Objective

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

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 make 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 with 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 that the team of engineers working with Reaveley Engineers on the project prepared. This problem seems simple enough, however, the difficulty comes along 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.

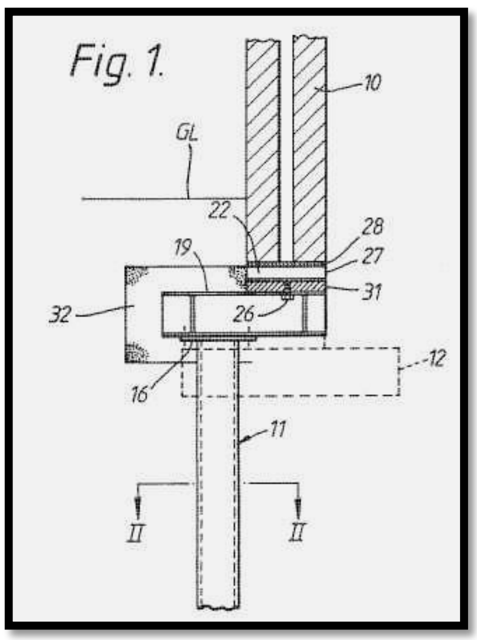
Preliminary Designs

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.



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.

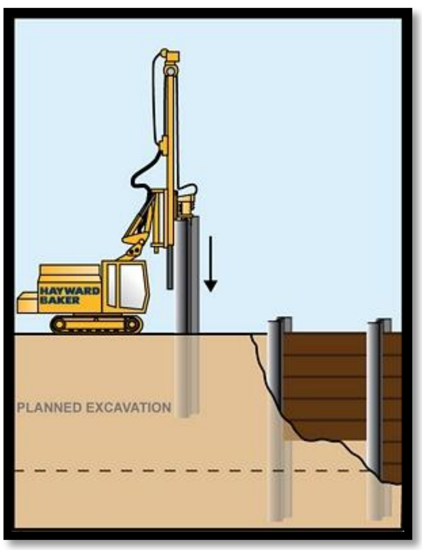
Why we decided not to use it

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

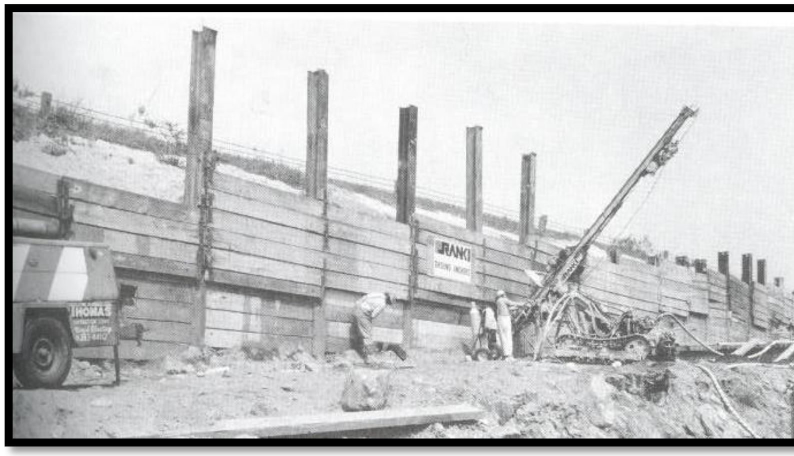
A soldier wall is a widely used soil retention system mainly used in situations where deep excavations are required with limited access. This type of soil retention is especially helpful when the construction site is adjacent to existing buildings or structures. In such situations, the soldier wall not 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.

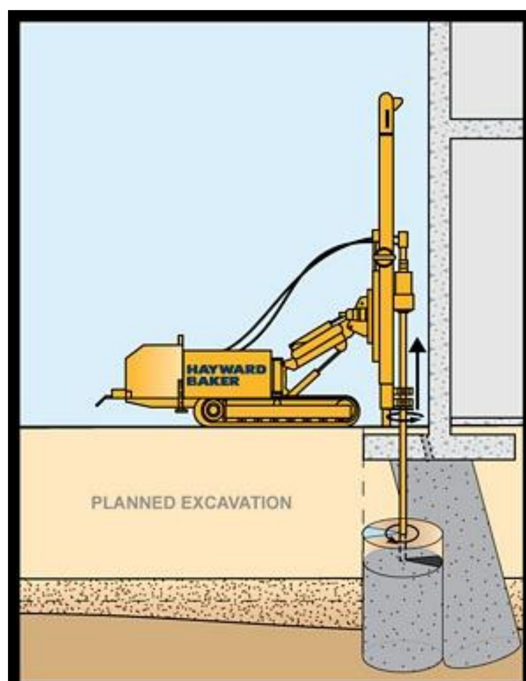


Negatives

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

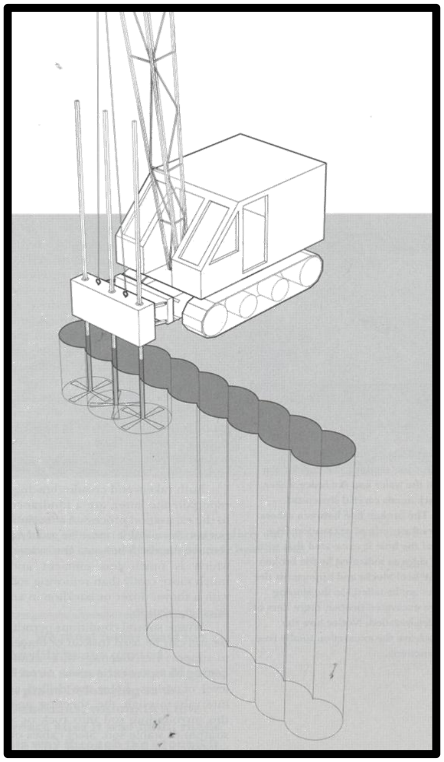
We really like the idea of how easy, fast, and cheap soldier walls are to install. Most importantly though, we were interested in the ability that soldier walls have at supporting existing foundations during deep excavation. We were hoping to be able to build the soldier wall right up against the existing 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.



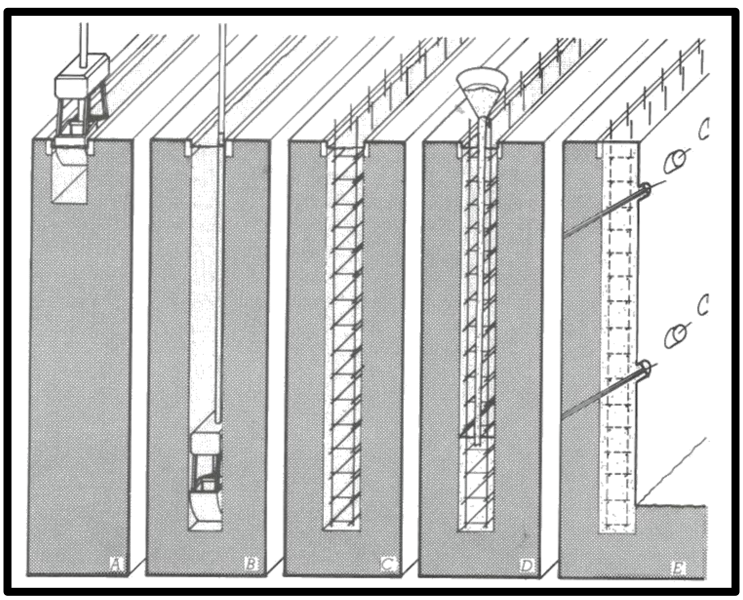
Positive
Jet grouting works very well in gravel and sand. The thick concrete wall is very strong and resists the lateral loads produced by the soil very effectively. Construction crews can excavate right up to the jet grout wall. This process is also good for rehabilitating existing foundations. The 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.

Negative
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.



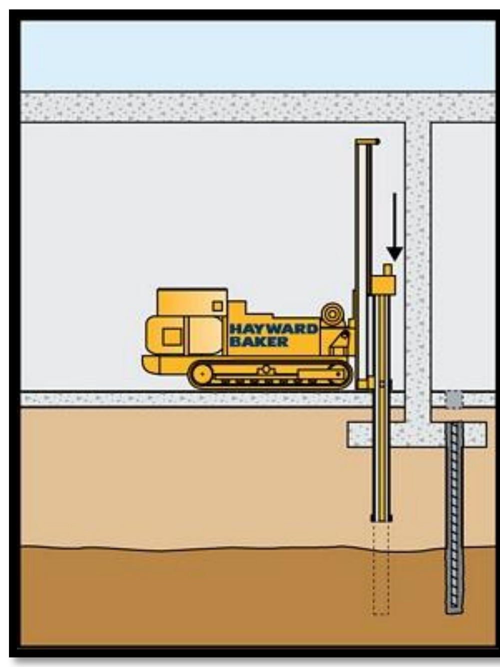
Positive
Slurry walls can be very used for very deep foundations. They can be built at least seven stories deep. They are very effective in that they retain soil during construction and continue to resist the lateral loads after the concrete has cured. They are used as permanent foundations. Slurry walls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

Negative
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.



Positive
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 micropilling 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.

Negative
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 in and of themselves, we were a little deflated. 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.

Defined

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 __feet below the lowest excavation depth. A system of __ wells, placed at a depth of __ feet will be place around the construction site (see image __for placement details). Each well will be connected to a central pump that will need to pumped at a rate of __ m^3/s in order to draw down the water table from __to __. After the excavation and construction process in completed, these wells can be taken out in order to allow the water table to restore itself.

Before any type of foundation can be built, the problems that arise from the presence of the previous foundation needed to be solved. We have decided to completely remove the weak, rubble foundation. This would be done by removing the old foundations sections at a time until the entire foundation is removed. 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 took place. After removing a section we would then replace them with a concrete mold. This mold would extend not only under the existing walls but also about__ feet beyond towards the outside of the building. In this protruding section we will be forming our underpinning system.

Through our research, the benefits and plausibility 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 because of their small size while still withstanding large loads. The micropiles will be placed__ feet apart from each other, __feet deep, and will completely circumference the building, creating an underpinning system for the entire existing structure.

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 approach. There is a certain type of connection that can be used to connect a metal lagging, called whalers, between the micropiles as excavation is in progress. These whalers will retain the soil and be able to transfer the soil loads to the micropiles. The whalers will also allow us to place pretension anchors back into the soil. Anchors will help the “soldier wall” support the underpinning system and ultimately the existing walls.

Once excavation is complete the foundation can be built. We have decided to use a simple box foundation. The wall will be __ inches thick and placed directly under the existing walls. The mat foundation will need to be __ inches thick with micropiles placed at __ intervals in order to withstand uplift forces from the high water table. Since the foundation will already be deep into the ground we will not have to worry about frost depth.

When the foundation has been completed and construction is over, the dewatering system will be taken out, resulting in a rise in the 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 concrete forms using ___ method along with the anchoring micropiles. We will also be placing a gravel layer __ inches thick with __ inch diameter perforated drains. Our underpinning system will allow us access to the outside of our foundation walls which makes this process possible. Connected to the perforated drain system will be a pump. This pump will be our second line of defense against the high water table. Ideally we would have liked to let gravity drain the water from under our foundation by running pipes south of the construction location where the natural lay of the land drops off dramatically. However, because of the large depth of our foundation (40 feet below the ground surface), this option is not possible. Therefore, we will need a pumping system that will pump water from beneath our foundation up to the nearby storm drains. This will need to be a long term pumping system that can be turned on periodically and especially in an emergency situation.

Positives
Space, room to add dewatering techniques, directly under existing walls, not to thick so have possibility of adding other basements, holds back soil as excavate, and holds up wall, system does not have to be taken out, solves problem of old foundation, solves water table problem, can be done 95% inside existing walls,

Negatives
Will take time but worth it for a good project, won't be cheap like soldier wall but cheaper difficult problem so solution won't ever be cheap,

Why we decided to use it

Overall we feel our final design better solves the problem with the fewest negative aspects.