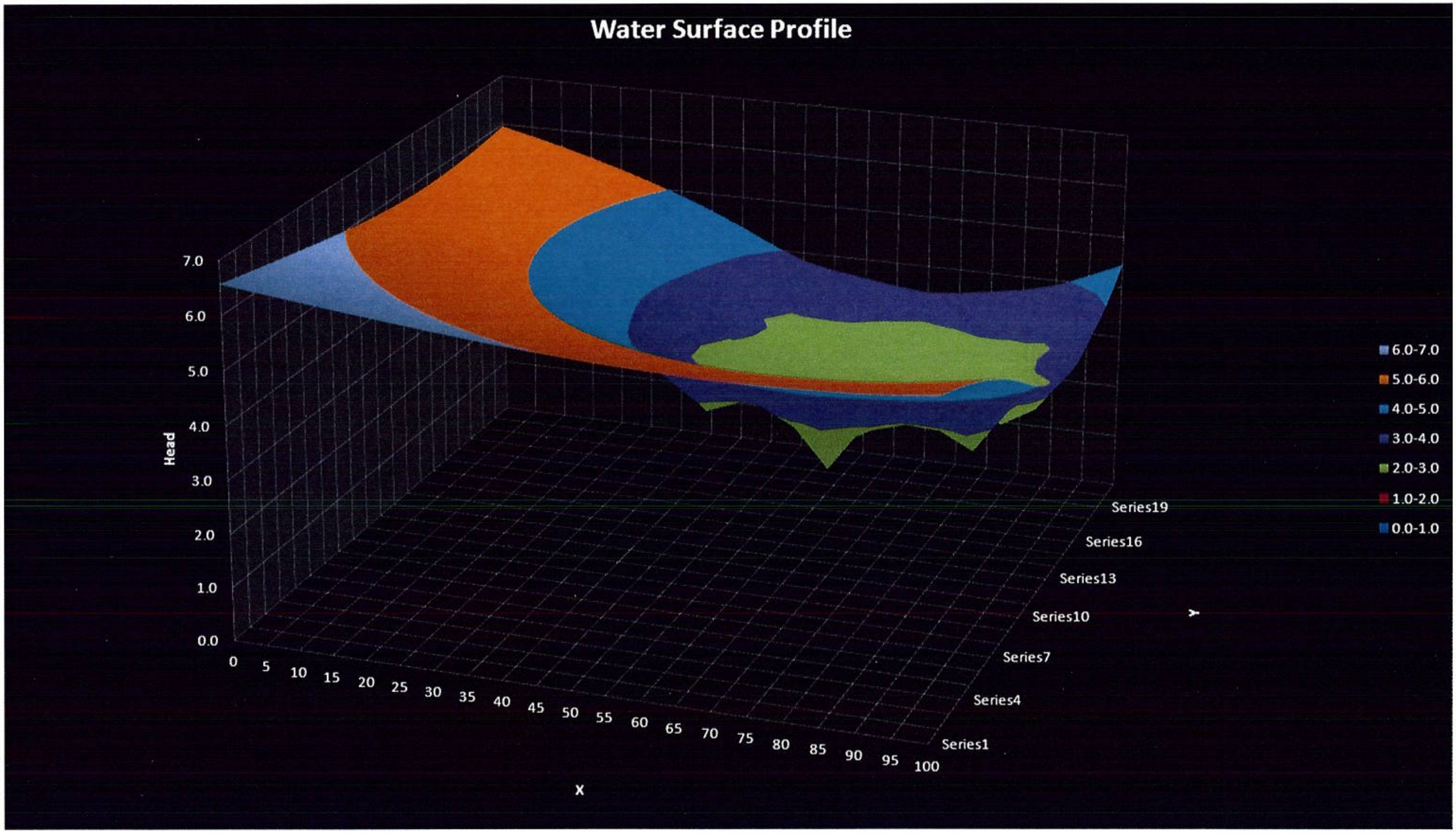


Y	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100	6.6	6.5	6.4	6.4	6.3	6.2	6.2	6.1	6.1	6.0	6.0	5.9	5.9	5.9	5.9	5.9	5.9	5.9	6.0	6.0	6.1
95	6.5	6.4	6.3	6.3	6.2	6.1	6.1	6.0	5.9	5.9	5.8	5.8	5.8	5.8	5.7	5.8	5.8	5.8	5.8	5.9	5.9
90	6.4	6.3	6.3	6.2	6.1	6.0	5.9	5.9	5.8	5.7	5.7	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.7	5.7	5.8
85	6.3	6.3	6.2	6.1	6.0	5.9	5.8	5.7	5.6	5.6	5.5	5.4	5.4	5.4	5.4	5.4	5.4	5.5	5.5	5.6	5.7
80	6.3	6.2	6.1	6.0	5.9	5.8	5.7	5.6	5.5	5.4	5.3	5.2	5.2	5.2	5.2	5.2	5.2	5.3	5.3	5.4	5.5
75	6.2	6.1	6.0	5.9	5.8	5.6	5.5	5.4	5.3	5.2	5.1	5.0	5.0	4.9	4.9	4.9	5.0	5.0	5.1	5.2	5.3
70	6.1	6.0	5.9	5.8	5.6	5.5	5.4	5.2	5.1	5.0	4.8	4.8	4.7	4.6	4.6	4.7	4.7	4.8	4.9	5.0	5.1
65	6.1	5.9	5.8	5.7	5.5	5.4	5.2	5.0	4.9	4.7	4.6	4.5	4.4	4.3	4.3	4.3	4.4	4.5	4.6	4.7	4.9
60	6.0	5.9	5.7	5.6	5.4	5.2	5.0	4.8	4.6	4.4	4.2	4.1	4.0	3.9	3.9	3.9	4.0	4.1	4.3	4.4	4.7
55	5.9	5.8	5.7	5.5	5.3	5.1	4.9	4.6	4.3	4.0	3.8	3.7	3.6	3.4	3.3	3.4	3.6	3.7	3.8	4.1	4.4
50	5.9	5.7	5.6	5.4	5.2	5.0	4.7	4.4	4.0	3.5	3.1	3.2	3.1	2.8	[illegible]	2.9	3.2	3.2	3.1	3.7	4.1
45	5.9	5.7	5.5	5.3	5.1	4.9	4.6	4.2	3.8	3.2	2.7	2.9	2.9	2.6	2.4	2.7	2.9	2.8	2.5	3.4	3.9
40	5.8	5.7	5.5	5.3	5.0	4.8	4.5	4.1	3.7	3.2	2.9	2.8	2.8	2.7	2.6	2.7	2.8	2.8	2.9	3.3	3.8
35	5.8	5.6	5.4	5.2	5.0	4.7	4.4	4.0	3.5	3.1	2.9	2.8	2.7	2.7	2.6	2.7	2.7	2.7	2.8	3.2	3.7
30	5.8	5.6	5.4	5.2	5.0	4.7	4.4	3.9	3.4	2.6	2.6	2.7	2.7	2.7	2.6	2.6	2.6	2.6	2.4	2.7	3.5
25	5.8	5.6	5.4	5.2	5.0	4.7	4.4	3.9	3.4	[illegible]	2.6	2.7	2.7	2.6	2.6	2.6	2.6	2.6	2.4	2.8	3.5
20	5.8	5.6	5.5	5.2	5.0	4.7	4.4	4.0	3.6	3.1	2.8	2.7	2.7	2.6	2.6	2.6	2.6	2.7	2.8	3.2	3.7
15	5.8	5.7	5.5	5.3	5.1	4.8	4.5	4.1	3.7	3.3	2.9	2.8	2.7	2.5	2.4	2.5	2.7	2.7	2.9	3.3	3.8
10	5.9	5.7	5.5	5.3	5.1	4.9	4.6	4.3	3.9	3.4	2.5	2.8	2.8	2.5	1.5	2.5	2.8	2.7	2.4	3.5	4.0
5	5.9	5.8	5.6	5.4	5.2	5.0	4.7	4.5	4.1	3.7	[illegible]	3.2	3.2	3.0	2.7	3.0	3.2	3.2	3.3	3.8	4.2
0	6.0	5.8	5.7	5.5	5.3	5.1	4.9	4.7	4.4	4.1	3.8	3.7	3.6	3.5	3.5	3.5	3.6	3.7	3.9	4.2	4.5

X

KEY

- ○ Well
- — Outline of Structure
- ▨ Drawdown is below required limit


Water Surface Profile
Head
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
X
Series1
Series4
Series7
Series10
Series13
Series16
Series19
Y
6.0-7.0
5.0-6.0
4.0-5.0
3.0-4.0
2.0-3.0
1.0-2.0
0.0-1.0

DEVELOPMENT LENGTH OF EXISTING WALL

LOADS / LOAD COMBOS

$$h := 45\text{ft}$$

$$DLb := 125\,\frac{\text{lbf}}{\text{ft}^2}\cdot h = 5625\cdot\frac{\text{lbf}}{\text{ft}}$$

$$DLs := 120\,\frac{\text{lbf}}{\text{ft}^2}\left(\frac{2}{3}\right)\text{ft} = 80\cdot\frac{\text{lbf}}{\text{ft}}$$

$$DL := DLb + DLs = 5705\cdot\frac{\text{lbf}}{\text{ft}}$$

Load Combo - 0

$$TL := DL = 5705\cdot\frac{\text{lbf}}{\text{ft}}$$

We designed the development length based off of a simply supported beam with x being the distance between the supports.

We are designing for just the wall loads because we are finding how wide just the wall can span. From the Steel Manual the density for common brick is 125pcf.

Because we are not designing, we do not need to use a load combination.

ANALYSIS

$$x := 6\text{ft} \qquad hi := 8\text{in}$$

$$E := 57000\,\frac{\text{lbf}}{\text{in}^2}\cdot(3000)^{.5} = 3122018.578\cdot\frac{\text{lbf}}{\text{in}^2}$$

$$I := \frac{\left(1 + \frac{2}{3}\right)\text{ft}\cdot hi^3}{12} = 853.333\cdot\text{in}^4$$

$$Mmax := \frac{TL\cdot x^2}{8} = 25673\cdot\text{lbf}\cdot\text{ft}$$

$$Vmax := \frac{TL\cdot x}{2} = 17115\cdot\text{lbf}$$

$$Delta := \frac{5\cdot TL\cdot x^4}{384\cdot E\cdot I} = 0.06244\cdot\text{in} \qquad Deltamax := \frac{x}{600} = 0.12\cdot\text{in}$$

Assuming we use the modulus of elasticty of concrete with an f'c of 3000.

To be conservative we will use the height of two layers of brick (8in) to use in our moment of intertia.

As we did we will need to place a steel plate with edges up around the wall every ft or so. Drilling the laps on the side into the wall. This will hold the bricks from separating and falling.

UNDERPINNING DESIGN

Design of Cantilever System

$a := 3\text{ft} \qquad b := 4\text{ft} \qquad cc := 1\text{ft}$

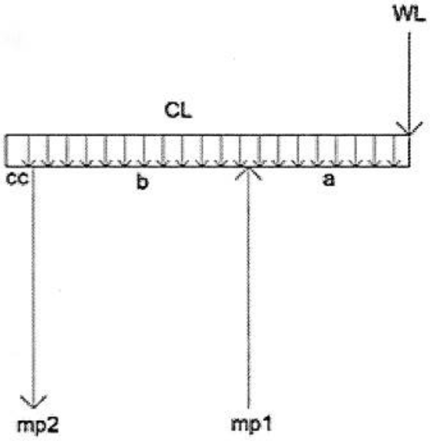
$wc := 2\text{ft} \qquad hc := 1\text{ft}$

$l_b := 6\text{ft}$

$h := 45\text{ft}$

$$WL := 125\frac{\text{lbf}}{\text{ft}^3}\cdot\frac{5}{3}\text{ft}\cdot l_b\cdot h = 56.25\cdot\text{kip}$$

$$CL := 120\frac{\text{lbf}}{\text{ft}^3}\cdot wc\cdot hc = 0.24\cdot\frac{\text{kip}}{\text{ft}}$$



Assuming density of brick 125pcf multiplied by the thickness of the wall which is 1 2/3 ft

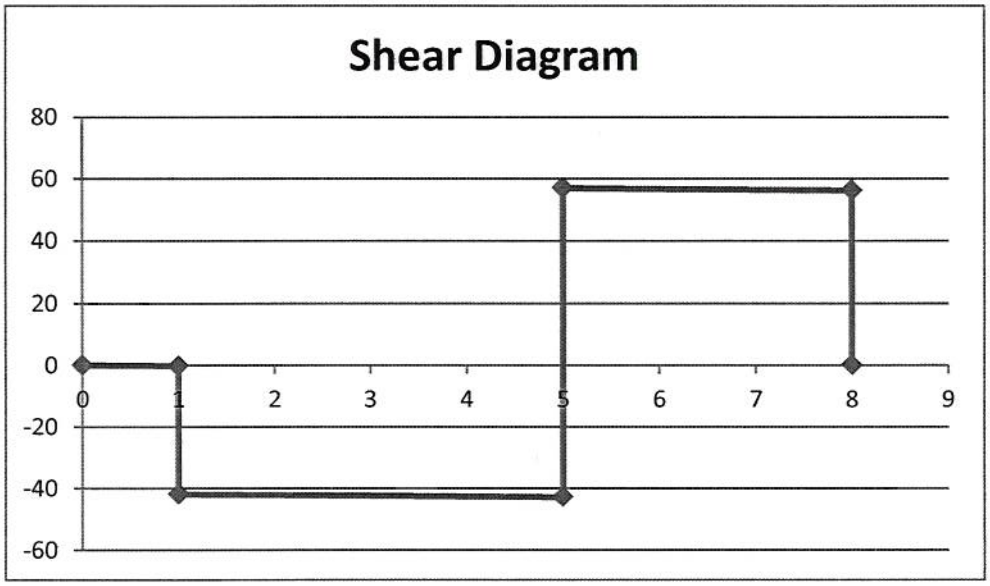
Sum of moments at mp2

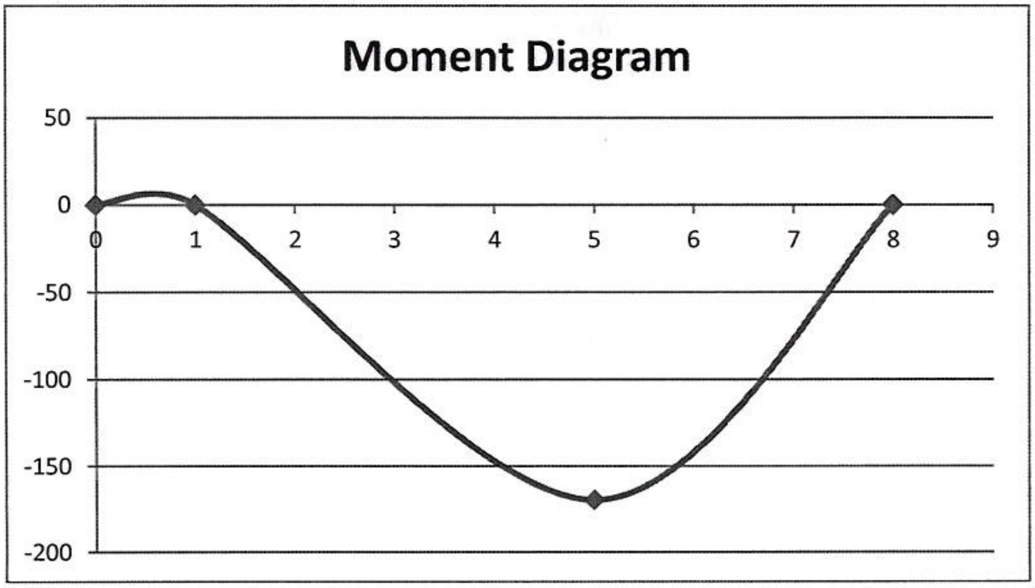
0 = mp1*b - WL(a+b) - (a+b)^2*CL/2 + c^2*CL/2

$$mp1 := \frac{WL\cdot(a+b) + \frac{(a+b)^2\cdot CL}{2} - \frac{cc^2\cdot CL}{2}}{b} = 99.878\cdot\text{kip}$$

Sum of Forces in the y direction

$$mp2 := mp1 - WL - CL\cdot(a+b+cc) = 41.708\cdot\text{kip}$$





Micropile Design for Compression

$$\text{alphabond} := 20\frac{\text{lbf}}{\text{in}^2}$$

Taking this number from Micropile Design Manual (pg 5-21). We are basing the number off of a sand (some silt, gravel) and a Type A installation (gravity grout only).

$$\text{FS} := 2.5$$

$$\text{Db} := 10\text{in}$$

$$\text{Lb} := 35\text{ft}$$

We are calculating for after excavation has taken place.

$$\text{Pgallw} := \frac{\text{alphabond}}{\text{FS}}\cdot\pi\cdot\text{Db}\cdot\text{Lb} = 105.558\cdot\text{kip}$$

Note: Whalers, anchors, and soil nails will be necessary.

Micropile Design for Tension

Taking this number from Micropile Design Manual (pg 5-21). We are basing the number off of a sand (some silt, gravel) and a Type B installation (casing withdrawal).

$$\text{alphabond2} := 25\frac{\text{lbf}}{\text{in}^2}$$

$$\text{Dbt} := 8\text{in}$$

$$\text{Lbt} := 15\text{ft}$$

We will be removing the casing on the second micropiles because it increases strength at a little cost. On the inside micropiles we cannot take out the casing because we need to weld on whalers after excavation takes place.

$$\text{Pgallwt} := \frac{\text{alphabond2}}{\text{FS}}\cdot\pi\cdot\text{Dbt}\cdot\text{Lbt} = 45.239\cdot\text{kip}$$

MAT FOUNDATION DESIGN

Soil Pressure

$$qa := (40ft - 15ft)\cdot 62.4\frac{lbf}{ft^3} = 1.56\cdot\frac{kip}{ft^2}$$

qs is from the upward force of the water on the bottom or our mat foundation

Design of Micropile

$$alphabond := 25\frac{lbf}{in^2}$$

$$FS := 2.5$$

$$Db := 6in$$

$$Lb := 15ft$$

$$U := \frac{alphabond}{FS}\cdot\pi\cdot Db\cdot Lb = 33.929\cdot kip$$

U is from our micropile capacity

Building Load

$$TLunfactored := 16.9675kip$$

$$Uwuf := \frac{TLunfactored}{48} = 0.353\cdot kip$$

$$TLfactored := 25.8655kip$$

$$Uwf := \frac{TLfactored}{48} = 0.539\cdot kip$$

Building is 100 ft by 150 ft. We will assume a grid of:
- wall load on edge of 8 on long side and 6 on short side
- micropiles 6 by 4

Spacing:
longside = 25 ft
Shortside = 25 ft

1. Find R and Ru

$$R_0 := Uwuf\cdot 24 + U\cdot 24 = 822.785\cdot kip$$

$$R_u := Uwf\cdot 24 + U\cdot 24 = 827.234\cdot kip$$

$$ss := 25ft$$

$$sl := 25ft$$

$$B := 100ft$$

$$Ll := 150ft$$

2. Find U.R. and qs

$$UR := \frac{R_u}{R_0} = 1.005$$

See attached engineering paper for diagram.

$$qs := UR\cdot qa = 1.568\cdot\frac{kip}{ft^2}$$

3. Find ex and ey

Sum of moments about the y' axis

$$\text{xbar} := \frac{(2\cdot\text{Uwf} + 6\cdot\text{U})\cdot(8\cdot\text{ss}) + (8\cdot\text{Uwf})\cdot(1\text{ft} + 99\text{ft})}{R_u} = 50\cdot\text{ft}$$

$$e_x := \text{xbar} - \frac{B}{2} = 5.828 \times 10^{-15}\cdot\text{ft}$$

Sum of moments about the x' axis

$$\text{ybar} := \frac{(6\cdot\text{Uwf})\cdot(1\text{ft} + 149\text{ft}) + (2\cdot\text{Uwf} + 4\cdot\text{U})\cdot(18\cdot\text{sl})}{R_u} = 75\cdot\text{ft}$$

$$e_y := \text{ybar} - \frac{\text{Ll}}{2} = 0\cdot\text{ft}$$

4. Find Soil Pressure q

$$A_0 := B\cdot\text{Ll} = 15000\cdot\text{ft}^2$$

$$I_x := \frac{1}{12}\cdot B\cdot\text{Ll}^3 = 28125000\cdot\text{ft}^4$$

$$I_y := \frac{1}{12}\cdot\text{Ll}\cdot B^3 = 12500000\cdot\text{ft}^4$$

$$M_x := R_u\cdot e_y = 0\cdot\text{ft}\cdot\text{kip}$$

$$M_y := R_u\cdot e_x = 0\cdot\text{ft}\cdot\text{kip}$$

q = Ru/A + Mx*y/Ix + My*x/Iy

See Excel Sheet for Equation and Table

$\text{qmax} := 0.455\frac{\text{lbf}}{\text{ft}^2}$ which is less than qs= 1.563 lb/ft^2

5. Find d

Critical corner column - factored load of 0.539 kips
edge colunmn - factored load of 0.539 kips
interior column - factoted load of 33.93 kips

$\text{ratio1} := \frac{\text{Uwf}}{2} = 0.269\cdot\text{kip}$ $\text{ratio2} := \frac{\text{Uwf}}{3} = 0.18\cdot\text{kip}$ $\text{ratio3} := \frac{\text{U}}{4} = 8.482\cdot\text{kip}$

Corner Column

$Vu := Uwf = 0.539 \cdot kip$

$bo = 48 + d$ (in)

$Vc := 4psi \cdot .75 \cdot (4000)^{.5} = 0.19 \cdot ksi$

Vc*bo*d=Vu solve for d

d = .059 in

See attached engineering paper for diagrams and work.

Center Column

$Vu2 := U = 33.929 \cdot kip$

$bo = 24 + 4d$ (in)

d = 4.32 in

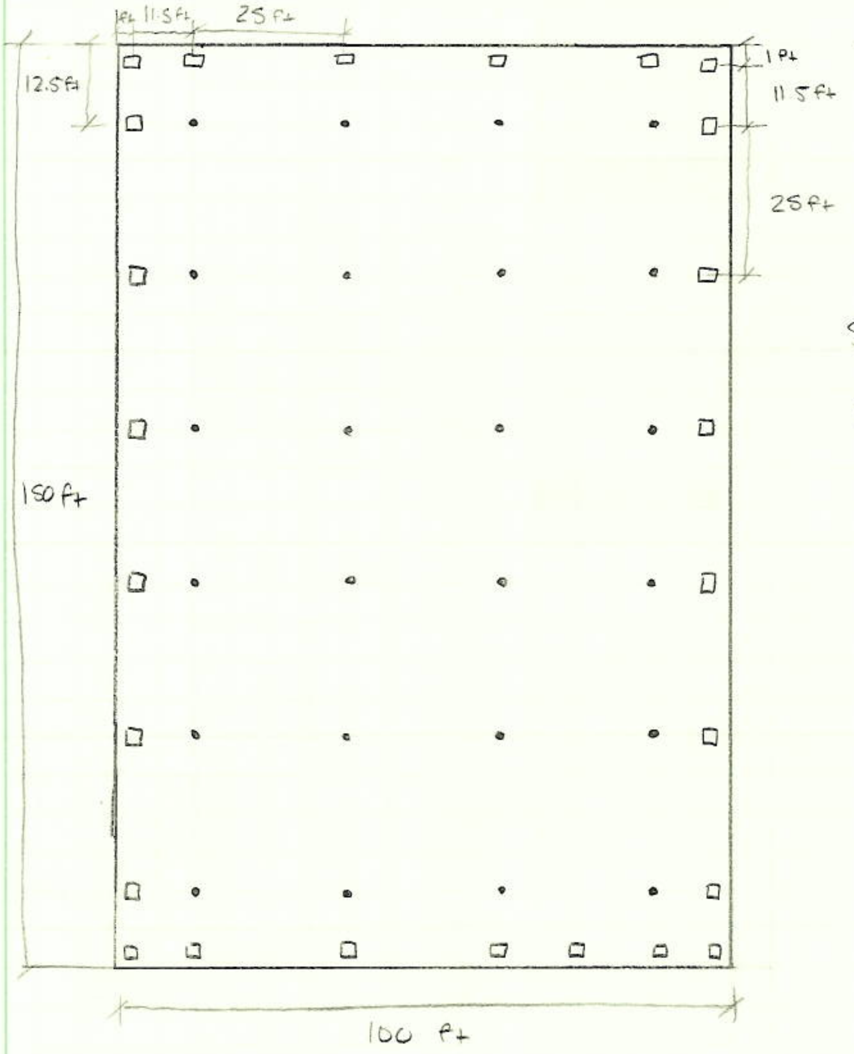
Total Thickness = d + 3 in cover + 1 in steel = 8.5 in

In order to decrease the displacement between the micropiles and in order to decrease the number of micropiles needed, we ran the program using a total depth of two feet for the concrete slab.

The steel requirement was the uniform and equal for the top and bottom in both the x and y directions.

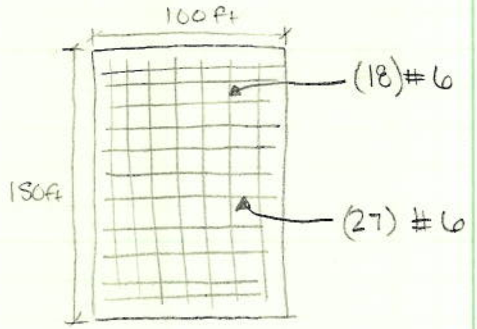
Required Steel: As = 0.576 in^2/ft

We will use: # 6 bars at 5.5 in spacing (As=0.59)



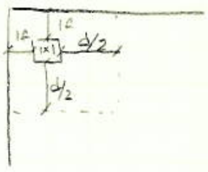
KEY
□ EQUIVALENT WALL LOADS
• MICROPILES

STEEL (TOP & BOTTOM)
IN BOTH X & Y
DIRECTIONS
#6 BARS @ $5\frac{1}{2}$in SPACING



DETERMINING DEPTH (d)

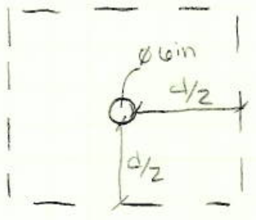
CORNER COLUMN:



$V_u = 0.539$
$b_o = (2ft + d/2)\,2 = 48 + d$ (in)
$V_c = 0.19$

$(0.19)(48+d)d = 0.539$
$d = 0.059$ in

CENTER COLUMN:



$V_u = 33.929$
$b_o = (6in + d)4 = 24 + 4d$ (in)
$V_c = 0.19$

$(0.19)(24+4d)d = 33.929$

$d = 4.32$in

PART 4 OF MAT FOUNDATION DESIGN

Ru= 6820.327 kip
A= 15000 ft^2
Ix= 28125000 ft^4
Iy= 12500000 ft^4
Mx= 0 kip ft
My= 0 kip ft

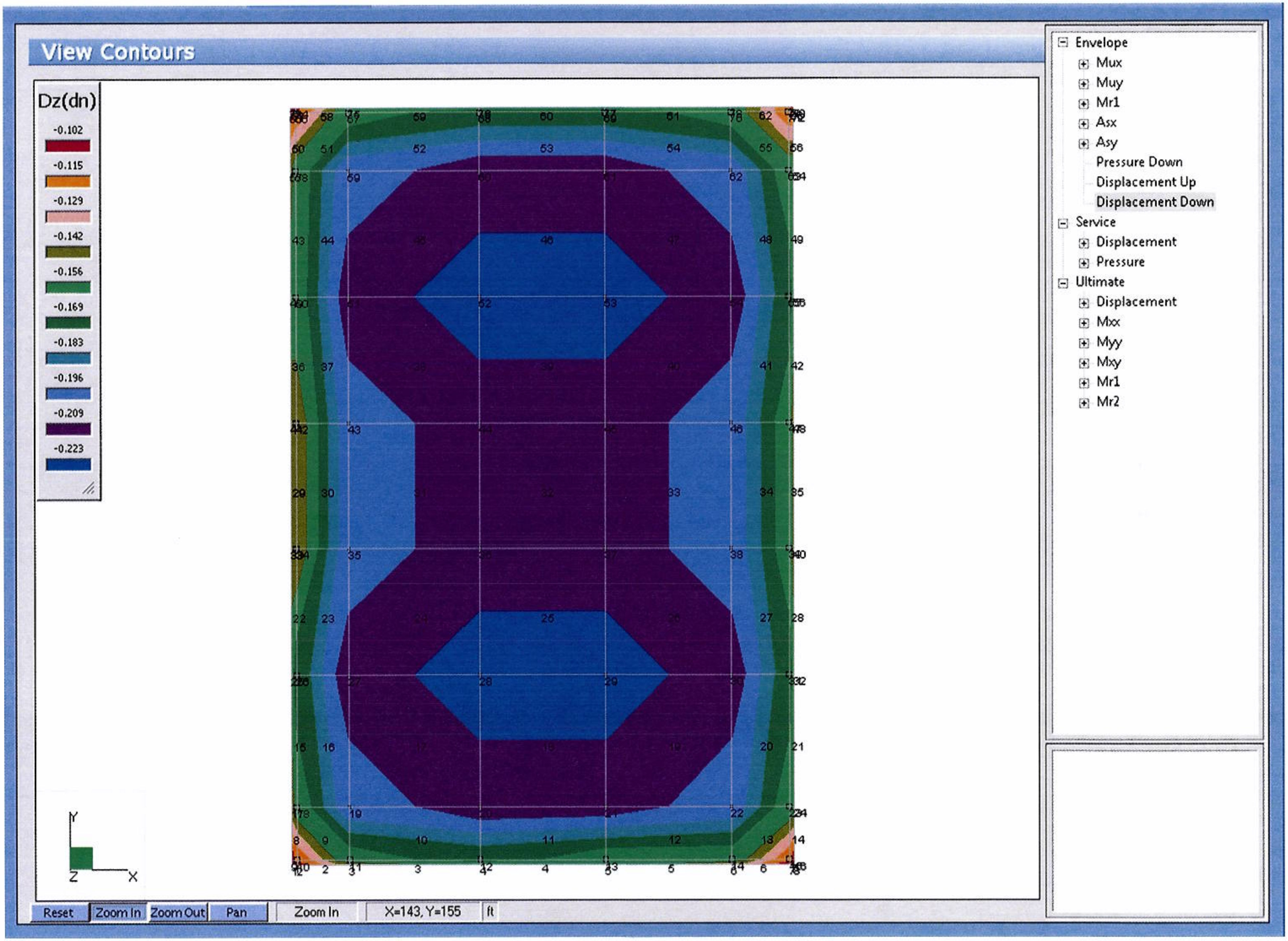
qmax= 0.455

q= Ru/A +Mx*y/Ix + My*x/Iy

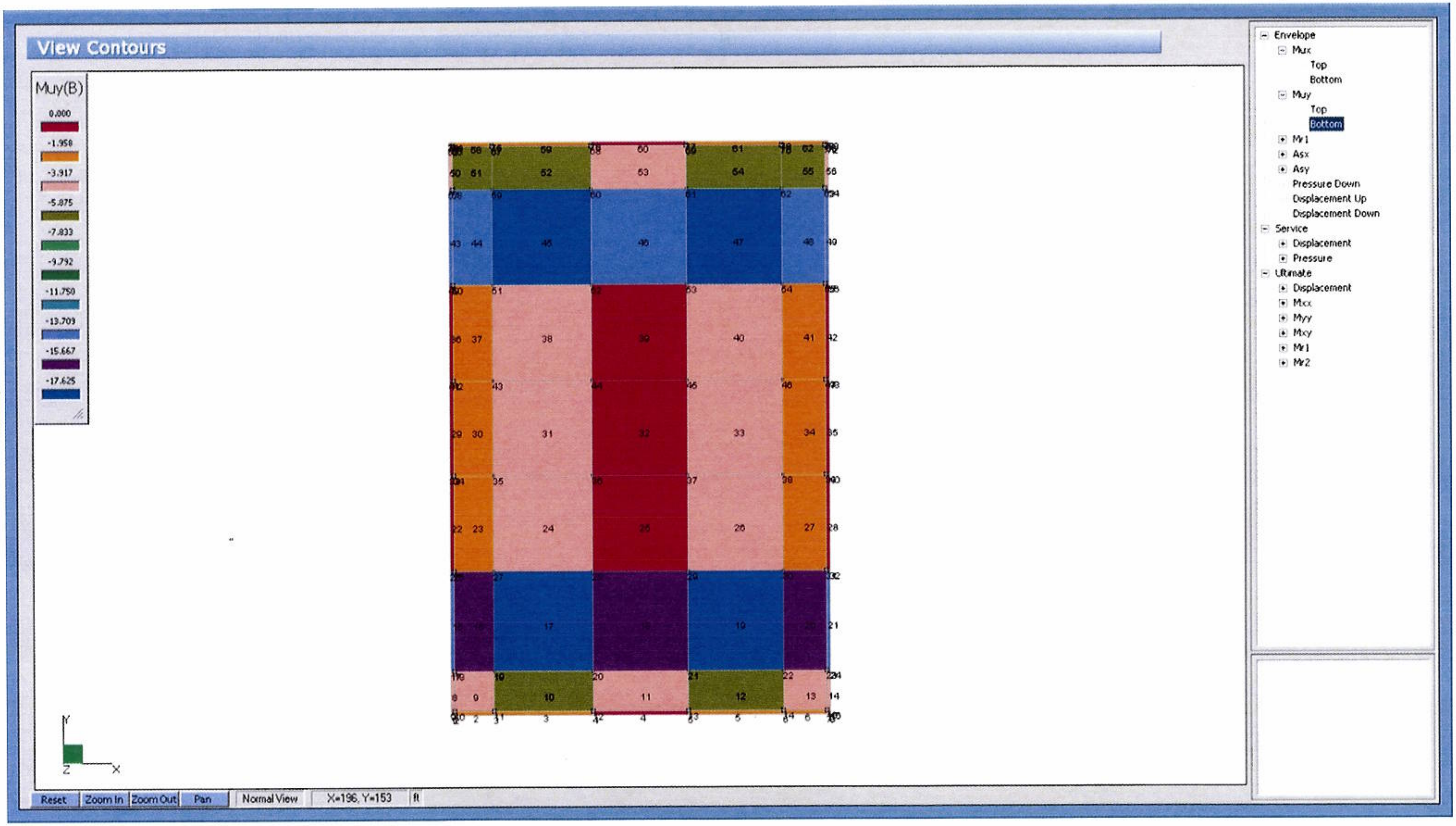
Point	Q/A	x (ft)	(My/Iy) x	y (ft)	(Mx/Ix) y	q (ksf)
1	0.455	-49	0.0000	74	0.00000	0.455
2	0.455	-37.5	0.0000	74	0.00000	0.455
3	0.455	-12.5	0.0000	74	0.00000	0.455
4	0.455	12.5	0.0000	74	0.00000	0.455
5	0.455	37.5	0.0000	74	0.00000	0.455
6	0.455	49	0.0000	74	0.00000	0.455
7	0.455	-49	0.0000	62.5	0.00000	0.455
8	0.455	-37.5	0.0000	62.5	0.00000	0.455
9	0.455	-12.5	0.0000	62.5	0.00000	0.455
10	0.455	12.5	0.0000	62.5	0.00000	0.455
11	0.455	37.5	0.0000	62.5	0.00000	0.455
12	0.455	49	0.0000	62.5	0.00000	0.455
13	0.455	-49	0.0000	37.5	0.00000	0.455
14	0.455	-37.5	0.0000	37.5	0.00000	0.455
15	0.455	-12.5	0.0000	37.5	0.00000	0.455
16	0.455	12.5	0.0000	37.5	0.00000	0.455
17	0.455	37.5	0.0000	37.5	0.00000	0.455
18	0.455	49	0.0000	37.5	0.00000	0.455
19	0.455	-49	0.0000	12.5	0.00000	0.455
20	0.455	-37.5	0.0000	12.5	0.00000	0.455
21	0.455	-12.5	0.0000	12.5	0.00000	0.455
22	0.455	12.5	0.0000	12.5	0.00000	0.455
23	0.455	37.5	0.0000	12.5	0.00000	0.455
24	0.455	49	0.0000	12.5	0.00000	0.455
25	0.455	-49	0.0000	-12.5	0.00000	0.455
26	0.455	-37.5	0.0000	-12.5	0.00000	0.455
27	0.455	-12.5	0.0000	-12.5	0.00000	0.455
28	0.455	12.5	0.0000	-12.5	0.00000	0.455
29	0.455	37.5	0.0000	-12.5	0.00000	0.455
30	0.455	49	0.0000	-12.5	0.00000	0.455
31	0.455	-49	0.0000	-37.5	0.00000	0.455
32	0.455	-37.5	0.0000	-37.5	0.00000	0.455
33	0.455	-12.5	0.0000	-37.5	0.00000	0.455
34	0.455	12.5	0.0000	-37.5	0.00000	0.455
35	0.455	37.5	0.0000	-37.5	0.00000	0.455
36	0.455	49	0.0000	-37.5	0.00000	0.455

37	0.455	-49	0.0000	-62.5	0.00000	0.455
38	0.455	-37.5	0.0000	-62.5	0.00000	0.455
39	0.455	-12.5	0.0000	-62.5	0.00000	0.455
40	0.455	12.5	0.0000	-62.5	0.00000	0.455
41	0.455	37.5	0.0000	-62.5	0.00000	0.455
42	0.455	49	0.0000	-62.5	0.00000	0.455
43	0.455	-49	0.0000	-74	0.00000	0.455
44	0.455	-37.5	0.0000	-74	0.00000	0.455
45	0.455	-12.5	0.0000	-74	0.00000	0.455
46	0.455	12.5	0.0000	-74	0.00000	0.455
47	0.455	37.5	0.0000	-74	0.00000	0.455
48	0.455	49	0.0000	-74	0.00000	0.455

DEFLECTIONS



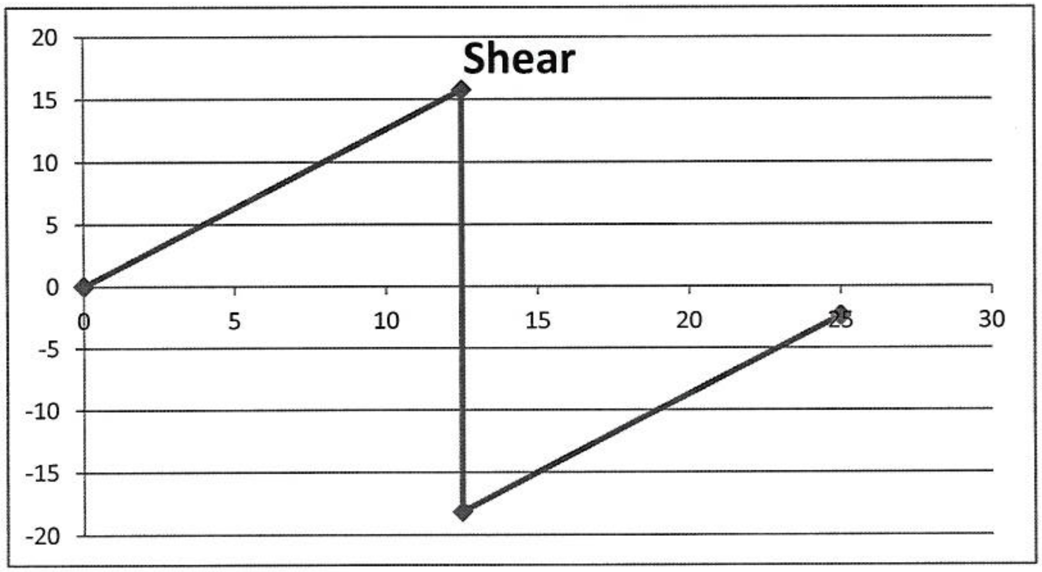
MOMENTS ON BOTTOM IN Y DIRECTION



Priliminary Simple Analysis to Determine Depth of Mat Foundation

Pm	33.9	kip
weight c	0.15	ksf
tc	2	ft
DLc	0.3	k/ft
DLs	1.56	k/ft
L	25	ft

X	V
0	0
12.5000	15.75
12.5000	-18.15
25.0000	-2.4



MAT FOUNDATION DESIGN LOADS

Pg 233 of soils book

Upward Force

$Hw := 40ft - 15ft = 7.62\,m$

$gamawater := 62.4\,\frac{lbf}{ft^3}$

$width := 100ft$ $\quad$ $lengthw := 150ft$

$Pup := Hw\cdot width\cdot lengthw\cdot gamawater = 23400\cdot kip$

$qa := Hw\cdot gamawater = 1.56\cdot\frac{kip}{ft^2}$

Wall Force

$CW := 150\,\frac{lbf}{ft^3}\cdot 2.75ft\cdot 35ft = 14437.5\cdot\frac{lbf}{ft}$

$floornum := 4$

Assuming four floors and one roof

$DLf := 850\,\frac{lbf}{ft}$ $\quad$ $DLr := 350\,\frac{lbf}{ft}$

$LLf := 1000\,\frac{lbf}{ft}$ $\quad$ $SLr := 330\,\frac{lbf}{ft}$

$TLf := (1.2\cdot DLf + 1.6\cdot LLf)\cdot floornum = 10480\cdot\frac{lbf}{ft}$

$TLr := 1.2\cdot DLr + 1.6\cdot SLr = 948\cdot\frac{lbf}{ft}$

$TL := TLf + TLr = 11428\cdot\frac{lbf}{ft}$

$TLfinal := TL + CW = 25865.5\cdot\frac{lbf}{ft}$

FOUNDATION WALL DESIGN

Finding Lateral Earth Pressures

Pg 429 soils book

$Ko := .45$

From geotect report based on the assumption that the walls are stationary during construction and that the backfilling is granular.

$H_t := 30ft$

$H_1 := 15.ft$

Assuming water table is at 15 ft because over time the water table could get this high.

$H_2 := H_t - H_1 = 15 \cdot ft$

Assuming the basement is going down 30ft from the existing grade.

$gama := 125 \frac{lbf}{ft^3}$ $gamawater := 62.4 \frac{lbf}{ft^3}$

At point x=0, P = 0

$P_0 := 0$

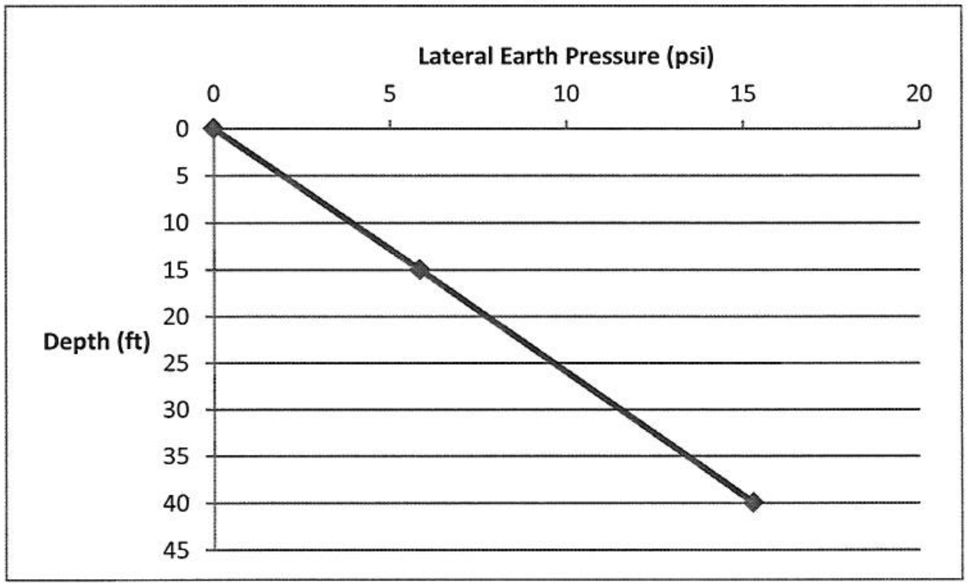
At point x=H1

$P_1 := Ko \cdot gama \cdot H_1 = 5.859 psi$

At point x=Ht

$P_2 := Ko \cdot \left[gama \cdot H_1 + (gama - gamawater) \cdot H_2\right] + gamawater \cdot H_2 = 15.294 psi$

Pressure Distribution From Excel



Design of Foundation Wall

$\text{phi} := .75 \quad f_c := 4000\text{psi} \qquad Vc := 2\text{psi}\cdot\text{phi}\cdot(4000)^{.5} = 94.868\ \text{psi}$

$LF := 1.6 \qquad f_y := 60000\text{psi}$

From 0 to 15 ft

$P_o := (P_1)\cdot LF\cdot 1\text{ft}\cdot H_1\cdot .5 = 10125\ \text{lbf}$

$$d_o := \frac{P_o}{Vc\cdot \text{ft}} = 0.741\ \text{ft}$$

We will be using 2.75 ft for the entire wall so the bentenite water proofing will work.

From 30 to15 ft

$P := \left[P_1\cdot H_2 + .5\cdot(P_2 - P_1)\cdot H_2\right]\cdot LF\cdot 1\text{ft} = 36552.6\ \text{lbf}$

$$d := \frac{P}{Vc\cdot 1\text{ft}} = 2.676\cdot\text{ft}$$

We acknowledge that this design is over conservative because the underpinning system will actually hold back the lateral earth pressures.

Design of Steel

From 0 to 15 ft

$$M_o := P_o\cdot\frac{H_1}{3} = 50625\cdot\text{lbf}\cdot\text{ft}$$

$$f_o := .9\cdot x\cdot f_y\cdot\left(d_o - \frac{x\cdot f_y}{1.7\cdot f_c\cdot 12\text{in}}\right)$$

Solving for x (see engineering paper attached):

$A_{s1} := 1.41$ in^2/ft

$$\text{rho} := \frac{A_{s1}}{(12)\cdot\frac{d_o\cdot 12}{\text{ft}}} = 0.013$$

Check: > 0.0031
< 0.0217

Use # 8 bars at 6 in (As = 1.57)

From foundation design (Ce En 542) notes.

From 15 to 30 ft

$$M := \left(P_1 \cdot H_2 \cdot \frac{H_2}{2} LF \cdot 1ft\right) + \left[\left(P_2 - P_1\right) \cdot .5 \cdot H_2 \cdot \frac{H_2}{3} \cdot LF \cdot 1ft\right] = 233388 \cdot lbf \cdot ft$$

$$f_1 := .9 \cdot y \cdot f_y \cdot \left(d - \frac{y \cdot f_y}{1.7 \cdot f_c \cdot 12in}\right)$$

Solving for y (see engineering paper attached):

$A_{s2} := 1.67$ in^2/ft

$$rho2 := \frac{A_{s2}}{(12) \cdot \frac{d_o \cdot 12}{ft}} = 0.016$$

Check: > 0.0031
< 0.0217

Use # 8 bars at 5.5 in (As = 1.71)

From foundation design (Ce En 542) notes.

Design of Steel - Foundation Wall

FROM 0 to 15 ft

$M_0 = 50625$ lb/ft $d = 9$ in $f_y = 60$ ksi
$\varnothing = 0.9$ $b = 12$ in $f'_c = 4$ ksi

$$M_0 = \varnothing A_s f_y \left(d - \frac{A_s f_y}{1.7 f'_c b}\right)$$

$$(12)(50.625\ \text{k/ft}) = (0.9) A_s (60) \left(9 - \frac{A_s(60)}{(1.7)(4)(12)}\right)$$

$$0 = 607.5 - 486 A_s + 39.706 A_s^2$$

$$A_s = 1.41\ \text{in}^2/\text{ft}$$

FROM 15 to 30 ft

$M = 233.388$ k/ft $d = 32.2$ in $f_y = 60$ ksi
$\varnothing = 0.9$ $b = 12$ in $f'_c = 4$ ksi

$$M = \varnothing A_s f_y \left(d - \frac{A_s f_y}{1.7 f'_c b}\right)$$

$$(12)(233.388) = (0.9) A_s (60) \left(32.2 - \frac{A_s(60)}{(1.7)(4)(12)}\right)$$

$$0 = 2800.656 - 1738.8 A_s + 39.706 A_s^2$$

$$A_s = 1.67\ \text{in}^2/\text{ft}$$