Thesis Final Report

Rendering courtesy of DAVIS

The Office Building

Brett Miller

Dr. Gannon | Construction

4/9/2014

The Office Building | Washington, D.C.


Rendering Courtesy of Gensler

BUILDING INFORMATION

Building Name: The Office Building
Location: Washington, DC
Occupant: Unknown
Primary Occupancy Type: Office Building
Size: 108,000 GSF
Number of Stories above Grade: 9 Stories

PROJECT TEAM

Owner: Mid Atlantic Realty
General Contractor: James G. Davis Construction
Architect: Gensler
Civil Engineer/Landscape Architect: Wiles Mensch Corporation
Structural Engineer: Granzow Structural Engineers
MEP Engineer: B&A Consulting Engineers
Verticle Transportation Consultant: Michael Blades & Associates

STRUCTURE

Drilled Piles
Mat Slab
Concrete Structure

ARCHITECTURE

Glass and Metal Panel Curtain Wall
Glass Feature Wall
Green Roof

MECHANICAL

(2) Cooling Towers
(2) 125 Ton Chillers
(2) 6000 CFM Air Handling Units
(1) 2235 CFM Rooftop Air Unit

CONSTRUCTION INFORMATION

Design-Bid-Build Delivery Method
22 Month Construction Duration
$30 Million Total Cost

ELECTRICAL

120/208 V 3 Phase Service
2 Feeds
400 KW/500KVA Rooftop Generator

SPECIAL THANKS

MRP | REALTY

DAVIS

Brett Miller | Construction Option

<http://www.engr.psu.edu/ae/thesis/portfolios/2014/bwm5151/index.html>

Executive Summary

Over the course of the 2013/2014 academic year, The Office Building was analyzed to see if any alternative systems could be implemented to save time or cost. Multiple benefits were uncovered through these explorations, and replacement strategies were developed.

Because the support of excavation was such a vital part of The Office Building, it was important to research various types of retaining structures. Sheet piles, soldier piles and lagging, slurry walls, and top down construction were all examined and the advantages and disadvantages were discovered. This research was used throughout the first two analyses to help choose alternative designs.

The first analysis evaluates the foundation walls of the project. The original design consisted of Cast-in-Place concrete with the soldier piles and lagging used. Because of the complex support of excavation, the CIP concrete wall system had extremely long durations and high labor costs. The proposed system substituted shotcrete in for the CIP concrete. A structural breadth was done to calculate the loads on the foundation wall. The shotcrete substitution saved over $77,000 and accelerated the schedule by 33 days.

Analysis 2 examined the secant wall on the west end of the project. It was thought that the secant wall had a long schedule, and wasteful costs. A slurry wall was analyzed as a replacement to the secant wall. This second analysis did not meet the original expectations. It was believed that the slurry wall would save a small amount of cost and accelerate the schedule. After the analysis was performed, the slurry wall ended up costing over $190,000 more and had the same duration as the secant wall.

The final analysis was done on value engineering and primarily looked at cost, with a little regard to the schedule. The main electrical feeder was the depth studied. The original copper wiring was compared to aluminum wiring as well as aluminum busway. For an electrical breadth, the aluminum wiring and busway were both sized. Once sized, the systems were compared. It was determined that the aluminum wiring would save a total of $83,000 but take an extra four days. The aluminum busway was found to save just under $138,000 and accelerate the schedule by five days.

Acknowledgements

Academic

Dr. Ed Gannon

Dr. Robert Leicht

Dr. Craig Dubler

Industry

MRP | REALTY

DAVIS

Gensler

Special Thanks

The James G. Davis Construction Project team

Rebecca Nordby - Balfour Beatty Construction

Granzow Structural Engineers

McClone Construction Company

PerLectric Inc

Family and Friends

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Section 1 - Project Overview

Project Summary

The Office Building is a nine story, 108,000 square foot tower located in the Washington, D.C. metropolitan area. The new tower, designed by Gensler, will be home to eight floors of office space, a ground floor of retail, and three levels of underground parking. The $30.5 million GMP was granted to James G. Davis Construction Corporation in March of 2013 with a substantial completion date set for March 23, 2015.

The building is supported by a micro pile system, on top of which sits a mat slab with an average thickness of five feet. This mat slab supports the entire structure, the majority of which is cast-in-place (CIP) concrete. The penthouse roof is constructed of structural steel frames with metal roof decking. The West foundation wall sits next to a secant wall used to support the neighboring foundation.

The main roof of the building includes approximately 3,000 square feet of green roof and a 1,800 square feet terrace. The façade is a curtain wall comprised mostly of glass with some metal panels on the South side of the building. As seen in Figure 1.1, the curtain wall gives the building a more modern look.

Figure 1.1 - Rendering NE Corner | Courtesy of

The original project schedule had a duration of 22 months. Early in the process, the project hit a five month delay during the demolition phase. This created an opportunity for schedule acceleration scenarios to be analyzed and implemented on the project. Potentially, further analysis can be performed to realize the full benefits of an alternate foundation wall scenario. In addition, the secant wall will be analyzed to see if substituting a slurry wall in will accelerate the schedule. Finally, an alternative system of bus duct will be analyzed as a potential substitution to copper wire around the two switch gears.

Client Information

The Office Building is being developed by local real estate operating company, Mid-Atlantic Realty Partners, LLC. Also known as MRP, Mid-Atlantic Realty Partners was founded in 2005 and strives to work with investors and project teams in vibrant markets. Not only will this building enhance MRP's wide portfolio of top-of-the-line office, retail, and hospitality projects, it will also generate a great deal of revenue by being a quality centered building.

Keys to Satisfaction

As MRP is going to hold the lease to The Office Building after construction, it is very important to them that the project finish on schedule to maximize leasing profits. The cost of the project is also very important to the owner which is why they have value engineered many things out of the building. Although MRP does not want the project to go over their original budget, they are very focused on quality. This is one reason why they have placed a LEED Gold standard on the project. To maintain this goal, MRP has set aside approximately 3,000 square feet of the main roof to be green space, they have included a fitness center and locker rooms have been placed on the first level of parking, every floor has floor to ceiling windows to allow for the most natural light, and every level of parking contains a charging station for electronic vehicles.

Existing Conditions

When this project started, a nine-story steel framed building, built on the site, needed to be demolished. The project team was able to demolish the façade and some of the interiors of the building, but the raze permit had to be granted by the city in order for the structure to be demolished. In order for a raze permit to be granted, all utilities must be capped and no asbestos can be present. During the demolition phase of The Office Building, the presence of asbestos kept arising. These unexpected occurrences meant that the raze permit could not be granted. After the asbestos abatement was complete, the raze permit was finally issued five months after originally planned, pushing the schedule back.

Local Conditions

The Office Building is being built on a very congested site in an urban area, which can be seen in Appendix 1-A. Adjacent to the project site are two nine-story historic buildings. The building to the West borders the property line as the building to the South is separated from the site by a 20 foot alleyway. To the North and East lie a 90 foot wide road and an 85 foot wide road, respectively. Also to the North, a transportation authority tunnel restricts Northward expansion of the excavation by one quarter of an inch.

Phasing

The Office Building is located in the urban environment of Washington, D.C. The project site sits at the corner of a busy intersection of the city. This urban setting puts restrictions on hours of work as well as hours of deliveries.

Adjacent to the site are two nine story historic buildings as well as a transportation authority tunnel along the property line. These factors restrict the space for material storage and truck staging.

Because of these constraints, the site layout plans do not change much between phases of construction. The fence stays in its primary location throughout the construction process. Three phases to highlight will be the following:

- Early Excavation
- Structure Placement
- Façade Installation

Layout drawings for these phases can be seen in Appendix 1-B.

Early Excavation

As seen in Appendix 1-B, a ramp will be in place at the southeast corner for trucks to remove the soil from the site. Material storage for lagging will be located on the south side of the site along the back ally. Excavators will work in the excavation exhuming earth and loading trucks. Other drill rigs will be there as well to install auger cast piles and the secant piles along the west wall. Eventually the large equipment and ramp will need to come out of the hole to continue excavating down another 25 feet.

Structural Placement

Due to the fact that the structure is mostly comprised of concrete, two locations will be provided for truck staging and pump trucks. One will be at the North end of the site and the other at the Southeast side. To fit the trucks in the staging area at the east side of the site, the portable toilets will be moved along the back ally. The general contractor's trailer will be moved to where the sub storage trailer was during the early excavation stage. The sub storage trailer will then be moved to where the general contractor's trailer was and the subcontractor office trailer will be placed on top of the storage trailer.

Façade Installation

The façade installation is to start before the completion of concrete to speed up the schedule. When this process starts up, one of the larger material storage areas will be moved into the building to make room for a rough terrain crane. The east pump truck will also be taken away due to the concrete wrapping up.

Project Delivery Method

To encourage competitive pricing for the project, MRP went with a design-bid-build delivery system for The Office Building. Within this system, the build team holds no financial contract with the design team. The main players in the design team have lump sum contracts with the architect, M. Arthur Gensler Jr. & Associates who has a lump sum contract with the owner. Engineering Consulting Services (ECS) is a third party inspector hired by the owner with a lump sum contract to monitor quality and perform testing. Lastly, the specialty contractors have lump sum contracts with James G. Davis Construction Corporation, the general contractor, who has a cost plus fee with Guaranteed maximum price (GMP) contract with the owner. The system of contracts is shown below in figure 1.2.

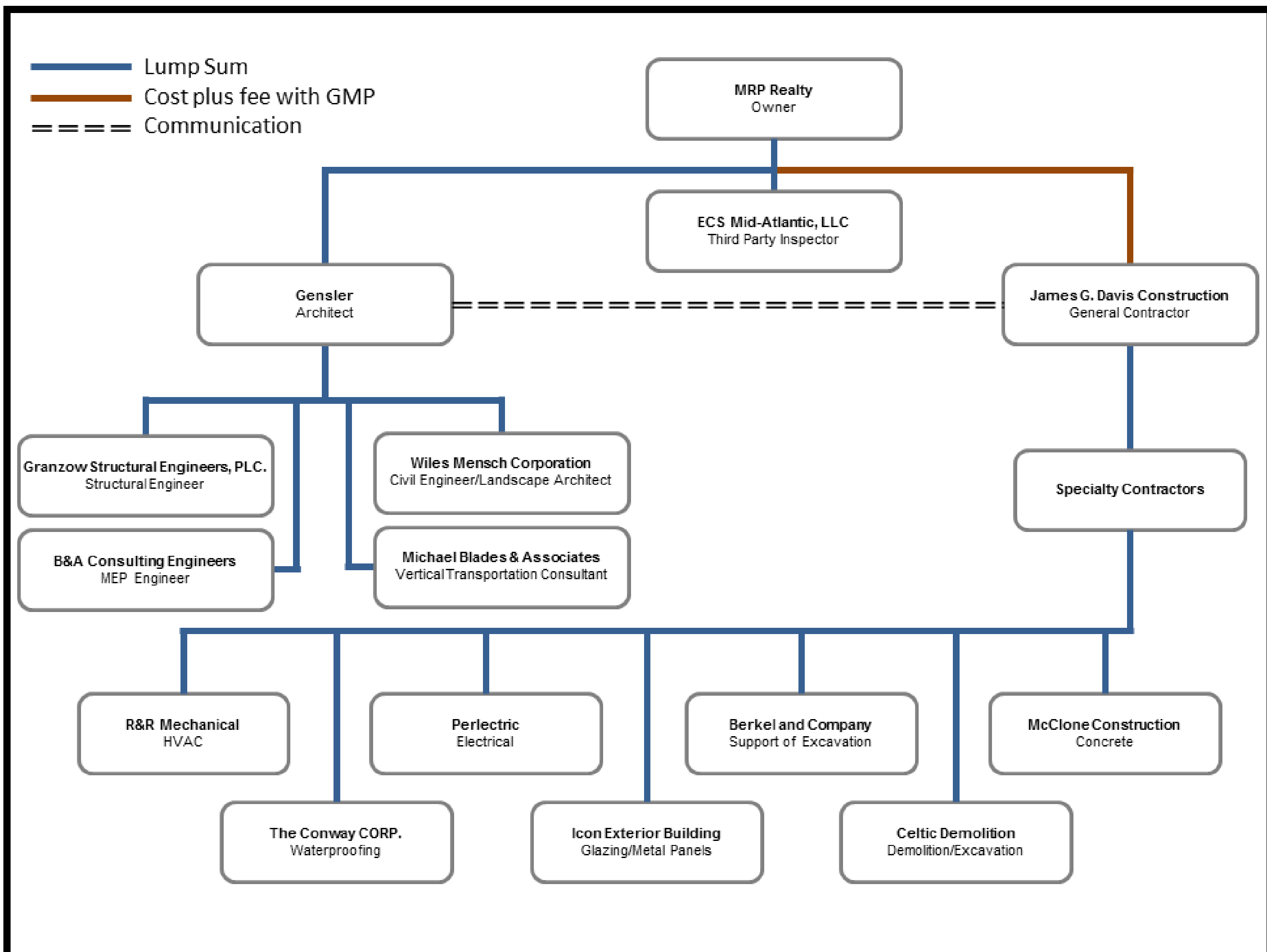

Figure 1.2 - Project Delivery System Contract Diagram

Staffing Plan

The staffing chart, as shown above in figure 1.3, details the structure of the DAVIS project team responsible for The Office Building. The project team works under the management of the headquarters of the company in Rockville, MD.

In looking at the organizational chart further, Dennis Cotter is an Executive Vice President at DAVIS and is the acting Principal-in-Charge of this project. Under Mr. Cotter, Pranav Pandya, a Vice President of one of the base building divisions at DAVIS, is the Vice President of The Office Building project. John Pacitti, a Senior Project Manager, heads the Project Management side with Will Cox as a Project Manager and Drew Heilman as a Project Engineer. On site, Fred Dandeneau, a Senior Project Superintendent, works hand in hand with Doug Bauer, an outside employee contracted with DAVIS, to command the field side of operations. Under Mr. Dandeneau and Mr. Bauer, the field operations are concluded with Lester Funkhouser, Jr. as a Superintendent, Mike Cumberland as the Senior Layout Engineer, and Anthony O'Neal as the Assistant Layout Engineer.

This staffing structure is typical for DAVIS on a building of this size. On larger projects, more Project Managers and Engineers would be incorporated as needed, as well as Superintendents.

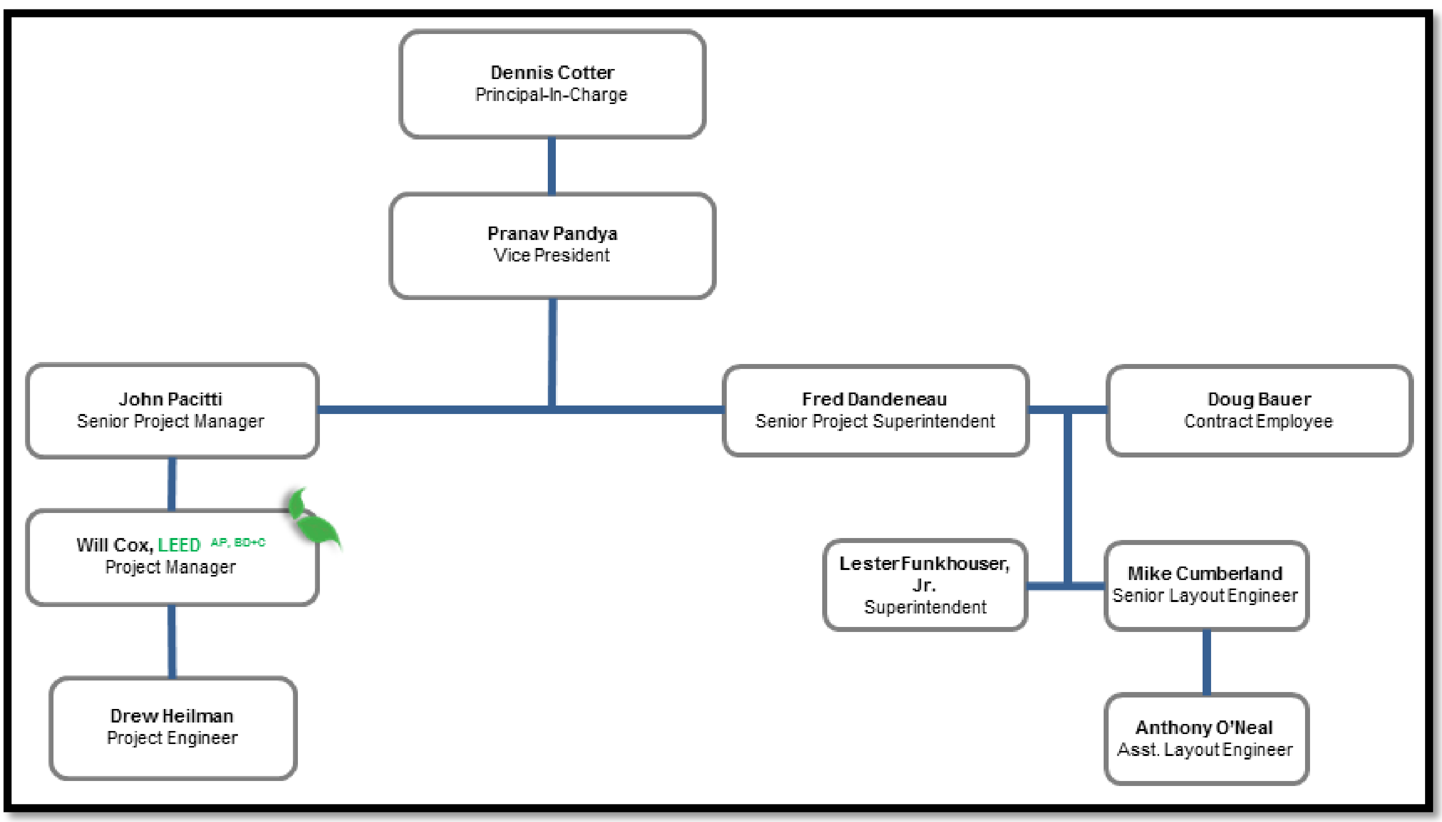

Figure 1.3 – Staffing Organizational Chart

Building Systems Summary

The new building will have a concrete structure with thirty by forty foot column spacing throughout. The mechanical system consists of two cooling towers, two chillers, two air handling units, and variable air volume devices throughout the building to produce zone heating. These components are housed either in the mechanical penthouse or on the roof of the building with the exception of the VAV's, which are housed above the drop ceiling on floors two through nine. The retail space on the first floor will be controlled by chilled water while the rest of the building has forced air.

The fire suppression system is a wet sprinkler system with a siamese fire connection at the street level. This will allow the fire department to flow water to the building's standpipes in each staircase in the case of a fiery emergency.

The electrical system consists of two separate feeds, both at 120/208 V three phase power, one for each of the 4,000 amp switchboards located on the first parking level. There is also a 400 kilowatt, 500 kilovolt-amp generator on the rooftop level.

The building enclosure consists completely of a curtain wall system. Due to the close proximity of the neighboring buildings, the west side of the building, along with portions of the south wall, consists of metal panels, where the rest of the façade is comprised of glass. The mixture of metal panels and glass for the curtain wall can be seen in figure 1.4.

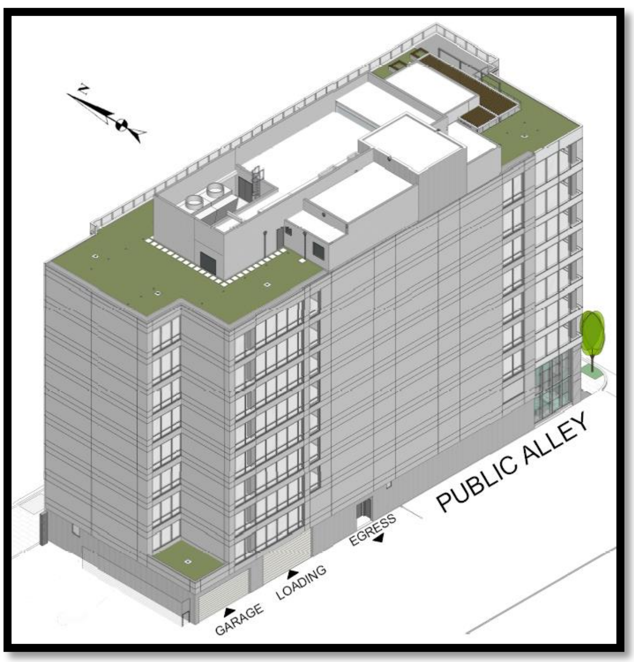

Figure 1.4 – Axonometric Image Southeast Corner | Courtesy of DAVIS

In addition to the 3,000 square foot green roof mentioned previously, the project team is implementing many items to obtain MRP's goal of LEED Gold. A few of these implementations include a fitness center and locker rooms on the first parking level, the use of materials manufactured and harnessed within 500 miles from the site, recycling the material from the demolished building, and even vehicle charging stations on every level of parking in the garage.

Project Cost Evaluation

The Office Building has a total project cost of $30 million with a building construction cost of about $23 million. This construction cost excludes land costs site work and fees. As figure 1.5 shows, the cost of constructions comes out to approximately $213 per square foot.

Construction Cost:	$23,000,000.00
Total Area:	108,000 SF
Construction Cost per Square Foot:	$212.97

Figure 1.5 – Actual Building Cost per Area

Detailed Structural Estimate

*Refer to Appendix 1-C for full detailed structural estimate

The structural system for this building consists mainly of cast-in-place concrete with a secant wall on the west side of the building and steel members holding just the penthouse roof. The foundation is a mat slab with micro piles. Instead of finding a typical bay for the building, this estimate was broken up per floor due to inconsistencies. The components of the structure are compared in figure 1.6.

	Typical Floor	Estimated Building
Concrete	$358,815.73	$6,430,258.70
Rebar	$36,721.86	$601,539.04
Structural Steel	N/A	$84,849.77
Total	$395,537.59	$7,116,647.51

Figure 1.6 – Cost comparison of structure components

Concrete

The concrete for the exterior walls of the parking garage were lumped into the quantity with the first parking level concrete and the floor of the third parking level is the mat slab, therefore the three parking levels share the same floor area but have differing concrete volumes. Because of differing concrete thickness, the third through ninth floor share the same floor area, while the second through seventh floors share the same concrete volume. The main components of the material cost include:

- Concrete costs
- Formwork
- Plastic or blankets

The plastic or blankets are for the concrete slabs. A waste factor of 5% was used for all costs, giving a value of $9.43 million.

Concrete Reinforcing

The reinforcing throughout the build is much like the concrete in that it is typical for most floors but larger on others. The typical floors contain about 21 tons of rebar while the penthouse contains more due to the heavy mechanical loads. The third parking floor has about 79 tons of rebar because of the matt slab, as mentioned above. The cost for the rebar is simpler than the concrete in that it is just price of the steel reinforcing and the labor price for installation. The reinforcing steel also used a 5% waste factor, giving a total cost of $601 thousand.

Structural Steel

As mentioned above, the penthouse roof is the only location of structural steel. Like the rest of the building, a typical bay could not be used because of variations of steel shapes and sizes. The costs associated with the structural steel include: steel costs, labor costs, and equipment costs. Like the rest of the structure, a 5% waste factor was added to all steel costs. As Table 2 shows, the structural steel cost is much lower than that of the concrete. This is because the steel was such a small part of the building.

MEP Assembly Estimate

*Refer to Appendix 1-D for full MEP assembly estimate

This assembly estimate focused on the main parts of the following building systems:

- Plumbing
- Mechanical
- Fire protection
- Electrical

The assembly estimate breakdown, shown in figure 1.7, describes how these systems compare to each other in cost.

Description	Cost
Plumbing	$510,625.92
Mechanical	$1,224,720.00
Fire Protection	$734,993.74
Electrical	$3,465,060.32
Total	$5,935,399.98

Figure 1.7 – Assembly Estimate

The pluming and fire protection costs represent typical systems for a building of this size.

The mechanical system in The Office Building is a water-to-air system which consists of cooling towers, chillers, and air handling units. This system pushes air throughout the office space on the second to ninth floors and pumps water to multiple variable-volume-air devices in the retail space on the first floor. For this system the estimated cost came in a little low, but an assembly estimate is only accurate with 10%.

The electrical system for this building consists of a switch board serving the upper half of the building and a switchboard serving the lower half of the building. There is also a diesel powered generator on the rooftop. The estimated costs seems accurate to the system in The Office Building.

General Conditions Estimate

A general conditions estimate was performed on The Office Building and the results can be seen in Appendix 1-E. The estimate is made up of the following:

- Personnel on site
- Material required by the general contractor
- Equipment used by the general contractor to complete the project
- Insurance and bonds required for the general contractor.

For the sake of the estimate, a few positions had to be lumped together, but the outcome was still accurate. An example of this would be a layout engineer and a project engineer sharing the role of field engineer. After combining the four components of the estimate listed above, a total was calculated to be just over $3 million.

Section 2 | Retaining Structures Research

The support of an excavation is critical in ensuring that the earth does not cave-in. Retaining structures are determined by different factors of the excavation such as: the level of the water table, the type of soil being excavated, the depth of the excavation, the accessible space around the excavation, or even the type of foundation of the building. There are many different types of support including the following, which will be discussed in this report:

- Sheet piling
- Soldier beam and lagging
- Slurry walls
- Top down construction

Sheet Piling

Sheet piling is the process in which thick sheets of metal, (typically steel), are inserted into the soil around an excavation, as seen in figure 2.1. These sheets can be driven with an impact hammer, vibrated with a vibratory hammer, or statically pushed with a hydraulic load system. After the sheets have been placed, crews can go through and excavate the soil out of the hole. Once the foundation is complete, the sheet piles may be required for support, or may be taken out

Figure 2.1 – Sheet Piling | Courtesy of Maxx Piling

Advantages

Because of the interlocking of each sheet, this style of support is ideal when dealing with water. The joining of the sheets can handle anything from a spring trying to seep water into a site, an excavation going below the local water table, or even an excavation built adjacent to a river or channel. In most instances, the horizontal ground pressures can be carried without additional bracing. This is a good method when building in an area with low timber production, such as in the Netherlands.

Disadvantages

Sheet piles may be difficult to drive into compact or rocky soil due to continual surface area. Also, it may be difficult to extract the sheets from the ground even if the sheets are not required for structural purposes. Although, bracing is not required under most circumstances, it will be required when dealing with high water tables (in comparison to the excavation) or when bordering water. In order to maintain a watertight envelope, each sheet must be accurately placed and linked to its precursor which can be, at times, extremely difficult. This system can also become quite costly due to the amount of steel, and also very time consuming. Lastly, this system is constrained by the desired depth of the excavation. The sheets used can only be manufactured so large and cannot be welded together.

Soldier Piles and Lagging

The process of using soldier piles begins with the installation of the piles, typically steel wide flanges, being placed around the perimeter of the excavation with about six to ten feet uniformly between them. The piles are usually driven with an impact hammer, like the sheet piles. Once in place, the excavation of the soil and installation of the lagging can begin. The lagging consists of three to four inch thick wood planks are placed horizontally between the steel piles to hold back the remaining earth. Usually these planks are given a spacing of one to two inches apart to allow for the seepage of water. By allowing this leaching of the water, the horizontal pressure from water pushing on the lagging can be eliminated. With no water remaining in the earth behind the lagging, the soil remains drier which causes it to have a higher shear strength and a lower occurrence of sliding. When this type of support is used for shallow excavations, the walls are usually cantilevered, but when the excavation is deeper, the walls are required to be braced or use tied backs to maintain their rigidity.

Figure 2.2 – Soldier Pile and Lagging | Courtesy of

Advantages

Because of their more compact surface area, soldier piles can permeate denser soils than sheet piling. These piles can also be lengthened by welding a new wide flange onto the previous one to reach remarkable depths. Because the perimeter is enclosed primarily in wood and not steel, this system is much more economical than sheet piling. These spaces between the steel also make installation much faster.

Disadvantages

Although soldier piles can be driven through most soil, they cannot penetrate every kind and require expensive drilling. When they do breach through rock, the installation can be very noisy causing restricted work times in areas with noise ordinances. Because the soil is held back with wood, usually with spacing between each board, this system is not ideal when dealing with high water tables. If this system is required in such environments, expensive dewatering systems must be used. Although this system is typically less expensive and faster to install than most others, it is not the most rigid retaining system and may move under certain pressures.

Concrete Slurry Walls

A slurry wall is a cast-in-place concrete wall with a thickness ranging from 18 inches to 5 feet and can have a depth of up to 400 feet. The reinforced concrete wall is broken up into, typically, 25 foot wide panels extending to the fully required depth. Once complete, the wall will not only act as a retaining wall during the excavation and foundation phases, but also as the permanent foundation wall for the building. The wall may be built one of two ways depending on the installation of the panels. These panels may be built consecutively or alternatively. Through the consecutive approach, the first panel is completed, followed by the panels on each side. Under the alternating method, every other panel is completed; these are called primary panels. The primary panels are constructed with space of equal width to the panels in between them for the secondary panels to be placed later. The completion of the secondary panels creates a continuous wall. There are a few steps before the concrete can be placed, which are outlined in figure 2.3. To begin, a trench must be excavated, typically with a bucket in the shape of a clamshell. As the clamshell bucket pulls out soil, the void is immediately filled with bentonite slurry. This slurry creates positive static pressure on the walls of the excavation to eliminate the chance of a cave-in. Once the trench is completely excavated and filled with slurry, the steel reinforcing cage is lowered into the trench. After the reinforcement is installed, concrete is pumped into the trench, displacing the lighter bentonite slurry, which is pumped into tanks for reuse.

New technology has been introduced where the cast-in-place concrete panel has been replaced by a reinforced precast concrete panel, which is simply lowered into place. In this scenario, the slurry contains bentonite, as well as cement. The slurry remains liquid when the panel is placed, and sets up to hardened cement to hold the panel in place. The precast panels are manufactured with tongue-and-groove joints to form the continuous wall.

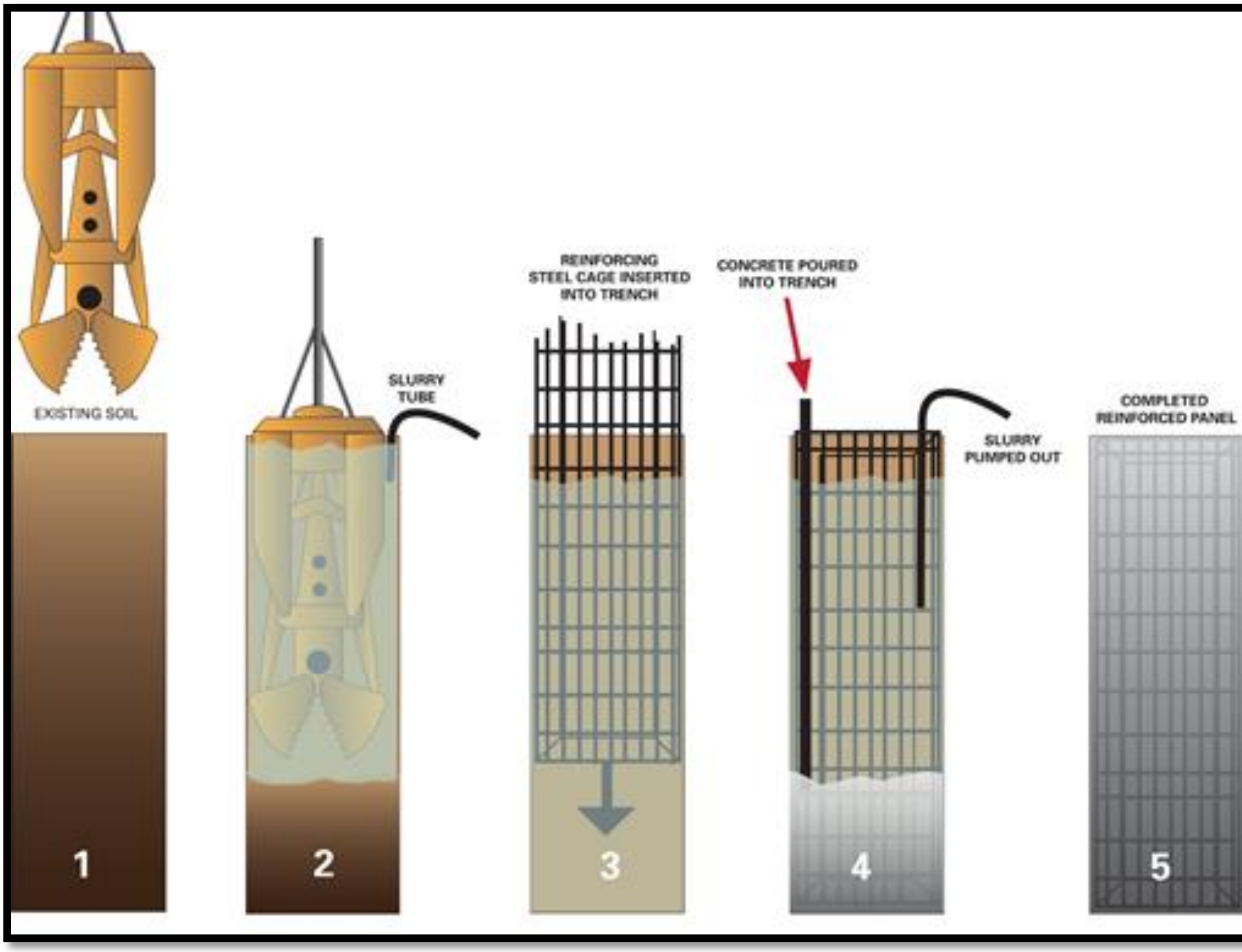

Figure 2.3 – Stages of a Slurry Wall | Courtesy of Massachusetts General Hospital

Advantages

This system is great when dealing with a high water table or wet soil. Slurry walls may be a better technique when dealing with rocky soil that cannot be breached by piles. This system may also be an alternative for sheet or soldier piles when the depth is no longer economical. As mentioned before, these concrete walls can be used as the foundation walls for the building, after acting as the retaining structure during the project.

Disadvantages

The biggest drawbacks to slurry walls are their cost and duration. The process of digging a trench around an excavation and filling it with steel and concrete is extremely time consuming and can take longer depending on the type of soil. As such, the cost of materials, equipment, and labor are more than that of both sheet and soldier piles. Although the use of precast wall panels may slightly reduce the duration, it will not reduce the cost. Once the wall is complete and excavation has begun, anchors or tie-backs may be required to keep the wall in place.

Top Down Construction

Top down construction is a newly developed technique which combines deep foundations and mining into its process. This method starts with the perimeter of the building being enclosed by slurry walls which will act as the foundation walls once the project is complete. To account for interior columns, caissons with temporary steel liners are drilled to a substantial depth. The caisson is then filled with concrete up to the bottom of the lowest floor of the building. For a steel framed building, columns are inserted into the caissons above the lowest floor and are then backfilled with sand. Once backfilled, the caisson liners are removed. An under-slab is then poured at ground level to provide a base for the structural floor which is then poured afterward. Openings are left in the slabs for equipment to excavate and remove soil below the slabs. As figure 2.4 shows, the soil is excavated until the next floor is reached, at which time the two slabs are poured and the process repeats itself. In lieu of the under-slab and structural slab, a concrete slab atop steel beams and metal decking may be used.

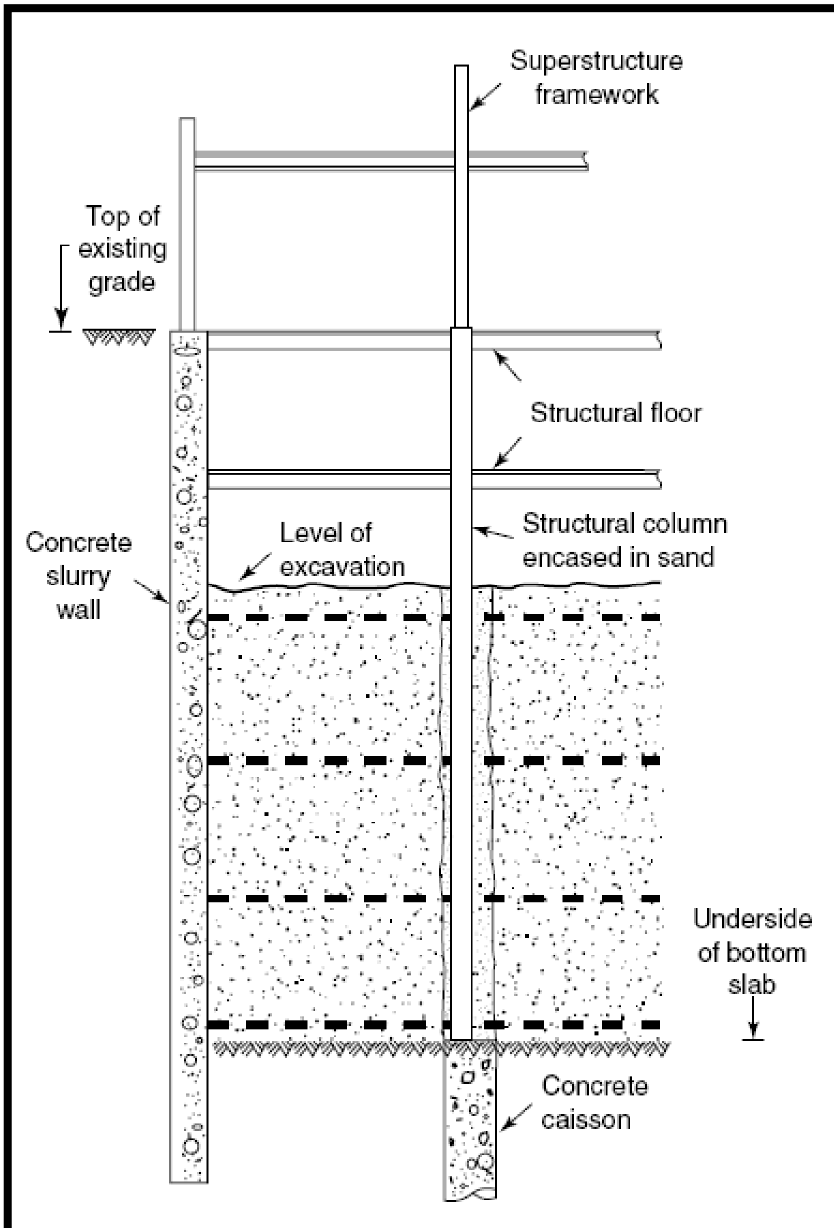

Figure 2.4 – Top Down Construction | Courtesy of Andres

Advantages

Top down construction has many advantages including all of those that come with using a slurry wall. When building next to neighboring buildings, this method reduces the likelihood of the surrounding ground, or buildings, settling during excavation. As the project moves down through excavations, each floor slab installed offers lateral support for the foundation walls; this in turn eliminates the use of bracing or tiebacks. Since the underground columns are in place, the above ground structure can be erected while the substructure is being excavated and poured. By building in opposite directions from the ground floor, schedule time is drastically reduced.

Disadvantages

Unless designing for a large scale project, the cost to implement top down construction would not be an economically sound idea. This technique also relies heavily on the geotechnical conditions of the soil. If the soil cannot withstand the weight of the building, a thick concrete mat slab would be required on every floor to prevent the building from sinking.

Conclusion

These are just four of the many types of retaining structures that are used in the construction of buildings. Although sheet piling is a great system when water is an issue, the type of soil and depth of excavation make this technique inadequate for The Office Building. With a neighboring dewatering system below the excavation of The Office Building, the lack of water retention is not an issue, and with the inexpensive and fast installation, soldier piles and lagging are an ideal solution for a retaining structure. Slurry walls, although acting as a retaining support and a permanent foundation wall, are much too expensive for the entire project but might be an area of exploration for a small section of the project. Top down construction would have been a great idea with schedule as one of the owner's concerns for The Office Building. Unfortunately, this project requires a five foot thick mat slab on the bottom level which would have been required on every underground level to keep the building from sinking if this technique was chosen.

Section 3 | Foundation Walls (Analysis 1)

Opportunity Identification

As mentioned in Section 2, The Office Building uses soldier piles and lagging for its retaining structure. Because of The Office Building's existing conditions, common support of excavation (SOE) techniques were replaced by a more challenging system. In normal practice, tiebacks are used to provide resistance from lateral earth loads for the wood lagged retaining walls. In the case of The Office Building, a system comprised of wales and bracing keep the wood lagged walls from caving into the site, as shown in figure 3.1. To keep the cross bracing in place, the system is tied into every soldier pile, (located about every 7.5 feet), by a wide flange. These wide flange tie-ins create many obstructions on the site that need to be worked around. When the time comes to pour the concrete foundation walls, every cross bracing connection to a pile will need to be formed around, as seen in figure 3.2. Once the structure is to strength and the cross bracing can be removed, the remaining holes will require grout to fill them in. This process won't occur, however, until crews are pouring concrete on the fourth floor of the building.

Figure 3.1 - SOE System | Courtesy of DAVIS

Figure 3.2 – Formed Tie-in | Courtesy of

Background Research

Forming around every SOE tie-in is a very labor intensive task. Because of this, the foundation walls have long schedule durations and large costs. Both of these factors, time and money, along with quality, are the main concerns of the owner. Research will be conducted to find a more efficient alternative to the cross bracing/CIP concrete combination, in order to appease all of the owner's concerns. Research can also be conducted to find popular foundation wall systems near the location of this project. With this known, basic costs and simple durations can be compared to see if an alternate system is more feasible than the original.

Potential Solutions

A replacement to the Cast-in-Place concrete walls incorporates the use of shotcrete. The installation techniques can be evaluated based off of material, labor, and equipment costs as well as schedule duration. A major effort will be placed on accelerating the schedule due to the raze permit delaying the project schedule in the demolition phase.

Solution Method

- Choose the best system for the particular project
- Determine the costs and installation durations of the alternative systems
- Compare all aspects to the Cross bracing/CIP system
- Propose or reject the alternative system based on the weights measured

Resources

- Industry Professionals
- AE Faculty
- DAVIS Project Team
- Applicable reference materials

Expected Outcome

On typical projects, the use of shotcrete is more expensive than that of CIP concrete. It is expected, however, that an increase in cost will be less than the decrease in labor cost of the CIP concrete system. Also the potential duration is expected to be less than the time required to form every fit out. For these reasons any alternative system will produce an accelerated schedule as well as a decrease in the cost.

Shotcrete Background

Before comparisons came be made, research must be done to fully understand the use of shotcrete. Shotcrete is a spray form of concrete that is distributed through a hose and pneumatically projected at a high velocity onto a surface, as seen in figure 3.3. Shotcrete is most recognized for its use in swimming pools, water features and skate parks, but its versatility makes it a great material for

Figure 3.3 – Shotcrete Installation |

construction. Due to the high velocity of the projected shotcrete, the material is compacted upon placement. This means the shotcrete forms as it is sprayed, eliminating the use of formwork. It must be remembered that anytime formwork is used, it takes time and manpower to not only erect the forms but also to take them down. For this reason, anytime the amount of formwork can be reduced, the schedule and budget both benefit.

Sizing a Shotcrete Foundation Wall – Structural Breadth

To fully understand the role the shotcrete will play in the building as a foundation wall, structural calculations were computed and the forces acting on the walls were comprehended. These forces were used to analyze the thickness of the wall. After discussions with industry professionals, it was concluded that typical shotcrete walls were one inch thicker than a CIP walls in the same scenario. This is to ensure the shotcrete wall can withstand the lateral loads.

The original system utilized concrete with a 28 day compressive strength of 6,000 psi and walls that stepped from 14" thick on the P3 level to 12" thick on the P2 and P1 levels. The reinforcing steel was kept the same for both situations.

The geotechnical report was used to find the equations, shown in figure 3.4, for the lateral earth pressure and the horizontal surcharge loads acting on the wall. Knowledge obtained through the Civil Engineering (CE) 397A: Geotechnical Engineering class and from advisors and structural students was used to complete the calculations within this breadth. RISA 2-D was also used to determine the shear forces and moments acting on the walls.

Any and all tables used for this breadth can be found in Appendix 3-A.

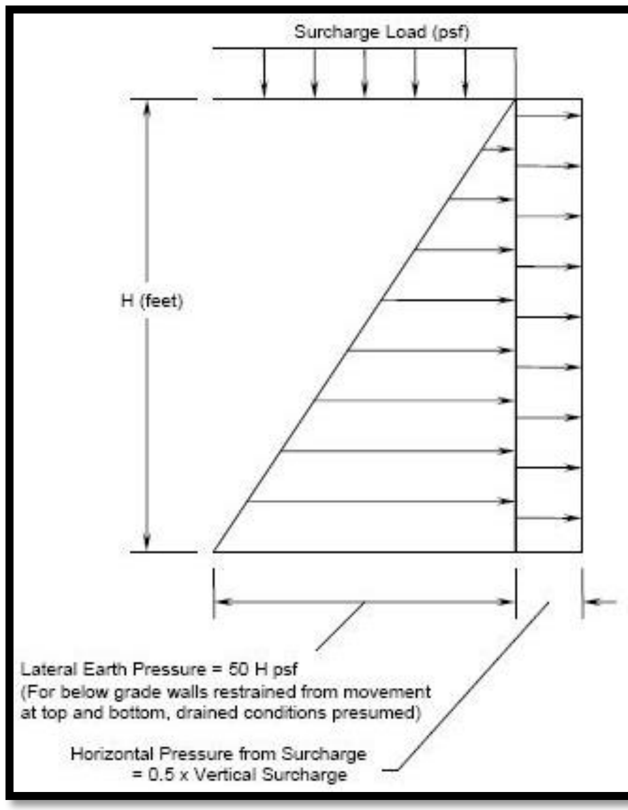

Figure 3.4 – Lateral Pressure Diagram | Courtesy of DAVIS

| Design Calculations |

Before the shear forces and moments can be computed, the loads acting on the walls must be calculated. The lateral earth pressure (P_1) is a triangular distributed load that grows larger the deeper the wall. In the case of The Office Building, the foundation walls are typically 29' tall. This height gives us a maximum lateral pressure at the base of the wall of 1,450 plf.

$$\mathrm{P_1} = 50\mathrm{H}\,psf \rightarrow (50) \times (29) = 1{,}450\,psf \times 1' = 1{,}450\,plf$$

The horizontal surcharge load (P_2) is half of the vertical surcharge load (P_0), which, in this case, is a resultant of the roadway adjacent to The Office Building. Using AASHTO H-25 Lane Load, it was discovered that P_0 is 800 pounds per "lane foot." This lane foot is equal to 12' (the width of a normal lane of traffic). The vertical surcharge load is only calculated out 29' from the building (the height of the foundation wall). Once the width of P_0 load is determined, it is found that the vertical surcharge load is 67 plf, making the horizontal surcharge load 33.5 plf.

Vertical Surcharge Load (P_0):

$$P_0 = \frac{800\ lbs}{1\ Lane\ Foot} \times \frac{1\ Lane\ Foot}{12\ ft} = 67\ plf \rightarrow P_2 = \frac{67}{2} = 33.5\ plf$$

Since the gravity load of the wall is negligible, these two distributed loads can be used to compute the reactions, shear forces, and moments of the wall. Using RISA 2-D software, the maximum shear force was found to be 6.4 kip and the maximum moment was found to be 9.4 ft-k. The IBC Hydrostatic Load Combination equations are used to find the factored values for shear and moment.

$$V_u = 1.6V_{Max} \rightarrow 1.6 \times 6.4\ k = 10.24\ k$$

$$M_u = 1.6M_{Max} \rightarrow 1.6 \times 9.4\ 'k = 15.04\ 'k$$

With these values, we can find the depth of the wall using one way shear formulas. Note that the steel reinforcing stays the same as in the CIP concrete scenario. By doing this, it was assumed that the wall has #7 bars and #5 bars running on both sides of the walls and the reinforcing has 3" of cover from the face of the wall. A level of safety comparable to the original design was used to obtain a 14" wall.

$$V_u = \phi V_n = \phi 2\sqrt{(f'c)}bd$$

$$10{,}240\ lbs = 0.75(2)\sqrt{6000}(12)d$$

$$d = \frac{10{,}240\ lbs}{1.5\sqrt{6000}(12)} = 7.34 \rightarrow 14$$

$$d = 14'' - 2(0.875'') - 2(0.625'') - 2(3'') = 5''$$

Next, flexure is checked to find the size and spacing of the rebar.

$$a = \frac{A_S f_y}{0.85 f'c\ b} = \frac{A_S(60{,}000)}{0.85(6{,}000)(12)} = 0.98A_s$$

$$M_u = \phi\, M_n = \phi A_s f_y \left(d - \left(\frac{a}{2} \right) \right)$$

$$15.04'k \left(\frac{12in}{ft} \right) = 0.9A_s(60) \left(5 - \frac{0.98A_s}{2} \right)$$

Through the quadratic formula, A_s is found to be 0.719 in^2. This area, now, must be checked with the minimum requirements for reinforcing, in this wall, running both vertically and horizontally. The values can be compared to the rebar spacing chart in appendix 3-A, which shows #7 bars at 18" O.C. to have an A_s of 0.40 in^2.

$$\rho = \frac{A_s}{bh}$$

Vertical: $\rho_{minV} = 0.0015 \rightarrow A_{s\ minV} = 0.0015(12)(14) = 0.252\ in^2$

Horizontal: $\rho_{minH} = 0.0020 \rightarrow A_{s\ minH} = 0.0020(12)(14) = 0.336\ in^2$

Ductility is the last to be calculated. This calculation will show how well the wall will deform under tensile stress. If ε_s is greater than the minimum of 0.005, then the wall will not be too brittle and will hold up to the loads applied.

$$\varepsilon_s = \frac{0.003}{c}(d - c) \quad c = \frac{a}{0.85} = \frac{0.98A_s}{0.85} = 1.153A_s$$

$$\varepsilon_s = \frac{0.003}{1.153A_s} \times (5 - 1.153A_s)$$

$$\varepsilon_s = \frac{0.003}{1.153 \times 0.719} \times \big(5 - (1.153 \times 0.719)\big) = 0.0151$$

$$0.0151 > 0.005 \therefore \phi = 0.9$$

These calculations show that a wall, 14" thick in the most critical zones, is more than capable of withstanding the loads placed on it. The wall may seem over-reinforced, but this is only to ensure accuracy during installation. As you can see from figure 3.5, the tensile stress alternates sides going up the wall. The tensile side of the wall is where the reinforcing is required, and although putting reinforcing on the required side seems economical, there is a large margin of error during the installation phase. For this reason, the reinforcing on one side is mirrored on the other.

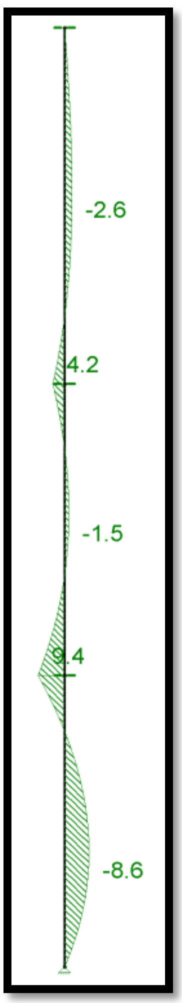

Figure 3.5 – Moment Diagram

Cost Analysis

For this cost analysis, the shotcrete system was compared to the CIP Concrete system through material, labor, equipment, and total costs. The total material cost encapsulates the costs of the concrete, the costs of reinforcing (this is the same in both systems), and the costs of formwork (for the CIP system only). As predicted, the cost of concrete for the shotcrete system was higher than that of the CIP system; however, the cost of the formwork required for the CIP systems is much greater than the concrete difference. Because the cost of reinforcing is the same, the savings in material cost alone, by switching to the shotcrete system, is almost $43 thousand. The labor cost of the shotcrete system is less than half of the CIP due to the lack of formwork installation. Lastly, the total equipment cost for the shotcrete system is slightly more than the CIP system, costing almost an extra $5 thousand. All in all, switching the foundation walls from CIP to shotcrete gives us a total savings of just over $77 thousand. This cost comparison can be seen in figure 3.6.

Cost Comparison							
System	Concrete	Formwork	Rebar	Total Material	Labor	Equipment	Total
Cast-in-Place	$78,269.01	$83,503.24	$67,810.94	$229,583.19	$69,120.00	$16,240.77	$314,943.96
Shotcrete	$118,776.60	$0.00	$67,810.94	$186,587.54	$30,240.00	$20,989.00	$237,816.54
Savings	-$40,507.59	$83,503.24	$0.00	$42,995.65	$38,880.00	-$4,748.23	$77,127.42

Figure 3.6 – CIP vs Shotcrete Cost Comparison

The material and equipment costs came from an industry professional, as well as the information to find the labor costs. The labor cost of the CIP system was based on a five man crew with an average $288 per manday totaling $1,440 per day. The labor cost of the shotcrete system was based on a seven man crew with an average $288 per manday totaling $2,016 per day. Although the difference in the unit cost of labor is so large, the duration of the shotcrete is drastically shorter than that of the CIP. It must be noted that subcontractor overhead and fees are not included in these numbers.

Any and all tables used for this cost analysis can be found in Appendix 3-B.

Schedule Analysis

One of the primary goals of this analysis was to determine if the shotcrete system had a shorter duration than the CIP system. After discussions with industry professionals, it was determined that a crew of five men could finish, on average, 25’ of wall in one day. The P3 foundation wall has a longer duration due to its extra thickness and differing depths around the level. All in all, the CIP system is scheduled to take a total of 48 days to complete the three underground floors. It was also determined that a 7 man crew could shoot approximately 50 yd^3 per day. It is recommended that shotcrete by installed in 10’ high lifts. This is not a problem for the P2 and P3 levels, but the P1 level, having 11' high walls, will have to be done in two lifts, giving this level a longer duration. Ultimately, the total schedule for the shotcrete system is a mere 15 days. The comparison of the two systems, shown in figure 3.7, reveals the shotcrete system takes 33 days less than the CIP system.

Schedule Comparison				
System	P1	P2	P3	Total
Cast-in-Place	12	12	24	48
Shotcrete	4.5	4.0	6.5	15
Savings	19.5	8.0	5.5	33

Figure 3.7 – CIP vs Shotcrete Schedule Comparison

The Original schedule and shotcrete schedule can be seen in Appendix 3-C. With the CIP foundation wall system, levels P3, P2, and P1 have 24 day, 27 day, and 29 day durations, respectively. The P3 duration only incorporates the exterior walls because the mat slab is encapsulated in the Foundations section of the schedule. The P2 and P1 durations include not only the exterior walls, but the columns and deck areas as well.

The shotcrete foundation wall system durations are 7 days, 19 days, and 22 days respectively for levels P3, P2, and P1. Like the CIP system, the P3 duration only incorporates the exterior walls and the P2 and P1 durations include exterior walls, columns, and deck areas.

Conclusion and Recommendation

This analysis evaluated whether any cost savings or schedule acceleration could occur by switching the Cast-in-Place concrete foundation walls in the underground parking levels, P1-3, to a shotcrete system. The original system had many structural tie-ins for the extreme support of excavation that needed to be formed around. As expected, the shotcrete system not only saved over $77 thousand, but it accelerated the schedule 33 days by eliminating the formwork required. Switching from the original CIP system to the shotcrete system is recommended due to its faster schedule and less expensive cost.

Section 4 | Neighboring Foundation Support (Analysis 2)

Opportunity Identification

The building adjacent to the West side of The Office Building lies on the property line, which the foundation is built against. Because of this, the neighboring building's foundation must be taken into account when planning the excavation. If there is not adequate support on the west end of the project site, the ground could give way allowing the neighboring building to tip, or worse, collapse into the excavation. To prevent this, the project team designed a secant pile system, seen in figure 4.1, to be installed before excavation could begin. Unfortunately, this secant pile design pushed back an already delayed schedule.

Figure 4.1 – Secant Wall | Courtesy of DAVIS

Background Research

Secant piles are drilled concrete piles that interlock to create a continuous wall. In order to incorporate the interlocking feature, the piles are done in an every-other sequence. To begin, the primary piles are drilled and poured. After a short time of curing, typically three days, the secondary piles are drilled. The strength of the primary piles must be hard enough to keep their shape, but soft enough to allow for the drilling of the secondary piles without trouble. Once drilled reinforcing, usually a wide flange beam, is lowered into the secondary pile hole and concrete fills in the space. Figure 4.2 shows the cross section of a secant wall with the primary piles in blue and the secondary in red.

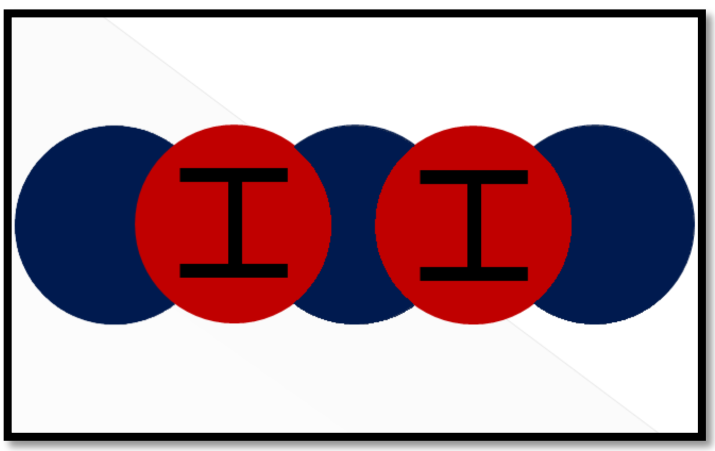

Figure 4.2 – Secant Wall Cross Section

This process of back and forth positioning of the drill rig is a very time consuming method that should be looked at as an area of possible schedule acceleration. Also, the drilling of the secondary piles involves drilling out much of the concrete used for the primary piles; this is a very costly and wasteful measure. Research will be conducted to find if a less wasteful, more economical, and faster system exists.

Potential Solution

A replacement to the secant wall system would be the slurry wall system discussed in Section 2 | Retaining Structures Research. The similar installation techniques can be evaluated based off of mobilization, material, labor, and equipment costs as well as schedule duration.

Solution Method

- Research the implementation of a slurry wall system.
- Compare all aspects to the original secant wall system.
- Propose or reject the alternative system based on the weights measured

Resources

- Industry Professionals
- DAVIS Project Team
- Applicable reference materials

Expected Outcome

Typically, slurry walls are expensive when compared to other retaining structures. It is believed that the extra cost will be alleviated in comparison by the amount of wasted concrete used in the primary piles. The expectation is that the acceleration in the schedule will make up for the small cost difference of the systems. Because of the owners concerns of cost and schedule, if the schedule can be reduced and cost the remains the same, the new system should be implemented.

Cost Analysis.

In this cost analysis, the slurry wall system was compared to the secant wall system through mobilization, material, labor, equipment, and total costs. The total material cost encapsulates the costs of the concrete, reinforcing, and the bentonite slurry in the slurry wall system. Surprisingly, the material cost for the slurry wall is almost double that of the secant wall. As expected, the cost of labor and equipment is less for the slurry wall, but the secant wall costs less in transportation and mobilization. In total, when the two systems were expected to have relatively the same price, the slurry wall, as seen is figure 4.3, costs almost $200 thousand more.

Cost Comparison					
System	Material	Labor / Manpower	Equipment	Transportation / Mobilization	Grand Total
Secant Wall System	$230,000	$117,000	$78,000	$126,000	$551,000
24" thick Slurry Wall	$408,000	$86,000	$70,000	$180,000	$744,000
Savings	-$178,000	$31,000	$8,000	-$54,000	-$193,000

Figure 4.3 – Secant Wall vs Slurry Wall Cost Comparison

All costs came from industry professionals and are based off of union rates in the Washington, D.C. area. A five man crew was assumed for both systems in the analysis. Because this was only part of the support of Excavation specialty contractor's scope of work, overhead and fees are not incorporated in this estimate.

Schedule Analysis

The main goal of this analysis was to determine if the slurry wall system had a more accelerated schedule than the secant wall system. After talking with professionals in the industry, it was determined that a crew of five men could excavate and pour the slurry wall in a week, compared to the two weeks it would take the secant wall system. This meets the expectation that the slurry wall would have a faster schedule than the secant. However, the mobilization and demobilization for the equipment used in the installation of the slurry wall would take two weeks, twice as long as the secant wall. As figure 4.4 shows, the extra week gained in the construction of the slurry wall is lost on the equipment, leaving the two systems with the same duration.

Schedule Comparison in Weeks			
System	Mob/Demob	Wall Construction	Total
Secant Wall System	1	2	3
24" thick Slurry Wall	2	1	3
Savings	-1	1	0

Figure 4.4 – Secant vs Slurry Schedule Comparison

Conclusion and Recommendation

This analysis evaluated whether any cost savings or schedule acceleration could occur by switching the West side secant wall system, implemented to support the neighboring building, to a slurry wall system. It was expected that the two systems would have similar costs while the slurry wall would have a shorter schedule. This analysis found that not only did the slurry wall cost almost $200 thousand more than the secant, but the schedules were the same length. Essentially, switching to the slurry wall system would equate to spending more money to obtain no return in schedule acceleration. For this reason, the recommendation is to maintain the secant wall system design.

Section 5 | Value Engineering (Analysis 3)

Opportunity Identification

There were numerous factors that pushed the project over budget, including extra costs involved by the delay in the raze permit, and the costs affected by the abatement of the asbestos. The excavation phase was another area where costs unexpectedly built up. Through most of the excavation phase, unforeseen obstructions were continually found. To help alleviate the pain of a growing budget, value engineering should be looked at to see where the owner may save money.

Background Research

The Project team has worked with the owner to find certain opportunities for value engineering. This includes eliminating the following:

- A rooftop irrigation system and cistern
- 40 VAV's on the office levels
- Black steel piping and provide PVC piping in garage levels
- LED light fixtures and provide fluorescent
- Tapered insulation at penthouse roof and provide sloped steel

These eliminations and substitutions helped the owner save over $980,000. There is more potential for cost reduction, however, within the electrical system of the project. The Office Building utilizes the well-known system of copper wire and metallic conduit. Because the price of copper is so high, this is a great area of focus. The main cost lies in the feeder. These are the biggest sets of wire and would be the most costly. For this reason, this analysis will look at replacements for the feeder. The feeder in The office Building utilizes seven sets of four (three phase and one neutral) 500kcmil cable and 1/0 Cable per set.

Potential Solution

Replacements to the copper wire feeder running through the building could be aluminum wire feeder, or even aluminum busway. All costs, including material and labor, will be evaluated. Schedule, although it is not the main concern of this analysis, will also be evaluated to see if any schedule acceleration can occur.

Solution Method

- ❖ Size the aluminum wire and aluminum busway (electrical breath)
- ❖ Determine the costs and installation durations of the wiring and busway systems
- ❖ Compare all aspects in cost and duration

- Determine the best option of the three
- Propose the most economical system based on the weights measured

Resources

- Industry Professionals
- DAVIS Project Team
- Electrical Students
- AE Faculty
- Applicable reference materials

Expected Outcome

It is believed that, although aluminum is cheaper than copper, the extra wire and conduit would make the system a more expensive alternative. However, a busway created from aluminum would be both economical and be able to handle the high loads very easily. For these reasons, the busway will be more economical and have a shorter schedule

Aluminum Wiring Background

Although aluminum wiring sounds similar to copper wiring, the two are very different. Copper is much more desired than aluminum, but most of this stems from a bad past for aluminum wiring. A copper shortage in the 1950's and a housing boom in the 1960's gave rise to a new electrical wiring age. Aluminum was brought into homes as a substitute for copper. Unfortunately, because of the huge demand, proper testing was bypassed and industrial aluminum cable was directly substituted for copper. In order to understand this flaw, the characteristics of this industrial cable, originally used for electrical transmission lines, must be briefly analyzed.

These electrical transmission lines had to be lightweight so the transmission towers were not too expensive to build. They had to have the highest conductivity possible in order to minimize any loss of electricity over extremely long distances. Lastly, the lines needed to have a high tensile strength to maximize the length of spans and minimize the amount of transmission towers. These characteristics are essentially the opposite of what is desired in a building, but it would take years of research and testing to discover this.

The same time copper was in short supply, so was brass. What this meant was that the brass screws in electrical devices were replaced with steel. Due to the high demand, this action was also not tested and put into practice too soon. The simple substitution of a screw, turned into a big problem. The two metals were, in fact, not compatible, and what resulted was the occurrence of residential fires. The thermal expansion coefficients for steel and copper are similar, but this is not the case for steel and aluminum. This dissimilarity between steel and aluminum cause the two metals to expand and contract at different rates. Because of this, the connection begins to gradually develop a smaller contact area, which in turn, results in an increased resistance. As this resistance increases, the temperature of the termination increases, causing fires.

After years of gaining a bad reputation for house fires, aluminum wiring went through a major change. A new aluminum alloy, designed specifically for powering buildings and homes, was created. In this new alloy, the main characteristics, such as elongation, creep, thermal stability, and flexibility, were much closer to those of copper. Also in the new age of aluminum wiring, testing was being done on material compatibilities. With this new alloy and correct testing, aluminum wiring was much more reliable than before. Unfortunately, the new alloy is still fighting through the bad reputation of the old.

Aluminum wiring has jumped through hurdles to fight its way out of the bad reputation; however, that does not mean the new aluminum alloy used has created a perfect wire. Besides the old reputation of aluminum wiring, there are metallurgical properties of aluminum that cause people to choose the more expensive copper substitute.

The first problem with aluminum is its corrosion rate. Aluminum corrodes quickly when exposed to air, and this corrosion is not visibly obvious. The corroded aluminum becomes an insulator which resists the amount of electric flow. Because of lack of visibility of the corrosion, the exposed aluminum can lead to localized heating without any warning signs.

The second problem with aluminum is what is known as cold flow. When pressure is placed on aluminum, the metal will gradually conform to the physical constraint resulting in a reduction in pressure. This means that connections made with aluminum conductors progressively loosen over time and the aluminum flows out of the joint. For this reason, special connectors are used that incorporate springs into their designs. The springs maintain a clamping pressure on the connection to lessen the tendency of the aluminum to flow.

These metallurgical properties make aluminum an inferior conductor to copper. Consequently, to get the same ampacity, larger cables are required for aluminum than would be for copper.

Busway Background

According to the National Electrical Manufacturers Association (NEMA), a busway is a prefabricated electrical distribution system consisting of bus bars in a protective enclosure, including straight lengths, fittings, devices, and accessories. Busway includes continuous metallic bus bars (usually copper or aluminum), insulation and a housing. Figure 5.1 shows a breakdown of a piece of busway.

Busways are a common way to distribute large loads, easily, through a building. Busway sections are easily connected and can supply power to any part of a building. Typically, busway takes fewer man-hours to install or change than normal wire and conduit systems. Generally, a distribution system will consist of busway, cable, and conduit. In this way, the busway is the feeder, which runs power from a switchboard to a switch or panelboard where the power is then transferred to cable, and in turn, feeds a piece of equipment such as a motor or light. This example shows what is assumed in this analysis, that the busway only acts as the feeder.

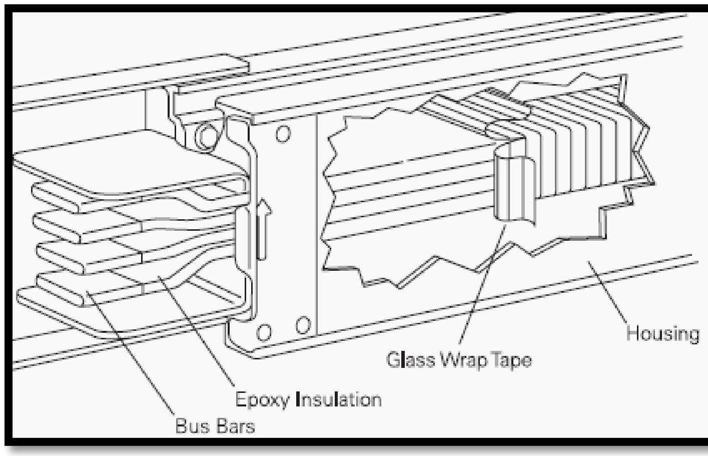

Figure 5.1 – Busway Breakdown | Courtesy of Siemens

Aluminum busway has many of the same characteristics as aluminum wiring. When aluminum is used for the busway, special connectors (like those mentioned above) are required. The epoxy insulation shown in figure 5.1 help reduce the rate at which aluminum corrodes.

Sizing Aluminum Wiring & Busway – Electrical Breadth

Before the cost and schedule analyses can be performed, the aluminum wiring and busway must be sized. The 2011 National Electrical Code (NEC) was used to size the aluminum wiring. To begin, the two switchboards were observed to have 2500 amperes each. This meant that whatever system was installed had to be capable of handling at least this much current. Table 310.15 (B) (16) out of the NEC was used first to determine the size of wire to choose. In normal practice, most projects put an upper size limit of 500 kcmil on the wiring. This means that any load larger than 310 A (380 A for copper) would require more than one cable. In order to accommodate the 2,500 A of current flowing through the feeder, nine sets of cable would be required.

$$\frac{2500\ A}{310\ A} = 8.06 \rightarrow 9\ Sets * 310\ A = 2790\ A$$

Clearly, nine sets of cable would be enough to handle more than 2,500 A, leaving the switchboards as the protecting device. This gives us nine sets of four (three phase and one neutral) 500kcmil cable. Once the current carrying conductor is sized, Table 250.66 from the NEC is used to size the grounding wire. In this case, 1/0 cable is chosen for each set. Lastly, Table C.1 is used to determine the size of conduit required for each set of cable. This shows that four 500 kcmil cables and one 1/0 cable can fit in a 4” diameter metallic conduit. The tables used for NEC 2011 Tables used can be found in Appendix 5-A.

In order to size the busway, General Electric's Spectra Series Busway product data is used. Table 8.1 shows that for aluminum busway, 2,500 A would require two bars with a thickness of 1-1/8" for each phase and neutral. This can be seen in figure 5.2 where "A" is equal to 15.5". The tables used to size the busway can be found in Appendix 5-B.

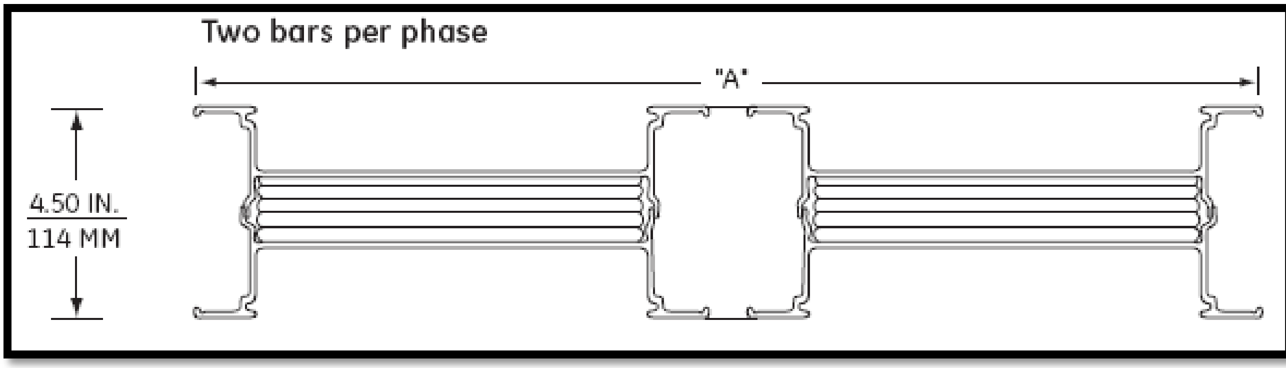

Figure 5.2 – Busway Cross Section | Courtesy of GE

Cost Analysis

For this cost analysis, the original copper wiring system was compared to both an aluminum wiring system and an aluminum busway system through material and labor costs. Originally, it was thought that the extra cable required for aluminum to carry the same loads as copper would push the system to a more expensive alternative; this was not the case. The aluminum wiring had smaller costs for both material and labor. As figure 5.3 shows, switching to this system would save over $83, 000. The expected outcome of the busway was that it would be less expensive than the copper wiring, which was determined to be true. Overall, the material and labor costs were both less expensive, bringing the total savings to just under $138,000, as seen in figure 5.3.

Cost Comparison						
System	Cost			Savings		
	Material	Labor	Total	Material	Labor	Total
Copper Wiring	$181,477.67	$181,866.65	$363,344.32	$ -	$ -	$ -
Aluminum Wiring	$131,210.06	$148,959.18	$280,169.24	$50,267.61	$32,907.47	$83,175.08
Aluminum Busway	$171,568.70	$53,777.36	$225,346.06	$9,908.97	$128,089.29	$137,998.26

Figure 5.3 – Copper Wire, Aluminum Wire, & Aluminum Busway Cost Comparison

Schedule Analysis

It was determined that, because the crews would be working on multiple floors, three crews would be used for the aluminum wiring and two crews for most of the busway installation, in order to keep the durations relatively similar to those of the copper wiring. When the number of crews increased, the change was made in the labor cost as well. Because the numbers for this analysis were taken from R.S. Means, the durations were given factors multiplied by the unit of measure. These values were calculated to the nearest hour, which was later converted into days. As figure 5.4 shows, the busway system takes five days less than the copper wiring, and aluminum wiring takes six days longer.

Schedule Comparison				
System	Duration		Savings	
	Hours	Days	Hours	Days
Copper Wiring	366	46	-	-
Aluminum Wiring	394	50	-28	-4
Aluminum Busway	324	41	42	5

Figure 5.4 – Copper Wire, Aluminum Wire, & Aluminum Busway Schedule Comparison

Conclusion and Recommendation

The main goal of this analysis was to find whether any cost saving alternatives existed for a copper wire feeder. It was found, unexpectedly, that the aluminum wire was a more economical alternative to the copper wire, but this system had a duration long than the original's. The aluminum busway, met expectations by being less expensive that the copper wire system by just under $138,000. This system also had a shorter duration by five days. It is recommended that the aluminum busway system be substituted for the copper wire system in The Office Building. This will accelerate the schedule, and will accomplish the main goal of this analysis, which was to save the owner money.

Conclusion and Recommendations

Over the course of the 2013/2014 academic year, The Office Building was analyzed to see if any alternative systems could be implemented to save time or cost. Multiple benefits were uncovered through these explorations, and replacement strategies were developed.

Because the support of excavation was such a crucial part of The Office Building, it was important to research different types of retaining structures. Sheet piles, soldier piles and lagging, slurry walls, and top down construction were all studied and the advantages and disadvantages were discovered. This research was used throughout the first two analyses to help choose alternative designs.

The first analysis looks at the foundation walls of the project. The original design consisted of Cast-in-Place concrete with the soldier piles and lagging used. Because of the extensive support of excavation, the CIP concrete wall system had extremely long durations and high labor costs. The proposed system substituted shotcrete in for the CIP concrete. A structural breadth was done to calculate the loads on the foundation wall. The shotcrete substitution saved over $77,000 and accelerated the schedule by 33 days.

Analysis 2 examined the secant wall on the west end of the project. It was thought that the secant wall was long, tedious, and wasteful. A slurry wall was analyzed as a replacement to the secant wall. This second analysis did not meet the original expectations. It was believed that the slurry wall would save a small amount of cost and accelerate the schedule. After the analysis was performed, the slurry wall ended up costing over $190,000 more and had the same duration as the secant wall.

The final analysis was done on value engineering and primarily looked at cost, with a little consideration in the schedule. The main electrical feeder was the depth studied. The original copper wiring was compared to aluminum wiring as well as aluminum busway. For an electrical breadth, the aluminum wiring and busway were both sized. Once sized, the systems were compared. It was determined that the aluminum wiring would save a total of $83,000 but take an extra four days. The aluminum busway was found to save just under $138,000 and accelerate the schedule by five days.

Through these conclusions, it is recommended that the foundation walls be switched to shotcrete, the secant walls are left as designed, and the copper wire feeder by switched to aluminum busway. The changes brought about from the analyses would save an overall total of $215,000. These changes would also accelerate the schedule by a total of 38 work days.

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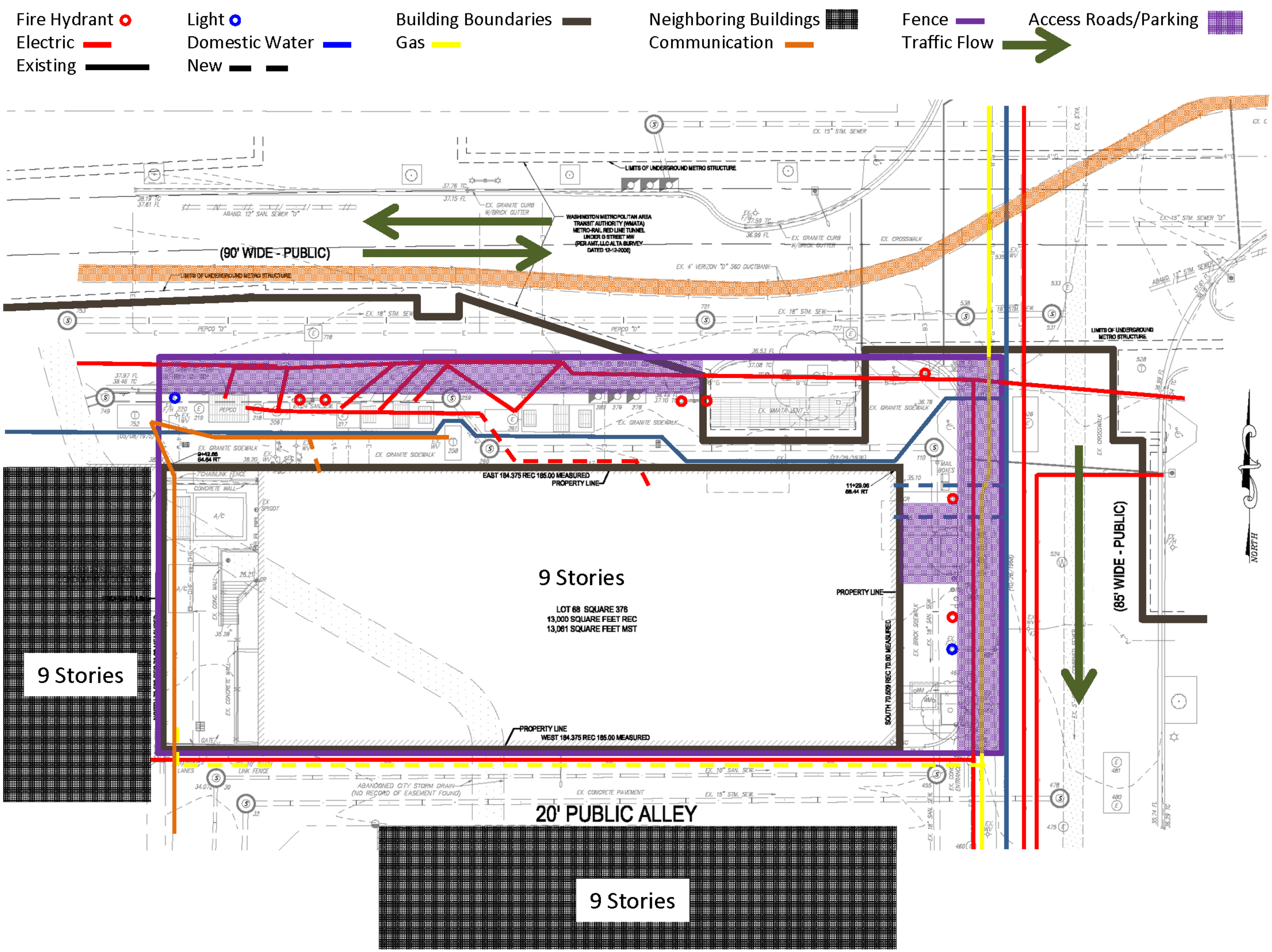
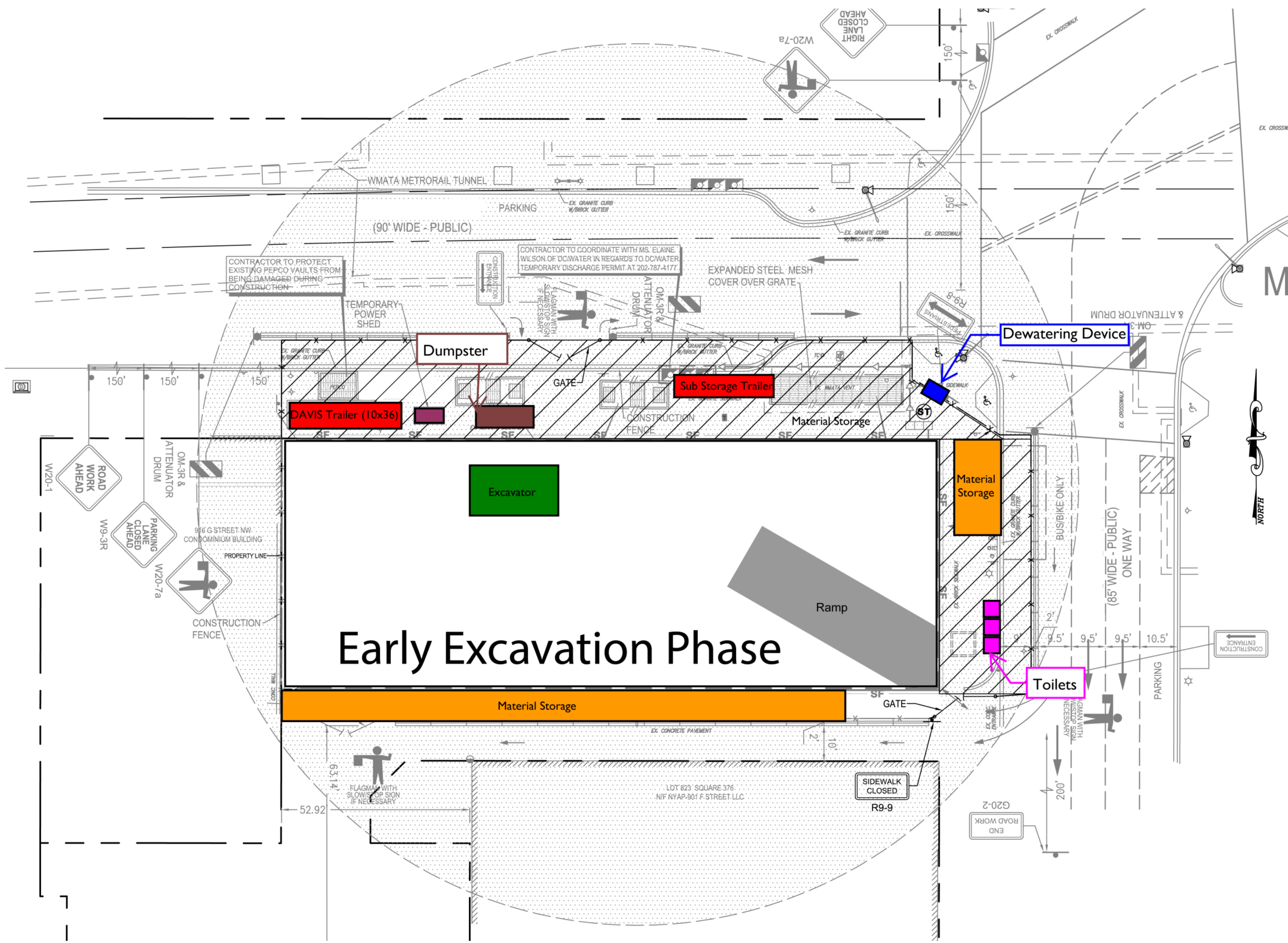
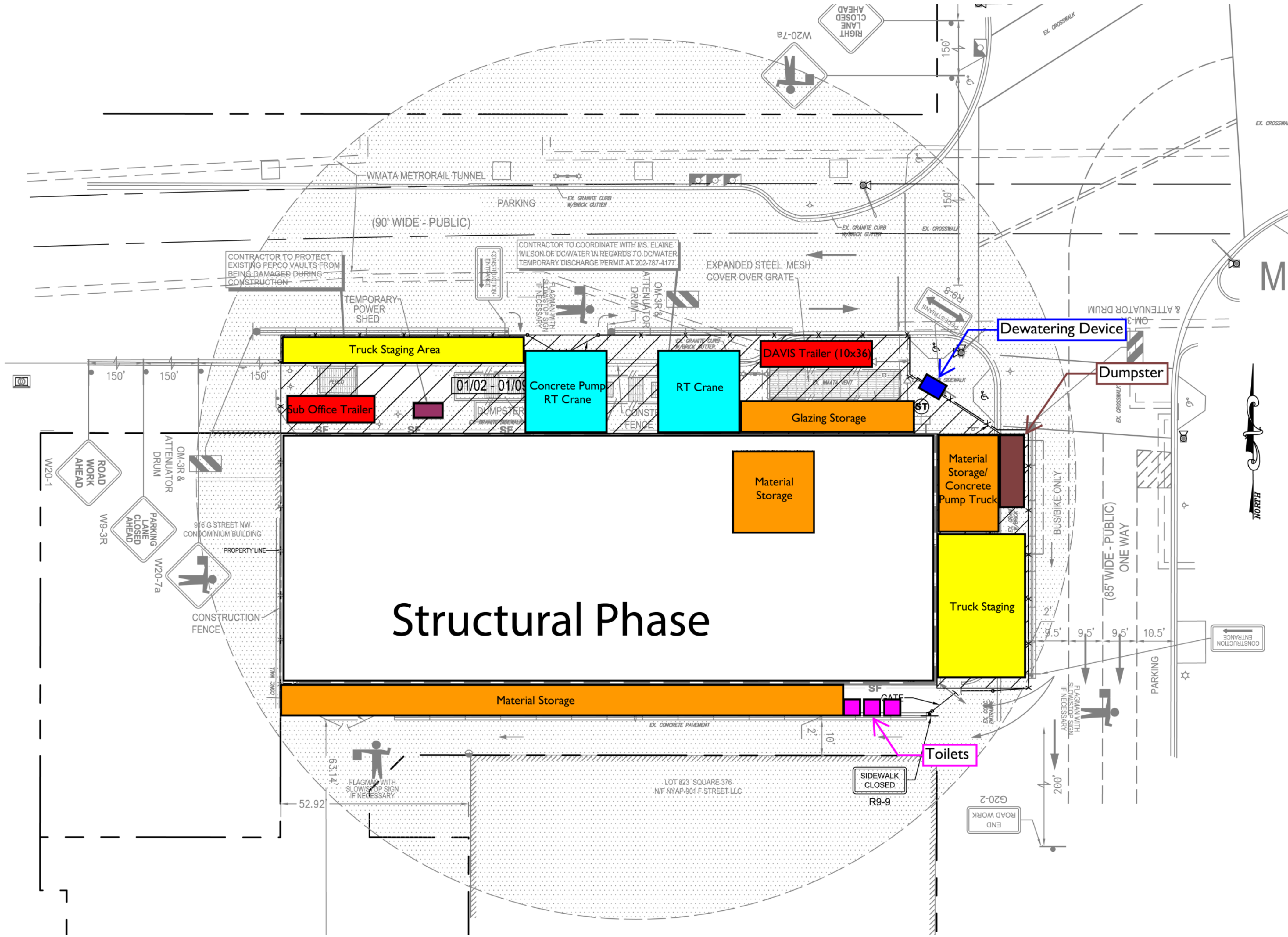
Appendix 1-A | Local Conditions

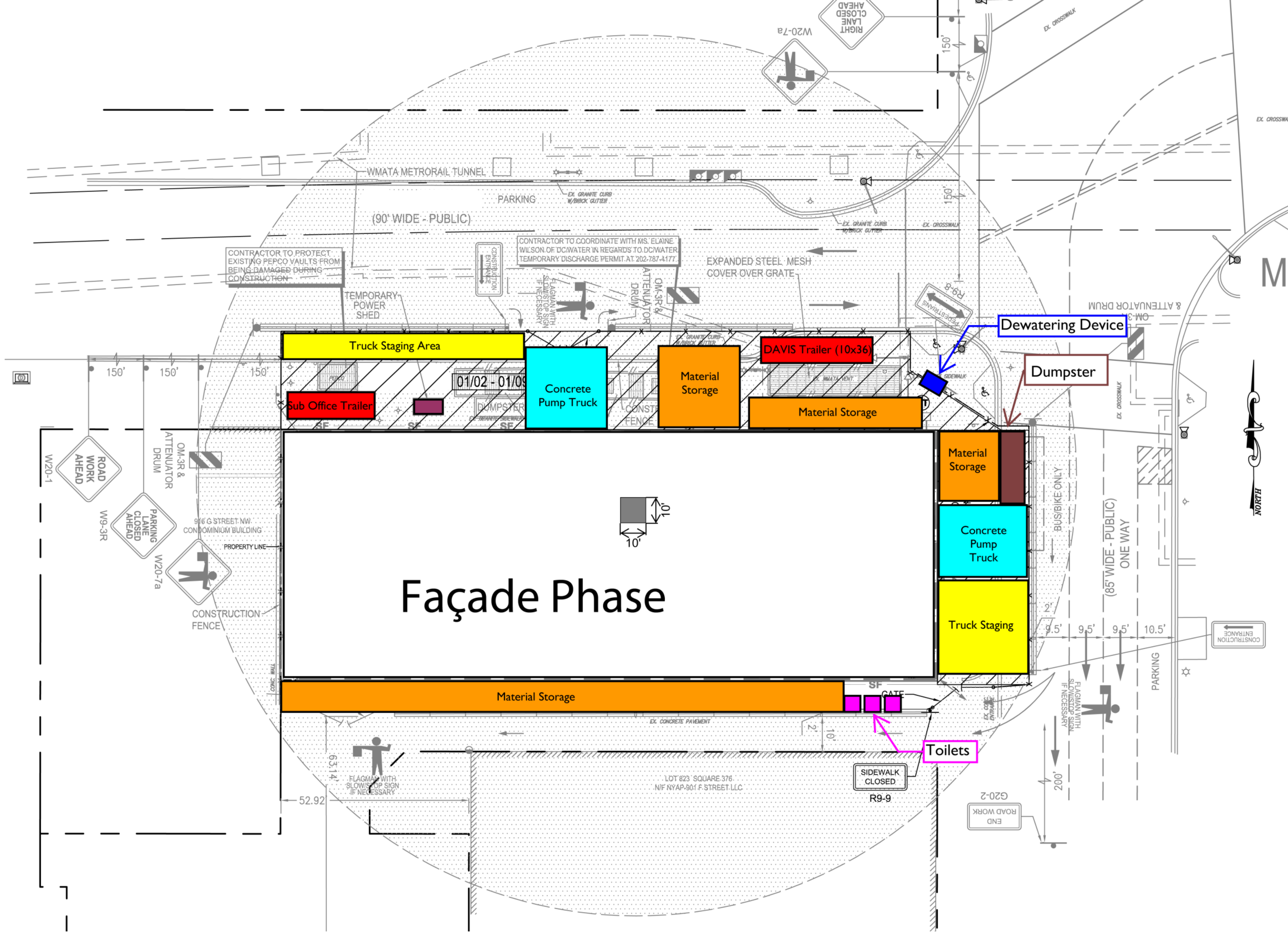

Fire Hydrant
Light
Building Boundaries
Neighboring Buildings
Fence
Access Roads/Parking
Electric
Domestic Water
Gas
Communication
Traffic Flow
Existing
New
(90' WIDE - PUBLIC)
(85' WIDE - PUBLIC)
20' PUBLIC ALLEY
9 Stories
LOT 68 SQUARE 376
13,000 SQUARE FEET REC
13,061 SQUARE FEET MST
9 Stories
9 Stories
PROPERTY LINE
EAST 184.375 REC 185.00 MEASURED
PROPERTY LINE
WEST 184.375 REC 185.00 MEASURED
SOUTH 70.509 REC 70.60 MEASURED
LIMITS OF UNDERGROUND METRO STRUCTURE
NORTH

Appendix 1-B | Phasing Diagrams



Early Excavation Phase
Dumpster
DAVIS Trailer (10x36)
Sub Storage Trailer
Material Storage
Dewatering Device
Excavator
Material Storage
Ramp
Toilets
Material Storage
WMATA METRORAIL TUNNEL
PARKING
(90' WIDE - PUBLIC)
CONTRACTOR TO PROTECT EXISTING PEPCO VAULTS FROM BEING DAMAGED DURING CONSTRUCTION
CONTRACTOR TO COORDINATE WITH MS. ELAINE WILSON OF DCWATER IN REGARDS TO DCWATER TEMPORARY DISCHARGE PERMIT AT 202-787-4177
EXPANDED STEEL MESH COVER OVER GRATE
TEMPORARY POWER SHED
GATE
CONSTRUCTION FENCE
ROAD WORK AHEAD
W20-1
PARKING LANE CLOSED AHEAD
W9-3R
W20-7a
OM-3R & ATTENUATOR DRUM
916 G STREET NW CONDOMINIUM BUILDING
PROPERTY LINE
CONSTRUCTION FENCE
BUS/BIKE ONLY
(85' WIDE - PUBLIC) ONE WAY
PARKING
SIDEWALK CLOSED
R9-9
LOT 823 SQUARE 376 N/F NYAP-901 F STREET LLC
FLAGMAN WITH SLOW/STOP SIGN IF NECESSARY
EX. CONCRETE PAVEMENT
GATE
NORTH


Structural Phase
Truck Staging Area
Sub Office Trailer
01/02 - 01/09
Concrete Pump
RT Crane
RT Crane
DAVIS Trailer (10x36)
Glazing Storage
Dewatering Device
Dumpster
Material Storage
Material Storage/ Concrete Pump Truck
Truck Staging
Material Storage
Toilets
WMATA METRORAIL TUNNEL
PARKING
(90' WIDE - PUBLIC)
CONTRACTOR TO PROTECT EXISTING PEPCO VAULTS FROM BEING DAMAGED DURING CONSTRUCTION
TEMPORARY POWER SHED
CONTRACTOR TO COORDINATE WITH MS. ELAINE WILSON OF DCWATER IN REGARDS TO DCWATER TEMPORARY DISCHARGE PERMIT AT 202-787-4177
EXPANDED STEEL MESH COVER OVER GRATE
OM-3R & ATTENUATOR DRUM
ROAD WORK AHEAD
W20-1
PARKING LANE CLOSED AHEAD
W9-3R
W20-7a
916 G STREET NW CONDOMINIUM BUILDING
PROPERTY LINE
CONSTRUCTION FENCE
FLAGMAN WITH SLOW/STOP SIGN IF NECESSARY
LOT 823 SQUARE 376 N/F NYAP-901 F STREET LLC
SIDEWALK CLOSED
R9-9
GATE
52.92'
63.14'
BUS/BIKE ONLY
(85' WIDE - PUBLIC) ONE WAY
PARKING
CONSTRUCTION ENTRANCE
ROAD WORK END
G20-2
RIGHT LANE CLOSED AHEAD
R9-8
NORTH



Façade Phase
Truck Staging Area
Sub Office Trailer
Concrete Pump Truck
Material Storage
DAVIS Trailer (10x36)
Material Storage
Dewatering Device
Dumpster
Material Storage
Concrete Pump Truck
Truck Staging
Material Storage
Toilets
WMATA METRORAIL TUNNEL
PARKING
(90' WIDE - PUBLIC)
CONTRACTOR TO PROTECT EXISTING PEPCO VAULTS FROM BEING DAMAGED DURING CONSTRUCTION
CONTRACTOR TO COORDINATE WITH MS. ELAINE WILSON OF DCWATER IN REGARDS TO DCWATER TEMPORARY DISCHARGE PERMIT AT 202-787-4177
EXPANDED STEEL MESH COVER OVER GRATE
TEMPORARY POWER SHED
ROAD WORK AHEAD
W20-1
PARKING LANE CLOSED AHEAD
W9-3R
W20-7a
916 G STREET NW CONDOMINIUM BUILDING
PROPERTY LINE
CONSTRUCTION FENCE
SIDEWALK CLOSED
R9-9
LOT 823 SQUARE 376 N/F NYAP-901 F STREET LLC
FLAGMAN WITH SLOW/STOP SIGN IF NECESSARY
BUS/BIKE ONLY
(85' WIDE - PUBLIC) ONE WAY
PARKING
NORTH
10'
10'
52.92'
150'
200'

Appendix 1-C | Detailed Structural Estimate

Concrete									$6,430,258.70
Location	Unit	Volume	Material ($/CY)	Material Total	Labor ($/CY)	Labor Total	Equipment ($/CY)	Equipment Total	Total
Piles	CY	498	$215.78	$107,458.44	$76.84	-	$10.69	-	$107,458.44
P3	CY	5612	$215.78	$1,210,957.36	$76.84	$431,226.08	$10.69	$59,992.28	$1,702,175.72
P2	CY	696	$215.78	$150,182.88	$76.84	$53,480.64	$10.69	$7,440.24	$211,103.76
P1/Exterior Walls	CY	2627	$215.78	$566,854.06	$76.84	$201,858.68	$10.69	$28,082.63	$796,795.37
Level 1	CY	1422	$215.78	$306,839.16	$76.84	$109,266.48	$10.69	$15,201.18	$431,306.82
Level 2	CY	1183	$215.78	$255,267.74	$76.84	$90,901.72	$10.69	$12,646.27	$358,815.73
Level 3	CY	1183	$215.78	$255,267.74	$76.84	$90,901.72	$10.69	$12,646.27	$358,815.73
Level 4	CY	1183	$215.78	$255,267.74	$76.84	$90,901.72	$10.69	$12,646.27	$358,815.73
Level 5	CY	1183	$215.78	$255,267.74	$76.84	$90,901.72	$10.69	$12,646.27	$358,815.73
Level 6	CY	1183	$215.78	$255,267.74	$76.84	$90,901.72	$10.69	$12,646.27	$358,815.73
Level 7	CY	1183	$215.78	$255,267.74	$76.84	$90,901.72	$10.69	$12,646.27	$358,815.73
Level 8	CY	1200	$215.78	$258,936.00	$76.84	$92,208.00	$10.69	$12,828.00	$363,972.00
Level 9	CY	1216	$215.78	$262,388.48	$76.84	$93,437.44	$10.69	$12,999.04	$368,824.96
PH/House Roof	CY	769	$215.78	$165,934.82	$76.84	$59,089.96	$10.69	$8,220.61	$233,245.39
PH Roof	CY	206	$215.78	$44,450.68	$76.84	$15,829.04	$10.69	$2,202.14	$62,481.86
Total				$4,605,608.32		$1,601,806.64		$222,843.74	$6,430,258.70

Rebar									$601,539.04
Location	Unit	QTY	Material ($/Ton)	Material Total	Labor ($/Ton)	Labor Total	Equipment ($/Ton)	Equipment Total	Total
Piles	Ton	11	$1,103.00	$12,133.00	$645.66	$7,102.26	-	-	$19,235.26
P3	Ton	79	$1,103.00	$87,137.00	$645.66	$51,007.14	-	-	$138,144.14
P2	Ton	17	$1,103.00	$18,751.00	$645.66	$10,976.22	-	-	$29,727.22
P1	Ton	14	$1,103.00	$15,442.00	$645.66	$9,039.24	-	-	$24,481.24
Level 1	Ton	22	$1,103.00	$24,266.00	$645.66	$14,204.52	-	-	$38,470.52
Level 2	Ton	21	$1,103.00	$23,163.00	$645.66	$13,558.86	-	-	$36,721.86
Level 3	Ton	21	$1,103.00	$23,163.00	$645.66	$13,558.86	-	-	$36,721.86
Level 4	Ton	21	$1,103.00	$23,163.00	$645.66	$13,558.86	-	-	$36,721.86
Level 5	Ton	21	$1,103.00	$23,163.00	$645.66	$13,558.86	-	-	$36,721.86
Level 6	Ton	21	$1,103.00	$23,163.00	$645.66	$13,558.86	-	-	$36,721.86
Level 7	Ton	21	$1,103.00	$23,163.00	$645.66	$13,558.86	-	-	$36,721.86
Level 8	Ton	21	$1,103.00	$23,163.00	$645.66	$13,558.86	-	-	$36,721.86
Level 9	Ton	21	$1,103.00	$23,163.00	$645.66	$13,558.86	-	-	$36,721.86
PH/House Roof	Ton	23	$1,103.00	$25,369.00	$645.66	$14,850.18	-	-	$40,219.18
PH Roof	Ton	10	$1,103.00	$11,030.00	$645.66	$6,456.60	-	-	$17,486.60
Total				$379,432.00		$222,107.04			$601,539.04

Structural Steel									$84,849.77
Size	Unit	QTY	Material ($/LF)	Material Total	Labor ($/LF)	Labor Total	Equipment ($/LF)	Equipment Total	Total
W8x10	LF	102.4	$14.94	$1,529.48	$4.94	$505.73	$2.66	$272.32	$2,307.53
W8x18	LF	47.3	$31.35	$1,481.29	$4.94	$233.42	$2.66	$125.69	$1,840.39
W10x12	LF	21.0	$17.92	$376.32	$4.94	$103.74	$2.66	$55.86	$535.92
W10x22	LF	65.1	$32.92	$2,143.09	$4.94	$321.59	$2.66	$173.17	$2,637.85
W10x30	LF	22.1	$44.70	$985.64	$4.94	$108.93	$2.66	$58.65	$1,153.22
W10x33	LF	20.5	$49.12	$1,005.73	$5.38	$110.16	$2.90	$59.38	$1,175.27
W14x22	LF	8.4	$38.67	$324.83	$2.99	$25.12	$1.61	$13.52	$363.47
W16x26	LF	273.0	$38.67	$10,556.91	$2.96	$808.08	$1.59	$434.07	$11,799.06
W16x31	LF	206.9	$46.50	$9,618.53	$3.29	$680.54	$1.77	$366.12	$10,665.19
W16x36	LF	36.8	$59.57	$2,189.20	$3.70	$135.98	$2.00	$73.50	$2,398.67
W16x45	LF	102.9	$67.15	$6,909.74	$3.70	$380.73	$2.00	$205.80	$7,496.27
W16x57	LF	141.8	$88.35	$12,523.61	$3.75	$531.56	$2.00	$283.50	$13,338.68
W18x60	LF	26.3	$97.19	$2,551.24	$4.74	$124.43	$1.94	$50.93	$2,726.59
W21x50	LF	58.3	$74.72	$4,354.31	$4.02	$234.27	$1.65	$96.15	$4,684.73
W24x62	LF	35.7	$92.48	$3,301.54	$3.85	$137.45	$1.57	$56.05	$3,495.03
HSS4-1/2x4-1/2x1/4	LF	30.5	$18.72	$570.02	$4.27	$130.02	$2.31	$70.34	$770.39
HSS6x4x1/2	LF	225.8	$30.48	$6,880.86	$4.58	$1,033.94	$2.45	$553.09	$8,467.88
HSS6x6-1/4x1/4	LF	81.9	$30.48	$2,496.31	$4.58	$375.10	$2.45	$200.66	$3,072.07
HSS8x8x3/8	LF	38.9	$66.18	$2,571.09	$4.94	$191.92	$2.66	$103.34	$2,866.35
HSS8x8x5/16	LF	20.7	$56.73	$1,176.44	$4.24	$87.93	$2.28	$47.28	$1,311.65
HSS16x16x3/8	LF	17.9	$91.74	$1,637.56	$3.84	$68.54	$2.10	$37.49	$1,743.59
Total				$75,183.72		$6,329.15		$3,336.89	$84,849.77

Complete Cost					$7,116,647.51
	Material Total		Labor Total	Equipment Total	Total
Total Structure	$5,060,224.04		$1,608,135.79	$448,287.67	$7,116,647.51

Appendix 1-D | MEP Assemblies Estimate

Quantity	Assembly Number	Description	Unit	Total ($/Unit)	Complete Total
Plumbing					$510,625.92
Quantity	Assembly Number	Description	Unit	Total ($/Unit)	Complete Total
48	D20101102080	Water closet, vitreous china, bowl only with flush valve, wall hung	Ea.	$2,807.89	$134,778.72
9	D20102102040	Urinal, vitreous china, stall type	Ea.	$2,390.52	$21,514.68
58	D20104404380	Service sink w/trim, vitreous china, wall hung 22" x 20"	Ea.	$3,906.23	$226,561.34
2	D20107101720	Shower, stall, baked enamel, terrazzo receptor, 36" corner angle	Ea.	$3,375.96	$6,751.92
20	D20108201840	Water cooler, electric, wall hung, 8.2 GPH	Ea.	$1,841.07	$36,821.40
11	D20202401820	Electric water heater, commercial, 100< F rise, 50 gallon tank, 9 KW 37 GPH	Ea.	$6,552.01	$72,072.11
13	D20402101880	Roof drain, DWV PVC, 2" diam, piping, 10' high	Ea.	$932.75	$12,125.75
Mechanical					$1,224,720.00
Quantity	Assembly Number	Description	Unit	Total ($/Unit)	Complete Total
108000	D30301103520	Packaged chiller, air cooled, with fan coil unit, offices, 40,000 SF, 126.66 ton	S.F.	$11.34	$1,224,720.00
Fire Protection					$734,993.74
Quantity	Assembly Number	Description	Unit	Total ($/Unit)	Complete Total
12000	D40104101080	Wet pipe sprinkler systems, steel, ordinary hazard, 1 floor, 10,000 SF	S.F.	$4.57	$54,840.00
96000	D40104101180	Wet pipe sprinkler systems, steel, ordinary hazard, each additional floor, 2000 SF	S.F.	$3.80	$364,800.00
13	D40203100640	Wet standpipe risers, class I, steel, black, sch 40, 8" diam pipe, 1 floor	Floor	$19,471.13	$253,124.69
13	D40203100660	Wet standpipe risers, class I, steel, black, sch 40, 8" diam pipe, additional floors	Floor	$4,786.85	$62,229.05
Electrical					$3,465,060.32
Quantity	Assembly Number	Description	Unit	Total ($/Unit)	Complete Total
2	D50101301000	Underground service installation, includes excavation, backfill, and compaction, 100' length, 4' depth, 3 phase, 4 wire, 277/480 volts, 2000 A	Ea.	$66,839.80	$133,679.60
192	D50102300560	Feeder installation 600 V, including RGS conduit and XHHW wire, 2000 A	L.F.	$596.56	$114,539.52
4	D50102400400	Switchgear installation, incl switchboard, panels & circuit breaker, 120/208 V, 2000 A	Ea.	$39,498.90	$157,995.60
48	D50102504000	Panelboard, 4 wire w/conductor & conduit, NQOD, 120/208 V, 600 A, 10 stories, 75' horizontal	Ea.	$61,589.20	$2,956,281.60
400	D50902101000	Generator sets, w/battery, charger, muffler and transfer switch, diesel engine with fuel tank, 400 kW	kW	$256.41	$102,564.00
Total MEP					$5,935,399.98

Appendix 1-E | General Conditions Estimate

General Conditions

Quantity	LineNumber	Description	Unit	Total Material	Total Labor	Total Equipment	Final Total
100	013113200020	Field Personnel, clerk, average	Week	$ -	$ 77,500.00	$ -	$ 77,500.00
300	013113200100	Field personnel, field engineer, minimum	Week	$ -	$ 472,500.00	$ -	$ 472,500.00
120	013113200180	Field personnel, project manager, minimum	Week	$ -	$ 348,000.00	$ -	$ 348,000.00
45	013113200220	Field personnel, project manager, maximum	Week	$ -	$ 172,125.00	$ -	$ 172,125.00
200	013113200240	Field personnel, superintendent, minimum	Week	$ -	$ 565,000.00	$ -	$ 565,000.00
100	013113200160	Field personnel, general purpose laborer, average	Week	$ -	$ 217,500.00	$ -	$ 217,500.00
1	015113500170	Temporary electrical power equipment (pro-rated per job), underground feed, 3 uses, 1200 amp	Ea.	$ 5,035.00	$ 2,337.50	$ -	$ 7,372.50
22	015113500170	Commissioning, basic building commissioning, maximum	Month	$ 553.85	$ 257.13	$ -	$ 810.98
22	015113500170	Cleaning up, clean up after job completion, allow, max	Month	$ 1,107.70	$ 514.25	$ -	$ 1,621.95
1	015113500170	Workers' compensation & employer's liability insurance, carpentry, general	Payroll	$ -	$ 353.66	$ -	$ 353.66
22	015113500170	Insurance, public liability, average	Month	$ 2,237.55	$ 1,038.79	$ -	$ 3,276.34
1	015113500170	Insurance, contractor's equipment floater, minimum	Value	$ 25.18	$ 11.69	$ -	$ 36.87
22	015113500170	Builders Risk Insurance, standard, minimum	Month	$ 265.85	$ 123.42	$ -	$ 389.27
1	015213200400	Office Trailer, furnished, buy, 50' x 10', excl. hookups	Ea.	$ 26,076.00	$ 1,776.50	$ -	$ 27,852.50
22	015213200400	Commissioning, basic building commissioning, maximum	Month	$ 2,868.36	$ 195.42	$ -	$ 3,063.78
22	015213200400	Cleaning up, clean up after job completion, allow, max	Month	$ 5,736.72	$ 390.83	$ -	$ 6,127.55
1	015213200400	Workers' compensation & employer's liability insurance, carpentry, general	Month	$ -	$ 280,570.95	$ -	$ 280,570.95
22	015213200400	Insurance, public liability, average	Month	$ 11,588.17	$ 789.48	$ -	$ 12,377.65
1	015213200400	Insurance, contractor's equipment floater, minimum	Value	$ 130.38	$ 8.88	$ -	$ 139.26
22	015213200400	Builders Risk Insurance, standard, minimum	Month	$ 1,376.81	$ 93.80	$ -	$ 1,470.61
18	015113800700	Temporary Utilities, temporary construction water bill per month, average	Month	$ 1,326.06	$ -	$ -	$ 1,326.06
22	015113800700	Commissioning, basic building commissioning, maximum	Month	$ 145.87	$ -	$ -	$ 145.87
22	015113800700	Cleaning up, clean up after job completion, allow, max	Month	$ 291.73	$ -	$ -	$ 291.73
11	015419600100	Crane crew, tower crane, static, 130' high, 106' jib, 6200 lb. capacity, monthly use, excludes concrete footing	Month	$ -	$ 133,705.00	$ 298,575.20	$ 432,280.20
22	015419600100	Commissioning, basic building commissioning, maximum	Month	$ -	$ 14,707.55	$ 32,843.27	$ 47,550.82
22	015419600100	Cleaning up, clean up after job completion, allow, max	Month	$ -	$ 29,415.10	$ 65,686.54	$ 95,101.64
30	015416500100	Forklift crew, all-terrain forklift, 45' lift, 35' reach, 9000 lb. capacity, weekly use	Week	$ -	$ 77,838.90	$ 88,818.00	$ 166,656.90
22	015416500100	Commissioning, basic building commissioning, maximum	Month	$ -	$ 8,562.28	$ 9,769.98	$ 18,332.26
22	015416500100	Cleaning up, clean up after job completion, allow, max	Month	$ -	$ 17,124.56	$ 19,539.96	$ 36,664.52
3	015433101200	Rent finisher concrete floor gas riding trowel, 96" wide, Excl. Hourly Oper. Cost.	Month	$ -	$ -	$ 4,495.92	$ 4,495.92
250	015623100020	Barricades, wood, fixed, 3 rail, 5' high, 3 rail @ 2" x 8"	L.F.	$ 1,562.50	$ 12,972.50	$ -	$ 14,535.00
22	015623100020	Commissioning, basic building commissioning, maximum	Month	$ 171.88	$ 1,426.98	$ -	$ 1,598.86
22	015623100020	Cleaning up, clean up after job completion, allow, max	Month	$ 343.75	$ 2,853.95	$ -	$ 3,197.70
200	015626500100	Temporary Fencing, chain link, 6' high, 11 ga	L.F.	$ 604.00	$ 544.00	$ -	$ 1,148.00
22	015626500100	Commissioning, basic building commissioning, maximum	Month	$ 66.44	$ 59.84	$ -	$ 126.28
22	015626500100	Cleaning up, clean up after job completion, allow, max	Month	$ 132.88	$ 119.68	$ -	$ 252.56
Total				**$ 61,646.68**	**$ 2,440,417.64**	**$ 519,728.87**	**$ 3,021,793.19**

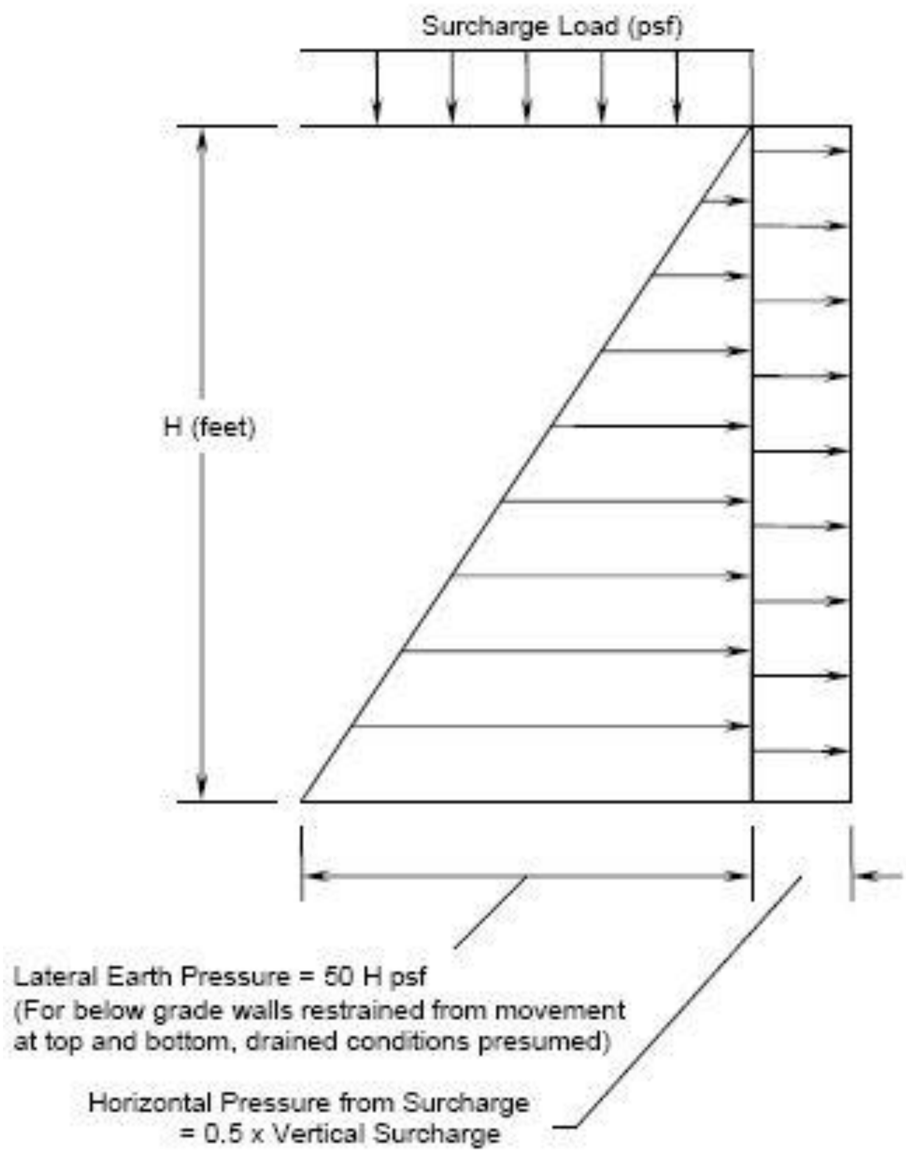
Appendix 3-A | Structural Breadth

TABLE A - 4 AREAS OF REINFORCING BARS PER FOOT OF SLAB (IN.^{2})

Bar Number

Bar Spacing	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
2"	0.30	0.66	1.20	1.86						
2½"	0.24	0.53	0.96	1.49	2.11					
3"	0.20	0.44	0.80	1.24	1.76	2.40	3.16	4.00		
3½"	0.17	0.38	0.69	1.06	1.51	2.06	2.71	3.43	4.35	
4"	0.15	0.33	0.60	0.93	1.32	1.80	2.37	3.00	3.81	4.68
4½"	0.13	0.29	0.53	0.83	1.17	1.60	2.11	2.67	3.39	4.16
5"	0.12	0.26	0.48	0.74	1.06	1.44	1.90	2.40	3.05	3.74
5½"	0.11	0.24	0.44	0.68	0.96	1.31	1.72	2.18	2.77	3.40
6"	0.10	0.22	0.40	0.62	0.88	1.20	1.58	2.00	2.54	3.12
6½"	0.09	0.20	0.37	0.57	0.81	1.11	1.46	1.85	2.34	2.88
7"	0.09	0.19	0.34	0.53	0.75	1.03	1.35	1.71	2.18	2.67
7½"	0.08	0.18	0.32	0.50	0.70	0.96	1.26	1.60	2.03	2.50
8"	0.08	0.16	0.30	0.46	0.66	0.90	1.18	1.50	1.90	2.34
9"	0.07	0.15	0.27	0.41	0.59	0.80	1.05	1.33	1.69	2.08
10"	0.06	0.13	0.24	0.37	0.53	0.72	0.95	1.20	1.52	1.87
11"	0.05	0.12	0.22	0.34	0.48	0.65	0.86	1.09	1.39	1.70
12"	0.05	0.11	0.20	0.31	0.44	0.60	0.79	1.00	1.27	1.56
13"	0.04	0.10	0.18	0.29	0.41	0.55	0.73	0.92	1.17	1.44
14"	0.04	0.09	0.17	0.27	0.38	0.51	0.68	0.86	1.09	1.34
15"	0.04	0.09	0.16	0.25	0.35	0.48	0.64	0.80	1.02	1.25
16"	0.04	0.08	0.15	0.23	0.33	0.45	0.59	0.75	0.95	1.17
17"	0.03	0.08	0.14	0.22	0.31	0.42	0.56	0.71	0.90	1.10
18"	0.03	0.07	0.13	0.21	0.29	0.40	0.53	0.67	0.85	1.04

LATERAL EARTH PRESSURE DIAGRAM



Appendix 3-B | Cost Analysis

Cast-in-Place Concrete Cost Breakdown													
Floor	Volume (cu yd)	Concrete Unit Cost ($/cu yd)	Concrete Cost	Formwork Unit Cost ($/ft)	Formwork Cost	Rebar Cost	Total Material Cost	Labor Unit Cost ($/Day)	Labor Cost	Equipment Unit Cost ($/cu yd)	Equipment Cost	Total
P3	205	118.41	$24,274.05	$78.37	$25,901.29	$21,021.39	$71,196.73	$1,440.00	$34,560.00	24.57	5036.85	$110,793.58
P2	188	118.41	$22,261.08	$78.37	$23,746.11	$18,987.06	$64,994.25	$1,440.00	$17,280.00	24.57	4619.16	$86,893.41
P1	268	118.41	$31,733.88	$78.37	$33,855.84	$27,802.49	$93,392.21	$1,440.00	$17,280.00	24.57	6584.76	$117,256.97
Total:			$78,269.01		$83,503.24	$67,810.94	$229,583.19		$69,120.00		$16,240.77	$314,943.96

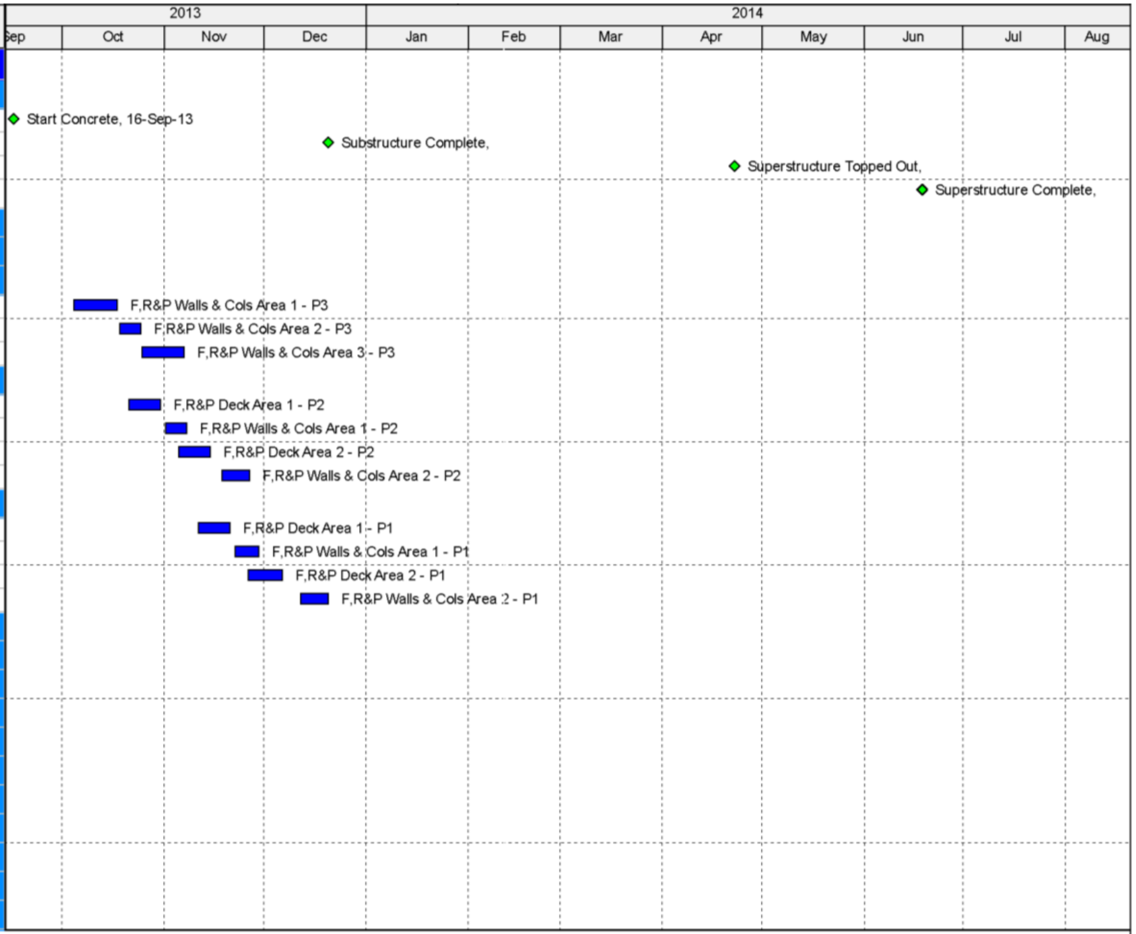
Shotcrete Cost Breakdown										
Floor	Volume (cu yd)	Concrete Unit Cost ($/cu yd)	Concrete Cost	Rebar Cost	Total Material Cost	Labor Unit Cost ($/Day)	Labor Cost	Equipment Unit Cost ($/cu yd)	Equipment Cost	Total
P3	234	$157.32	$36,812.88	$21,021.39	$57,834.27	$2,016.00	$9,072.00	$27.80	$6,505.20	$73,411.47
P2	216	$157.32	$33,981.12	$18,987.06	$52,968.18	$2,016.00	$8,064.00	$27.80	$6,004.80	$67,036.98
P1	305	$157.32	$47,982.60	$27,802.49	$75,785.09	$2,016.00	$13,104.00	$27.80	$8,479.00	$97,368.09
Total	755		$118,776.60	$67,810.94	$186,587.54		$30,240.00		$20,989.00	$237,816.54

Appendix 3-C | Schedule Analysis

CIP Schedule Breakdown		
Floor	Wall Length (ft)	Duration (Day)
P3	330.5	24
P2	303.0	12
P1	432.0	12
Total	1066	48

Shotcrete Schedule Breakdown		
Floor	Volume (cu yd)	Duration (Day)
P3	234	4.5
P2	216	4
P1	305	6.5
Total	755	15

Activity ID	Activity Name	Original Duration	Start	Finish
Structure		196	16-Sep-13	18-Jun-14
Milestones		196	16-Sep-13	18-Jun-14
A1000	Start Concrete	0	16-Sep-13	
A1010	Substructure Complete	0		20-Dec-13
A1020	Superstructure Topped Out	0		22-Apr-14
A1030	Superstructure Complete	0		18-Jun-14
Tower Crane		11	27-Sep-13	11-Oct-13
Foundations		24	16-Sep-13	17-Oct-13
Level P3		24	04-Oct-13	06-Nov-13
A1160	F,R&P Walls & Cols Area 1 - P3	10	04-Oct-13	17-Oct-13
A1170	F,R&P Walls & Cols Area 2 - P3	5	18-Oct-13	24-Oct-13
A1180	F,R&P Walls & Cols Area 3 - P3	9	25-Oct-13	06-Nov-13
Level P2		27	21-Oct-13	26-Nov-13
A1190	F,R&P Deck Area 1 - P2	8	21-Oct-13	30-Oct-13
A1200	F,R&P Walls & Cols Area 1 - P2	5	01-Nov-13	07-Nov-13
A1210	F,R&P Deck Area 2 - P2	8	05-Nov-13	14-Nov-13
A1220	F,R&P Walls & Cols Area 2 - P2	7	18-Nov-13	26-Nov-13
Level P1		29	11-Nov-13	20-Dec-13
A1230	F,R&P Deck Area 1 - P1	8	11-Nov-13	20-Nov-13
A1240	F,R&P Walls & Cols Area 1 - P1	5	22-Nov-13	29-Nov-13
A1250	F,R&P Deck Area 2 - P1	8	26-Nov-13	06-Dec-13
A1260	F,R&P Walls & Cols Area 2 - P1	7	12-Dec-13	20-Dec-13
Ground Level		26	06-Dec-13	13-Jan-14
Level 2		27	30-Dec-13	04-Feb-14
Level 3		26	10-Jan-14	14-Feb-14
Level 4		27	21-Jan-14	26-Feb-14
Level 5		27	31-Jan-14	10-Mar-14
Level 6		26	13-Feb-14	20-Mar-14
Level 7		26	25-Feb-14	01-Apr-14
Level 8		25	07-Mar-14	10-Apr-14
Level 9		26	18-Mar-14	22-Apr-14
Roof		27	28-Mar-14	05-May-14
Penthouse		31	05-May-14	16-Jun-14



Actual Level of Effort | Remaining Work | Milestone
Actual Work | Critical Remaining Work

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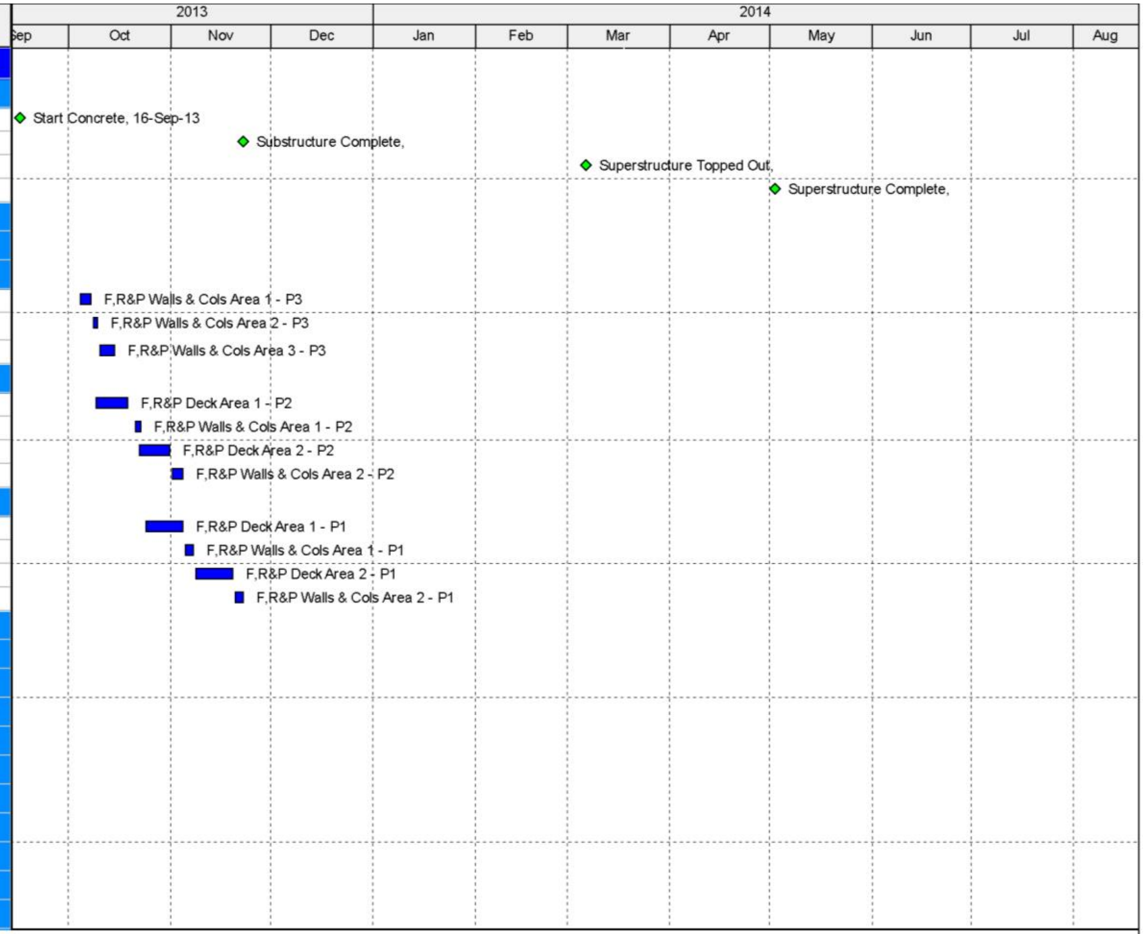
TASK filter: All Activities

Activity ID	Activity Name	Original Duration	Start	Finish
Shotcrete		163	16-Sep-13	02-May-14
Milestones		163	16-Sep-13	02-May-14
A1000	Start Concrete	0	16-Sep-13	
A1010	Substructure Complete	0		22-Nov-13
A1020	Superstructure Topped Out	0		06-Mar-14
A1030	Superstructure Complete	0		02-May-14
Tower Crane		11	27-Sep-13	11-Oct-13
Foundations		24	16-Sep-13	17-Oct-13
Level P3		7	04-Oct-13	14-Oct-13
A1160	F,R&P Walls & Cols Area 1 - P3	2	04-Oct-13	07-Oct-13
A1170	F,R&P Walls & Cols Area 2 - P3	2	08-Oct-13	09-Oct-13
A1180	F,R&P Walls & Cols Area 3 - P3	3	10-Oct-13	14-Oct-13
Level P2		19	09-Oct-13	04-Nov-13
A1190	F,R&P Deck Area 1 - P2	8	09-Oct-13	18-Oct-13
A1200	F,R&P Walls & Cols Area 1 - P2	2	21-Oct-13	22-Oct-13
A1210	F,R&P Deck Area 2 - P2	8	22-Oct-13	31-Oct-13
A1220	F,R&P Walls & Cols Area 2 - P2	2	01-Nov-13	04-Nov-13
Level P1		22	24-Oct-13	22-Nov-13
A1230	F,R&P Deck Area 1 - P1	8	24-Oct-13	04-Nov-13
A1240	F,R&P Walls & Cols Area 1 - P1	3	05-Nov-13	07-Nov-13
A1250	F,R&P Deck Area 2 - P1	8	08-Nov-13	19-Nov-13
A1260	F,R&P Walls & Cols Area 2 - P1	3	20-Nov-13	22-Nov-13
Ground Level		26	04-Nov-13	10-Dec-13
Level 2		27	13-Nov-13	20-Dec-13
Level 3		26	21-Nov-13	30-Dec-13
Level 4		27	03-Dec-13	09-Jan-14
Level 5		27	13-Dec-13	21-Jan-14
Level 6		26	26-Dec-13	30-Jan-14
Level 7		26	09-Jan-14	13-Feb-14
Level 8		25	21-Jan-14	24-Feb-14
Level 9		26	29-Jan-14	05-Mar-14
Roof		27	11-Feb-14	19-Mar-14
Penthouse		31	19-Mar-14	30-Apr-14



Actual Level of Effort | Remaining Work | Milestone
Actual Work | Critical Remaining Work

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TASK filter: All Activities

Appendix 5-A | NEC 2011 Sizing Tables

Table 310.15(B)(16) (formerly Table 310.16) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

	Temperature Rating of Conductor [See Table 310.104(A).]						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			Size AWG or kcmil
18	—	—	14	—	—	—	—
16	—	—	18	—	—	—	—
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
10**	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
500	320	380	430	260	310	350	500
600	350	420	475	285	340	385	600
700	385	460	520	315	375	425	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	445	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	525	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	555	665	750	470	560	630	2000

*Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).
**Refer to 240.4(D) for conductor overcurrent protection limitations.

Table 250.66 Grounding Electrode Conductor for Alternating-Current Systems

Size of Largest Ungrounded Service-Entrance Conductor or Equivalent Area for Parallel Conductors (AWG/kcmil)		Size of Grounding Electrode Conductor (AWG/kcmil)	
Copper	Aluminum or Copper-Clad Aluminum	Copper	Aluminum or Copper-Clad Aluminum
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250	4	2
Over 3/0 through 350	Over 250 through 500	2	1/0
Over 350 through 600	Over 500 through 900	1/0	3/0
Over 600 through 1100	Over 900 through 1750	2/0	4/0
Over 1100	Over 1750	3/0	250

Table C.1 Maximum Number of Conductors or Fixture Wires in Electrical Metallic Tubing (EMT) (*Based on Table 1, Chapter 9*)

CONDUCTORS											
	Conductor Size	Metric Designator (Trade Size)									
Type	(AWG kcmil)	16 (½)	21 (¾)	27 (1)	35 (1¼)	41 (1½)	53 (2)	63 (2½)	78 (3)	91 (3½)	103 (4)
RHH, RHW, RHW-2	14	4	7	11	20	27	46	80	120	157	201
	12	3	6	9	17	23	38	66	100	131	167
	10	2	5	8	13	18	30	53	81	105	135
	8	1	2	4	7	9	16	28	42	55	70
	6	1	1	3	5	8	13	22	34	44	56
	4	1	1	2	4	6	10	17	26	34	44
	3	1	1	1	4	5	9	15	23	30	38
	2	1	1	1	3	4	7	13	20	26	33
	1	0	1	1	1	3	5	9	13	17	22
	1/0	0	1	1	1	2	4	7	11	15	19
	2/0	0	1	1	1	2	4	6	10	13	17
	3/0	0	0	1	1	1	3	5	8	11	14
	4/0	0	0	1	1	1	3	5	7	9	12
	250	0	0	0	1	1	1	3	5	7	9
	300	0	0	0	1	1	1	3	5	6	8
	350	0	0	0	1	1	1	3	4	6	7
	400	0	0	0	1	1	1	2	4	5	7
	500	0	0	0	0	1	1	2	3	4	6
	600	0	0	0	0	1	1	1	3	4	5
	700	0	0	0	0	0	1	1	2	3	4
	750	0	0	0	0	0	1	1	2	3	4
	800	0	0	0	0	0	1	1	2	3	4
	900	0	0	0	0	0	1	1	1	3	3
	1000	0	0	0	0	0	1	1	1	2	3
	1250	0	0	0	0	0	0	1	1	1	2
	1500	0	0	0	0	0	0	1	1	1	1
	1750	0	0	0	0	0	0	1	1	1	1
	2000	0	0	0	0	0	0	1	1	1	1
TW	14	8	15	25	43	58	96	168	254	332	424
	12	6	11	19	33	45	74	129	195	255	326
	10	5	8	14	24	33	55	96	145	190	243
	8	2	5	8	13	18	30	53	81	105	135
RHH*, RHW*, RHW-2*, THHW, THW, THW-2	14	6	10	16	28	39	64	112	169	221	282
RHH*, RHW*, RHW-2*, THHW, THW	12	4	8	13	23	31	51	90	136	177	227
	10	3	6	10	18	24	40	70	106	138	177
RHH*, RHW*, RHW-2*, THHW, THW, THW-2	8	1	4	6	10	14	24	42	63	83	106

Appendix 5-B | Spectra Series Busway Sizes

		Rated Load Amps	Bar Width x 1/4" Thickness		Ohms x 10-3/100 Ft. Line-to-Neutral			Voltage Drop – Concentrated Load① Line-to-Line/100 Ft. @ 100% Rated Load, 25°C Amb. Power Factor							
			IN	MM	R	X	Z	.3	.4	.5	.6	.7	.8	.9	1.0
Aluminum	Spectra Series II	225	0.750	19	9.11	3.75	9.85	2.46	2.76	3.04	3.30	3.53	3.72	3.83	3.55
		400	1.125	29	6.38	3.12	7.10	1.69	1.87	2.04	2.19	2.32	2.42	2.46	2.21
		600	1.750	44	4.32	2.35	4.92	3.68	4.03	4.36	4.65	4.89	5.06	5.11	4.49
	Spectra Series	225	1.625	41	4.09	1.28	4.29	.95	1.09	1.23	1.36	1.47	1.57	1.65	1.59
		400	1.625	41	4.20	1.28	4.39	1.72	1.98	2.22	2.46	2.67	2.86	3.01	2.91
		600	1.625	41	4.52	1.28	4.70	2.68	3.10	3.50	3.88	4.24	4.56	4.81	4.70
		800	2.875	73	2.48	.79	2.60	2.08	2.38	2.67	2.94	3.19	3.41	3.57	3.44
		1000	3.375	86	2.17	.68	2.27	2.25	2.58	2.90	3.20	3.47	3.71	3.90	3.76
		1200	4.25	108	1.73	.55	1.81	2.17	2.49	2.79	3.07	3.33	3.56	3.73	3.60
		1350	5.75	146	1.24	.41	1.31	1.78	2.04	2.28	2.51	2.71	2.89	3.03	2.90
		1600	6.50	165	1.12	.36	1.18	1.88	2.16	2.42	2.66	2.89	3.08	3.23	3.10
		2000	8.25	210	.89	.29	.94	1.88	2.15	2.41	2.65	2.88	3.07	3.21	3.08
		2500	(2)4.50	(2)114	.82	.26	.86	2.14	2.45	2.75	3.03	3.29	3.52	3.69	3.55
		3000	(2)5.75	(2)146	.64	.21	.67	2.04	2.33	2.61	2.87	3.11	3.32	3.47	3.33
		3200	(2)4.50	(2)114	.51	.25	.55	2.21	2.44	2.63	2.82	2.96	3.60	3.10	2.67
		4000	(2)8.25	(2)210	.45	.14	.47	1.86	2.14	2.40	2.65	2.88	3.08	3.23	3.12
Copper	Spectra Series II	225	0.750	19	5.10	3.75	6.33	1.99	2.13	2.26	2.36	2.43	2.47	2.43	1.99
		400	0.750	19	5.58	3.75	6.72	1.82	1.96	2.09	2.20	2.28	2.33	2.31	1.93
		600	1.125	29	3.86	3.12	4.96	2.15	2.29	2.41	2.50	2.56	2.58	2.51	2.01
	Spectra Series	225	1.625	41	2.33	1.28	2.66	.75	.82	.89	.94	.99	1.03	1.03	.91
		400	1.625	41	2.38	1.28	2.70	1.34	1.47	1.59	1.70	1.79	1.85	1.87	1.65
		600	1.625	41	2.48	1.28	2.79	2.04	2.25	2.44	2.61	2.75	2.86	2.90	2.58
		800	1.625	41	2.62	1.28	2.92	2.78	3.08	3.35	3.60	3.81	3.97	4.04	3.63
		1000	2.25	57	1.90	.98	2.14	2.61	2.87	3.12	3.33	3.52	3.65	3.70	3.29
		1200	2.875	73	1.49	.79	1.69	2.50	2.74	2.97	3.17	3.34	3.46	3.50	3.10
		1350	3.375	86	1.27	.68	1.44	2.41	2.65	2.86	3.05	3.21	3.33	3.37	2.97
		1600	4.25	108	1.00	.55	1.14	2.29	2.51	2.71	2.88	3.03	3.13	3.16	2.77
		2000	5.75	146	.73	.41	.84	2.11	2.31	2.49	2.65	2.78	2.88	2.90	2.53
		2500	7.50	191	.57	.32	.65	2.06	2.26	2.43	2.59	2.72	2.81	2.83	2.47
		3000	(2)4.00	(2)102	.53	.29	.58	2.26	2.48	2.68	2.86	3.00	3.11	3.14	2.73
		3200	(2)4.50	(2)114	.51	.25	.55	2.21	2.44	2.63	2.82	2.96	3.60	3.10	2.67
		4000	(2)5.75	(2)146	.37	.21	.42	2.16	2.36	2.54	2.70	2.83	2.92	2.94	2.56
		5000	(2)7.50	(2)191	.28	.16	.32	2.05	2.24	2.41	2.56	2.69	2.77	2.79	2.42

Table 11.1
Plug-in and Feeder, all bus UL Listed @600 Volts

		AC Ampere Rating	Fig. No.	Standard Bar				+1 Bar				DC Ampere Rating	Approximate Weight lbs./ft.	
				"A" Width		Bar Sizes Width x Thickness		"A" Width		Bar Size				
				Inches	MM	Inches	MM	Inches	MM	Inches	MM		3-Wire	4 Wire
Aluminum	Spectra Series II	225	11.3	3.00	76	.75 x .25	19 x 6	-	-	-	-	225	5	5
		400	11.3	3.38	86	1.13 x .25	29 x 6	-	-	-	-	600	6	6
		600	11.3	4.00	102	1.75 x .25	44 x 6	-	-	-	-	800	7	8
	Spectra Series	225	11.1	4.38	111	1.63 x.25	41 x 6	4.38	111	1.63	41	600	5	6
		400	11.1	4.38	111	1.63 x.25	41 x 6	4.38	111	1.63	41	—	5	6
		600	11.1	4.38	111	1.63 x.25	41 x 6	5.00	127	2.25	57	800/1000	5	6
		800	11.1	5.63	143	2.88 x.25	73 x 6	6.13	156	3.38	86	1350	6	7
		1000	11.1	6.13	156	3.38 x.25	86 x 6	7.00	178	4.25	108	1600	7	8
		1200	11.1	7.00	178	4.25 x.25	108 x 6	7.25	184	4.50	114	—	8	9
		1350	11.1	8.50	216	5.75 x.25	146 x 6	9.25	235	6.50	165	2500	9	10
		1600	11.1	9.25	235	6.50 x.25	165 x 6	11.00	279	8.25	210	—	10	12
		2000	11.1	11.00	279	8.25 x.25	210 x 6	15.00	381	(2)4.25	(2)108	3000	12	15
		2500	11.2	15.50	394	(2)4.50 x.25	(2)114 x 6	18.00	457	(2)5.75	(2)146	4000	17	20
		3000	11.2	18.00	457	(2)5.75 x.25	(2)146 x 6	19.50	495	(2)6.50	(2)165	—	19	23
		3200	11.2	19.5	495	(2)6.50 x.25	(2)165 x 6	-	-	-	-	5200	21	24
		4000	11.2	23.00	584	(2)8.25 x.25	(2)210 x 6	-	-	-	-	6000	25	30
Copper	Spectra Series II	225	11.3	3.00	76	.75 x .25	225	-	-	-	-	225	7	7
		400	11.3	3.00	76	.75 x .25	600	-	-	-	-	600	7	7
		600	11.3	3.38	86	1.13 x .25	800	-	-	-	-	800	8	9
	Spectra Series	225	11.1	4.38	111	1.63 x.25	41 x 6	4.38	111	1.63	41	800	8	9
		400	11.1	4.38	111	1.63 x.25	41 x 6	4.38	111	1.63	41	—	8	9
		600	11.1	4.38	111	1.63 x.25	41 x 6	4.38	111	1.63	41	—	8	9
		800	11.1	4.38	111	1.63 x.25	41 x 6	5.00	127	2.25	57	1000/1200	8	9
		1000	11.1	5.00	127	2.25 x.25	57 x 6	5.63	143	2.88	73	1350/1600	10	12
		1200	11.1	5.63	143	2 7/8 x.25	73 x 6	6.13	156	3.38	86	—	12	15
		1350	11.1	6.13	156	3.38 x.25	86 x 6	7.00	178	4.25	108	2000	14	17
		1600	11.1	7.00	178	4.25 x.25	108 x 6	7.25	184	4.50	114	2500	16	20
		2000	11.1	8.50	216	5.75 x.25	146 x 6	9.25	235	6.50	165	3000	21	26
		2500	11.1	10.25	260	7.50 x.25	191 x 6	11.00	279	8.25	210	4000	26	33
		3000	11.2	14.50	368	(2)4.00 x.25	(2)102 x 6	15.00	381	4.25	108	5000	32	40
		3200	11.2	15.50	394	(2)4.50 x.25	(2)114 x 6	-	-	-	-	5200	34	43
		4000	11.2	18.00	457	(2)5.75 x.25	(2)146 x 6	19.50	495	(2)6.50	(2)165	6000	42	52
		5000	11.2	21.50	546	(2)7.50 x.25	(2)191 x 6	23.00	584	(2)8.25	(2)210	8000	52	66