ANALYSIS 1: Alternative Foundation System

Problem Identification

Bridgeside II sits on 25 to 40 feet of man placed fill that was placed after the demolition of J&L Steel. The fill has variable strengths and properties and is unsuitable to support the building loads with a typical shallow foundation system. Therefore a deep foundation system was utilized to reach bedrock. Steel H-piles were selected; however, due to existing concrete foundations and steel debris they could not be easily driven. The majority of the piles had to be pre-drilled with a rotary hydraulic drill. The drill was able to break through concrete but was not effective with the steel debris. Some of the shallow debris had to be excavated out of the site. The extensive amount of drilling created schedule delays and increased the foundation costs.

Proposal

Potential foundation systems that could be used include Micro piles, a Mat Slab, and Drilled Caissons. I plan on investigating the cost, schedule, and feasibility of these systems to determine an appropriate replacement for the driven H-piles. The structural requirements will also need to be analyzed to determine the required strengths, sizes, and reinforcing.

Goal

The goal of this analysis is to determine a new foundation system that can be installed more efficiently and in less time. Cost savings will also be strived for but the main purpose of this analysis is to create a schedule reduction. Bridgeside II faced schedule delays while installing the deep foundation system due to underground obstructions. This created delays because the majority of the piles had to be predrilled, which is a slow process. Creating a schedule reduction is important to the owner, The Ferchill Group, because once the building is complete they can lease the space and start collecting payments. Also once 50 percent of the building is leased, the owner can begin the next speculative building in the Pittsburgh Technology Center.

Methodology

1) Research alternative foundation systems that could be applied to the Bridgeside II project.
2) Calculate structural requirements to determine the necessary foundation strengths and sizes.
3) Compare the cost and schedule of the current deep foundation system with alternative foundation systems.

Current Foundation System - Steel H-Piles

Steel H-piles were selected as the foundation system due to the variable fill on site; however, the amount of underground obstructions were underestimated. Test borings and knowledge of the previous site use warned of potential concrete and steel obstructions. The owners chose to provide a $150,000 allowance for pre-drilling that was consumed along with an additional $135,000. In addition, approximately $4,000 was spent to remove shallow obstructions. Some of the obstructions could be driven through but if the pile experienced excessive driving stresses then the pile integrity would be decreased.

There are two types of driven piles; end bearing piles and friction piles. End bearing piles are driven into rock far under the building surface. Friction piles rely on the soil pressure around the pile to prevent uplift from occurring. Friction still provides support for end bearing piles because when the pile is driven the soil compresses around it, increasing the frictional force. End bearing piles were utilized for the Bridgeside II project due to the poor soil conditions. Each pile had to be driven to refusal into bedrock that was 45 to 55 feet below the surface. The two sizes of H-piles used were HP 10x57 and HP 14x73 which have a capacity of 210 kips and 260 kips respectively.

The following are the advantages and disadvantages of a driven steel pile foundation system.

Advantages:

- Can be driven in long lengths
- Can be driven easily and quickly through soft soils
- The piles can carry heavy loads
- Limited soil displacement which is important if the soil is contaminated
- Steel piles can easily be cut or spliced for different lengths
- Can be anchored into flat or sloped rock

Disadvantages:

- Underground objects or boulders can block or deviate the pile
- Corrosion can occur
- Relatively expensive
- The hammer is noisy and the vibrations can disrupt or damage adjacent structures
- Requires a lot of headroom

Cost and Schedule

The total duration to construct the driven pile foundation system is **123 days**. This also includes the time for constructing the concrete foundations including the pile caps, grade beams, piers, and foundation walls. The phasing of the foundation system enables the structural steel erection to overlap the foundation construction by 25 days. This time needs to be considered when comparing other systems because the construction phases will vary. Tables 1.1 and 1.2 show the schedules for the foundations and structural steel. The total cost for the piles, including pre-drilling and driving, is $905,565. The concrete foundation's cost is $214,435, which totals to **$1,119,999** for the entire foundation system. Table 1.3 shows the costs for the piles and each of the concrete foundation structures.

Table 1.1 – Foundation Schedule

Foundations	123 days	Wed 11/21/07	Fri 5/9/08
Pre-drill Piles	47 days	Wed 11/21/07	Thu 1/24/08
Install H-Piles	36 days	Tue 12/18/07	Tue 2/5/08
Concrete Pile Caps	60 days	Tue 1/8/08	Mon 3/31/08
Concrete Grade Beams and Piers	64 days	Tue 1/29/08	Fri 4/11/08
Concrete Foundation Walls	30 days	Wed 3/12/08	Tue 4/22/08
Grout Base Plates	11 days	Fri 4/25/08	Fri 5/9/08

Table 1.2 – Partial Steel Schedule

Structural/Misc. Steel	137 days	Mon 4/7/08	Tue 10/14/08
Erect Structural Steel	20 days	Mon 4/7/08	Mon 5/12/08
Detailing and Decking	56 days	Fri 4/11/08	Fri 6/27/08
Stair ST-1/ST-2	14 days	Wed 5/7/08	Mon 5/26/08

Table 1.3 – Driven Pile Estimate

Driven Pile Estimate	
Item	Cost
Pre-Drilling	$285,000
Steel H-Piles	$620,565
F/R/P Pile Caps	$39,039.56
F/R/P Grade Beams and Piers	$75,354.92
F/R/P Foundation Walls	$18,583.76
Concrete - 3000 psi	$81,456
Total Cost	**$1,119,999**

Drilled Caissons

Drilled Caissons are installed by augering a large hole with a diameter ranging between 30 and 72 inches and backfilling the holes with concrete. The geotechnical engineer stated that if drilled caissons were used for the Bridgeside II project the minimum required diameter would be 30 inches and the allowable end bearing capacity would be 15 kips per square foot. In addition the contractor would be required to install a temporary casing to support the walls and control groundwater inflows. Casings are not always required if the soils have a large enough cohesion force such as most clays. However, the soil on site is variable and requires the use of a temporary casing. Drilled Caissons are also required to reach bedrock resulting in 45 to 55 foot depths.

The following are the advantages and disadvantages of a Drilled Caisson foundation system.

Advantages:

- Large diameters can be used which results in fewer piles
- Can be installed in long lengths
- Minimal noise and vibration levels
- No risk of ground heave

Disadvantages:

- Obstructions can damage the auger
- Risk of groundwater infill
- Large amount of soil displacement
- The bottoms must be cleaned out before concrete is poured
- The concrete must cure before supporting any loads

Based on knowledge of the site and the geotechnical report, it is guaranteed that obstructions, groundwater, and contaminated soils will be an issue for installing Drilled Caissons. Since the caissons will be bigger than the driven piles the auger will face a larger amount of obstructions. This may result in the auger getting stuck or damaged on the concrete and steel debris. The site is adjacent to the Monongahela River which adds the risk of increased groundwater levels. Initial test borings showed that groundwater depths range from 24 to 45 feet. This may result in the water needing to be pumped if the casings are infiltrated before concrete can be poured. Boring reports also revealed the existence of contaminated soils ranging from 24 to 40 feet deep. Since the Drilled Caissons will displace the contaminated soils appropriate measures will need to be taken to store and remove the soil from the site. Based on this information and recommendations from the geotechnical engineer Drilled Caissons will not be investigated any further due to the amount of potential schedule delays.

Mat Slab Foundation

A mat slab foundation is a continuous concrete slab that covers the entire building area. The slabs are typically several feet thick and are heavily reinforced. Mat slabs can carry heavy loads because the loads are distributed over the entire slab; however, they are very dependent on the soil conditions beneath it. The soil beneath the slab needs to be consistent and have a bearing capacity strong enough to support the building loads. If the soil is not consistent then differential settlement could occur. The geotechnical engineer recommends that a two foot undercut be dug from the Bridgeside II site and replaced with a compacted engineered fill. This will provide a level and consistent surface for the mat slab to be placed on. If necessary, piles can be installed to support weaker areas within the slab. Mat Slabs are simple to construct and can result in schedule reductions and cost savings but attention must be given to trade coordination. Once the slab is being poured, no other trades can be working within the building footprint. In addition the MEP trades need to coordinate with the Mat Slab contractor to allow for any underground utilities that need to be installed prior to the concrete pour.

The following are the advantages and disadvantages of a Mat Slab foundation.

Advantages:

- Relatively inexpensive
- Simple to construct
- Distributes heavy loads over the entire slab
- Very stable and durable if the soil conditions are sufficient

Disadvantages:

- Differential settlement can occur
- Must be done correctly the first time
- Substantial excavation is necessary
- Tying the rebar is time consuming
- Limits underground utility access

Structural Analysis

- Slab Area: 32,038 SF
- Live Loads: 24,956 kips
- Dead Loads: 56,556 kips
- Critical Column Load(Pu): 805 kips
- Slab Thickness:
    - Punching shear controls the thickness : $4d^2+2d(b+c) = Pu/vc$
        - b and c are the base plate dimensions for the column
        - $vc = 0.75(4)\text{sqrt}(3000)/1000 = 0.164$ kips
        - d = 25.71" use 30" for slab thickness
- Reinforcing: #6's @ 12" o.c. – 3 layers each way
- Allowable bearing pressure = 1,500 psf
- Actual bearing pressure = 2,168 psf
    - Soil bearing pressure is unacceptable for the building loads
        - 2 foot undercut is required per the geotechnical engineer

See Appendix E for the complete calculations

Cost and Schedule Comparison

The Mat Slab Foundation will take approximately 112 days to complete. The majority of the time will be spent tying the rebar cage. Most likely, additional crews would be utilized to expedite the work. Compared to the original foundation schedule the mat slab can be constructed in 11 fewer days. However, the steel erection cannot begin until the concrete slab has cured. In the original foundation schedule the steel erection was able to start before all the foundations were constructed. In the Mat Slab schedule the steel erection cannot begin until 4/24/08, which is 14 days slower than the Driven Pile schedule. Additional schedule delays are possible if the excavation crew encounters many obstructions when excavating the slab area. Table 1.4 shows the schedule for the Mat Slab construction.

The Mat Slab will cost approximately $704,252, which is a substantial cost savings of $415,747 compared to the original foundation costs. Additional costs are likely to be incurred during excavation and to remove contaminated soils. In addition, the 14 day schedule delay will reduce the rent income by $274,000, which will reduce the cost savings to $141,747. Table 1.5 shows the cost breakdown for the Mat Slab construction.

Table 1.4 – Mat Slab Schedule

Mat Slab Foundation	112 days	Wed 11/21/07	Thu 4/24/08
Slab Excavation	10 days	Wed 11/21/07	Tue 12/4/07
Undercut Fill	3 days	Wed 12/5/07	Fri 12/7/07
Tie Reinforcing	63 days	Mon 12/10/07	Wed 3/5/08
Pour Mat Slab	8 days	Thu 3/6/08	Mon 3/17/08
F/R/P Piers	2 days	Tue 3/18/08	Wed 3/19/08
Slab Curing	28 days	Tue 3/18/08	Thu 4/24/08

Table 1.5 – Mat Slab Estimate

Mat Slab Estimate				
Item	Quantity	Unit	Cost/Unit	Total Cost
Excavation	9493	CY	$1.59	$15,093.87
Fill	2373	CY	$3.96	$9,397.08
Hauling	9493	CY	$4.16	$39,490.88
Reinforcing	145	Tons	$1,800	$261,000.00
Concrete Placing	3115	CY	$8.90	$27,723.50
Concrete - 3000 psi	3140	CY	$110.00	$345,400.00
F/R/P Concrete Piers	-	-	-	$6,146.44
			Total	**$704,252**

Micro Piles

Micro Piles are small diameter, high capacity piles that are drilled into the ground. The piles are constructed with a structural steel casing and filled with a high strength cement grout. The type of drill used is a rotary drill with carbide teeth. Since micro piles are smaller in diameter they can be advanced through the ground at a higher speed and can break through materials with greater ease than a caisson casing or a driven pile. Based on conversations with Penn State professor, Walter Schneider, it was determined that at 10" diameter pile with a 250 kip capacity would be sufficient to support the building loads for Bridgeside II. Micro Piles are supported by skin friction in soil and rock. On the Bridgeside II site the piles will need to be drilled 45 to 55 feet into bedrock.

The following are the advantages and disadvantages of a Micro Pile foundation.

Advantages:

- Appropriate for any type of ground condition
- Can penetrate most obstacles
- Low noise and vibration
- Can be installed in low headroom situations
- Design loads can range from 3 to 500 tons

Disadvantages:

- If there are no obstacles they are more time consuming than a driven pile
- Expensive
- Ground water infill can be an issue

Cost and Schedule Comparison

The original schedule was delayed due to the unforeseen amount of pre-drilling. Two crews were used on site to help expedite the schedule. One crew would pre-drill the piles while the other crew would drive them. Micro Piles do not require pre-drilling and both crews can be used for drilling. This results in a 6 pile per day production rate and a schedule reduction of 24 days. The Micro Piles will be drilled in the same locations as the Driven Piles; therefore, the concrete foundation structures will keep the original design. The structural steel is still able to overlap the foundation construction, which results in the entire schedule being reduced by **24 days**. Table 1.6 shows the schedule for the Micro Pile foundations.

Micro Piles cost about $120 per linear foot, which is more expensive than the original H-piles. Changing the foundation system to Micro Piles will cost an additional $120,435. However, the Micro Piles also reduce the schedule by 24 days and allows the building to be rented sooner. The additional 24 days of rent time will increase the owner's income by approximately $387,000. Taking this into consideration, the use of Micro Piles will result in a cost savings of **$266,565**. A breakdown of the Micro Pile foundation costs can be seen in table 1.7.

Table 1.6 – Micro Pile Schedule

Micro Pile Foundation	99 days	Wed 11/21/07	Mon 4/7/08
Install Micropiles	29 days	Wed 11/21/07	Mon 12/31/07
Concrete Pile Caps	60 days	Fri 12/7/07	Thu 2/28/08
Concrete Grade Beams and Piers	54 days	Fri 12/28/07	Wed 3/12/08
Concrete Foundation Walls	30 days	Mon 2/11/08	Fri 3/21/08
Grout Base Plates	11 days	Mon 3/24/08	Mon 4/7/08

Table 1.7 – Micro Pile Estimate

Micro Pile Estimate	
Item	**Cost**
Micro Piles	$1,026,000
F/R/P Pile Caps	$39,039.56
F/R/P Grade Beams and Piers	$75,354.92
F/R/P Foundation Walls	$18,583.76
Concrete - 3000 psi	$81,456
Total cost	**$1,240,434**

Conclusions and Recommendations

After analyzing three different foundation systems it was determined that the Micro Pile foundation system will provide the greatest cost savings and schedule reduction. Since Bridgeside II is being leased upon completion it is important to complete the building as quickly as possible. This enables the owner to begin collecting rent from the building occupants. It is also important because they can start their next project in the Pittsburgh Technology Center at an earlier date. A Micro Pile system is also the most feasible because it faces the least resistance to obstructions and will not displace any soil that may be contaminated.

In conclusion I recommend the use of a Micro Pile foundation system over a driven H-pile system because based on my analysis it will result in a schedule reduction of 24 days and a cost savings of $266,565.