

7.0 Redesign of Deep Foundation System

Structural Breadth

7.1 Introduction

The foundation of a building provides the building block for the successful completion of an entire project. As a critical phase in the big picture of a construction project, the foundation system operation needs to flow smoothly and cause minimal disruption to following activities to allow our healthcare facilities to open and serve communities faster. A deep foundation system only enhances the need for a reliable, cost efficient method.

7.2 Problem Statement

The current deep foundation system, 150 caissons under the three bed towers, has created multiple issues during construction because of the subsurface site conditions and lack of ability for the entire caisson to rest on adequate bearing rock where intended. This has created numerous schedule delays and cost implications.

7.3 Goals

The analysis will focus on determining a more appropriate system that meets or exceeds all the contract document specifications, greatly improves work flow related to schedule requirements, and maintains a suitable cost.

7.4 Methodology

The following steps will be taken to adequately research this topic:

1. Perform a quantity takeoff of the current deep foundation system
2. Consult industry professionals, research, and identify alternative deep foundation systems that meet the goal.
3. Compare and contrast each system based on initial reviews of constructability, value, and schedule enhancement.
4. Choose best system and design an alternate foundation system based on building loads and other structural variables.
5. Evaluate the alternative system's cost and schedule impacts.
6. Conduct a comparative analysis of the two systems with a primary focus on cost and schedule and a secondary focus on safety.
7. Recommend alternative solution as a viable deep foundation system.

7.5 Tools and Resources

1. Washington County Regional Medical Center Construction Documents and Specifications

2. Gilbane Building Company
3. Penn State Architectural Engineering Faculty
4. Industry Professionals
5. R.S. Means 2008/2009

7.6 Expectations

After conducting all the applicable research and calculations, I expect to have developed an alternative deep foundation system that meets or exceeds the requirements for the project. I also expect the new system to maintain a suitable cost and alleviate schedule concerns. Overall I expect the new system to be a better choice of deep foundation than the original caissons.

7.7 Current Foundation System

As discussed earlier in this report, the Washington County Regional Medical Center has three, five story bed towers that are supported by a deep foundation system. The system chosen for the project was drilled piers, or caissons. A deep foundation system must be utilized in the medical center's situation because of high column loads and deep zones of soft compressible clayey soils. These conditions would cause undesirable differential settlement under a simpler shallow foundation system. There are 150 caissons divided among the three bed towers. The depth varies from approximately six feet to about fifty feet; nevertheless, all of the caissons must reach an adequate rock surface with bearing pressure of 80,000 pounds per square foot. Figure 7.1, as seen on the right, shows the two main problems with the current system. The first problem is the severely sloping rock formation that measures approximately a forty-five degree angle. The second problem is the probe used to identify the location of adequate bearing rock is significantly smaller than the caissons. This caused the reports to show a higher elevation of rock. Consequently, when the much larger diameter caisson drill was used, adequate bearing rock was not reached until a much lower elevation.

Figure 7.1: Caisson Diagram

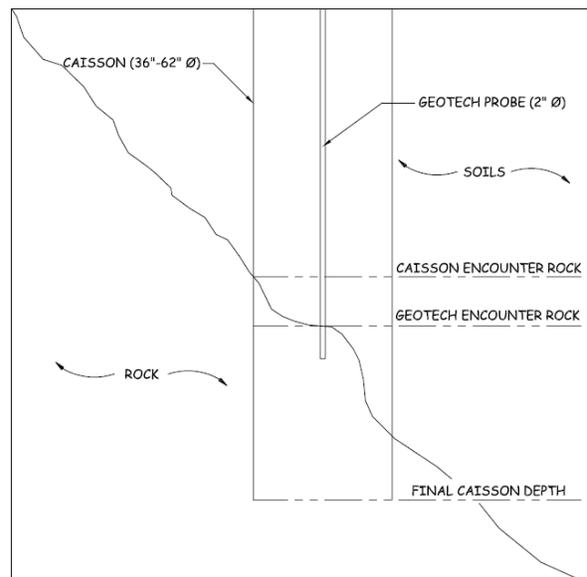


Figure 7.1 is for diagrammatic purposes only and was drawn by the author, not to scale.

7.8 Alternative Method Analysis

The following table, Table 7.1, shows an initial analysis of alternate deep foundation systems. Each system, through proper design, would be able to meet the minimum project requirements of the construction documents and specifications. The initial analysis will be

based primarily on constructability with secondary emphasis on value engineering, and schedule enhancement. Each system is listed and includes the most significant project constraint associated with its construction.

Table 7.1: Initial Alternate Foundation Analysis

INITIAL ALTERNATE FOUNDATION ANALYSIS	
Alternate System	Major Project Constraint
Mat Foundation	Severely sloped rock on site would cause problems excavating a level surface for the mat. This would create a large additional expense on an already expensive system.
End Bearing Piles	End bearing piles need to be avoided because of vibrations from pounding. The outpatient facility on the same site will stay operational throughout construction and vibrations would cause procedural issues.
Friction Piles	Friction piles sound good, but the soil conditions would not provide adequate friction to meet requirements. They too would cause too much vibration.
*Geopiers	Geopiers are a soil enhancement method that would allow the soils to achieve greater bearing capacity. This would then allow a shallow foundation system to be used on top of them. However, vibrations become a major issue when crushing and driving the stone used.
Minipiles	No major constructability issues. May be expensive and time consuming, but hopefully cheaper and faster than drilled piers.

**Geopiers is a registered trade mark name by the Geopier Foundation Company*

Minipiles seem to be a very functional solution. They are a drilled system, contrary to what their name may imply. They could alleviate the troubles encountered by the caissons mainly because of the diameter of the shafts. Minipiles range from five to seven inches, which compares significantly better to the two inch probe utilized for subsurface exploration. They could also drill and manage the Karst terrain, as discussed earlier in this report, which lies under the surface of the site.

7.9 Redesign of Deep Foundation System

The minipile foundation design starts with determining the gravity loads of each of the columns that will bear on the minipiles. The drawings give the load of each column. The ultimate bearing capacity of the minipiles is the next key to design. The geotechnical reports propose that when a minipile foundation design is considered, the bearing capacity and size

of the minipile should be 250 kips and 5 inches diameter, respectively. The load from the drawings is then divided by the 250 kips per minipile. This will provide the number of minipiles per column. There are five different groups of piles. They are the following:

- 2 minipiles
- 4 minipiles
- 5 minipiles
- 6 minipiles
- 8 minipiles

Odd numbered groupings were to be avoided because of the complicated form they present to cap. The exception is 5. Five minipiles can be grouped easily. The next step is to design the caps for the minipiles. The following is a sample calculation for the pile cap design:

Based on

Load transported through column = 392 kips

392 k / 250 kips per minipile = 2 minipiles

Actual capacity = 392 k / 2 = 196 kips

$M_{max} = 196 \text{ kips (3 ft)}$

$M_{max} = 588 \text{ 'k}$

$$\rho = 0.85 \beta_1 (f'_c / f_y) (Eu / (Eu + 0.005))$$

$$\rho = 0.85(0.85)(3/60)(0.003/(0.003 + 0.005))$$

$$\rho = 0.0135$$

$M_u = \phi M_n$ assume $b = 36''$

$$588 \text{ 'k} (12''/1') = 0.90 \times \rho \times 60 \text{ bd}^2 \times (1 - 0.59 ((\rho f_y) / f'_c))$$

$$7056 \text{ in-kips} = 0.90 \times 0.0135 \times (60 \text{ bd}^2) \times (1 - 0.59 ((0.0135 \times 60)/3))$$

$$\text{bd}^2 = 9326 \text{ in}^3$$

$$d = 16'' \text{ OK}$$

$$A_s = \rho \text{ bd}$$

$$A_s = 0.0135 \times 36'' \times 16''$$

$$A_s = 7.78 \text{ in}^2$$

$$\text{Use 8 \#9's} \Rightarrow A_s = 8 \text{ in}^2 \text{ OK}$$

$$h = 16 + 2.5'' \text{ (clear cover)}$$

$$h = 18.5'' \approx 20''$$

$$d = 17.5''$$

$$A_s = 7056 / (0.90 \times 60 (17.5 - 2.5))$$

$$A_s = 8.71 \text{ in}^2$$

$$\text{Use 9 \#9's} \Rightarrow A_s = 9 \text{ in}^2 \text{ OK - Bottom Reinforcement}$$

Shear

$$V_c = (2\sqrt{f'c}(b)(h))/1000$$

$$V_c = (2\sqrt{3000}(36)(17.5))/1000$$

$$V_c = 69 \text{ kips}$$

$$\phi V_n = 0.5(0.75)69$$

$$\phi V_n = 25.9 \text{ kips}$$

$$V_u/\phi - V_c = V_s = 196/0.75 - 69$$

$$V_s = 192 \text{ kips}$$

$$V_s \leq 8\sqrt{f'c} bwd$$

$$= 8\sqrt{3000}(36)(17.5)$$

$$= 276 \text{ kips} < 192 \text{ kips OK}$$

$$S_{\min} = \min(d/4 \text{ controls}) = 17.5/4$$

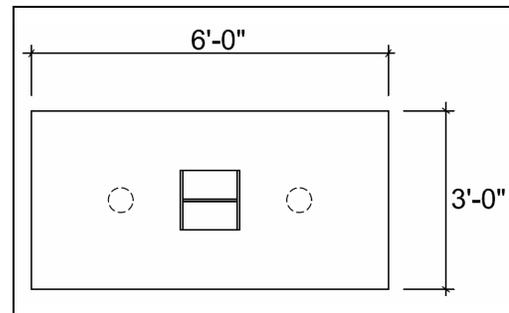
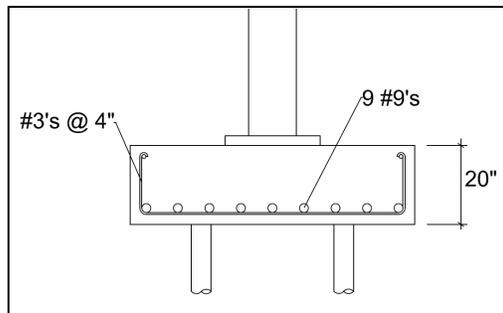
$$S_{\min} = 4.375'' \approx 4''$$

$$A_{v_{\min}} = \max((50(b)(s))/60 \text{ controls}) = (50(36)(4))/60$$

$$A_{v_{\min}} = 0.12 \text{ in}^2$$

Use #3 stirrups @ 4" as minimum Shear Reinforcement

Figure 7.2: Elevation of Sample Minipile Cap **Figure 7.3:** Plan of Sample Minipile



This design was calculated based on per pile width. This allowed for easy calculation of all five different load cases.

The lateral loads are currently being carried by grade beams over the caissons and cap. This system will still work with the minipile foundation system. Therefore, no design alterations were considered to address the lateral loads. Also, the uplift will be controlled with the rock socket. Each minipile is required to include a 10 foot rock socket.

7.10 Schedule Review

The following is a summary schedule comparison of the two deep foundation system durations.

Table 7.2: Schedule Comparison

SCHEDULE COMPARISON				
Construction Time				
System	Quantity	Unit	Output (Unit/Day)	Total (Days)
Caissons	150.0	Caissons	1.5	103.0
Minipiles	532.0	Minipiles	11.0	53.2
Difference				49.8

The original duration of the caissons was to be 50 days. However, as explained previously, the underlying terrain and unforeseen rock slope conditions caused the schedule for the caissons to double. The final duration was 103 days.

Since the minipiles are significantly smaller in diameter the terrain and rock slope will not affect the minipile duration. Also, the probe will be able to determine the rock depth much more accurately because the diameter of the probe is very close to the diameter of the minipile. With these specific site conditions in mind, a 10% buffer will be added to cover some delays. This is the reason the total days on Table 7.2 does not equal the quantity divided by the output. The difference as shown in the table is 49.8 or 50 days. This equates to a 48% percent reduction in schedule time.

7.11 Budget Review

An in depth cost breakdown of each system is provided in Appendix K. The following table, Table 7.3, is a summary comparison of the two systems' costs. Again, a buffer of 10% was added into the costs because of the underground, unexpected conditions related to the project site.

Table 7.3: Cost Comparison Summary

COST COMPARISON				
System	Labor (\$)	Material (\$)	Equipment (\$)	Total
Caissons	\$759,826.61	\$295,632.12	\$798,114.90	\$1,853,573.62
Minipiles	\$520,383.27	\$203,568.88	\$585,336.19	\$1,440,217.16
Difference				\$413,356.46

The table shows a 22% reduction in cost. The two major costs differences are shown in the labor and equipment costs. The labor costs can be attributed to the rebar cages. The minipiles do not require rebar cages for reinforcement; they only need the special casings left in place after drilling. The caissons need rebar cages fabricated and lowered into the holes. This process is much more labor and time intensive.

7.12 Constructability and Logistics

7.12.1 Constructability

The construction of the minipile foundation system should pose less construction issues than the caisson foundation system. As mentioned in the sections preceding, the terrain and rock slope present major challenges with deep foundation work. The probe used to determine the elevation of the rock and the material that will be drilled through is 2 inches in diameter. The caissons range from 30 inches to 66 inches in diameter. The minipile rigs drill a 5 inch diameter hole. This means that predicting the exact elevation and material make-up of the underground conditions are much more accurate when using the closest diameter rig. Less uncertainties and risks are taken with the smaller hole. The caissons have a much higher degree of risk associated with them.

The rigs used for drilling both size diameter holes are comparable machines. These machines, as shown in Figure 7.4 to the right, are drilling rigs. This machine can drill holes up to 80 inches in diameter. Therefore, the same rig is used when drilling small holes and large holes. The number of rigs will depend on the pace that is achieved during construction. If the minipile construction were to fall behind, more rigs may be brought on site to help make up time. This would pose area issues. However, since the drilling happens early on in construction, the few other activities that are being performed can work around these extra rigs. Again, there is plenty of room on the site if this situation were to present itself.

Figure 7.4: Drill Rig



The schedule and budget both include minipile cap and caisson cap information in them. Another issue is the coordination that needs to occur between the two trades that install the minipiles and that cap the minipiles. The sizes have changed and the materials within the minipile caps have changed. Both were accounted for, but need to be strictly coordinated so that the critical deep foundation work can start the job off on a positive note.

7.12.2 Safety

Safety is always a concern on any jobsite. The minipile foundation system provides less safety risk during inspection and testing. The main aspect of safety is the inspecting of the holes. First, the caissons are tested by sending an engineer in each hole to inspect the drilling operation and to pick out any defects or imperfections. The minipile foundation, since it is much smaller, requires a different testing mechanism that does not involve sending an

individual into the hole. A computer camera system may be used and may cost more, but the individual's safety is of primary importance.

7.13 Conclusion and Recommendations

The minipile deep foundation system provides a very constructible and economical solution for transferring the building's loads to bedrock. It provides significant schedule reduction. Since project start-up is very crucial to the overall project schedule, saving time may prove critical in the big picture. This may also allow other contractors to start earlier, thus compressing the project schedule. The cost of the minipiles is significantly less than the caisson costs. The main savings come from the constructability issues that should be able to be avoided with the minipile construction. The minipile foundation also lessens the risk of injury to an on site worker because no one has to be lowered into a large hole to inspect the inside.

I would highly recommend the minipile deep foundation system as a substitute to the caisson foundation. The main reasons lay in the budget and schedule. Both are greatly reduced from the caissons. There are no real constructability issues with the minipile foundation system and overall seems to be a much better fit with the constraints on the Washington County Regional Medical Center construction site.