Senior Thesis Final Report

Louis at the 14th

Washington, D.C.

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Construction Option

Advisor Ed Gannon

9 April 2014

LOUIS

THE JBG COMPANIES

Balfour Beatty Construction

14th St. & U St., NW   Washington, DC 20009

rendering courtesy of JBG Companies

Russell Voigt

Construction Option

Residential & Retail Use

9 Stories

$47M

267,000 SF (GFA)

LEED Silver

Design-Bid-Build

Owner: The JBG Companies
Georgetown Strategic Capital

CM: Balfour Beatty Construction

Architect: Eric Colbert & Associates PC

Engineers: Bowman Consulting
Smislova, Kehnemui & Associates, PA
Summit Engineers, Inc.

CONSTRUCTION

March 2012 – March 2014

•adjacent 2 story buildings •existing 1-2 story demolition
•cast-in-place concrete pours •apartment turnover dates
•dewatering during foundation work
•soldier pile & tieback excavation support

STRUCTURAL SYSTEM

•Cast-in-place concrete frame
•Two-way post-tensioned suspended slabs
•Curtain wall glazing system
•Micropile deep foundation

MEP SYSTEM

•Water-to-Air; 290 ton cooling capacity
•1425 MBH heating capacity
•Penthouse mechanical room
•Parking garage houses 2 boilers, fire pump service room, & water meter room

ARCHITECTURE

•below grade parking garage with retail spaces at street level topped with residential apartments
•Enclosed primarily by aluminum window systems, metal panels, & masonry veneer
•Apartment complex includes fitness center, rooftop pool & lounge

rendering courtesy of JBG Companies

ELECTRICAL SYSTEM

•(2) *120/208V 3ϕ switchboards serving apartments*
•*3ϕ switchboard serving retail spaces*
•*(1) 265/460V*(2) electrical closets per floor
•Emergency Generator *265/460V 3ϕ*
•Main electrical room in parking garage

http://www.engr.psu.edu/ae/thesis/portfolios/2014/rjv5057/index.html

Executive Summary

This report compiled in accordance with senior thesis requirements discusses the design and construction of *Louis at the 14th* in a series of four primary analyses. These analysis topics collectively offer insight into providing the most effective, efficient, and safest foundation system for the building.

Analysis #1: Prevention Through Design for Foundations & Excavations

While prevention through design is more commonly practiced in designing the finishing details of buildings, this research highlights less common ways of applying prevention through design techniques to the foundation of a building and the excavation it requires. Its intention is to point out ways of changing design documents, specifications, and means and methods of excavation as well as the most hazardous elements of such work in order to provide the safest work environment.

Analysis #2: Foundation System Study

The schematic design of the foundation system was heavily challenged by soil conditions and the budget of the project. Had the schematic design taken a different direction, this analysis investigates that alternative option by utilizing a single mat slab design instead of a combination micropile and spread footing design. A structural study is also performed to aid in revealing the advantages and disadvantages of the mat slab system in comparison to that used on the actual project.

Analysis #3: Site Specific Safety Plan

By applying the findings of Analysis #1 to the foundation redesign of Analysis #2, a site specific safety plan is developed for the excavation phase. This plan focuses on identifying the risks and hazardous environments introduced by the mat slab design and provides analysis on the safest means and methods of protection and safety in accordance with the prevention through design research.

Analysis #4: Geothermal Loop System

In an effort to further exploit the building foundation area, this analysis looks into the installation of a closed-loop geothermal system with a well field installed in accordance with the actual micropile system used for the northern foundation. A mechanical study is completed to appropriately size the wells to serve the heating and cooling demands of the ground floor retail space of the building. The impact to the project budget and schedule are investigated as well as the overall constructability of the geothermal well field.

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My Fellow AE Classmates
My Family & Friends

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Project Overview

Introduction

Located in northwest Washington, D.C. at the corner of 14th St & U St, JBG Companies proposed a nine-story LEED Silver certified concrete high-rise with retail spaces at street level and 268 luxury apartment units throughout the majority of the building. Construction of this building was originally scheduled to take place from March 3, 2011 to November 29, 2013.

Rendering provided by JBG Companies

Client Information

JBG Companies is the primary owner of the building receiving consulting services from Georgetown Strategic Capital. It is the main business model of JBG Companies to develop real estate into profitable opportunities that enhance the community of the Washington Metropolitan Area. The schedule is the most critical element of their priorities because the sooner the contractor can turn over the residential spaces to the tenants, the sooner the owner can begin leasing space. JBG Companies also prides itself in providing the highest quality products in the community, with the budget the most flexible of these critical elements. The retail spaces are turned over to the tenants first as warm & lit spaces only, no finishes or interior work is required for this contract. It was originally scheduled that two floors at a time would be turned over per completion, but actual events caused the residential spaces to be turned over on two separate dates reliant on the completion of each floor.

Delivery Method

This job was delivered via design-bid-build, Eric Colbert & Associates being the head architect and Balfour Beatty Construction acting as the construction manager-at-risk. Balfour Beatty Construction was awarded the guaranteed maximum price contract after conducting their best & final offer with the other low bidder. Their subcontractors were hired based mainly on their low bid and scope of work, although their past relationships with Balfour Beatty, their prequalifications, financial strength, and bonding capacity were strongly considered, as well.

Staffing Plan

On the design team was Bowman Consulting acting as the civil engineer, SK & A Group as the structural engineer, Summit Engineers as the MEP engineer, and Cecconi Simone as the interiors consultant. Balfour Beatty Construction awarded Miller & Long Concrete Construction the concrete contract, TD Industries the HVAC contract, Berlin Steel the metals contract, Inspiration Plumbing Company the plumbing contract, and Electric General Corp the electrical contract.

The management team of Balfour Beatty Construction was headed by one project executive directing one project accountant, three superintendents, and one project manager. The project manager lead a team of two assistant project managers and one project engineer who had assumed responsibilities primarily based on trades of work.

Design & Construction Overview

Site Details

Photo by Russell Voigt

Located at the corner of 14th St and U St in Washington, D.C., the east side of the proposed building sits on the edge of the sidewalk of 14th St, while the rear of the building meets a public alley. Adjacent buildings, one of which houses the field office, adjoin the north and south sides of the property. The public sidewalk on 14th St was closed for the majority of the construction, directing passerby through street parking spaces accompanied by flagmen as necessary. The trees shown were also protected throughout the duration of construction.

Due to the adjacent buildings, piles supporting excavation work were required to be drilled instead of driven because of noise & vibration concerns. Potential complaints constantly threatened the temporary shutdown of operations on a day-by-day basis. The proposed 9-story building ties into the existing historic preservation area on the north side of the footprint.

Temporary jobsite parking on the NW corner of the property could be accessed through the public alley, but once work had sufficiently progressed in the parking garage on the south side, it was used for parking to allow work to continue on the northern footprint.

All adjacent buildings are three stories or less, so potential tower crane interferences were minimal; however, space is needed east of the building footprint on the existing sidewalk (as pictured), so the municipality was paid to close the sidewalk and parking meters to utilize that space and redirect pedestrian traffic through the street parking spaces with overhead protection. The primary entrance & exit was on 14th street with flagmen directing pedestrians and traffic for deliveries or as needed.

See Appendix A for site plan.

Demolition & Excavation

Demolition included <2-story retail spaces, and restaurants along with paving areas on the west side of the property. During excavation, adjacent building foundations, although extremely close to the building footprint, were not deep enough to prevent the use of tie-backs supporting the soldier pile support system. The T Street post office building required additional support using bracket piles on the actual project.

The perimeter of this area had soldier piles, lagging, and tiebacks installed to support the excavation, along with extra support protecting the historic façade on the east edge. The deepest area of the foundation is located where the underground parking garage is on the south side of the building footprint. Sump pits and dewatering systems were installed in this area, as well.

Temporary ramps were put into place to adjoin the garage level, north foundation level, and the street level. Soil was hauled out using these ramps and the gates on 14th St. Contractors had extra access for equipment and accessories through the public alley to the west.

Structural System

The proposed building is supported by a reinforced concrete frame (cast-in-place) resting on a foundation of drilled micropiles in the northern half and spread footings in the southern half. The northern slab-on-grade is a regular 8" flat slab of normal weight concrete with unbonded two-way post-tensioned suspended slabs above. Plywood sheeting & shoring was used for curing each floor. A tower crane & bucket was used for concrete placement.

Prior to the superstructure taking its place, a tower crane was installed with the pad located at the center east edge of the building footprint. The swing radius was able to reach the farthest northwest corner of the property at this point. The adjacent buildings on the south are not of significant concern to the swing radius, but the 9-story building to the west was a critical obstacle that requires careful attention.

Changes commenced as the structure rose, one being the loading dock and trash chute located in the public alley. Material hoists were also installed as necessary. Once the cast-in-place concrete work was completed in the garage levels, contractors were able to use the garage entrance for parking and material storage pending the demands of remaining work in those spaces.

Mechanical System

The mechanical system is water-to-air for the common areas and ground floor, which is equipped with 14 water source heat pumps, 2 boilers, and a rooftop cooling tower. Separated from the ground floor, the residential units utilize a ductless split system throughout the building with rooftop air handling units. The two boilers are located in the parking garage below grade with a fire pump service room and water meter room.

Electrical & Lighting System

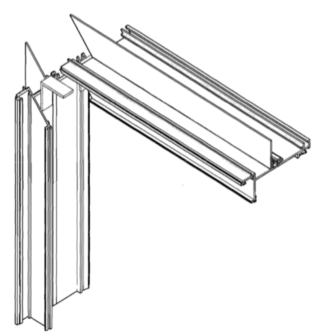
The electrical system is fed by 3 utility ductbanks tying into three 4000A switchboards, two 120/208V 3ϕ's for the residential apartments and one 265/460V 3ϕ for the ground floor retail spaces. Minimal redundancy is incorporated into the building, as only one diesel engine driven emergency generator (300 KW/375 KVA 265/460V 3ϕ) is proposed to mainly serve the fire pump service room as required. The main electrical room is located in the parking garage level, while 2 electrical closets accompany each floor.

Below grade, 4' tubular fluorescent fixtures primarily light the parking garage spaces. At the ground level, 4' fluorescent utility fixtures occupy the main retail spaces with compact fluorescent recessed downlights in vestibules and smaller spaces. Common areas in the above residential floors contain 24" & 42" linear fluorescent lights as well as incandescent pendant light fixtures in areas open to multiple floors. Typical apartment units utilize compact fluorescent downlight fixtures, vanity fixtures, utility fixtures, and recessed pinhole lights in the closets.

Constructability Issues

Window System

The amount of glazing that encloses *Louis at 14th* makes the window systems a critical element of success in itself, but they also require precise attention to detail during installation as well as the scheduled activities for the window assemblies and adjacent ongoing work. All window system installation lay on the critical path of the schedule since it contributes to the watertight enclosure milestone.



-window receptor details

A mockup schedule was exercised to serve different areas of the building façade that demanded different assembly and trade coordination. It was critical for all subcontractors involved in these assemblies to have all adequate materials, such as flashing, on site and ready for installation to avoid delays or trade clashes. Upon their delivery, windows were stocked on their designated level until installation.

The receptors were the first pieces of the window to be installed, which immediately followed the installation of exterior sheathing and channels. The installation of these receptors precedes air & vapor barrier detailing and spray, which are then followed by the brick veneer & metal panels. The masonry work ongoing for the brick veneer would take place two stories below the window receptor installation. It was between these to stories where the glass would be put into place. Coordination issues with the channels came up where they had clashed with window height dimensions & flashing details, while flashing issues posed other complications involving its installation before & after the necessary trades.

The primary challenge of the window assemblies was its demanding attention to detail and the criticalness of trade coordination. The façade of the building during the enclosure phases was very busy at multiple levels, and the successful installation of these window systems influenced several trades and was affected by others, as well. The amount of times this work was repeated on the project was enough to have a critical impact on its success.

Dewatering Wells

The dewatering well system proved to be a critical element of the project schedule, as unforeseen groundwater conditions caused major delays early in construction. The original dewatering plan was designed according to the geotechnical investigation, which suggested less groundwater than what was discovered once excavation commenced.

The dewatering process required investigation regarding its effects on adjacent properties, as well as the monitoring of drilling spoils for contaminants, which were found in some wells. The water spoils also needed to be controlled as found necessary, since there was one instance where the spoils escaped the sediment control barriers and found its way into the alley.

Once the bracket pile was installed, the temporary dewatering system running off of generator power was actively pumping to mitigate subsurface water conditions, an environmental consultant was required to test the discharge water. The dewatering contractor also needed to validate the presence of underpinning pits near the adjacent building that had recorded settlement due to local undermining in the past.

The project team better judgment was challenged to determine at which point it was necessary to turn off the dewatering system and leave it to the sump pits & subdrainage to manage the remaining groundwater.

Historic Façade Protection

Located on the east edge of the building footprint is an existing historical brick façade that required support and protection throughout every phase of the project. It is the façade of the east existing building that was demolished earlier in the job, and the contractor would receive allowances as necessary for the work required to preserve it.

After it was questioned that, in its condition, the façade would not be able to sustain itself once the rest of the existing building was demolished, it was determined by the restoration contractor that bracket piles would be installed along the edge of the façade with beams connecting the piles to the façade masonry with bracket plates.

This temporary structure would be the main means of support and protection during excavation and other phases. Extra precaution was taken during the excavation next to the façade, as extra steel plates were installed at the top of the piles to deflect debris and avoid damage to the façade.

The extra bricks removed during demolition were required to be salvaged, palletized, and stored for future use by the new tenant, as well. This extra material was picked off the site with a boom truck and transported to another JBG Companies nearby.

Historic Façade support perspective.
Photo by Balfour Beatty Construction

Project Cost Evaluation

Square Foot Estimate

The most basic R.S. Means square foot estimate yielded a cost of $47 million at $176/SF, which is much higher than the original construction budget, but this is likely due to the primary wall construction of the actual building being less labor intensive than that available in R.S. Means Square Foot Costs 2012. For 8-24 story apartment buildings, the closest exterior wall type was "Face brick with Concrete Block Backup." Although there are CMUs on the actual building, they only continue from the foundation up to just above grade, not the entirety of the building height, which is a poured-in-place concrete frame with a combination of glazing systems, metal panels, and masonry veneer. Another likely inaccuracy, especially pertaining the mechanical systems, is the mixed-use aspect of the proposed building, as a good portion of the ground floor is made up of retail space, not residential apartments. It should be noted that the actual construction cost has exceeded the original budget mainly due to unforeseen dewatering challenges and concrete work delays.

General Conditions Estimate

The general conditions expenses for Louis at the 14th are portrayed in this estimate using R.S. Means 2012 cost data. Ordinary items on the actual project have been assigned to similar or exact items in the cost data to be as realistic as possible. Specific items not included in this estimate are identified in Appendix C for reference.

The tower crane is the most costly item of the materials & equipment in the estimate. Swing staging serves as another critical item as much of the building façade requires these types of lifts for installation. Other material items that are not as critical include signage, fencing, plywood protection, and material for temporary pathways during excavation.

HVAC, power, and lighting expenses result from the project site and the field office. The field office located in the north adjacent building is responsible for other items such as rent, phone bills, and office supplies. The project staff wages include that of one project executive, two project managers, one project engineer, three superintendents, and three laborers.

The actual general conditions cost of the project is very similar to the estimate priced by R.S. Means. This suggests that the actual general conditions are common to the industry, the only differing aspects being the field office located in an existing building. The closing of the public sidewalk yields extra costs in the actual project scenario, but being on a tight site saves on expenses in other areas, as well, since space must be more efficiently utilized and may save on costs.

Plumbing Assemblies Estimate

R.S. Means 2012 cost data accurately represented the components of the plumbing system through its available items. Most of the items priced were quantified by analyzing a typical apartment and its plumbing components, then multiplying them by the number of other apartments and similar areas. The actual cost of the system is very close to this assemblies estimate which is likely due to the number of repeated apartment units in the building, which is simple to accurately represent.

Mechanical Assebmlies Estimate

The mechanical systems were represented as accurately as possible while keeping in mind the components serving different parts of the building since there are retail spaces, apartments, and underground parking. By carefully examining the included items in each R.S. Means assembly, the cooling tower assembly and the rooftop unit assembly were eliminated to avoid double counting conditioned areas, as the assemblies included in the estimate are similar enough to represent the entire building system with their included components.

This estimate is slightly over the actual system cost, which is likely because of the different types of spaces previously noted that R.S. Means cannot represent as accurately.

Electrical Assemblies Estimate

All major electrical systems were assigned to line item assemblies priced by R.S. Means 2012. The major components of the electrical system such as the switchgears, generator, and panelboards were accurately represented by the pricing data. Quantities of these major components were quantified very accurately, as well.

Minor components including the receptacles, wall switches, and lighting fixtures, all of a wide variety of types, were grouped into the same type that best represented the majority of the item. Light fixtures, in particular, were not as accurately matched with R.S. Means items due to its limited fixture types available. Quantities of these minor items were also simplified similarly to the concrete approach in which quantities were generated from a typical reoccurring section of the building, and then multiplied to appropriately match the entire area. The parking garage lighting and the apartment lighting areas were approached differently due to the drastically different demands of their respective spaces.

The actual cost of the electrical system is very close to that estimated, which is likely because this electrical design is fairly common amongst other residential buildings.

Detailed Structural System Estimate

The structural system estimate includes cast-in-place concrete slabs, columns, walls, and auger-cast piles. The foundation, slab-on-grade, and roof were quantified separately, as well as the above-grade and below-grade structures. These areas were separated due to their similar reoccurring features of each that could easily be repeated to provide quick & accurate quantity estimation.

The foundation system included auger-cast piles, pile caps, foundation walls, and shear walls in the elevator shaft. Since there were several size types of pile caps, all pile caps were assumed to be the same average size of 7'x7'. The same approach was used for the auger-cast piles, as their depths ranged slightly, but a uniform depth was used for all 54 piles. The foundation walls and shear walls were calculated more accurately by their exact dimensions. Small grade beams, foundation wall steps, and garage ramp slopes were not included in the calculations.

The remainder of the quantity take-off performed is based on a typical reoccurring bay between columns lines D&E and 3&4 (see Appendix B). The quantities generated by this bay are then multiplied by the number of times a similar bay reoccurs on that floor since the floor area varies by floor. This particular bay was chosen because it seemed to be the most average, reoccurring bay on every floor of the building that would yield an accurate representation of the rest of each floor.
Using this method, the slabs and columns were calculated for that particular bay and then multiplied to match the total area of each floor. The penthouse and roof slab were calculated separately and more precisely due to their more manageable size.

The pricing of these quantities is designated by line items in R.S. Means 2012 cost data as referenced. R.S. Means items were assigned to take-off items as similar as possible. The only possible source of significant pricing error may occur for the auger-cast piles, as there was not an exact item in R.S. Means to match it. The pile costs were estimated based on the costs of other individual items such as concrete, rebar, & drilling as referenced. The actual cost of the superstructure is slightly higher than this estimated cost, which can possibly be due to scheduling differences or post-tensioning complications.

See Appendix B for all detailed calculations.

Value Engineering

Included in the bid by Balfour Beatty Construction was a list of voluntary value engineering suggestions that could potentially save JBG Companies a significant part of their budget while maintaining the quality product for which each party always aims.

The majority of these suggestions that were implemented on the project included changes to more economical materials with similar performance specifications, one being the countertops installed in each of the residential units that were substituted for a different type of countertop fabricated in China. The laminate flooring was also substituted with a 5/16" laminate flooring manufactured by Mohawk.

Where sprinkler mains were designed to utilize black steel pipes, CPVC was used instead, as well as for domestic water lines; however, these materials in the parking garage areas were required to remain steel to meet building codes. Another material change occurred in the stainless steel trash chutes, which were changed to aluminized steel chutes.

All of the previously mentioned material substitutes adequately maintained JBG's goal in regards to quality, while other suggestions did not sufficiently meet this goal or did not suit other priorities well enough.

One suggestion that could not be utilized included the substitution of metal panels for more masonry veneer, as previously described for the sake of schedule acceleration. This change would require fewer trades working on the building enclosure at a time and offer simpler constructability. While it would potentially be able to accelerate the project schedule, too, the aesthetics of this change would be too great a difference and the final product would not look as originally intended.

As most of the residential units host a balcony with custom glass railings, it was suggested that standard manufactured glass railing be used. These standardized railings did not cooperate with the original design, nor did a potential change from painted galvanized railings to aluminum railings, as they created an unwanted aesthetic discontinuity on the balconies.

It was suggested that insulation requirements on vertical storm risers and vents be deleted since building codes did not require them, but acoustical considerations with adjacent apartments determined this change to be unfavorable to the occupants.

Other suggestions offered by Balfour Beatty Construction included implementing a ballasted roof instead of a green roof, utilizing Sovent piping, offering alternative plumbing packages, water heaters, locksets, cabinetry, and other specific masonry details that would ease constructability.

Overall, very few value engineering changes influenced the aesthetic appeal of the building's interior and exterior, while more of the implemented changes occurred where they would not be as noticeable.

Project Schedule Overview

Basic Summary

The notice to proceed on the project construction was issued in March of 2012. Excavation posed to be most variable in the schedule as geotechnical reports suggested likely dewatering work would be necessary, which ended up delaying the actual schedule significantly since more groundwater was encountered than expected. The concrete pours would also play a varying factor until top-out due to usual complications and weather delays. As the superstructure neared completion, interior MEP rough-ins, carpentry, finishes, and all other trades followed from the ground up in accordance with their proposed turnover date. Ground floor retail spaces were turned over with only core & shell work completed as specified by the contract. Retail tenants were then be responsible for their own interior work.

Detailed Project Schedule

The following schedule (see Appendix C) was assembled using Primavera P6 software and is meant to simplify the actual project schedule into its major phases & sequences. The primary workflow of each sequence is portrayed from the ground level up to penthouse.

The actual project schedule incorporates workflow moving across different areas of the building footprint at each level. It also includes more detailed activities focusing on work occurring in more specific areas of the building such as the fitness center, rooftop lounge area, and interior suites.

The first several activities portrayed are the fabrication & delivery of materials, as many are long-lead items and/or require prefabrication work prior to arriving on the jobsite. The initial work to take place on the actual jobsite includes the demolition of several 2-story retail spaces and a parking lot. A section of an existing historic building façade needs appropriate protection installed before excavation begins, as well.

The excavation phase includes the installation of lagging & tiebacks, drilled piles, sump pits, and dewatering wells. This is one of the most unpredictable durations and critical activities on the project because of the dewatering systems being installed and the unknown groundwater conditions. The actual project schedule suffered major delays due to these complications.

Another critical element follows with the cast-in-place concrete structure extending to the highest elevations of the building. Included in these activities are all slabs, columns, stairwells, shafts, and, also, concrete masonry units.

The critical path then follows all trades involved in the enclosing the building to reach the watertight milestone as soon as possible. This work includes primarily framing, sheathing, windows, masonry assemblies, and roofing.

The remaining activities are organized by floor because the project is turned over as floors are completed, the ninth floor being the last. Mechanical, plumbing, and electrical rough-in work control the critical path on each floor, followed by insulation & drywall, fixtures & GRD's, doors, casework, and finally all finishes. The ground level retail spaces do not require finishes as that scope of work is excluded from the project contract.

Schedule Acceleration Opportunities

Louis at the 14th, originally scheduled to start construction in March of 2012 and finish by December of 2013, proposed a challenging schedule with several key elements and threats to its success.

The fabrication and early approval of specific building components and long-lead items early in the project hold major potential to impact the critical path later in the schedule, making early organization and communication a key to timely completion.

Other than the early approval of key items, the critical path begins with the excavation and foundation phases, which introduces one of the largest scheduling risks of the project mainly because of unknown subsurface conditions. As a certain amount of groundwater is to be expected according to the geotechnical reports, there is always still a degree of uncertainty that can cause major delays on the critical path. Occurring on the actual project, more groundwater than expected was discovered that caused time-consuming complications with the dewatering systems and foundation work.

The ascending cast-in-place concrete superstructure then assumes control of the critical path, which is sensitive to logistical and weather delays. Much of the time consumed is governed by sufficient shoring & curing time. It is also essential to have the appropriate penetrations and sleeves identified and planned for the following mechanical, electrical, and plumbing rough-in work that occurs later on the critical path after the building enclosure is installed.

The building enclosure includes the installation of metal panels, brick façade, and window systems. This is a sensitive operation because instead of having more of the same materials, there are several different types occurring that can complicate the installation process. Several mock-ups were constructed on the actual project to mitigate this risk and simplify the process for the different tradesmen. This issue was considered in value engineering options, as well.

The finishes unavoidably complete the critical path on each floor, which involves a long and complex approval process because many materials used are foreign and take longer for review. They also needed to adequately satisfy the aesthetic goals of every space of the building.

Throughout the schedule, the tightly congested site also posed the constant risk of error in appropriately executing the traffic control plan, public safety plan, and abiding by the constraints of the adjacent properties. All of these sensitive aspects had serious potential to shut down the jobsite at any time and further delay the critical path.

Potential activities where the critical path could have been accelerated occur in the activities previously described through careful planning and proper execution. Otherwise, a general approach used the by the project team is to take advantage of early start dates and float flexibility to condense activities closer together. Certain finish-to-start relationships between activities technically do not have this potential, but planning & preparation for the start of an activity can create opportunities to prepare for activities ahead of time, execute work more quickly, and save time on the critical path.

In order to accelerate the critical path as such, early involvement by each and every party involved is the most critical and most costly key to making it successful. For example, lack of planning and coordination can leave substantially more work by missing MEP sleeves and penetrations that can delay rough-in activities immediately following. Coordination among trades and work crews are essential to schedule acceleration.

Analysis #1: Prevention Through Design

Introduction

Prevention through design is a concept aiming toward preventing and controlling occupational injuries, illnesses, and fatalities by designing building elements in a way that minimizes hazards and risks associated with the construction, manufacture, use, and maintenance of a building. It can be a cost-effective means of enhancing occupational health and safety, and it is a growing industry trend with more and more management practices trying to implement prevention through design in its buildings.

This analysis provides supporting statistics suggesting the need for improvements in safety for excavations, it identifies common excavation practices and the risks associated with each, and it provides an overall perspective on the potential for prevention through design to be effectively applied to a building excavation.

Excavation & Trenching Accident Statistics

•The fatality rate for excavation work is 112% higher than the rate for general construction.

•Two workers are killed every month in trench collapses.

• "Two cubic yards of soil weigh about 6,000 pounds. If you're buried, you'll suffocate in less than three minutes. Even if you survive, the weight of the soil is likely to cause serious internal injuries."

•Out of 3,945* worker fatalities in private industry in calendar year 2012, 775 or 19.6% were in construction. The leading causes of worker deaths on construction sites were falls, followed by struck by object, electrocution, and caught-in/between. These "Fatal Four" were responsible for nearly three out of five (56%) construction worker deaths in 2012*, BLS reports. Eliminating the Fatal Four would save 435 workers' lives in America every year.

- Falls – 278 out of 775 total deaths in construction in CY 2012 (36%)
- Struck by Object – 78 (10%)
- Electrocutions – 66 (9%)
- Caught-in/between – 13 (2%)

Cave-ins: 1000 injuries/year; 140 permanent disability, 54 deaths (76%)
Struck by excavator and components: 50 deaths

General Precautions of Excavations & Foundation Work

An excavation is any man-made cut, cavity, trench, or depression in an earth surface formed by earth removal. The following apply to all types of excavation work and may pose a hazard if not carefully and sufficiently considered:

Air Monitoring – Hazardous atmospheres can occur inside excavations deeper than 4 feet such as oxygen deficiencies or poisonous gases resulting from nearby activity, such as equipment fumes, landfills, sewers, or other potential hazards that can be expected. It is even possible for the soils to be contaminated by leaking lines or storage tanks causing a dangerous atmosphere. In these cases, the oxygen levels should be tested and proper respiratory protection or ventilation should be sufficiently provided for those working in the area. This protective equipment along with the oxygen levels should continue to be tested to ensure worker safety and acceptable levels of oxygen are present. Should a hazardous atmosphere quickly occur and a rescue is needed, emergency rescue equipment such as a breathing apparatus, safety line & harness, and basket stretcher should be readily available.

Underground Utilities – Existing underground are always a safety concern during any type of excavation, regardless of how much or how little is known about the project site. Before an excavation begins, it is required by OSHA to determine only the approximate location of existing utility installations that may include sewer, telephone, fuel, electric, water, or other underground lines. The owner or utility company should be made aware of the proposed excavation before proceeding. They are required to determine the exact locations of their underground installations, but the excavating contractor may proceed with caution if the owner or utility company cannot respond or find its exact location within 24 hours.

Inspections – The designated competent person with appropriate training in soil analysis, protective systems, OSHA regulations, and appropriate authority is responsible for conducting inspections for all of the dangers and hazards discussed. They must be able to classify soils and their condition, select protective systems and oversee their installation, and then inspect the systems on at least a daily basis before each shift. Potential cave-ins, protective system failures, hazardous atmospheres and conditions are all points of interest during inspection. Such inspections should be conducted following unfavorable weather or disruptive operations such as blasting.

Spoil Pile Placement – When displacing soils from the excavation, it is very important to dispose of the soils in a safe place that will not affect the support of the excavation, the equipment being used, or interfere with other ongoing operations. Placing soils too close to the edge of an excavation can overload the protective system and cause a cave-in or fall back into the excavation where people are working. Depending on conditions, excavated soils should be disposed of at least 2 feet from the edge of the excavation. If this is not possible, they may need to be temporarily hauled to a safe location. Methods of excavation protection may be used to protect and control soil piles, as well.

Access & Egress – It is required by OSHA to adequately provide safe access and egress to all types of excavations deeper than 4 feet using ladders, steps, ramps, and other means to avoid fall injuries. These are required to be within 25 feet of any worker in the excavation because if the area should become hazardous, workers' safety can depend on how quickly they can escape the excavation. Ramps that are structurally designed methods should always be designed and inspected by a competent person.

Fall Protection – Falling into an excavation is a major concern during these types of operations, therefore it is required by OSHA that employees be protected from the edges of excavations when 6 feet or deeper. Protection can include guardrail systems, fences, barricades, or covers as approved by a competent person. Walkways crossing over excavations from 6 feet or higher require guardrails, as well. Personal fall arrest systems, safety nets, or warning line systems may be necessary depending on the nature of the work taking place.

Water Accumulation – Certain amounts of water can cause soils to become unstable and make an excavation become very hazardous. Water can undermine the sides of an excavation, causing extra stress on protection systems and negatively affect means of egress. Water removal equipment should be used to control and prevent excessive water accumulation. Diversion ditches, dikes, and other means of controlling the amount of water in the excavation may be utilized. A competent person should inspect these methods and evaluate these potential hazards, especially after heavy rains.

Protection of Excavations

Interlocking Sheet Piling

Commonly used for excavation protection from seepage or construction below the water table, interlocking sheet piling may be used for temporary or permanent installation. They are ideal in their resistance to lateral and bending forces, but also have a fair amount of axial strength that can reduce the load on interior columns by distributing forces to the perimeter and maximize space in the building. Sheet piles are also optimal for projects with strict plot limits because they do not occupy much space on the building perimeter. Sheet pile wall thicknesses can range from 3/8" to 3/4".

They are becoming increasingly popular as permanent walls for underground parking structures because of their impervious protection and quick installation, and they eliminate the need to build an entirely separate wall. Often times groundwater, excavation, and shoring issues in the design of underground structures drive up the costs of such foundations, but by utilizing sheet piles in the structural design, underground parking structures become more economical to build. This approach to underground parking has been more popular in Europe for the last 20 years and is often a regular preference over other alternatives methods of design.

Designs that incorporate permanent use of interlocking sheet piles allow for more ease and speed of construction since they require less manpower and resources than other alternatives. The driving and/or extraction of sheet piling can be troublesome in dense, rocky soils, but in most cases only a vibrohammer is sufficient for installation. Although the use of interlocking sheet piles still require bracing and dewatering, it generally does not require waterproofing or reinforcing like cast-in-place concrete structures would need.

Safety Application:

Risks and hazards associated with this type of excavation support mainly include its proper and sufficient installation and the equipment being used to drive the sheet piles into the ground. Proper and accurate alignment of each sheet pile section is critical, otherwise Since the amount of labor and materials is reduced compared to other methods, a more open, cleaner work area is guaranteed with fewer factors present to potentially cause safety hazards that more cluttered work sites would have.

The use of "man cages" to carry workers to elevations necessary to interlock each pile poses a major risk in the installation process. Typically the man cage is lifted by a crane and placed into position at the top of the sheet pile hooked by bent metal bars. The worker in the cage can then guide piles into position as they are placed. Adequately securing the cage to the top of the sheet pile can be dangerous and is a major concern. Man cages are also commonly overloaded causing failure and can also leave a worker exposed to hazards while raising and lowering the cage. Weather can quickly cause further complications with this operation, as well, especially when sheet piles are being hoisted and placed into position.

Other common alternatives to the man cage that offer safer means of installation for workers include the use of elevated platforms, walkway walings and trestles, and sheet pile threaders, which mechanically assist in interlocking and securing each sheet pile as it is lifted into position.

Vibratory hammers usually used to drive the sheet piles into the ground are relatively safe pieces of equipment that can be operated by one person. It is critical to inspect the equipment in detail on a daily basis, including the condition of the sheet piles being installed. Also, the ground surrounding the area where installing the pile can become unstable while operating the vibratory hammer, so sufficient precautions concerning adjacent ongoing work is critical.

Photo by Balfour Beatty Construction

Solider Pile & Lagging

An economical and adaptive method of supporting excavations is the use of steel solider piles and timber sheeting as shown above. This support requires the driving of steel wide flange, concrete, or wood piles vertically into the ground around the perimeter of the excavation and then placing wooden planks horizontally in between each of the piles. These wood planks are spaced so as to mitigate the buildup of water pressure in the soil and thus resist the tendency to slide out. Piles may be drilled if pile driving cannot be used, which takes longer to install but is just as effective in supporting the soils.

Safety Application:

Occasionally the buildup of pressure behind the lagging can become too great, causing a blowout to occur in which the soils violently break through into the excavation. This can obviously be a serious risk and cause major damage to equipment and be fatal to workers in the excavation. Therefore it is critical that this type of support system is designed and inspected appropriately for the soils being supported.

If excessive groundwater exists, seepage into the excavation may occur through the lagging causing hazardous conditions. Since the lagging is designed to relieve hydrostatic pressure by controlled seepage, if the soils do not contain free-draining materials such as clays then a build-up of hydrostatic pressure may still occur and cause the lagging to fail.

Pile driving equipment should be inspected in detail on a daily basis before use, as well as the piles being installed. When operating the pile driver mounted on a crane, a signal person should be in full view of the work area. Eye-protection and hearing protection are highly recommended when in the vicinity of the operating equipment. Piles can be subjected to buckling and bending, making them difficult to handle while being stored and placed. The rigging for such handling is critical to doing this safely and should be inspected by competent persons. Workers should not be in the near vicinity of the hammer during operation unless it is secured by the leads.

Caisson Drilling

Many buildings often utilize caissons in its foundation designs, which are similar to cast-in-place piles but have a much larger diameter with heavy reinforcing steel. They are designed to carry loads from the bottom of a building down to suitable load bearing soils that can up to 200 feet below the surface.

Drilled caissons are the most common type of caissons used for today's building foundations. This work involves the use of a drill rig to drill into the ground at the appropriate location and to the necessary depth needed to reach the load bearing soils, usually bedrock. As the hole progresses deeper and deeper, steel casings are placed in the hole to avoid it from collapsing on itself. As the drill rig excavates soil from the hole with an auger and suction buckets, it displaces the soils away from the hole, which are then completely removed by loaders.

Photo by Russell Voigt

Once the hole has been excavated to the appropriate radius and depth, the cage of reinforcing steel is picked by a crane from the staging area and placed into the hole. Once the concrete pour begins, the casings supporting the edges of the hole are removed as the concrete level rises. It is common to use bentonite slurry walls with or in place of the casings depending on the depths of the caissons. In this case, the slurry would be pumped out of the hole and into a storage tank as the concrete displaces the volume inside the caisson.

Safety Application:

Caisson drilling can become very hazardous depending on the site size and the number of drill rigs being operated at one time. Like most other equipment, the drill rigs should be inspected on a daily basis and sufficiently be maintained, especially the augers and attachments being used for the excavation. Spoil piles from the holes being drilled need to be kept at a manageable level so as not to interfere with the support of the hole or other ongoing operations.

One hazard in particular to workers on the ground involves the vicinity of the swing radius for the drill rig because as the drill rigs removes spoils from the hole, it swings around to dispose of these spoils in a separate pile to be removed from the site. All sides of the drill rig pose a hazard to workers on the ground as this rotation occurs, as collisions with both the auger and the back end of the rig can occur. For this reason, it is important to carefully and clearly mark off these areas to keep inattentive people from wondering into this area as the drill rig is being operated.

The most hazardous aspect of caisson drilling operations is the risk of workers on the ground falling into the hole being drilled. Fall protection is highly critical for anyone assisting the drill rig operator in inspecting the hole as it is being drilled. This includes the use of portable guardrail systems sufficiently placed into the ground, or if the casing supporting the excavation is left protruding up to a certain height as required by OSHA, this can serve as adequate fall protection as well. In this case, the casing should be measured constantly as the hole is drilled, as settlement can occur causing the casing to fall down to a level that does not adequately protect the hole. In other cases, the use of personal fall arrest systems are necessary and should be anchored and secured as required by OSHA. These can be very useful and safe while the excavation is left unprotected for a short amount of time, such as when casings or rebar cages are being placed or while the concrete is being placed.

Holes should never be left unattended without being adequately marked and protected. Falling into the hole at any point during these operations is by far the most hazardous and common danger associated with caisson drilling.

Benching & Sloping

When the excavation area is located at a project site with few to little adjacent buildings or obstructions, benching or sloping the edges of the excavation can be ideal depending on the soil type. Benching and sloping involve excavating to the appropriate depth of the area required plus the necessary area around the perimeter required to bring the excavation back up to grade level, which can be sloped in a straight line or stepped in a way that tends to the guidelines of the soils being extracted.

Different soils require shallower or steeper maximum allowable slopes and step ratios because they can be more or less stable. Generally, the flatter the slope the safer the excavation will be. This is the most critical aspect of this method for excavation that can make a very safe environment or a very dangerous one that is highly prone to cave-ins. Accurately identifying the soil and judging its condition along with other potential factors such as weather are highly important to determining the appropriate dimensions for the sloping or stepping of the excavation edges. This should always be determined by a competent person with accurate information at hand. For excavations deeper than 20 feet, it must be determined by a registered professional engineer.

Access and egress can widely vary depending on the dimensions of the excavation, but general practices and methods previously discussed can easily apply in the sloping/stepping approach.

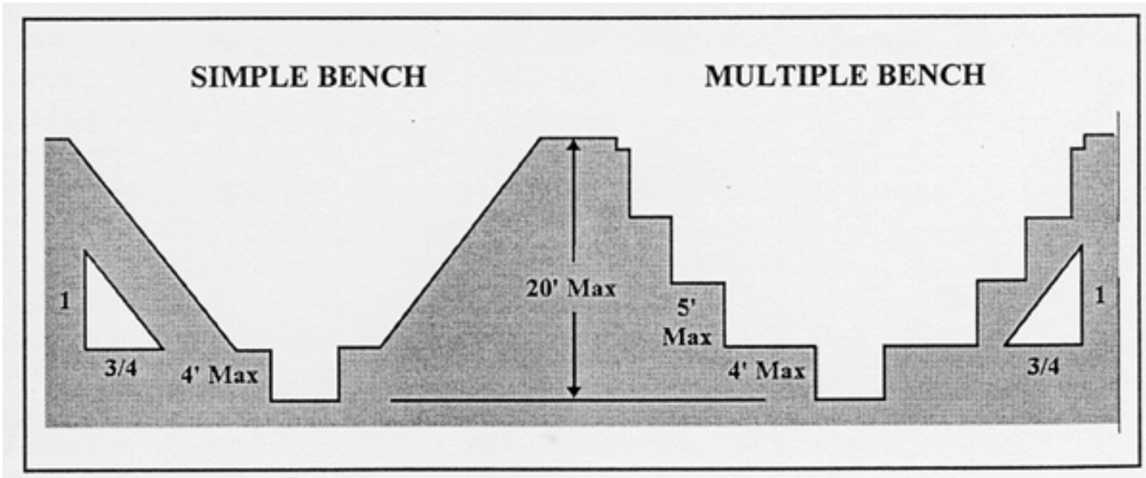


Image by ehso.com

Safety Application

Specific to this method of excavation, risks mainly involve falls into the excavation and cave-ins. To avoid workers from falls into the excavation, the perimeter of the excavated area needs to be adequately marked with fall protection incorporated where found appropriate by the competent persons.

Cave-ins can be avoided by choosing the slope/step angle on the safer side of what the soil type indicates and what conditions allow. Weather, vibration, and pressure from nearby equipment are capable of causing failures quickly or slowly. Signs of failure may appear before failure occurs, which may include cracks, bulges, or clumps of soil falling away from the excavated edge.

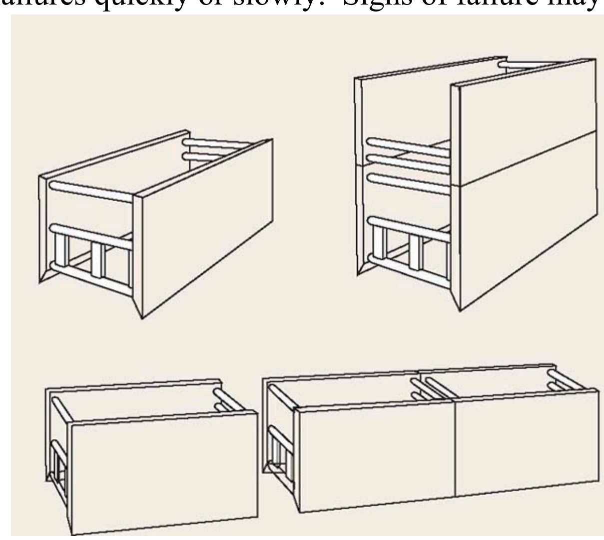


Image by osha.gov

Trenching

Trenching can seem like a minor priority compared to the primary excavation of the building excavation, but it can be just as hazardous and requires just as much attention to safety. By definition, a trench is deeper than it is wide, and no more than 15 feet wide at the bottom.

They are commonly required for the installation of underground utilities and infrastructure.

Fall protection at the top of the trench requires the same safety measures as does a large excavation, and may be supported by sloping or stepping, as well. Unique to trenching is the use of trench boxes or shields to support the edges of a trench. Protection for trenches 20 feet or deeper, protection must be designed or approved by a registered professional engineer in order to ensure that it is sufficient for the soil types and dimensions being supported. If the trench box is approved and used appropriately, it is a very safe means of protection with only the common risks of excavations being major concerns. Trenches 5 feet deep or greater require a protective system like this unless the excavation consists entirely of stable rock.

Other Support Systems

Other systems highly involved in excavations that can introduce more risk on the jobsite include shoring, underpinning, tiebacks, and bracing. These are all very common and useful methods of support that require strict involvement with registered professional engineers and competent persons.

When determining how these methods are utilized, it is vital to consider adjacent hazards in the vicinity of these systems that they can impact.

Installing and loading such systems according to details specified by the approved design is critical to the safety of their uses. Common and hazardous errors usually occur by overloading the systems or incompletely securing members.

Prevention Through Design Applied

As explained in detail in Technical Report #3, prevention through design can be focused around permanent use of a building, such as maintenance demands and operations, or it can be focused around the building process, on which this particular analysis is based.

In applying prevention through design techniques to the excavation phase of a building, the type and dimensions of the foundation system carry the most potential for making a positive impact on the safety of its construction. While most other opportunities to make the excavation as safe as possible are in the hands of the contractors, this critical aspect is the responsibility of the professional engineers designing the foundation, including the structural engineers and the geotechnical engineers.

A common problem with this role in prevention in design is that designers and engineers are not contractually obligated to use the absolute safest options and details in their work, leaving the majority of the risks associated with their design in the hands of the contractors. Traditional delivery methods like design-bid-build do not allow for designer and contractors to consult with one another to select the safest, most effective designs, so design-build jobs where the contractors are more involved in the designs of the building have more opportunity to utilize prevention through design.

Contractors commonly have the freedom to choose the means, methods, and safety precautions that they will utilize on a project as allowed by the specifications. Therefore, contractors must prioritize the cost and the time associated with what they choose to utilize, and safety considerations are commonly overlooked in making such decisions. The most critical aspect safety aspect based on this research is the support/protective system chosen as appropriate for the soils and the adjacent areas of activity.

Tips for Design Engineers:

•Specify safe means & methods that are most appropriate for the work required; do not write specifications that are generally applied to any type of work

•Be aware of critical dimensions or regulations that can easily be implemented into a design that will be safer and/or easier to execute on-site; for example, underground piping can be located less than 5' below the surface to avoid the need to have a more difficult protection system

•Design foundations to be as consistent and uniform as possible, as varying depths or features can be more hazardous

•Accurately locate underground utilities

•Adequately investigate ground conditions and provide accurate geotechnical report

•Work with contractors to select the most appropriate methods of excavation support and protection

•Utilize permanent use of excavation support, specifically interlocking sheet piling

•Be conservative in benching & sloping requirements for soils; assume soils to be in their weakest condition

•Keep trenches as shallow as design constraints will allow

Tips for Contractors:

•Preplan the organization of the excavation operation in detail; initial planning will not only allow for a safer environment, but will also cut down on mistakes that can prolong the schedule and/or hurt the project budget

•Maintain strict attention to all OSHA regulations and guidelines

•Designate responsibility for full-time inspection and supervision of the ongoing excavation

•Consult design engineers and inquire about safety in their intentions

•Maintain strong communication with design engineers during the excavation to pinpoint spontaneous changes that could be hazardous

•When specifications allow, choose the means or methods best suited for the conditions and hazards of the jobsite, not the cheapest or easiest

•Take extra precautions for congested excavations where different operations may be hazardous to each other

•Plan excavation and disposal of soils in a way that sufficiently controls spoils without making the spoil pile(s) hazardous to other jobsite operations

•Choose necessary fall protection for specific areas of the excavation based on the its dimensions and fall potential

•Devote regular attention to the weather forecast so as to adequately prepare for dangerous conditions, specifically water accumulation in the excavation

•Choose safety precautions based on excavation support systems being used and be proactive in reducing the risks associated with that specific system

•Hold every worker responsible for strictly following rules and regulations; do not tolerate "cutting corners"

Recommendation & Conclusion

Prevention through design allows for opportunities to make for a safer work environment primarily during construction while the excavation is taking place. The most critical safety aspects deal with the means and methods chosen by contractors to perform the designed work, and that they are properly executed as intended. This particularly involves the management of the soils and earthwork, that they are sufficiently controlled and supported with groundwater management systems to maintain safe conditions.

The single most proactive action that can prevent the most accidents is the overall planning of the entire operation that demands effective communication between the contractors performing the work and the engineers accurately measuring risks associated with that work. For this reason, it is highly recommended that a project intending to utilize prevention through design techniques should be delivered via design-build, in which the contractors and engineers are involved in the designs together and are contractually obligated to cooperate at the highest level.

Analysis #2: Foundation System Study

Introduction

This analysis investigates details on a decision made in the design phase of the actual Louis at the 14th project in which the entire foundation system concept was changed from a mat slab system to a combination of of spread footings and capped micropiles. This change restricted the underground parking garage deeper into the southern portion of the building footprint only, leaving the northern portion of the building at grade level.

A basic structural breadth is performed to determine the size of the mat slab that would have been utilized had this design change never occurred. The impact to the schedule and budget of this proposed mat slab system is analyzed and compared to the actual results from the spread footing and micropile system, as well as its constructability in coordinating with other aspects of the project.

Geotechnical Report Overview

The final geotechnical report was presented to design engineers on January 6, 2011 with services performed on October 5, 2010 and the notice to proceed for construction being March 13, 2012. Its contents included the results of field investigation, soil laboratory testing, and engineering analysis of the data.

The existing site conditions consist of several buildings up to three stories in height as well as pavements areas. The pavement areas include up t three inches of asphalt and up to six inches of gravel beneath. It was understood that adjacent historical buildings would be retained and may require underpinning.

With the proposed building to have six stories at its southern half of the site and nine stories at the northern half, both were originally intended to each have two levels of below-grade parking.

Lowest Floor Level: EL 76.5
Maximum Unfactored Wall Load: 10 kips per foot
Maximum Unfactored Column Load: 800 kips

The field investigation included five test borings using hollow stem augers in the proposed building footprint as shown below. Subsurface materials encountered were assigned to five different strata that include existing fill, terrace deposits, and residual laurel formations. These soils encountered were classified as mainly clays and sands.

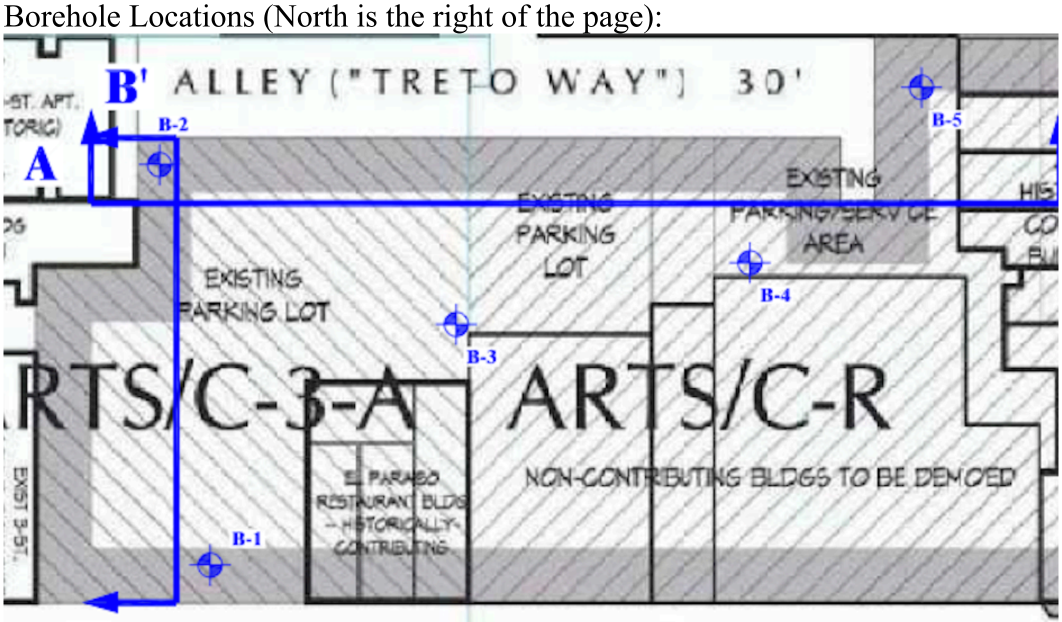
Boring	Depth (ft.)	Sample Type	Stratum	Description of Soil Specimen	Sieve Results		Atterberg Limits			Natural Moisture Content (%)	Remarks
					Percent Retained # 4 Sieve	Percent Passing # 200 Sieve	LL	PL	PI		
B-3	5.0-6.5	Jar	B1	sandy FAT CLAY (CH)	0.0	69.4	50	19	31	23.4	-
B-3	13.5-15	Jar	B1	FAT CLAY (CH) with sand	0.0	75.8	60	22	38	25.2	-
B-3	20-21.5	Jar	B2	clayey SAND (SC)	0.0	47.8	28	21	7	28.4	-
B-3	25-26.5	Jar	B1	SILT (ML) with sand	0.0	82.0	20	16	4	31.1	-
B-3	31-32.5	Jar	B1	sandy silty CLAY (CL-ML)	0.0	53.6	25	21	4	40.5	
B-4	38.5-40	Jar	C1	silty SAND (SM)	4.6	17.4	55	40	15	45.5	-

The project site is located in the Piedmont Physiographic Province, which mainly consists of highly weathered metamorphic and igneous bedrock. The geological history of each stratum encountered are believed to have been a result of previous site development, terrace deposits, residual materials derived from physical and chemical weathering of underlying bedrock, and a combination of other geological theories.

The groundwater conditions encountered are as follows:

Test Boring No.	Depth to Groundwater (feet)	Groundwater Elevation (feet)
B-1	7.0	EL 91
B-2	19.0	EL 79
B-3	15.5	EL 83.5
B-4	16.0	EL 83
B-5	11.0	EL 88

Borehole Locations (North is the right of the page):



It should be noted that these measurements may vary, as fluctuations due to seasonal changes, construction activity, weather, and others factors are likely to have an impact. A temporary ground water observation standpipe was installed in boring B-4 to allow for observations and test boring log information.

Temporary dewatering during all excavations was highly recommended, which includes a strong system of sumps and pumps in the excavation with deep well points around the perimeter in an attempt to lower the water table of the area.

Permanent subdrainage was also a critical recommendation that consists of perimeter and underfloor subdrainage.

Recommended Foundation Type

Based on this geotechnical report, the original recommendation for the building foundation was to utilize a mat slab as loose and soft soils extend up to ten feet below the proposed lowest floor.

Technical design recommendations for the mat slab foundation included:

Maximum contact pressure: 2,000 psf
Modulus of subgrade reaction k_s=100 pci for 1 SF plate
Hydrostatic uplift pressures not required with permanent underfloor subdrainage
3-4" concrete work mat recommended on freshly excavated subgrade

Mat slabs tend to be overdesigned because of the additional cost and uncertainty of analysis, it is not expensive to overdesign the system relative to the total project cost, and the extra safety margins are modest in expenses.

As-built Foundation Type

Although the original geotechnical report recommended a mat slab system supporting two levels of parking throughout the entirety of the building footprint, changes were made to this design following a cost analysis comparing the system to a series of spread footings and micropiles.

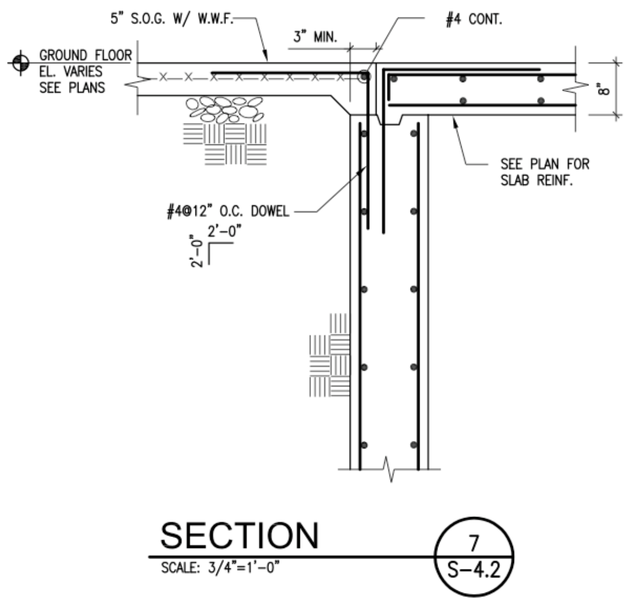
The soil supporting what would have been the lowest, second level of underground parking was determined to be very weak and would have required a 4-5' thick mat slab foundation; however, if the parking garage was taken one level deeper to much stronger soils, the foundation could be adequately supported by spread footings.

There were also minor concerns at the northern end of the building footprint where existing historic structures would have to be underpinned without knowing much about their condition or how they could be safely supported.

As a result of this cost analysis performed, the foundation was redesigned and built by making three levels of underground parking limited to the southern half of the footprint only, maintaining the same number of parking spaces and leaving the northern foundation left to support only a ground level floor. This design change designated spread footings to the supporting structure of the southern half of the building and capped micropiles 14" in diameter supporting the northern half of the building.

Differential Settlement Potential

Since the foundation design chosen for construction involves two different foundation systems supporting the same building, this introduces a greater risk of differential settlement, which is when a part of a building foundation settles differently than its counterparts. This can ultimately result in bending and deflection of the structure causing major problems to the entire building.



This is a section portraying the joint connecting the northern slab-on-grade with the southern elevated slab of the parking garage where complications may occur due to differential settlement.

With micropiles supporting the northern half of the building and spread footings supporting the other, there is a decent chance that one of these systems will settle differently than the other and potentially cause damage to the building. A likely area of potential damage is the joint where the slabs of each foundation meet, as pictured in the section below. The original mat slab foundation supporting the entire building as one system poses less of a risk with this type of issue because it would act as one structural system with more equal settlement occurring throughout its area.

Proposed Mat Slab Design

A mat slab is essentially made up of spread footings large enough that they are connected with one another, forming one entire slab that supporting all of the column and wall loads. They are commonly used to combat soils with low bearing capacity. They can become more economical than spread footings when spread footings occupy over half of the building footprint and less labor would be required to install one large mat slab.

This mat slab design is intended to abide by the results of the geotechnical report more closely and reveal any critical aspects about the mat slab approach through further analysis that may prove it to be more beneficial to the project than the actual two-part foundation used for the building.

Structural Breadth

Slab Area = 44,175 ft
Perimeter = 900 LF

$\phi = 0.9$ for flexure $\quad \phi = 0.75$ for shear

Maximum soil contact pressure = 2,000 psf

Total load at top of footing for all columns = 56,000 kips
(20,770 kips northern footprint
35,230 kips southern footprint)

$$\frac{total\ gravity\ load}{building\ area} \leq soil\ bearing\ capacity$$

$$\frac{56{,}000\ kips}{44{,}175\ SF} \times 1{,}000\,\frac{lbs}{kip} = 1{,}268\ psf \leq 2{,}000\ \text{psf}$$ ✓

Largest Columns Loads: southern footprint = 1,100 kips, 18x24, column #46

northern footprint = 810 kips, 16x24, column #107

Calculate Q:

P = 1,100 kips $\quad P_D$ = 500 kips $\quad P_L$ = 600 kips

$P_u = 1.2\ P_D + 1.6\ P_L$ = 1560 kips

$Q = \frac{P_u}{A} = \frac{1{,}560}{270} = 5.77\ ksf$ → 5.77 ksf x 1,000 lbs/kip x (1'/12")^2 = 40.12 psi

Calculate V_c:

$V_c = \phi 4\sqrt{f_c'}$

$V_c = 0.75(4)\sqrt{4{,}000} = 190\ psi$ (4,000 psi concrete to be used)

To calculate the size of the mat slab, column #46 is used to evaluate punching shear with a tributary area of 20' x 13.5' that represent the largest column and the largest bay of the structure.

Calculate d:

$d^2\,(V_c + \frac{q}{4}) + d\,(V_c + \frac{q}{2})w = \frac{q}{4}\,(BL - W^2)$

V_c = 190 psi   q = 40.12 psi   W = 24"   B = 162" or 13.5'   L = 246" or 20' 6"

$d^2\,(190 + \frac{40.12}{4}) + d\,(190 + \frac{40.12}{2})w = \frac{40.12}{4}\,(162 \times 246 - 24^2)$

d = 33.5"

Calculate h:

$h = d + 3 + d_{b/2}$

h = 36.875 → 40"

d with clearance adjustment: d = 40 – 3 – 0.375 = 36.625"

Calculate ℓ:

$\ell = \frac{\text{L−column width}}{2} = \frac{20.5-2}{2} = 9.25'$

Calculate ϕM_n *using #6 bars @ 12" spacing*:

$$\phi M_n = \phi A_s(60\ ksi)(d - \frac{a}{2})$$

$$\phi M_n = 0.75A_s(60\ ksi)\left(d - \frac{1.96A_s}{2}\right)$$

$$\phi M_n = 98.8\ \text{ft} \cdot k$$

Calculate M_u (maximum moment):

$M_u = \frac{q \times \ell/2}{2} = \frac{5.77 \times 9.25/2}{2} = 246.9\ \text{ft} \cdot k$

$\frac{M_u}{4d} = \frac{246.9}{4(36.625)} = 1.679\ in^2 \quad \rightarrow use\ \#9\ rebar\ size$

$$\phi M_n \rightarrow 310.86\ \text{ft} \cdot k \ > 247\ \text{ft} \cdot k$$ ✓

a = 1.96(2) = 3.92”

$C = \frac{3.92}{0.85} = 4.611"$

$\varepsilon = \frac{0.003}{4.611}(36.5 - 4.611) = 0.0207\frac{in}{in} > 0.005$ ✓ for $\phi = 0.9$

Final Result: 36” thick mat slab; 4,000 psi concrete w/ #9 rebar @ 6” o.c.

Construction Schedule Impact

Foundation work on the actual project was scheduled between August 8 and September 26, 2012 for a total of 35 workdays. This work primarily included the installation of footings, strap beams, foundation walls, columns, and the slab on grade. The auger pressure grouted piles were scheduled between May 31 and September 25, a total of 90 workdays with one drill rig.

The following information by RS Means is used to analyze production for the installation of the proposed mat slab system:

Item/Activity	Quantity	Unit	Crew	Daily Output	Labor Hours	Total Hours	Total Days
Concrete Placement:							
Foundation mats, over 20CY,							
direct chute, pumped	5317	CY	C-20	110	0.582	3094	48
						2 crews:	**24**
*crew C-20 includes:							
1 labor foreman, 5 laborers, 1 cement finisher, 1 equip operator, 2 gas engine vibrators, 1 concrete pump							
Rebar Placement:							
Slab on grade, #3 to #7	300.4	Ton	4 Rodm	2.3	13.913	4179	131
(#9 not available)						**20 Rodm:**	**26**
				Mat Slab Total Work Days:			**50**

In order to keep the mat slab option more realistic and fairly competitive with the actual schedule of 35 workdays, the number of crews was adjusted. Productivity would be slightly slower than portrayed for #9 rebar, which is heavier than the #7 rebar used in this estimation.

According to this information, the mat slab installation is much faster with a total of about 50 workdays, while the system actually used was technically 125 workdays. This difference is largely due to the drilling of the micropiles occupying 90 workdays with one drill rig. Assuming two drill rigs would have allowed for twice the production, this would put the original operation at a total of 80 workdays, which is still longer than the complete mat slab installation.

It is arguable as to whether the mat slab installation would have been completed this much faster than the micropile/spread footing system because coordinating such operations are completely different, allowing for different opportunities for acceleration that may or may not have been utilized. Overall, this mat slab system installation is surely a competitive option regarding the project schedule.

Budget Impact

As previously mentioned, the primary reason behind the decision to replace the originally recommended mat slab system with the spread footing/micropile combination was the likely higher cost of the mat slab.

Mat slabs generally use extra materials to compensate for the work that would otherwise be required to form and place individual spread footings and piers. They also require intense quality control and attention to detail while the mat slab is being placed since they are usually very thick and monolithically poured.

03 30 53.40 Concrete In Place			**Cost Each**		
Item/Activity	*Unit*	*Material*	*Install*	*Equipment*	*Total*
Foundation mat (3000psi), over 20 CY	CY	178	87	0.58	265.58
	5317			Cost:	$1,412,185
Reinforcing Steel	ton		general rule of thumb:		
#9 rebar	300.4		$2500/ton		
				Cost:	$751,026
			TOTAL COST:		**$2,163,211**

With a total estimate of about $2 million, the mat slab system most appropriate for this building is most likely much more expensive than the actual system used. The actual foundation utilizing micropiles and piers was a total cost of about $750,000, the deep southern portion accounting for 40% of this cost and the micropile system at grade for the other 60%.

Constructability Concerns

The primary challenge in managing a successful installation of this mat slab system is maintaining a continuous workflow and effective mobilization on and around the entire construction site during the operation.

Requiring about 500 truckloads of concrete, there would be very heavy traffic throughout the site requiring careful access and egress planning and execution. This need creates other constraints regarding the public, more specifically the heavier public traffic on 14th Street during peak works hours. For this reason, the pour would need to be scheduled in accordance with this constraint during either off hours or an off day, depending on local laws and regulations.

The planning and organization of staffing as well as types and quantities of equipment to be used on site is also very critical to this workflow, as major complications can occur if not enough workers are available or there is not a sufficient supply of back-up parts or standby equipment. The selection of equipment can affect this organization depending on their constraints, such as the use of pump stations, their location, and their reach versus the use of conveyors to reach more difficult areas like the northwest corner.

Another major constraint relating to the scheduling of this operation relates to the time of year in which this massive concrete pour would be occurring…August. Large amounts of concrete create a lot of heat that can create complications during this time of year that require extra measures to be taken such as the use of retarders, ice, or other means of heat and hydration stabilizing admixtures in the concrete mixes. Such measures should be planned in accordance with the weather forecast and adjusted as necessary in addition to routine quality control while taking place.

Recommendation & Conclusion

The reasoning behind the incorporation of either the proposed mat slab system or the concrete pier and micropile system is highly dependent on the priorities of the owner regarding time, cost, and quality. According to the results of this analysis, it is clear the mat slab system is much more expensive than its alternate option chosen for construction; however, the risk involving the possibility of differential settlement with the differing northern and southern foundation types can arguably favor the mat slab system in regards to ensuring the quality of the building structure. These critical aspects resulting from each foundation design outweigh the subtle scheduling differences of each system. Therefore, the mat slab system is not recommended on this particular project if the budget were to be the top priority, but it is recommended in the best interest of preserving the quality of the building.

Analysis #3: Site Specific Safety Plan

Introduction

The proposed safety plan is specific to the Louis at the 14th excavation for the foundation redesign described in Analysis #2. The alternate mat foundation proposed requires a different approach to its excavation than that used on the actual project, and it takes careful consideration in utilizing prevention through design techniques as researched in Analysis #1. By taking the entirety of the work site down to the same level instead of having two separate elevations of work areas, this design already puts the safety of the jobsite at an advantage.

The intention of this safety plan is to provide the safest work environment possible relative to the excavation work. Routine off-site practices, common documentation, orientation programs and similar safety efforts are not included if they are not unique to this site excavation.

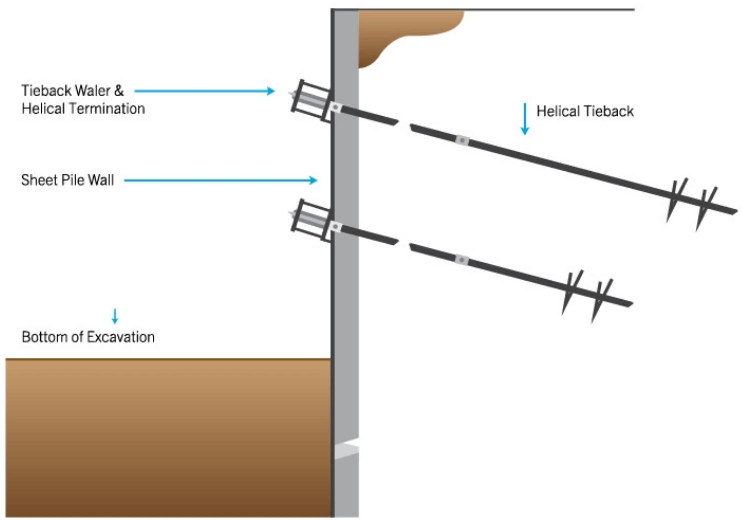
Excavation Support

The actual excavation of Louis at the 14th utilized a drilled solider pile and wooden lagging system supporting the entirety of the southern half of the building foundation, which reached a depth 32 feet below the original site elevation. A total of about 900 linear feet required this protection around its perimeter. The northern end of the foundation did not require any type of protection or support because it was designed to be at grade.

As part of this analysis in accordance with the foundation redesign described in Analysis #2, interlocking sheet piling is utilized instead of the soldier pile and lagging system in an effort to provide a safer environment and possibly other benefits to be discussed, as well.

According to the research of Analysis #1, interlocking sheet piling can be advantageous over solider pile and lagging systems for several reasons. The most critical reason for choosing this method of support is that interlocking sheet piling is designed to withstand hydrostatic pressure and to be watertight. It was recommended in the geotechnical report that the free-draining soldier pile and lagging system be used, but with the hindsight knowledge that excessive seepage occurred on the actual excavation, the use of a watertight support system may mitigate the complications caused by the risky groundwater conditions. The fat clays throughout much of the soil also do not drain as freely as other soils and are more capable of contributing to hydrostatic pressures that can cause a hazardous blowout.

Not only are interlocking sheet piles likely safer in this environment, but they also provide the opportunity to serve as permanent structural components of the foundation system, maximizing the space around the perimeter of the parking garage. This would replace the concrete foundation walls and the extra work that they would require after already installing another support system. By using permanent structurally designed sheet piling, it is likely that the construction schedule can be accelerated in this approach. Like the solider pile and lagging, interlocking sheet piles would need to be anchored by means of tie-backs or tie rods because the maximum height of a cantilevered, unanchored sheet pile system is about 15 feet depending on conditions. Anchored sheet piles can safely support depths up to about 35 feet, so this type of system would easily and safely support this particular excavation at a depth of about 22 feet.



Sheet pile system with helical tie-backs. Image by EBS Geostructural, Inc.

The design of the permanent sheet pile system with tiebacks would require further structural design work by professional engineers. Calculations based on an average equivalent fluid pressure of about 1320 psf, additional soil types and their pressures, and appropriate surcharge loads within a forty-five degree angle of the sheet piling system in order to select the most appropriate type and gauge of piling as well as the tie back system to be installed.

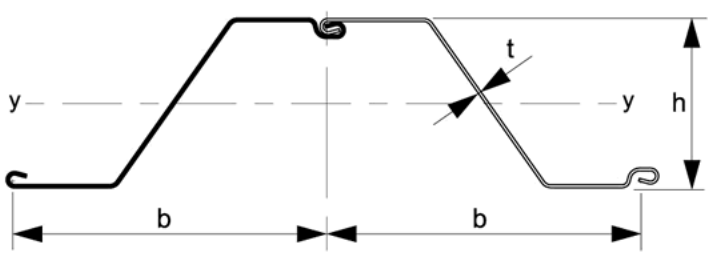


Image by J Steel Australasia

The sheet piling would most likely be designed utilizing Z sheets, shown above, which are ideal for higher walls that require greater bending strength.

The safest design of the sheet pile and tie back system would require structural condition surveys for all existing structures within 1.5 to 2 times the depth of the excavation, or 33 to 44 feet. This area would include all adjacent buildings with the exception of 14th Street.

The cost, however, would be higher than the solider pile and lagging system. A basic calculation using R.S. Means was calculated below, which does not include extra costs for high strength sheet piles or the tiebacks that would be needed. The cost of the tieback system would be very similar to that used with the soldier pile and lagging system used on the actual project. The total estimated cost of a basic sheet pile system is $565,290. The actual project budget used $1,525,000, which included the excavation support system *and* deep foundation work. Therefore, it is safe to assume that a fully engineering sheet pile system to support the excavation and replace the foundation walls would exceed this budget.

Although the permanent sheet piling system is more expensive upfront, it does eliminate the need to install cast-in-place foundation walls if designed appropriately, which would save significant costs on material and require fewer activities in the construction schedule. More importantly, it would mean fewer ongoing activities on the jobsite and open up extra space that would allow for a safer work environment.

Sheet Piling System Costs (per SF)							
Perimeter	Depth	SF					
900	22	19800					
			Material	**Labor**	**Equipment**	**Total**	**Total + O&P**
20' deep excavation, 27 psf, left in place			$21.50	$3.07	$3.98	$28.55	$32.50
		Cost:	**$425,700**	**$60,786**	**$78,804**	**$565,290**	**$643,500**

Dewatering System

The dewatering system, permanent and temporary, is a critical aspect of the safety plan because if the groundwater is not adequately managed, it can create hazardous environments in many different aspects, especially with ongoing excavation operations. It can create potential long-term problems with the finished building structure, as well.

The permanent sub drainage system used on the actual Louis at the 14th project site entailed 7 dewatering wells, 6 around the perimeter of the underground parking structure and 1 in the center of the parking structure. Each of these wells is 60 feet deep and 30 inches in diameter with 1 horsepower submersible pumps at the bottom of each well. No wells were used in the northern footprint area where the lowest floor level is at grade. The wells pump groundwater through a series of 4 inch diameter tubing to a sump pit and grit chamber for outlet. It is assumed that this well system is adequate for the permanent building structure, and therefore a similar system shall be used in this analysis with a different layout of well locations to accommodate the larger excavation area.

Throughout the excavation phase, complications involving excessive groundwater seepage occurred on multiple occasions, possibly indicating the need for stronger temporary dewatering pumps. Geotechnical report details provide a limited amount of information on these elements and essentially leave the responsibility in the hands of the contractor to adequately evaluate and verify groundwater conditions as the excavation proceeds.

Although this is very challenging to predict and with the benefit of hindsight, extra temporary sump pits and pumps are to be used in order to ensure the safest conditions. This excavation is 10 feet shallower than the original design used and is also about 43,500 square feet of space, while the original was only about 15,000 square feet. Although only one permanent sump pit was installed in the original design, due to these differences, one sump pit will be utilized at both the northern half and the southern half of the building footprint to account for the extra area of excavation.

As for the dewatering well locations, the larger dimensions of the proposed excavation shall require more wells to be installed but at shallower depths. There will be 4 additional wells installed to account for the northern excavation, making a total of 11 dewatering wells to be installed. After professionally designed, these wells would likely be 40-50 feet deep instead of 60 feet, and would likely have the same diameter as the originally used wells.

A monitoring program is to be developed, as well, which will record the effect of the dewatering operations on the adjacent buildings to ensure that dewatering-induced settlements will be minimized. If the findings of the program reveal such settlements or effects, the dewatering systems will need to be modified immediately, or additional underpinning of adjacent structures may be necessary. The weather forecasts and expected amounts of precipitation should be taken into serious account as the system is modified, as well.

Please see Appendix E for dewatering plans.

Public Safety

Safety to the public is another primary concern in addition to the safety of those working on site, especially since this project site is located in a congested area with highly active public areas bordering the entire property. The public safety plan in accordance with this foundation redesign is highly similar to that used on the actual Louis at the 14th project.

As portrayed on the site plans in Appendix E, the north and south side of the building footprint are tightly pinned against adjacent occupied buildings, most of which are only one story high with the exception of a nine-story building in the northwest corner of the site. The T Street Post Office building was underpinned using bracket piles on the actual project, which would need a similar modifications for the excavation of this redesign.

An example of underpinning by bracket piles utilized for the adjacent post office building to the south in the actual construction and will likely be needed for the nine-story building in the adjacent northwest corner for the proposed redesign. Photo by moretrench.com

Since the northwest footprint was originally designed to have the lowest floor level at grade, this redesign being two stories deeper will likely introduce the need for underpinning the adjacent nine-story building. This matter would need to be verified by professional engineers and acted on as appropriate.

On the actual project, concerns were raised regarding pile driving and the disturbance it would cause to these neighboring building occupants. As a result, all pile-type installations were required to be drilled to minimize this potential disturbance. This constraint shall apply to this analysis and its construction operations, also. The vibratory hammers to be used in the installation of the sheet piling system are not as disruptive to adjacent properties as pile driving since they focus vibrations vertically with little horizontal vibrations, but they may be a slight step further in causing inconveniences than drilling.

14th Street borders the east side of the property is the main means of access and egress to the project site, with a public alley to the west available for limited use, as well. Only a small portion of the public alley may be occupied for a short time because there are residential garages in the two-story brick building that need to be accessible to the residents at all times.

The utilization of 14th Street and abiding by public rules and regulations had proven to require careful attention to detail in coordinating with ongoing construction operations. In order to provide adequate space for truck deliveries along this street, the same steps are to be taken as those used for the actual project. This involves the closing of the existing sidewalk and several parking meter spaces, leaving the bike lane between these spaces and active traffic open. This curb lane closure may only occur during the hours of 9:30am to 3:30pm and therefore must be coordinated with deliveries and other operations requiring this extra space.

Above is a view of the actual project from 14th Street portraying the obstruction onto the public sidewalk requiring signage and protection as appropriate for the ongoing construction. (picture by Russell Voigt)

Sidewalk protection for pedestrian traffic along 14th Street shall be provided, as the ongoing work deems appropriate. For example, it will likely require the highest level of protection with overhead coverage during operations occurring at the southeast footprint and while the historic façade preservation work is active, but once the intensity and nature of the work taking place in this area allows for it, the sidewalk protection may be removed or mitigated.

Signage and flagging will be a critical aspect of the entire site, as well, but especially on 14th street where the majority of public exposure and site access/egress will occur. It is important that the contractor provides appropriate flagging operations during work hours and adequate signage that portray potential hazards and dangers in and around the jobsite.

Workflow

The excavation operations are to proceed from south to north, beginning with two critical areas that may require additional adjustments or modifications. These areas include the T Street post office one-story building, which will require underpinning as previously mentioned, as well as the historic façade preservation. Appropriately protecting these two areas as soon is possible will ensure that the work is sufficiently completed and provide a safety cushion before the ongoing work becomes too busy to adequately manage these areas.

Two ramps were used during the actual excavation of the southern three-story parking garage, one installed from grade level to one story below grade and the other down to the lowest parking garage level three stories below grade.

With the entire footprint being excavated at the same level, this allows for more flexibility in option with access and egress that can be very beneficial in removing spoils. Therefore, three different ramps will be utilized as the excavation proceeds from south to north. As portrayed in the workflow plan in Appendix E, two ramps are to be installed on opposite ends of the footprint along 14th Street that shall be the main means of access and egress for spoil removal. Flagmen shall be stationed at each of the gates in front of the 14th Street ramps to avoid interference and disruptions by vehicle and pedestrian traffic.

An additional ramp will be utilized on the west side of the excavation allowing for the use of the public alley as needed.

Potential Hazards & Common Pitfalls

•Excessive deflection or shifting of the sheet pile system causing failure or the need to reinstall the section

•Displacing stockpile materials haphazardly while installing the sheet pile system, adding excessive surcharge loads on the support system before it is installed

•Inadequate temporary dewatering systems can result in standing water or unstable soil conditions

•Site congestion with dump trucks removing soils with likely interference or delays from 14th Street traffic

•Debris falling or equipment operating in the vicinity of the adjacent properties, especially the diverted sidewalk

•Poor quality control on the permanent dewatering system can lead to costly complications later in the project or after occupancy

-Poor quality control on the installation of the sheet pile system or the condition and care of the soils recommended for installation can lead to immediate failure or the system or excessive settlement causing damage

•Inadequate communication between professional engineers and the contractors may affect any and all of the discussed topics, which can create a small inconvenience or an extremely hazardous situation

Recommendation & Conclusion

Stringent quality control should be maintained on a daily basis, especially for the monitoring of soils and groundwater conditions. Once installed, the sheet pile system should be monitored for vertical and horizontal movements, and the geotechnical engineer should then review results on a regular basis. Any type of protective system should be inspected by a competent person on a daily basis, also.

Adjacent properties and the impact of the construction on them should be a regular priority not only for the sake of safety, but to avoid getting the jobsite shutdown from complaints or violations.

Contractors involved in the excavation work should be involved in design decisions and strategies as early as possible, regardless of the project delivery system. The design-build approach is highly recommended in fully utilizing prevention through design techniques and taking every appropriate safety measure as possible. Contractors understand and recognize the potential hazards in a design more easily than a professional engineer and should be encouraged to provide their input in designs or means and methods whenever possible.

Overall, predetermined planning and organization is key to executing this safety plan in a way that is most efficient to complete the job and provides a safe environment to those on site and in the public.

Analysis #4: Geothermal Loop System

Introduction

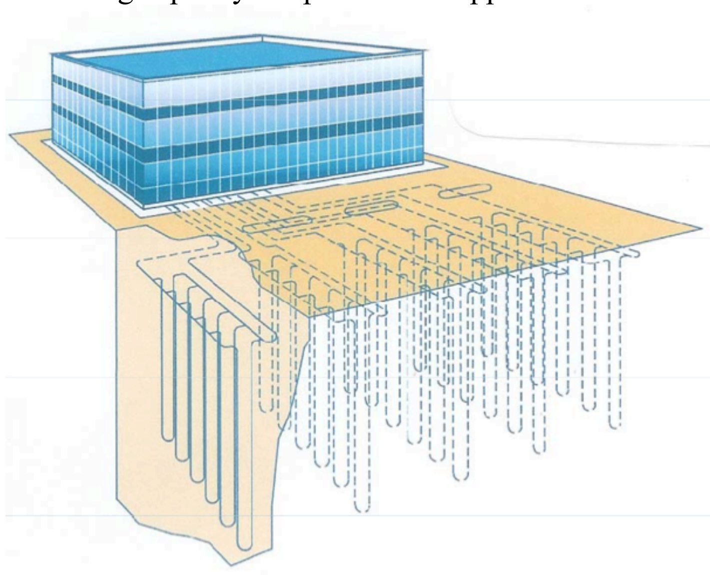
The existing mechanical design of Louis at the 14th is a water-to-air system that serves the entirety of the building, including ground floor retail spaces and residential units above. Since the water source heat pumps are provided by the retail tenants, this allows an opportunity for the tenant to request the installation of ground source heat pumps to save on energy costs in the future.

Complimenting the design used to build Louis at the 14th with the northern footprint built at grade, ground source heat pumps can possibly be installed with wells located underneath this portion of the building, fully utilizing the entirety of the building footprint. The well locations would coordinate with the locations of the micropiles, and the wells will also be convenient to drill since the micropiles being drilled would use similar, if not the same equipment.

The feasibility of this concept is analyzed regarding building loads, energy costs, project budget, and project schedule to determine if this would be a favorable option for the ground floor retail tenants to request.

Mechanical Breadth

The ground floor retail space relies on a water-to-air system separate from the rest of the building, which contains 14 water source heat pumps with two 5 SF direct outdoor air intake louvers and two 5 SF relief/exhaust louvers. These 14 water source heat pumps are designed to accommodate about 13,020 SF of floor space for a total of 93 nominal tons of heating and cooling capacity as specified in Appendix F.



Vertical closed-loop geothermal system. Image by Gipe Associates, Inc.

The well field to be located in the northern portion of the building footprint faces major constraints regarding the area available to install the walls. The adjacent building structures and micropile foundation system leave very little flexibility to locate the geothermal wells.

It is arguable as to whether or not this area allows for enough ground space to place the wells far enough apart such that the soil conductivity is not interfered with. A general rule of thumb is to allow for 300 SF of well field area per ton of heating and cooling. With a 93 ton load, this rule would require at least 27,900 SF when only about 17,000 SF is available in the northern footprint area.

Another possible constraint to the effectiveness of this ground source heat pump is the spacing of the wells because each well depends on the thermal conductivity of the soil around it by a certain radius determined by thermal conductivity testing. This area is typically a diameter of 15 to 20 feet, both of which have been assessed in the site plans located in Appendix F. The 15ft diameter spacing was chosen for this analysis because the 20ft spacing was proven to require too much area for the number of wells needed unless they were drilled unreasonably deep. Therefore, depending on constructability and coordination with foundation structure and utilities, about 52 wells can fit into the footprint area with 15ft spacing.

It was determined that by using a $1^{1}/_{4}$" U-tube pipe and 10% propylene (antifreeze), 150ft of bore length per ton can be achieved with a ground temperature of 57°F. Therefore, 46 boreholes at a depth of 300ft and 1 borehole at 150ft would prove sufficient for the 93 ton load of the ground floor retail space.

As for the water source heat pumps specified in Appendix F, they can remain exactly the same design but instead of being connected to the boiler and cooling towers, they are to be connected to the well system. By totaling the required flow rates of these heat pumps for hydronic heating and cooling, the flow rate through the U-tube of the geothermal system is determined and the well field pump size can also be determined. This total of 296 gallons per minute calculated with a head loss of 1 gpm per 100ft of pipe would require a total flow rate of about 436 gpm to adequately feed this series of heat pumps.

Lastly, by adding the geothermal loops, these 14 water source heat pumps lessen the loading on the boilers and cooling tower, allowing them to be significantly downsized. The ground floor retail was designed with dedicated boilers, each with a 712.5 MBH output capacity, along with its own 155-ton capacity cooling tower. With this ground-coupled heat pump system, only one boiler of 244 MBH heating capacity would be needed with a 63-ton cooling tower, both of which are specified in Appendix F.

Construction Schedule Impact

This ground source heat pump system shall obviously require extra additional time in the critical path schedule of the project during the excavation phase. A major advantage, however, is that the auger pressure grouted micropiles being drilled and installed in the northern footprint will require the same types of equipment that these geothermal wells demand, saving mobilization time and further utilizing the use of the equipment already being paid for.

One geothermal well typically takes 1-2 days for complete installation. 1.5 wells per drill rig per day for complete installation is used for this analysis. With two drill rigs being used, this schedule shall complete all 47 wells in about 35 workdays.

The drilling of the auger pressure grouted piles on the actual project was scheduled in a window of almost 4 months from May 31 to September 25. The installation of strap beams and foundation walls follow this activity on the critical path, which will now follow the completion of the geothermal wells, also. By adding the drilling of the geothermal wells to this portion of the project schedule, it will delay these successors by 35 workdays along with the final project completion.

It is likely that this delay will be at a maximum because by installing the ground source heat pumps on the ground floor to these geothermal wells, less work will be required in this original schedule since these heat pumps were originally scheduled and intended to be installed in accordance with the larger cooling tower and boiler system. Therefore the ultimate impact of the geothermal system installation to the original project schedule is slightly lesser than described.

Budget Impact

The final cost of this system may vary depending on sources and different rules of thumb commonly used for project estimation.

The following expenses are according to David Hoffman guide to commercial geothermal system fundamentals:

Initial Cost: $23-$45/SF → $299,460-$585,900
Energy Costs (annual): $0.80-$1.10/SF → $10,416-$14,322
Maintenance Costs (annual): $0.10/SF → $1,302

The United State Department of Energy estimates full installation of the geothermal system to be approximately $1,500-$3,000/ton of nominal capacity, which would amount to between $139,500 and $279,000 for this particular system. The amount of cooling energy will be reduced by 30-50%, while heating energy will see a reduction of 20-40% when compared to more traditional systems. Based on these guidelines, the payback period of this geothermal loop system is 4 to 5 years.

It should be noted that these cost estimations do include the actual heat pumps in these approximations. Since the actual water source heat pumps will not be changed for this proposed design, they are excluded from the next estimation to determine how much additional budget would be required compared to the actual design used.

R.S. Means Green Building Cost Data provides detailed cost information for a 50-ton geothermal heat pump system, which was adjusted to better represent this particular system as follows:

Geothermal Heat Pump System 50 Ton, Vertical Loops, 200 LF Per Ton					
System D3050 248 1000			Cost Each		
Item/Activity	*Quantity*	*Unit*	*Material*	*Install*	*Total*
Mobilization Excavator	2	Ea		544	544
Mobilization crew and equipment	2	Ea		377	377
Mobilization drill rig	2	Ea		169	169
Drill wells 6" diameter	100	CLF		68300	68300
Pipe loops 1 1/2" diameter	200	CLF	28000	38800	66800
Pipe headers 2" diameter	1600	LF	3696	3840	7536
U-fittings for pipe loops	50	Ea	225.5	857.5	1083
Header tee fittings	100	Ea	1410	2900	4310
Header elbow fittings	10	Ea	63.5	182.5	246
Excavate trench for pipe header	475	BCY		3534	3534
Backfill trench for pipe header	655	LCY		1873.3	1873.3
Compact trench for pipe header	475	ECY		1168.5	1168.5
Circulation pump 5 HP	1	Ea	9825	835	10660
Pump control system	1	Ea	1350	635	1985
Pump guages	2	Ea	79	44	123
Pump gauge fittings	2	Ea	151	44	195
Pipe insulations for pump connection	12	LF	33.84	81	114.84
Pipe for pump connection	12	LF	203.4	364.92	568.32
Pipe fittings for pump connection	1	Ea	32	187.7	219.7
Install thermostat wells	2	Ea	15.6	114.28	129.88
Install guage wells	2	Ea	15.6	119.42	135.02
Thermometers, stem type	8	Ea	308	750.72	1058.72
Gauges, pressure or vacuum	1	Ea	860	278	1138
Pipe strainer for pump	1	Ea	165	283	448
shut valve for pump	1	Ea	630	305	935
Expansions joints for pump	2	Ea	660	224	884
Heat pump 50 tons	1	Ea	40000	13200	53200
		Total:	$87,723	$140,012	$227,735
Adjusted			**$19,723**	**$86,922**	**$105,555**
300 LF/ton; excludes heat pumps & mobilization					

R.S. Means also specifies pricing for the boilers and cooling tower of the original design and are compared to the resized equipment:

Item/Activity	*Quantity*	*Unit*	*Material*	*Install*	*Total*
Original Design:					
162 ton Forced-Draft Type Cooling Tower					
	1	TonAC	172	9.95	181.95
					$29,476
1,460 MBH Gas/Oil Fired Boiler					
	2	Ea	28400	6300	34700
					$69,400
Proposed Design:					
300 MBH Gas/Oil Fired Boiler					
	1	Ea	10400	2675	13075
					$13,075
91 ton Stainless Steel Induced Draft Cooling Tower					
	1	Ea	32100	1325	33425
					$33,425
Total Savings:	**$52,376**				

Based on these observations, the proposed geothermal well system will initially cost about $100,000 more than the original system design, but it will save about $50,000 in resizing the boilers and cooling tower. Therefore the ultimate additional budget needed for this geothermal system is about $50,000.

Constructability Concerns

The construction procedure required for the installation of this geothermal well system involves site plan development, well drilling, loop insertion, grouting, the excavation of trenches followed by header installation, and the flushing of the lines with charging of antifreeze. Throughout this process, there are a few key concerns and potential complications that should be addressed.

Regarding materials, quality products that can withstand harsh conditions are essential in preventing any complications that would require excavating to the geothermal loop to make such repairs. For example, instead of threaded plastic pipe connections, thermal fusion welding should be specified that are able to endure much wider temperature ranges without damage or leaks.

Since the sizing of each element of the geothermal loop is critical to the design and performance of the system, it is vital that the contractor adheres to design specifications and do not use alternative materials or methods without being approved by the engineer. Because there was a trend of uncertainty in the soil conditions of the actual project, it is advised that the design engineer be involved on site in order to determine more accurate heat transfer properties of the soil that can impact the design and performance of the system.

While sealing and grouting the vertical loops, quality control is critical because failure to completely grout voids can cause a loss of natural artesian pressure, aquifer contamination, or commingling of water from different aquifers that can become a threat to public health. The void space between the piping and the borehole should be grouted in a continuous manner from bottom to top using appropriate grout placement operations. Additional grout will likely be required after a few hours of settlement occur.

One single party should be designated responsibility for the installation of the entire geothermal loop system in order to ensure that installation, startup, and proper operation of the system are sufficiently completed. Plumbers, well drillers, and HVAC contractors are involved in addition to all other contractors performing other work on site with whom coordination would take place.

The most critical aspect of the proposed geothermal loop system is the location of the well field being located beneath the foundation and directly adjacent to the micropiles. This arrangement would require a structural analysis by a professional engineer to ensure that the vertical loops will not interfere with the performance of this foundation system. On the other hand, if this arrangement were to be approved by a professional engineer, the thermal conductivity of the soils would still be affected by the interference of the micropiles located throughout the well field, which is already a tight squeeze to begin with.

On the other hand, there is current industry research investigating the feasibility and effectiveness of structurally encasing geothermal piping inside micropile and caisson foundation systems, which would drastically cut down on additional drilling time needed and mitigate congestion on the construction site. Such an application could be more appropriate for this particular building and prove to be successful.

Lastly, depending on local health department permitting ordinances, the location of these geothermal wells can be in violation of minimum horizontal separation from other existing elements such as drinking wells, public water supply wells, on-site wastewater systems, sewer lines, and property boundaries.

Recommendation & Conclusion

Based on this analysis, installing a ground coupled heat pump system for the ground floor retail would greatly benefit the tenant's energy bills if the project budget and schedule could endure the additional work. Unfortunately, the constructability issues that are likely to arise in the full design and installation process would cause complications and put the effectiveness of the system in jeopardy. The location of the wells in coordination with the foundation, soil conductivity, and other existing constraints is the most challenging aspect of this analysis that may or may not allow for the successful installation and operation of this system.

If the current research were to find that encased geothermal loops in such foundation systems are, indeed, effective and advantageous, then this proposition would then be recommended.

Final Conclusion

Many different perspectives and elements of the Louis at the 14th project have been considered and investigated throughout the fall and spring semesters as reported. These specific analysis topics collectively focused on the foundation system of the building and exploiting the building footprint in the most efficient, effective, and safest manner possible. All ideas and suggestions surfacing from these analyses are investigative in nature and should not be considered errors made by the actual project team.

The findings of the analyses have proven to show potential benefits in alternative approaches suggested, but also have identified additional risks and challenges associated with them, as well.

The prevention through design research conducted concerning building foundations and excavations revealed itself to be more difficult in pinpointing specific risks and hazards that can be avoided by design when compared to other finishing elements of a building. While the foundation design has minimal flexibility in adjusting for safety without large expenses, the contractor holds the majority of responsibility in the safest means and methods being chosen for its installation.

Since engineers and contractors each have differing but valuable expertise, it is critical that each party actively communicates throughout the duration of the job. For this reason, the design-build delivery system is highly recommended for implementing such prevention through design efforts.

Although the mat slab foundation was the initial system of choice as preferred by the geotechnical report, its analysis has proven to match the expectations held by the actual project team in that it would have been much more expensive than the alternative combination system chosen for installation. On the other hand, the risk of differential settlement over time is a legitimate concern and may or may not cause future complications.

The geothermal loop system offers a practical energy alternative for ground floor tenants and fully exploits the building footprint in combination with the northern micropile foundation system. The constructability concerns, however, make such a system arguably too challenging to proceed with such risks and would be best left to the judgment of a full professional engineering investigation. The pending research on encasing geothermal loops within such foundation systems could be an appropriate solution to these constraints and should be seriously considered for future analyses.

Overall, this report highlights the critical impacts on a building project that a foundation system and its counterparts are capable of making. Such elements can thus be adjusted, changed, or enhanced in ways that greatly influence the schedule, budget, quality, safety, and overall success of a construction project.

Bibliography

"A 'Different' Approach to Below-Grade Garage Construction." Dean Abbondanza. September 2004. Accessed February 1, 2014 <http://www.parkingtoday.com/articledetails.php?id=72>.

Andres, Cameron and Ronald Smith. Principles and Practices of Commercial Construction: 8th Edition. Upper Saddle River, NJ: Pearson Education, Inc., 2009.

"Best Practices for Geothermal Vertical Closed-Loop Installations." Michigan DNRE: Groundwater Division Well Construction Unit. April 2010. Accessed March 26, 2014. <https://michigan.gov/documents/deq/dnre-wb-dwehs-wcu-bestpracticesgeothermal_311868_7.pdf>.

Bowles, Joseph E. Foundation Analysis and Design: Fourth Edition. New York, NY: McGraw-Hill, Inc. 1988.

"Commonly Used Statistics." Occupational Safety & Health Administration. Accessed February 2, 2014. <https://www.osha.gov/oshstats/commonstats.html>.

"CAL/OSHA Pocket Guide for the Construction Industry." California Occupational Safety & Health Administration. December 10, 2004. Accessed February 3, 2014. <www.cal-osha.com>.

Das, Braja M. Principles of Foundation Engineering. United States of America: Cengage Learning 2011.

"Excavations." Occupational Safety & Health Administration. Revised 2002. Accessed February 2, 2014. <https://www.osha.gov/Publications/OSHA2226/2226.html>.

"Excavations: Safe Practices for Small Business Owners and Contractors." Oregon OSHA. Accessed February 2, 2014. <http://www.cbs.state.or.us/osha/pdf/pubs/2174.pdf>.

"Excavations: Sloping and Benching." Occupational Safety & Health Administration. Accessed February 2, 2014. <https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10932>.

"Fall Protection." Occupational Safety & Health Outreach Program. Accessed February 2, 2014. <https://www.osha.gov/doc/outreachtraining/htmlfiles/subpartm.html>.

"Geothermal Savings Calculator." Climate master Geothermal Heat Pump Systems. Accessed March 20, 2014. <http://www.climatemaster.com/residential/geothermal-savings-calculator/sc01.php?version=2>.

"Ground-Source Heat Pumps Applied to Federal Facilities-Second Edition." U.S. Department of Energy: Pacific Northwest National Laboratory. March 2001. Accessed March 26, 2014. <http://smartenergy.illinois.edu/pdf/Archive/GroundSourceHeatPumpApplication.pdf>.

Hoffman, David R. "Geothermal Heating and Cooling Fundamentals: ASHRAE Philadelphia Chapter." Gipe Associates, Inc. Baltimore, MD. Accessed March 27, 2014. <http://phila.ashraechapters.org/storage/0910.pdf>.

International Ground Source Heat Pump Association. Accessed March 20, 2014. <http://www.igshpa.okstate.edu/geothermal/commercial.htm>.

Jeppesen, Kris Charles. Fundamentals of Commercial Geothermal Wellfield Design. GHP Systems, Inc. Brookings, SD: 2010. <http://www.ghpsystems.com/wp-content/uploads/Fundamentals_of_Commercial_Geothermal_Wellfield_Design.pdf>.

"OSHA Fact Sheet: Trenching and Excavation Safety." Occupational Safety & Health Administration. Accessed February 2, 2014. <https://www.osha.gov/Publications/trench_excavation_fs.html>.

Pile Buck Steel Sheet Piling Design Manual. Pile Buck, Inc. United States of America: 1987.

"Pile Foundation Construction Inspection: Class Reference Guide." Illinois Department of Transportation. Revised February 2012. Accessed February 5, 2014. <http://www.dot.state.il.us/bridges/pdf/S19%20Reference.pdf>.

"Prevention Through Design." National Institute for Occupational Safety and Health. October 9, 2013. Accessed February 2, 2014. <http://www.cdc.gov/niosh/topics/ptd/>.

"Sheet piles offer an economical solution." September 20, 2008. Accessed February 2, 2014. <http://www.constructionweekonline.com/article-3636-sheet-piles-offer-an-economical-solution/#.Uvw1aXlFAdt>.

"Trenching and Excavation." OSHA Construction eTool. Occupational Safety & Health Administration. Accessed February 2, 2014. <https://www.osha.gov/SLTC/etools/construction/trenching/mainpage.html>.

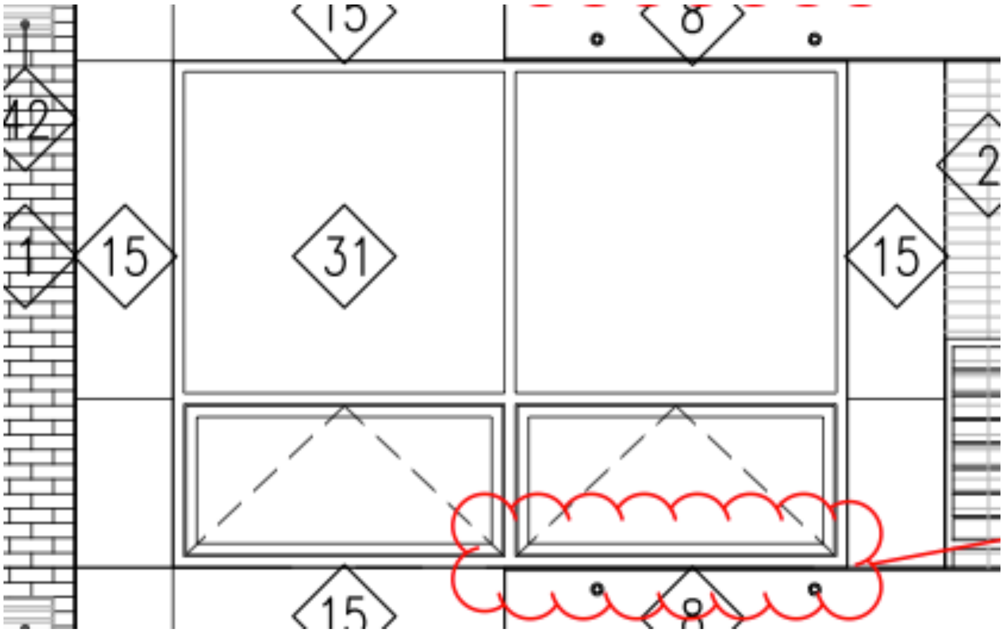
"Underground Parking Sheet Piles Applications." ESC Steel, Inc. Accessed February 2, 2014. <http://escsteelinc.com/sheet-pile-applications/underground-parking.html>.

Waier, Phillip R. RS Means Building Construction Cost Data: 72nd Annual Edition. Reed Construction Data, LLC. Norwell, MA: 2013.

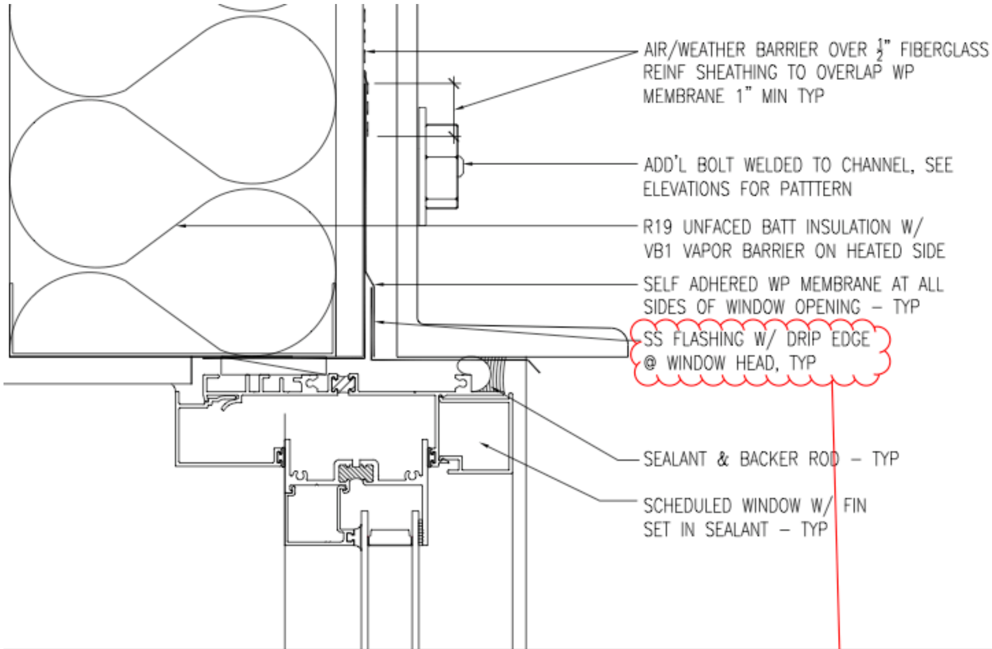
Waier, Phillip R. RS Means Green Building Construction Cost Data: 4th Annual Edition. Reed Construction Data, LLC. Norwell, MA: 2013.

Appendix A – Design & Construction Supporting Documents

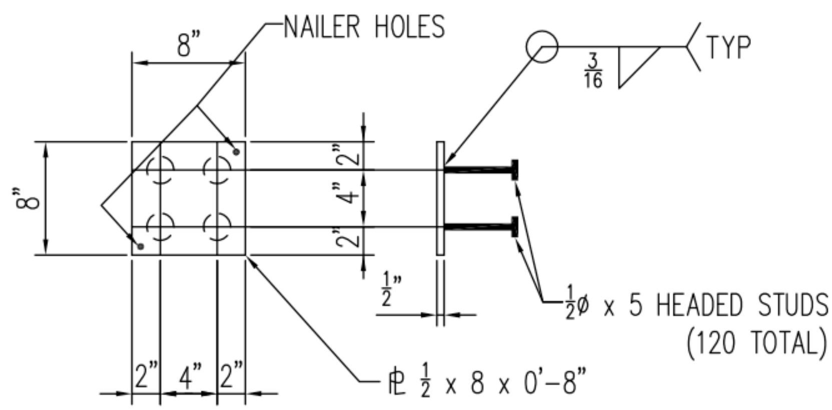
Constructability Concerns: Supporting Sketches



^common window detail with adjacent masonry & metal panels

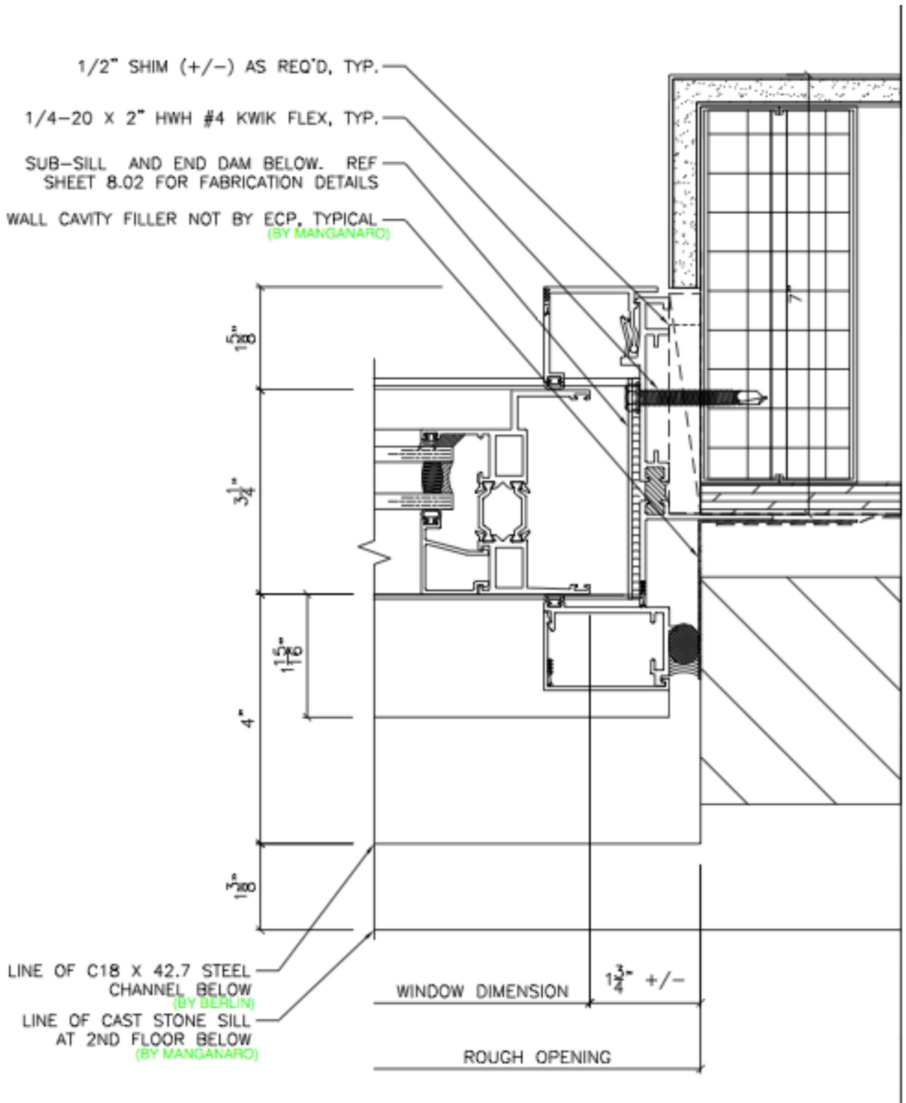


9 HEAD DETAIL AT BAY
SCALE: 1/2 SIZE

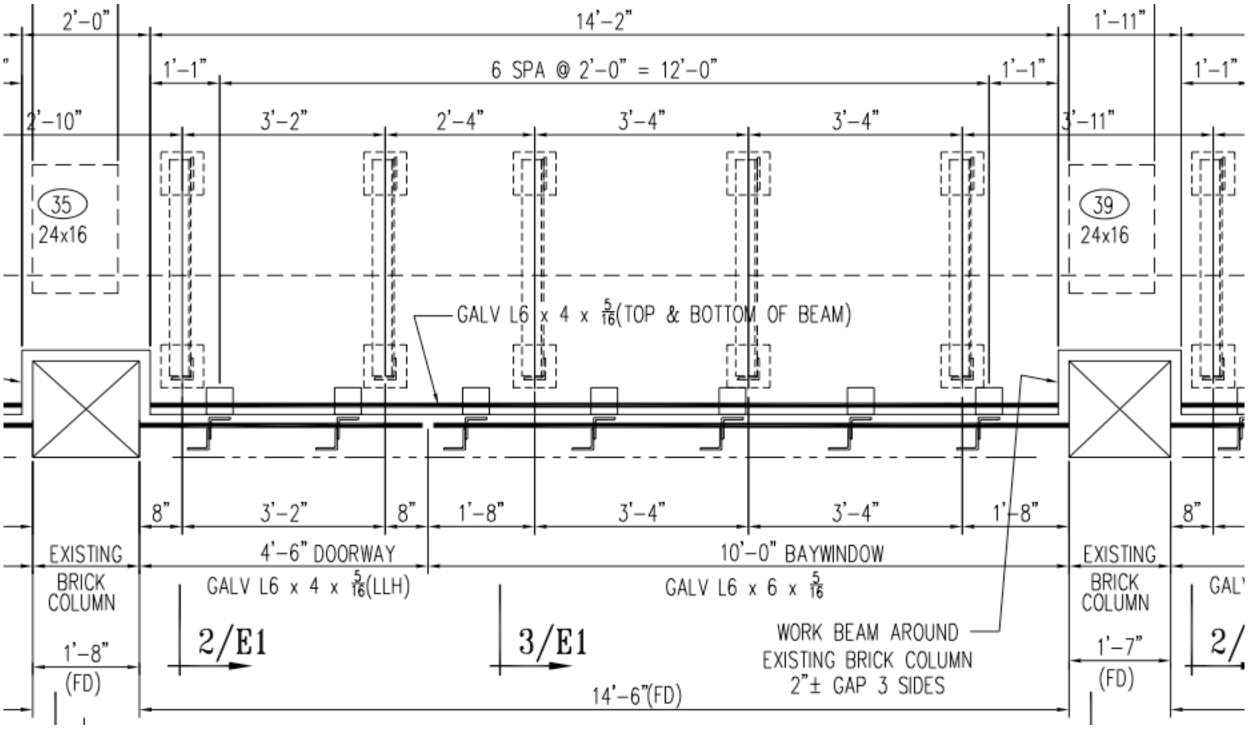


30 ~ EMBED PLATES ~ E32–1P2
6/S–4.4 NO PAINT

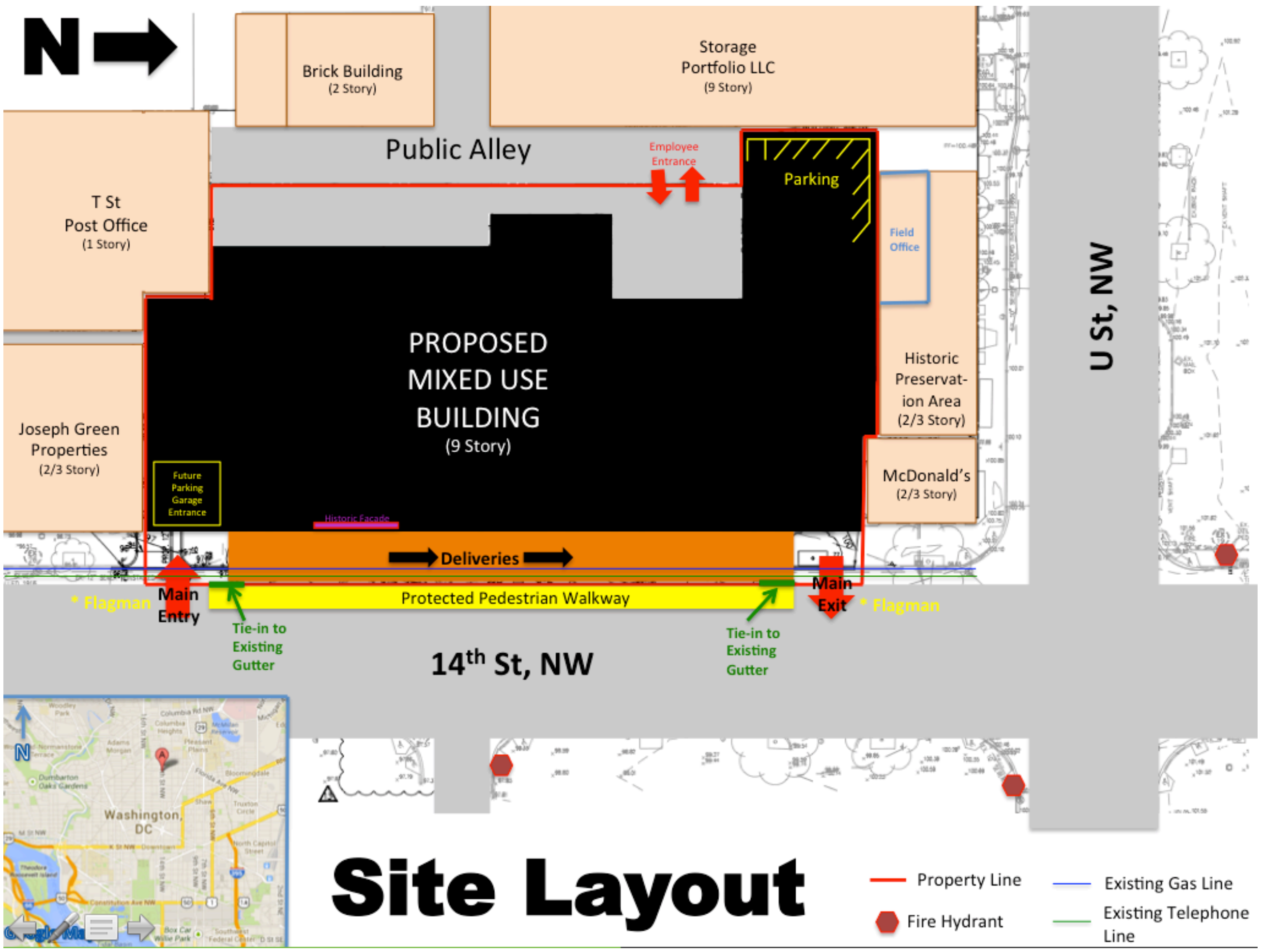
^embed plates installed on historic facade



^window receptor installation detail



^historic façade support plan


N
Brick Building
(2 Story)
Storage
Portfolio LLC
(9 Story)
Public Alley
Employee
Entrance
Parking
Field
Office
T St
Post Office
(1 Story)
PROPOSED
MIXED USE
BUILDING
(9 Story)
Historic
Preservat-
ion Area
(2/3 Story)
Joseph Green
Properties
(2/3 Story)
Future
Parking
Garage
Entrance
McDonald's
(2/3 Story)
U St, NW
Deliveries
* Flagman
Main
Entry
Protected Pedestrian Walkway
Main
Exit
* Flagman
Tie-in to
Existing
Gutter
14th St, NW
Tie-in to
Existing
Gutter
Washington
DC
Site Layout
Property Line
Fire Hydrant
Existing Gas Line
Existing Telephone
Line

Appendix B – Project Cost Evaluation

General Conditions Estimate								
RSM#	Element	Quantity	Unit	Material	Labor	Equipment	Total	Total + O&P
100	Tower Crane		month	0	8600	23600	32200	38900
		10		$0	$86,000	$236,000	$322,000	$389,000
3000	Detour Signs		Ea	2.24	14.2		16.44	24.5
		15		$34	$213	$0	$247	$368
200	Chain Link Fence		LF	4.39	1.42	0	5.81	7
		200		$878	$284	$0	$1,162	$1,400
100	Plywood Protection		SF	1.74	5.55	0	7.29	10.4
		400		$696	$2,220	$0	$2,916	$4,160
50	Temp Gravel Road		SY	4.35	2.52	0.51	7.38	9.2
		100		$435	$252	$51	$738	$920
1100	Ramp		SF	1.85	2.61	0	4.46	6.05
		300		$555	$783	$0	$1,338	$1,815
	Power		CSF/Flr/Month	0	0	0	80	90
		10		$0	$0	$0	$800	$900
120	Office Supplies		month	75	0	0	75	82.5
		15		$1,125	$0	$0	$1,125	$1,238
140	Phone Bill		month	81	0	0	81	89
		15		$1,215	$0	$0	$1,215	$1,335
160	Lights & HVAC		month	152	0	0	152	167
		15		$2,280	$0	$0	$2,280	$2,505
20	Swing Staging		Ea	4900	0	0	4900	5375
		6		$29,400	$0	$0	$29,400	$32,250
100	Equipment Mobilization 7(		Ea	0	73	142	215	269
		12		$0	$876	$1,704	$2,580	$3,228
120	Field Engr Avg		Week		1325		1325	2050
	(1)	60			$79,500		$79,500	$123,000
160	LaborerAvg		Week		1425		1425	2175
	(3)	180			$256,500		$256,500	$391,500
200	Project Manager Avg		Week		2150		2150	3350
	(3)	180			$387,000		$387,000	$603,000
260	Superintendent Avg		Week		2000		2000	3100
	(3)	180			$360,000		$360,000	$558,000
	Office Rent			$3000/month				$45,000
	Permits			0.5-2%				$940,000
	TOTAL							**$3,099,618**

Actual Cost: $2,966,400

Actual Cost	
General Conditions	$2,966,400
ALLOWANCES	
Lost Meter Revenue Fee	$36,000
Exterior Signage	$15,000
Project Screen	$10,000
Restoration of Historical Façade Masonry &	$12,761
Façade Repair	$25,000
Additional Wood Structural Work	$2,239
Access Control System, CCTV/Video Surveil	$168,000
(allowances subtotal)	**$269,000**

Other Estimated Costs			
Insurance	Builders Risk Avg	0.50%	$235,000
	Workers Comp Avg	14%	$6,439,000
Performance Bond		2.50%	$1,175,000
O&P		12%	$5,640,000
Taxes	Social Sec	7.65%	$3,595,500
	Unemployment	7.80%	$3,666,000
Engr Fees	Elec Engr fee	4.1-10.1%	$2,350,000
	Mech Engr fee	4.1-10.10%	$2,350,000
	Struct Engr fee	1-2.5%	$940,000

Plumbing Assemblies Estimate

Code	Element	Quantity	Unit	Material	Install	Total
1760	Kitchen Sink System		Ea	1100	785	1885
		270		$297,000	$211,950	$508,950
1840	Laundry Sink System		Ea	1450	835	2285
		20		$29,000	$16,700	$45,700
2160	Three-Fixture Bathroom- (		Ea	3125	2325	5450
		280		$875,000	$651,000	$1,526,000
1820	50 Gallon Electric Water H		Ea	5075	1175	6250
		270		$1,370,250	$317,250	$1,687,500
1960	Roof Drain Systems- 3" d		Ea	360	790	1150
		50		$18,000	$39,500	$57,500
				TOTAL PLUMBING COST:		$3,825,650

Actual Cost: $3,739,000

Mechanical Assemblies Estimate						
Code	**Element**	**Quantity**	**Unit**	**Material**	**Install**	**Total**
1480	Unit Heater 5032 MBH 67(		SF	4.35	3.52	7.87
		267000		$1,161,450	$939,840	$2,101,290
1080	Boiler 1088 MBH		Ea	14900	6500	21400
		2		$29,800	$13,000	$42,800
1300	Closed Loop Water Coolec		SF	3.45	3.1	6.55
		267000		$921,150	$827,700	$1,748,850
1440	Split System with Air Cool(		SF	2.91	3.49	6.4
		267000		$776,970	$931,830	$1,708,800
				TOTAL HVAC COST:		$5,601,740
Other:						
1320	Cooling Tower Systems		SF	7.33	8.1	15.43
		267000		$1,957,110	$2,162,700	$4,119,810
1280	Rooftop Units		SF	10.7	4.93	15.63
		267000		$2,856,900	$1,316,310	$4,173,210

Actual Cost: $4,365,000

Electrical Assemblies Estimate						
Code	**Element**	**Quantity**	**Unit**	**Material**	**Install**	**Total**
320	1200A 120 Switchgear		Ea	17500	4325	21825
		7		$122,500	$30,275	$152,775
400	2000A 120 Switchgear		Ea	31800	5425	37225
		3		$95,400	$16,275	$111,675
1060	100A Panelboard		Ea	3475	4350	7825
		25		$86,875	$108,750	$195,625
520	Receptacles 10/1000SF		SF	0.59	2.33	2.92
		200000		$118,000	$466,000	$584,000
400	Wall Switches 10/1000SF		SF	0.54	1.59	2.13
		200000		$108,000	$318,000	$426,000
920*	Generator 300 kW		kW	10000	800	10800
		1		$10,000	$800	$10,800
600	Fluoresecent Strip Fixtures		SF	2.95	6	8.95
		60000		$177,000	$360,000	$537,000
1240	Fluorescent Recessed Fixt		SF	4.78	10.45	15.33
		50000		$239,000	$522,500	$766,500
520	T5 Linear Fluoresc 10fixtur		SF	1.63	3.62	5.25
		100000		$163,000	$362,000	$525,000
640*	Recessed Downlight 47 fix		SF	2	5	7
		100000		$200,000	$500,000	$700,000
2520	265/460V 800 A Motor 20		Ea	12000	4375	16375
		2		$24,000	$8,750	$32,750
				TOTAL ELECTRIC COST:		**$4,042,125**

Actual Cost: $4,242,000

Structural System Estimate: Cast-In-Place Concrete								
RSM#	**Element**	**Quantity**	**Unit**	**Material**	**Labor**	**Equipment**	**Total**	**Total + O&P**
940	columns concrete		CY	685	635	53	1373	1800
		968.56		$663,461	$616,001	$51,333	$1,329,827	$1,743,400
5950	Pile Caps concrete		CY	154	64	0.43	218.43	268
		343		$52,822	$22,295	$147	$74,921	$91,924
400*	AGM Piles		CY	150	51.5	9.3	210.8	285
		281.92		$42,288	$14,801	$2,622	$59,428	$80,347
1950	elev slab concrete		CY	268	183	14.7	465.7	595
		5094.06		$1,365,207	$937,306	$74,883	$2,372,302	$3,030,963
4350	walls concrete (12')		CY	135	174	14.6	323.6	430
		1889.06		$255,023	$330,585	$27,580	$611,298	$812,294
4700	SOG		CY	114	42	0.36	156.36	191
		1019.38		$116,210	$43,833	$367	$159,391	$194,702
						TOTAL CONCRETE COST:		$5,953,630

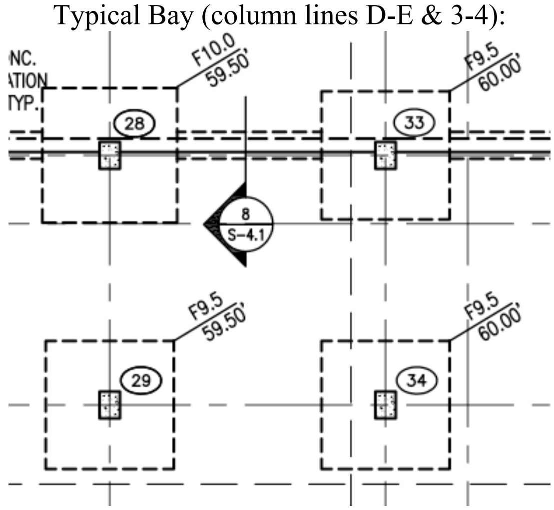
Actual Cost: $7,090,000

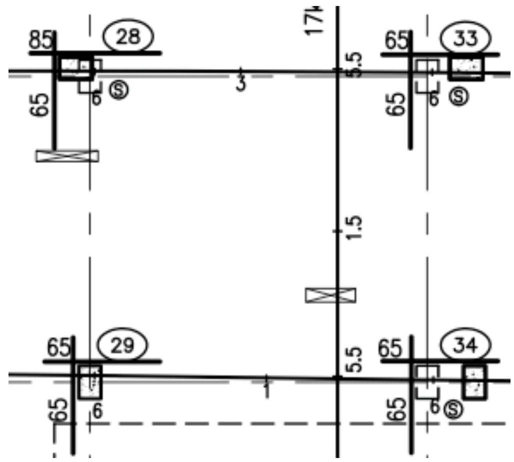
Concrete Structure Take-off									
Level	**Slab Area**	**Perimeter**	**Element**	**#**	**W**	**L**	**t**	**CY**	**Rebar**
P3	23420	647	Footings						#8
			S	22	7	7	2.25	89.83	2464
			M	27	10	10	3.17	316.67	6480
			L	5	17	11	2.92	101.00	3355
			Fdtn Wal	1	14	647	1	335.48	
			SOG				0.42	361.42	wwf
									#4
P1, P2	23420	647	SOG				0.75	650.56	
G	15700	580	slab				0.75	436.11	
									wwf
4	32300	1190	slab				0.58333333	697.84	
8	28900	1100	slab				0.58333333	624.38	wwf
Penthouse	11200	590	slab				1	414.81	#4

Foundation							
	Pile Caps	L	W	A	t	#	CY
		7	7	49	3.5	54	343
	Auger Cast Piles		d	h			
	*94lbs rebar/pile	=6.5 tons	1.17	52		137	281.92
	Foundation Wall			P	h	t	CY
				647	27.75	1	664.97
	Shear Walls (elevators)			LF	h	t	CY
			SW1	30	111	1	123.33
			SW4	38	111	1	156.22

Parking Garage Levels (Bay D-E & 3-4):								
		W	L					
		20.479	18.5					
	Susp Slab	A	t	CY	bays/floor	floors	total CY	
		378.8615	0.6667	9.355072669	48	3	1347.13	
	SOG	54556.056	0.4167	841.9144444				
				total WWF				
				54556.056	SF			
	Columns	L	W	h	CY/column	olumns/floo	floors	total CY
		1.5	2	11.5	1.2777778	54	3	207
Ground Level +								
	SOG (other half)							
	Part 1	W	L	A	t	CY		
		100	115	11500	0.4166667	177.469136		
	Part 2	75	63	4725		total WWF		
						16225	SF	
	Susp Slab (bay D-E & 3-4)							
		W	L					
		20.479	18.5					
		A	t	CY	bays/floor	floors	total CY	
		378.8615	0.5833	8.184811591	75	8	4910.89	
	Columns	L	W	h	CY/column	olumns/floo	floors	total CY
		1.5	2	11.5	1.2777778	70	8	715.56
	Penthouse Slab	A	P	t	CY			
		3825	590	1	141.67			
		L	W		#4 Rebar			
		45	85		7650	LF		
		Columns	L	W	h	CY/column	#	total CY
			1.5	2	11.5	1.27777778	36	46
	Roofslab	L	W	A	t	CY		
		28	60	1680	0.667	41.50		

Typical Bay (column lines D-E & 3-4):



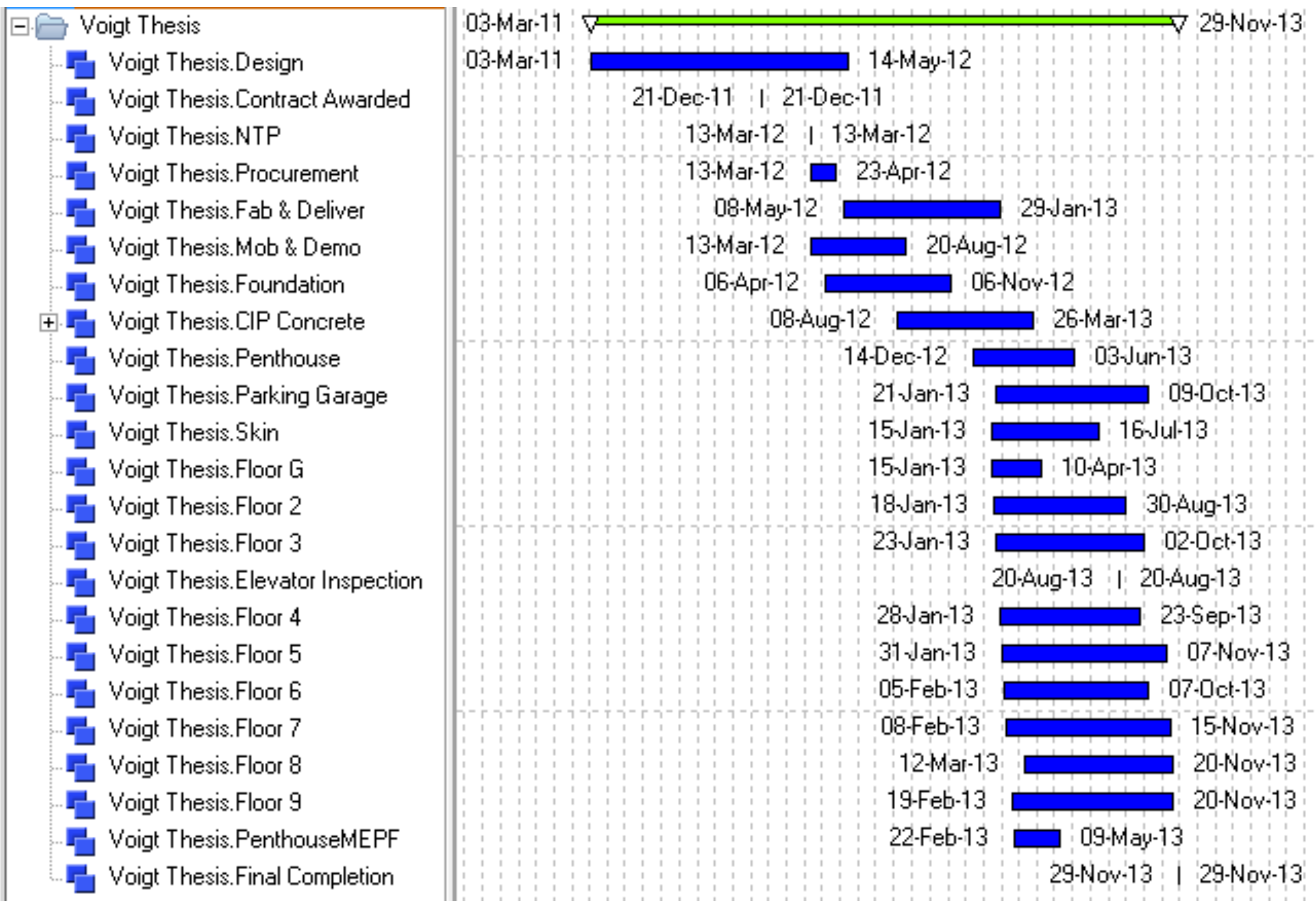


For Pricing Reference:							
Code	**Element**	**Unit**	**Materia**	**Labor**	**Equip**	**Total**	**Total O&P**
7750	column formwork	SFCA	0.67	3.09	0	3.76	5.5
2150	Elev Slabs	SF	1.32	3.85	0	5.17	7.4
2150	SOG Edge Forms	LF	0.82	4.95	0	5.77	8.5
4230	Foundation Walls	SFCA	0.76	9.3	0	10.06	15.2
2550	Shear Walls	SFCA	0.66	5.3	0	5.96	8.85
1000	Shoring	Ea	0	13.05	0	13.05	20
250	Column Reinforcir	ton	1000	695	0	1695	2200
700	Wall Reinforcing	ton	1000	530	0	1530	1950
200	6x6 WWF	CSF	17.35	25.5	0	42.85	59.5
3100	Post-tensioning pl	SF	0.59	0.27	0	0.86	1.08
3105	...tensioning	SF	0	0.21	0.01	0.22	0.35
940	**columns concrete**	**CY**	**685**	**635**	**53**	**1373**	**1800**
1950	**elev slab concrete**	**CY**	**268**	**183**	**14.7**	**465.7**	**595**
4350	**walls concrete (12**	**CY**	**135**	**174**	**14.6**	**323.6**	**430**
4700	**SOG**	**CY**	**114**	**42**	**0.36**	**156.36**	**191**
5950	**Pile Caps concrete**	**CY**	**154**	**64**	**0.43**	**218.43**	**268**
400	**5000psi concrete**	**CY**	**108**	**0**	**0**	**108**	**119**
1550	placing elev slab	CY	0	25.5	10.95	36.45	50.5
3000	placing foundatior	CY	0	9.25	4.02	13.27	18.5
3510	add per story afte	CY	0	1.32	0.57	1.89	2.65
4100	placing pile caps	CY	0	15.05	6.5	21.55	30
4400	placing SOG	CY	0	25.5	10.95	36.45	50.5
1700	core drilling	Ea	2.93	72.5	12.5	87.93	129

Mat Slab Redesign:

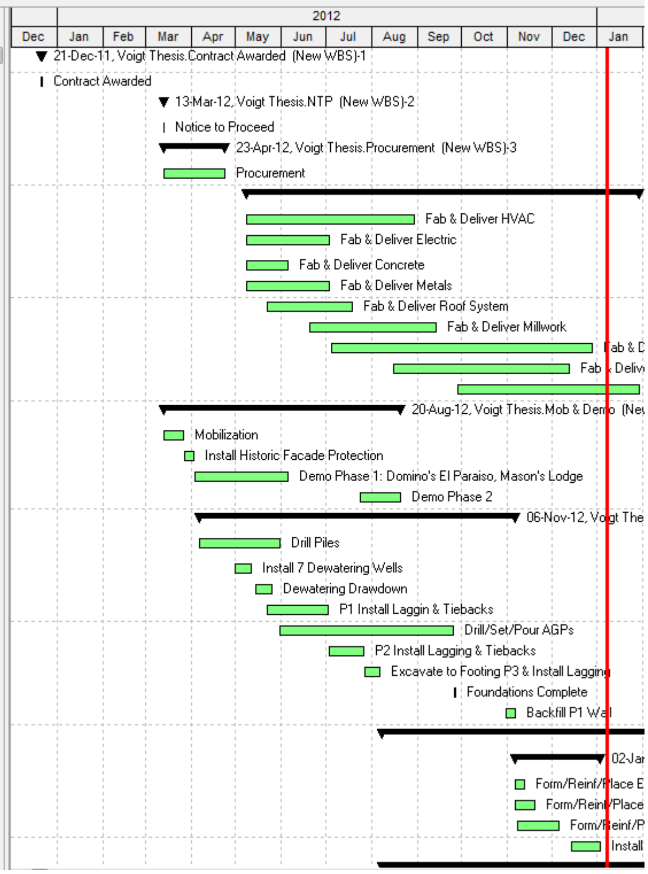
Quantity Take-off			
***waste factors not included**			
item	*area (SF)*	*t (in.)*	*CY*
concrete 4,000psi			
work mat	44175	3	409
mat slab	44175	36	4908
		Total CY:	**5317**
#9 rebar each way @ 6" o.c.	*L (ft)*	*W (ft)*	*LF rebar*
area 1	27	116	12528
area 2	286	141	161304
area 3	36	20	2880
		Total LF:	**176712**
	(3.4 lbs/LF)	**Tons:**	**300.4**

Appendix C – Project Schedule Details

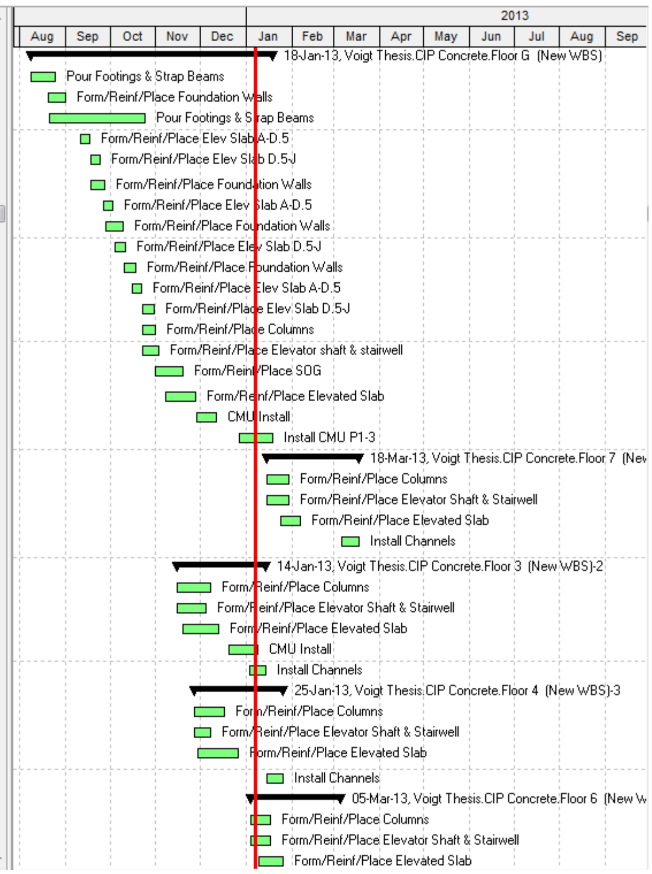

Voigt Thesis
Voigt Thesis.Design
Voigt Thesis.Contract Awarded
Voigt Thesis.NTP
Voigt Thesis.Procurement
Voigt Thesis.Fab & Deliver
Voigt Thesis.Mob & Demo
Voigt Thesis.Foundation
Voigt Thesis.CIP Concrete
Voigt Thesis.Penthouse
Voigt Thesis.Parking Garage
Voigt Thesis.Skin
Voigt Thesis.Floor G
Voigt Thesis.Floor 2
Voigt Thesis.Floor 3
Voigt Thesis.Elevator Inspection
Voigt Thesis.Floor 4
Voigt Thesis.Floor 5
Voigt Thesis.Floor 6
Voigt Thesis.Floor 7
Voigt Thesis.Floor 8
Voigt Thesis.Floor 9
Voigt Thesis.PenthouseMEPF
Voigt Thesis.Final Completion
03-Mar-11 29-Nov-13
03-Mar-11 14-May-12
21-Dec-11 21-Dec-11
13-Mar-12 13-Mar-12
13-Mar-12 23-Apr-12
08-May-12 29-Jan-13
13-Mar-12 20-Aug-12
06-Apr-12 06-Nov-12
08-Aug-12 26-Mar-13
14-Dec-12 03-Jun-13
21-Jan-13 09-Oct-13
15-Jan-13 16-Jul-13
15-Jan-13 10-Apr-13
18-Jan-13 30-Aug-13
23-Jan-13 02-Oct-13
20-Aug-13 20-Aug-13
28-Jan-13 23-Sep-13
31-Jan-13 07-Nov-13
05-Feb-13 07-Oct-13
08-Feb-13 15-Nov-13
12-Mar-13 20-Nov-13
19-Feb-13 20-Nov-13
22-Feb-13 09-May-13
29-Nov-13 29-Nov-13

Layout: Classic Schedule Layout | Filter: All Activities

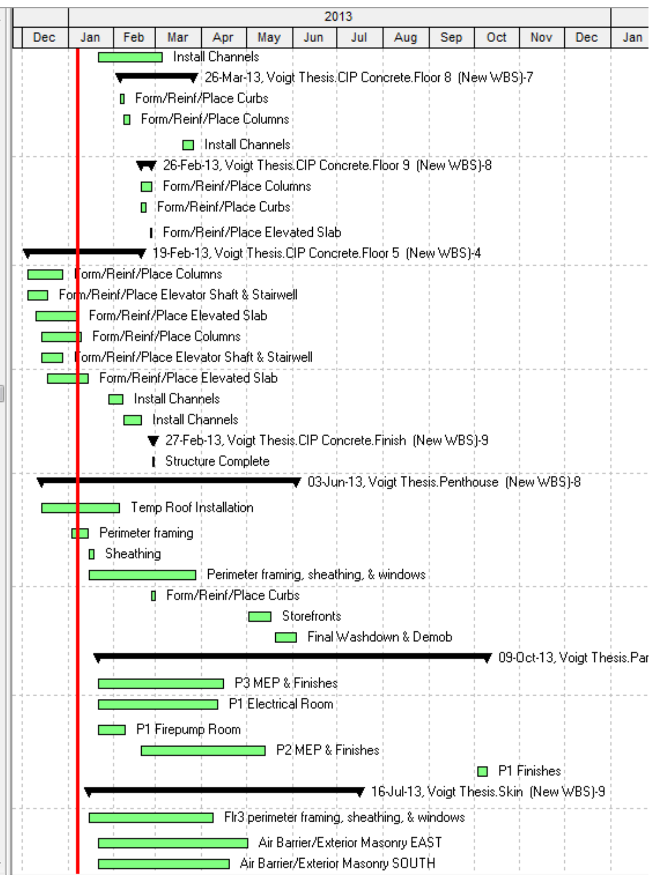
#	Activity ID	Activity Name	Original Duration	Start	Finish
5	**Voigt Thesis.Contract Awarded (New WBS)**		1	21-Dec-11	21-Dec-11
6	A1000	Contract Awarded	1	21-Dec-11	21-Dec-11
7	**Voigt Thesis.NTP (New WBS)-2**		1	13-Mar-12	13-Mar-12
8	A1020	Notice to Proceed	1	13-Mar-12	13-Mar-12
9	**Voigt Thesis.Procurement (New WBS)-3**		30	13-Mar-12	23-Apr-12
10	A1030	Procurement	30	13-Mar-12	23-Apr-12
11	**Voigt Thesis.Fab & Deliver (New WBS)-4**		185	08-May-12	29-Jan-13
12	A1040	Fab & Deliver HVAC	80	08-May-12	29-Aug-12
13	A1050	Fab & Deliver Electric	40	08-May-12	03-Jul-12
14	A1060	Fab & Deliver Concrete	20	08-May-12	05-Jun-12
15	A1090	Fab & Deliver Metals	40	08-May-12	03-Jul-12
16	A1080	Fab & Deliver Roof System	40	22-May-12	18-Jul-12
17	A1070	Fab & Deliver Millwork	60	20-Jun-12	13-Sep-12
18	A1100	Fab & Deliver Windows	124	05-Jul-12	28-Dec-12
19	A1110	Fab & Deliver Doors & Frames	83	16-Aug-12	12-Dec-12
20	A1120	Fab & Deliver Woodwork	85	28-Sep-12	29-Jan-13
21	**Voigt Thesis.Mob & Demo (New WBS)-5**		113	13-Mar-12	20-Aug-12
22	A1130	Mobilization	10	13-Mar-12	26-Mar-12
23	A1160	Install Historic Facade Protection	5	27-Mar-12	02-Apr-12
24	A1140	Demo Phase 1: Domino's El Paraiso, Mason's	45	03-Apr-12	05-Jun-12
25	A1150	Demo Phase 2	20	24-Jul-12	20-Aug-12
26	**Voigt Thesis.Foundation (New WBS)-6**		150	06-Apr-12	06-Nov-12
27	A1170	Drill Piles	38	06-Apr-12	30-May-12
28	A1220	Install 7 Dewatering Wells	10	30-Apr-12	11-May-12
29	A1230	Dewatering Drawdown	10	14-May-12	25-May-12
30	A1180	P1 Install Laggin & Tiebacks	29	22-May-12	02-Jul-12
31	A1240	Drill/Set/Pour AGPs	82	31-May-12	25-Sep-12
32	A1190	P2 Install Lagging & Tiebacks	17	03-Jul-12	26-Jul-12
33	A1200	Excavate to Footing P3 & Install Lagging	7	27-Jul-12	06-Aug-12
34	A1250	Foundations Complete	1	26-Sep-12	26-Sep-12
35	A1210	Backfill P1 Wall	5	31-Oct-12	06-Nov-12
36	**Voigt Thesis.CIP Concrete (New WBS)-7**		283	08-Aug-12	17-Sep-13
37	**Voigt Thesis.CIP Concrete.Floor 2 (New WBS)-1**		39	06-Nov-12	02-Jan-13
38	A1440	Form/Reinf/Place Elevator Shaft & Stairwell	5	06-Nov-12	12-Nov-12
39	A1450	Form/Reinf/Place Columns	10	06-Nov-12	19-Nov-12
40	A1460	Form/Reinf/Place Elevated Slab	19	08-Nov-12	05-Dec-12
41	A1470	Install Channel	12	14-Dec-12	02-Jan-13



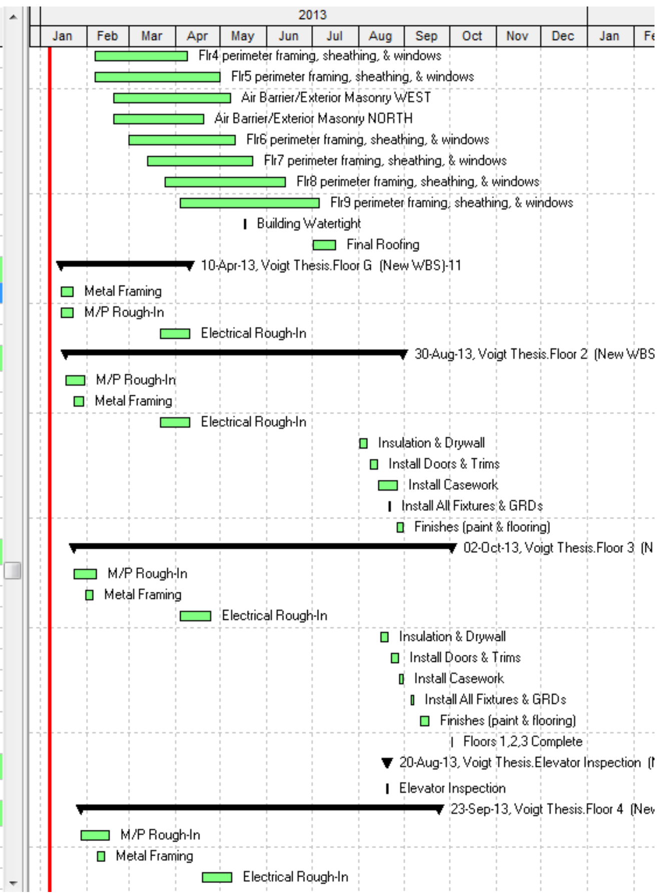
#	Activity ID	Activity Name	Original Duration	Start	Finish
42	Voigt Thesis.CIP Concrete.Floor G (New WBS)		114	08-Aug-12	18-Jan-13
43	A1260	Pour Footings & Strap Beams	13	08-Aug-12	24-Aug-12
44	A1270	Form/Reinf/Place Foundation Walls	10	20-Aug-12	31-Aug-12
45	A1380	Pour Footings & Strap Beams	46	21-Aug-12	24-Oct-12
46	A1280	Form/Reinf/Place Elev Slab A-D.5	5	11-Sep-12	17-Sep-12
47	A1290	Form/Reinf/Place Elev Slab D.5-J	5	18-Sep-12	24-Sep-12
48	A1300	Form/Reinf/Place Foundation Walls	8	18-Sep-12	27-Sep-12
49	A1310	Form/Reinf/Place Elev Slab A-D.5	5	26-Sep-12	02-Oct-12
50	A1320	Form/Reinf/Place Foundation Walls	8	28-Sep-12	09-Oct-12
51	A1330	Form/Reinf/Place Elev Slab D.5-J	6	04-Oct-12	11-Oct-12
52	A1340	Form/Reinf/Place Foundation Walls	7	10-Oct-12	18-Oct-12
53	A1350	Form/Reinf/Place Elev Slab A-D.5	5	16-Oct-12	22-Oct-12
54	A1360	Form/Reinf/Place Elev Slab D.5-J	6	23-Oct-12	30-Oct-12
55	A1390	Form/Reinf/Place Columns	7	23-Oct-12	31-Oct-12
56	A1400	Form/Reinf/Place Elevator shaft & stairwell	9	23-Oct-12	02-Nov-12
57	A1410	Form/Reinf/Place SOG	14	31-Oct-12	19-Nov-12
58	A1420	Form/Reinf/Place Elevated Slab	14	07-Nov-12	27-Nov-12
59	A1430	CMU Install	10	28-Nov-12	11-Dec-12
60	A1370	Install CMU P1-3	16	27-Dec-12	18-Jan-13
61	Voigt Thesis.CIP Concrete.Floor 7 (New WBS)-6		45	15-Jan-13	18-Mar-13
62	A1690	Form/Reinf/Place Columns	11	15-Jan-13	29-Jan-13
63	A1700	Form/Reinf/Place Elevator Shaft & Stairwell	11	15-Jan-13	29-Jan-13
64	A1710	Form/Reinf/Place Elevated Slab	10	24-Jan-13	06-Feb-13
65	A1720	Install Channels	9	06-Mar-13	18-Mar-13
66	Voigt Thesis.CIP Concrete.Floor 3 (New WBS)-2		40	15-Nov-12	14-Jan-13
67	A1480	Form/Reinf/Place Columns	16	15-Nov-12	07-Dec-12
68	A1490	Form/Reinf/Place Elevator Shaft & Stairwell	13	15-Nov-12	04-Dec-12
69	A1500	Form/Reinf/Place Elevated Slab	18	19-Nov-12	13-Dec-12
70	A1520	CMU Install	12	20-Dec-12	08-Jan-13
71	A1510	Install Channels	8	03-Jan-13	14-Jan-13
72	Voigt Thesis.CIP Concrete.Floor 4 (New WBS)-3		42	27-Nov-12	25-Jan-13
73	A1530	Form/Reinf/Place Columns	15	27-Nov-12	17-Dec-12
74	A1540	Form/Reinf/Place Elevator Shaft & Stairwell	9	27-Nov-12	07-Dec-12
75	A1550	Form/Reinf/Place Elevated Slab	19	29-Nov-12	26-Dec-12
76	A1560	Install Channels	9	15-Jan-13	25-Jan-13
77	Voigt Thesis.CIP Concrete.Floor 6 (New WBS)-5		43	04-Jan-13	05-Mar-13
78	A1650	Form/Reinf/Place Columns	10	04-Jan-13	17-Jan-13
79	A1660	Form/Reinf/Place Elevator Shaft & Stairwell	10	04-Jan-13	17-Jan-13
80	A1670	Form/Reinf/Place Elevated Slab	13	09-Jan-13	25-Jan-13



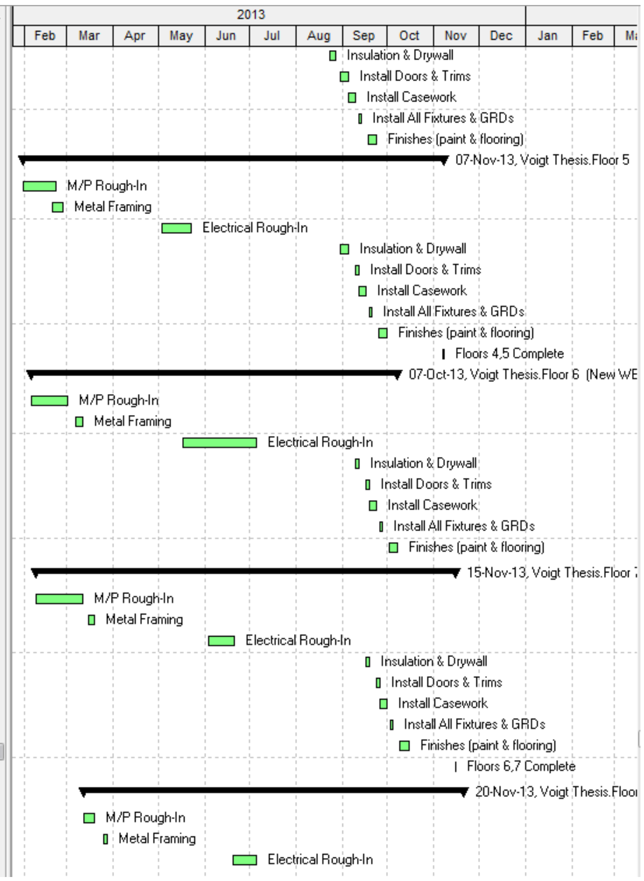
#	Activity ID	Activity Name	Original Duration	Start	Finish
81	A1680	Install Channels	32	21-Jan-13	05-Mar-13
82	Voigt Thesis.CIP Concrete.Floor 8 (New WBS)-7		36	05-Feb-13	26-Mar-13
83	A1740	Form/Reinf/Place Curbs	3	05-Feb-13	07-Feb-13
84	A1730	Form/Reinf/Place Columns	3	07-Feb-13	11-Feb-13
85	A1750	Install Channels	6	19-Mar-13	26-Mar-13
86	Voigt Thesis.CIP Concrete.Floor 9 (New WBS)-8		6	19-Feb-13	26-Feb-13
87	A1760	Form/Reinf/Place Columns	6	19-Feb-13	26-Feb-13
88	A1770	Form/Reinf/Place Curbs	4	19-Feb-13	22-Feb-13
89	A1780	Form/Reinf/Place Elevated Slab	2	25-Feb-13	26-Feb-13
90	Voigt Thesis.CIP Concrete.Floor 5 (New WBS)-4		53	05-Dec-12	19-Feb-13
91	A1570	Form/Reinf/Place Columns	17	05-Dec-12	28-Dec-12
92	A1580	Form/Reinf/Place Elevator Shaft & Stairwell	10	05-Dec-12	18-Dec-12
93	A1590	Form/Reinf/Place Elevated Slab	19	10-Dec-12	07-Jan-13
94	A1610	Form/Reinf/Place Columns	17	14-Dec-12	09-Jan-13
95	A1620	Form/Reinf/Place Elevator Shaft & Stairwell	10	14-Dec-12	28-Dec-12
96	A1630	Form/Reinf/Place Elevated Slab	18	18-Dec-12	14-Jan-13
97	A1600	Install Channels	8	28-Jan-13	06-Feb-13
98	A1640	Install Channels	9	07-Feb-13	19-Feb-13
99	Voigt Thesis.CIP Concrete.Finish (New WBS)-9		1	27-Feb-13	27-Feb-13
100	A1790	Structure Complete	1	27-Feb-13	27-Feb-13
101	Voigt Thesis.Penthouse (New WBS)-8		119	14-Dec-12	03-Jun-13
102	A1990	Temp Roof Installation	35	14-Dec-12	04-Feb-13
103	A1940	Perimeter framing	8	03-Jan-13	14-Jan-13
104	A1950	Sheathing	4	15-Jan-13	18-Jan-13
105	A1980	Perimeter framing, sheathing, & windows	52	15-Jan-13	27-Mar-13
106	A1930	Form/Reinf/Place Curbs	3	26-Feb-13	28-Feb-13
107	A1960	Storefronts	12	02-May-13	17-May-13
108	A1970	Final Washdown & Demob	10	20-May-13	03-Jun-13
109	Voigt Thesis.Parking Garage (New WBS)-1		185	21-Jan-13	09-Oct-13
110	A2010	P3 MEP & Finishes	61	21-Jan-13	15-Apr-13
111	A2030	P1 Electrical Room	59	21-Jan-13	11-Apr-13
112	A2040	P1 Firepump Room	15	21-Jan-13	08-Feb-13
113	A2020	P2 MEP & Finishes	60	19-Feb-13	13-May-13
114	A2050	P1 Finishes	5	03-Oct-13	09-Oct-13
115	Voigt Thesis.Skin (New WBS)-9		129	15-Jan-13	16-Jul-13
116	A1800	Flr3 perimeter framing, sheathing, & windows	60	15-Jan-13	08-Apr-13
117	A1880	Air Barrier/Exterior Masonry EAST	73	21-Jan-13	01-May-13
118	A1910	Air Barrier/Exterior Masonry SOUTH	65	21-Jan-13	19-Apr-13



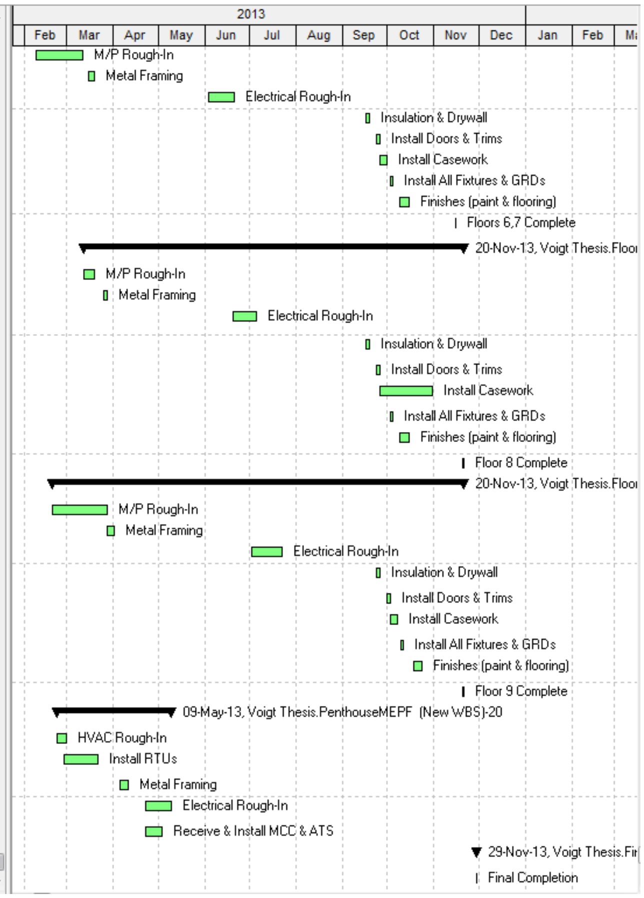
#	Activity ID	Activity Name	Original Duration	Start	Finish
119	A1810	Flr4 perimeter framing, sheathing, & windows	44	06-Feb-13	08-Apr-13
120	A1820	Flr5 perimeter framing, sheathing, & windows	60	06-Feb-13	30-Apr-13
121	A1890	Air Barrier/Exterior Masonry WEST	56	19-Feb-13	07-May-13
122	A1900	Air Barrier/Exterior Masonry NORTH	44	19-Feb-13	19-Apr-13
123	A1830	Flr6 perimeter framing, sheathing, & windows	51	01-Mar-13	10-May-13
124	A1840	Flr7 perimeter framing, sheathing, & windows	51	13-Mar-13	22-May-13
125	A1850	Flr8 perimeter framing, sheathing, & windows	58	25-Mar-13	13-Jun-13
126	A1860	Flr9 perimeter framing, sheathing, & windows	65	04-Apr-13	05-Jul-13
127	A1920	Building Watertight	1	17-May-13	17-May-13
128	A1870	Final Roofing	10	02-Jul-13	16-Jul-13
129	**Voigt Thesis.Floor G (New WBS)-11**		62	15-Jan-13	10-Apr-13
130	A2060	Metal Framing	6	15-Jan-13	22-Jan-13
131	A2070	M/P Rough-In	6	15-Jan-13	22-Jan-13
132	A2080	Electrical Rough-In	14	22-Mar-13*	10-Apr-13
133	**Voigt Thesis.Floor 2 (New WBS)-12**		159	18-Jan-13	30-Aug-13
134	A2100	M/P Rough-In	9	18-Jan-13	30-Jan-13
135	A2090	Metal Framing	5	23-Jan-13	29-Jan-13
136	A2110	Electrical Rough-In	14	22-Mar-13	10-Apr-13
137	A2120	Insulation & Drywall	3	02-Aug-13	06-Aug-13
138	A2140	Install Doors & Trims	3	09-Aug-13	13-Aug-13
139	A2150	Install Casework	9	14-Aug-13	26-Aug-13
140	A2130	Install All Fixtures & GRDs	2	21-Aug-13	22-Aug-13
141	A2160	Finishes (paint & flooring)	4	27-Aug-13	30-Aug-13
142	**Voigt Thesis.Floor 3 (New WBS)-13**		178	23-Jan-13	02-Oct-13
143	A2180	M/P Rough-In	12	23-Jan-13	07-Feb-13
144	A2170	Metal Framing	3	31-Jan-13	04-Feb-13
145	A2190	Electrical Rough-In	15	04-Apr-13	24-Apr-13
146	A2200	Insulation & Drywall	3	16-Aug-13	20-Aug-13
147	A2220	Install Doors & Trims	3	23-Aug-13	27-Aug-13
148	A2230	Install Casework	3	28-Aug-13	30-Aug-13
149	A2210	Install All Fixtures & GRDs	2	05-Sep-13	06-Sep-13
150	A2240	Finishes (paint & flooring)	4	11-Sep-13	16-Sep-13
151	A2780	Floors 1,2,3 Complete	1	02-Oct-13	02-Oct-13
152	**Voigt Thesis.Elevator Inspection (New WB**		1	20-Aug-13	20-Aug-13
153	A2770	Elevator Inspection	1	20-Aug-13	20-Aug-13
154	**Voigt Thesis.Floor 4 (New WBS)-14**		168	28-Jan-13	23-Sep-13
155	A2260	M/P Rough-In	15	28-Jan-13	15-Feb-13
156	A2250	Metal Framing	3	08-Feb-13	12-Feb-13
157	A2270	Electrical Rough-In	14	19-Apr-13	08-May-13



#	Activity ID	Activity Name	Original Duration	Start	Finish
158	A2280	Insulation & Drywall	3	23-Aug-13	27-Aug-13
159	A2300	Install Doors & Trims	3	30-Aug-13	04-Sep-13
160	A2310	Install Casework	3	05-Sep-13	09-Sep-13
161	A2290	Install All Fixtures & GRDs	2	12-Sep-13	13-Sep-13
162	A2400	Finishes (paint & flooring)	4	18-Sep-13	23-Sep-13
163	**Voigt Thesis.Floor 5 (New WBS)-15**		198	31-Jan-13	07-Nov-13
164	A2330	M/P Rough-In	16	31-Jan-13	21-Feb-13
165	A2320	Metal Framing	6	19-Feb-13	26-Feb-13
166	A2340	Electrical Rough-In	14	03-May-13	22-May-13
167	A2350	Insulation & Drywall	3	30-Aug-13	04-Sep-13
168	A2370	Install Doors & Trims	3	09-Sep-13	11-Sep-13
169	A2380	Install Casework	3	12-Sep-13	16-Sep-13
170	A2360	Install All Fixtures & GRDs	2	19-Sep-13	20-Sep-13
171	A2390	Finishes (paint & flooring)	4	25-Sep-13	30-Sep-13
172	A2790	Floors 4,5 Complete	1	07-Nov-13*	07-Nov-13
173	**Voigt Thesis.Floor 6 (New WBS)-16**		172	05-Feb-13	07-Oct-13
174	A2420	M/P Rough-In	19	05-Feb-13	01-Mar-13
175	A2410	Metal Framing	3	07-Mar-13	11-Mar-13
176	A2430	Electrical Rough-In	34	17-May-13	05-Jul-13
177	A2440	Insulation & Drywall	3	09-Sep-13	11-Sep-13
178	A2460	Install Doors & Trims	3	16-Sep-13	18-Sep-13
179	A2470	Install Casework	3	19-Sep-13	23-Sep-13
180	A2450	Install All Fixtures & GRDs	2	26-Sep-13	27-Sep-13
181	A2480	Finishes (paint & flooring)	4	02-Oct-13	07-Oct-13
182	**Voigt Thesis.Floor 7 (New WBS)-17**		198	08-Feb-13	15-Nov-13
183	A2500	M/P Rough-In	22	08-Feb-13	11-Mar-13
184	A2490	Metal Framing	3	15-Mar-13	19-Mar-13
185	A2510	Electrical Rough-In	14	03-Jun-13	20-Jun-13
186	A2520	Insulation & Drywall	3	16-Sep-13	18-Sep-13
187	A2540	Install Doors & Trims	3	23-Sep-13	25-Sep-13
188	A2550	Install Casework	3	26-Sep-13	30-Sep-13
189	A2530	Install All Fixtures & GRDs	2	03-Oct-13	04-Oct-13
190	A2560	Finishes (paint & flooring)	5	09-Oct-13*	15-Oct-13
191	A2800	Floors 6,7 Complete	1	15-Nov-13*	15-Nov-13
192	**Voigt Thesis.Floor 8 (New WBS)-18**		179	12-Mar-13	20-Nov-13
193	A2570	M/P Rough-In	6	12-Mar-13	19-Mar-13
194	A2000	Metal Framing	3	25-Mar-13	27-Mar-13
195	A2580	Electrical Rough-In	11	20-Jun-13	05-Jul-13



#	Activity ID	Activity Name	Original Duration	Start	Finish
183	A2500	M/P Rough-In	22	08-Feb-13	11-Mar-13
184	A2490	Metal Framing	3	15-Mar-13	19-Mar-13
185	A2510	Electrical Rough-In	14	03-Jun-13	20-Jun-13
186	A2520	Insulation & Drywall	3	16-Sep-13	18-Sep-13
187	A2540	Install Doors & Trims	3	23-Sep-13	25-Sep-13
188	A2550	Install Casework	3	26-Sep-13	30-Sep-13
189	A2530	Install All Fixtures & GRDs	2	03-Oct-13	04-Oct-13
190	A2560	Finishes (paint & flooring)	5	09-Oct-13*	15-Oct-13
191	A2800	Floors 6,7 Complete	1	15-Nov-13*	15-Nov-13
192	**Voigt Thesis.Floor 8 (New WBS)-18**		179	12-Mar-13	20-Nov-13
193	A2570	M/P Rough-In	6	12-Mar-13	19-Mar-13
194	A2000	Metal Framing	3	25-Mar-13	27-Mar-13
195	A2580	Electrical Rough-In	11	20-Jun-13	05-Jul-13
196	A2590	Insulation & Drywall	3	16-Sep-13	18-Sep-13
197	A2610	Install Doors & Trims	3	23-Sep-13	25-Sep-13
198	A2620	Install Casework	25	26-Sep-13	30-Oct-13
199	A2600	Install All Fixtures & GRDs	2	03-Oct-13	04-Oct-13
200	A2630	Finishes (paint & flooring)	5	09-Oct-13*	15-Oct-13
201	A2810	Floor 8 Complete	1	20-Nov-13*	20-Nov-13
202	**Voigt Thesis.Floor 9 (New WBS)-19**		194	19-Feb-13	20-Nov-13
203	A2650	M/P Rough-In	27	19-Feb-13	27-Mar-13
204	A2640	Metal Framing	3	28-Mar-13	01-Apr-13
205	A2660	Electrical Rough-In	14	02-Jul-13	22-Jul-13
206	A2670	Insulation & Drywall	3	23-Sep-13	25-Sep-13
207	A2690	Install Doors & Trims	3	30-Sep-13	02-Oct-13
208	A2700	Install Casework	3	03-Oct-13	07-Oct-13
209	A2680	Install All Fixtures & GRDs	2	10-Oct-13*	11-Oct-13
210	A2710	Finishes (paint & flooring)	4	18-Oct-13*	23-Oct-13
211	A2820	Floor 9 Complete	1	20-Nov-13*	20-Nov-13
212	**Voigt Thesis.PenthouseMEPF (New WBS)-**		55	22-Feb-13	09-May-13
213	A2740	HVAC Rough-In	5	22-Feb-13	28-Feb-13
214	A2730	Install RTUs	17	27-Feb-13	21-Mar-13
215	A2720	Metal Framing	4	05-Apr-13	10-Apr-13
216	A2750	Electrical Rough-In	14	22-Apr-13	09-May-13
217	A2760	Receive & Install MCC & ATS	10	22-Apr-13	03-May-13
218	**Voigt Thesis.Final Completion (New WBS)-**		1	29-Nov-13	29-Nov-13
219	A2830	Final Completion	1	29-Nov-13*	29-Nov-13



Appendix D – Analysis #2: Foundation Details

Concrete pier + footing
Footings range from 4'6"x4'6" to 11'x11'
Elevations 59-64'

14"d auger pressure grouted piles w/caps
Tip elevations 46-49'

Spread Footings
Elevations 96.5'

Existing Foundation

Activity ID	Activity Name	Original Duration	Remaining Duration	Start	Finish
Floors					
Concrete					
No Sub Sequence					
CONCP305	Pour Footings & Strap Beams - East	8	8	08-Aug-12	17-Aug-12
CONCP320	Pour Footings & Strap Beams - North	10	10	10-Aug-12	23-Aug-12
CONCP310	Pour Footings & Strap Beams - South	7	7	15-Aug-12	23-Aug-12
CONCP315	Pour Footings & Strap Beams - West	5	5	20-Aug-12	24-Aug-12
CONCP325	Form/Reinf/Place Foundation Walls/Col P3 to I	5	5	20-Aug-12	24-Aug-12
CONCP350	Form/Reinf/Place Elevator/ Sump Pits	5	5	20-Aug-12	24-Aug-12

Actual Work ◆ ◆ Milestone

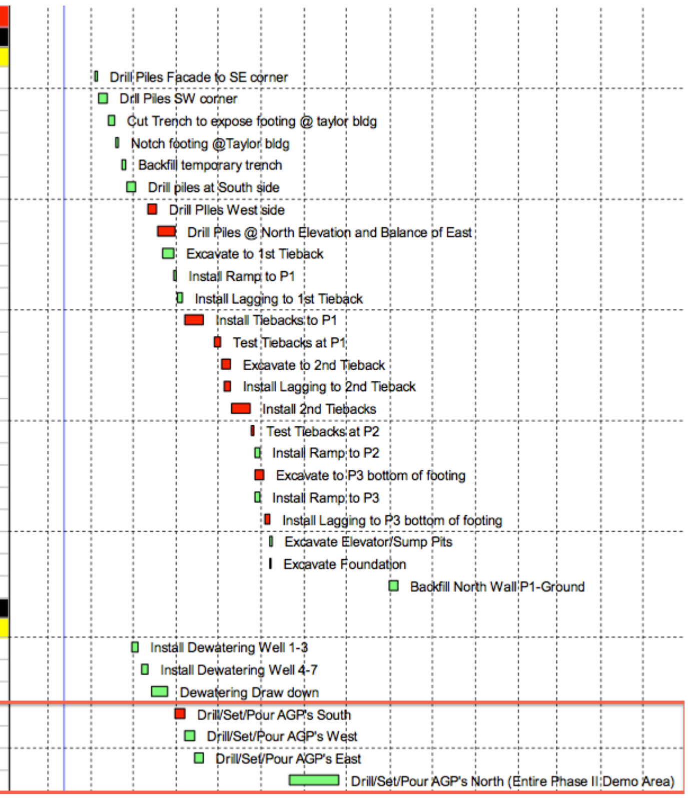
Remaining Work

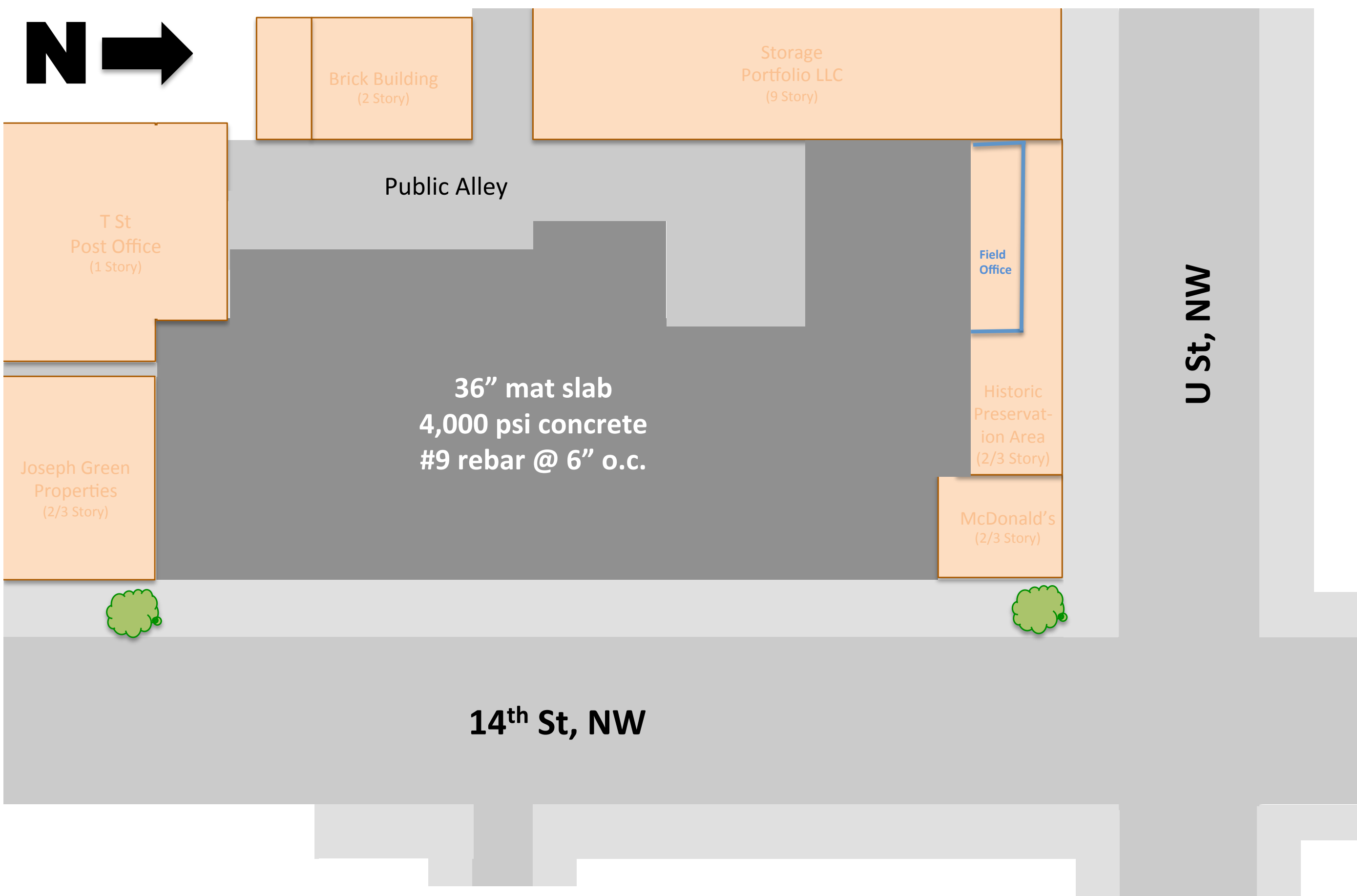
Critical Remaining Work

J Street - Baseline revised 4-18

y ID	Activity Name	Original Duration	Remaining Duration	Start	Finish
CONCP355	Form/Reinf/Place Elevator Shaft	3	3	24-Aug-12	28-Aug-12
CONCP330	Form/Reinf/Place Foundation Walls/Col P3 to I	5	5	24-Aug-12	30-Aug-12
CONCP340	Form/Reinf/Place Foundation Walls/Col P3 to I	5	5	24-Aug-12	30-Aug-12
CONCP335	Form/Reinf/Place Foundation Walls/Col P3 to I	5	5	27-Aug-12	31-Aug-12
CONCP345	Install Underdrain/Prep & Pour SOG A-D.5	5	5	04-Sep-12	10-Sep-12
CONCP360	Form/Reinf/Place Stairwell to P2	2	2	11-Sep-12	12-Sep-12
CONCP365	Install Underdrain/Prep & Pour SOG D.5-J	5	5	11-Sep-12	17-Sep-12
CONCP300	Form/Reinf/Place Elevated Slab A-D.5	5	5	11-Sep-12	17-Sep-12
CONCP370	Form/Reinf/Place Elevated Slab D.5-J	5	5	18-Sep-12	24-Sep-12
CONCP220	Form/Reinf/Place Foundation Walls/Col P2 to I	4	4	18-Sep-12	21-Sep-12
CONCP260	Form/Reinf/Place Stairwell to P1	5	5	18-Sep-12	24-Sep-12
CONCP210	Form/Reinf/Place Foundation Walls/Col P2 to I	4	4	24-Sep-12	27-Sep-12
CONCP230	Form/Reinf/Place Foundation Walls/Col P2 to I	4	4	24-Sep-12	27-Sep-12

Foundations					
Excavation					
No Sub Sequence					
SUBS1000	Drill Piles Facade to SE corner	3	3	03-Apr-12	05-Apr-12
SUBS1040	Dril Piles SW corner	5	5	06-Apr-12	12-Apr-12
SUBS1080	Cut Trench to expose footing @ taylor bldg	3	3	13-Apr-12	17-Apr-12
SUBS1090	Notch footing @Taylor bldg	3	3	18-Apr-12	20-Apr-12
SUBS1100	Backfill temporary trench	3	3	23-Apr-12	25-Apr-12
SUBS1110	Drill piles at South side	5	5	26-Apr-12	02-May-12
SUBS1030	Drill Piles West side	5	5	11-May-12	17-May-12
SUBS1120	Drill Piles @ North Elevation and Balance of Ea	8	8	18-May-12	30-May-12
EXCA1000	Excavate to 1st Tieback	5	5	22-May-12	29-May-12
EXCA1070	Install Ramp to P1	2	2	30-May-12	31-May-12
SUBS1011	Install Lagging to 1st Tieback	3	3	01-Jun-12	05-Jun-12
SUBS1010	Install Tiebacks to P1	10	10	07-Jun-12	20-Jun-12
SUBS1020	Test Tiebacks at P1	3	3	28-Jun-12	02-Jul-12
EXCA1020	Excavate to 2nd Tieback	4	4	03-Jul-12	09-Jul-12
SUBS1050	Install Lagging to 2nd Tieback	3	3	05-Jul-12	09-Jul-12
SUBS1060	Install 2nd Tiebacks	10	10	10-Jul-12	23-Jul-12
SUBS1070	Test Tiebacks at P2	3	3	24-Jul-12	26-Jul-12
EXCA1050	Install Ramp to P2	2	2	27-Jul-12	30-Jul-12
EXCA1040	Excavate to P3 bottom of footing	5	5	27-Jul-12	02-Aug-12
EXCA1120	Install Ramp to P3	2	2	27-Jul-12	30-Jul-12
SUBS1160	Install Lagging to P3 bottom of footing	2	2	03-Aug-12	06-Aug-12
EXCA1100	Excavate Elevator/Sump Pits	2	2	07-Aug-12	08-Aug-12
EXCA1110	Excavate Foundation	1	1	07-Aug-12	07-Aug-12
EXCA1080	Backfill North Wall P1-Ground	5	5	31-Oct-12	06-Nov-12
Foundations					
No Sub Sequence					
SITE1070	Install Dewatering Well 1-3	5	5	30-Apr-12	04-May-12
SITE1080	Install Dewatering Well 4-7	5	5	07-May-12	11-May-12
SITE1310	Dewatering Draw down	10	10	14-May-12	25-May-12
SITE1030	Drill/Set/Pour AGP's South	5	5	31-May-12	06-Jun-12
SITE1050	Drill/Set/Pour AGP's West	5	5	07-Jun-12	13-Jun-12
SITE1040	Drill/Set/Pour AGP's East	5	5	14-Jun-12	20-Jun-12
SITE1060	Drill/Set/Pour AGP's North (Entire Phase II Der	25	25	21-Aug-12	25-Sep-12

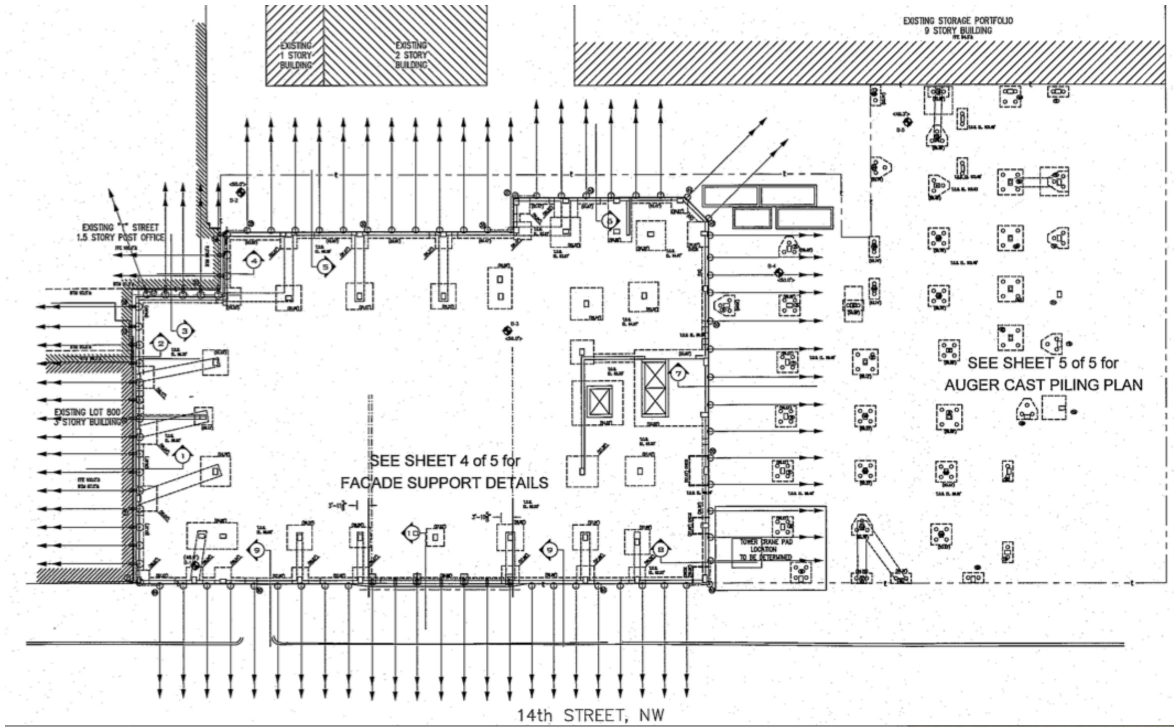


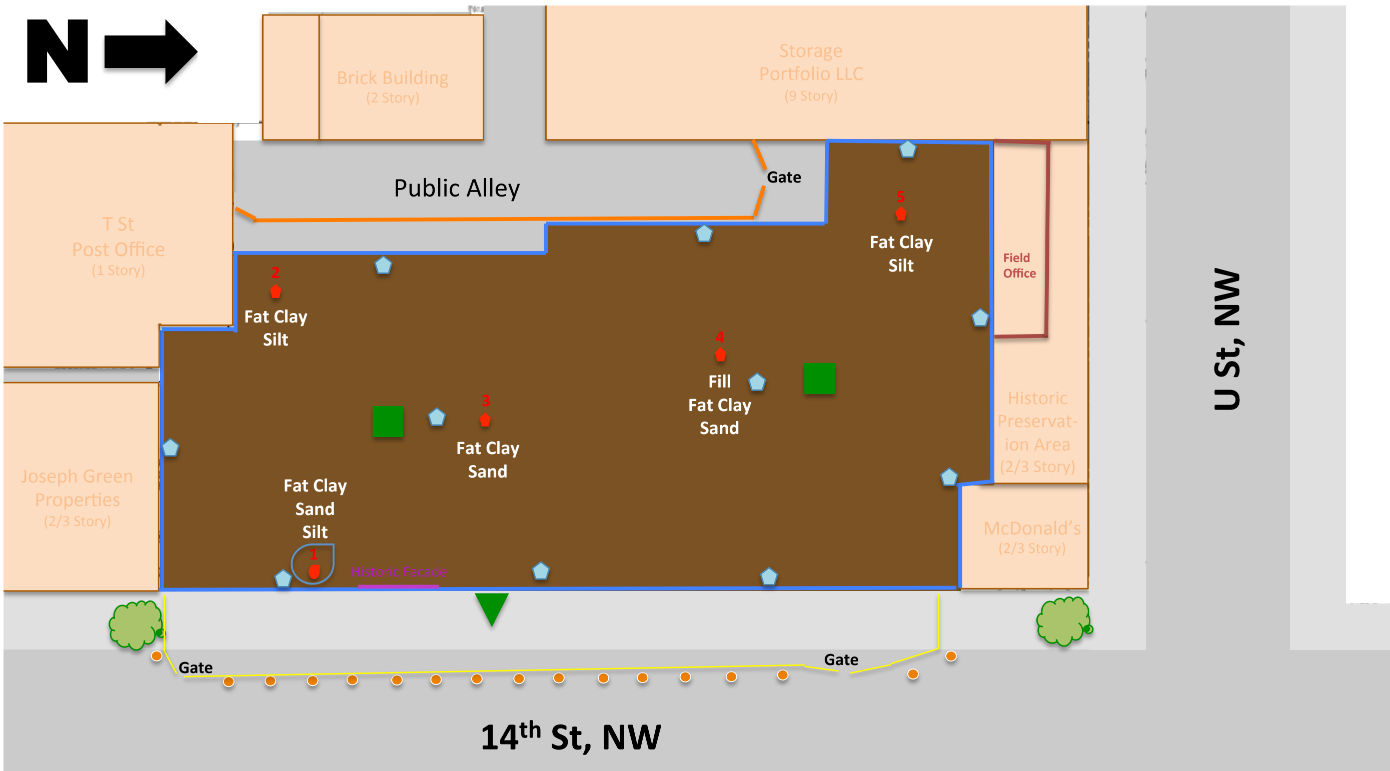


Proposed Mat Slab Foundation

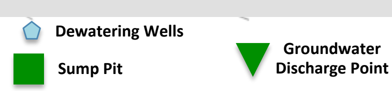
Appendix F – Analysis #3: Detailed Safety Plans

Actual Excavation Support Plan:

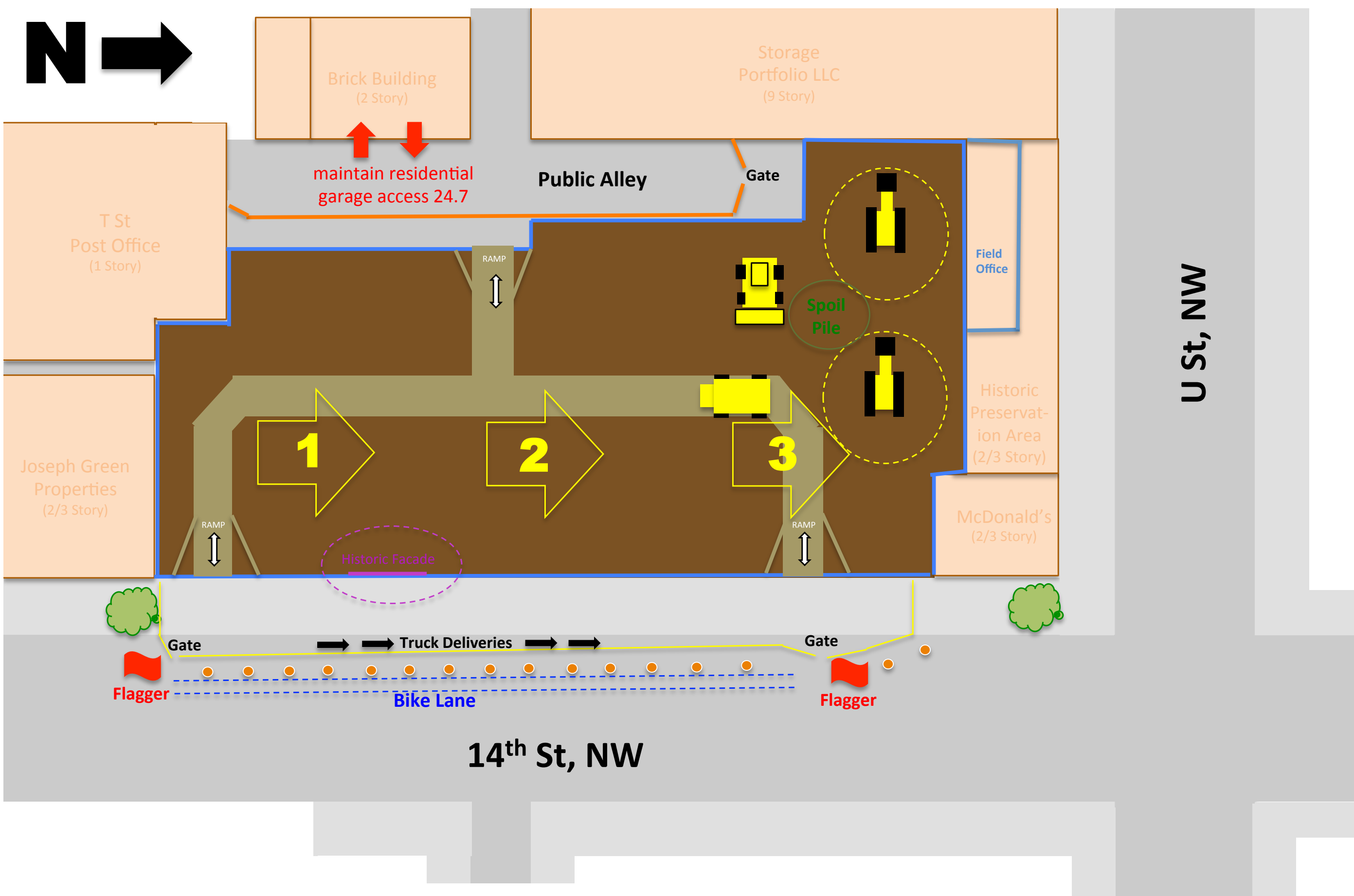




Test Boring No.	Depth to Groundwater (feet)	Groundwater Elevation (feet)
B-1	7.0	EL 91
B-2	19.0	EL 79
B-3	15.5	EL 83.5
B-4	16.0	EL 83
B-5	11.0	EL 88



Ground Conditions



Excavation Access/Egress & Workflow

Actual Dewatering System

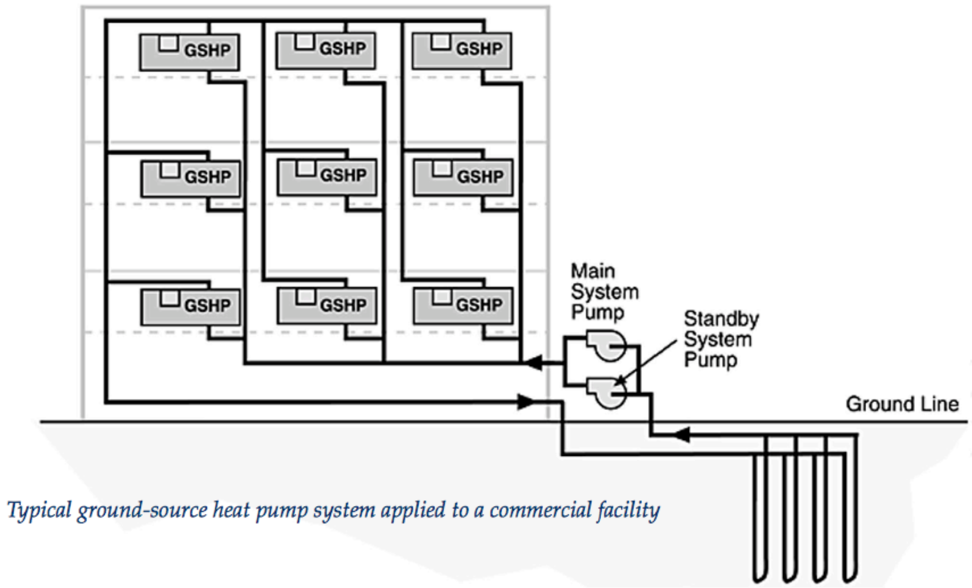
Dewatering Wells

Sump Pit

Groundwater
Discharge Point

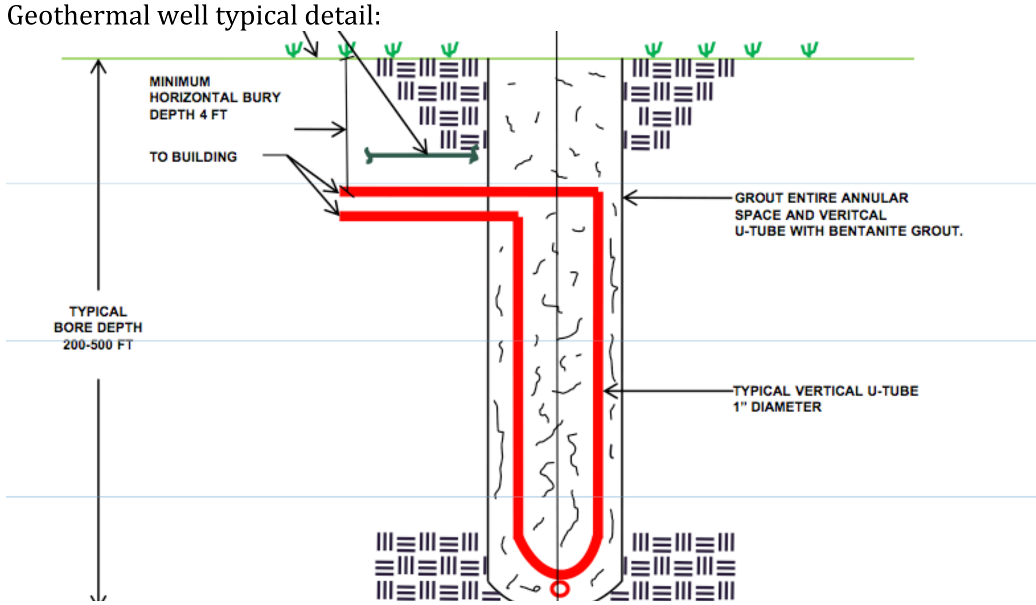
Appendix F – Analysis #4: Geothermal Details

Ground Source Heat Pump schematic as proposed:



Typical ground-source heat pump system applied to a commercial facility

Geothermal well typical detail:



WATER SOURCE HEAT PUMP SCHEDULE (PROVIDED BY TENANT)

TAG	CFM	NOMINAL TONS	ESP	HYDRONIC COOLING					HYDRONIC HEATING				BASIS OF DESIGN		ELECTRICAL DATA			NOTES
				FLOW RATE	MAX WPD	EAT	SENSIBLE	TOTAL	FLOW RATE	MAX WPD	EWT	TOTAL			MCA	MOCP	VOLTAGE	
			IN WG	GPM	FEET	(DB/WB)	MBH	MBH	GPM	FEET		MBH	MANUFACTURER	MODEL OR SERIES	AMPS	AMPS		
WSHP-1-3	2,000	5.0	0.4	16	–	80/67	47.7	58.4	18	–	70	66.3	MAMMOTH	WHSP 062	–	–	480/3/60	1-6
WSHP-4-14	2,800	7.0	0.4	22	–	80/67	69.0	83.8	22	–	70	96.1	MAMMOTH	WHSP 084	–	–	480/3/60	1-6

NOTES:
1. UNITS SHALL BE EQUIPPED WITH ECM MOTORS.
2. R-410 REFRIGERANT ONLY.
3. COORDINATE ALL ELECTRICAL REQUIREMENTS PRIOR TO ORDER.
4. PROVIDE UNIT WITH MERV 6 FILTER.
5. WSHP'S SUPPLIED BY TENANT
6. TENANT TO PROVIDE HOT GAS REHEAT DEHUMIDIFICATION AS REQUIRED.
7. SELECT UNITS WITH ALLOWANCE FOR 20% PROPYLENE GLYCOL SOLUTION.

SCHEDULE AS EXAMPLE ONLY WSHP'S BY TENANT.

ASI#6 ADDED NOTE.
11/27/12 LR

Table 3
RECOMMENDED LEVELS OF ANTIFREEZE SOLUTIONS FOR GCHP SYSTEMS

Recommended % Volume of Propylene Solutions

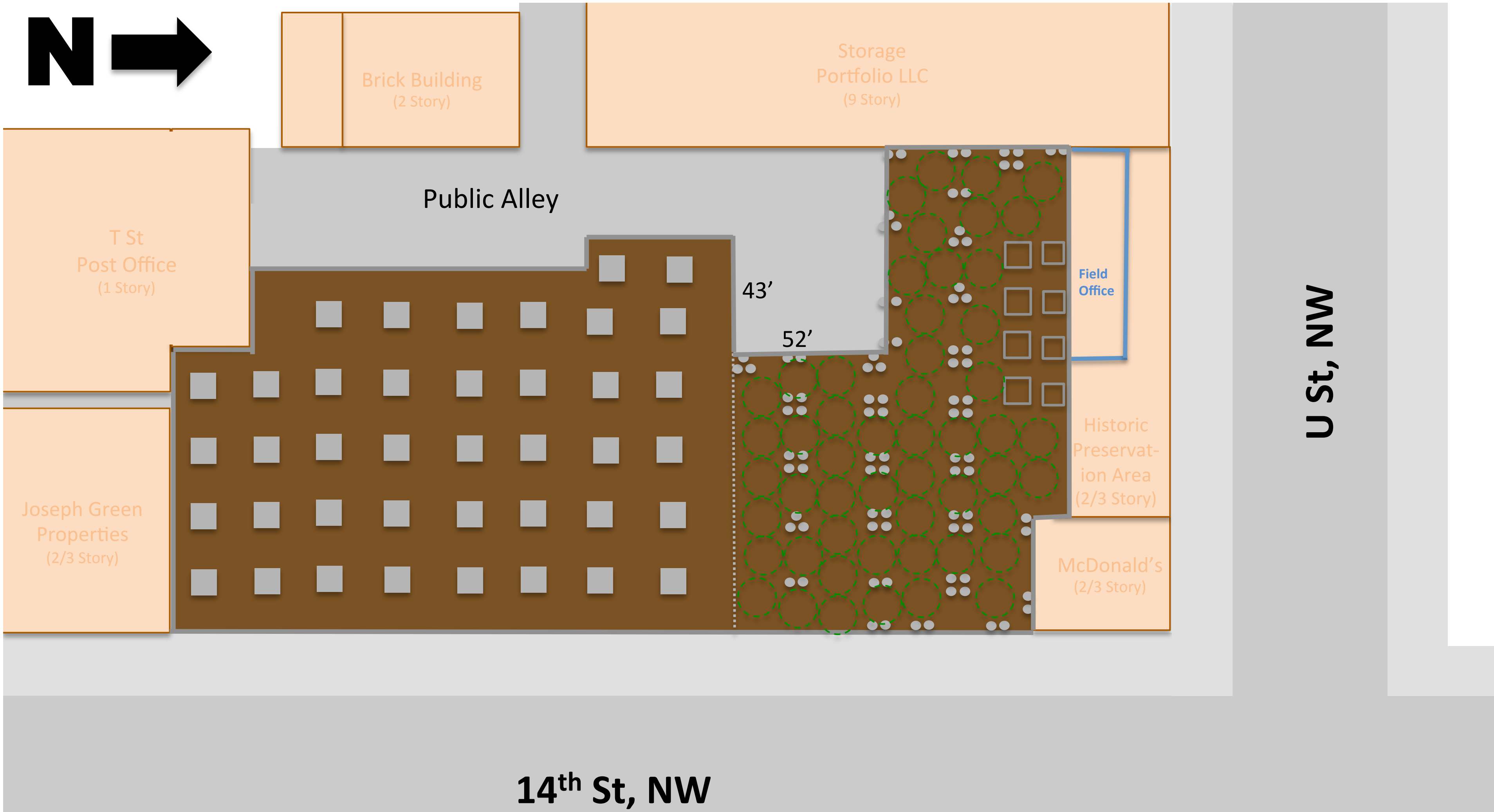
Coil Type	Pitch Ft. pipe/Ft.trench	% by Volume 60 to 63°F Ground	% by Volume 52 to 59°F Ground	% by Volume 44 to 51°F Ground
Slinky	10	10	15	20
6-Pipe or Eqv. Slinky	6	10	15	20
2-Pipe	2	10	15	20
Vertical (3/4" Pipe)	2	0	10	20
Vertical (1 ¼" Pipe)	2	0	10	20

Warning more antifreeze will be required if loops are shorter than those recommended in Tables 1 and 2.

Table 1. Recommended Lengths of Trench or Bore Per Ton For GCHPs
Multiply length of trench by pitch to find required length of pipe.
See Tables 4 and 5 for Thermal Conductivity of Soils and Rocks.

	Pitch	**Ground Temperature - °F**						
Coil Type (See Figure 1 for Details)	**Ft. of Pipe per Ft. Trench (or Bore)**	**44 to 47° F**	**48 to 51° F**	**52 to 55° F**	**56 to 59° F**	**60 to 63°F**	**64 to 67°F**	**68 to 70°F**
Horz. 10-Pitch Slinky	10	125	120	115	120	125	150	180
Horz. 6-Pipe/6-Pitch Slinky	6	180	160	150	160	180	200	230
Horz. 4-Pipe/4-Pitch Slinky	4	190	180	170	180	190	220	260
Horz. 2-Pipe	2	300	280	250	280	300	340	400
Vertical U-tube (3/4" Pipe)	2	180	170	155	170	180	200	230
Vertical U-tube (1" Pipe)	2	170	160	150	160	170	190	215
Vertical U-tube (1¼" Pipe)	2	160	150	145	150	160	175	200

Table 1 based on k=0.6 Btu/hr-ft-°F for horizontal loops and k=1.2 Btu/hr-ft-°F for vertical loops and an annular fill/grout conductivity of 0.85 in vertical loops. For other conditions:

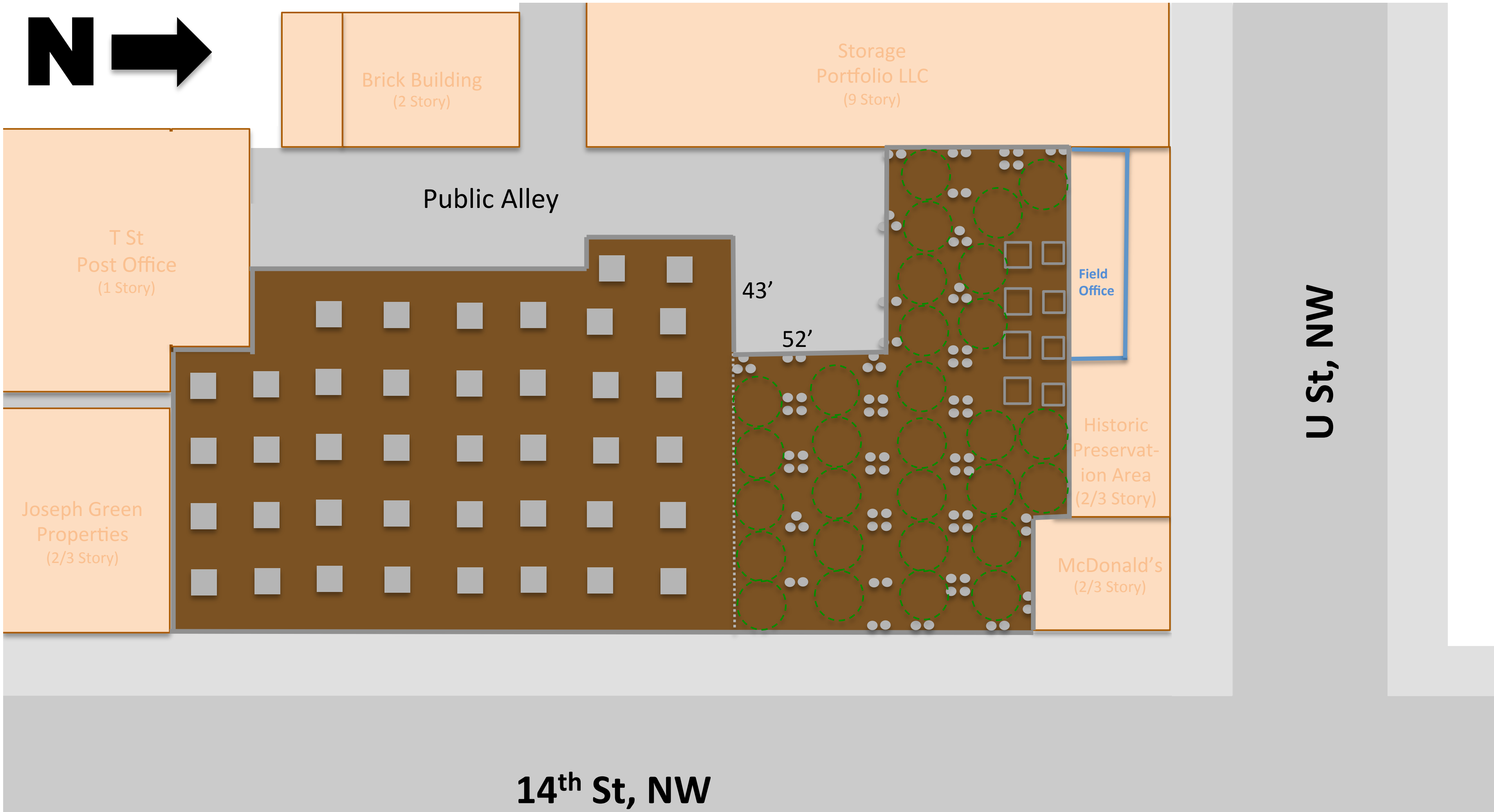


Concrete pier + footing
Footings range from 4’6”x4’6” to 11’x11’
Elevations 59-64’

14”d auger pressure grouted piles w/caps
Tip elevations 46-49’

Spread Footings
Elevations 96.5’

Spacing: 15’d # Wells: 52



Concrete pier + footing
Footings range from 4’6”x4’6” to 11’x11’
Elevations 59-64’

14”d auger pressure grouted piles w/caps
Tip elevations 46-49’

Spread Footings
Elevations 96.5’

Spacing: 20’d # Wells:29

SPX

Recold JT Series

COOLING TOWER

Recold®

Recold, the pioneer of Dri-Fan forced draft evaporative coolers, now applies this principal to the cooling of process water. With the fan in the supply air stream, away from the high humidity air leaving the tower, the fan shaft and bearing are assured longer life.

SYSTEM

The process water enters the spray tree at the top of the unit, is sprayed down onto the heat exchanger surface or "fill", giving up heat to the counterflowing air before returning to the system from the sump pan. Moist air does not enter the fan assembly, resulting in longer life and fewer service problems.

HYDROSPRAY NOZZLES

Hydrospray nozzles are made of non-ferrous material, sized and spaced for optimum wetting of fill. The even distribution of spray across the fill material is extremely important in evaporative equipment.

ACCESSIBILITY

Recold cooling towers are designed for maximum accessibility for inspection and cleaning. Recold patented access doors on both sides of the unit provide ample access to the spray nozzles, fill, eliminators, bleeds and sump pan for service and maintenance. Recold access doors provide a complete air and water tight seal without gaskets or fasteners, and are "quick opening."

CONSTRUCTION

Recold cooling towers are constructed of 300 series stainless steel (basin, fill supports and access doors) and heavy gauge hot dipped G-235 galvanized steel per ASTM A-525.

BLOWERS

A single, slow-speed forward curve blower is used for optimum efficiency and minimum noise. Each blower is balanced to eliminate unit vibration on Recold's high precision electronic balancing equipment. Large blowers are made from galvanized steel and subject to careful quality control throughout. Fan shafts are coated to prevent corrosion. The blower drives are selected at 150% of rated brake horsepower.

Bearings are self-aligning, ball-bearing type, with external lubricating fittings and selected for 2000,000 hour average bearing life. Rugged, OSHA approved, belt guard and screen are provided for protection. Motor is mounted on an adjustable base.

INTEGRATED ASSEMBLY

Recold cooling towers are completely assembled at the factory and shipped as a unit.

FILL

High efficiency is accomplished by using a PVC fill design that provides the maximum amount of wetted surface within allowable airside pressure drop. Fill is conveniently sized for easy removal. The cooling tower fill shall be high efficiency, self-extinguishing PVC, a minimum of 40 mils thick. It shall have a flame spread rating of 25 per ASTM standard E-84 and be impervious to rot, decay, fungus or biological attack.

DRIFT ELIMINATORS

Eliminators are constructed of PVC assembled in removable, easy to handle sections. A three-pass design allows three changes in air flow resulting in decreased drift rates. The use of durable PVC eliminates the corrosion problems associated with galvanized eliminators.

TESTING

All Recold cooling towers are tested under the close supervision of the Quality Control Department before being released for shipment. Fans are run and spray systems operated to assure quiet, balanced operation without leaks, water carryover or vibration. Nozzles are checked for proper distribution.

Use this data for preliminary layouts only. Obtain current drawing from your Marley/Recold sales representative.

The **UPDATE** web-based selection software — available at spxcooling.com — provides JT Series model recommendations based on customer's specific design requirements.

Recold JT Series Cooling Tower — Schematic

MODEL	DIMENSIONS inches								ACCESS DOORS				SUMP gallons note 4
									FAR SIDE		NEAR SIDE		
	A	B	C note 2	D	H	J	K	R	TOP	BOTTOM	TOP	BOTTOM	
JT1830	80	76	31	84	–	6	53	61¼	1	1	–	–	43
JT2140	96	76	37	102	–	6	65	61	1	1	–	–	64
JT2550 - JT2565	115¾	77	45¼	124	51¼	6	76¾	65	1	1	1	1	95
JT3175 - JT3185	139½	80¼	55½	144	51	6	92	67	1	1	1	1	163
JT31100	139½	80¼	55½	144	51	6	92	67	1	1	1	1	163
JT37110 - JT37130	172¼	92½	66⅞	180¼	71¾	6	115	71	2	1	2	1	248
JT37140	172¼	92½	66⅞	180¼	71¾	6	115	71	2	1	2	1	248
JT40160 - JT40180	184¼	98½	93¼	192	84½	8	115	78	2	1	2	1 note 1	374
JT40215 - JT40240	208	98½	93⅜	217	96½	8	139¼	78	2	1	2	1 note 1	454
JT40265	208	98½	93⅜	217	96½	8	139¼	78	2	1	2	1 note 1	454
JT49290 - JT49310	221	118½	100½	225	80	10	139½	102	2	2	2	2 note 1	748
JT49340 - JT49360	245½	118½	100½	248	104	10	164½	102	2	2	2	2 note 1	880
JT49390 - JT49415	268	118½	100½	273	128	10	188	102	2	2	2	2 note 1	1012

Note

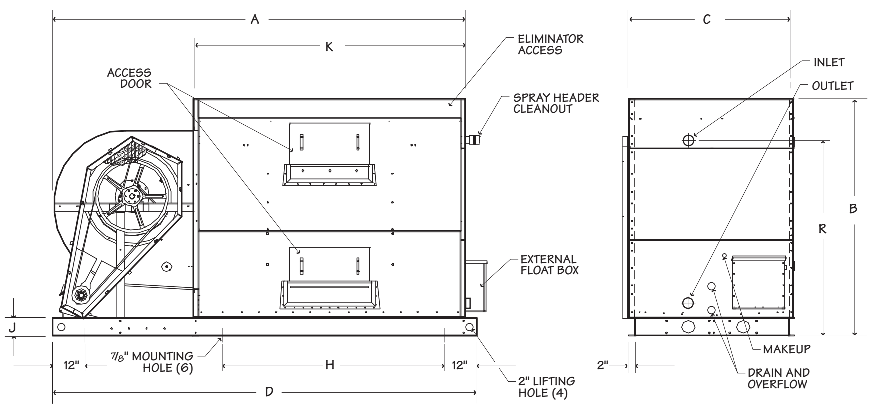
1 An additional bottom access door is installed on inlet connection end.

2 Overall width of unit at base rail is C plus 1".

3 Maximum overall height at blower (fan) section is 118".

4. Water level at top of overflow stand pipe

5 Discharge duct flange is C minus 3" and K minus 3".



Model JT	1830	2140	2550	2565	3175	3185	31100	37100	37130	37140	40160	40180	40215	40240	40265	49290	49310	49340	49360	49390	49415
Nominal Tons†	26	36	47	57	73	83	92	113	130	142	164	178	195	212	232	264	280	300	325	340	364
Supply FPT	½	½	½	½	¾	¾	¾	1	1	1	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼
Drain FPT	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	5	5	5	5	5	5
Inlet MPT	2½	3	3	4	4	4	(2) 3	(2) 4	(2) 4	(2) 4	(2) 4	(2) 4	(2) 4	(2) 4	(2) 4	(2) 5	(2) 5	(2) 5	(2) 6	(2) 6	(2) 6
Outlet MPT	4	4	6	6	6	6	6	6	6	6	6	6	6	6	6	8	8	8	8	8	8
Fan Diamter	18	21	25	25	31	31	31	37	37	37	40	40	40	40	40	49	49	49	49	49	49
Fan RPM	625	600	430	500	350	400	462	360	410	445	385	415	385	415	430	243	267	246	271	253	278
Fan CFM	5880	8060	10800	13300	15700	17100	20200	24000	27300	29700	39100	42500	45100	47200	50300	55500	61000	64500	71000	74200	84500
Motor hp* (0"=¼" SP)	2	3	3	5	5	7.5	10	10	15	20	20	25	20	25	30	25	30	30	40	40	50
Motor Frame	145T	182T	184T	184T	213T	215T	215T	254T	254T	256T	284T	256T	284T	286T	284T	284T	286T	286T	324T	324T	326T
Shipping Weight lb	853	1142	1597	1616	2504	2528	2557	3906	3943	3988	5133	5194	5579	5675	5709	7886	7916	8486	8624	8978	9028
Operating Weight lb**	1210	1675	2390	2410	3870	3900	3915	5980	6010	6060	8250	8310	9365	9460	9500	14120	14150	15820	16000	17410	17460

† Nominal tons are based upon 95°F HW, 85°F CW, 78°F WB and 3 GPM/ton. The UPDATE web-based selection software provides JT model recommendations based on specific design requirements.

* For static pressure from ¼" to ½" ESP, use next size larger motor.
** At normal operating water level in cold water basin.
Note: All piping connections are for standard GPM. Consult Recold for other flow rates.

CAPACITY CONTROLS

Dual Fan Motors—The dual fan motor package is available as a proven energy saving capacity control option. It consists of furnishing a high efficiency motor, a 1200 RPM, low speed motor, two sets of drives and belts, extended fan shaft and motor bases on opposite sides of the blower. A UL control-starter panel is available as a completely wired package for one point connection.

Variable Speed Drive—A Variable Speed Drive automatically minimize the tower's noise level during periods of reduced load and/or reduced ambient temperature without sacrificing the system's ability to maintain a constant cold water temperature. This is a relatively inexpensive solution, and can pay for itself quickly in reduced energy costs.

Electric Damper Controls—An electric damper control package is available as an accessory for modulating the internal damper system. A proportional solid state actuator is factory mounted below the fan scroll and attached to the damper shaft by connecting linkage. A sensing bulb connected to the actuator by a capillary tube is normally mounted in the unit pan water basin for monitoring the system. However, when specified, a pressure control may be supplied for field mounting to allow direct head pressure control. An end switch located inside the motor actuator may be adjusted to cycle the fan motor on for pressure rise and off when dampers close.

CASING INSULATION

In order to further reduce the heat loss from the unit coil, factory installed insulation on exterior coil panels is available. A protective coat of paint is applied to the insulation for protection from the weather elements.

CONTROL – STARTER PANEL

Contains the fan motor starter, disconnect switch, thermostat sensing the cold water temperature to control the fan motor and control transformer when required by the supply power characteristics. All components are contained in a NEMA 12 enclosure with UL label and mounted on the unit. Fan motor and controls are factory wired to the panel to provide single point connection for users power supply.

Panels for dual fan-motor arrangement include elapsed time meters for both motors to aid in determining energy savings. NEMA 3R and 4 enclosures are also available.

VIBRATION ISOLATORS

Spring type vibration isolator rails may be supplied for field installation—some units will require base frame structural support.

ELECTRONIC WATER LEVEL CONTROL

The electronic water level control package provides a constant and accurate means of monitoring water level in the unit. For this reason, it is often recommended for those installations which require year round operation in low ambient conditions.

The complete package includes an electric float switch with stilling chamber which is factory installed in the pan section of the unit. An electric solenoid valve for water make-up is shipped loose for remote installation. All wiring must be provided in the field by others.

PAN HEATER

The use of a remote sump tank located indoors is a common form of pan water freeze protection for evaporative cooling equipment. However, for those installations which will not allow this type of system, freeze protection may be provided by electric immersion heaters or steam or hot water coils installed in the pan.

The electric heater package consists of immersion heaters installed in the pan to provide efficient even heat distribution. Standard heaters are selected to provide approximately 40°F pan water at -10°F ambient temperature. A low water cutout switch is supplied to prevent heater operation when the elements are not completely submerged. The heaters are monitored by a sump thermostat with remote sensing bulb located in the pan water. All heaters and controls are factory installed for field wiring by others.

NOTE: Pan heater packages are designed to prevent pan water freezing during unit shutdown with fans and pump idle.

STAINLESS STEEL CONSTRUCTION

In addition to the standard stainless steel basin, fill supports and access doors, 300 stainless steel construction is offered as an option for upper casing panels.

SPX®

SPX COOLING TECHNOLOGIES, INC.

550 W MERCURY LANE

BREA, CALIFORNIA 92821 USA

P: 714 529 6080

F: 714 529 3603

spxcooling@spx.com

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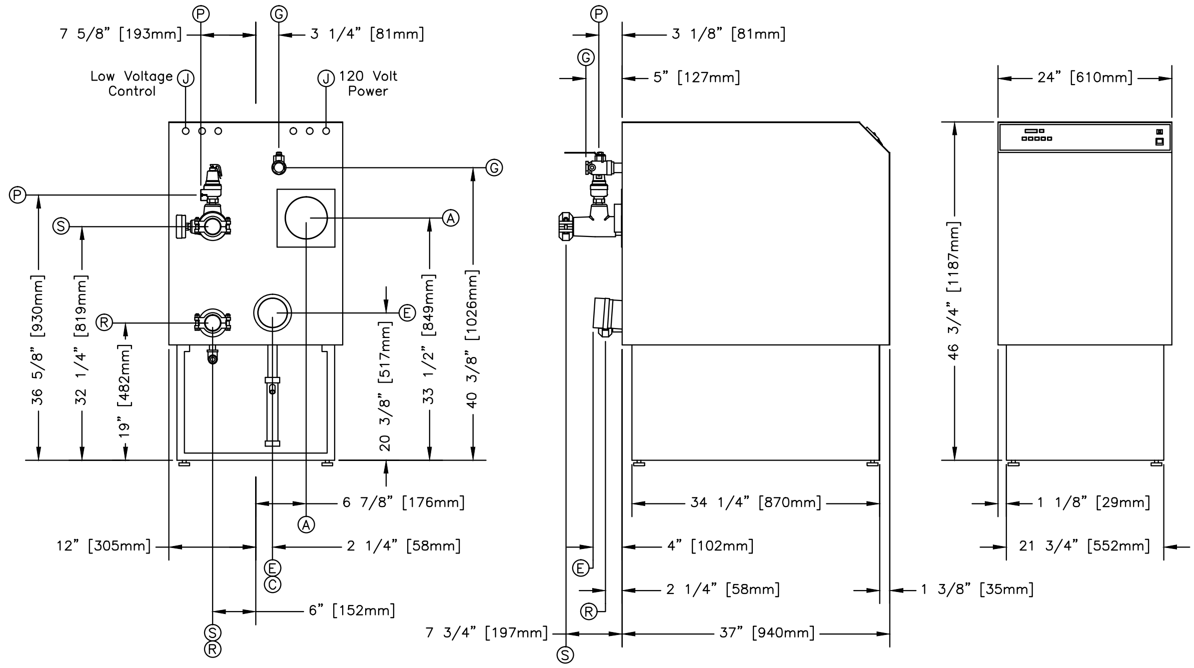
ISSUED 2/2012 RECOLD JT-TECH-07A

MACH® Model C-300
ENVI® Control



Service Clearances:
24" [610mm] Above
36" [914mm] Front

The MACH® Boiler requires category IV venting (condensing-positive pressure) as defined in ANSI Z223.1/NFPA 54/CSA-B.149 Latest Edition.
Harsco Industrial, Patterson-Kelley reserves the right to make changes at any time without notification.

BOILER CONNECTIONS:	
Ⓐ Combustion Air Inlet	6" dia stub
Ⓒ Condensate Drain	3/4"
Ⓔ Exhaust Vent	100mm ID (4"nom ID)
Ⓖ Main Gas Connection	3/4" NPT-F
Ⓙ Wiring Junction Boxes	as marked
Ⓟ Pressure Relief Valve	see list for selection
Ⓡ Boiler Water Return, Victaulic clamp	2" pipe, grooved
Ⓢ Boiler Water Supply, Victaulic clamp	2" pipe, grooved

Victaulic is a registered trademark of Victaulic Company, Easton, PA, USA

BOILER CONTROLS: ASME CSD-1 is standard. Complies with GE GAP (IRI) guidelines GAP.4.1.0 and GAP.4.1.3. Complies with FM Global 6-4/12-69 Section 1.0
Main Gas Train: see gas train submittal
Integrated Boiler Control, ENVI® Series
Operating Thermostat, 70°-195°F (21°-91°C)
High Limit Thermostat, Manual Reset, 100-200°F (38°-93°C)
High Exhaust Pressure Switch
LWCO, Probe Type, Manual Reset
Air Switch, Differential Pressure Type
Combustion Blower, Variable Speed, 100 watt (0.13 hp)

C.S.A. CERTIFIED RATINGS AND CAPACITIES		
Fuel	☐ Natural Gas(NG)	☐ Propane(LP)
Input, BTU/hr		300,000
Output, BTU/hr		276,000
Boiler HP:		8.3
Maximum Inlet Gas Pressure:		14"w.c.
Minimum Inlet Gas Pressure:		3.5"w.c.

Electrical Requirements	120v, 1ph, 60hz
Total Operating Amps	less than 5 amps
Operating Weight	420 lbs.
Water Content	2.9 gallons

A.S.M.E. Section IV Design Data	
Maximum Pressure	80 psig
Maximum Temperature	200°F
Heated Wet Surface Area:	10.66 sq.ft.
Flow rate @ 20°F ΔT	28 GPM
Flow rate @ 40°F ΔT	14 GPM

Pressure Relief Valve/Press-Temp Gauge Shipped Loose for Field Installation		
☐	30 PSIG 3/4"	0-100psi/30-240°F
☐	50 PSIG 3/4"	0-100psi/30-240°F
☐	60 PSIG 3/4"	0-100psi/30-240°F
☐	75 PSIG 3/4" x 1"	0-240psi/30-240°F
☐	80 PSIG 3/4" x 1"	0-240psi/30-240°F

HARSCO
INDUSTRIAL
Patterson-Kelley