April 4, 2011

SENIOR THESIS FINAL REPORT

PENN STATE AE SENIOR THESIS

SUPPORT SERVICES BUILDING

PENN STATE MILTON S. HERSHEY MEDICAL CENTER – HERSHEY PA

WILL LAZRATION

CONSTRUCTION MANAGEMENT

DR. RILEY

SUPPORT SERVICES BUILDING

Penn State Milton S. Hershey Medical Center - Hershey PA

PENNSTATE HERSHEY Milton S. Hershey Medical Center

Project Overview

- **Function:** Mixed Use- Warehouse/Office
- **Size:** 42,796 SF
- **Number of Stories:** 2 +1000SF Basement
- **Construction Type:** II
- **Construction Dates:** 6/1/2010 – 9/30/ 2011
- **Construction Cost:** $14,395,331 GMP
- **Delivery Type:** Design-Bid-Build
- **Zoning:** (MC) Medical Campus zoning district for Derry Township, PA

Project Team

- **Owner:** Penn State Milton S. Hershey Medical Center
- **Architect:** Highland Associates
- **Consultant:** Relocation Consulting & Mgmt, Inc.
- **Geotechnical Consultant:** Hillis-Carnes Engineering Assoc.
- **Civil Engineer:** Gannett Fleming
- **Consulting Civil Engineer:** Acker Associates, Inc.
- **Landscape Architect:** Pennoni Associates, Inc.
- **ICRA Consultants:** EIC Consultants
- **Construction Manager:** Alexander Building Construction Co.

Architecture

Building Facades:

- 4” Arriscraft masonry veneer with a deep sandblasted finish, color Driftwood
- Centria Formwall Flush Smooth metal panels, color #9946 Silversmith
- Centria Formwall Graphics Flush Smooth metal panels, color #9948 Champagne Bronze
- Glass curtain wall comprised of either 7” or 4 ½” framing with 1” thick PPG-Atlantic Solorban 60 (green tinted) glass

Roofing:

- 1 1/2” metal roof deck, 2 layers of 2” ridged insulation, 1/4” dens-deck sheathing, and cold applied asphalt roofing

Sustainability

Project is expected to achieve a LEED Certified rating for LEED 2.2 by;

- Diverting 75% of construction waste from landfills
- Effective use of materials made from recycled content, regional materials, certified woods, and rapid renewable materials (8 credits)
- Low water consumption (5 credits)
- Higher efficiency mechanical system and advanced commissioning (4 credits)
- High indoor air quality (8 credits)
- Additional 5 credits for Sustainable Sites by reducing heat island effect, and minimizing the building footprint

Structural

- Rigid Steel Superstructure cast on micropiles and gradebeams
- Total of 152 120-Ton micropiles, 60 of which are battered
- Average micropile length of 67’ with 12’ minimum embedment into bedrock
- Typical column size: W13x33
- Typical beam & girder sizes: W14x22, W18x35 & W21x44
- SOG at Tunnel Level is a 12” one-way slab
- SOG at 1st level is a 6” slab
- Elevated slabs are 3 1/2” NW concrete supported by 2” composite metal deck w/ 3/4” shear studs.

Mechanical

- Primary System: VAV w/ reheat coils
- 3 Roof Top Units capable of providing 136 Ton cooling, 1,214MBH heating, and 30,000 CFM of air.
- 2 Gas Boilers supply 45 GPM & 140°F water each
- 18 Exhaust Fans located at key locations
- MERV 8 Filters
- 2 types of fire suppression systems: wet sprinkler system & early suppression fast response (ESFR)

Electrical

- 13.8KV power stepped down by 500KVA transformer to 277/480V 3Ø to feed building.
- 600A Main Distribution Panel
- 150KVA Transformer to step power down to 208Y/120V for additional 8 panel boards
- 17-277V light fixtures and 3-120V light fixtures

Specialty Systems

- Compressed Air System w/ 2-100 gallon air compressors
- High Pressure Spray System—Splash N Dash model manufactured by the Jim Coleman Company.
- Paint Booth—Paint Booth Technologies Model PBT-IE-1212.
- Vertical Transportation: 12,000lb freight elevator & 3,000lb passenger elevator

WILL LAZRATION - CONSTRUCTION MANAGEMENT

http://www.engr.psu.edu/ae/thesis/portfolios/2011/wjl5012/index.html

ACKNOWLEDGEMENTS

I would like to personally thank all of those who helped for their support, assistance, and guidance over the past two semesters with my senior thesis project.

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Mr. Chris Sylves

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(S) – Contributes to Structural Breadth, (E) –Contributes to Electrical Breadth

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EXECUTIVE SUMMARY

Senior Thesis Final Report is intended to discuss the findings and conclusions of the three analyses that were performed on the Penn State Milton S. Hershey Medical Center's Support Services Building. The 42,796SF facility started construction on June 1st 2010 and is schedule for completion by September 2011. Each of first two analyses were selected in order to add value, decrease schedule duration, or fix a constructability issue within the project. Analysis three was selected in order to incorporate renewable energy sources and increase the sustainability of the Support Services Building. This will help make it a platform for Penn State to conduct further research into operating techniques of buildings with this technology and develop the best way to incorporate renewable energy sources into their new building projects in the future.

ANALYSIS 1: ***RE-DESIGN OF FOUNDATION SYSTEM***

PSUHMC's Support Services Building was set on a micropile foundation system based on the recommendations of the Geotechnical Report. The report however was based on column loads that far exceed actual column loads for almost two-thirds of the structure. This analysis took a further look into the soil conditions, actual loading conditions, and a new foundation for two-thirds of the building was designed utilizing Geopier Rammed Aggregate Pier and larger spread footings. To replace the micropile foundation for two thirds of the building required the addition of an additional column line to account for differential settlement between the two different foundation systems. Looking at the project's schedule, the re-design of the foundation saved two weeks off the initial project schedule. In total, the re-design of the foundation system saved almost $123,000.00 off the original cost of the project.

ANALYSIS 2: ***ROOFING COMPARISON & ELIMINATION OF OFFSET ROOF***

The Support Services Building utilized HMC's standard cold-applied BUR roofing system. This system is expensive and can have major schedule implications. Also, a 3,600 SF section of the main roof was offset 5' to hide the RTU's. This analysis was broken down into two parts. Part I researched and compared several different roofing types with a pros and cons comparison, with the RoofPoint rating system by the Center for Environmental Innovation in Roofing, and with a schedule and cost comparison. It was discovered that when compared on a sustainability aspect, virtually all of the roofing types were the same and that owners are no longer limited when selecting a sustainable roof. It was determined that the cold-applied BUR was the correct choice; however it was calculated that a TRO roof could have saved the project $87,000.00 and a week on the projects schedule. Part II analyzed the elimination of the offset roof. It was found that the $55,000.00 cost savings to eliminate the offset roof would have been worth exposing the RTU's.

ANALYSIS 3: ***DESIGN TO INCREASE SUSTAINABLE FEATURES USING RENEWABLE ENERGY SOURCES***

Under the original design, the building is on track to achieve a LEED Certified rating upon completion. However the project has utilized very few sustainable techniques that could provide financial benefits to Hershey Medical Center or to Penn State. The focus of this analysis was to increase the sustainability of the SSB by adding renewable energy sources. Part I of this analysis looked into replacing the original air-to-air system with a geothermal system. It was found that the added cost to go with a geothermal system would have been approximately $478,000.00. In Part II of this analysis, a 71.68kW photovoltaic system was designed for the building. Two options for installation of the system were given. Option one simply relocated the RTU's and would cost just under $500,000.00. Option 2, included the installation of the geothermal system and would cost $967,000.00. Total operating savings from the two systems were shown to be $10,000/year in electric costs for the PV array and 40-50% in total energy savings for the geothermal system. Installation of these systems will provide Penn State a larger platform to research the operating techniques of buildings with these systems and help them develop a way to incorporate this type of technology into their new building projects in the future.

PROJECT OVERVIEW

INTRODUCTION

Penn State Milton S. Hershey Medical Center is a state-of the-art research hospital and a branch campus of The Pennsylvania State University that houses the university's College of Medicine. Founded in 1966 by the Pennsylvania State University in large parts from a $50 million dollar gift from the Milton S. Hershey Foundation, the medical center has since grown to over 550 acres, 8,800 employees, and the College of Medicine emits over 600 students annually.

Currently the main receiving/loading dock and many of the main support/maintenance facilities for the hospital are located underneath the main hospital. Although adequate back in 1966, the space is too small and congested to meet the demands of the expanding medical center. It requires large delivery trucks to access the space by backing down the long, narrow lane one at a time because there isn't enough space for them to turn around underneath the hospital. Additional problems with the space included the lack of storage space and small tight quarters within the maintenance shops.

Seeing this major inefficiency, along with the construction of a new cancer center (2008) and children's hospital (currently under construction) the University's Board of Trustees approved the construction of the new Support Services Building to relocate the shipping/receiving dock and many of the medical center's maintenance shops into their own separate building. The Support Services Building will eliminate the inefficiencies of the existing shipping/receiving system, provide ample storage space, provide larger maintenance shops, and will meet the demands of the growing medical campus both now and in the future. Table 1 below summarizes general information about the building.

Building Name:	Support Services Building
Location:	500 University Drive Hershey, PA
Occupancy:	B & S1
Construction Type:	2B
Gross Building Area:	42,796 SF
Number of Stories:	2 +1000SF Basement
Construction Dates:	June 1, 2010 – September 30, 2011
Construction Cost:	$14,395,331 GMP
Delivery Type:	Design-Bid-Build

Table 1: General Building Information

Also identified by PSUHMC and the Penn State Board of Trustees as an additional inefficiency in the medical centers campus was the intersection between Lion Life Drive and Campus Drive. As shown in figure 1 one the next page, vehicles on Lion Life Drive have to wait at a stop sign and let vehicles on Campus Drive pass before turning left onto Campus Drive. With Lion Life Drive being the main access point to the hospital from west, the intersection quickly backs up during shift changes at the medical center. This is also the route in which all the medical supplies are delivered to the hospital. Included in the scope of work of the project was the alignment of Lion Life Drive with Campus Drive. As shown in figure 2 on the next page, the new alignment allows vehicles to travel from Lion Life Drive to Campus Drive without stopping at a stop sign. The alignment also enabled better access to the new Support Services Building for large delivery vehicles.

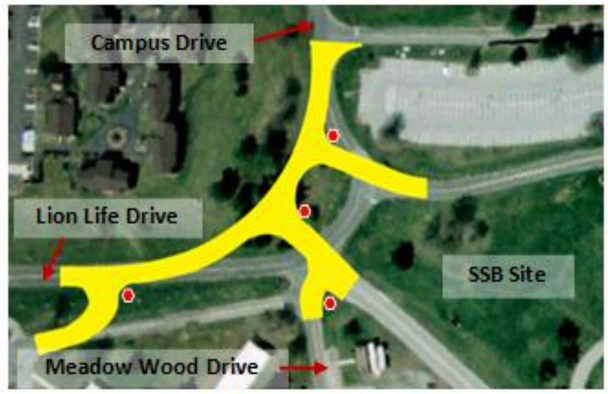


Figure 1: Existing Lion Life Drive & Campus Drive Intersection

Figure 2: New Lion Life Drive & Campus Drive Alignment

CLIENT INFORMATION

Penn State Milton S. Hershey Medical Center is state of the art hospital/research facility that is owned operated by the Pennsylvania State University. Located in Hershey, PA, it provides world class healthcare to thousands of people located in rural central Pennsylvania. It is the only level one pediatric trauma center located between Pittsburgh and Philadelphia. Throughout out all of its different departments, clinics, and institutes, one thing remains constant; their ability to provide the best healthcare available. HMC's ability to provide world-class heath care is due in large parts to cutting edge medical research and training provided through Penn State's School of Medicine. Thanks to the research, patients are able to receive cutting edge care, future healthcare professionals are provided with a world-class education, and new cures and diagnostics are discovered every day.

> *"Penn State Milton S. Hershey Medical Center, Penn State College of Medicine, and Penn State Hershey Children's Hospital are committed to enhancing the quality of life through improved health, the professional preparation of those who will serve the health needs of others, and the discovery of knowledge that will benefit all."*

PSUHMC Mission Statement

Overseeing the construction of the Support Services Building for the medical center is Penn State's Office of the Physical Plant (OPP). Given the high profile of the university, expectations are high for all of their projects. High quality of workmanship, higher end finishes, and completion on time and budget are a staple to any of the University's project. The Support Services Building is no exception to this.

Unique to this project, the demands to finish on budget are extremely high due to the fact that this project won't generate any revenue for the university/medical center. The university has budgeted a certain amount for the project and any overrun would cause the university to go over its annual budget. Also, due to a previous project on the medical center's campus that finished $20 million over budget, the University has made it clear they are looking to recover some of that $20 million on the Support Services Building project and 2 others on the medical center campus. Running over the expected completion date won't necessarily place a burden on the medical center; however it could possibly ruin a good working relationship between a contractor and the University.

As in all projects built by the university public safety and well being is key concern. Construction on the medical center campus however has even higher demands when compared to the other campuses. Unique to the medical center, all projects must follow ICRA (Infectious Disease Risk Assessment) guidelines. Every contractor must have a minimum of their foreman/superintendent go through an ICRA training class when working on the medical center campus, and projects in and around the main hospital require all employees to be trained. The medical center also prohibits large deliveries during specific hours (6:30A.M-8:30A.M & 3:30P.M.-6:00P.M.) in order to keep congestion down during shift changes. The medical center is also very stringent on the cleanliness of their roads. Tire washes are required on any project where open earth is exposed and often a full-time street sweeper is required. Knowing all of this is vital before any contractor considers working at the medical center.

PROJECT DELIVERY METHOD

Penn State Milton S. Hershey Medical Center's Support Services Building was built using the traditional **Design-Bid-Build** with a **CM at Risk** delivery method. Alexander Building Construction Co. is the CM at Risk for the project with a negotiated guaranteed maximum price (GMP) that was agreed upon once the project had been bought out. Included in the GMP are allowances to deal with unforeseen site issues such as unsuitable soils and sinkholes which are prone to the area. Traditionally the university uses the Design-Bid-Build delivery method on all of their major construction projects. With the Support Services Building's size and complexity, this type of delivery method is appropriate. Only subcontractors prequalified by both Alexander and Penn State were permitted to bid on the project. After holding scope review meetings with the three lowest bidders per bid package, a final lump sum contract was awarded to whomever Alexander and PSU selected. Typically the contract was awarded to the lowest bidder. Figure 3 below represents the contractual organization and lines of commutation of the project.

On the project, Alexander was required to submit a payment a Performance and Payment bond to university. In addition all subcontractors whose contract was greater than $1 million or was determined critical to the project, was also required to submit a performance and payment bond. Builders Risk Insurance for the project is provided by the University and Alexander is providing the General Liability Insurance. The University/Hershey Medical Center has also requested that the project use 10% of WBE/DBE/MBE participation. Each subcontractor was required to submit a form with their bid showing the amount of participation they intend to use.

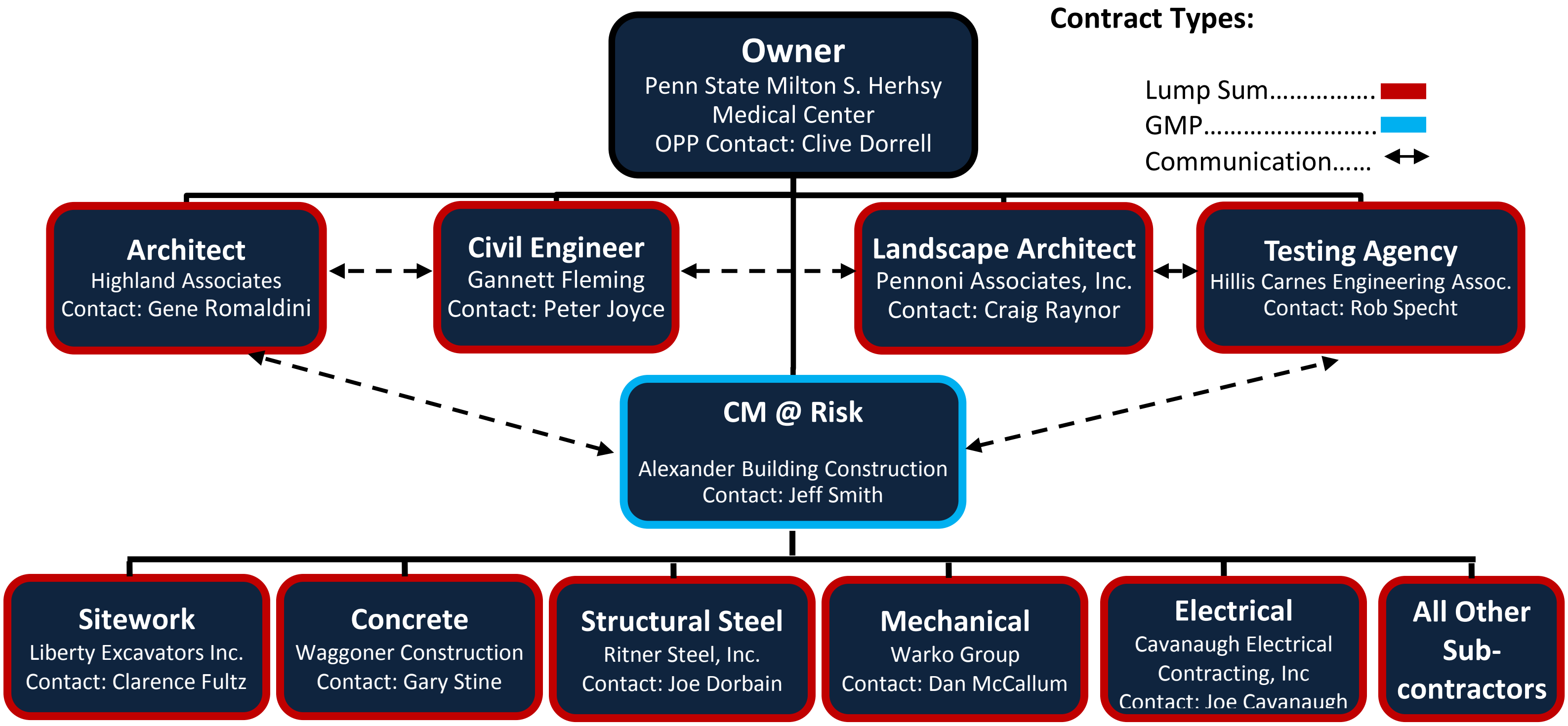


Figure 3: Project Organization Chart

PROJECT TEAM STAFFING PLAN

Alexander Building Construction Co. staffs their project based on project size and complexity. On a project such as the Support Services Building Alexander will utilize a Senior Project Manager, a Superintendent, a Project Manager, a Project Engineer, and a Project Assistant. Project permitting they will also utilize a Carpenter Foreman and an Intern. Behind all of their projects is a team of corporate support personnel located in the company's corporate office in Harrisburg, PA as shown in figure 4 below.

At Alexander a Senior Project Manager is typically responsible for over-seeing 3 - 4 projects. Typically a Senior PM is onsite 2 days a week. A Project Manager is responsible for over-seeing 2 - 3 projects and are generally onsite 3 - 4 days a week depending on project size and complexity. Superintendents are only responsible for one project at a time and on smaller projects can be the only team member onsite. Typically a Project Engineer is responsible for one project but can sometimes be responsible for more than one. Generally they work onsite 5 days a week depending on the project. On their larger project's Alexander will add a Project Assistant and an intern.

For the Support Services Building project all personnel shown in blue below in figure 4 are located in the field office located onsite. All other personnel are shown in red and located back at the main office. Once a week the MEP Coordinator and Cooperate Safety Director visit the site for inspections and meetings. Often the General Manager will also make a weekly visit to check the progress of the project.

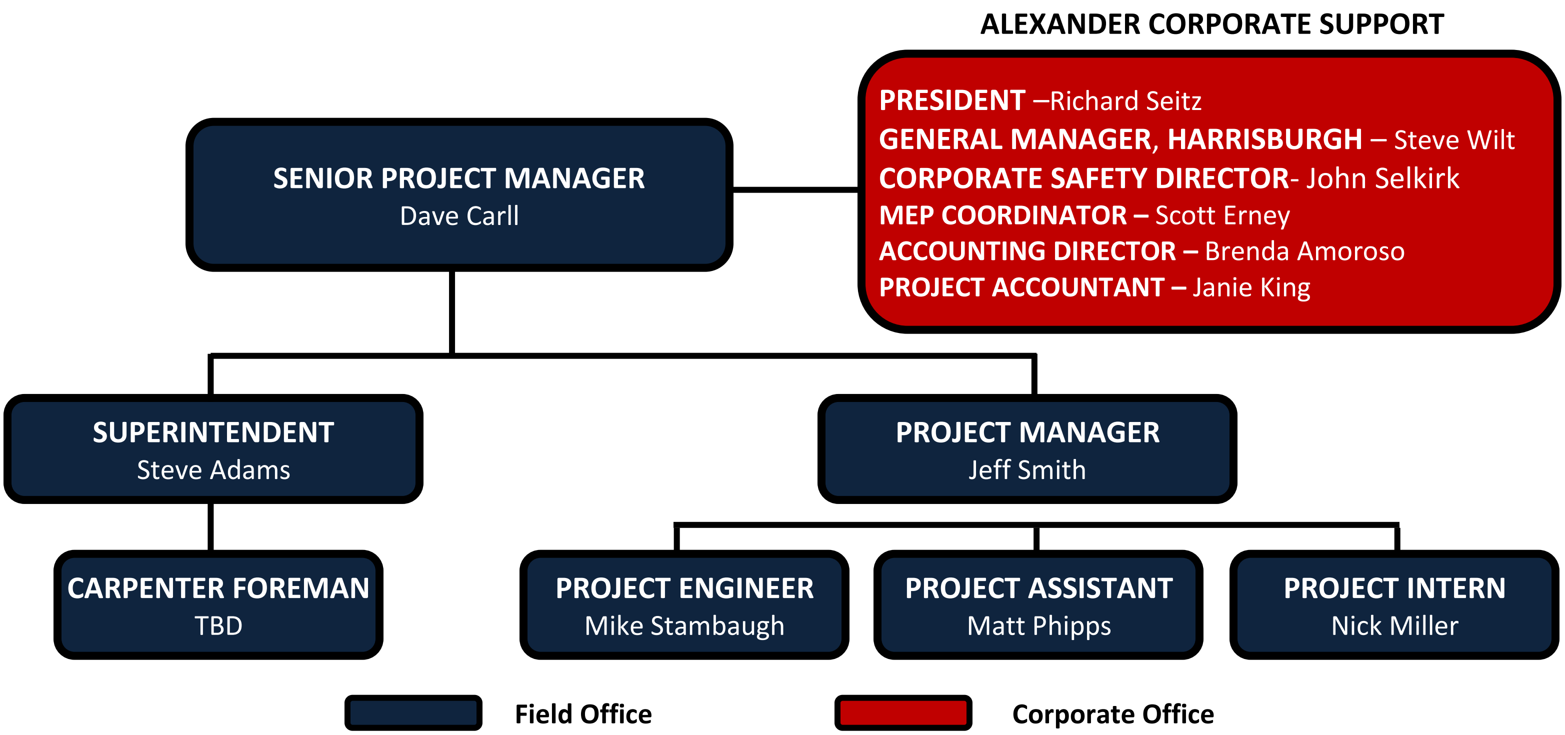


Figure 4: CM Staffing Plan

DESIGN AND CONSTRUCTION OVERVIEW

PROJECT LOCATION

Shown in figure 5 below, Penn State Hershey Medical Center is located just past Hummelstown, PA in Hershey PA where US Route 422 splits off from US Route 322 approximately 15 miles from downtown Harrisburg. The Support Services Building is being built on a triangular shaped site on the southwestern part of the medical center's campus. It is bordered on three sides by the following roads; Campus Drive, Long Lane, and Lion Life Drive. Adjacent to the eastern side of site is the one story NMR Research Facility and located due south of the site is the 2 story Long Lane Building.

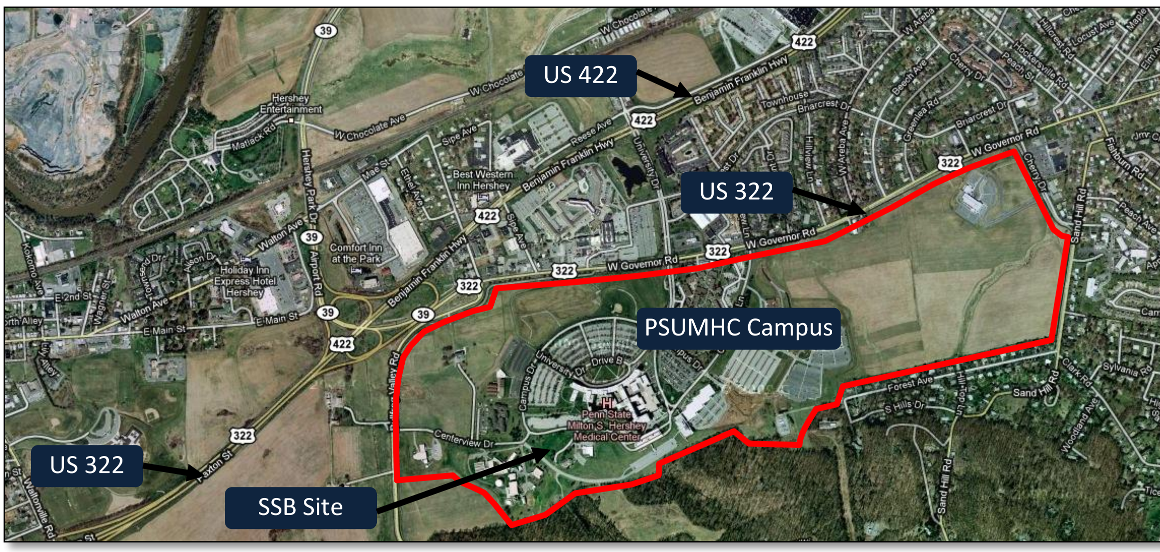


Figure 5: Arial View of Penn State Milton S. Hershey Medical Center & Surrounding Area.
Image taken from Google Maps

Located directly beneath the site (8-10 feet below grade) is a utility tunnel which houses the main steam and chilled water lines to the main hospital. The tunnel also serves as an access path for pedestrians and material distribution from the Animal Research Facility (ARF), Boiler Plant, and the existing loading dock/hospital. Shown in figure 6 at right, a portion of the new building will be constructed atop the tunnel. On the northern side of the tunnel the building will be three stories will the lower level matching that of the existing tunnel floor. It is here where a freight elevator will be located in order to move medical supplies from the new building to the existing hospital. Construction in and around the tunnel was closely via visual inspections and vibration monitoring to maintain the integrity of the tunnel and the utilities located within it.

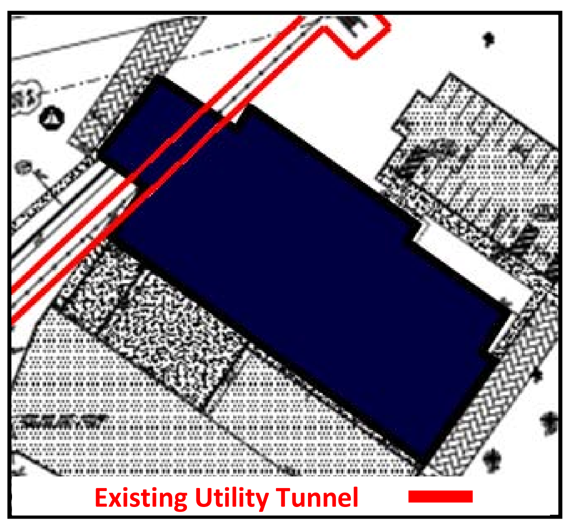


Figure 6: Location of Existing Utility Tunnel

*** See APPENDIX A for the Existing Conditions Site Plan**

LOCAL CONDITIONS

Central Pennsylvania (especially the Harrisburg/Hershey area) can be extremely difficult to build on due to the unpredictability of the karst bedrock formation known as the Epler Formation. Sinkholes can be a common occurrence on every jobsite. With the varying depth of bedrock, large commercial buildings typically utilize micropiles as a deep foundation system in the area. However recent success has been found in utilizing soil improvement methods, like Geopiers® in buildings with both large and small loads. Typically all new construction in the area utilizes a steel superstructure due to local building practices and availably of skilled local workforce.

From the Geotechnical Report the soils on the site are Bedington shaley silt which is known for is deep, well drained soil colluviums. As predicted the subsurface test borings showed the un-predictability of the bedrock formation. Eight test borings were taken and depth to bedrock varied from 36 feet to 52 feet across the site. However it has been found by prior experience on the medical campus for that number to increase within a few feet from the test boring. The borings also found than underneath the 4-5 inches of topsoil is a layer of silty sand (SM) with gravel ranging from 1-18 feet below grade. Below that is a layer of silt with sand (ML) extending down to bedrock. Groundwater was not encountered during the subsurface exploration, which is typical for at these depths in this area.

Due to the fact that Hershey Medical Centers is a major medical research facility that's serves a major portion of central Pennsylvania and houses the Penn State School of Medicine, parking in the hospitals parking lots in prohibited to contractors. With the triangular shaped site, space is a premium. To alleviate congestion most of the subcontractor trailers and parking will be located west of the site in Lot W off Lion Life Drive (See figure 7 below). There is room onsite however for the CM trailer, staff parking, and minimal subcontractor parking. The lot will also be utilized as a construction staging area.

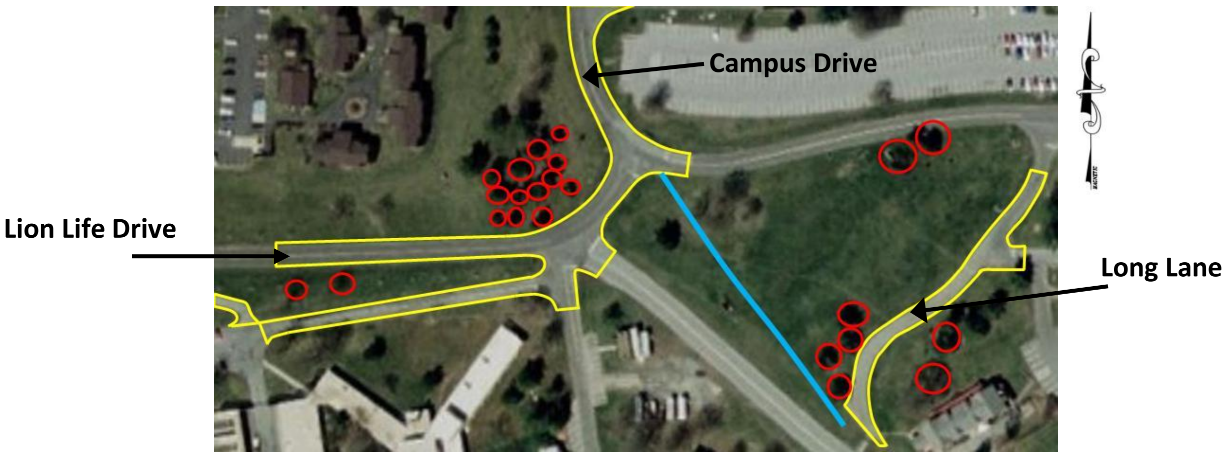
Figure 7: Lot W Contractor Parking & Staging Area. Image taken from Yahoo Maps

In the Harrisburg/Hershey area a typical 30YD dumpster costs $300 per offload and $50/ton for the contents. A 30YD dumpster typically holds around 5 ton of debris for a total of $550 per offload. In the past Alexander has found that dumpsters used for recycled materials (wood, metal, etc.) pay for themselves. Alexander figured that with 75% of construction waste being recycled to help achieve a LEED Certified rating, a dumpster full of non-recyclable material will need to be emptied every 2-3 weeks.

BUILDING SYSTEMS

DEMOLITION

Being that the site that was chosen for the location of the Support Services Building was a barren field minimal demolition was required. However there were approximately 25 evergreen trees, 400LF of an 18" corrugated metal storm drainage pipe, and 45,000SF of asphalt paving that was removed in order to construct the Support Services Building and Campus Drive realignment (See figure 8 below). Of the 45,000SF of asphalt that was removed, approximately 15,000SF came from the removal of a 480LF section of Long Lane (southern part of site) to make room for the building. The remaining 30,00SF of asphalt paving was removed as a part of the realignment of Campus Drive.



LEGEND

Limit of asphalt paving to be removed

18" underground corrugated metal storm drainage pipe to be removed

Tree to be removed

Figure 8: Demolition for Support Services Building

STRUCTURAL STEEL

Acting as the skeletal backbone of the Support Services Building is a rigid steel superstructure. Due to the primary function of the building, interior layout, and construction above the utility tunnel, all bay sizes are different with the largest bay being 31'x36'. Typical column sizes are W10x33 except for the 11 columns surrounding the 3,000 SF, 2-story Central Campus Storage in the center of the building. These 11 columns are the some heaviest pieces of structural steel in the project at over 2 ton/piece. Typical beam and girder sizes are W21x44, W14x22, and W18x35. The lower and upper roofs are supported by a combination of K-Series steel joists, except for the 3,000SF roof above the Central Campus Storage. It is supported by wide flange beams in order to support the weight of the three roof top units (RTU's).

To erect the structural steel, the construction team utilized a 100-ton crawler crane and a smaller mobile crane. As shown in figure 9 at right the crane will be able to track back and forth in the parking lot on the southern side of the building. The parking lot also provides ample room for deliveries and material lay-down areas.

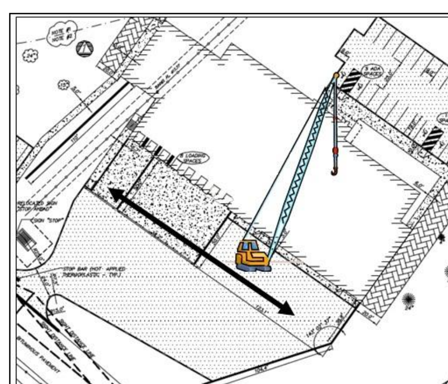


Figure 9: SSB Crane Location

CAST-IN-PLACE CONCRETE

Reinforced cast-in place concrete is utilized for pile caps, foundation walls, slab on grade, elevated slabs, and exterior site retaining walls. All concrete on the project is 4,000 PSI except for the elevated slabs which are 3,500 PSI concrete. All vertical formwork used on the project is Western Forms Flagship Elite series aluminum panels Typical panel sizes are 2'x2', 2'x4', and 2'x8'. Figure 10 below represents the features of a typical panel. All horizontal formwork is at the discrepancy of the subcontractor. Typically dimensional lumber is utilized, however metal is sometimes used (see figure 11 below). The formwork for the elevated slabs is a typical pour stop installed by the steel subcontractor.

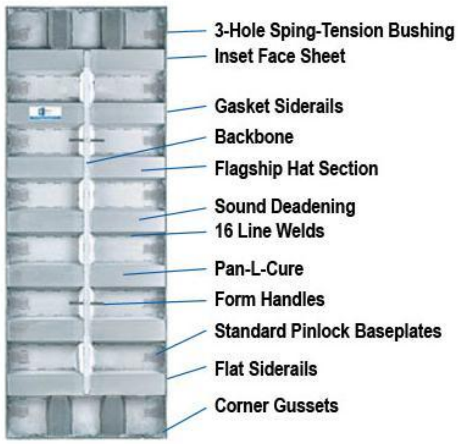


Figure 10: Western Forms Flagship Elite series aluminum panel.
Image taken from westernforms.com

Figure 11: Dimensional Lumber Formwork at Top of Pile Cap

MECHANICAL SYSTEM

The primary mechanical system for the Support Services Building is a forced air-to air system and a VAV system with reheat coils. In total the system contains 44 VAV's capable of providing between 150 – 1,340 CFM. At the heart of the system is the three roof top units (RTU's) and two condensing boilers. Total the three RTU's have a 87 Ton cooling capacity and are capable of providing 30,000 CFM's to the building. Located in the mechanical room on the second floor, each boiler is capable of providing 45 GPM at 140° supply water temperature.

To help maintain a high indoor air quality the Support Services Building is also equipped with a total of 18 exhaust fans ranging in size from 100 – 2000 CFM to keep harmful contaminants from re-entering the air system. The Support Services Building also has two rooftop make-up air units (MAU) that service the Paint Shop and Open Dock Area. To help achieve the LEED Certified rating the boilers and (MAU's) on the project are run off natural gas and all filers have a MERV-8 rating.

Located in the stair towers and vestibules are Cabinet Unit Heaters (CUH) to help heat these spaces. There are for different CUH's on the project ranging in size from 670 – 1210 CFM. To cool the IT rooms, and cool/heat the electrical and elevator machine rooms there is total of five split-system Air Conditioning Units (ACC) which are each individually connected to an Air Cooled Condensing/Heat Pump Unit (CNU) on the roof. All units have an energy efficiency rating of 16 SEER. The ACC's and CNU's for the two IT rooms are capable of providing 1 ton of cooling each. The ACC and CNU servicing the electrical room is capable of providing 1.5 tons of cooling and 20,400 BTUs of heating capacity. Lastly the two ACC's and CNU's servicing the two elevator machine rooms are capable of providing 3/4 ton cooling and 12,200 BTU's of heating capacty.

ELECTRICAL

PSUHMC's Support Services Building gets it power from an existing electrical ductbank that traverses the eastern side of the site. From the ductbank, the primary source (3 #300 KCMIL 15KV EPR cables) and the secondary source (3# 500 KCMIL EPR cables) feed into a PMH-9 Sectionalizing Switch with automatic source transfer control. From the sectionalizing switch 3 #2 15KV EPR cables run to an owner supplied 500KVA transformer. The primary side of the transformer takes the 13.8 KV incoming feed and is stepped down to 277/480V-3Ø on the secondary side feed to building.

From the transformer 2 sets of 4#350KCMIL run to the 600A main distribution panel inside the electrical room located on the 1st floor. From the main distribution panel the power is distributed to either the 3 Roof Top Units (RTU's), 2 elevators, one of 5 panelboards, or to a 150KVA transformer to step the power down to 208Y/120. From the 150KVA transformer the 208Y/120 is distributed to an additional 8 panelboards.

MASONRY

The Support Services Building has a combination of load bearing masonry walls, non-load bearing interior masonry walls, and masonry veneer. The two elevator shafts and three exterior stair towers are constructed of load bearing CMU walls. Two stair towers, stair 1 on the north side and stair 3 on the east side have 12" CMU exterior walls with a 4" Arriscraft Masonry Veneer with a deep sandblasted finish, color Driftwood. The masonry veneer is also carried around the lower portion of the building. The veneer is attached to the building using conventional masonry anchors ever 2 courses of CMU. Figure 12 at right show a finish and color sample of the stone veneer.

Figure 12: 4" Arriscraft Masonry Veneer w/ Deep Sandblasted Finish, Color Driftwood

Many of the first level interior walls are non-load bearing 8" CMU walls. This type of wall was chosen for its durably and for its 1-hr fire rating to separate all of the storage areas/shops. Beneath each CMU wall the SOG is haunched to support the weight of the wall. Several of the walls on the second level are also non-loading bearing CMU walls. Located directly underneath the CMU walls on elevated slabs is a steel beam to support the weight of the wall. To keep the wall from moving #5 dowels are drilled and grouted into the slab every 48".

To erect the CMU walls and apply the stone veneer the construction team will utilize both conventional scaffolding and hydro-mobile scaffolding. Interior CMU walls will be constructed off conventional scaffolding stacked as high as needed. The exterior walls and veneer will be constructed off the hydro-mobile scaffolding. Figure 13 at right shows a typical hydro-mobile scaffolding system.

Figure 13: Typical Hydro-Mobile Scaffolding. Image taken from hydro-mobile.com

CURTAIN WALL

Encasing the exterior of stair 2 in the northwest corner of the building and the vestibule on the north side of building is a two-story glass curtain wall system. The system chosen by the architect (Highland Associates) is a Kawneer 1600 series which features 2½” x 7 ½” aluminum members. For glazing the architect chose a 1” Solorban 60, color Atlantic (green-tinted) by PPG Industries, Inc. The stick-built system will be erected by the installer (Browns Glass) to within a 1/8” in 10 feet plumb tolerance and 1/8” in 20 feet level tolerance.

EXCAVATION SUPPORT

Due to a 20 foot change in elevation across the Support Services Building site and construction around an existing utility tunnel, excavation support was required. Soldier beam & lagging and underpinning were used as the excavation support on the project. Unique to the project, both systems are combined into one hybrid system for support at the existing tunnel. Figure 10 below shows the installation of a steel soldier pile at the existing tunnel.

To support the existing tunnel footer, a steel bracket is welded to the steel soldier beam underneath the bottom of the tunnel footer and the entire system is encased in concrete (see figure 11 at right). 3” hardwood lagging is then place between the steel beams on the excavation side.

Figure 10: Steel Soldier Pile Installation at Existing Tunnel

In the southwestern corner of the site soldier beams and lagging were also used for support where existing trees prohibited the slope of the excavation to be achieved. Typically these systems will be cut off 3 feet below grade and the remaining portion left in the ground.

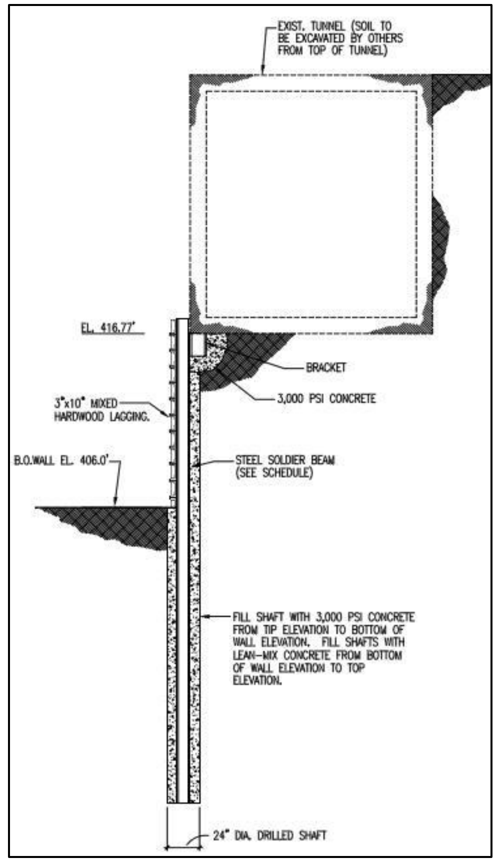


Figure 11: Hybrid of Soldier Beam and Underpinning System at Existing Tunnel

SPECIALTY SYSTEMS

FIRE PROTECTION

There are two types of fire protection systems for the Support Services Building. The final design of both is the responsibility of the Fire Protection subcontractor. The first type of system is an Early Suppression Fast Response (ESFR) and is located in the Central Campus Storage in the center of the building. The remaining parts of the building will be covered by a wet-sprinkler system with the tunnel level and 1st floor being classified as Ordinary Hazard Group 2. The 2nd floor is classified as Light Hazard Group.

COMPRESSED AIR SYSTEM

To meet the demands of the various support shops located in the building, the new Support Services Building will feature a compressed air system. The system is comprised of 1” main line with ¾” drops to the 13 different compressed air outlets. The piping is schedule 40 galvanized steel. Each outlet is a

Ingersoll Rand Series 3000 model with a 1-140 PSI regulator. At the heart of the system is a 2-stage Ingersoll Rand Model 7100E15-FPT30 Air Compressor with a 120 gallon tank capacity capable of supplying 51 CFM of compressed air.

LOW-VOLTAGE SYSTEMS

Included in the Support Services Building are several low-voltage systems. These include a fire-alarm system, security system, and a telecommunications system. The fire alarm system is to be purchased and installed by PSUHMC's fire alarm contractor, Johnson Controls, and is to be an extension of the Medical Centers Notifier Alarm Fire Alarm that was installed and maintained by Johnson Controls. The security system includes card reader's at all exterior doors as well the installation of new card readers inside the tunnel at the Animal Research Facility (ARF) end and at the main hospital end. Included in the security system is 4 security cameras mounted on the exterior of the building. Giving the intended function of the building, the telecommunications system is fairly basic. Typically there is a phone line and data outlets located in all of the offices as well as some of the shops.

PAINT BOOTH

Included in the Support Services Building is a fully functional, self standing paint booth. The paint booth is located inside the paint shop and has its own make-up air system. The paint booth itself is a Paint Booth Technologies Model PBT-IE-1212. The dimensions of the booth are 12' x 12' x 12'h. The paint booth is connected to its own 30" round stainless steel exhaust system.

PROJECT COST

Actual construction costs are based on 8/5/2010 GMP estimate by Alexander Building Construction Co. At that time most of the project had been bought purchased, therefore costs reflect subcontractor bid amounts (shown in table 2 below) and ABC estimates.

PROJECT PARAMETERS	
Square Footage:	42,796 SF
Building Perimeter:	735 LF
CONSTRUCTION COSTS (CC)	
Actual:	$10,534,083
Per SF:	$246.15
TOTAL PROJECT COSTS (TC)*	
Actual:	$14,395,331
Per SF:	$336.37

***Note:** $650,000 of allowances included in total construction costs.

MAJOR BUILDING SYSTEMS ESTIMATE SUMMARY			
System	**Cost**	**Per SF**	**Subcontractor**
Micropiles	$793,301	$18.54	Coastal Drilling East, LLC
Cast-In-Place Concrete	$794,887	$18.57	Waggoner Construction
Masonry	$854,900	$19.98	Caretti, Inc.
Structural Steel & Misc. Metals	$819,529	$19.15	Ritner Steel, Inc.
Roofing and Waterproofing	$642,633	$15.02	Warko Roofing
Aluminum, Glass, & Glazing	$139,150	$3.25	Browns Glass
Fire Protection	$114,500	$2.67	Victory Fire Protection
HVAC	$1,262,096	$29.49	Warko Group - HVAC
Electrical	$1,465,780	$34.25	Cavanaugh Electrical Contracting, Inc.

Table 2: Major Building Systems Cost Estimate

DETAILED STRUCTURAL ESTIMATE

*** See APPENDIX B for complete Detailed Structural System Estimate**

Using the complete set of detailed Construction Documents a complete detailed estimate was performed in lieu of a modular estimate. As shown below in table 3, both the structural and the CIP concrete estimate were within 6% of actual construction costs when similar line items were compared. Using the available information, it is felt that the two estimates are more than reasonable given the parameters and expectations of this thesis.

	Estimated	$/Unit	Actual	$/Unit	
Estimate	**Total:**		**Total**		**% Different**
CIP Concrete	$682,770.68	$359.35/CY	$718,936.00	$378.39/CY	5.03
Structural Steel	$756,388.69	$2,931.54/ton	$716,381.00	$2,761.17/ton	5.8

Table 3: Estimated vs. Actual Cost Comparison

Although only 42,796 SF, the Support Services Building is fairly complex in its own ways. First there are no typical bays located within the structure. Second, the superstructure of the building utilizes 38 different steel wide flange hollow tube steel sections. In total, the project utilized 258 tons of structural steel and over 1,900 CY of concrete. Table 4 below summarizes a more detailed breakdown of quantity and costs per CSI Masterformat for each component in the estimate.

CSI Code	Component	Unit	Unit Cost	Quantity	Cost
32000	Concrete Reinforcing	Ton	$478.61	293.16	$140,310.65
33000	CIP Concrete	CY	$123.09	1,900	$233,864.32
31000	Concrete Formwork	SFCA	$30.24	9,938*	$300,521.30
33510	Polished Concrete Floors	SF	$0.40	20,186	$8,074.40
51200	Steel Beams and Girders (A992)	Ton	$2,286.42	147.1	$336,331.84
51200	Steel Columns (A992)	Ton	$1,953.05	98.6	$192,571.22
52100	Steel Roof Joists	Ton	$1,919.71	12.6	$24,188.39
53100	Metal Floor Decking	SF	$2.85	20,000	$57,000
53100	Metal Roof Decking	SF	$2.05	25,330	$51,926.50
55000	Miscellaneous Steel Items	-	-	-	$94,370.74
				TOTAL:	**$1,439,159.37**

Table 4: Detailed Structural System Estimate Summary

***<u>Note:</u> Aluminum Panel formwork was used on project. Figure represents total amount of formwork required/2.5 to account for reuse of formwork.**

In order to produce an accurate estimate several factors and assumptions were taken into account throughout the estimate. Quantity take-offs were taken directly from the construction documents. A 10% waste factor was applied to both formwork and reinforcing and a 3% waste factor was added to the concrete total. RS Means Costsworks 2010 was utilized for all material, labor and equipment costs. Costworks allows several factors to be included in their prices such as; the location to be set to Harrisburg, PA, and time to be set to the 2nd Quarter of 2010. Therefore no additional factors had to be added for time and location. Costwork's Total Price w/Overhead and Profit was not utilized because it factors an 11% margin for profit and overhead. Instead, 3% was added to Costwork's Total Unit Price to formulate the Total w/Overhead and Profit to reflect lower profit margins that are prominent in the industry currently.

DETAILED PROJECT SCHEDULE

Beginning March 1st 2010 The Pennsylvania University & the Penn State Milton S. Hershey Medical Center began interviewing construction management firms for preconstruction & construction services for the Support Services Building (1st line item of Detailed Project Schedule in Appendix C). Shortly after on March 15th 2010, Alexander Building Construction Co. from Harrisburg, PA was selected as the CM. With a CM selected the project went before the University Board of Trustees and on March 19th 2010 final approval was given. A summary of the entire project timeline is shown below in Figure 12.

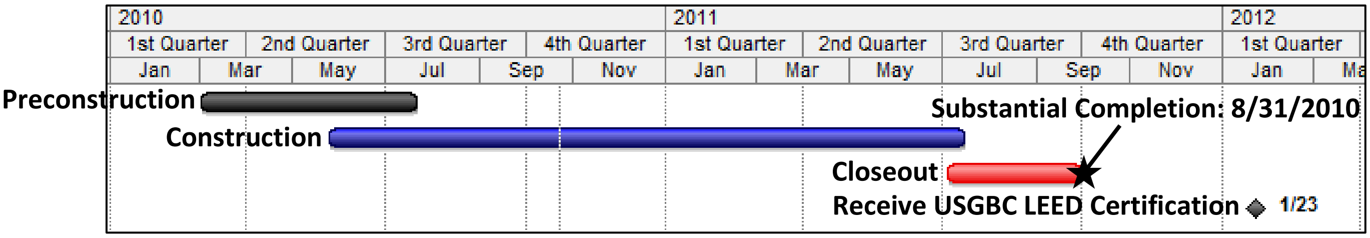


Figure 12: Summarized Project Timeline

Ground was broken on the Support Services Building on June 14th 2010 with site clearing and site utilities continuing throughout the entire month of June. Construction of the Campus Drive Realignment began on June 28th 2010 and by September 24th 2010 the new road was open to traffic.

Figure 13: Grade Beams & Foundation Walls at East Side of Building

Micropile installation began on the 1st of July and was followed by cast-in place concrete foundations components. Figure 13 at right shows completed concrete foundation elements with waterproofing applied, ready for backfill as of October 22nd 2010. Due to issues with the micropile installation, the project fell behind two weeks behind the original schedule dates. However, steel erection was still scheduled to begin at the end of October and was completed by Thanksgiving. It is during this time, the lost time due to micropile installation will be made up. After steel erection is complete, the exterior enclosure started and will continue throughout the winter and into the spring of 2011.

Interior fit-out began shortly after the New Year. The schedule showed the 2nd level starting first with the 1st level lagging the 2nd by three weeks. Actual construction is scheduled to be completed by the end of July 2011. The entire month of August 2011 is scheduled for final cleaning, testing & balancing, and final inspections. Substantial completion is scheduled for August 31st, 2011. Upon receiving substantial completion Alexander has devoted the month of September for commissioning, owner training, and movement of the owner's equipment/furniture into the building Final completion/Hospital Occupancy is scheduled for September 30, 2011. After final completion the current schedule shows the building receiving its LEED Certification by the end of January 2012.

*** See APPENDIX C for Detailed Project Schedule**

***Detailed Project Schedule is Based on Alexander's Original Construction Schedule**

SITE LATOUT PLANNING

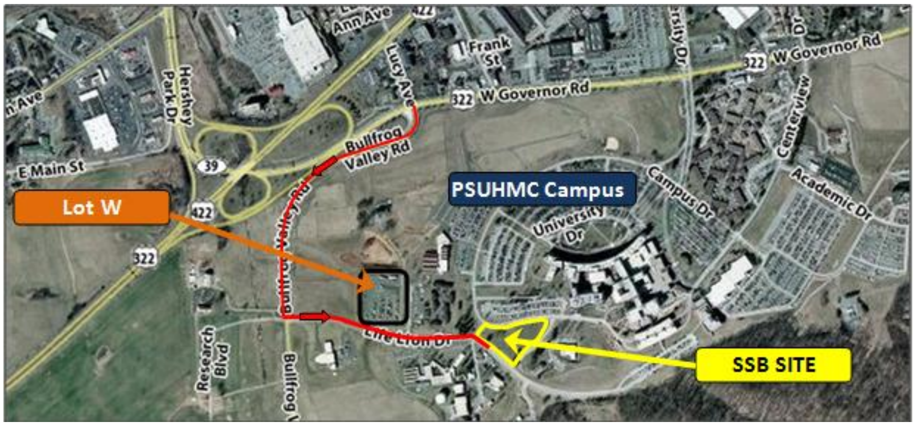


Figure 14: Construction Access to Support Services Building Site Image taken from Yahoo

As shown in figure 14 above the Support Services Building was built on a triangular shaped site on the southwestern part of the Penn State Milton S. Hershey Medical Center's campus. To eliminate congestion at the main entrance to the Hospital the primary construction access is from the west off Bullfrog Valley Road. Secondary access for smaller (personal) vehicles however is not restricted. With the odd shape of the Support Services site, space is a premium so to alleviate congestion onsite, many of the subcontractor's trailers and parking will be in Lot W (see Figure 14 above) off Lion Life Drive. The lot will also be utilized as a construction staging area.

Based on the Detailed Construction Schedule construction of the Support Services Building is broken up into 3 major phases; Sitework, Shell & Enclosure (includes superstructure), and Interior Fit-Out. Included in the Sitework phase is the road re-alignment of Campus Drive & Lion Life Drive which required phasing in order to maintain access to the hospital. Below, the site plan for Shell & Enclosure (Superstructure) and the three phases of the road re-alignment will be discussed with further detail.

Shell & Enclosure Site Plan

During the Shell & Enclosure the site is more congested than any other phase on construction. This is largely due to the amount of exterior work taking place. Structural steel will be erected using a 100 ton crawler crane located on the south side of the building. Vital to the success of the crane is the crane tracking area. This 35-foot wide path has to be free of obstructions in order for the crane to track back and forth during erection. It also has to be fairly level in order for the crane to be stabilized. To achieve this, the base course of asphalt will be installed in all three new parking lots prior to steel erection. Reach will not be an issue for the crane from the south side. The longest pick (shown in figure 15 at right) is just over 120' with the heaviest piece of steel being just over 2 tons. This is more than manageable. Once steel erection is complete, the area once taken by the crane will be utilized as more storage/lay-down area, but yet still leaving access to the western loading docks.

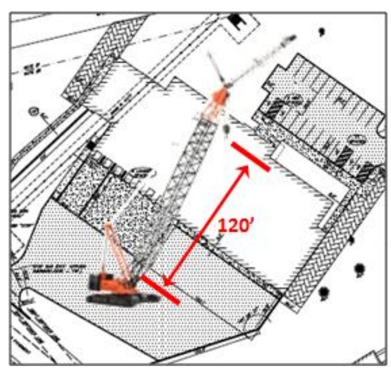


Figure 15: Longest Crane Pick

Space will be available onsite for limited material storage and lay-down areas for all contractors but the exact amount and location will be coordinated with Alexander's Superintendent. Typically material necessary for the week's activates will be store onsite with all other materials being store in Lot W. Space will also be available in the western parking lot for contractor office trailers and parking, but again is limited an overflow will utilize Lot W.

Due to the number of exterior CMU walls, stone veneer, and metal panel cladding a 15-foot area around the perimeter of the building has been reserved for scaffolding /all-terrain man-lifts necessary for installation of the finishes. Using the functional components of the building is also a key to all phases on construction. On the south side of the building there are eight loading docks that will be utilized as material and personnel access to the building.

*** See APPENDIX D for Shell & Enclosure Phase Site Layout Plan**

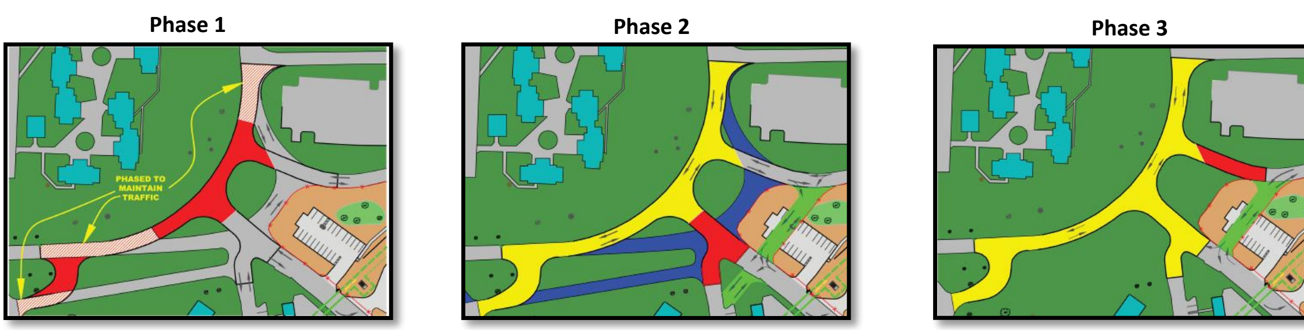
Road Realignment Phases

Immediately after the sitework subcontractor (Liberty Excavators) was selected, the two sides sat down and started developing phasing diagrams in order to figure out exactly how they were going to accomplish the re-alignment without shutting down the road. After closer examination, it was decided that since re-alignment involved three major roads, each road/intersection would be treated as a phase and constructed accordingly. Figure 16 below summarizes their plan. It was this plan that the medical center eventually signed off on and allowed construction to begin.

Phase one is the largest phase of the three and it ties Lion Life Drive into Campus Drive. Because sections of this phase overlap the existing roadway, extra phasing is required in order to maintain traffic flow. Liberty Excavators plan was to complete the base course of asphalt paving in the areas show in red in the left image first. Then utilizing flaggers the existing road they would install the wearing course of paving one lane at a time. Once completed, traffic was able to flow smoothly from Lion Life Drive onto Campus Drive

Phase two although smaller than phase one, was more complex. It involved the construction of a temporary roadway (shown in light green in the second image below) to allow traffic from ARF Drive and Meadow Wood Drive to be maintained. Also in phase two, Liberty Excavator's plan was to demolish the remaining portion of the existing roadway that was replaced.

Phase three was the smallest of the three and involved the final tie-in of Campus Drive. Again the same temporary roadway was utilized to maintain traffic from the east on Campus Drive. Upon completion of the asphalt paving, the temporary roadway was removed and all roads were now open to traffic. Lastly a landscaper was brought in and the whole was re-planted with grass and trees.



Key: Construction Temporary Completed Demolition

Figure 16: Road Realignment Phase Plans

GENERAL CONDITIONS ESTIMATE

*** See APPENDIX E for General Conditions Estimate**

A summarized version of the General Conditions Estimate for the Support Services Building can be seen below in Table 5. Cost amounts are an approximation based on Alexander's General Conditions Estimate and values from RS Means Costworks 2010.

GENERAL CONDITIONS SUMMARY				
DESCRIPTION	**UNIT**	**QUANTITY**	**UNIT RATE**	**COST**
Personnel	Month	15	$53,797.33	$806,960.00
Construction Facilities & Equipment	Month	15	$4,750.00	$71,250.00
Temporary Utilities/Services	Month	15	$2,265.00	$33,975.00
Miscellaneous	Month	15	$1,083.33	$16,250.00
Total	**Months**	**15**	**$61,895.66**	**$928,435.00**

Table 5: General Conditions Estimate Summary

As seen in Table 5 above, the General Conditions was broken down into four sections; Personnel, Construction Facilities & Equipment, Temporary Utilities/Services, and Miscellaneous. Included in the **Personnel** section is the entire management staff for the Construction Manager. As shown in figure 17 below, the Personnel section represents 87% of the total General Conditions Estimate. This is above the typical average for construction projects. However items like Site Fence (charged to the HMC Centerview Parking Garage Phase II project), permits, and insurance are not included in the General Conditions, which reflects why the Personnel percentage is above average.

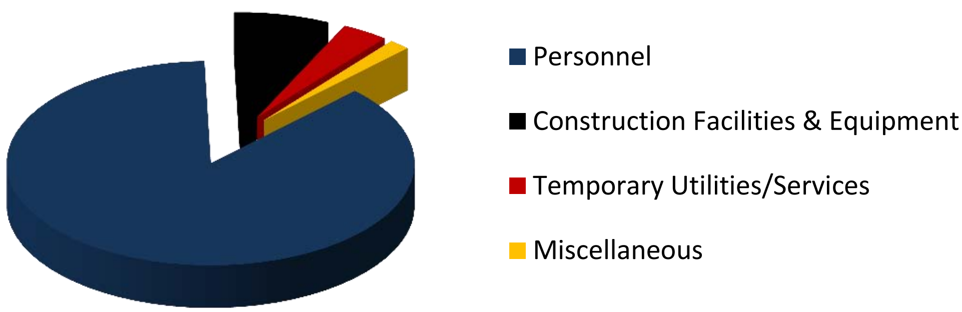


Figure 17: General Conditions Estimate Percent Break-Down

In the **Construction Facilities & Equipment** section are items such as the field office, dumpsters, expendable small tools, tire wash station, etc. Cost of **Temporary Utilities/Services** is drastically reduced on the Support Services Building Project compared to similar projects because the owner (Penn State Milton S. Hershey Medical Center) is paying for temporary water and power. Included in the Temporary Utilities section is other vital services to the construction team such as telephone service, internet service, use of Submittal Exchange, and field office cleaning. Comprising the final 2% of the estimate is the **Miscellaneous Costs** section which accounts for items like; signage, safety, office supplies, etc.

Overall the General Conditions Estimate is just over 7% ($21.69 SF) of the total construction cost which is fairly typical for a construction project.

ANALYSIS I: RE-DESIGN OF FOUNDATION SYSTEM (Part of Structural Breadth)

PROBLEM IDENTIFICATION

Design of the micropile foundation system for the Support Services Building was based per the recommendations of the Geotechnical Report. However the Geotechnical Report was generated using assumed column loads of 350K near the tunnel and 250K elsewhere. Based on actual column loads given to Alexander by the structural engineer, the 350K column load near the tunnel is acceptable, but the 250K column load elsewhere is well above the 98K column load average. In fact there are several columns whose load is less than 50K.

Issues also arose with the installation of the micropiles on the project. Upon installation of all 152 piles, the Micropile Contractor began testing several piles as required by the project's specifications. Of the first several piles tested, it was discovered that nearly 1/3 of them were failing before meeting the design load, yet alone the load they were supposed to be testing at. To solve the problem, all 152 piles were tested and any pile that failed was pulled out and a new pile was installed. This resulted in a 2-week increase in schedule duration. Afterwards, it was determined that the issue with piles failing resulted from the underlying bedrock and a lapse in quality control by the micropile contractor. Because of the karst bedrock formation, the voids within the bedrock filled with grout before the grout could get to the bottom of the pile; therefore the shortening the length of the pile, resulting in a weaker pile.

Although micropiles themselves are not a bad choice as a foundation system and the issues that arose with the SSB project are extremely rare, they are however a rather expensive foundation system. Alexander has constructed numerous buildings in the Hershey, PA area and felt that the micropile foundation system was overkill, and that the building could have been supported by different means. Total costs of the micropile contract were $791,301.00, and the Alexander team feels that if a different foundation system were utilized, the project could have seen a significant cost savings.

RESEARCH GOAL

The goal of this research is to perform a preliminary foundation re-design for the Support Services Building and asses the impacts on schedule and costs.

RESOURCES AND TOOLS USED

- CMT Representative – James Thorton – CE 397A Professor
- Alexander Personnel
- AE Faculty – Structural
- Industry Professionals – Geopier Representative
- Applicable Literature & Coduto Settlement Spreadsheet

EXPECTED OUTCOME

After completing extensive research, consulting industry professionals, and an in-depth preliminary redesign of the foundation system it is believed that a re-design of the foundation system will result in both a cost and schedule savings. Although a re-design of the foundation system may require some means of soil improvement, it is still believed that overall the re-designed foundation system will be a cost effective solution to the micropile foundation system.

Note: The purpose and findings of this analysis is to determine if another foundation system would have been effective on the Support Services Building project. By no means is it felt that the original foundation design was flawed or that any of the decisions made by all parties involved with the project were incorrect.

REVIEW OF GEOTECHNICAL REPORT

Before any re-design of the foundation system could occur, the Geotechnical Reported needed to be reviewed in further detail. Subsurface exploration for the Geotechnical Report consisted of drilling eight boreholes and conducting eleven test pits. Afterwards an in-depth laboratory study of the soils was conducted. To help gain a further understanding of the Geotechnical Report, it was reviewed with James P. Thornton – Geotechnical Engineer with CMT Laboratories Inc. and also a CE 397A professor for Penn State.

From the Geotechnical Report it was found that the site was primary native soils with fill in and around the existing utility tunnel. Underneath a thin layer topsoil, the next layer of soil, mostly Silty Sand with/without Gravel (SM) ranges from approximately 1 foot to 18 foot below grade. In this layer, approximately 31% of the material passes through the No. 200 sieve. Beneath this layer is a layer of lean clay to silt materials (ML), which ranges from the upper layer down to bedrock. Approximately 72% of material in lower layer passes through the No. 200 sieve. Approximate natural consistency limits of the soil are as follows: liquid limit: 19, plastic limit 22, and plasticity index of 17. Moisture content is between 20-35%. STP “N” values approximated from the boring log ranged from 13-30 which meant the soils are medium dense to dense and are relatively stiff. Using these values an estimated unit weight of 125 PCF can be approximated. Bearing capacity of the soils is approximately 2,000 PSF. No ground water was encountered during the subsurface exploration. Given the previous information, the soils were determined to be normally consolidated, which is to be expected for a primarily native site.

Average depth to bedrock was approximately 40 feet below grade, with a variation of 16 feet between the high and low. This number is expected and typical of the area. Hershey Pa. sits on what is known as the Epler Formation. The Epler formation is known to be fairly resistant to weathering, good for foundation support, and its irregular bedrock pinnacles. Bedrock such as the Epler formation is also known karstic bedrock. Karstic bedrock is known for its irregular formations and the potential for sinkholes.

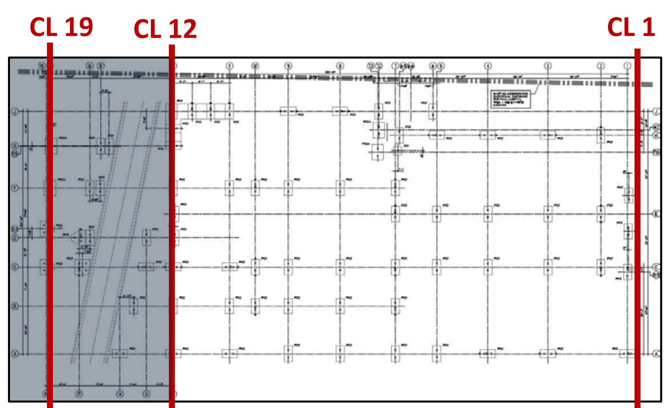


Figure 18: Tunnel Area of Support Services Building

As mentioned in the problem identification, assumed loads used for recommendation of a foundation system were 350k in the tunnel area and 250k elsewhere. As depicted in figure 18 at right what is considered the “tunnel area” is the area from columns lines 12-19. From the Geotechnical Report, based on the 350K load, estimated settlements using conventional foundations in the tunnel area were 2.65 inches. The remaining portion of the building from column lines 1 – 12, the building is slab-on-grade. Due do the change in elevation of the existing grade, in this area half of the building would but constructed on “cut” areas, while the other areas would be constructed on “fill” areas. Max fill is approximately 6.5 feet while max cut is approximately 3 feet to keep the finished floor elevation at 446’. Using conventional foundations, settlements in the area of max fill is estimated to be just less than 2” and 1.38” in the cut areas. Given the requirements set forth by the structural engineer of settlement under an inch and differential settlement under a half inch, the Geotechnical Report recommended the building get its support from a different layer (i.e. bedrock using micropiles). Within the Geotechnical Report, H-Piles, Cast-In-Place Caissons, and compaction grouting were all listed as other possible foundation methods to be used. Before any decision about a foundation re-design was made, actual column loads need to be looked at, and estimated settlements verified.

ACTUAL COLUMN LOADS (S)

Actual column loads (pile loads) were given in a spreadsheet to Alexander by the structural engineer on the project. These loads were then passed along from Jeff Smith – Project Manager for Alexander to me. Each pile load was then added together to form a total load on each pile cap. It is this total load on each pile cap that was used as the column load for purposes of the analysis. Table 6 at right shows an example of what was given by the structural engineer. A full version of this can be found in first three columns of the spreadsheet in **APPENDIX F.** Pile loads also included lateral loads (not shown) for the battered piles. Support for lateral loads will be discussed in more detail in later in this analysis.

Column Number	Column Load (k)				Total Column Load (k)
	North Pile	South Pile	East Pile	West Pile	
A-1	-	-	81	63	144
A-3	-	-	98	98	196
A-4	-	-	73	67	140
A-6	48	64	-	-	112
A-7	45	29	-	-	74
A-8	35	19	-	-	54

Table 6: Actual Column Loads

To verify the assumption that the sum of the pile loads can be used as column loads, a load analysis using tributary areas was performed on column A-7 to check the load given by the structural engineer. Column A-7 supports both a portion of the lower roof, 2nd floor, and the main roof as depicted in figure19 below. Each side of the tributary area is defined as half the distance between columns. Tributary areas for each respected zone for column A-7 are represented by the darker shaded areas.

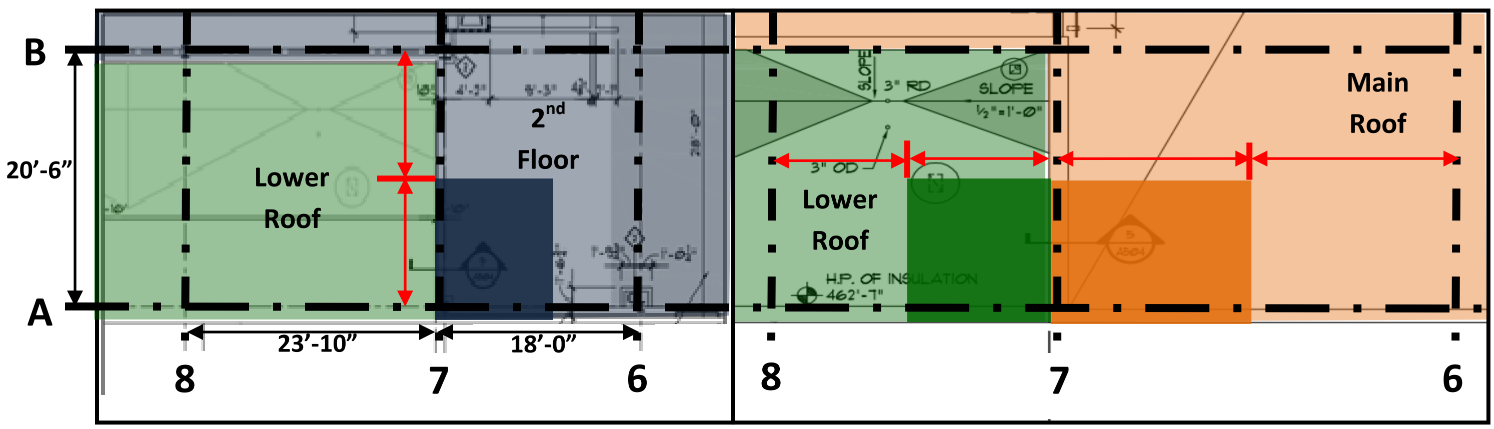


Figure 19: Tributary Area for Column A-7 (Not shown to scale)

The calculations for the tributary areas are as follows:

2nd Floor & Main Roof: $\left(\frac{18'-0"}{2}\right) * \left(\frac{20'-6"}{2}\right) = 92.25SF$ **Lower Roof:** $\left(\frac{23'-10"}{2}\right) * \left(\frac{20'-6"}{2}\right) = 122.18\ SF$

Loads Used for calculations are listed below. All Loads are in lb/SF

Lower & Main Roof:

BUR	20
Steel Framing	10
Misc. Dead Load	10
Snow	30
Total: 70	

2nd Floor:

Steel Framing	10
Steel Deck & Concrete	75
Misc. Dead Load	10
Live Load	80
Total: 175	

Exterior wall loads also contribute to the loads on column A-7. Exterior wall construction is CMU with 4" masonry for the first floor, and 6" metal stud with metal panels on the end floor. Exterior wall lengths per floor are 20'-11" for the first floor and 19'-3" for the second floor. Weights for the exterior walls are

15 lb/SF for the masonry and 6 lb/SF for the metal stud and metal panel. Total SF of each wall is found by taking total length by height of the wall and can be seen below.

1st Floor: $(20' - 11") * (16' - 0") = 334.72\ SF$ **2nd Floor:** $(19' - 3") * (17' - 0") = 327.25\ SF$

Using the above information and calculations, the total load on column A-7 was calculated and can been seen in table 7 at right. Using a safety factor of 2, the total calculated load on column A-7 was just over 76K. Looking at table 6, it can be seen that the load given by the structural engineer on column A-7 was 74K. This makes a difference of 2K between the calculated load and the load given by the structural engineer. Without doing a further in-depth loading analysis into column A-7, it was assumed that for the purposes of this analysis the column loads given by the structural engineer would suffice.

A-7 Load Calculation			
	Area (SF)	Load (lb/SF)	Total Load (lb)
2nd Floor	92.25	175	16,144
Lower Roof	122.18	70	8,553
Upper Roof	92.25	70	6,458
1st Floor Exterior Wall	334.72	15	5,021
2nd Floor Exterior Wall	327.25	6	2,291
		Total Load:	**38,138**
		Total Load with Safety Factor of 2:	**76,276**

Table 7: Column A-7 Load Calculation

After proving the loads given by the structural engineer were acceptable to use for this analysis, the 350K loads assumed in the tunnel area when the Geotechnical Report was created are considered acceptable and the micropile foundation in this area will remain as designed. The 250K loads assumed in the remaining portion of the building from column lines 1-12 is however well above the average of 98K. In fact several column loads are below 50K, with the maximum load at column A-3 (196K). Based on this, the foundation redesign only considered the portion of the building between column lines 1-12. From this point forward in the remaining portion of this analysis this area is all that will be covered.

ESTIMATED SETTLEMENTS USING CONVENTIONAL FOUNDATION ELEMENTS (S)

Before any re-design of the foundation was performed, settlements from the Geotechnical Report need to be verified using conventional square spread footings. Using a soil bearing capacity of 2,000 PSF, minimum spread footing sizes were found using the following method:

$$\boldsymbol{Minimum\ Lenght\ of\ Square\ Spread\ Fooding\ Size} = \sqrt{\frac{\boldsymbol{Column\ Load\ (k)}}{\boldsymbol{Soil\ Bearing\ Capacity\ (PSF)}}}$$

Two examples of minimum square spread footing sizes found using this calculation can be seen in table 8 at right. For a full listing of all the different columns, see the fourth and fifth columns in the spreadsheet in **APPENDIX F**.

Column Number	Total Column Load (k)	Min. Spread Footing Area per 2000 PSF Bearing Capacity (SF)	Min. Square Spread Footing Size per 2,000 PSF Soil
A-1	144	72	8'-6" x 8'-6"
A-3	197	98	9'-11" x 9'-11"

Table 8: Sample Results from Minimum Square Spread Footing Calculation

To check settlements, a spreadsheet was given by James P. Thornton from CMT Laboratories Inc. The spreadsheet was created in 2000 by Donald P. Coduto in conjunction with his book; ***Foundation Design: Principals & Practices Second Edition***. More information regarding the book can be found using its ISBN number: 013-5389706-0. The spreadsheet allows fast, quick estimates of settlements of shallow foundation elements given your input parameters. The spreadsheet calculates settlements based on what is known as the Schmertmann's Medthod of Settlement Analysis of Shallow Foundations. An in-depth description of how Schmertmann's Medthod works and what equations are used can be found in Chapter 7, pages 231-242 of Coduto's book. A brief description of how the method works and the equations used are shown on the next page.

Schmertmann's Medthod was developed in 1978 as a quick easy method for calculating settlement of spread footings. It is based on a physical model of settlement and uses what is called the Equivalent Modulus of Elasticity, Es. The Equivalent Modulus of Elasticity describes the stress-strain properties of soil using the compression index, Cc. It is larger than the modulus of elasticity (young's) but smaller than the confined modulus, M.

Total settlement is calculated as:

$$\boldsymbol{\delta} = C_1 C_2 C_3 \left(q - \sigma'_{zD}\right) \sum \frac{I_\epsilon H}{E_s}$$

where:

C1 = Depth Factor = $1 - 0.5\left(\frac{\sigma'_{zD}}{q - \sigma'_{zD}}\right)$
C2 = Secondary Creep Factor = $1 + 0.2\log\left(\frac{t}{0.1}\right)$
C3 = Shape Factor = $1.03 - 0.03\ {}^{L}\!/_{B} \geq 0.73$
q= bearing pressure
σ'$_{zD}$ = effective vertical stress at a depth D below the ground surface
H = thickness of soil layer
t = time since applied load
B = foundation width
L = foundation length
Es = equivalent modulus of elasticity = $\beta_o\sqrt{OCR} + \beta_1 N_{60}$

where:
Es = equivalent modulus of elasticity
βo, β1 = correlation factors from table 9 at right
OCR = overconsolidaton ratio
N60 = STP-N value corrected for field procedures.

Soil Type	βo (lb/ft2)	β1 (lb/ft2)
Clean sands (SW & SP)	100,000	24,000
Silty Sands & Clayey Sands (SM & SC)	50,000	12,000

Table 9: Correlation Factors for Es Equation

Iε = stain influence factor at midpoint of soil layer =

For square footings: $\boldsymbol{I}_\in = 0.667\, I_{\varepsilon p}\left(2 - Z_f/B\right)$

For Rectangular footings: $\boldsymbol{I_\varepsilon} = I_{\varepsilon s} + 0.111\left(I_{\varepsilon c} - I_{\varepsilon s}\right)(L/B - 1)$
where:
Z_f = depth from bottom of footing to midpoint of layer
$I_{\varepsilon c}$ = Iε for a continuous footing = $0.333 I_{\varepsilon p}\left(4 - Z_f/B\right)$
$I_{\varepsilon s}$ = Iε for a square footing ≥0
$I_{\varepsilon p}$ = peak strain factor = $0.5 + 0.1\sqrt{q - \sigma'_{zD}/\sigma'_{zP}}$
O'$_{zP}$ = initial vertical stress at depth of D + B/2 for square footings and D+B for continuous footings

The spread sheet calculates many of these factors for you. Required inputs by the user are: Type of Units; Shape of Foundation Element, Depth of Foundation Element, Depth of Groundwater Table, Unit Weight of the Soil, Load on Foundation Element, and Equivalent Modulus of Elasticity (Es). The Es can easily be calculated using the equation from above. A sample Es calculation using the parameters found in the Geotechnical Report can be seen below. This calculation was preformed for each of the different SPT-"N" values throughout the soil stratum.

$$\in \boldsymbol{s} = \mathbf{50{,}000}\sqrt{\mathbf{1}} + (\mathbf{12{,}000} * \mathbf{33}) = \mathbf{446{,}000}$$

A screenshot of the spreadsheet after all of the parameters were input for column A-1 and the settlement was calculated can be seen on the next page in figure 20.

SETTLEMENT ANALYSIS OF SHALLOW FOUNDATIONS
Schmertmann Method

Date	March 17, 2011					
Identification	Column A-1					
Input			**Results**		Depth interval	1
Units	E	E or SI			gamma w	62.4
Shape	SQ	SQ, CI, CO, or RE	q =	2322 lb/ft^2	gamma c	150
B =	8.5	ft	**delta =**	**1.70 in**	Wf	40640.63
L =	8.5	ft			uD	234
D =	3.75	ft			sigma zD'	234.75
P =	144	k			sigma zp' sq	500.8
Dw =		ft			sigma zp' con	766.85
gamma =	125	lb/ft^3			Iep square	0.704132
t =	50	yr			Iep contin	0.664964
					in or mm conv	12
					k or kN conv	1000

Units	E
Shape	SQ
C1	0.944
C2	1.540
C3	1.000

Depth to Soil Layer Top (ft)	Bottom (ft)	Es (lb/ft^2)	zf (ft)	I epsilon	strain (%)	delta (in)	zf/B	Ie square	contin
0.0	3.8								
3.8	4.8	446000	0.5	0.171	0.1163	0.0140	0.059	0.171	0.227
4.8	5.8	446000	1.5	0.313	0.2130	0.0256	0.176	0.313	0.282
5.8	6.8	470000	2.5	0.455	0.2938	0.0353	0.294	0.455	0.337
6.8	7.8	470000	3.5	0.598	0.3855	0.0463	0.412	0.598	0.391
7.8	8.8	206000	4.5	0.691	1.0167	0.1220	0.529	0.691	0.446
8.8	9.8	206000	5.5	0.635	0.9354	0.1122	0.647	0.635	0.501
9.8	10.8	458000	6.5	0.580	0.3841	0.0461	0.765	0.580	0.556
10.8	11.8	458000	7.5	0.525	0.3476	0.0417	0.882	0.525	0.610
11.8	12.8	266000	8.5	0.470	0.5354	0.0643	1.000	0.470	0.664
12.8	13.8	266000	9.5	0.414	0.4724	0.0567	1.118	0.414	0.638
13.8	14.8	266000	10.5	0.359	0.4095	0.0491	1.235	0.359	0.612
14.8	15.8	266000	11.5	0.304	0.3465	0.0416	1.353	0.304	0.586
15.8	16.8	266000	12.5	0.249	0.2835	0.0340	1.471	0.249	0.560
16.8	17.8	182000	13.5	0.193	0.3222	0.0387	1.588	0.193	0.534

Figure 20: Screenshot of Coduto Spreadsheet for Estimated Settlement of Column A-1 Using Conventional Square Spread Footing

Using the spreadsheet, estimated settlements were calculated for all of the columns from column line 1 through column line 12. Results of all of the settlement calculations can be found in the **APPENDIX G**. From the results of the settlement calculations, the estimated settlements in the Geotechnical Report were confirmed. The largest settlement (at A-3) is just under 2”, and the overall differential settlement is greater than ½”. Based on these findings, a means of soil improvement will be necessary in order to support the loads if the re-design is to eliminate the micropiles and/or deep foundation system.

GEOPIER® RAMMED AGGREGATE PIER SYSTEM

One type of soil improvement method is the Geopier Rammed Aggregate Pier System (RAP). Geopier® RAP’s are a proprietary intermediate foundation system designed by the Geopier Foundation Company and their associated companies. A relatively newer foundation system/ means of soil improvement, these rammed aggregate piers are constructed by drilling holes (2-3 ft dia.), and then filling them with densely compacted aggregate (done in 1-ft lifts). Compaction is achieved via vertical ramming rod as shown in figure 21 at right. Geopier’s work by forcing aggregate particles into the surrounding soil; therefore increasing the density of the soil. Geopier’s can increase the bearing capacity of the soil anywhere from 2,000 –

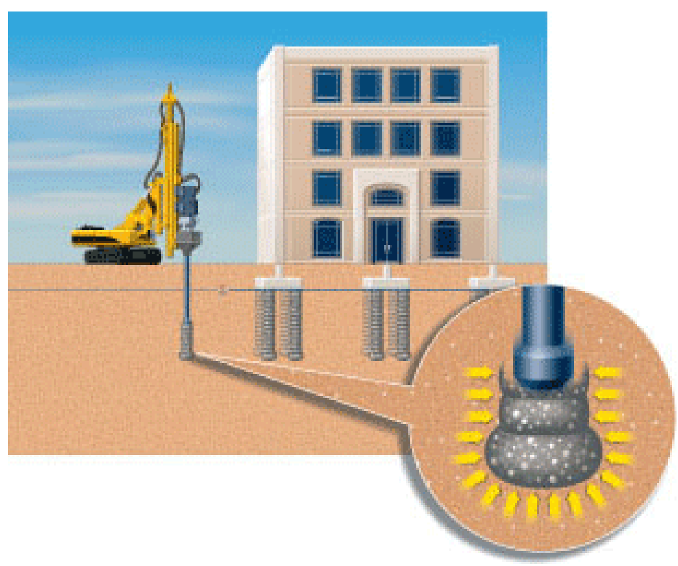


Figure 21: Geopier® Rammed Aggregate Pier System Installation
Image taken from Geopier.com

10,000 PSF depending on soil conditions. The actual RAP themselves are extremely dense and help transfer loads to the underlying soil. Geopier's also work by decreasing the depth of the compressible soil layer. Typical installations depths range from 12 to 35 ft. Using the Support Services Building as an example where the average depth to bedrock to be 40 ft, a 20ft Geopier would decrease the compressible soil layer from 40ft to 20ft; therefore reducing the settlement.

According to Geopier's website, they work well in soft to stiff clays and silts, making them a good choice for the Support Services Building. Geopier's have also been successfully used in the past on the Medical Center's campus. In 2010 the Centerview Parking Garage Phase II (also constructed by Alexander) successfully utilized Geopier's on the project as an alternative to a deep foundation system. Based on this, the re-design of the foundation system from column lines 1 to 12 utilized a Geopier RAP system.

FOUNDATION RE-DESIGN USING GEOPIER'S (S)

GEOPIER DESIGN GUIDELINES (S)

In order to re-design the foundation using Geopier's and larger spread footings (larger than the pile caps), more design information regarding Geopier's was needed. To gain this information, a phone interview was conducted with a representative (engineer) from the Geopier Foundation Company. After discussing the details of the Geotechnical Report, the building, and the Geopier's used on the parking garage project, the following list of assumptions for design guidelines was established:

- a 30" diameter pier element would increase the bearing capacity to approximately 5,000PSF
- for loads under 40K, 1 pier element would suffice
- for loads between 40K and 150K, 2 pier elements would suffice
- for loads greater than 150K, 3 pier elements would suffice
- for loads under 60K, a 14 ft pier would suffice
- for loads between 60K and 90k, a 16ft pier would suffice
- for loads between 90k and 130k, a 18ft pier would suffice
- for loads between 130K and 200K, a 20 ft pier would suffice
- spacing between Geopier Elements is equal to 2 x diameter = 5'-0"

These design guidelines were what was utilized for the foundation re-design.

SPREAD FOOTING SIZES (S)

To start the redesign of the foundation, minimum square spread footing sizes were calculated using an improved soil bearing capacity of 5,000PSF using the same equation to calculate spread footing size as used on page 27. Several results of the new sizes can be seen in table 10 at right. Beyond calculating the minimum square spread footing size, the minimum footing area was calculated using the simple equation, Area = Load/Bearing Capacity. A full listing of minimum square footings sizes and minimum footing areas for all of the columns based on the larger bearing capacity can be found in the sixth and seventh columns in the spreadsheet in **APPENDIX F**.

Column Number	Min. Spread Footing Area per Geopier® Soil Improvement to 5,000 PSF (SF)	Min Square Spread Footing Size per Soil Improvement to 5,000 PSF
A-1	36	6'-0" x 6'-0"
A-3	49	7'-0" x 7'-0"
A-4	35	5'-11" x 5'-11"

Table 10: Minimum Footing Area & Minimum Square Footing Size per 5,000 PSF Geopier Soil Improvement

Starting with the minimum sized square footings, the next step in re-designing the foundation involved drawing the actual spread footings in AutoCAD and checking the spacing between the Geopier elements.

For smaller loads less than 40K, which required square footings equal to or less than 5’-0” x 5’-0” and only one Geopier element, the design was simple and required no changes. However with the addition of a second Geopier element, complications with square footings arose. As shown below in the two leftmost footings in figure 22, minimum spacing between Geopier elements could not be achieved with 6 foot and 7 foot square foundation elements. However as shown in the far right spread footing, creating rectangular spread footings enabled the proper Geopier element spacing for the same area.

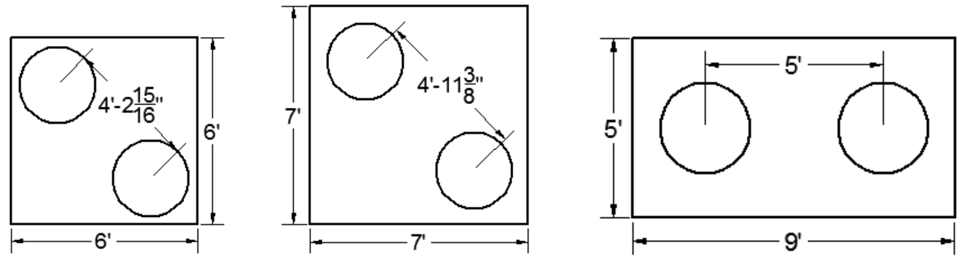


Figure 22: Spread Footing Design Utilizing Minimum Geopier Element Spacing

After discovering that rectangular spread footings were required to meet the minimum Geopier element spacing requirement, the next design factor encountered was the distance from the edge of Geopier element to the edge of the footing. Common practice requires that this distance be greater than 9”. This limited the minimum length of a rectangular footing to 9’-0”. When it came to the addition of a third Geopier element to the footing, a rectangular footing was no longer a viable solution. To solve the problem, a larger square footing element with a triangular layout to the Geopier elements was utilized as shown in the far right footing below in figure 23. In order to keep the design simplified for construction purposes, six different spread footings were developed and can be seen below in figure 23. A footing schedule was developed to provide a more detailed description of each footing can be found in table 11 at right.

FOOTING SCHEDULE				
ID	Footing Size	Depth (ft)	# of Geopier® Elements	Depth of Geopier®(s) (ft)
SF1	4'-0" x 4'-0"	3'-9"	1	14
SF2	5'-0" x 5'-0"	3'-9"	1	16
SF3	5'-0" x 9'-0"	3'-9"	2	18
SF4	5'-0" x 9'-0"	5'-0"	2	20
SF5	6'-0" x 10'-0"	3'-9"	2	20
SF6	10'-0" x 10'-0"	3'-9"	3	20

Table 11: New Footing Schedule

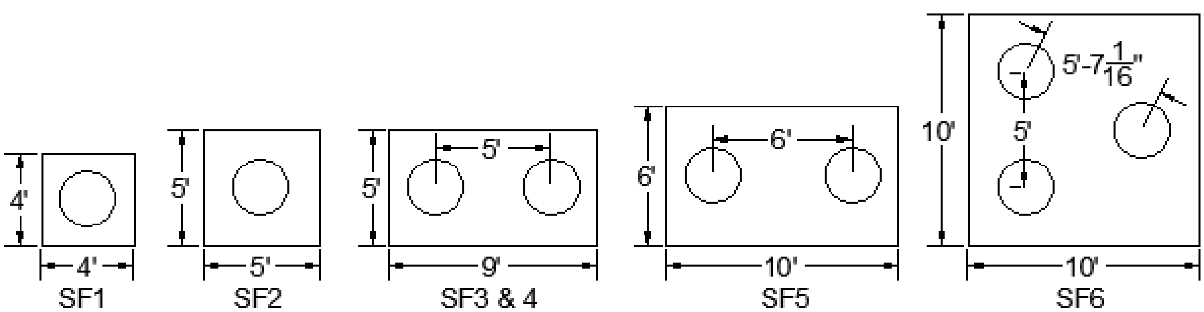


Figure 23: Final Spread Footing Designs (circles represent Geopier elements)

It was found that to minimize the different number of footing sizes for ease of construction and to achieve proper Geopier element spacing; many footings had an area larger than the required minimum calculated earlier. If anything, having a larger area than the minimum helped control the settlement even greater and allows the system to have a greater safety factor built into it. For a complete listing of footing sizes used per the design parameters with the footing area for each column see eighth and ninth columns in the spreadsheet in **APPENDIX F.**

SETTLEMENT CHECK OF NEW FOOTINGS

To check the settlement of the new spread footings the same spreadsheet was utilized as before. User inputs were changed within each footing depending on its specific parameters. Specifically the depth of the compressible soil layer and its corresponding equivalent modulus of elasticity and the footing sizes & shapes were the major changes. Depths of the new footings were assumed to be the same depth of the pile caps that they are replacing at 45". However it was discovered the 45" depth for SF3 was found to be inadequate in several locations to control settlement. Therefore additional depth to the footing was added until the settlement was within the limits of; 1 inch maximum with differential settlement less than ½ inch. It was found that a 60" depth was the minimum needed in these locations. This is why SF4 on the previous page came about (see table 11). Upon completion of the settlement analysis, it was found that max settlement using the Geopier's and larger spread footings was reduced to just under ¾" and differential settlement was under the requirement of ½". This satisfies the requirements set forth by the structural engineer as the original design guideline. For to see the results of the settlement check on the new footing elements see **APPENDIX G**.

FOUNDATION ELEMENTS RETAINED FROM ORIGINAL DESIGN

As in the original design, gradebeams connected all of the pilecaps. Gradebeams are essential in helping to control differential settlement and can often transfer small loads themselves. Therefore the new foundation system utilized the same gradebeams to connect the spread footings. All other original foundation parameters such as the foundation walls, areas of haunched slab, piers, and other misc. elements remained the same as in the original design. Essentially the only items being replaced are the pilecaps and micropiles. Again the re-design only considered column lines 1 through 12.

ADDITION OF COLUMN LINE 11.9 (S)

Replacing the micropile foundation system for larger spread footings with Geopiers for column lines 1-12 essentially created two separate buildings within one. This created a new issue that had to be resolved. With two different foundation systems in the same building, each would settle at different rates, therefore increasing the potential for major cracks in all elements along column line 12. To solve this dilemma the addition of an additional column line was required. As shown below in figure 24, column line 11.9 was added adjacent to column line 12. Foundation elements along column line 12 remained mostly as design (minus two pilecaps that needed to be rotated 90°). Therefore the new spread footing with Geopier foundation system is from column lines 1-11.9.

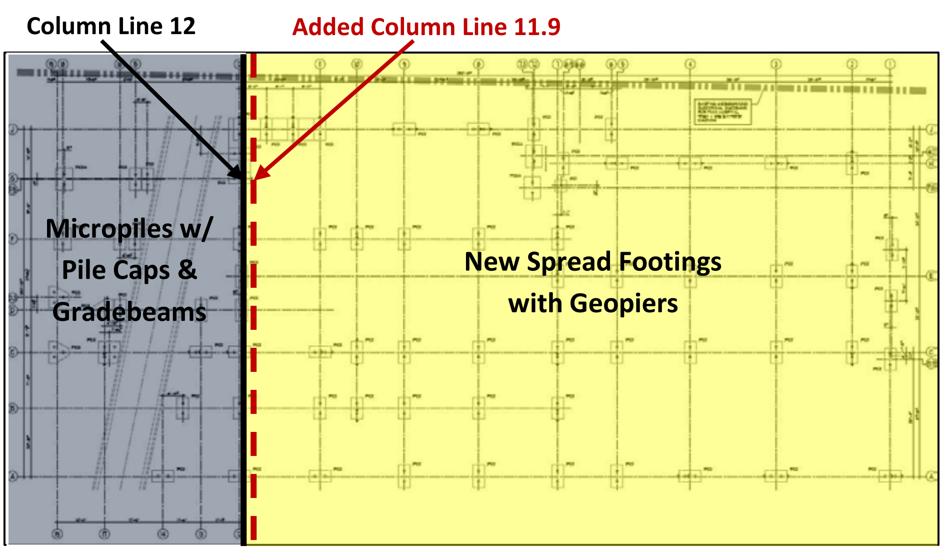


Figure 24: New Foundation Design with Added Column Line 11.9

Column line 12 was also chosen to separate the two foundation types because this was the column line separating the slab on grade and elevated slab for this first floor. To locate column line 11.9 from column line 12, the edge of slab dimension of 10 inches from the edge of steel for elevated slabs with a 3-inch space in-between the slabs was the limiting factor. Using those dimensions as shown in figure 25 below, the center of column line 11.9 is 2’-11” from the center of column line 12.

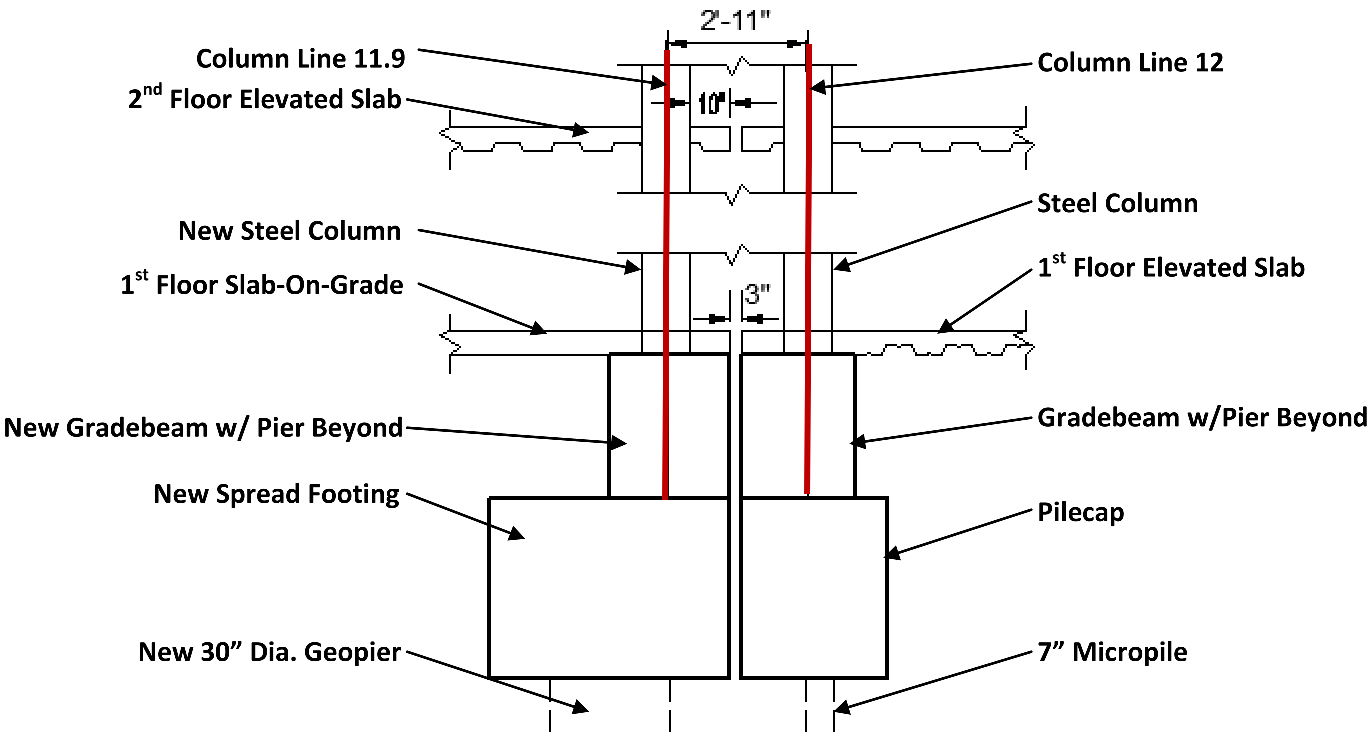


Figure 25: Section at Added Column Line 11.9

As part of the addition of column line 11.9, column J-12 was eliminated and replaced with column J 11.9. This resulted in the corner of the building to shift east (towards column line 11.9) 2’-11”. A clearer example of this is shown in figure 26 at right. This shift aligned the outside corner of the building with the added expansion/isolation joint (3” gap show above in figure 25). Room 114 – Medical Equipment Set-Up and room 208 EHS Supervisors will lose that 2’-11” of floor space. However even with a loss of space in these rooms there is still ample space leftover in the rooms to fulfill their intended purposes. With the addition of column line 11.9 and after aligning outside corner of the building with column line 11.9, the two separate foundation systems (and sections of the building) were able to act independently, and the issue of differential settlement between the two was solved.

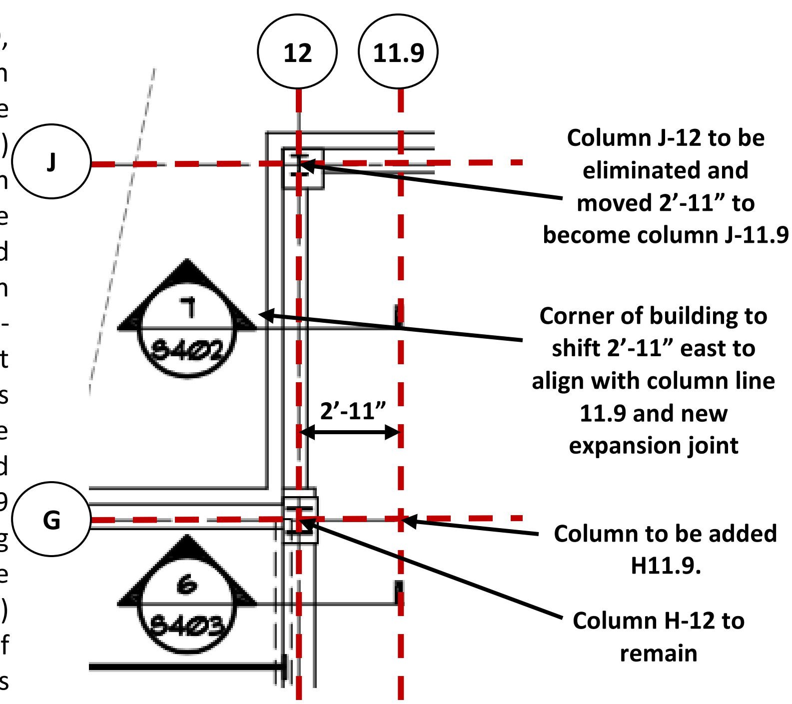


Figure 26: Building Corner to Shift to Column Line 11.9

COLUMN SIZING FOR COLUMN LINE 11.9 (S)

To size the added columns for the added column line 11.9, original tributary areas for columns along column line 12 were calculated. Then tributary areas to be supported by the added columns along column line 11.9 were calculated. Loads given by the structural engineer for columns along column line 12 were then split-up between the between the column on column line 12 and the added column on column line 11.9 by percent of the tributary area they supported. An example calculation can be seen below. Figure 27 below highlights the tributary area(s) from the calculation.

Column B-12 Tributary Area (Left Image) = $\left[\left(\frac{23'-1"}{2}\right)+\left(\frac{24'-5"}{2}\right)\right]*\left[\left(\frac{20'-6"}{2}\right)+\left(\frac{17'-0"}{2}\right)\right]=446SF$

Load given on column B-12 by structural engineer: 222K

Column B-11.9 Tributary Area (Right Image) = $\left(\frac{24'-5"}{2}\right)*\left[\left(\frac{20'-6"}{2}\right)+\left(\frac{17'-0"}{2}\right)\right]=228SF$

New Load on Column B11.9: = $\left(\frac{222k}{446\,SF}\right)*228SF=114K$

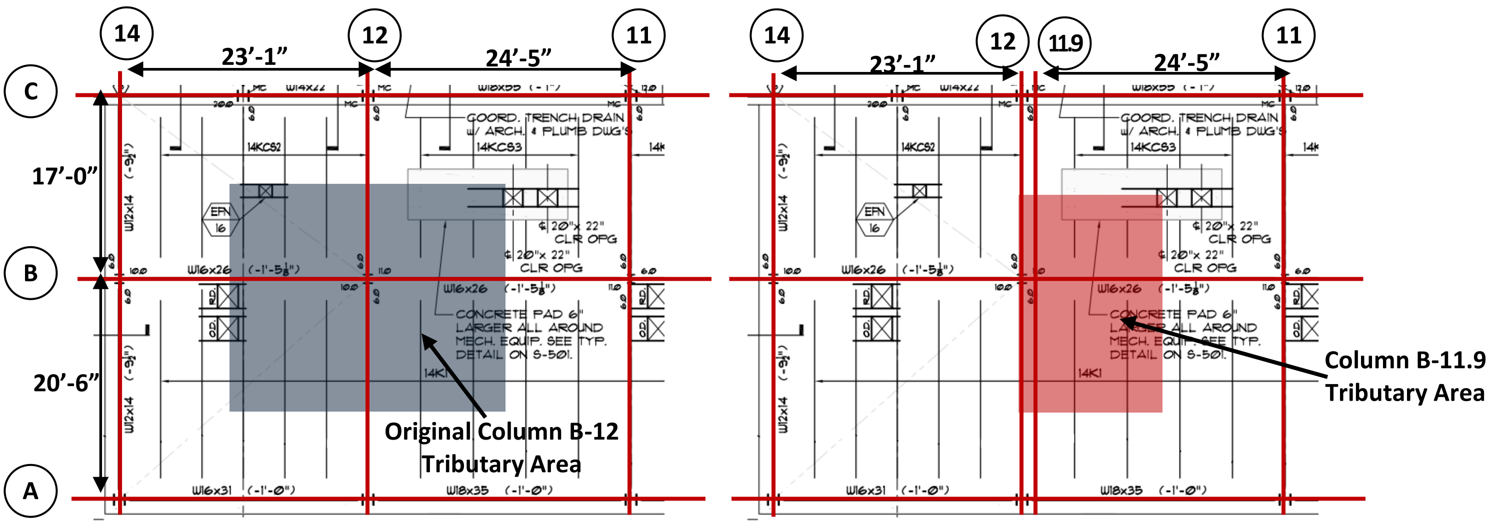


Figure 27: Before & After Tributary Areas of Column B-12 & Column B11.9

This same calculation was performed for all of the added columns along column line 11.9. Results of this calculation for all of the added columns along columns line 11.9 can be seen below in table 12. After loads were determined for these columns, a footing ID per table 11 was assigned and settlements of the footings for the added columns were checked using that same spreadsheet and methods as before.

Column Line 11.9 Column Calculations						
Existing Column	Existing Column Load (k)	Tributary Floor Area Supported By Existing Column (SF)	Tributary Floor Area Supported By Added Column (SF)	Load on Added Column (k)	New Spread Footing ID	Settlement (in)
A12	138	240	120	69	SF2	0.47
B12	222	446	228	114	SF3	0.56
C12	338	624	300	163	SF4	0.68
F12	418	738	312	178	SF6	0.57
G12	214	495	360	156	SF4	0.65
J12*	134	84	84	134	SF6**	0.48

* Corner column to replaced by column on new column line
** Larger footing used to account for removal of large continuous pile cap

Table 12: Results of Column Calculations, SF ID, & Settlements Results for Columns on Column Line 11.9

Once the loads on the added columns were known (approximated), the size was determined. Table 4.1-Available Strength in Axial Compression for W Shapes from the AISC manual (handouts from AE 404 class), was then used to size the columns. The ASD (Allowable Stress Design) column in the table was used to pick member sizes vs. the LRFD (Load & Resistance Factor Design) because it allows a particular W-shape to only support smaller loads at the same size. Because the loads on the new columns were approximated and no load factors were applied, it is felt this was a reasonable assumption. Table 13 at right summarizes the sizes of the added columns. Note that columns such as A 11.9 are oversized based on AISC Table 4-1, but W10x33 was the smallest column size utilized on the project, and it was felt that adding additional column sizes (even if smaller would support the loads) was unnecessary.

Column	Load (k)	Length	Size
A-11.9	69	16'-7"	W10x33
B-11.9	114	16'-7"	W10x33
C-11.9	163	35'-11"	W12x79
F-11.9	178	35'-11"	W12x79
G-11.9	156	35'-11"	W12x79
J-11.9	134	33'-7"	W10x33

Table 13: Column Line 11.9 Column Sizes

NEW FOUNDATION PLAN (S)

Once all of the elements of the foundation were sized, a new foundation plan was drawn in AutoCAD 2011. A screenshot of the drawing can be seen in figure 28 below and an approximate 1/16" = 1'-0" scaled plan can be found in **APPENDIX H**. Note that items shown in pink are a part of the original unchanged micropile foundation from columns lines 12-19. The grey angled lines represent the existing utility tunnel.

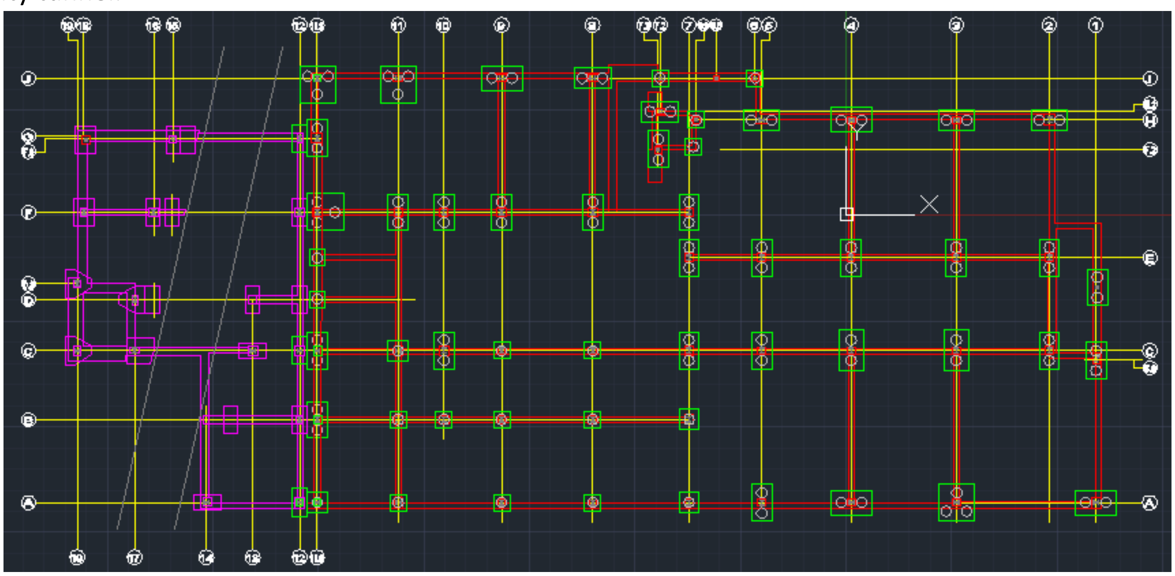


Figure 28: Screen Shot of Foundation Plan Draw in AutoCAD 2011

EXPANSION JOINT FLOOR PLATES

Creating the double column line to isolate the two foundation systems left a 3 inch gap between the floor slabs. To remedy this a floor plate needed to be specified. A good floor plate for this applicaton is NBF-300 manufactured by the Nystrom company and is show in figure 29 at right. This plate sits flush with the floor and complies with all ADA guidelines. It also comes with a one hour fire rating. Accoring to their specifications, the NBF-300 (3" gap) is capable of withstanding +/- 2 inche of movement while remaining flush. All of these characteristsics make this an ideal choice for a floor plate.

Figure 29: Nystrom NBF-300 Flexible Floor Plate
Image taken from Nystrom.com

LATERAL LOADS (S)

In the original design over one third of the micropiles were batter to support the lateral loads of the building. Transfer of lateral loads to the piles was via the rigid steel superstructure (welded moment connections). With the elimination of the micropiles, a new medthod to support the lateral loads on the building needed to be derived. Luckily as shown in figure 30 below, many of the interior walls, elevator shafts, and stair towers are constructed of CMU masonry walls. These can all become the new means of lateral support for the building by increaseing the reinforcing within the walls, grouting more of the cells, and attatching them to the structural steel. Included in the re-design the first floor CMU walls in the center of the building would extend all the way to the roof. With this, the rigid frame (welded connections) can be eliminated, which could even present a cost savings.

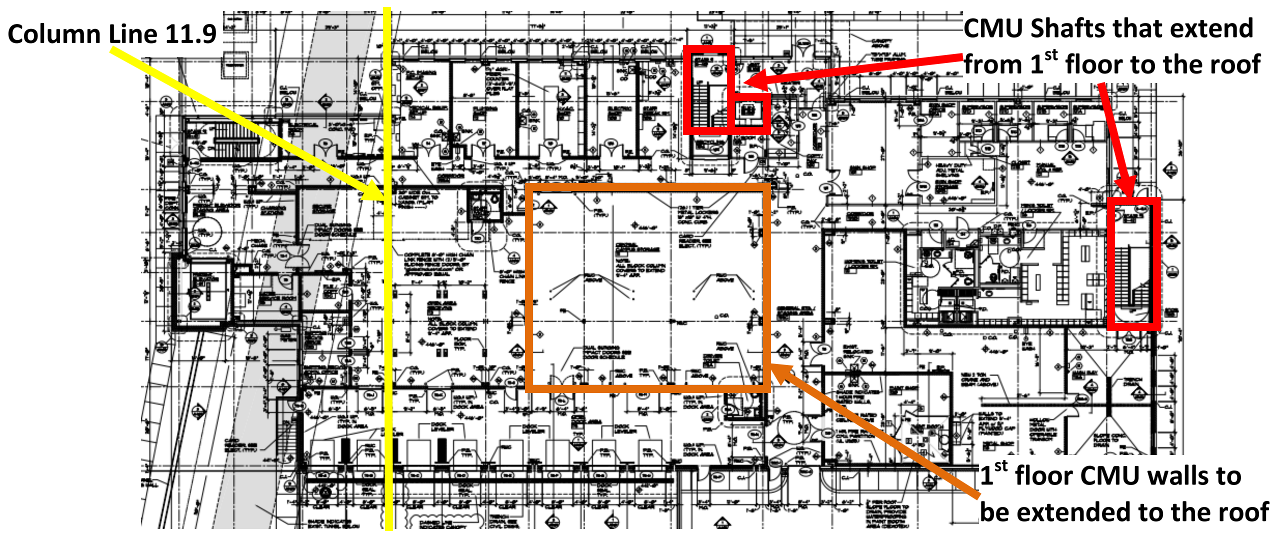


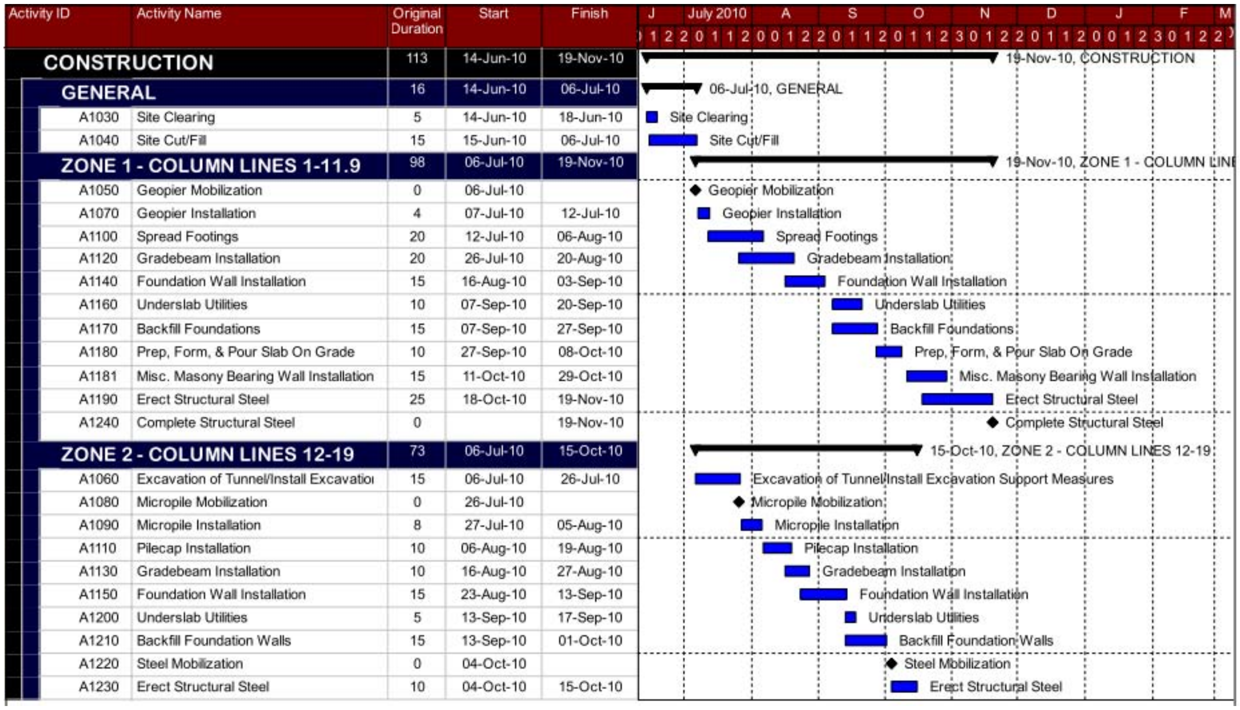
Figure 30: CMU Walls to Support Lateral Loads

SCHEDULE IMPLICATIONS

As in the detailed project schedule (See **APPENDIX C**), site clearing is scheduled to began on June 14th, 2010 and was followed by site cut/fill which will end on July 6th 2010. On July 6th is when the work for the new re-designed foundation can start. For a complete view of the schedule for the new foundation system see figure 31 on the next page. With two separate foundations, construction of both can occur simutainsouly at both ends of the building. This is designated by Zone 1 and Zone 2 in the schedule on the next page.

Starting July 6th, mobilization of Geopiers begins along with the start of excavation for column lines 12-19. Geopier installation takes roughly a week, while excavation and installation of excavation support takes three weeks to complete. After Geopier installation is complete, installation of the new spread footing can occur and takes roughly four weeks. When the excavation of the tunnel is completed, micropile installation can begin on July 27th. When compared to the original detailed project schedule, installation of both the micropiles and Geopiers with the re-design is completed a day before the the micropiles were originally scheduled to be completed.

Over the next several weeks, concrete foundation elements including the gradebeams and foundation installation takes place. By the middle of September all of the concrete foundation elements (minus the slab-on-grade) are complete. This is over two weeks earlier than in the original schedule. Without work occuring simutainsouly on both zones, this would not be possible. With Zone 1 encompassing a larger area, it takes longer for the concrete foundation elements to be completed in this area. This allows the same work in Zone 2 to lag Zone 1.



Activity ID	Activity Name	Original Duration	Start	Finish
CONSTRUCTION		113	14-Jun-10	19-Nov-10
GENERAL		16	14-Jun-10	06-Jul-10
A1030	Site Clearing	5	14-Jun-10	18-Jun-10
A1040	Site Cut/Fill	15	15-Jun-10	06-Jul-10
ZONE 1 - COLUMN LINES 1-11.9		98	06-Jul-10	19-Nov-10
A1050	Geopier Mobilization	0	06-Jul-10	
A1070	Geopier Installation	4	07-Jul-10	12-Jul-10
A1100	Spread Footings	20	12-Jul-10	06-Aug-10
A1120	Gradebeam Installation	20	26-Jul-10	20-Aug-10
A1140	Foundation Wall Installation	15	16-Aug-10	03-Sep-10
A1160	Underslab Utilities	10	07-Sep-10	20-Sep-10
A1170	Backfill Foundations	15	07-Sep-10	27-Sep-10
A1180	Prep, Form, & Pour Slab On Grade	10	27-Sep-10	08-Oct-10
A1181	Misc. Masony Bearing Wall Installation	15	11-Oct-10	29-Oct-10
A1190	Erect Structural Steel	25	18-Oct-10	19-Nov-10
A1240	Complete Structural Steel	0		19-Nov-10
ZONE 2 - COLUMN LINES 12-19		73	06-Jul-10	15-Oct-10
A1060	Excavation of Tunnel/Install Excavatio	15	06-Jul-10	26-Jul-10
A1080	Micropile Mobilization	0	26-Jul-10	
A1090	Micropile Installation	8	27-Jul-10	05-Aug-10
A1110	Pilecap Installation	10	06-Aug-10	19-Aug-10
A1130	Gradebeam Installation	10	16-Aug-10	27-Aug-10
A1150	Foundation Wall Installation	15	23-Aug-10	13-Sep-10
A1200	Underslab Utilities	5	13-Sep-10	17-Sep-10
A1210	Backfill Foundation Walls	15	13-Sep-10	01-Oct-10
A1220	Steel Mobilization	0	04-Oct-10	
A1230	Erect Structural Steel	10	04-Oct-10	15-Oct-10

Figure 31: New Foundation System Schedule

Once the concrete foundation elements are complete (minus the slab-on-grade) underslab utilities and backfill of foundation wall can occur. It is interesting to note that although encompassing a smaller area, backfill of the foundations in Zone 2 requires the same amount of time as Zone 1 due to the depth of the excavation. Once these activites are completed, structural steel can start on Zone 2, while the slab-on-grade is prepped and poured in Zone 1. Looking at the schedule, both the slab-on grade and structural steel erection for Zone 2 finish on the same day. This allows structural steel to move right onto Zone 1. Structural steel erection is completeed on November 19th, two weeks prior completed steel erection in the original schedule. Completing steel erection two weeks earlier relates in a direction correltion to the overall timeline of the project. With steel completed two week earlier, all activites that occur afterwards can get pushed forward two weeks, resulting in a two week savings in the entire project schedule with a new substantial completion date of August 17th, 2011.

IMPACTS ON SITE LOGISTICS

To verify if working work can occur simutainsouly in the two zones as meantioned above in the scheduling section, a closer look at the Shell & Enclosure site plan in **APPENDIX D** needed to be examined. Looking at the Shell & Enclosure Site Plan, it can be seen that there is ample room for work to occur simutainously in both zones. Because Zone 2 is such a small area and with the excavation of the tunnel in this area, the main access will be on the northern side of the tunnel near the small parking lot. There is also able room for storage of material in the northwestern portion of the site. Construction activites in Zone 1 will utilize the southernmost gate, and all of storage space in the southwestern coner of the site. Once steel erection begins in Zone 2, the crane can be positioned as far west as possible in the southern parking lot as before and still be able to reach. With the crane positioned on the west side of the parking lot, lay-down of steel can be placed in and around the smaller (northwestern) parking lot. Ample room on the eastern side of the parking lot still remains for the slab-on-grade work and pouring. After analyzing the site plan, it is felt that there is ample room for work to occur in both zone simutainously.

ESTIMATED COST SAVINGS

To calculate the estimated cost savings of the new design vs. the original micropile foundation first required the estimated cost of the new design. Detailed take-offs were performed utilizing the new foundation plan and the results can be seen below in tables 14 and 15 below. Take-off's for strucutral steel came from table 13 on page 35 with the addition of a steel beam between each column.

Spread Footings (4,000 PSI)							
ID	Size	Depth	Quantity	Concrete (CY)	Total Concrete (CY)	Reinforcing Weight (lbs)*	Total Reinforcing Weight (ton)
SF1	4'-0" x 4'-0"	45"	13	2.22	28.86	1,443.00	0.72
SF2	5'-0" x 5'-0"	45"	4	3.47	13.88	694.00	0.35
SF3	5'-0" x 9'-0"	45"	24	6.25	150	7,500.00	3.75
SF4	5'-0" x 9'-0"	60"	2	8.33	16.66	833.00	0.42
SF5	6'-0" x 10'-0"	45"	6	8.33	49.98	2,499.00	1.25
SF6	10'-0" x 10'-0"	45"	4	13.88	55.52	2,776.00	1.39
				Subtotal:	314.9	Subtotal	7.87
				3% Waste/Extra :	9	10% Waste/Extra:	0.79
				Total	324	Total	8.66

* Assume 50 lb reinforcing/CY of concrete

Table 14: New Spread Footing Take-Off

GEOPIER TAKE-OFFS					
Footing ID	Quantity	# of Geopier® Elements/ Footing	Total # of Geopier® Elements per Footing Type	Depth of Geopier® Element(s) (ft)	Total Length of Geopier® Elements per Footing Type (LF)
SF1	13	1	13	14	182
SF2	4	1	4	16	64
SF3	24	2	48	20	960
SF4	2	2	4	20	80
SF5	6	2	12	20	240
SF6	4	3	12	20	240
	Total # of Geopiers®:		93	Total Length (LF):	1,766

Table 15: Geopier Take-Off

Using these take-offs a detailed estimate of the new design was perfomred utilizing RS Means Costworks 2010, Geopier cost data from Centerview Parking Garage Phase II at PSUHMC, and numbers from industry professionals. Table 16 at right summarizes the result of the estimate. For a more detailed breakdown of the associated costs in each category, see **APPENDIX I**. Cost of the Geopiers account for nearly half of the total for the new design. Per talking with industy professionals, an approxiamte cost of $30,000 was determined to "beef up" the interior CMU walls so that they can support the lateral loads of the building. Note that a 5% contingency was added to the estimate to account for missed details within the design.

NEW DESIGN	
Geopiers®	$199,796.70
Spread Footings	$93,820.78
Added Gradebeam & Piers	$20,467.06
Expansion Joint	$14,240.45
Structural Steel	$32,065.51
CMU Lateral Load Walls	$30,000.00
Contingency	$18,171.11
Total Cost of New Design:	**$408,410.03**

Table 16: Summarized Cost Estimate for New Foundation Design

After the cost of the new design was calculated, the cost of the eliminated parts of the old foundation were calculated. Using the constuction documents, its was found that the new design eliminated 101 micropiles and 51 pilecaps. Estiamted costs for the removal of the 51 pilecaps was taken directly from the detailed structural estimate discussed on page 19. To get the estiamted cost of the ellimination of 101 micropiles, a cost per pile needed to be determined. This value was detemined by subtracting design, mobilization, and testing costs from the micropile contract value and then devided by the total number of piles on the project (152) as shown in the calcuation below. The total estiamted cost savings of the eliminated items is just over $502,700.00 and can be in a summarized version in table 17 below. A more detailed estimate of the eliminated items can be found in **APPENDIX I**.

Micropile Contract	$793,031.00
Engineering	-$50,000.00
Mobilization	-$25,000.00
Load Test	-$25,000.00
Subtotal:	$693,031.00
Total # of Piles	152
Cost per Pile:	**$4,559.41**

ELIMINATED ITEMS	
Micropiles	$460,500.86
Pilecaps	$27,214.29
Moment Connections	$15,000.00
Total of Deleted Items:	**$502,715.05**

Table 17: Summarized Cost Estimate for Eliminated Items

With the cost estimates for both the new design and the eliminated items completed, the last item that needs calcualted was the General Conditions cost per week. Table 18 below breaks the General Conditions Estimate on page 23 into a cost per week value.

GENERAL CONDITIONS SUMMARY				
DESCRIPTION	**UNIT**	**QUANTITY**	**UNIT RATE**	**COST**
Personnel	Week	65	$12,414.77	$806,960.00
Construction Facilities & Equipment	Week	65	$1,096.15	$71,250.00
Temporary Utilities/Services	Week	65	$522.69	$33,975.00
Miscellaneous	Week	65	$250.00	$16,250.00
Total Weeks		**65**	**$14,283.62**	**$928,435.00**

Table 18: General Conditions Cost per Week

With General Conditions cost/week calcualted, the total cost savings between the new design and the original foundation design was found. Subtracting the cost of the deleted elements of the original design and the savings in General Conditions cost as in the calculation below, resulted in a toal cost savings just under $123,000.00.

Cost of New Foundation Design	$408,410.03
Cost of Deleted Elements	-$502,715.05
General Conditions Savings (2 weeks)	-$28,567.25
Total Cost Savings:	**-$122,872.27**

CONCLUSION

After an in-depth study into a foundation re-design for the Support Services Building, the expected outcome that a alternative, lower cost foundation system would have worked was confirmed. Starting with a a more detailed look into Geotechnical Report with the help of James P. Thornton – Geotechnical Enginneer for CMT Labratories Inc a further understanding of the subsurface properties of the site was gained. Bearing capacity of the native soils was discovered to be approximately 2,000PSF. Average depth to bedrock is 40 feet, however the bedrock in the area is karstic. With a karstic bedrock formation, the potiential for high irregularites within the bedrock and sinkholes are often discovered. Assumed loads of

350K and 250K given at the time Geotechnical Report was generated were found to be high in many places. Given these assumed loads and the potiential for moderate to high settlements, the Geotechnical Report recommneded a micropile foundation for the building. From early on it was determined that the area known as the “tunnel area”, would remained as designed.

Actual loads given by the structural engineer were determined adequate to use for this analysis after performing a tributary load analysis for column A-7. Using these loads, minimum sqare spread footing sizes were determined using the 2,000PSF soil bearing capacty. Settlements for these footings where then checked using an spreadsheet calculator developed by Donald P. Conduto based on the Schmertmann’s Method. Initial settlement calculations confirmed that soil improvement was necessary if the micropile foundation were to be eliminated.

Geopiers were selected as the means for soil improvement as they have been successfully used on the medical center’s campus in the past. After a phone interview with an engineer from the Geopier Foundation Company, several design guidelines were determined. Using these guidelines new spread footings were developed using a new soil bearing capacity of 5,000PSF. It was discovered that the major limiting factor in the design was the minimum Geopier element spacing. This caused many of the new footings to be larger than the minimum required size. Settlements of the new design were checked to verify the design was within requirements.

To control differential settlement between the two foundation types, column line 11.9 was added adjacent to column line 12. This double column line allows the two portions of the building to act indepentely of each other. Columns for column line 11.9 were sized using tributary areas and AISC table 4-1. To fill the gap in the floor slabs at the double column line, a Nystrom NFB-300 floor plate was recommended. To support the lateral loads on the building, interior CMU walls already in the design can be altered to support the lateral loads.

With two separate foundation types, work can occur simutainsouly on both sections. Applying this principal to the projects schedule, structural steel is now completed two weeks earlier than in the original project schedule. This two week saving directly correltated to an over two week saving in the total duration of the project. It was also confirmed that work can occur simutainsouly on both portions of the building by examining the site logistics plan.

A detailed estimate of the new redesigned foundation system was found to be just over $408,000.00. After calculating the cost per micropile, the estimated cost of the eliminated elements of the original design was just under $502,800.00. General Conditions cost per week was found to be just over $14,000.00. Subtracting the cost of eliminated items and savings in General Conditions from the cost of the re-design resulted in a total cost savings of just under $123,000.00

Based on the findings of this analysis, I would have recommended that the Support Services Building utilize the Geopiers and larger spread footings in lieu of the micropile foundation. The cost savings of $123,000.00 is fairly signifcant. However when the price per Geopier ($2,148.00) is compared to the price per micropile ($4,559.41), the price difference is extremely significant. Increasing the size of the concrete foundation elements has a much smaller impact on the overall project cost as the difference between the Geopiers and micropiles. Micropile foundation system are excellent foundation systems, however Geopier’s most certainly offer a more cost effictive solution to them. In fact, Geopiers are becoming increasingly more popular within the construction industy with thousands of successfully completed projects since the company began in 1989.

ANALYSIS II: ROOFING COMPARISON & ELIMINATION OF OFFSET ROOF

PROBLEM IDENTIFICATION

Hershey Medical Center utilizes a cold-applied built up roof on all of their projects. With this type of roof, all of the exterior walls and parapet walls need to be installed prior to the installation of the roofing material, due to the interface detail between the two materials. This requires additional time before the building is 100% watertight. An added issue with the cold-applied is that it cannot be applied under certain temperatures. Giving the project schedule, the roofing has to wait until spring 2011 to be installed. Cold-applied BUR is a rather expensive roofing system, and Alexander personnel felt that a more cost effective roofing system could have been utilized on the project without sacrificing any performance criteria or sustainability aspects.

Mostly all of the mechanical equipment for the Support Services Building is located on the rooftop. To hide the majority of this equipment, the roof above the Central Campus Storage is offset 5'-0" below the main roof. Offsetting the roof also requires extra materials and added time to construct vs. if the roof was not offset. Several personnel on the project felt that the offset roof was an unnecessary added cost. However eliminating the offset roof exposes the mechanical equipment. It was felt that this trade-off to exposing the mechanical equipment would be justified by both cost and schedule savings. However due to the timeline of the project, the offset was never eliminated.

RESEARCH GOAL

The goals of this research is research different roofing material/systems and select a roofing system that that provides the greatest benefits to schedule, cost, and the environment and to analyze lines of site to determine if hiding the mechanical equipment it necessary, and to determine schedule and cost impacts associated with eliminating the offset roof.

RESOURCES AND TOOLS USED

- Industry Professionals – Randy Klein – Tremco Roofing Representative
- National Roofing Contractors Association – NRCA
- Center for Environmental Innovation in Roofing – RoofPoint rating system
- Alexander Personnel
- AE Faculty –Dr. Riley
- Roofing Manufacturers
- Applicable Literature

EXPECTED OUTCOME

After completing extensive research, comparing several roofing systems, and selecting the best roofing system for the project, it is believed there will be both a cost and schedule savings. It is believed that newer technology in roofing has allowed different types of roofing systems to meet or exceed the durability and sustainability of a cold-applied BUR roofing system at a lower cost. It is also believed the eliminating the offset will expose the mechanical equipment to a certain degree, but will be minimal and that the cost savings associated with eliminating the offset roof are worth exposing the mechanical equipment.

Note: In order to keep both parts of this analysis separate it is broken down into two sections; roofing system comparison and elimination of the offset roof. Both sections have the same common goal of providing both a schedule and cost saving to the project.

PART I: ROOFING TYPE COMPARISON

INTRODUCTION TO ROOFING

In its simplest form the definition of a roof is; the cover of the building. A roof provides protection from the outdoor environment for the buildings inhabitants and also helps maintain the quality of the controlled indoor environment of the building. However, the roof also poses one of the biggest threats to the buildings integrity. Selection of the improper roof system or improper installation can negatively impact the buildings performance and comfort greater than any other building system. Roofing installation can also have major implications on the schedule of a project. Until the roof is 100% watertight, much of the interior finish work cannot be completed.

Roofs can typically be classified into two main categories; flat or low slope (< 3:12 pitch, i.e. 14°), and steep slope (>3:12 pitch). For the purposes of this report and the Support Services Building, steep sloped roofs are not applicable and will not be gone into further detail. A typical flat or low-slope roof is comprised of the following layers; support structure, insulation, and outer protective layer. Examples of flat or low-sloped roofing systems include; built-up bitumen, single ply, modified membranes (modified bitumen), and vegetated. Each of these will be gone into further detail in the following section.

ROOFING TYPES

While all of the following roofing types are different, they do share some similarities in their construction. After researching each of the following roofing types it was discovered that the supporting structure of the Support Services Building, structural steel/steel bar joists and 1 ½" metal roof deck will be the same regardless of the roofing type. Additionally the amount of insulation, 2 layers of 2" rigid insulation would remain the same regardless of the roofing time. To see the differences between the different roof types, a closer look at each is required.

Built-Up Bitumen (BUR) aka "Gravel Roofs"

A built-up bitumen roof is one of the oldest types of roofing and has been utilized in the United States for over 100 years. Shown in figure 32 at right, it consists of multiple plies of reinforced fabric installed between alternating layers of bitumen (asphalt). The number of piles in cross section determines the type and durability of the roof. For example the type that Hershey Medical Center uses on all of their projects, including the SSB is 3-ply. The outermost layer is typically covered with a layer of aggregate. Built-up roofs are known for the durability, water tightness that they provide, and minimal maintenance. Built- up bitumen roofs are fully adhered and can be applied in one of two ways; either hot applied or cold each applied.

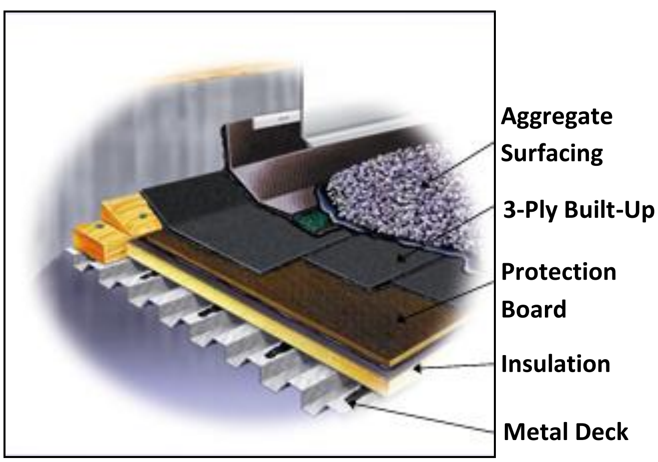


Figure 32: Built-Up Bitumen Roof.
Image provided by Tremco roofing

Hot Applied – The bitumen layer (asphalt) is heated in a kettle to anywhere between 375°F - 450°F and applied directly via a mop or mechanical spreader. It is the oldest method and most commonly used for built-up roofs.

Cold Applied – Is a relatively newer technology in built-up roofing (<20 years). In cold-applied, modified asphalt is utilized so that it doesn't have to be heated. The adhesive is either sprayed or broomed on. Because heat isn't needed for installation, cold applied BUR typically have a higher tensile strength. Cold applied also provides an alternative to the fumes (smell) of asphalt that is associated with hot applied.

Issus with Built-Up Bitumen

The most prevalent issue with built-up bitumen roofing systems is the high initial cost of installation and the time required for installation. Other than vegetated, BUR is the most expensive type of roofing system on the market. Flashing and interface details between the BUR and different exterior finish systems often more complex and require additional installation time vs. the other roofing types. Until recently, most LEED points were often unattainable with BUR when aggregate surfacing was utilized.

Single Ply Membranes

Single ply membrane roofing has grown significantly in popularity over the past thirty years. Single ply roofs are polymer based are fall into two basic classes; either thermosets (rubber) or thermoplastics (plastic). A polymer is a long string of molecules linked together. Themosets are held together by strong chemical bonds, therefore they aren't affected by heat as much as Thermoplstics which are held together by weaker bonds. Within each class there are several different sub-types. Each sub type is distinguished by the chemical composition of its polymers. The three most common single ply roofs are EDPM (thermoset), TPO (thermoplastic), and PVC (thermoplastic). Each of these sub-types will be discussed in further detail below. Technological advances in the manufacturing of these roofing systems have made them more economical, while increasing the strength of the membranes. Like the name says, a single ply membrane roof consists of a single membrane layer as the outer protective layer as shown in figure 33 above. Single ply membranes are available in a variety of colors but by far the most popular in the industry is white for its high solar reflectivity (SRI) value. A benefit of many single play roofs are that they can be 100% recycled when it needs replaces and are often easily repaired. Single ply roofs are considered by many to be a great roof with sustainability in mind and can help achieve several LEED points. Single ply membranes are also the cheapest roofing systems on the market and with their ease of installation have the shortest installation time.

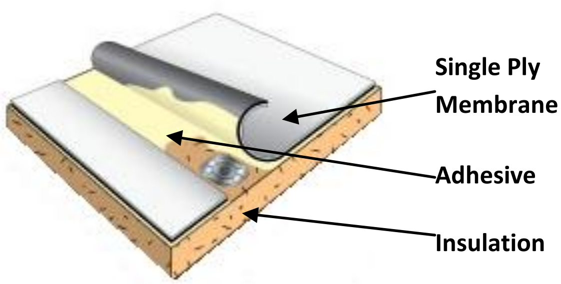


Figure 33: Single Ply Roof.

EPDM - Ethylene Propylene Diene Terpolymer – EPDM roofs where one of the first single ply roofs to hit the market roughly 40 years ago. It is a tried and proven system and is one of the most popular single ply membranes selected by owners and architects alike. According to the ERA (EPDM Roofing Association), over 1 billiion SF or EPDM roofing is installed annually in the United State alone. EPDM roofs are known for their resistance to extreme temperature swings, UV resistance, hail resistance, and wind uplift resistance. Available in white, EPDM roofs offer many benefits and can achieve both LEED points and can be ENERGY Star Certified.

PVC-Polyvinyl Chloride – PVC's roofs have also been around for over 40 years. PVC single ply roofs, unlike EPDM roofs are a thermoplastic. As mentioned on the previous page, thermoplastics have weaker molecular bonds. This allows PVC membranes to be more flexible (workable) and allows better heat-welding of the seams. Newer technology in the manufacturing of PVC to be blended with other polymers to form thicker more durable membranes such as KEE – Keytone Ethylene Ester or TPA – Tri-Polymer Alloy membranes. Like EPDM, PVC roofs are available in white which can help achielve LEED points and are 100% recyclable.

TPO- Thermoplastic Polyolefin – TPO roofs are relative newer technology in single ply roofs and have gained in popularity over the past 10 years. TPO membranes combine the workability of a PVC membrane, with the durability of an EPDM membrane. TPO membranes also do not contain any plasticizers, which were often added to roof membranes to increase flexibility, however weakened them at them molecular level. Like EPDM and PCV membranes, TPO membranes are easy to install and available in a variety of colors. However white it still the most common color chosen. TPO membranes have recently gained a stronghold in the market place and some consider them “true green roofs”. While more expensive than most EPDM’s and PVC’s, they are still relatively inexpensive when compared to Built-up Roofs. Only current downfall to TPO membranes are that since they are a newer technology, there is little known knowledge/data about the long-term performance of them.

Issues with single-Ply Membranes

Durability and redundancy are two of the biggest issues with single-ply membrane roofs. With only one layer of protection, single-ply membranes are at a much greater risk for being punctured. Although cheaper it is often recommended that if the roof is to have a lot of foot traffic, then single-ply is not your best option. New trends in the single-ply market add a fleece backer to the membrane to increase its durability; however it also increases the cost of the membrane. Other issues with single-ply membranes include; seaming issues and intolerance to ponding on the roof. Seaming issues arise with improper installation, and increased exposure to excessive heat (being elastomeric they expand and contract when heat is added). Single-plies often require maintenance & upkeep to increase their lifespan and maintain their reflectivity. When dirt builds on the roof, the white membranes lose their reflectivity, therefore reducing their efficiency.

Modified Membranes (Modified Bitumen)

Modified membranes were introduced to the roofing market in the United States back in the 1980’s. Modified membranes combine the advantages of a BUR with the ease of installation of a single-ply roof. As shown in figure 34 at right, modified membranes take the multiple plies of a BUR and combines them into a roll that can be installed more efficiently (similar to that of single-plies). These membranes can be either hot or cold applied. Hot applied requires use of a torch to heat the membrane so that it adheres to the roof. Cold Applied utilizes adhesives to adhere the membrane to the roof. Seams are typically heat welded. There are two different types of modified membranes that will be discussed on the next page.

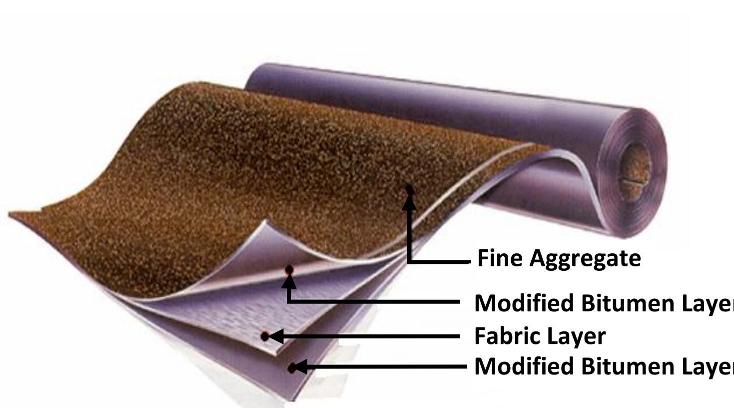


Figure 34: Modified Membrane Layers

SBS-Styrene Butadiene Styrene - SBS modified membranes are manufactured with rubber polymers. These rubber polymers allow the membrane to be elastic (workable) and allow it to expand and contract without breaking. SBS modified membranes can be either applied in a bed of hot asphalt, torch applied or cold applied. SBS membranes are also known for their superior durability and ability to resist water penetration.

APP-Atactic-Polypropylene - APP modified membranes are manufactured using a thermoplastic polymer giving them similar properties to PVC single-ply membranes. While less workable than SBS modified membranes, they still provided some flexibility and ability to resist temperature changes. APP membranes are mostly torch applied. APP modified membranes are also know for their UV resistance properties and its ability to resist water penetration.

Issues with Modified Membranes

Seaming and lap issues are the two most common issues with modified membrane roofing. Although the membrane itself is multiple layers (similar to BUR), the seams are the weakest point in the system when it comes to water penetration. Unlike BUR where layers are staggered, rolls of modified membrane roofing are lapped and melted together at the seams. Over time with the expanding and contracting of the membrane, the seams could crack, resulting in leaks. Blistering is another common issue with modified membranes. Although they provide increased durability compared to single-ply, they are typically not as durable as BUR.

Vegetated aka "Green Roofs"

Vegetated roofs are the newest type of roof to hit the market. Of all of the roofing types on the market, they provide the most sustainable aspects and can contribute to more LEED points than any other system. Benefits of green roofs include; decreased storm water run-off, greater thermal break between the controlled interior climate and the environment, greater acoustic properties, and reduced heat island effects. Additional benefits include reduced energy bills and feeling of being more environmentally friendly for the owner. Shown in figure 35 at right, a green roof is comprised of many layers. Atop the regular supporting structure and insulation, is a 100% waterproof membrane, a root stop, Styrofoam, layer to hold soil media, soil media, and lastly the vegetation.

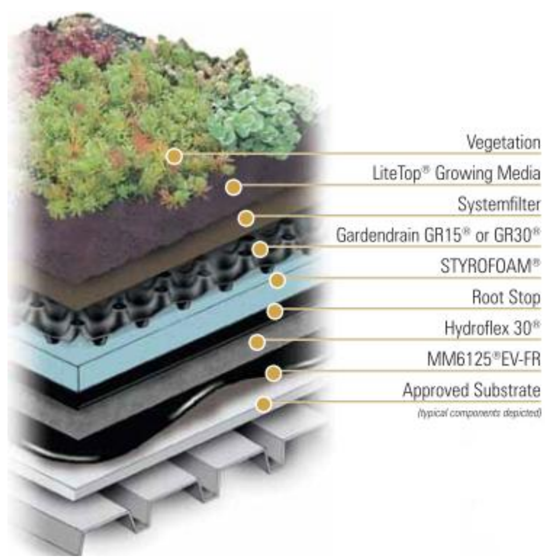


Figure 35: Extensive Green Roof Layers
Image taken from hydrotechusa.com/brochures/gardenroof

There are two main types of green roofs; extensive and intensive. Both are very similar, in composition, except when it comes to the depth of the soil media and the plant media. Extensive has a thinner soil layer (<6") and smaller growing media (small ground cover). It is the lightest of the systems and for the purposes of this report and the Support Services Building is the only one considered. Benefits of extensive green roofs include are that they require less maintenance, less weight, least expensive green roof, and can often be applied on a low-slope roof (<3:12, 14°) without specialty engineering systems.

Issues with Vegetated Roofs

A major issue with Vegetated roofs is the integrity of the waterproofing. It is common knowledge that one of the main purposes of a roof is to eliminate water and keep it from penetrating the buildings. Vegetated roofs however retain water, and expel it at significantly lower rates than regular roofs. Durability, longevity, and proper installation of the waterproofing membrane are vital to the success of a vegetated roof. Leaks can cost significantly more to repair with a vegetated roof compared to other roofing types. Another issue is what happens to the growing media in a drought? Plants need water to grow and survive. Although vegetated roofs utilize hardy plants, watering maybe required in long periods without rainfall. Vegetated roofs also cost significantly more ($5-10$/sf) for an extensive vegetated roof when compared to a BUR.

PRO'S & CON'S COMPARISON

In order to help select the preferred roofing type for the Support Services Building, table 19 below was constructed to show the pros and cons of each roofing type for comparison purposes. Table 19 also shows the advantages of each of sub-types compared to their counterparts. From table 19 we can see that BUR's have to most pros, while single-plies have the most cons, however other factors (such as environmental aspects & sustainability and cost) also need to be considered.

SYSTEM	PRO'S	CON's	TYPE	ADVANTAGES
Built-Up Bitumen	• True waterproofing • Low life cycle costs • High waterproofing • Maintainable • Ply redundancy • Abuse tolerant	• Higher labor costs • Higher initial costs • Slower installation • Membrane Slippage	**Hot Applied**	• Proven System • Can be installed in colder temperatures
			Cold Applied	• Little to no added heat needed for installation • Get performance of a built-up roof without the odor of asphalt (Great for renovations to occupied buildings)
Single Ply	• Low initial costs • Quick installation • Elastomeric (Stretchable)	• High life cycle costs • No ply redundancy • Abuse intolerant • Shrinkage/embrittlement • Ponding intolerant • Seaming problems	**EPDM**	• Resistant to temperature extremes • Exhibits least brittleness if freezing situations
			TPO	• Highly resistant to UV rays • Combines benefits of both EPDM & PVC • Environmentally friendly & recyclable • Don't contain any plasticizers
			PVC	• Heat Weldable • Durable - High puncture & impact resistance
Modified Membranes	• Factory surfacing option • Factory controlled sheet • High abuse tolerances	• Blistering • Lap integrity • Higher initial costs • Slower installation	**SBS**	• Greater low-temperature flexibility • Fatigue resistance • Higher softening point
			APP	• Higher strength • Lower elongation • Low initial costs
Vegetated	• Environmentally friendly • Increased insulation value • Can pay for itself • High waterproofing • Extend lifetime of base layers	• Higher initial costs • More expensive to repair • Require more maintenance	**Extensive**	• Lightest type of green roof • Requires less maintenance • Lower cost vs. other types of green roofs

Table 19: Pros & Cons Comparison of Different Roofing Types

ROOFPOINT COMPARISON

In order to further compare the different roof types, their environmental and sustainable aspects needed to be compared. They could have been compared using the LEED rating system; however LEED is more general in regards to the entire building and doesn't provide enough specifics and details in regards to the roofing itself. It has already been stated that the roof is one of the biggest threats to the building integrity and energy usage. Seeing the major role that roofs play in buildings and the lack of specifics n the LEED rating system, the Center for Environmental Innovation in Roofing developed the ***RoofPoint Rating System***. RoofPoint is a green rating system similar to LEED and other green rating systems, but is specific to roofing. The goal behind RoofPoint is to act as a guideline for the selection of environmentally innovative roofing systems; i.e. roofing systems that maximize energy efficiency and longevity while minimizing environmental impact. RoofPoint also serves as an assessment system to help architects/engineers/owners to compare several different roofing systems for a particular environmental application. Although roofs may not be fully recognized by LEED, RoofPoint is way for buildings to receive certification and recognition for participating in environmentally responsible roofing practices. Originated in 2009 the pilot version was made available to the public in early 2011. Table 20 below shows the RoofPoint comparison for all of the different roofing types.

ROOFPOINT RATING CHECKLIST								
SYSTEM	Built-Up Bitumen		Single Ply			Modified Membranes		Vegetated
TYPE	Hot Applied	Cold Applied	EPDM	TPO	PVC	APP	SBS	Extensive
SECTION 1: ENERGY MANAGEMENT								
Credit								
E1 - High R Roof Systems	x	x	x	x	x	x	x	x
E2 - Best Thermal Practices	x	x	x	x	x	x	x	x
E3 - Roof Surface Thermal Contribution	x	x	x	x	x	x	x	x
E4 - Roof Air Barrier	x	x	x	x	x	x	x	x
E5 - Rooftop Energy Systems								
E6 - Rooftop Daylighting								
SECTION 2: MATERIAL MANAGEMENT								
M1 - Recycled Content	x	x	x	x	x	x	x	x
M2 - Materials Reuse								
M3 - Roofing Waste Management	x	x	x	x	x	x	x	x
M4 - Low-VOC Materials	x	x	x	x	x	x	x	x
SECTION 3: WATER MANAGEMENT								
W1 - Roof Storm Water Retention								x
W2 - Roof-Related Water Use Reduction								
SECTION 4: DURABILITY / LIFE CYCLE MANAGEMENT								
D1 - Durable Roof Insulation System	x	x	x	x	x	x	x	x
D2 - Roof Drainage Design	x	x	x	x	x	x	x	
D3 - Roof Traffic Protection	x	x						x
D4 - Increased Wind Uplift Resistance								
D5 - Hygrothermal Analysis	x	x	x	x	x	x	x	x
D6 - Construction Moisture Management	x	x	x	x	x	x	x	x
D7 - Roof System Durability Enhancement	x	x	x	x	x			x
L1 - Roof Maintenance Program	x	x	x	x	x	x	x	x
L2 - Project Installation Quality Management	x	x	x	x	x	x	x	x
SECTION 5: ENVIRONMENTAL INNOVATION IN ROOFING								
IR 1 - Innovation in Design								
IR 2 - Exemplary Performance								
IR 3 - RoofPoint Roofing Professional								
Total Points	15	15	14	14	14	13	13	15

Table 20: RoofPoint Comparison of Different Roofing Types

In order to complete the RoofPoint checklist comparison additional research into different roofing material manufacturers was conducted and several assumptions were made. Table 21 below list all of the notes gathered and assumptions made per credit while completing the RoofPoint checklist.

Credit	Notes
SECTION 1: ENERGY MANAGEMENT	
E1 - High R Roof Systems	Polyisocyanurate Board Insulation (Type II) - R value = 7.2/inch. SSB has 4" = 28.8 R-value
E2 - Best Thermal Practices	2 Layers of 2" Rigid Insulation w/staggered joints & bottom layer mechanically fastened
E3 - Roof Surface Thermal Contribution	SSB used 3/8 marble with SRI of 78, Built-up Bitum SRI depends on final coating
E4 - Roof Air Barrier	Membrane creates air barrier
E5 - Rooftop Energy Systems	
E6 - Rooftop Daylighting	
SECTION 2: MATERIAL MANAGEMENT	
M1 - Recycled Content	Mostly all manufacturers produce materials made with recycled content
M2 - Materials Reuse	Could possibly be used, but was not considered. Assumed all products will be new from the factory
M3 - Roofing Waste Management	Is dependent on the GC/CM/Roofing Subcontractor to develop Waste management plan
M4 - Low-VOC Materials	Most Manufactuers produce products that meet the VOC requirements of this section
SECTION 3: WATER MANAGEMENT	
W1 - Roof Storm Water Retention	
W2 - Roof-Related Water Use Reduction	Would require the installation of a grey water system
SECTION 4: DURABILITY / LIFE CYCLE MANAGEMENT	
D1 - Durable Roof Insulation System	Most single-ply's can be adhered directly to insulation, however they can also be adhered to a protection board
D2 - Roof Drainage Design	The intent of this credit it to remove water, whereas a vegetated roof retains water
D3 - Roof Traffic Protection	Typ. nothing stops people from walking beyond the walkways, BUR are extremely durable and its impractical to walk on vegetated roofs
D4 - Increased Wind Uplift Resistance	
D5 - Hygrothermal Analysis	Installation of air/vapor barrier with
D6 - Construction Moisture Management	Construction Moisture Content Plan. Again would require GC/CM? Roofing Contractor to control & document moisture
D7 - Roof System Durability Enhancement	Use fleece-backed membrane's for Single-ply
L1 - Roof Maintenance Program	GC/CM/ Roofing contractor to create Roof Maintenance plan and service the roof if needed. This can easily be done.
L2 - Project Installation Quality Management	Install the roof and verify installation per a quality management program
SECTION 5: ENVIRONMENTAL INNOVATION IN ROOFING	
IR 1 - Innovation in Design	
IR 2 - Exemplary Performance	
IR 3 - RoofPoint Roofing Professional	

Table 21: Assumption & Research Notes used for RoofPoint Checklist Comparison (table 8)

Looking at the results of the RoofPoint comparison in table 8, it was discovered that when compared all of the different roofing systems scored very similar. In fact, the difference between the highest scoring roof (BUR & Vegetated) and the lowest (Modified Membranes) was only two points. If these same roofs where compared using LEED guidelines, the difference would have been much larger, with vegetated receiving the most points. This is certainly not the perception of the different roofing types to many in the construction industry. It is interesting to discover that when comparing only roofing types on a sustainable aspect, they are all very similar. It shows that manufactures have embraced the sustainability concept and now offer products for all roofing types that fulfill sustainable requirements of rating systems such as RoofPoint. Yes, these sustainable products often cost more than their non-sustainable counterparts for the same roof type, but that is not the point. These findings show that architects, engineers, and building owners alike are no longer limited to certain roofing types if they want to install a sustainable roof. This proves that the roofing industry has fully embraced sustainability, and has come a long way over the past twenty years. New materials and installation methods will continue to be developed; only pushing sustainable roofing into the future.

COST AND SCHEDULE COMPARISON

So far it has been shown that BUR's have the most pros and singly plies have the most cons per the pros and con comparison in table 19, and that when sustainable aspects are compared using a rating system such as RoofPoint, all of the different types are virtually similar. However before the preferred roofing system for the Support Service's Building was selected, cost and schedule implications of each type needed to be compared. Table 22 below shows typical cost, installation rates, and warranty periods for the different roof types compared within this report. Note that approximate cost includes all substrate materials such as insulation & protection board.

System	Type	Approx. Cost (SF)	Typical Installation Rate	Typical Warranty Period
Built-Up Bitumen	Hot Applied	\$13-\$15	20-25 square/day	15- 20 year
	Cold Applied	\$13-\$15	20-25 square/day	15- 20 year
Single Ply	EPDM	\$9-\$11	30-35 square/day	15- 20 year
	TPO	\$10-\$12	30-35 square/day	15- 20 year
	PVC	\$9-\$11	30-35 square/day	15- 20 year
Modified Membranes	APP	\$12-S14	25-30 square/day	15- 20 year
	SBS	\$13-S15	25-30 square/day	15- 20 year
Vegetated	Extensive	\$20-S25	5 square/day	10-15 year

Table 22: Cost, Installation Rate, & Warranty Comparison

As predicted, vegetated is the most expensive at around \$25/SF while single plies are the cheapest at around \$12/SF. Installation rates also fall along the lines that were predicted. It was interesting to discover however that and SBS Modified Membrane has the same cost as a typical BUR. Savings in these types of roofs result in typically a faster installation rate. On a final note, it is interesting to see that all of the roof types have the same warranty period. It must be noted that when it comes to a typical warranty period, the longer the warranty, the less that is covered.

Based on all three of the previous comparisons, one could argue that a single-ply roof could have been a cost effective alternative solution to the cold-applied built-up roof utilized on the SSB. In fact, Alexander proposed as a Value Engineering item to use a TPO instead. To further show the cost savings if a TPO roof has been chosen vs. the cold-applied built-up roof see the tables 23 and 24 below.

COLD -APPLIED BUR & TPO COST COMPARISON					
Roof Type	Total SF of Roof	Cost/SF	Total Cost	Installation Rate (SQ/day)	Total Installation Duration (workdays)
Cold Applied Built-Up Bitumen	24,440	\$15.00	\$366,600.00	20	13
Single Ply - TPO	24,440	\$12.00	\$293,280.00	30	8
		Difference:	\$73,320.00	Difference:	5

Table 23: Cold Applied BUR & TPO Cost & Installation Comparison

From table 23, it can be seen that on material costs alone, a TPO roof would have saved the SSB project over \$73,000.00 and the project would have seen a week in schedule reduction. This week comes from the fact that with the roof being finished earlier, interior finishes can start earlier. It is important to note however that installation of any type of roof typically required temperatures of 40°F and rising for proper adhesion. With the SSB roof being installed in late winter, early spring, this could be a significant factor. One thing a TPO roof would allow in winter installations is if the weather was to break and temperatures rise above install temperature, a larger area can be installed per day. To calculate total savings (assuming a 1 week reduction in schedule) with the installation of the TPO roof, General Conditions cost for that week must also be calculated. Table 24 below shows General Conditions Cost for the project per week.

GENERAL CONDITIONS SUMMARY				
DESCRIPTION	UNIT	QUANTITY	UNIT RATE	COST
Personnel	Week	65	$12,414.77	$806,960.00
Construction Facilities & Equipment	Week	65	$1,096.15	$71,250.00
Temporary Utilities/Services	Week	65	$522.69	$33,975.00
Miscellaneous	Week	65	$250.00	$16,250.00
Total Weeks		**65**	**$14,283.62**	**$928,435.00**

Table 24: SSB General Conditions Cost Per Week

From table 24, it is shown that the general conditions cost for the SSB is just over $14,000.00/week. Combining both cost savings results in a total of just over $87,600.00 as shown below.

Material	$73,320.00
General Conditions	$14,283.62
Total Cost Savings:	**$87,603.62**

With cost and installation differences compared for the different roofing types and the total cost savings if a TPO roof were utilized in lieu of the cold-applied BUR calculated, there are several important questions that needed to be answered before the final decision was made about the preferred roofing type for the SSB.

IMPORTANT QUESTIONS & ANSWERS BEFORE SELECTING A ROOF

All of these questions were derived from a Tremo Roofing powerpoint about Roofing Decisions and through phone interviews with Randy Kline – Senior Field Advisor for Tremco Roofing

1. **Will there be foot traffic?** If so, multi-ply roofing is probably best.
2. **Do you want to maintain a proven system?** If so, BUR is probably best.
3. **Is cost the most important consideration?** If so, single-ply is probably best.
4. **Are local wind and fire codes met?** Typically all types meet this requirement.
5. **Are their specific insurance requirements?** If so, contact the insurance representative before selecting a roofing type
6. **Is achieving the most LEED points possible the most important consideration?** If so vegetated is probably best
7. **Is the amount of maintenance required a consideration?** If so, BUR or Modified Membrane is probably best.
8. **Is aesthetics the most important consideration?** If so, vegetated or single ply is probably best.

All of these questions should be considered before any roofing type is selected. It is important for architect, engineering, and construction managers to keep these considerations in mind when specifying a roofing type or proposing a roofing type for Value Engineering purposes. In the end, the owner's needs, wants, and use of the building should ultimately be considered when a roof is specified.

CONCLUSION FOR PART I: ROOFING TYPE COMPARISON

Through in-depth research into several different types of roofing materials it has been found there is no one single preferred roofing material that is universal for every project. In fact the decision process is much more complex. It was shown that every roofing type has its pros and cons associated with it, with BUR having the most pros in general, but it is also one of the more costly roofing types. It was also found that when compared solely on sustainable aspects using a green rating system such as RoofPoint by the Center for Environmental Innovation in Roofing, that all the different roofing types are virtually similar. It is obvious that roofing manufactures have embraced the idea of green building and sustainably and offer sustainable products for all types of roofs. When cost and schedule were compared, the results were as predicted. Singly ply roofing is both the cheapest and has the quickest installation rate while BUR's and vegetated were the most expensive and had the slowest installation rates. It was shown that if the SSB project had utilized a TPO roof vs. the cold-applied BUR, a week could have been saved on the project with a total cost savings over $87,600.00. Several other important questions were also pointed out that need to be answered before a roofing type is selected.

Based on all of the comparisons and after answering the 8 questions on the previous page, it is my recommendation that the cold-applied BUR was the proper choice for the Support Services Building. In fact, Hershey Medical Center tried single-ply roofing on some smaller projects several years ago, and were dissatisfied. Their buildings tend to see a high volume of foot traffic on the roofs, and they found out that single plies didn't hold up to the abuse. They've found that they had better luck with the BUR that was installed on the original hospital built back in 1966, and that is why they went back to BUR's. Using cold-applied allows installation without the fumes of asphalt, which is great for a medical environment. From a sustainably standpoint, the cold-applied BUR used on the SSB is the same or better than a single-ply. Yes this roof costs more, but there is also something that can be said about giving the owner what they want.

PART II: ELIMINATION OF OFFSET ROOF

INTRODUCTION TO OFFSET ROOF

Mostly all of the mechanical equipment for the Support Services Building is located on the rooftop. To hide this equipment, the roof above the Central Campus Storage is offset 5'-0" below the main roof. Figure 36 below highlights this area as well as the surrounding roof heights.

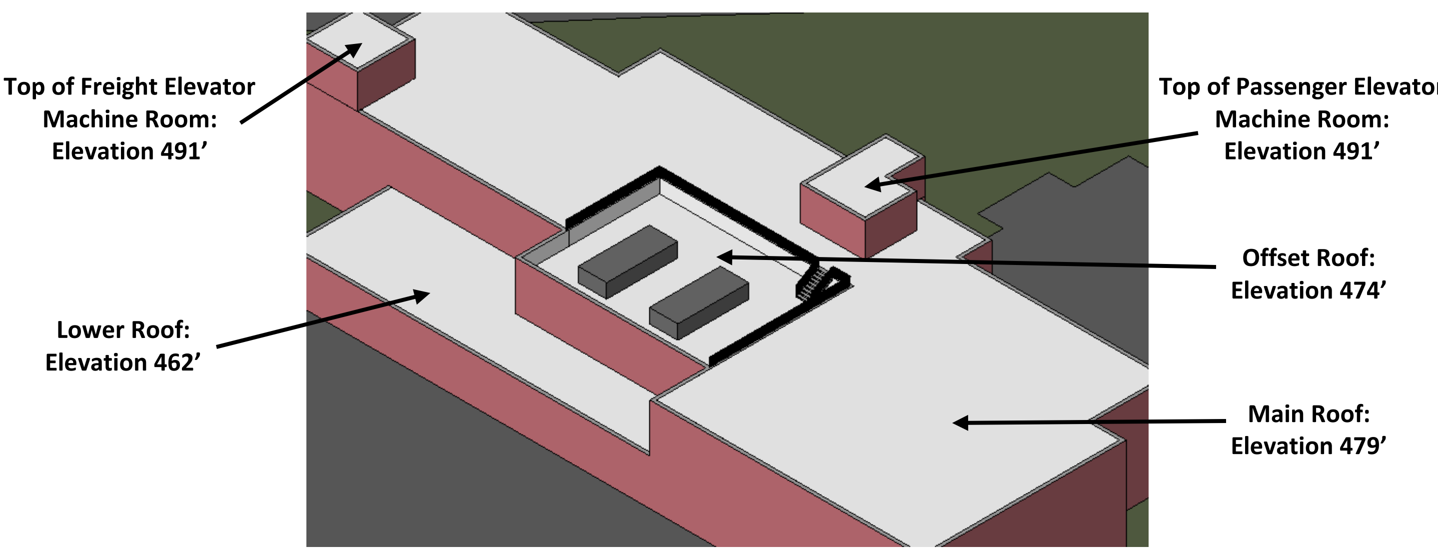


Figure 36: Support Services Building Roof Elevations

Creating the offset requires both addition time and material vs. if there roof were not offset. Adding to the difficulty of the offset is the cold-applied BUR used on the project. With this type of roof, all of the parapet walls need to be completed prior to final installation of the roofing material, due to the interface detail between the two materials. Per my interview with Jeff Smith, project manager for Alexander on the project, he noted that given the nature of the building, offsetting the roof like this is unnecessary and if it wasn't offset there could be a significant cost savings. Looking at it from an architectural standpoint, eliminating the offset roof would expose the RTU's. Before it can be determined if eliminating the offset the roof would have been beneficial, a line of sight study needed to be performed to determine the locations in which the RTU's would be visible from. After that estimated cost and schedule savings need to be calculated to see the total savings.

LINE OF SIGHT STUDY

Using Autodesk Revit Architecture, a mass model of the SSB without the offset roof was created in order to perform the line of sight study. Model lines were then drawn from the RTU's to the edge of the building and extended out until they hit the ground. Lines were drawn at numerous angles in order for the study to cover a broad surrounding area. Figure 37 at right shows a summarized version of what the model with model lines looked like. It should be noted that no model lines were drawn to the north because elevation changes in the grade would eliminate a direct line of site to the RTU's.

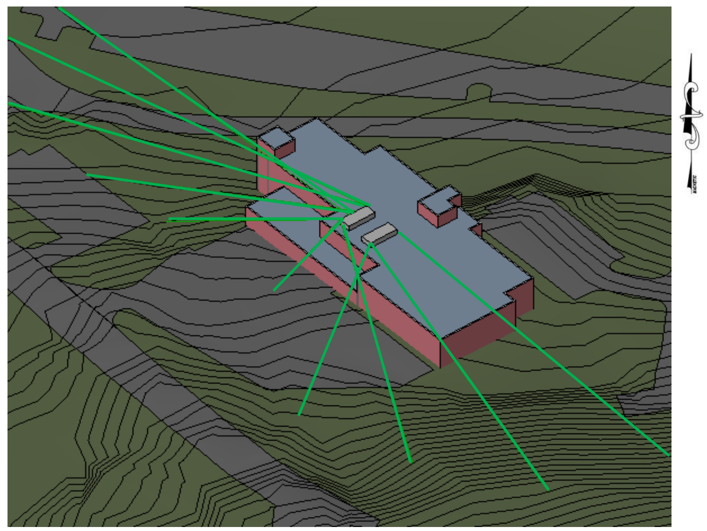


Figure 37: Revit Model with Sight Lines of SSB Without Offset Roof

To gain a better understand of the distance away from the building that the RTU's would be visible; the model lines were then studied in elevation views. Individual elevation views were created perpendicular to each model line to insure the model lines were viewed in the correct orientation/plane. Figure 38 below shows two of the elevation views with model lines extended to grade.

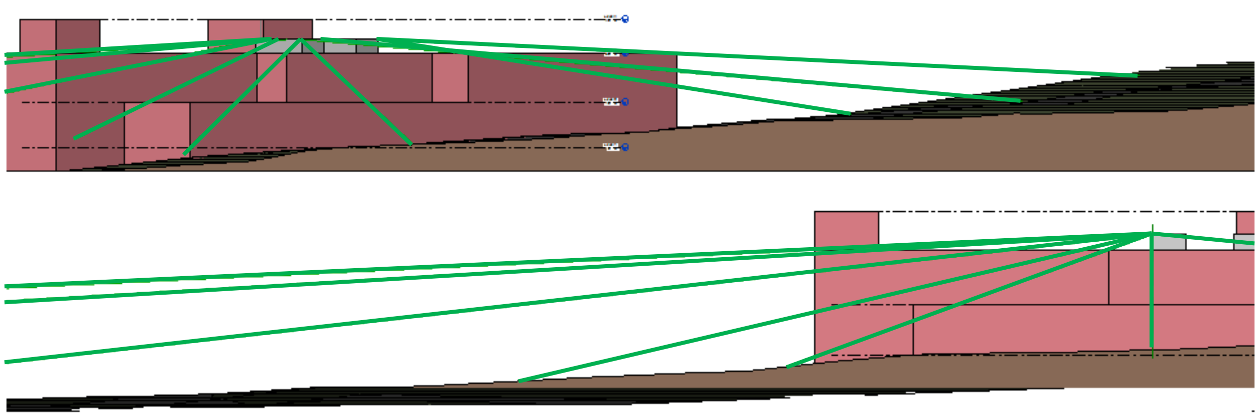


Figure 38: Revit Model Elevation Views w/ Model Lines Extended to Grade

Note that although model lines are visible in multiple elevations, proper care was taken to insure that only the model line perpendicular to each elevation view was examined. Model Lines were thickened afterwards for better clarity.

Upon completion of analyzing the model lines in elevation view, the site model was replaced with a representative Google Maps image as shown in figure 39 at right. Connecting the tips of the model lines, a path was generated highlighting the points at RTU's become visible as you walk away from the building. Highlighting the path, figure 40 below was generated. All areas shaded in red represent locations in which the RTU's are visible. The dark red line represents the path mentioned above.

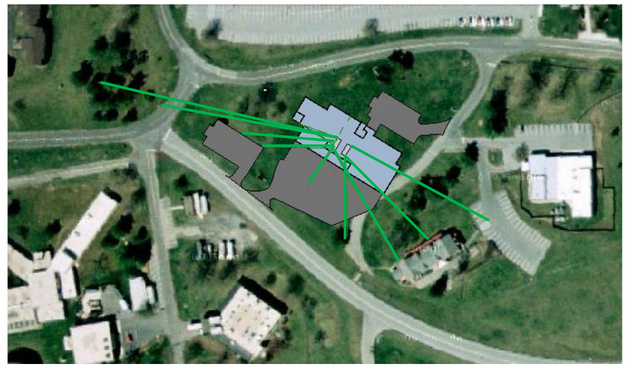


Figure 23: Combination of Revit Model & Google Map Image

Figure 40: Locations Were RTU's Are Visible

Looking at figure 40, the RTU's are visible from approximately due west – due east, rotated counter-clockerwise. At first glance this area represents a major portion of the surrounding area and one could conclude that this is too large of an area for the RTU's to be visible. However, upon closer examination, the area located south of the SSB building is undistributed forest and farmland. Looking at figure 41 below, this is clearly visible. Located southeast of the building site (behind the NMR research facility) is a steep hill, on top of which is a parking lot with forest beyond. To the southwest is the Animal Research Facility (ARF) and various utility buildings with farmland and forest beyond. After looking at the bigger picture, much of the area in which the RTU's are visible if the offset roof is eliminated, has limited public visibility.

Figure 41: Surrounding Area of Support Services Building

MATERIAL ESTIMATE

As mentioned before, creating the offset roof requires additional materials to construct. Eliminated items include: structural steel, painted galvanized handrail w/ supports & mounting brackets, set of galvanized stairs, exterior wall sheathing, 3-ply cold applied- asphalt roofing(applied vertical) w/misc. details. Many of these items can be seen in figure 42 below.

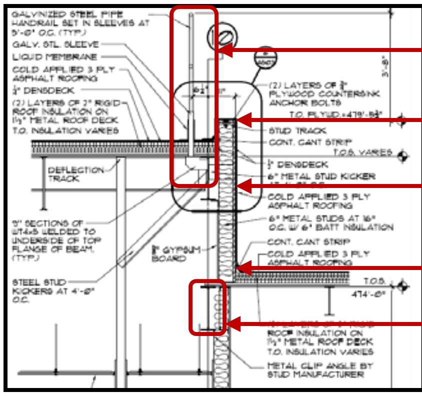


Figure 42: Eliminated Materials w/ Elimination of Offset Roof

After performing a detailed take-off of the items mentioned above using the construction documents, an estimate (table 25 below) of the material savings was calculated using RS Means Costsworks 2010 along with a subcontractor quote. A misc. metals subcontractor was utilized get a price for the galvanized handrail and stairs due to their complexity to estimate.

OFFSET ROOF MATERIAL ESTIMATE

Item	Description	Unit	Quantity	Unit Price	Total Inc. 15 % O & P Markup	Total Cost
Structural Steel						$6,970.28
	W 18 x 35	LF	34.13	$43.75	$50.31	$1,717.17
	W 18 x 35	LF	14.33	$43.75	$50.31	$720.98
	W 18 x 35	LF	22.5	$43.75	$50.31	$1,132.03
	W 18 x 35	LF	23.0	$43.75	$50.31	$1,157.19
	W 16 x 31	LF	11.42	$37.93	$43.62	$498.13
	W 16 x 31	LF	23.0	$37.93	$43.62	$1,003.25
	W 16 x 31	LF	17.0	$37.93	$43.62	$741.53
Perimeter Wall						$15,957.17
	1/2" DensDeck Sheathing	SF	1,210	$2.08	$2.39	$2,894.32
	3/4" Plywood (Roof Curb)	SF	300	$3.48	$4.00	$1,200.60
	3/8" Anchorbolts w/ nuts and washers	EA	100	$1.25	$1.44	$143.75
	Cold Applied 3-Ply Asphalt Roofing (Vertical)	SF	1,210	$8.00	$9.20	$11,132.00
	Cant Strip	LF	340	$1.50	$1.73	$586.50
42" Galvanized Handrail (Subcontractor Quote*)						$9,653.00
	2" OD pipe railing with 3/4" pickets @ 4" O.C.	LF	62**	$131.50	-	$8,153.00
	Painting (1 coat shop prime + 2 finish coats)	EA	1	$1,500.00	-	$1,500.00
5' Wide Galvanized Steps (Subcontractor Quote*)						$8,450.00
	7 treads @ 10" w/ 6'-0 landing & handrail	EA	1	$7,750.00	-	$7,750.00
	Painting (1 coat shop prime + 2 finish coats)	EA	1	$700.00	-	$700.00
					Total in Material Savings	$41,030.45

* Quote includes fabrication, delivery, installation, mounting hardware/brackets, & markup

** Actual removal was 140LF, 78LF was then added along south side per removal of parapet wall (see figure 34 on page 39)

Table 25: Elimination of Offset Roof Material Estimate

SCHEDULE SAVINGS

Creating the offset roof also requires additional time vs. if the roof were at the same elevation as the surrounding main roof. Mainly the offset roof requires the construction of the 5' high perimeter wall to be constructed before the roofing material can be applied. The wall itself is not considered a material savings however, since it defines the boundary of the central campus storage. Items such as the painted galvanized handrail and stairs also were not considered as schedule saving items because they do not directly affect the total schedule of the project like that of finished roofing. Any time savings in completion of the roofing directly affects the total project duration because interior finishes can begin once the roofing is complete. Table 26 below shows the calculated estimated schedule savings for eliminating the offset roof. Durations were both estimated from phone conversations with Alexander personnel and RS Means Costworks 2010.

OFFSET ROOF SCHEDULE SAVINGS					
Item	**Description**	**Unit**	**Quantity**	**Production Rate/day**	**Total Installation Tme (days)**
Structural Steel					
	W18x35 Beams	EA	4	35	0.11
	W16x31 Beams	EA	3	35	0.09
	Bolted Connections	EA	14	40	0.35
Perimeter Wall					
	6" Metal Stud Wall	LF	140	100	1.40
	1/2" Dens Deck Sheathing	SF	1,210	1,125	1.08
	2 Layers 3/4" Plywood (Roof Curb)	LF	140	325	0.43
	3/8" Anchorbolts w/ nuts and washers	EA	100	150	0.67
	Cold Applied 3-Ply Asphalt Roofing (Vertical)	SF	1,210	1,550	0.78
	Cant Strip	LF	280	2,000	0.14
	Total Estimated Schedule Savings (Days):				**5.04**

Table 26: Estimated Schedule Savings with Elimination of Offset Roof

TOTAL COSTS SAVINGS

As shown in table 26 above, the estimated schedule savings with the elimination of the offset roof is approximately five workdays. For the purposes of this report, five days will be utilized to calculate the savings in General Condition's costs. A General Conditions cost per week summary for the project can be seen in table 27 below. For a more detailed description of the breakdown of these costs see table 24 on page 50.

GENERAL CONDITIONS SUMMARY			
Total Weeks	**65**	**$14,283.62**	**$928,435.00**

Table 27: General Conditions Cost/Week for the Support Services Building

From table 27, it is shown that the general conditions cost for the SSB is just over $14,000.00/week. Combining both the material and General Conditions cost savings results in a total of just over $55,300.00 as shown below.

Material	$41,030.45
General Conditions	$14,283.62
Total Cost Savings:	**$55,314.07**

CONCLUSION FOR PART II: ELIMINATION OF OFFSET ROOF

After conducting a line of sight study, it was found that once the offset roof was eliminated, the RTU's would be visible from west to east on a counter-clockwise path. It was shown however that in the area in which the RTU's are visible there is limited public visibility and there is mostly farmland and forest. It was estimated that eliminating the offset roof resulted in over $41,000.00 in material savings. Elimination of the offset roof also produced an estimated five days in schedule savings due to the direct connection between roofing and interior finishes. In total it was shown that the elimination of the offset roof would result in a potential savings of over $55,000.00.

Based on the finding of this section, I would have recommended that the offset roof be eliminated. The Support Services Building is not an architectural wonder (statement building) on the medical center's campus. It is a support facility for the entire campus and therefore hiding the RTU's is not necessary. The cost savings of $55,000.00 is well worth eliminating the offset roof and exposing the RTU's. Figure 43 below shows a mass model drawn in Autodesk Revit Architecture of what the Support Services Building would have looked like with the elimination of the offset roof.

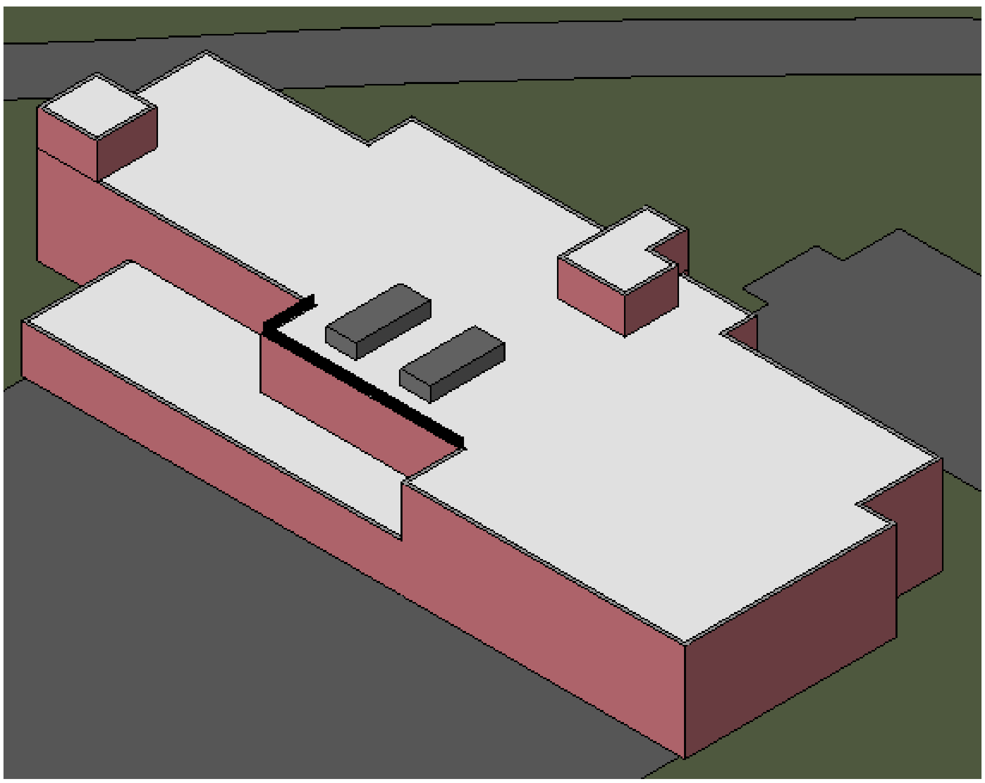


Figure 43: Mass Model of Support Services Building with Elimination of Offset Roof

ANALYSIS III: DESIGN STUDY TO INCREASE SUSTAINABLE FEATURES USING RENEWABLE ENERGY SOURCES (Part of Structural & Electrical Breadth)

PROBLEM IDENTIFICATION

Currently the Support Services Building project is slated to achieve Penn State's LEED requirement of a LEED Certification rating upon completion. However, the project utilized very few sustainable techniques that could provide financial benefits to Hershey Medical Center or Penn State. Penn State's current LEED standards don't push project teams to pursue higher ratings or add onsite renewable energy sources. Features such as photovoltaic roof panels, a solar hot water heater, or a geothermal heat pump system could be very beneficial to HMC to offset the operating costs of the building and reduce its carbon footprint. Unlike most buildings on the medical centers campus, the Support Services Building will generate no income to offset operating costs.

Although Penn State conducts extensive research into renewable energy sources for buildings, none of their actual buildings utilized these systems. Most research is conducted on a small scale, or on projects outside of Penn State's network of facilities. The Support Services Building provides an ample platform for Penn State to incorporate renewable energy sources into a building, and provide a larger "in-house" research facility, and set an example for other universities to follow.

RESEARCH GOAL

The goal of this research is to design a preliminary PV energy system to offset the Support Services Building energy usage to possibly become Penn State's first "Net-Zero" building. It is also the goal of this research to eliminate the current rooftop HVAC system for a more energy efficient one.

RESOURCES AND TOOLS USED

- Industry Professionals
- Alexander Personnel
- AE Faculty – Dr. Riley – AE 498D Solar Class
- Computer Design Software – AutoCAD 2011 and Revit Architecture 2011
- PV Watts - Online Solar Calculator
- PV Manufacturers – Sunpower
- Applicable Literature

EXPECTED OUTCOME

Through research and analysis, it is expected that in order to add renewable energy (onsite) resources to the Support Services Building will result in a significant cost increase. It is expected that the initial up-front cost will be offset by lower operating cost, however full payback make take decades to achieve. Because the Support Services Building is relatively small when compared to other Penn State facilities, it will provide Penn State the opportunity on a larger scale to research the these systems, determine energy savings and refine operating techniques of buildings with these systems. If would provide Penn State a platform to research and redefine their LEED policies to start incorporating this technology into all of their new projects. It would be model for future sustainable buildings for Penn State.

Note: This analysis is broken down into two parts. **Part 1-Preliminary Design of a Geothermal Heat Pump System** will look at replacing the gas-fired RTU's with more efficient geothermal packaged units. **Part 2-Installation of a PV Array** will look at adding a solar PV array on the rooftop to generate onsite electricity for the building. Both systems will increase the initial cost, however will both result in a smaller carbon footprint and reduced operating costs.

PART I: PRELIMINARY DESIGN OF A GEOTHERMAL HEAT PUMP SYSTEM

INTRODUCTION TO GEOTHERMAL

Geothermal heat pump systems utilize the natural properties of the earth (temperature) to provide heating and cooling for buildings vs. petroleum based fuel sources. After a depth of approximately 15 feet, the earth temperature remains constant between 55 and 65°F year-round. Heat/Cooling is achieved via circulating a liquid (water or glycol solution) through pipes (loops) and then through a heat exchanger, which heats or cools the air to be distributed. In heating mode, the cold liquid is sent out from the system and extracts heat from the ground as depicted in figure 44 below. In cooling mode, the opposite occurs. Warm water is sent out from the system to expel its extra heat to the ground and return at a cooler temperature as depicted in figure 45 below.

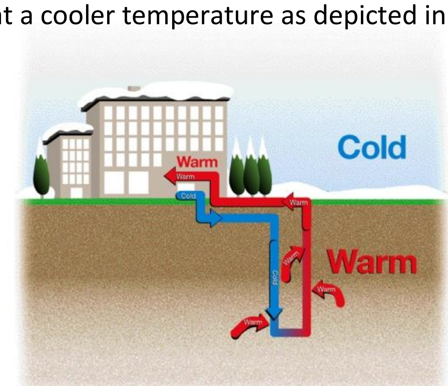


Figure 44: Geothermal Heating Mode
Image taken from www.mcquay.com

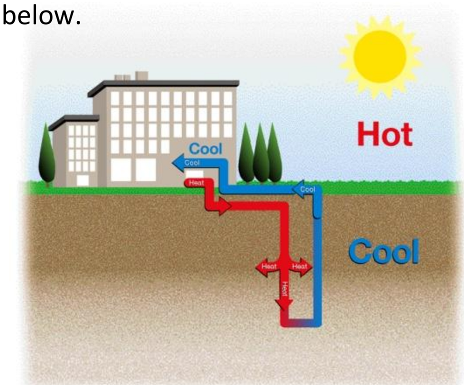


Figure 45: Geothermal Cooling Mode
Image taken from www.mcquay.com

Geothermal heating/cooling can be achieved via several methods. These include horizontal ground loops, vertical ground loops, and pond loops. Each type can easily be defined by looking at its name. Horizontal ground loops are installed by digging trenches and running the loop piping within the trenches. Large space is required for installation of horizontal ground loop systems. Vertical ground loops are drilled wells (ranging from 250-500ft deep) into the ground. There are two types of vertical loop systems. An open-loop system utilizes groundwater as the liquid for the system. Groundwater is pulled from the ground through the system and then returned back to the source. A closed-loop system utilizes a water-glycol system run in continuous piping to extract and expel the heat in the ground. Closed-loop systems are the preferred method when adequate groundwater in unavailable. Pond loops run through a nearby pond or large body of water. They work the same way as ground loops in at a certain distance beneath the surface of the water temperature remains constant. For the purposes of this analysis, a closed-loop system will be utilized since there are no bodies of water nearby, and that availability for groundwater is unclear.

TOTAL HEATING/COOLING LOADS HANDLED BY RTU'S

In order to size the geothermal system to replace the existing gas-fired RTU system, the total heating and cooling capacities of the three RTU's needed to be calculated. It should be noted the intention is to only replace the RTU's that service the building. Additional systems such as the make-up air system for the loaded dock area, and the individual small split-systems that serve the IT rooms, electrical rooms, and elevator machine rooms will remain as designed.

Geothermal units are conventionally sized by ton(s) of refrigeration. A ton of refrigeration is defined the amount of energy (BTU's) one ton of ice in a period of 24 hours. This is equivalent to 12,000 BTU's per hour of energy removal. Looking at the mechanical schedule for the RTU's, total loads are given in MBH

(1,000 BTU/hr) for both heating and cooling. Cooling was the higher of the two values for all three RTU's and was utilized to size the new geothermal system. To convert the load given in the mechanical schedule from MBH to Ton, the following equation was used.

Load in MBH * 1,000 = Total BTU/hr => (Total BTU/hr) / 12,000 BTU/Ton = # of Ton's

Using this equation, the calculation for RTU-1 can be seen below.

$$(474\ MBH * 1{,}000) = 474{,}000\ BTU/hr \quad \longrightarrow \quad \left(\frac{474{,}000\ BTU/hr}{12{,}000\ BTU/ton}\right) = 39.5\ tons$$

Using the same equation as above RTU-2 was determined to be approximately equivalent to 10.1 tons and RTU-3 was determined to be approximately equivalent to 37.8 tons. In total the combination of all three units is approximately 87.4 tons (39.5+10.1+37.8). It is this number (87.4 tons) that is to be the minimum size of the geothermal system.

DIFFERENT METHODS FOR GEOTHERMAL SYSTEMS IN COMMERCIAL BUILDINGS

In talking with Chris Sylves from Nittany Geothermal and Terry Mangold from The Warko Group, there are several ways to break down a building for geothermal zones. Both ways utilized packaged geothermal units with a built-in heat exchanger and fan to condition the air. One option is to break the building into small zones (sometimes per room basis) and install small individual packaged units located above the ceiling. This method eliminates the need for extensive runs of ductwork to distribute the air. However meeting minimum outside air requirements per ASHRAE standards is harder to achieve. The second option breaks the building into larger zones (smaller than zones covered by conventional air handling equipment) and use larger packaged geothermal units. Using this method requires ductwork to distribute the air to several rooms/areas. However it allows the units to be centrally located in mechanical rooms where it is easier to draw in the necessary outside air requirements. With the Support Services Building being relatively small (42,000 SF), the second method mentioned above was used in the preliminary design of a geothermal system.

CALCULATING NEW GEOTHERMAL ZONES

Before the building could be broken into new smaller geothermal zones, estimated loads per room needed to be determined. After talking with several industry experts, it was determined that the best way to approximate these loads (without doing in-depth load calculations)would be to find the volume of each space and divide it by the total load of the RTU servicing that room. These calculations can be seen below in table 28.

RTU-1						
#	Room	Length (ft)	Width (ft)	Ceiling Height (ft)	Total Volume (CF)	Amount of Cooling (ton)
Lower Level						**4.44**
G100	Corridor	25	22	27	14,850	3.90
		15	5	27	2,025	0.53
First Floor						**21**
106	Staff Break Room	24	13	10	3,120	0.82
108	Electric Shop	24	12.5	15	4,500	1.18
110	HVAC Shop	24	17	15	6,120	1.61
112	Plumbing Shop	24	16	15	5,760	1.51
113	Open Area/Receiving	51	46	15	35,190	9.25
113A	Shipping Receiving Admin Office	8.5	12	9	918	0.24
113B	Shipping Receiving Office	10	12	9	1,080	0.28

RTU-3						
#	Room	Length (ft)	Width (ft)	Ceiling Height (ft)	Total Volume (CF)	Amount of Cooling (ton)
First Floor						**28.21**
101	Sign Shop	26	24	13	8,112	2.98
101A	Sign Shop Office	14	9.5	9	1,197	0.44
101B	Sign Shop Storage	12	19	13	2,964	1.09
102	Copy/Fax	15	7	9	945	0.35
104	Recycling	5	9	6.83	307	0.11
118	Metal Shop	35	29	13	13,195	4.84
		36	20	13	9,360	3.43
120	Paint Shop	18.5	32	13	7,696	2.82
121	Manual Stg./ Reference	22	28	10	6,160	2.26
121A	Supervisor	10	9	9	810	0.30

113C	File/Copy	9	12	9	972	0.26
114	Medical Equip. Set-Up	24	15	10	3,600	0.95
199A	Corridor	125	7	10	8,750	2.30
EL115	Freight Elevator Staging Area	28	19	15	7,980	2.10
Second Floor						**14.56**
202	Recycling	5	9	6.83	307	0.08
204	Staff / Break Area	20	13	9	2,340	0.62
204A	Copy/Fax	12	7	9	756	0.20
206	Multipurpose Room	25	17	9	3,825	1.01
207	EHS Secure Storage	32	9	9	2,592	0.68
208	EHS Supervisors	39	25	9	8,775	2.31
209	Men's Toilet	17	12	9	1,836	0.48
210	Computer Workstations	27	9	10	2,430	0.64
211	Women's Toilet	17	12	9	1,836	0.48
213	Janitors Closet	8	5	9	360	0.09
214	EHS Equipment Repair & Cleaning	17	9	9	1,377	0.36
		8	12	9	864	0.23
216	EHS Staff Area	10	12	9	1,080	0.28
		28	13	9	3,276	0.86
219	EHS Equipment Parking	21	10	15	3,150	0.83
299	Corridor	32	8	10	2,560	0.67
299A	Corridor	136	7	10	9,520	2.50
299B	Corridor	19	9	10	1,710	0.45
EL 200	Lobby	24	9	17	3,672	0.97
EL 219	2nd FLR. Elevator Staging Area	19	11	15	3,135	0.82
				Total:	**150,266**	**39.50**
				Cubic Feet per Ton:	**3,804**	

121B	Supervisor	10	9	9	810	0.30
121C	Supervisor	10	9	9	810	0.30
121D	Supervisor	10	9	9	810	0.30
122	Women's Locker Room	24	14	9	3,024	1.11
124	Janitors Closet	4	8	9	288	0.11
126	Men's Locker Room/Toilet	24	30	9	6,480	2.38
199	Corridor	13	7	10	910	0.33
199B	Corridor	44	6	10	2,640	0.97
199C	General STG./ Staging Area	74	14	10	10,360	3.80
Second Floor						**9.54**
200	Office	61	33	10	20,130	7.39
		19	19	10	3,610	1.32
200A	Office	14	9	9	1,134	0.42
200B	Office	14	9	9	1,134	0.42
				Total:	**102,886**	**37.76**
				Cubic Feet per Ton:	**2,725**	

RTU-2						
First Floor						
111	Central Campus Storage	49	61	27	80,703	10.1
				Total:	**80,703**	**10.10**
				Cubic Feet per Ton:	**7,990**	

Table 28: Load Per Room Calculation for Existing RTU's

Before new zones were created using these values, an approximate size of the new packaged geothermal units needed to be determined. Chris Sylves from Nittany Geothermal recommended that Climatemaster packaged geothermal units be utilized. Looking at their brochure on their larger commercial series, the largest size unit available is 25 tons. Using 25 tons as the max unit size, new zones were created using the ton/room numbers from table 28 above. Final use and locations of the rooms was also considered when the new zones were created. Table 29 below shows the breakdown of rooms for the new geothermal zones. Note that each zones is color coded to go along with figure 46 on the next page. Although 25 tons was the maximum size a zone could be, most of the zones worked out to be much smaller. Looking at figure 46, it is clear to see why smaller zones are preferred over larger (25-ton) zones.

Zone 1		
Area		Required Cooling (ton)
G100	Corridor	4.44
106	Staff Break Room	0.82
108	Electric Shop	1.18
110	HVAC Shop	1.61
112	Plumbing Shop	1.51
114	Medical Equip. Set-Up	0.95
199A	Corridor	2.30
EL115	Freight Elevator Staging Area	2.10
	Total Required Capacity:	14.91

Zone 2		
Area		Required Cooling (ton)
113	Open Area/Revieving	9.25
113A	Shipping Recving Admin Office	0.24
113B	Shipping Receiving Offive	0.28
113C	File/Copy	0.26
111	Central Campus Storage	10.1
	Total Required Capacity:	20.13

Zone 3

Area		Required Cooling (ton)
202	Recycling	0.08
204	Staff / Break Area	0.62
204A	Copy/Fax	0.20
206	Multipurpose Room	1.01
207	EHS Secure Storage	0.68
208	EHS Supervisors	2.31
209	Mens Toilet	0.48
210	Computer Workstations	0.64
211	Womens Toilet	0.48
213	Janitors Closet	0.09
214	EHS Equipment Repair & Cleaning	0.59
216	EHS Staff Area	1.15
219	EHS Equipment Parking	0.83
*220	New Mixed-Use Space	1.18
299A	Corridor	2.50
299B	Corridor	0.45
EL 219	2nd Floor Elevator & Staging Area	0.82
	Total Required Capacity:	14.11

Zone 4

Area		Required Cooling (ton)
101	Sign Shop	2.98
101A	Sign Shop Office	0.44
101B	Sign Shop Storage	1.09
102	Copy/Fax	0.35
104	Recycling	0.11
121	Manual Stg./ Reference	2.26
121A	Supervisor	0.30
121B	Supervisor	0.30
121C	Supervisor	0.30
121D	Supervisor	0.30
122	Womens Locker Room/Toliet	1.11
124	Janitors Closet	0.11
126	Mens Locker Room/Toliet	2.38
199	Corridor	0.33
199B	Corridor	0.97
	Total Required Capacity:	13.31

Zone 5

Area		Required Cooling (ton)
118	Metal Shop	8.28
120	Paint Shop	2.82
199C	General STG./ Staging Area	3.80
	Total Required Capacity:	14.90

Zone 6 *

Area		Required Cooling (ton)
200	Office	8.71
200A	Office	0.42
200B	Office	0.42
299	Corridor	0.67
EL 200	Lobby	0.97
	Total Required Capacity:	11.18

Table 29: New Geothermal Zone Sizes

* Zone 6 to be oversized to account for future fit out of shell space

Figure 46: New Geothermal Zone Zones

GEOTHERMAL UNIT SPECIFICATION & NUMBER OF REQUIRED WELLS

Once sizes of the new zones were determined, packaged geothermal units needed to be specified. Using the Climatemaster Tranquility TVL series sales brochure (located in **APPENDIX J**), specific sized units were specified for each zone based on the required loads. After units were selected, the total number of geothermal wells was determined. Number of wells was determined using the approximation of 1-400ft well can handle 3 tons of load. Discussing this with several industry experts, they felt this was a reasonable approximation, but noted that actual values vary depending on specific site soil conditions. Table 30 at right lists each specified unit and the total number of required wells.

GEOTHERMAL UNITS				
Zone	**Required Capacity (ton)**	**Packaged Geothermal Unit**	**Rated Capacity (ton)**	**# of Required Wells***
1	14.91	Climatemaster TVL-192	16	6
2	20.13	Climatemaster TVL-300	25	8
3	14.11	Climatemaster TVL-192	16	6
4	13.31	Climatemaster TVL-192	16	6
5	14.90	Climatemaster TLV-192	16	6
6	11.18	Climatemaster TVL-240	20**	7
			Total Number of Wells:	**39**

*** Assuming 1-400ft well is rated at 3 ton, # of wells determined per size of unit**

**** Unit oversized to allow for future fit-out of shell space**

Table 30: Geothermal Unit Specification w/ Number of Required Wells

GEOTHERMAL WELL LOCATION

Although the site for the Support Services Building is fairly small and irregular, there is ample room for the geothermal wells in the southwestern corner of the site. Using a 15-foot center to center spacing between wells, all 39 wells fit into the red-shaded area shown in figure 47 at right. If additional wells are required, there is still ample space in this area for more wells to be drilled. This space also provides a good direct line to the southwestern corner of the building for the horizontal piping to be run back to the manifold.

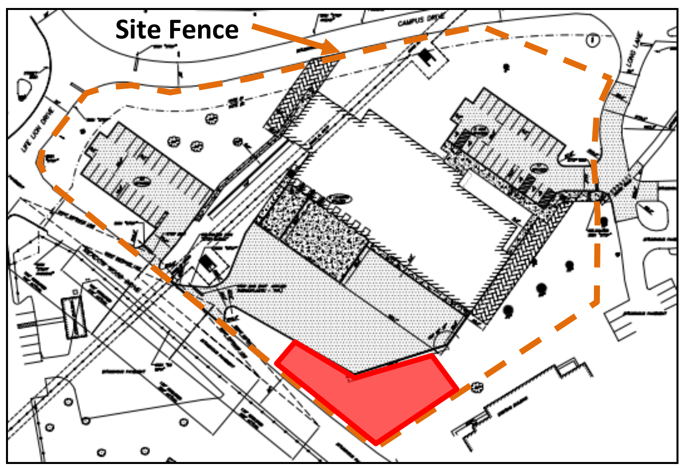


Figure 47: Geothermal Well Location

RELOCATION OF MECHANICAL ROOM

With the addition of six new packaged geothermal units and the associated expansions tanks and pumps that go along with them, the existing mechanical room on the 2nd floor was found to be inadequate to house them. However if the mechanical room is moved into the shell/fit-out space as shown in figure 48 below, there is ample room for the new units as well as all the equipment housed in the original mechanical room. In fact, only the area shaded in green in the figure 48 at right of the shell space would need to be utilized to form the new mechanical room. Relocating the old mechanical room into the shell space creates a new 550SF space (shown in blue) that could be utilized for a variety of purposes.

Figure 48: Proposed Location of New Mechanical Room In Shell/Fit-out Space

Locating the geothermal units in the shell space will also enable outside air to drawn in via louvers installed in the exterior wall to meet fresh air requirements of ASHRAE 62.1. Developing a way to meet this fresh air requirement was critical since it was lost when the RTU's were eliminated. This fresh air can be pre-mixed with return air from the system before entering the geothermal units. Exhausted air can still be achieved via the 18 exhaust fans located throughout the original design.

BENEFITS TO EXISTING VAV SYSTEM & DOMESTIC HOT WATER SYSTEM

Talking with Terry Mangold from The Warko Group, because larger zones was developed (in lieu of a zone per room) the existing VAV system with reheat coils could remained as designed. This will enable the greater control of thermal comfort and humidity control in the individual spaces located within each zone. The existing system utilizes two gas-fired boilers to heat the water to 140°F to be distributed throughout the system. With the installation of the geothermal units, excess heat from the heat exchanger can be utilized to preheat the water, reducing the amount of energy required from the boilers. This same technique can be utilized to pre-heat water for the domestic hot water system as well. Pre-heated water from the geothermal system is extra "free energy" that will allow both systems to use up to 50% less energy.

IMPACTS ON SCHEDULE ***Based on Detailed Project Schedule in APPENDIX C**

From the detailed project schedule it can be seen that Site Cut/Fill finishes on 7-6-2010. Given this, installation of the geothermal wells and horizontal piping can start concurrently with the start of the micropiles. Total calculation of the geothermal installation was based on completing one well and associated horizontal piping per day. From figure 49 below it can be seen that installation of the wells and associated piping is completed on 8-27, midway through the installation of the gradebeams. At this point the horizontal pipes will be have been run inside the footprint of the building with vertical stub-ups to be connected onto later.

ID	Task Name	Duration	Start	Finish
1	Site Clearing	5 days	Mon 6/14/10	Fri 6/18/10
2	Site Cut/Fill	15 days	Wed 6/16/10	Tue 7/6/10
3	Micropile Installation	25 days	Mon 7/5/10	Fri 8/6/10
4	Pilecaps	20 days	Mon 7/26/10	Fri 8/20/10
5	Gradebeams	30 days	Mon 8/9/10	Fri 9/17/10
6	Drilling Mobilization	0 days	Mon 7/5/10	Mon 7/5/10
7	Well Installation & Horizontal Piping	40 days	Mon 7/5/10	Fri 8/27/10

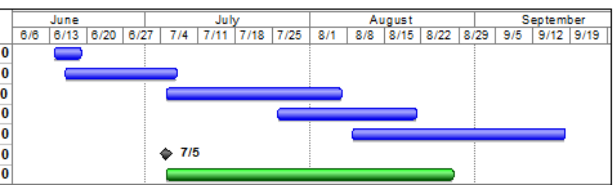


Figure 49: Geothermal Work Outside Buildings Footprint in Relation to Other Activities

Although the external (outside the buildings footprint) work associated with the geothermal installation is completed on 8-27, a large portion of work with the system still remains. Installation of the packaged units, expansion tanks, pumps, and ductwork will occur once structural steel has been erected and floors are poured. This is exactly the same as a conventional HVAC system. In talking with several mechanical contractors, they felt that interior work associated with the system would take the same amount of time as the existing system. Although some activities will take longer to complete, other activities will have shorter durations, and overall it would not increase or decrease the projects schedule. Based on this, it is a reasonable assumption to say that all work associated with the geothermal system will be completed within the timeframe of the original HVAC work and substantial completion of the project is still 8-31-2011.

IMPACTS ON SITE LOGISTICS

Looking at the location of the geothermal well zone in figure 47 on page 62 at the Shell & Enclosure Site Plan in **APPENDIX D**, it can been seen that the material storage area the dumpsters in the southwestern corner of the site conflict with each other. To avoid the conflict, material storage in the area simply won't be available until installation of the geothermal wells is complete. During this time, the main work occurring onsite is installation of the micropiles, pilecaps and gradebeams. These activities don't typically require large storage areas; therefore elimination of this storage area won't place a major burden on the site. The dumpsters can be moved to the parking lot area by the subcontractor trailers. Again, once the underground geothermal work is completed, the dumpsters can be relocated back to the southwestern corner and this area can also be used for material storage.

A semi-major impact will however occur with the installation of the horizontal piping from the wells to the building. These require a trench to be dug from the well zone to where they turn up inside the building. This trench will completely shut down equipment traffic around the southwestern corner of the building. Access will be available for smaller pieces of equipment in-between the pilecaps, however once gradebeams start and for larger equipment, site traffic will have be limited to going around the northern side of the site. It is also possible during this time that limited access is available from to northern parking lot by Alexander's trailer. Once the trench is backfilled, movement around the site will no longer be limited.

ESTIMATED COSTS

Estimated cost of the switch from the original RTU system to the new geothermal system was calculated using various sources. To get the estimated costs of the geothermal well and horizontal piping installation cost data from several industry experts and from RS Means Costworks 2010, was compared with the average price was utilized. Costs of the new Climatemaster geothermal units came from a phone interview with a local Climatemaster distributor. This cost included both cost to purchase the units and installation costs. Cost information for the removal of the RTU's was obtained via a Alexander estimates. Again costs shown include both material and installation. Lastly estimated costs for misc. added or deleted elements were obtained by talking with industry experts and Alexander personnel. Table 31 below shows the total estimate for both added and eliminated items.

ADDED ITEM ESTIMATE

Item	Description	Unit	Quantity	Unit Price	Total Cost
Geothermal Wells & Horizontal Piping					**$468,000.00**
	Drill & Install (39*400LF/well)	LF	15,600	$23.00	$358,800.00
	Horizontal Piping	LF	4,200	$26.00	$109,200.00
Climatemaster Tranquility TVL Packaged Geothermal Units					**$111,900.00**
	Climatemaster TVL-192	EA	4	$17,800.00	$71,200.00
	Climatemaster TVL-240	EA	1	$19,200.00	$19,200.00
	Climatemaster TVL-300	EA	1	$21,500.00	$21,500.00
Other					**$35,000.00**
	Expansion Tanks/Pumps	LS	1	$20,000.00	$20,000.00
	Misc. Added Items	LS	1	$15,000.00	$15,000.00
			Total Cost of Added Items		**$614,900.00**

ELIMINATED ITEM ESTIMATE

Item	Description	Unit	Quantity	Unit Price	Total Cost
RTU's					**$102,000.00**
	RTU-1	EA	1	$37,000.00	$37,000.00
	RTU-2	EA	1	$30,000.00	$30,000.00
	RTU-3	EA	1	$35,000.00	$35,000.00
Boiler					**$15,200.00**
	Climatemaster TVL-240	EA	1	$15,200.00	$15,200.00
Other					**$20,000.00**
	Misc. Deleted Items w/ Old System	LS	1	$20,000.00	$20,000.00
			Total Cost of Eliminated Items		**$137,200.00**

Table 31: Estimated Added & Eliminated Cost to Add Geothermal System

In total, the total cost to replace the existing system with a geothermal system is just under $478,000.00 ($614,900.00 - $137,200.00). This would represent nearly a 35% increase to the cost of the original system. Upon closer examination, roughly 98% of the added cost is associated with the installation of the geothermal well and horizontal piping. This is typically for geothermal installations. The majority of the added cost (and often is the deciding factor upon installing a geothermal system) is within the external components of the system.

ANNUAL ENERGY SAVINGS

Although exact annual savings were not calculated, estimated energy savings with the new geothermal system is roughly 30-50% for heating and 40-60% for cooling. In total, anywhere between 45 and 50% energy savings for an entire year can be achieved. Geothermal systems also require significantly less maintenance when compared to air to air systems. Although there is not exact value for this amount, it could potentially add up to an additional 10% in operating costs savings.

CONCLUSION FOR PART I

After conducting research into ground-source geothermal systems and designing a preliminary geothermal system to replace the original air-to-air RTU system of the Support Services Building, the expected outcome was confirmed. A geothermal system would have added approximately an additional $487,000.00 or 4% to the original cost of the project. Nearly all of the added cost is associated with the installation of the geothermal wells and horizontal piping, which is typical for any ground-loop geothermal installation. However with the installation of the geothermal system, annual energy costs can be reduced up to 50%.

Using cubic foot calculations, loads were calculated to size the new packaged geothermal units. Climatemaster, a leading manufacturer of geothermal equipment, was chosen as the preferred equipment manufacture for the new geothermal units. Their Tranquility TVL series has units available up to 25 tons. Using 25 tons, the building was broken into larger zones vs. small roomed sized zones to keep the design simplified. It was shown to install the necessary equipment for geothermal system the original mechanical room was too small and needed to be relocated into the Shell/Fit-out Space. The original VAV with reheat system remained in order to provide greater thermal comfort and to control humidity within each zone. Added benefits of the geothermal system included pre-heating water to be using in for both the VAV system and the domestic hot water system.

Installation of the geothermal system was found to have no impact on the original projects schedule. Once the wells and horizontal piping was completed, the remaining installation of the system would be very similar to the installation of the original HVAC system. Movement around the site would however be impacted while the geothermal wells and horizontal piping was being installed. Trenches required for the horizontal piping would cut-off traffic around the southwestern corner of the building till completed. Luckily, only pilecaps and gradebeams are to be installed during this time. A material storage area and the dumpsters will also have to be moved until the wells and piping is completed.

Based on the findings of this analysis, I would have recommended a geothermal system be strongly considered for the Support Services Building. Although it would have cost more up front, it would eventually pay for itself. Penn State keeps builds buildings for longevity. It would also give Penn State the opportunity to conduct more research on operating techniques to maximize the efficiency of the system. It is estimated that it could also have increase the LEED rating from Certified to Bronze. It also would show that Penn State is committed to implementing more sustainable energy into their buildings.

PART II: INSTALLATION OF A PV ARRAY

INTRODUCTION TO PHOTOVOLTAIC'S

Photovoltaic's is a type of solar technology that utilizes the properties of certain semi-conductors (mostly crystalline silicon) to convert solar radiation into electricity (DC). Invention of the PV cell dates back to 1954 where researchers at Bell Laboratories developed the PV cell for to power remote telephone stations. This early PV cell had efficiencies up to 6%. Since then technology in the industry has greatly improved with some manufactures claiming efficiencies up to 20%. In this time cost of solar cells and PV installation has dropped drastically and with cost of fossil fuels only increasing, have caused the technology and installation of these system to gain in popularity.

PV systems and solar is considered to be the greatest sustainable renewable resource. According to some estimates over 350,000,000 terawatt hours of solar direct solar radiation hit the earth's surface every year. Compare that with an average estimate of 200,000 terawatt hours of available energy from wind energy year, 6,000,000 terawatt hours of coal reserves left in the earth, 1,000,000 terawatt hours of petroleum left, and 400,000 terawatt hours of natural gas. In 2004, total global consumption of energy was estimated to be approximately 130,000 terawatt hours. To put this into perspective, a terawatt is equal to 1 trillion kilowatts, or 1 with 15 zeros behind it. From these figures it can easily be seen that we will eventually run out of fossil fuels, but we will never consume as much energy as that hits the earth surface from the sun. This is why interest in solar technology and PV installations has increased tenfold over the past 20 years.

There are three basic types of PV systems; grid-connected, off-grid, and grid-connected with battery backup. For the Support Services Building and this analysis, a grid-connected system will be considered. In a typical grid-connected system the PV array utilizes solar modules to generate the electricity. A solar module (like the one shown in figure 50 at right) is comprised solar cells connected in series and parallel to produce a certain amount of electricity (Watts). Typical number of cells per module include 60, 72, or 96 ranging anywhere from 150-300+ Watts. Modules are then connected into parallel strings and run to an inverter. The inverter converts the DC energy from the array into usable AC electricity to be either supplied to loads of the building or be sold back to the grid. Included in the typical installation of these systems is also a combination of disconnects and fuses. Note that there are several other ways for these systems to be connected and several other types of inverters that can also be utilized. For the Support Services Building, the basic grid-connected system will be designed into further detail.

Figure 50: Trinasolar TSM-DC01 185W Solar Module
Image Taken from Trinasolar.com

In order to design a PV array for main roof of the Support Services Building, the offset roof from Analysis II of this report would be eliminated with either of the following two situations:

1. The 3 RTU's are relocated from the main roof to the lower roof to allow more room for the PV Array.
2. The 3 RTU's are eliminated per the installation of a geothermal system as described in Part I of this analysis.

With the RTU's removed from the main roof, an extra 3,600 SF of free space will be available for a larger PV array to be installed and provide more power to the building.

SOLAR ANGELS

Penn State Milton S. Hershey Medical Center is located at 76.64°W longitude, 40.28°N latitude, and at elevation of 600ft. Before any shading analysis or design could be performed, location of the sun in the sky needed to be calculated. Sun position was calculated using the Sun Angle Calculator by Sustainable by Design for the following days; Spring Equinox (March 21st), Summer Solstice (June 22nd), Fall Equinox (September 23rd), and Winter Solstice (December 21st). A screenshot of the calculator can be seen in figure 51 at right. On these days, sun position was found for the three times of the day that define the optimum solar window (9:00 A.M. – 3:00 P.M.). Sun position was also calculated for 12:00 P.M. (noon) for these same days. The sun position found for each time and day found using the calculator can be found in table 32 below.

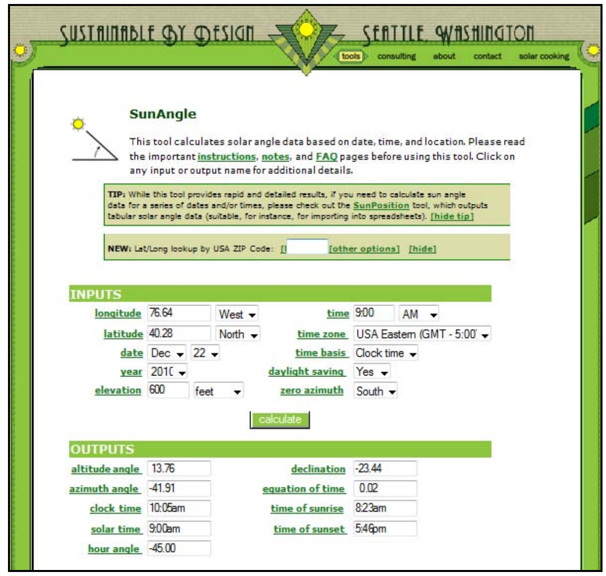


Figure 51: Sun Angle Calculator from Sustainable by Design

Day	Spring Equinox - March 20th/21st		
Time	9:00 A.M.	12:00 P.M.	3:00 P.M.
Altitude Angle (°)	30.66	49.98	35.14
Azimuth Angle (South = 0°)	-60.43	-5.33	54.25

Day	Fall Equinox - September 22nd/23rd		
Time	9:00 A.M.	12:00 P.M.	3:00 P.M.
Altitude Angle (°)	32.93	49.89	32.61
Azimuth Angle (South = 0°)	-57.11	0.30	57.39

Day	Summer Solstice - June 21st/22nd		
Time	9:00 A.M.	12:00 P.M.	3:00 P.M.
Altitude Angle (°)	47.2	73.07	50.34
Azimuth Angle (South = 0°)	-81.5	-6.6	78.15

Day	Winter Solstice - December 21st/22nd		
Time	9:00 A.M.	12:00 P.M.	3:00 P.M.
Altitude Angle (°)	13.1	26.27	14.42
Azimuth Angle (South = 0°)	-42.91	-1.33	40.87

Table 32: Sun Angle's/ Location in Sky

SITE SHADE ANALYSIS

To consider the addition of PV's to the roof of the Support Services Building, first required a closer examination into the site. Idea conditions for PV arrays have zero shade during the optimum solar window (9:00 A.M. – 3:00 P.M.). Looking at figure 52 below, it can be seen that the site for the Support Services Building is completely shade-free during the optimum solar window. The coniferous trees located just south of the site will be eliminated per the construction of the new building.

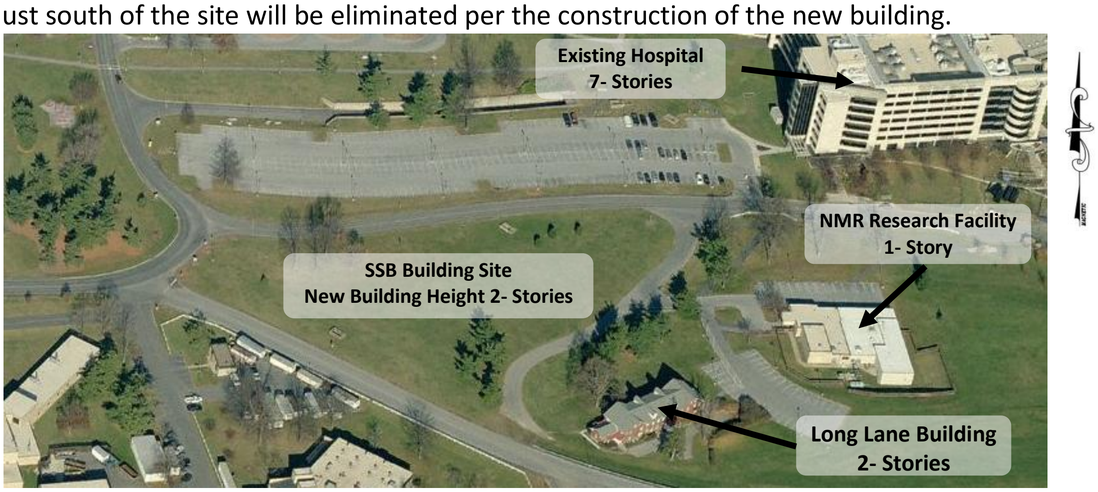
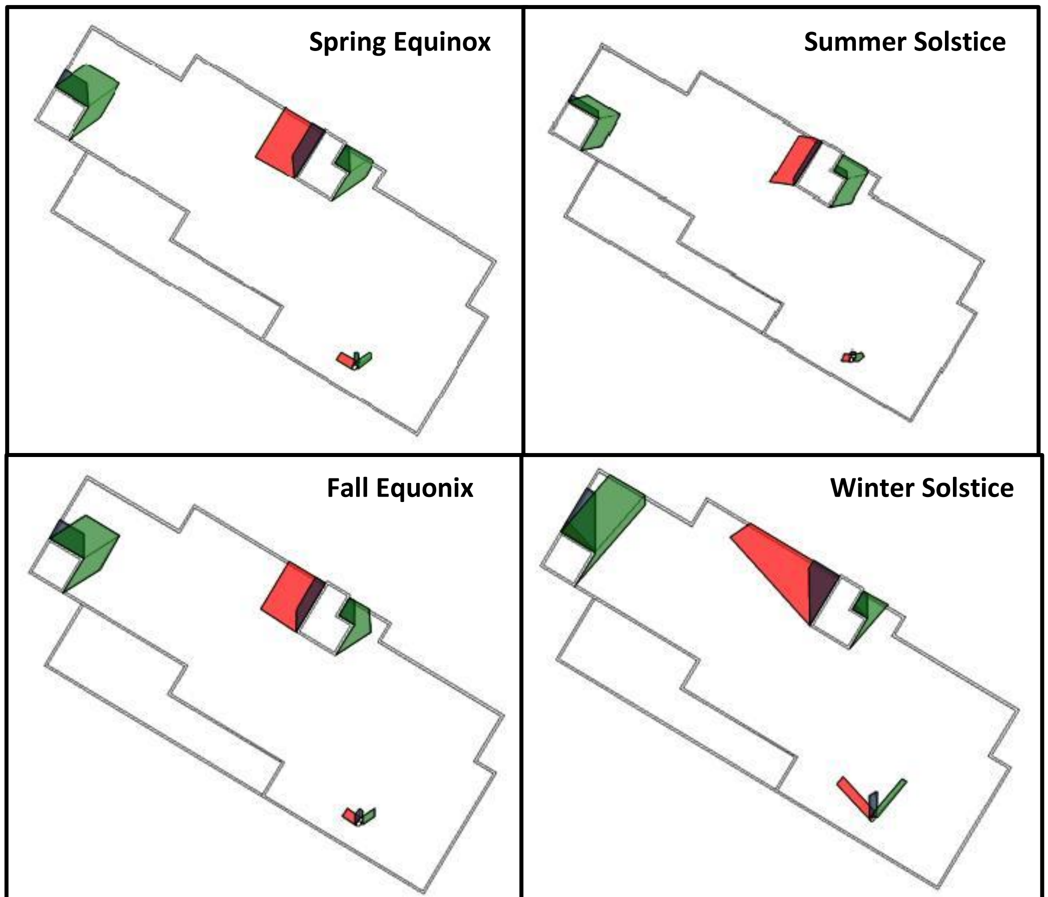


Figure 52: Shade Free Support Services Building Site. Image Taken from Bing.com

ROOFTOP SHADOW ANALYSIS

Although the RTU's were removed from the main roof level, there were still several projections above the main roof height could potentially shade large portions of the roof, making it not optimal to place solar modules in these locations. Projections of particular concern were the two elevator machine rooms and paint booth exhaust. Using the solar angles from table 32 on the previous page, and a mass building model produced in Autodesk Revit Architecture, a study of shadows produced by these projects was performed. The results of the shadow analysis can be seen below in figure 53. Note that each color corresponds to a particular time of day (red for 9:00 A.M., blue for 12:00 Noon, and green for 3:00 P.M.)



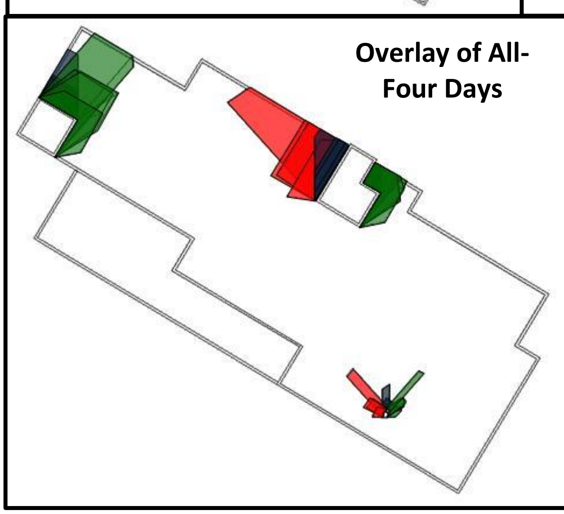


Figure 53: Rooftop Shadow Analysis

From these images it can be easily seen that the worst shadowing occurs on the day of Winter Solstice. The Image at left is a combination of all four days or the areas that at some point during the year will be covered by shadows. Total power output by a PV array decreases exponentially even one module of a string is covered by shadows. Because of this effect, it is vital that no modules are placed in any of the areas shown in color in the image at right. This will result in a smaller system, but will result in the array producing maximum available power given solar conditions at a particular time.

SOLAR MODULE SELECTION

Before the array layout and total size of the system was designed, a solar module needed to be specified. There are dozens of different manufactures of solar modules in the market today. Each produces a variety range on module sizes for almost any application. Each module will have specific characteristics that will affect the design and these characteristics vary from module to module. If you were to ask each manufacture, they would say their product is the best on the market. In order to select the best module to for the design, several modules were compared side-by-side and listed below in table 33.

SOLAR MODULE COMPARISON												
Manufacturer	Model	# of Cells	Length (inches)	Width (inches)	Peak Power (W)	Efficiency (%)	Rated Voltage (V)	Rated Current (A)	Open Circuit Voltage (V)	Short Circuit Current (A)	Weight (lbs)	Warranty (Yrs)
SunPower Corporation	E19/320	96	61.39	41.18	320	19.6	54.7	5.86	64.8	6.24	41	25
SunPower Corporation	E19/238	72	61.39	31.42	238	19.1	40.5	5.88	48.5	6.25	33.1	25
Kyocera Solar, INc.	KD240GX-LFB	60	65.43	37.99	240	13.9	29.3	8.06	36.9	8.59	46.3	20
Yingli	YGE 235	60	64.96	38.98	235	14.4	29.5	7.97	37	8.54	43.7	20
Amerisolar	AS-6P	60	64.41	39.05	220	13.4	29.2	7.51	36.5	7.94	48.5	25
Shap	NU-U240F1	60	64.6	39.1	240	14.7	30.1	7.98	37	8.65	44.1	25
Trina Solar	TSM-240DA05	60	64.95	39.05	240	14.7	30.6	7.84	37.5	8.38	43	25

Table 33: Solar Module Comparison

Looking at table 33 above, it is easily seen that the Sunpower E19-320 module in the first row would make an excellent choice for the project. It delivers more power (320W) per area and weighs less than any other of the modules. This module is likely to be one of the most expensive, if not the most expensive of the modules listed, but again initial cost is not the most important consideration of this analysis. The manufacturers spec sheet for the Sunpower E19-320 can be found in **APPENDIX K**.

ARRAY ORIENTATION AND TILT

Ideally for a fixed array (one that doesn't follow the sun's path), modules should be oriented due south or as close as possible. However for aesthetic reasons it is common convention to align the modules with the roof edge. The Support Services Building is rotated 31° W off of due south. Optimum tilt angles for fixed arrays are; latitude - 15° for summer, latitude + 15° for winter, equal to latitude for spring and fall. However for the Hershey Pa, this would mean an array tilt angle of 55° in the winter. This would significantly increase the inner row spacing to avoid shading, which would significantly decrease total system size. In Hershey Pa, maximum solar gain occurs during the summertime months. Designing a system to achieve maximum solar gain in winter seems kind of ridiculous. In order to determine the best array orientation and tilt, different array tilt angels (0-50°) and the two orientations (due south, and rotated 31°) was compared. To start, shadow lengths were calculated based on winter solstice sun angles as shown in figure 54 below for each array tilt and orientation to determine the minimum row spacing.

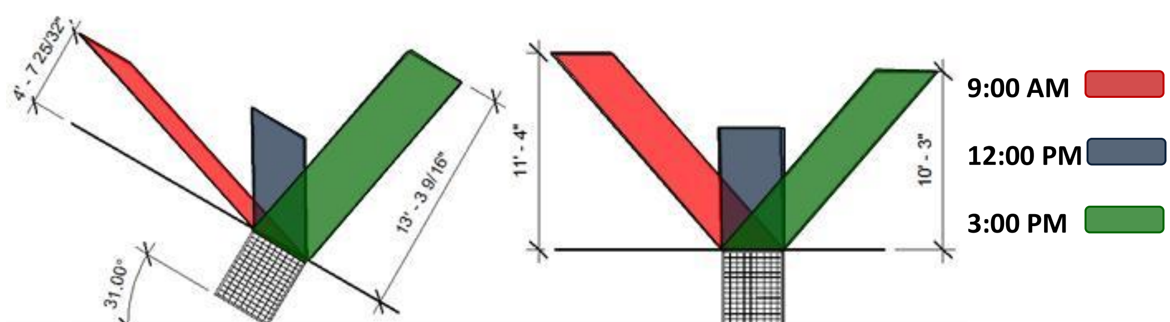
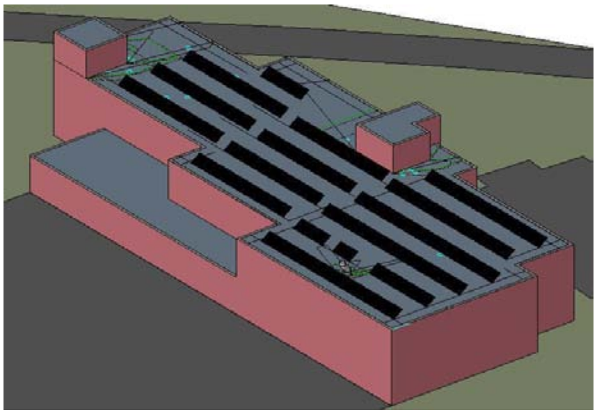


Figure 54: Solar Module Shadows

Note that these shadows only longest shadow given off by the back of the module at an array tilt angle of 40°. It is interesting to see that minimum row spacing is actually shorter for the module facing due south vs. the one rotated 31°. Next, using these minimum row to row spacing values, the total maximum number of modules possible per orientation and array tilt was found using the Autodesk Revit mass model. A 31° rotated array with an array tilt angle of 35 is represented in the left image in figure 55 below, while an array facing due south with the same array tilt angle of 35° is shown in the right image. A six foot space was left around the perimeter of the building for safety reasons. You can also see from these images that no modules were placed within the shaded areas found earlier.



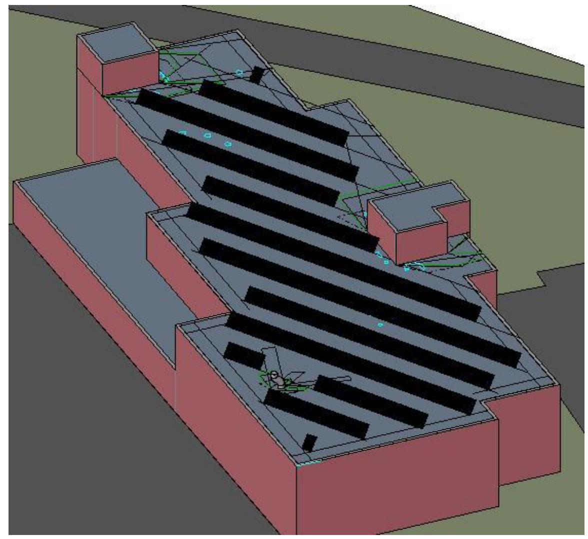
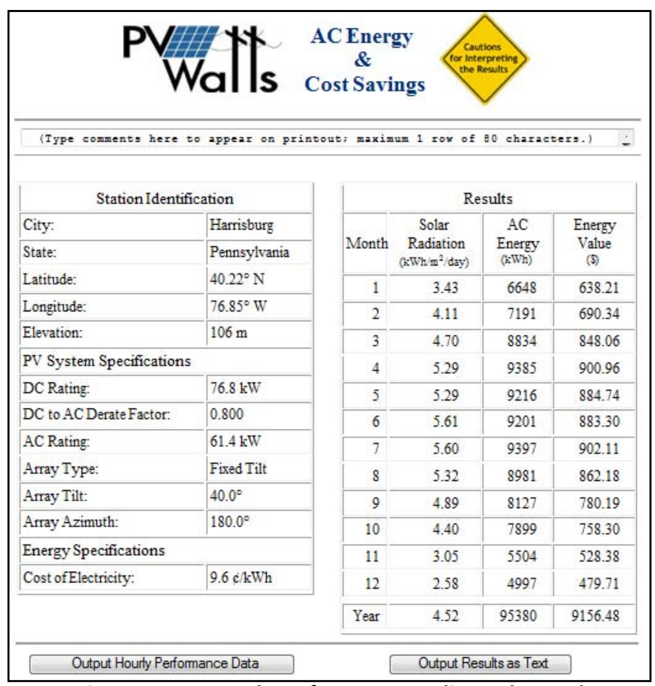


Figure 55: Revit Model Showing Max Number of Solar Modules per 35°Array Tilt and the Two Array Orientations

Using the maximum module numbers for each angle (0-50° in 5° increments), the total estimated output of each orientation was calculated using the online PV software tool; PVWatts. Set for Harrisburg, PA, the only user input parameters that changed were the size of the system in kW (# of panels * 320), and array azimuth (211 ° for rotated orientation; 180+31). A screenshot for an array layout of due south with 40° array tilt can be seen at right in figure 56.



PVWatts AC Energy & Cost Savings

Cautions for Interpreting the Results

(Type comments here to appear on printout; maximum 1 row of 80 characters.)

Station Identification	
City:	Harrisburg
State:	Pennsylvania
Latitude:	40.22° N
Longitude:	76.85° W
Elevation:	106 m
PV System Specifications	
DC Rating:	76.8 kW
DC to AC Derate Factor:	0.800
AC Rating:	61.4 kW
Array Type:	Fixed Tilt
Array Tilt:	40.0°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	9.6 ¢/kWh

Month	Solar Radiation (kWh/m²/day)	AC Energy (kWh)	Energy Value ($)
1	3.43	6648	638.21
2	4.11	7191	690.34
3	4.70	8834	848.06
4	5.29	9385	900.96
5	5.29	9216	884.74
6	5.61	9201	883.30
7	5.60	9397	902.11
8	5.32	8981	862.18
9	4.89	8127	780.19
10	4.40	7899	758.30
11	3.05	5504	528.38
12	2.58	4997	479.71
Year	4.52	95380	9156.48

Output Hourly Performance Data | Output Results as Text

Figure 56: Screenshot of PVWatts Online Solar Tool

Table 34 on the next page summarizes the results for all of the different array tilt angles and orientations. When comparing the two orientations, it was found that below a 40° array tilt angle, more modules could be placed on the roof if faced due south. This is the opposite of what was expected. It is believed this is due in large parts to the rectangular shape of the roof vs. a squarer roof. It can also be seen that modules facing due south generated more electricity than the rotated ones at the same array tilt. Note that this above was calculated with the modules mounted in the portrait position. Horizontal orientation of a module with an array tilt of 30° revealed that fewer panels could be placed on the roof. Although row to row spacing was reduced, the additional length of the panel could not be accounted for.

ARRAY ORIENTATION & TILT COMPARISON								
Tilt	**Angle**	**Array Orientation**	**Min. Row Spacing to Avoid Shading**	**Max # of Panels**	**Size of System (kW)**	**Average Solar Radiation (kWh/m^2/day)**	**Annual AC Energy (Deterate Factor of 0.8) (kWh)**	**kWh/ Panel/ Year**
Fixed Tilt	50°	Rotated 31°	14'-9"	230	73.60	4.25	85,111	370.05
		Due South	12'-9"	228	72.96	4.40	88,134	386.55
	40°	Rotated 31°	12'-9"	240	76.80	4.35	91,353	380.64
		Due South	11'-4"	242	77.44	4.51	95,829	395.99
	35°	Rotated 31°	11'-10"	252	80.64	4.41	97,118	385.39
		Due South	9'-9"	253	80.96	4.55	101,033	399.34
	30°	Rotated 31°	10'-5"	248	79.36	4.42	95,832	386.42
		Due South	8'-8"	269	86.08	4.54	107,280	398.81
	25°	Rotated 31°	8'-10"	279	89.20	4.40	107,223	384.31
		Due South	7'-7"	282	90.24	4.51	111,690	396.06
	20°	Rotated 31°	7'-4"	300	96.00	4.36	114,381	381.27
		Due South	6'-1"	307	98.24	4.45	119,961	390.75
	15°	Rotated 31°	5'-5"	339	108.48	4.30	127,199	375.22
		Due South	4'-11"	350	112.00	4.37	134,012	382.89
	10°	Rotated 31°	4'-0"	429	137.38	4.22	157,517	367.17
		Due South*	3'-9"	386	123.52	4.26	143,755	372.42
	5°	Rotated 31° *	2'-6"	429	137.38	4.11	153,040	356.74
		Due South*	2'-3"	386	123.52	4.13	138,711	359.35
	0°	Rotated 31°**	0'-0"	516	165.12	3.98	177,359	343.72
		Due South**	0'-0"	478	152.96	3.98	164,233	343.58
Adjustable Tilt	40°	Rotated 31°	12'-9"	240	76.80	5.07	107,821	449.25
		Due South	11'-4"	242	77.44	5.15	110,672	457.32
	35°	Rotated 31°	11'-10"	252	80.64	5.07	113,212	449.25
		Due South	9'-9"	253	80.96	5.15	115,702	457.32
	30°	Rotated 31°	10'-5"	248	79.36	5.07	111,415	449.25
		Due South	8'-8"	269	86.08	5.15	123,020	457.32

* 4'-0" Between rows maintained for maintenance access

** Double panel rows with 4'-0" space between rows

Table 34: Array Orientation and Tilt Comparison

From the table it was concluded that the due south orientation was the preferred method to orient the array. Looking at figure 57 at right, the maximum module output/year occurs at a fixed tilt of 35°. However if we look at the bottom portion of table 34 above, we can see that our output goes up if the array is able to change tilt throughout the year. In fact the module output increase by almost 60kwH/year/module. Given this, the design layout will be facing due south, with minimum spacing set by the 35° array tilt, with single axis-tracking (adjustable tilt).

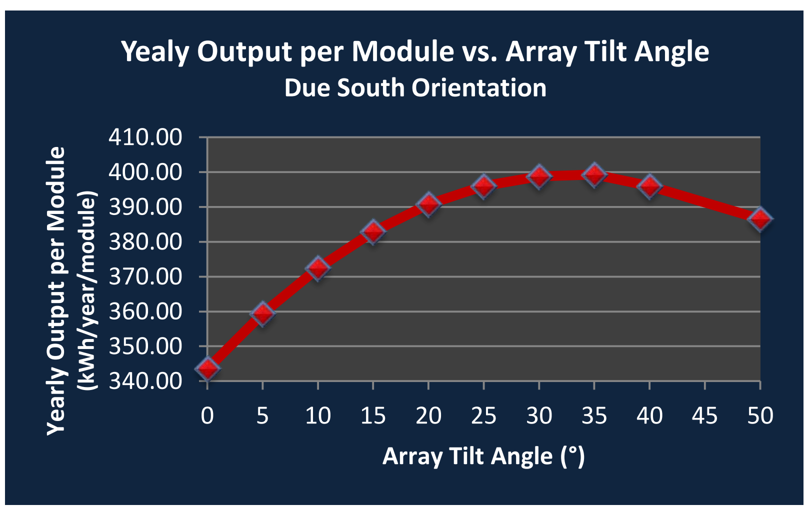


Figure 57: Module Yearly Output vs. Tilt Angle for Due South Orientation

MAX NUMBER OF MODULES PER STING (E)

Per the NEC 690.7 the maximum voltage of a PV system is 600V. This means that string sizes cannot be greater than 600V. Since strings are simply two or more modules wired in series, total voltage is a simply calculated as voltage/module times the number of modules. However when ambient temperature goes down, voltage of a PV module goes up. Per the NEC, total voltage is calculated at the lowest recorded ambient temperature, using Voc (open circuit voltage => I =0) and temperature coefficients. According to ASHRAE, the lowest recorded temperature in Harrisburg, Pa was -17°C. Harrisburg is only 13 miles from Hershey, so this temperature is acceptable. From the Sunpower E19-320 data sheet in APPENDIX K, Voc = 64.8V and the temperature coefficient for voltage is -0.1766 V/°C. Adjusted voltage for minimum ambient temperature is calculated as;

$$Adj\ Voltage = \{(Lowest\ Recorded\ Temperature\ ℃ - 25℃) * (temp.coefficient\ V/℃)\} + V_{OC}$$

Using the numbers from above: $\{(-17℃ - 25℃) * \ (-0.1766V/℃)\} + \ 64.8 = 72.22\ V$

Max Number of Modules per Sting = $\frac{600V}{72.22V} = 8.30 => 8\ modules\ string\ max$

Check: = $8\ module\ in\ seres * 72.22\frac{V}{module} = 577.76\ V < 600V => \boldsymbol{Ok}$

FINAL ARRAY LAYOUT & SYSTEM SIZE (E)

Using 8 modules/string as calculated above and the 35° array tilt minimum spacing of 9'-9", the final array layout was figured using the Revit model. To allow space for movement around the roof, the same 6' safety distance around the perimeter of the roof was maintained, and a 5'-0" between strings was also utilized. Again, no modules were placed within the shaded zones of the roof during the optimum solar window. Each eight-module string will be mounted on a custom fabricated rack designed to hold exactly eight modules. Each rack will be adjustable to allow the array tilt angle to be changed throughout the year. Part of the reasoning behind the of the installation of the array is to enable Penn State to conduct research on a larger scale, the adjustability of the array tilt is a great feature beyond just increasing the total output of the system. In total, it was found that 28, 8-module strings fit onto the roof as shown below in figure 58.

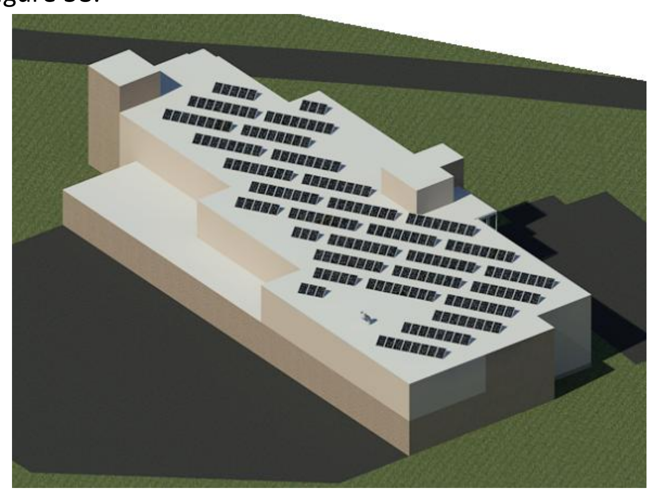


Figure 58: Final Array Layout & Orientation

Of the 28 strings, three strings had to be broken into five modules + three modules to be mounted separately in lieu of all together. All eight modules will still be wired in series to retain the string size. With 28 strings of eight modules, the total rated sized of the system is;

$$28\ strings * 8\frac{modules}{string} * 320\frac{W}{module} = \boldsymbol{71.68\ kW}$$

STRUCTURAL IMPACT (S)

With the addition of solar modules to the roof the existing roof support structure needed to be analyzed to determine if it was adequate to support the added weight of the modules and mounting racks, or if member size needed to be increased. The main support structure for the roof is comprised of both steel joists and structural steel beams. In the shaded areas in figure 59 below, the primary support comes from the steel joists, while the areas not shaded get their support from structural steel beams. In total there are eight different areas of steel joists each represented by a different color. The large area not shaded in the center of the image, is where the eliminated offset roof is. From before, this is where the RTU's were originally located before they were moved to gain additional space to the PV array. If the structural steel was adequate to support the RTU's in this area, it is a reasonable assumption to assume that it will support the weight of the added PV array. Therefore only the areas which utilize steel joists (shaded areas) need to be analyzed further. Note that the red line in figure 59 defines the boundary of the PV array.

Area	Joist Size	O.C. Spacing
A-1	26K7	6'-0"
A-2	16K3	6'-0"
A-3	24K6	6'-0"
A-4	24K5	6'-0"
A-5	12K1	5'-0"
A-6	16K2	5'-0"
A-7	10K1	5'-0"
A-8	24K6	6'-0"

Figure 59: Main Roof Support Means & PV Array Boundary

Due to the building's rotation from due south (31°W) and the orientation of the array (due south), it was decided the best way to determine the added weight each joist would have to support would be to determine an approximate lb/SF value that the added array adds to the roof. From the Sunpower E19-320 data sheet in APPENDIX K, the weight of a module is 41lb.Assuming the weight of the mounting rack per module is approximately 50lb, then the total weight is then 91lb. Dimensions of the module are 5'-1" x 3'-5". With row to row spacing of 9'-9", it can be seen by the equation below that the total area taken up by one module and one space is equal to approximately 51SF.

$$\{Panel\ Length(5.08') + Row\ Spacing\ (9.75')\} * Panel\ Width\ (3.42') = 50.72SF \approx 51SF$$

From this the weight of the added PV array per SF of roof can be calculated as: 91lb / 51Sf = 1.78lb/SF ≈2. Combining this with the other roof loads;

Roof Live Load:

Snow 30

Total: 30

Roof Dead Load:

BUR 20

Misc. Dead Load 5

PV Array 2

Total: 27

Note: weight of steel joint will be factored in later.

Factored Load for LRDF Design = $1.2(Dead\ Load) + 1.6(Live\ Load)$

Using numbers from above: Factored Load = $1.2(27\ lb/SF) + 1.6(30\ lb/SF) = 80.4lb/SF$

Steel joists are sized per the load in PLF (pounds per linear foot). To get the load on each joist in PLF, the 80.4 lb/SF had to be multiplied to the tributary area each joist supports. Shown in figure 60 on the next page, tributary area per joist is equal to half the distance between each joist or 3 feet x spaces = 6 feet.

Multiplying: $80.4PSF * 6ft = 482.4\ PLF$

Using the LRDF design table for K-series steel joists from the Steel Joist Institute (SJI), the weight of the 26K7 for area A-1 in figure 59 on the previous page is found to be 9PLF. Adding this to the 482.4 results in total load of 491.4PLF. Thus if the 26K7 cannot support the load, a larger size will be required. To shown how this is determined, a joist from A-1 will be sized in the example below.

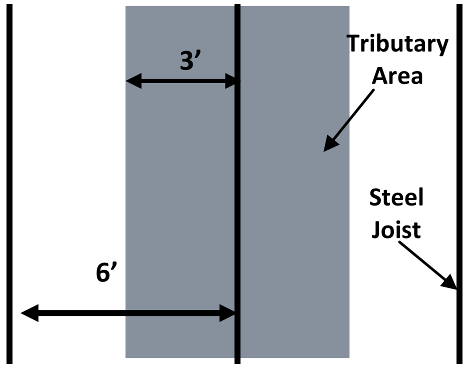
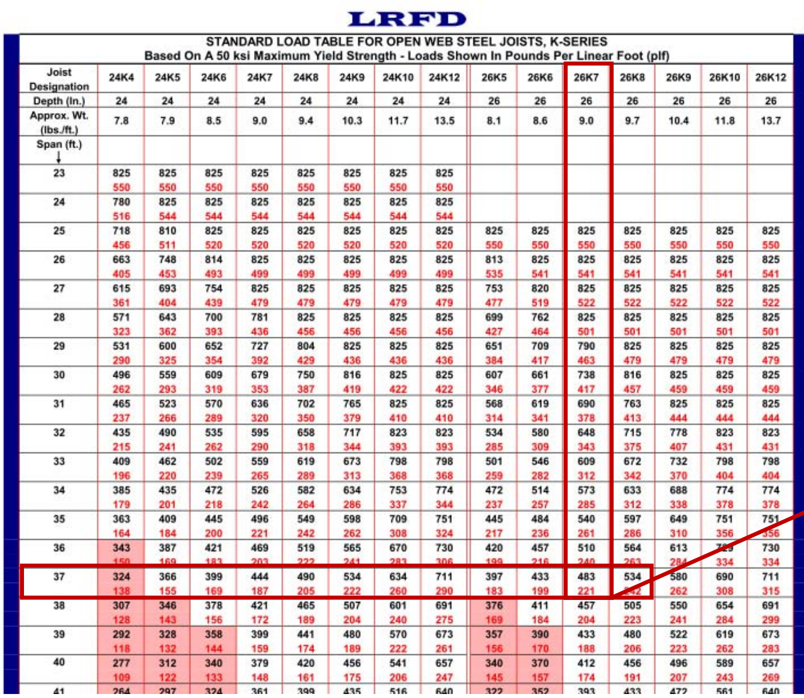


Figure 60: Steel Joist Tributary Area

Joist span in A-1 is 37'-0" Using the Steel Joist Institute's LRFD design table shown below in figure 61, its can be seen that the maximum load a 26K7 can support with a joist span of 37'-0" is 483 PLF. This is lower than the load of 491.4 PLF calculated above. Looking at the next available size, 26K8 with the 37'-0" joist span, has a maximum load of 534PLF. Therefore in order to support the weight of the added array, 26K8 steel joists need to be utilized.



LRFD

STANDARD LOAD TABLE FOR OPEN WEB STEEL JOISTS, K-SERIES
Based On A 50 ksi Maximum Yield Strength - Loads Shown In Pounds Per Linear Foot (plf)

Joist Designation	24K4	24K5	24K6	24K7	24K8	24K9	24K10	24K12	26K5	26K6	26K7	26K8	26K9	26K10	26K12
Depth (In.)	24	24	24	24	24	24	24	24	26	26	26	26	26	26	26
Approx. Wt. (lbs./ft.)	7.8	7.9	8.5	9.0	9.4	10.3	11.7	13.5	8.1	8.6	9.0	9.7	10.4	11.8	13.7
Span (ft.) ↓															
23	825 550	825 550	825 550	825 550	825 550	825 550	825 550	825 550							
24	780 516	825 544	825 544	825 544	825 544	825 544	825 544	825 544							
25	718 456	810 511	825 520	825 520	825 520	825 520	825 520	825 520	825 550	825 550	825 550	825 550	825 550	825 550	825 550
26	663 405	748 453	814 493	825 499	825 499	825 499	825 499	825 499	813 535	825 541	825 541	825 541	825 541	825 541	825 541
27	615 361	693 404	754 439	825 479	825 479	825 479	825 479	825 479	753 477	820 519	825 522	825 522	825 522	825 522	825 522
28	571 323	643 362	700 393	781 436	825 456	825 456	825 456	825 456	699 427	762 464	825 501	825 501	825 501	825 501	825 501
29	531 290	600 325	652 354	727 392	804 429	825 436	825 436	825 436	651 384	709 417	790 463	825 479	825 479	825 479	825 479
30	496 262	559 293	609 319	679 353	750 387	816 419	825 422	825 422	607 346	661 377	738 417	816 457	825 459	825 459	825 459
31	465 237	523 266	570 289	636 320	702 350	765 379	825 410	825 410	568 314	619 341	690 378	763 413	825 444	825 444	825 444
32	435 215	490 241	535 262	595 290	658 318	717 344	823 393	823 393	534 285	580 309	648 343	715 375	778 407	823 431	823 431
33	409 196	462 220	502 239	559 265	619 289	673 313	798 368	798 368	501 259	546 282	609 312	672 342	732 370	798 404	798 404
34	385 179	435 201	472 218	526 242	582 264	634 286	753 337	774 344	472 237	514 257	573 285	633 312	688 338	774 378	774 378
35	363 164	409 184	445 200	496 221	549 242	598 262	709 308	751 324	445 217	484 236	540 261	597 286	649 310	751 356	751 356
36	343 150	387 169	421 183	469 203	519 222	565 241	670 283	730 306	420 199	457 216	510 240	564 263	613 284	[illegible] 334	730 334
37	324 138	366 155	399 169	444 187	490 205	534 222	634 260	711 290	397 183	433 199	483 221	534 242	580 262	690 308	711 315
38	307 128	346 143	378 156	421 172	465 189	507 204	601 240	691 275	376 169	411 184	457 204	505 223	550 241	654 284	691 299
39	292 118	328 132	358 144	399 159	441 174	480 189	570 222	673 261	357 156	390 170	433 188	480 206	522 223	619 262	673 283
40	277 109	312 122	340 133	379 148	420 161	456 175	541 206	657 247	340 145	370 157	412 174	456 191	496 207	589 243	657 269
41	264	297	324	361	399	435	516	640	322	352	393	433	472	561	640

Figure 61: Steel Joist Institute LRFD Steel Joist Design Table

Deflection Check: Number shown above in red is max allowable un-factored live load to produce a deflection of 1/360. To get 1/240 deflection, multiply by 1.5. => 242 x 1.5 = 363 PLF

Actual Live Load = 30 x 6 = 180PLF => ***OK***.

SUMMARY OF JOIST SIZING PER ADDED PV ARRAY						
Area	Joist Span	Original Joist Designation	Load (PLF)	Max Load (PLF)	Resize (Y/N)	New Joist Size (or Original)
A-1	37'-0"	26K7	491.4	483	Y	26K8
A-2	23'-0"	16K3	488.7	462	Y	16K4
A-3	34'-0"	24K6	491	502	N	24K6
A-4	33'-2"	24K5	490.7	462	Y	24K6
A-5	18'-4"	12K1	487.4	448	Y	12K3
A-6	21'-6"	16K2	487.9	499	N	16K2
A-7	12'-7"	10K1	487.4	718	N	10K1
A-8	34'-0"	24K6	491	502	N	24K6

Table 35: Summary of Joist Sizing Determination per Added PV Array

This same procedure was repeated for all eight shaded area in figure 59 and the results can be seen in table 35 at right. Of the original joist sizes, four of them are able to support the added weight of the PV array, while the other four had to be increased to the next available joist size.

INVERTER SELECTION (E)

Initial selection of an inverter was based on three parameters. First, the inverter had to have a rated capacity larger than size of the system (71.68kW), but not significantly larger. Second, the output electricity of the inverter had to be 3-phase, 480V 60Hz to match the main feeder into the building for a load side connection of the system. Lastly the inverter had to have a built it MPPT (Maximum Power Point Tracking) system. Using the three parameters, the Satcon Powergate Plus 75kW inverter was selected. Product data sheets for the Satcon inverter can be found in **APPENDIX L**. To verify that this inverter would work, two additional parameters still needed to be checked/verified.

- The max input amperage of the input for the combiner box (6 at 80A per data sheet in APPENDIX L)
  - System Design: 4 sets of 7 strings (see figure 62 below)

    $$Combiner\ Input\ per\ design = \ (I_{sc}\ per\ sting * number\ of\ strings) * 1.25 * 1.25\ < 80A$$

    (1.25 multipliers per NEC)
  - From Sunpower E19-302 Data Sheet (APPENDIX K); Isc = 6.24A

    $$Input\ to\ combiner: 6.24\frac{A}{string} * 7\ strings * 1.25 * 1.25 = 68.14A\ < 80A => OK$$

  Note: 80A fuse could be replaced with 70A fuse

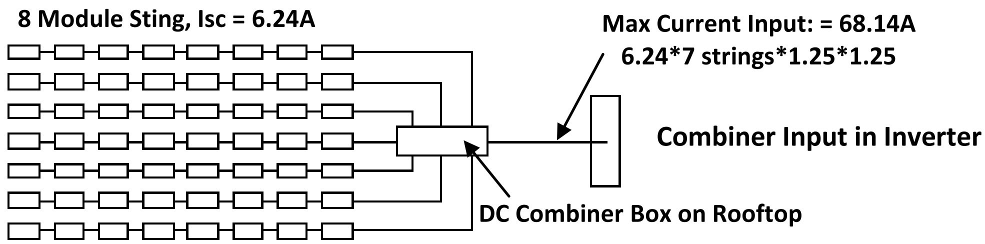


Figure 62: Group of 7 Strings per Single Input in Inverters Combiner Box

Note: System design consists of three additional groups of strings wired in parallel identical to the one shown at right. All four groups are wired in parallel at to the inverters combiner to make 28 parallel stings.

- Minimum System Voltage at least 20% above minimum MPPT voltage
  - From Satcon data sheet (APPENDIX L), minimum MPPT voltage; 315V
  - Minimum module voltage is calculated at max recorded ambient temperature + 30°C for roof mount (Per ASHRAE; 36°C for Harrisburg, PA)
  - From Sunpower E19-320 data sheet (APPENDIX K); Voc = 64.8V, temp. coefficient = -0.1766V/°C

$$Adj\ Voltage = V_{OC} - \{(Highest\ recorded\ temperature\ ℃ + 30℃ - 25℃) * (temp. coefficient\ V/℃)\}$$

Using the numbers from above: $64.8 + \{(36℃ + 30℃ - 25℃) * \ (-0.1766V/℃)\} = \ 57.65V$

$$57.65\frac{V}{module} * 8\frac{modules}{string} = 460.5V$$

$$460.5V\ > 315V * 1.2 = 378 => \boldsymbol{OK}$$

After checking the two parameters, it was determined that the Satcon 75kW would make a good choice for the project. Added benefits to the inverter are that it is engineered for outdoor installation, has built-in DC & AC disconnect switches, has a built-in transformer, and is capable of being compatible with third party monitors systems.

INVERTER LOCATION

To minimize the DC wire loss, and to provide easy access to the inverter it was decided to mount the inverter on the roof on the northern side of the freight elevator machine room as shown in figure 63 at right. Locating the inverter there will keep it out of direct sunlight, and help protect is it from the elements (although it is engineered to be mounted outdoors. Listed at 2,100lbs per the inverter data sheet in APPENDIX L, the structural steel beam roof structure in this area will easily be able to support the added weight of the inverter. At 80" tall the inverter will be visible from the north but then again, but the backside of the array is also visible. If aesthetics are that big of a concern, the mounting racks of the array and the inverter cabinet can be painted to blend in with the surrounding materials.

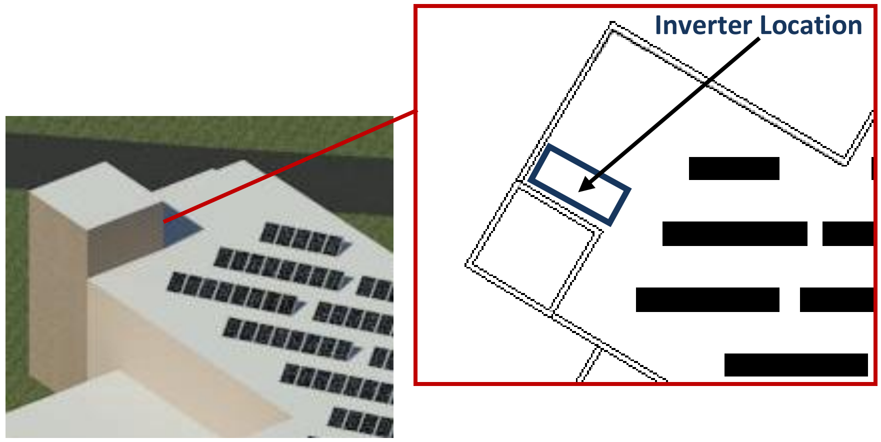


Figure 63: Inverter Location

3-Phase, 480V 6Hz output from the inverter can run out run down though a utility shaft created inside the building and once below the first floor can turn 90 degrees, run underground to the inverter, and then turn 90 degrees upward into a service tap combiner box to be mounted between the transformer and where the main feed enters the building. This interconnection between the AC output from in inverter and the utility service will be gone into further in the section below.

LOAD SIDE CONNECTION (E)

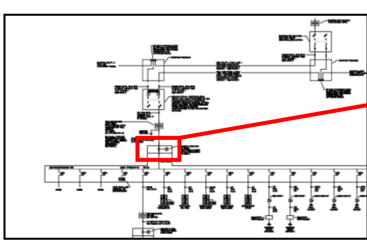
As mentioned above the PV system will tie into the existing system with a load side connection as shown below in figure 64. The service tap combiner box will take the 3-phase 480V feed from the 500kVa transformer and the 3-phase 480V from the inverter and combine them into one single feed for the building. From the Satcon 75kW data sheet in APPENDIX L, max current output per phase is given as 91A. Wire size for the wires from the inverter to the inverter was determined as follows:

91A x 1.56(NEC multiplier) = 142 A/wire

Per NEC table 310.15(B)(2)(a): multiplier for 4 -6 current carrying conductors in raceway = 0.8

Per NEC table 310.16 (90°C Wire): 2/0 AWG x (0.8) = 156A >142A => ***Ok***

Note: No temperature multiplier used since conduits will be buried below grade.



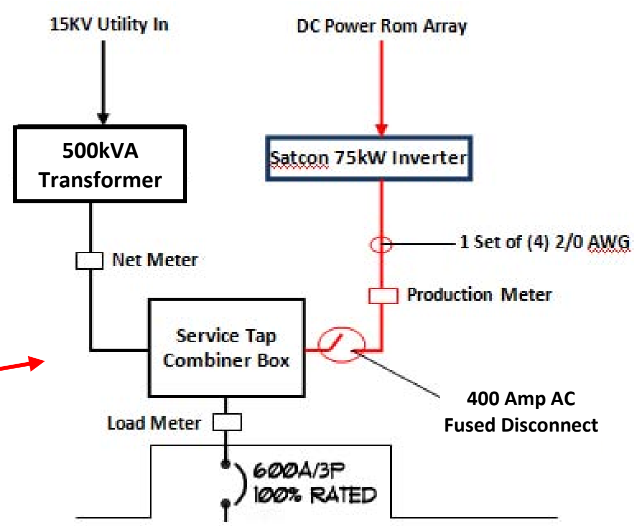


Figure 64: Load Side Connection of PV System

Although the Sacton 75kW inverter has built in AC and DC fused disconnects, it is a good idea to add a fused AC disconnect switch at the combiner box on the PV side. Size of the disconnect switch was determined as follows; $91\frac{A}{phase} * 3\ phases * 1.25(NEC\ Multiplier) =\ 341.25A$. Ideally a 350A fused disconnect switch would be acceptable, but the next largest size is 400A; therefore a 400A fused disconnect switch is used. Note that the interrupt ratting on the fused disconnect switch needs to be greater than the maximum current output of the transformer, or 600A$\left(500kVA/(.480kV * \sqrt{3}\right)$. To monitor the system, meters were installed as shown in figure 64 on the previous page to monitor production of the array, total usage by the building, and net usage (load – produced from PV array).

WIRE SIZING FOR DC COMPONENTS (E)

Wire sizes for the DC components will fall into one of two categories; string to combiner box wire, or from DC combiner box to inverter wire. As shown in figure 65 at right, each eight module string will run to the DC combiner box located on the roof. Each DC combiner box will combine seven stings of modules. From the combiner box, a single feed will run to the inverter.

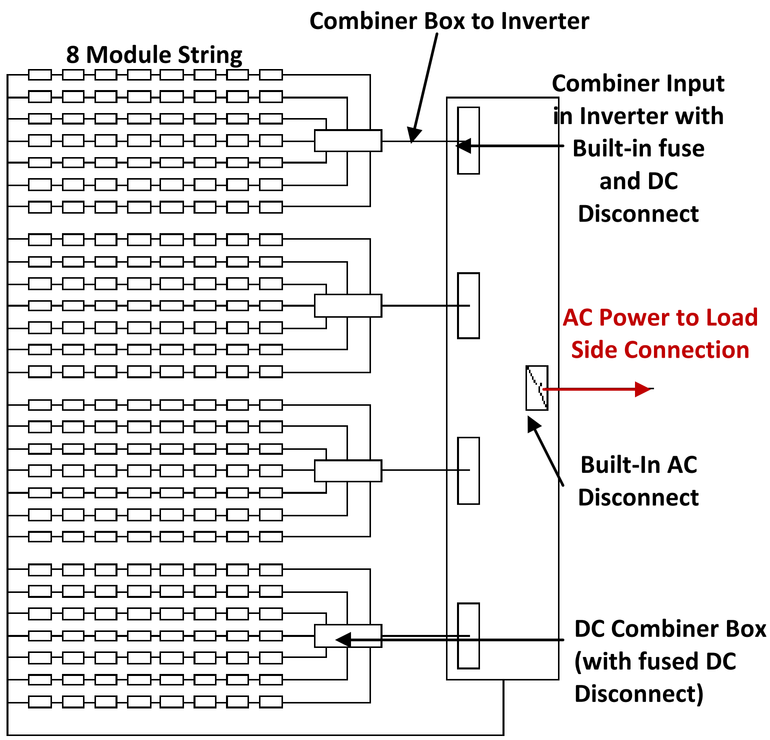


Figure 65: Diagram of Array (DC) Side of Inverter

__Sting to Combiner Box Wire Sizing:__

- From module data sheet: Isc =6.24A
- Assume separate conduit runs from each string to combiner box => no current carrying conductor multiplier
- From NEC Table 310.15(B)(2)(c): Ambient temperature adjustment for conduits mounted ½" to 3 ½" above roof: 22°C
- ASHRAE maximum ambient temperature for Harrisburg, PA: 36°C

  Adjusted Temperature = (36°C + 22°C) = 58°C
- From NEC Table 310.16 temperature correction factor for other than 30°C: 0.71 for 90°C wire

Maximum String Current = 6.24A * 1.56 (NEC multiplier for wire sizing) = 9.73A

From NEC Table 310.16, #12 AWG 90°C Wire = 25A * .71 = 17.75A> 9.73 => ***Ok***.

Note: Although #12AWG could be used for module to module connections in each string; however a common practice is to use a minimum size of #10AWG for PV installations therefore #10AWG will be used.

__DC combiner Box to Inverter Wire Sizing:__

Maximum Current in Wire = 9.73A/sting * 7 strings = 68.11A
Separate conduit runs to inverter from each combiner box => no current carrying conductor multiplier.
Temperature correction factor: (same as above): 0.71

From NEC Table 310.16, #3 AWG 90°C wire = 100A * 0.71 = 71A > 68.11A => ***OK***

Note: As Required by NEC, a 100A fusible DC disconnect will be installed at the combiner box.

Power Loss Check

Each combiner box will be mounted on the mounting rack of the last string in each group. Therefore limiting the length of the run of the smaller DC wires. With the combiner boxes mounted in this location, the following approximate wire lengths were used for power loss calculation.

- Combiner Box to Inverter: Average for all 4 combiner boxes: 90 ft
- String length to combiner box: Average for all 28 strings: 50 ft

Power Loss is Defined as; $\dfrac{(Number\ of\ Current\ Carrying\ WIres)*(Wire\ Factor)*\left(\frac{Length}{1000}\right)*I^2}{Total\ Watts}$

- From NEC Table 8, conductor resistance for each wire are as follows: 1.26Ω/kFT for #10 AWG and .254Ω/kFT for #3AWG.

Power Loss for Strings: $\dfrac{\left(\frac{2\ current\ carrying\ conductors}{string}\right)*\frac{1.26\Omega}{kFT}*\frac{50ft}{1000}*5.86^2}{8\ modules*320\ W/module}*28\ strings = 3.7\%$

Power Loss for Combiner Boxes: $\dfrac{\left(\frac{2\ current\ carrying\ conductors}{string}\right)*.\frac{254\Omega}{kFT}*\frac{90ft}{1000}*(5.86*7)^2}{8\frac{modules}{strng}*\frac{320W}{module}*7\ strings}*4\ boxes = .95\%$

Total wire loss using these wire sizes would be 3.7 + .95 = 4.65%. This is above the exceptable range of 2-4% therefore wire sizes need to be increased to #8 AWG for sting to combiner box and #2 AWG for cominber box to inverter. Module to module wire size can reamin at #10 AWG. Re-doing the power loss calcualtion with the larger wire sizes results in a total power loss of 3.65% which is withing the accectable range. Figure 66 below summarizes the DC wire sizes for the system.

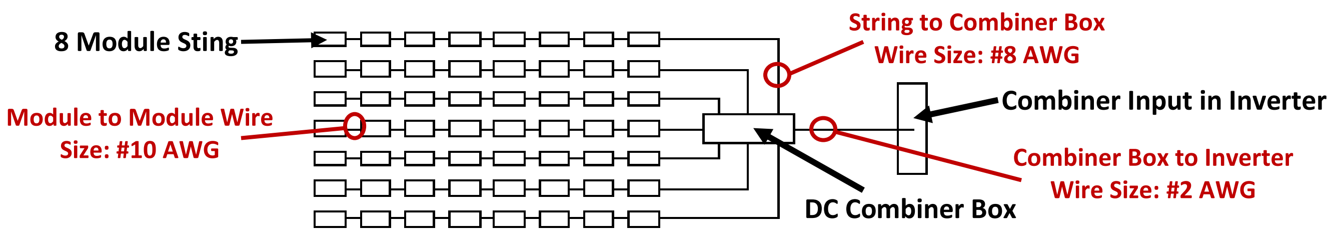


Figure 66: Final Wire Sizes for DC Side of System

IMPACT ON SCHEDULE AND SITE LOGISTICS

With the addition of the PV array and all of it's components, both the projects shcedule and site logistics needed to be examined. Mounted on the roof, they array will have to wait until the roofing is completed beofre installation. The only item compnent that needs to be installted prior to the roof installation is the roof curbs for the mounting racks to mount to. Installation of these can occur concurrently with the installaton of the metal deck and roof installaton and therefore won't effect the actual roofing shcedule. Once the roof is complete, mounting racks, modules, and conduits can be installed. It estiamted that it will take approximately a week to install all of the mounting racks and the modules with the aid of a crane. It is possible that modules can be mounted on the racks offsite, and pre-wired and set onto the roof as units ,which could easily decrease the installation of these items to two or three days. Since the installation will likey occur while interior work is being completed, the crane can be positioned in the parking lot on the southern side of the building for this and will not have any effect on the site logstics.

Work associated with the load side connection can also occur later in the project. Conduit from the building to where the combiner box/panel is located can be roughed-in while site utilites are being installed, but is not vital that it is installed at this time. Final installaton of the combiner panel/box can also also occur after the building is energized. This work can occur at night, to reduce the effects on construction during the day. Final array wiring and and installation of the inverter can occur after the modules and mounting racks are installed. In talking with a local PV installter, they estimate that a system line this will have a total installation of approximately a month (if everything is ready for them).

ESTIMATED COSTS OF THE SYSTEM

Estimated cost of the added PV system to the Support Services Building was calculated using various sources including; RS Means Costwoks 2010, Alexander Estimates, and Supplier/Installer estimates. Cost of the Sunpower E19-320 solar modules came from a local authorized Sunpower supplier in Doylestown, Pa. Sunpower modules cannot be purchased separately and installed by a third party (subcontractor). Instead Sunpower authorized suppliers not only provide but also install the modules. After discussing the design parameters of the system with them, an estimate of $2,100.00/module was determined to be a good approximation. Cost's included in this approximation; module cost, mounting rack, and installation costs. Cost for the Satcon 75kW came per a phone interview with a sale representative for the company. The remaining costs came from a combination RS Mean Costworks 2010 and Alexander Estimates. Table 36 below shows the estimated costs for the PV system.

PV SYSTEM ESTIMATE					
Item	**Description**	**Unit**	**Quantity**	**Unit Price**	**Total Cost**
Resized Steel Joists					**$1,106.20**
	Change From 26K7 to 26K8	LF	518	$0.90	$466.20
	Change from 16K3 to 16K4	LF	322	$0.72	$231.84
	Change from 24K5 to 24K6	LF	432	$0.80	$345.60
	Change from 12K1 to 12K3	LF	92	$0.68	$62.56
Sunpower E19-320 Solar Modules					**$476,400.00**
	Purchase & Installation	EA	224	$2,100.00	$470,400.00
	Roof Curbs	LS	1	$10,000.00	$6,000.00
Sacton Powergate Plus 75kW Inverter					**$36,000.00**
	Purchase & Installation	EA	1	$36,000	$36,000.00
Wire					**$5,538.00**
	# 8 AWG	LF	2,400	$1.20	$2,880.00
	#2 AWG	LF	720	$2.65	$1,908.00
	2/0 AWG	LF	200	$3.75	$750.00
Misc.					**$26,740.00**
	400A Fused AC Disconnect	EA	1	$1,640.00	$1,640.00
	Combiner Panel/Box	EA	1	$3,200.00	$3,200.00
	DC Combiner Boxes	EA	4	$1,200.00	$4,800.00
	100A Fused DC Disconnect	EA	4	$525.00	$2,100.00
	Conduit/ Fasteners/Misc. Items	LS	1	$15,000.00	$15,000.00
				Total Cost:	**$545,784.20**

Table 36: Estimated Cost of Added 71.68kW PV System

In total the added cost of the PV system was found to be just under $545,800.00, or $7.62/W. Comparing this with the estimated cost of $7.50/W in the 2010 US Department of Energy Annual Energy Report, it is felt that this cost estimate is within acceptable limits. Taking a closer look at the estimate, the added cost to increase several of the steel roof joists to the next size is minimal. In fact, it only accounts for .2% of the total costs of the system. It goes to show that most roofs in new construction have enough safety factored into the design to easily account for the added weight of a PV system to the roof.

Note: Total cost of the system does not include a cost to add/tie in a third party monitoring system or sun tracking system. Array tilt angle will have to be manually adjusted to follow the sun throughout the year. Estimated cost to install a sun-tracking system to change the array tilt automatically would be an additional $25,000.00.

As mentioned in the introduction to Part II of this analysis, installation of the PV array would require that the offset roof be eliminated and either the RTU's be eliminated or relocated. Total cost associated with either option can be seen in table 37 at right. Option 1, moving the RTU's to the lower roof would save almost $50,000.00 on the initial cost of the PV system, while adding the geothermal system would cost an additional $473,000.00.

TOTAL COST TO INSTALL PV SYSTEM		
Option	**Description**	**Total Cost**
Option 1: Move RTU's to Lower Roof		**$495,003.93**
	PV System	$545,318.00
	Elimination of Offset Roof	$55,314.07
	Move RTU's to Lower Roof	$5,000.00
Option 2: Replace RTU's with Geothermal System		**$967,703.93**
	PV System	$545,318.00
	Elimination of Offset Roof	$55,314.07
	Add Geothermal System	$477,700.00

Table 37: Estimated Total Cost to Add PV System per RTU Option

ESTIMATED YEARLY ENERGY SAVINGS

Using the PVWatts online solar calculator, estimated total yearly output of usable AC electricity from the PV system is 102,240kWh. In talking with the electrical engineer on the project, it is estimated that the Support Services Building will consume anywhere between 1,000 -2,000kWh/day depending on the usage of the shop equipment and the day of the week (weekends will consume less than weekdays). Using an average daily consumption of 1,500kWh/day, the estimated yearly consumption can be approximated at 547,500kWh. In total the PV array will produce approximately 19% of the total energy consumption of the building.

To calculate the estimated yearly savings in electrical operating costs, the state average of $0.09kWh was used. Using this, the estimated value of the AC electricity produced by the array is just under $10,000.00. A $10,000.00 yearly savings in electric operating costs would result in a 50-year payback period under option 1 shown above in table 37. This is rather large payback period and because Penn State is still a publically funded university, it is not eligible for any of the tax credits or rebates normally associated with the installation of PV systems. However Penn State will own and operate this building for well over the 50-year payback period, therefore they will eventually see the benefits of the added system.

CONCLUSION FOR PART II

After performing an in-depth site analysis for the Support Services Building, it was determined that the site provides an ideal location for the installation of a PV array to the rooftop of the buildings. Using the online Sun Angle Calculator by Sustainable by Design, the location of the sun in the sky was determined for the two solstices and two equinoxes at 9:00 AM, 12:00 PM, and 3:00 PM, which define the optimum solar window. A shadow analysis was then performed on both the site and the rooftop to determine the best location on the rooftop to place modules.

To maximize the amount of useable rooftop space for installation of the modules the offset roof was eliminated per Analysis II, and the RTU's can be either relocated to the to lower roof, or eliminated per the installation of a geothermal system as shown in Part I of this analysis.

After comparing several different PV modules, the Sunpower E19-302 was determined to be the best choice for the project. Using a Revit model the maximum number of panels per array tilt angle and module orientation was determined. Surprisingly, it was found that more modules could be placed in the due south orientation vs. rotated to match the orientation of the building. Using the online solar calculator PVWatts, module output per year, per array tilt angle was calculated. The results of this

showed that the max output per panel is with an array tilt of 30-35°. Using this, it was determined that the system would be designed with minimum row to row spacing at the 35° tilt and a due south orientation. Mounting the system with a one-axis tracking to follow the sun above the horizon throughout the year resulted in an increased production of 60 kWh/year/panel.

With an NEC maximum voltage of a PV array of 600V, maximum string size was calculated at eight modules. Using 8 module strings sizes, it was found that 28 strings could fit onto the rooftop for a total system size of 71.68kW. A structural analysis was performed on the steel roof joists to determine if they could supported the added weight of the PV array and mounting racks. It was determined that half of the steel joists where adequate to support the added weight, while the other half needed to be resized to the next available size.

For an inverter a Satcon Powergate Plus 75kW was selected. With a maximum number of 6 combiner inputs in the inverter, it was decided to wire combine seven strings in a DC combiner box for a total of four inputs into the inverter. The best location for the inverter was determined to be on the northern side of the freight elevator machine room on the rooftop. To tie into the electrical system of the building, a load-side connection was determined to be best. Wire sizes, fuse sizes, and disconnect sizes were calculated for all parts of the system. In performing power loss calculations it was determined that minimum wire sizes per NEC requirements were inadequate, and that wire sizes had to be increased to limit the total power loss to under 4%.

Because the addition of the PV System is external to the overall project, it was shown that it would not have any impacts on the overall project schedule or site logistics. Only roof curb installation would occur before the installation of the roof. All other installation would occur after the roof is completed. To save on installation time of the modules and mounting rack, they can be prefabricated offsite and installed as one unit. Work associated with the load side connection can occur either before or after final power is turned on.

Total estimated cost of the system was calculated using a combination of supplier estimate, Alexander estimates, and RS Means Costworks 2010. Total system cost is just under $500,000.00 if the RTU's are relocated to the lower roof and just over $967,000.00 with the installation of a geothermal system. Estimated value of the electricity produced by the system is approximately $10,000.00/year. Given that, estimated payback time for the system assuming the RTU's are relocated to the lower roof, and with no rebates or tax credits, was found to be 50 years.

Based on the findings in part II, I would have recommended the installation of a PV array for the SSB. With the cap on electric prices removed and the price of electricity produced from fossil fuels only going to increase, having a PV array to generate a portion of the buildings electric usage will only become more beneficial. Penn State builds their buildings for longevity therefore the 50 year payback period isn't that big of an issue for them. If initial upfront costs are not a major concern, I would also recommend the installation of the geothermal system in conjunction with the PV system. Both systems will help offset the operating cost of the building will become increasingly more popular in the future. Installing them now on the smaller SSB, will allow greater research into the operating techniques of buildings with these systems and allow Penn State to determine the best way to incorporate them into their buildings of the future. Installing these systems will also be a step in the right direction for Penn State to become more energy independent, and will make a model for other universities to follow.

SUMMARY OF RECOMMENDATIONS

ANALYSIS I: REDESIGN FOUNDATION SYSTEM

Based on the findings of this analysis, I would have recommended that the Support Services Building utilize the Geopiers and larger spread footings in lieu of the micropile foundation. The cost savings of $123,000.00 is fairly signifcant. However when the price per Geopier ($2,148.00) is compared to the price per micropile ($4,559.41), the price difference is extremely significant. Increasing the size of the concrete foundation elements has a much smaller impact on the overall project cost as the difference between the Geopiers and micropiles. Micropile foundation systems are excellent foundation systems, however Geopier's most certainly offer a more cost effictive solution to them. In fact, Geopiers are becoming increasingly more popular within the construction industy with thousands of successfully completed projects since the company began in 1989.

ANALYSIS II: ROOFING COMPARISON & ELIMINATION OF OFFSET ROOF

Based on all of the comparisons in part I, it is my recommendation that the cold-applied BUR was the proper choice for the Support Services Building. In fact, Hershey Medical Center tried using single-ply membrane roofing on some smaller projects several years ago, and were dissatisfied. Their buildings tend to see a high volume of foot traffic on the roofs, and they found out that single plies didn't hold up to the abuse. In fact, they've had better luck with the BUR that was installed on the original hospital built back in 1966, and that is why they went back to BUR's. Using cold-applied allows installation without the fumes of asphalt, which is great for a medical environment. From a sustainably standpoint, the cold-applied BUR used on the SSB is the same or better than a single-ply. Yes this roof costs more, but there is also something that can be said about giving the owner what they want.

Based on the finding of part II, I would have recommended that the offset roof be eliminated. The Support Services Building is not an architectural wonder (statement building) on the medical center's campus. It is a support facility for the entire campus and therefore hiding the RTU's is not necessary. The cost savings of $55,000.00 is well worth eliminating the offset roof and exposing the RTU's

ANALYSIS III: DESIGN STUDY TO INCREASE SUSTAINABLE FEATURES USING RENEWABLE ENERGY SOURCES

Based on the findings in both parts of this analysis, I would have recommended the installation of a PV array for the SSB. With the cap on electric prices removed and the price of electricity produced from fossil fuels only going to increase. Having a PV array to generate a portion of the buildings electric usage will only become more beneficial as cost of electricity goes up. If initial upfront costs are not a major concern, I would also have recommended the installation of the geothermal system in conjunction with the PV system. Initial project cost would only be approximated 7% more or $22.61 SF more. Both systems will offset the operating cost of the building and are becoming increasingly more popular.

Installing both systems on the smaller SSB, will allow Penn State to conduct greater research into the operating techniques of buildings with these systems. It will also allow Penn State to determine the best way to incorporate this type of technology into their new buildings of the future. Installing these systems will also be a step in the right direction for Penn State to become more energy independent, and will make a model for other universities to follow. It also would show that Penn State is committed to implementing the renewable onsite energy sources they research into their buildings. It is estimated that implementing these systems could also have increase the LEED rating from Certified to Bronze or Silver.

LESSON'S LEARNED

ANALYSIS I: REDESIGN OF FOUNDATION SYSTEM

- Spread footing design utilizing Geopier's is often governed by minimum Geopier element spacing, not increased soil bearing capacity when two or more Geopier elements are required.
- Cost to increase concrete foundation element sizes is minimal compared to total cost of project, when compared to the cost of a deep foundation system.
- When additional engineering and mobilization costs are considered, adding a second foundation type to a project isn't as cost effective as one would assume.
- Recommending a foundation type in a Geotechnical Report is a difficult decision and is often based on many unknown factors.

ANALYSIS II: ROOFING COMPARISON & ELIMINATION OF OFFSET ROOF

- Sustainable roofing is no longer limited to single-ply membranes and vegetated roofs
- Roofing manufacturers have embraced sustainability and now offer a wide variety of products for just about any application
- Selection of lower cost roof as a Value Engineering Item is not always the best solution. Many things need to be considered when selecting a roof type for a project
- Some owners such as Penn State & Hershey Medical Center know what they want, and are willing to pay the added costs.
- Hiding mechanical equipment is not always worth the added cost depending on the purpose & location of the building

ANALYSIS III: DESIGN STUDY TO INCREASE SUSTAINABLE FEATURES USING RENEWABLE ENERGY SOURCES

- Installation of the deep wells and horizontal piping back to the manifold comprises over 95% of the added costs of a geothermal system vs. a conventional air to air HVAC system
- When a building is rotated at such a large angle off due south, more modules can fit on the roof using a due south module orientation (depending on shape of roof)
- More modules and a larger system don't always mean that you get more for your money. Initial cost vs. energy produced should always be considered when sizing a system.
- Mounting modules in a landscape manner can increase size of system, but not always.
- Wire sizes are often sized based on power loss calculations, not minimum size as required by NEC.
- Cost to increase steel joist sizes to the next available size is minimal ($0.65-$1.50LF) to support added weight of PV systems on rooftops.

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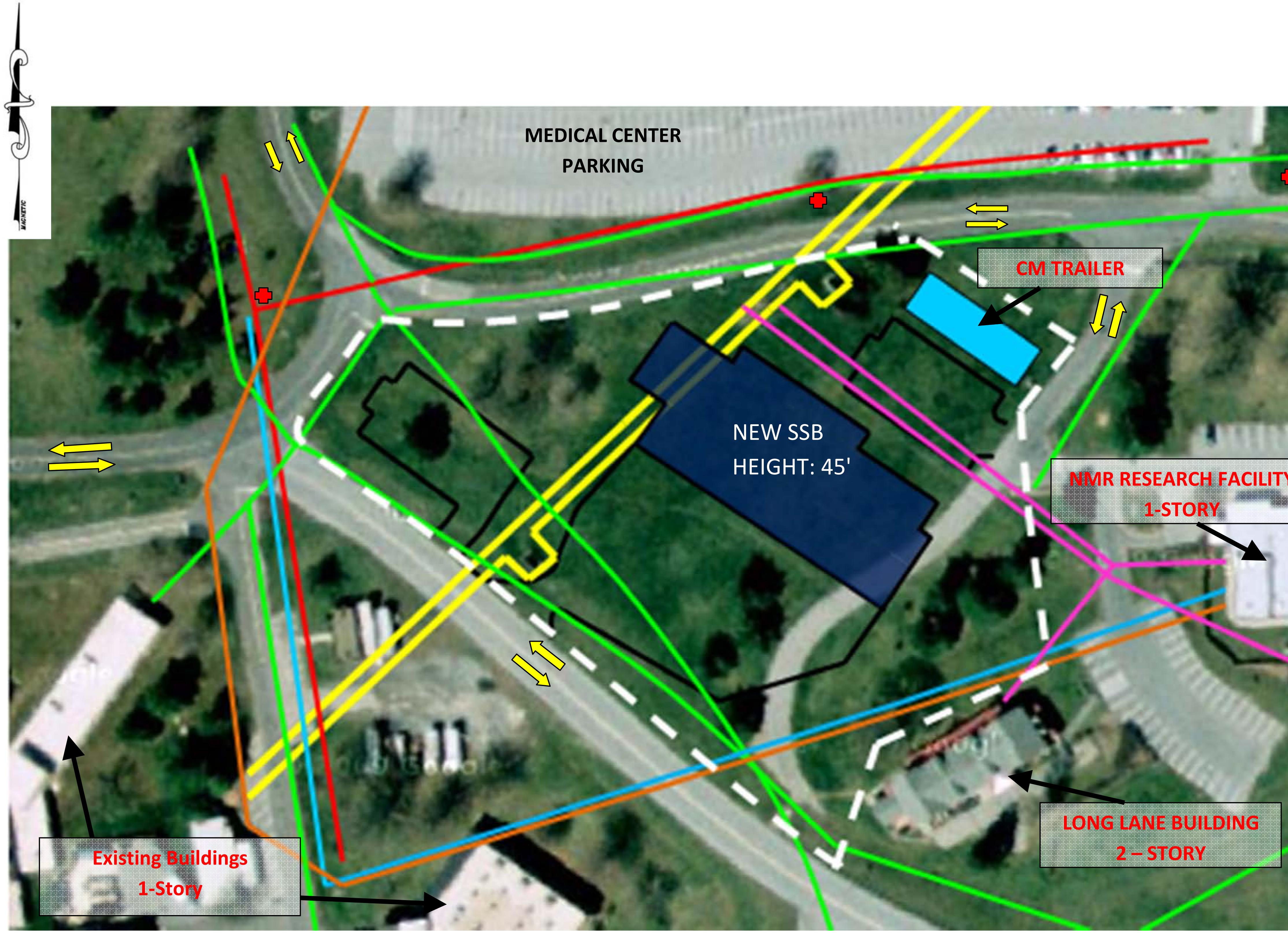
APPENDIX A – EXISTING CONDITIONS SITE PLAN



LEGEND:

EXISTING UTILITIES:

STORM..................

SANITARY.............

WATER..................

FIRE LINE...............

ELECTRIC...............

EXISTING UTILITY TUNNEL.................

SYMBOLS:

CONSTRUCTION FENCE

VEHICULAR TRAFFIC

FIRE HYDRANT

SUPPORT SERVICES BUILDING

EXISTING CONDITIONS SITE PLAN

September 29, 2010

WILL LAZRATION - CM

APPENDIX B – DETAILED STRUCTURAL SYSTEM ESTIMATE

CAST-IN PLACE CONCRETE ESTIMATE

Description	Unit	QTY	Bare Material	Bare Labor	Bare Equipment	Bare Total	Total Inc. O &P	Total Cost
REINFORCING								
Pile Caps	Ton	6.04	$784.32	$753.61	-	$1,537.93	$1,614.83	$9,759.43
Grade Beams	Ton	20.20	$784.32	$985.49	-	$1,811.09	$1,901.64	$38,418.54
Foundation Walls	Ton	20.20	$784.32	$985.49	-	$1,811.09	$1,901.64	$38,418.54
SOG & Structural Slabs	Ton	20.53	$784.32	$685.10	-	$1,469.42	$1,542.89	$31,679.14
Elevated Slabs	CSF	220	$24.77	$27.40	-	$52.17	$54.78	$12,051.27
Piers	Ton	6.18	$784.32	$753.61	-	$1,537.93	$1,614.83	$9,983.74
							TOTAL:	**$140,310.65**
CONCRETE								
Pile Caps (4,000 PSI)	CY	294	$101.15	$9.16	$0.41	$101.14	$115.78	$33,987.22
Grade Beams (4,000 PSI)	CY	307	$101.15	$12.21	$5.15	$108.93	$123.96	$38,073.82
Foundation Walls (4,000 PSI)	CY	317	$101.15	$14.63	$6.21	$112.41	$127.61	$40,496.14
SOG & Structural Slabs (4,000 PSI)	CY	594	$101.15	$14.58	$0.64	$106.79	$121.71	$72,258.25
Elevated Slabs (3,500 PSI)	CY	324	$98.04	$15.70	$6.61	$110.77	$125.89	$40,754.24
Piers (4,000 PSI)	CY	65	$101.15	$14.63	$6.21	$112.41	$127.61	$8,294.65
							TOTAL:	**$233,864.32**
FORMWORK								
Grade Beams	SFCA	4,776	$22.66	$5.91	-	$28.57	$30.00	$143,258.24
Foundation Walls	SFCA	3,667	$22.66	$6.18	-	$28.84	$30.28	$111,052.21
Piers	SFCA	1,540	$22.66	$5.91	-	$28.57	$30.00	$46,210.85
							TOTAL:	**$300,521.30**
Polished Concrete Floors								
Finishing	SF	20,186	-	$0.22	$0.07	$0.29	$0.40	$8,074.40
							TOTAL CONCRETE ESTIMATE:	**$682,770.68**

STRUCTURAL STEEL ESTIMATE

Description	Unit	QTY	Bare Material	Bare Labor	Bare Equipment	Bare Total	Total Inc. O &P	Total Cost
BEAMS								
W8x10	LF	152.3	$11.13	$5.15	$3.11	$19.39	$19.97	$3,041.69
W8x13	LF	59.5	$16.70	$5.15	$3.11	$24.96	$25.71	$1,529.67
W8x15	LF	111.64	$16.70	$5.15	$3.11	$24.96	$25.71	$2,870.13
W8x24	LF	4.5	$26.68	$5.61	$3.39	$35.68	$36.75	$165.38
W10x12	LF	173.81	$13.34	$5.15	$3.11	$21.60	$22.25	$3,866.92
W10x19	LF	34.5	$24.38	$5.15	$3.11	$32.64	$33.62	$1,159.86
W12x14	LF	882.82	$17.80	$3.51	$2.12	$23.43	$24.13	$21,305.01
W12x19	LF	145.75	$24.38	$3.51	$2.12	$30.01	$30.91	$4,505.18
W12x26	LF	63	$28.98	$3.51	$2.12	$34.61	$35.65	$2,230.51
W12x35	LF	44.49	$39.10	$3.81	$2.30	$45.21	$46.57	$2,071.73
W12x53	LF	45	$64.40	$4.12	$2.48	$71.00	$73.13	$3,290.85
W12x87	LF	16.5	$96.60	$4.82	$2.91	$104.33	$107.46	$1,773.09
W14x22	LF	689.24	$28.98	$3.12	$1.88	$33.98	$35.00	$24,122.99
W14x43	LF	68.34	$47.84	$3.81	$2.30	$53.95	$55.57	$3,797.55
W16x26	LF	587.26	$28.98	$3.08	$1.87	$33.93	$34.95	$20,523.50
W16x31	LF	454.01	$34.50	$3.43	$2.08	$40.01	$41.21	$18,709.89
W18x35	LF	1,255.88	$39.10	$4.65	$2.12	$45.87	$47.25	$59,335.43
W18x40	LF	307.60	$44.62	$4.65	$2.12	$51.39	$52.93	$16,281.79
W18x55	LF	115.26	$61.18	$4.90	$2.23	$68.31	$70.36	$8,109.61
W21x44	LF	690.08	$48.76	$4.20	$1.91	$54.87	$56.52	$39,000.63
W21x50	LF	234.66	$55.66	$4.20	$1.91	$61.77	$63.62	$14,929.80

W24x55	LF	637.49	$61.18	$4.03	$1.83	$67.04	$69.05	$44,019.45
W24x68	LF	134.26	$75.90	$4.03	$1.83	$81.76	$84.21	$11,306.41
W30x99	LF	29.25	$110.40	$3.72	$1.69	$151.81	$156.36	$4,573.66
W30x132	LF	36.08	$147.20	$3.86	$1.75	$152.81	$157.39	$5,678.79
HSS 6x2x1/4"	# 12 Ft Sect.	3	$253.00	$57.43	$34.80	$345.23	$355.59	$1,219.96
HSS 6x4x1/4"	# 12 Ft Sect.	3	$253.00	$57.43	$34.80	$345.23	$355.59	$1,087.50
HSS 8x4x1/4"	# 12 Ft Sect.	3	$368.00	$57.43	$34.80	$460.23	$474.04	$1,449.76
HSS 8x8x3/8"	# 12 Ft Sect.	3	$368.00	$57.43	$34.80	$460.23	$474.04	$1,290.96
HSS 12x4x1/4"	# 12 Ft Sect.	1	$1,104.00	$68.04	$38.66	$1,206.94	$1,243.15	$1,829.50
HSS 12x6x1/4"	# 12 Ft Sect.	7	$1,104.00	$68.04	$38.66	$1,206.94	$1,243.15	$8,561.15
HSS 18x8x5/16"	# 12 Ft Sect.	2	$1,104.00	$68.04	$38.66	$1,206.94	$1,243.15	$2,693.49
							TOTAL:	$336,331.84
COLUMNS								
W10x33	LF	605.72	$50.14	$2.99	$1.81	$54.94	$56.59	$34,276.49
W10x39	LF	62.84	$50.14	$2.99	$1.81	$54.94	$56.59	$3,556.00
W10x49	LF	66.42	$75.90	$3.14	$1.89	$80.93	$83.36	$5,536.63
W10x68	LF	35.92	$75.90	$3.14	$1.89	$80.93	$83.36	$2,994.22
W12x79	LF	62.25	$96.60	$3.14	$1.89	$101.63	$104.68	$6,516.26
W12x120	LF	910.23	$133.40	$3.22	$1.94	$138.56	$142.72	$129,905.11
HSS 6x6x1/4"	# 12 Ft Sect.	17	$253.00	$57.43	$34.80	$345.23	$355.59	$6,000.53
HSS 8x8x5/16"	# 12 Ft Sect.	8	$368.00	$57.43	$34.80	$460.23	$474.04	$3,785.97
							TOTAL:	$192,571.22
ROOF JOISTS								
10K1	LF	97.32	$2.72	$3.81	$1.83	$8.36	$8.61	$838.00
12K1	LF	91.65	$3.11	$3.04	$1.47	$7.62	$7.85	$719.32
14K1	LF	266.5	$3.27	$3.04	$1.47	$7.78	$8.01	$2,135.57
14KCS2	LF	153	$3.27	$3.04	$1.47	$7.78	$8.01	$1,226.05
14KCS3	LF	68	$3.27	$3.04	$1.47	$7.78	$8.01	$544.91
16K2	LF	129	$3.43	$2.54	$1.22	$7.19	$7.41	$955.34
16K3	LF	322	$3.43	$2.54	$1.22	$7.19	$7.41	$2,384.64
18KCS2	LF	287	$4.20	$2.29	$1.10	$7.59	$7.82	$2,243.68
24K5	LF	444.21	$5.18	$2.08	$1.00	$8.26	$8.51	$3,779.25
24K6	LF	544.85	$5.18	$2.08	$1.00	$8.26	$8.51	$4,635.47
26K7	LF	525	$5.66	$2.08	$1.00	$8.74	$9.00	$4,726.16
							TOTAL:	$24,188.39
MISCELLANEOUS								
2"-19 Gauge Metal Floor Deck	SF	20,000	$1.80	$0.56	$0.05	$2.41	$2.85	$57,000.00
1 1/2"-22 Gauge Metal Roof Deck	SF	25,330	$1.16	$0.43	$0.03	$1.62	$2.05	$51,926.50
4 1/2" x 3/4" Shear Studs	EA	2,078	$1.86	$0.41	$0.05	$2.31	$2.75	$5,714.50
L3x3	LF	175.34	$4.37	$24.18	$2.97	$31.52	$32.47	$5,692.52
							TOTAL:	$159,906.47
							TOTAL STRUCTURAL STEEL ESTIMATE:	$712,997.92

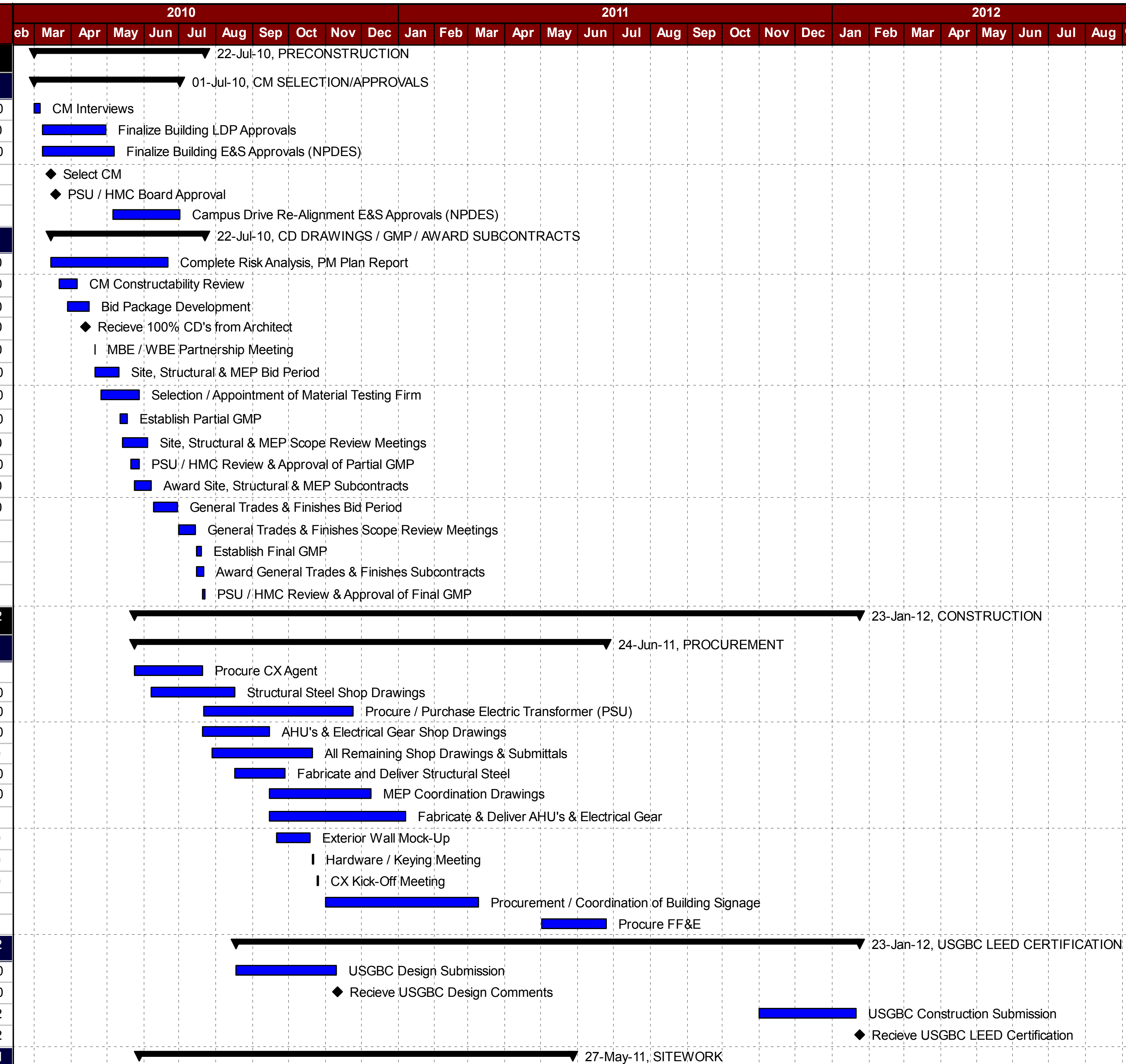
APPENDIX C – DETAILED PROJECT SCHEDULE

SUPPORT SERVICES BUILDING
PENN STATE MILTON S. HERSHEY MEDICAL CENTER - HERSHEY PA

WILL LAZRATION
CONSTRUCTION MANAGEMENT

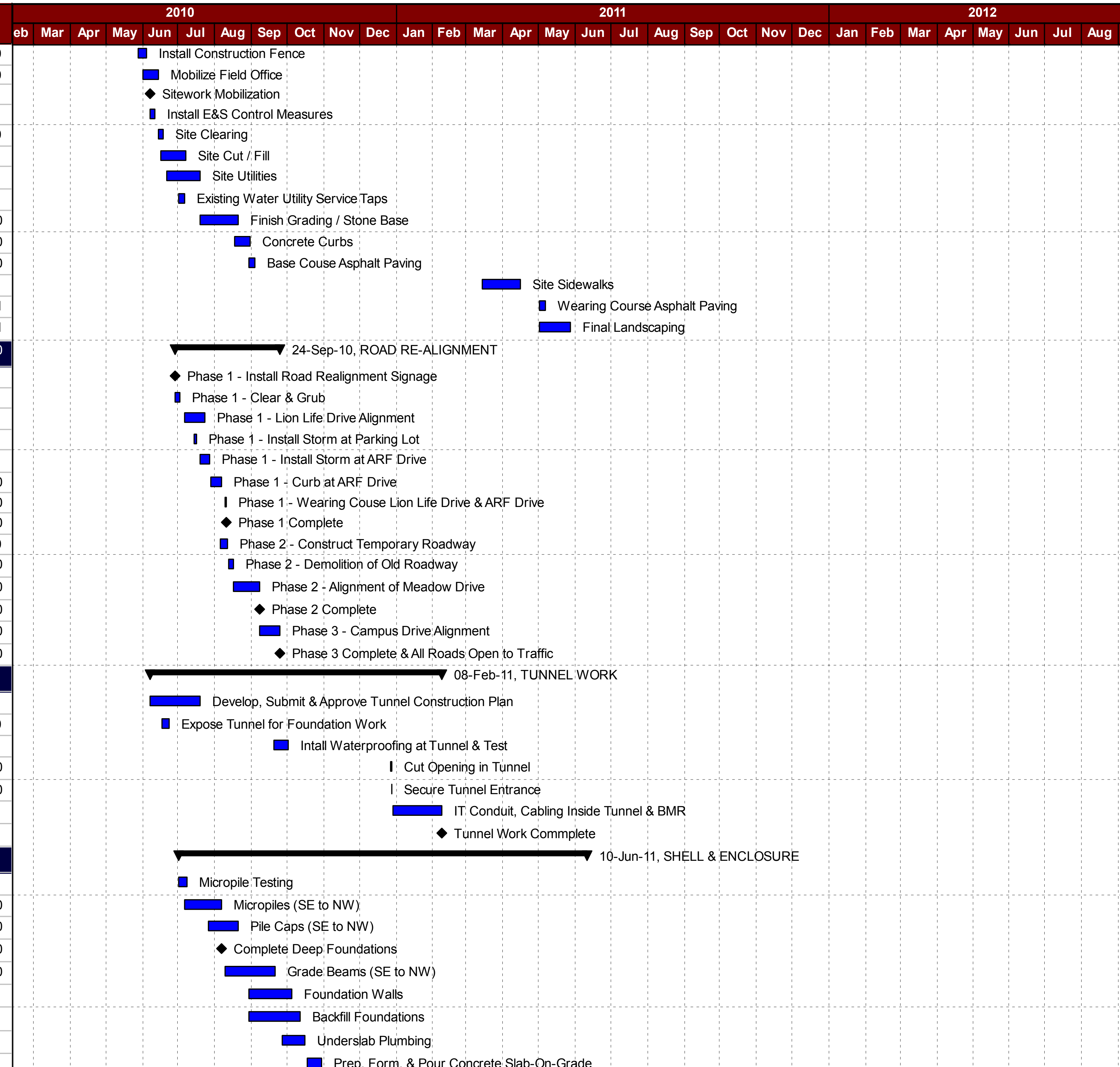
DETAILED PROJECT SCHEDULE
TECHNICAL ASSIGNMENT 2

Activity ID	Activity Name	Original Duration	Start	Finish
	PRECONSTRUCTION	102	01-Mar-10	22-Jul-10
	CM SELECTION/APPROVALS	88	01-Mar-10	01-Jul-10
A1980	CM Interviews	5	01-Mar-10	05-Mar-10
A2330	Finalize Building LDP Approvals	40	08-Mar-10	30-Apr-10
A2340	Finalize Building E&S Approvals (NPDES)	45	08-Mar-10	07-May-10
A2350	Select CM	0	15-Mar-10	
A2360	PSU / HMC Board Approval	0	19-Mar-10	
A2370	Campus Drive Re-Alignment E&S Approvals (NPDES)	40	06-May-10	01-Jul-10
	CD DRAWINGS / GMP / AWARD SUBCONTRACTS	92	15-Mar-10	22-Jul-10
A2380	Complete Risk Analysis, PM Plan Report	70	15-Mar-10	21-Jun-10
A2390	CM Constructability Review	12	22-Mar-10	06-Apr-10
A2400	Bid Package Development	15	29-Mar-10	16-Apr-10
A2410	Recieve 100% CD's from Architect	0		13-Apr-10
A2420	MBE / WBE Partnership Meeting	1	21-Apr-10	21-Apr-10
A2430	Site, Structural & MEP Bid Period	15	21-Apr-10	11-May-10
A2431	Selection / Appointment of Material Testing Firm	25	26-Apr-10	28-May-10
A2440	Establish Partial GMP	5	12-May-10	18-May-10
A2450	Site, Structural & MEP Scope Review Meetings	15	14-May-10	04-Jun-10
A2460	PSU / HMC Review & Approval of Partial GMP	6	21-May-10	28-May-10
A2470	Award Site, Structural & MEP Subcontracts	10	24-May-10	07-Jun-10
A2480	General Trades & Finishes Bid Period	15	09-Jun-10	29-Jun-10
A2490	General Trades & Finishes Scope Review Meetings	10	30-Jun-10	14-Jul-10
A2500	Establish Final GMP	3	15-Jul-10	19-Jul-10
A2510	Award General Trades & Finishes Subcontracts	5	15-Jul-10	21-Jul-10
A2520	PSU / HMC Review & Approval of Final GMP	3	20-Jul-10	22-Jul-10
	CONSTRUCTION	430	24-May-10	23-Jan-12
	PROCUREMENT	279	24-May-10	24-Jun-11
A1989	Procure CX Agent	40	24-May-10	20-Jul-10
A1990	Structural Steel Shop Drawings	50	07-Jun-10	16-Aug-10
A2530	Procure / Purchase Electric Transformer (PSU)	90	21-Jul-10	24-Nov-10
A2540	AHU's & Electrical Gear Shop Drawings	40	20-Jul-10	14-Sep-10
A2550	All Remaining Shop Drawings & Submittals	60	28-Jul-10	20-Oct-10
A2560	Fabricate and Deliver Structural Steel	30	16-Aug-10	27-Sep-10
A2570	MEP Coordination Drawings	60	15-Sep-10	09-Dec-10
A2580	Fabricate & Deliver AHU's & Electrical Gear	80	15-Sep-10	07-Jan-11
A2590	Exterior Wall Mock-Up	20	21-Sep-10	18-Oct-10
A2591	Hardware / Keying Meeting	1	21-Oct-10	21-Oct-10
A2592	CX Kick-Off Meeting	1	25-Oct-10	25-Oct-10
A2593	Procurement / Coordination of Building Signage	90	01-Nov-10	09-Mar-11
A2600	Procure FF&E	40	02-May-11	24-Jun-11
	USGBC LEED CERTIFICATION	371	17-Aug-10	23-Jan-12
A1760	USGBC Design Submission	60	17-Aug-10	09-Nov-10
A2610	Recieve USGBC Design Comments	0		10-Nov-10
A2620	USGBC Construction Submission	60	31-Oct-11	20-Jan-12
A2630	Recieve USGBC LEED Certification	0		23-Jan-12
	SITEWORK	255	28-May-10	27-May-11



Actual Work — Critical Remaining Work — Summary
Remaining Work — Milestone

Activity ID	Activity Name	Original Duration	Start	Finish
A2000	Install Construction Fence	5	28-May-10	04-Jun-10
A2640	Mobilize Field Office	10	01-Jun-10	14-Jun-10
A2650	Sitework Mobilization	0	07-Jun-10	
A2660	Install E&S Control Measures	5	07-Jun-10	11-Jun-10
A2670	Site Clearing	5	14-Jun-10	18-Jun-10
A2680	Site Cut / Fill	15	16-Jun-10	07-Jul-10
A2690	Site Utilities	20	21-Jun-10	19-Jul-10
A2700	Existing Water Utility Service Taps	3	01-Jul-10	06-Jul-10
A2710	Finish Grading / Stone Base	25	19-Jul-10	20-Aug-10
A2720	Concrete Curbs	10	17-Aug-10	30-Aug-10
A2730	Base Couse Asphalt Paving	5	30-Aug-10	03-Sep-10
A2740	Site Sidewalks	25	14-Mar-11	15-Apr-11
A2750	Wearing Course Asphalt Paving	5	02-May-11	06-May-11
A2760	Final Landscaping	20	02-May-11	27-May-11
ROAD RE-ALIGNMENT		63	28-Jun-10	24-Sep-10
A2010	Phase 1 - Install Road Realignment Signage	0	28-Jun-10	
A2810	Phase 1 - Clear & Grub	5	28-Jun-10	02-Jul-10
A2820	Phase 1 - Lion Life Drive Alignment	14	06-Jul-10	23-Jul-10
A2830	Phase 1 - Install Storm at Parking Lot	3	14-Jul-10	16-Jul-10
A2840	Phase 1 - Install Storm at ARF Drive	7	19-Jul-10	27-Jul-10
A2850	Phase 1 - Curb at ARF Drive	8	28-Jul-10	06-Aug-10
A2860	Phase 1 - Wearing Couse Lion Life Drive & ARF Drive	2	09-Aug-10	10-Aug-10
A2870	Phase 1 Complete	0		10-Aug-10
A2880	Phase 2 - Construct Temporary Roadway	5	05-Aug-10	11-Aug-10
A2890	Phase 2 - Demolition of Old Roadway	3	12-Aug-10	16-Aug-10
A2900	Phase 2 - Alignment of Meadow Drive	16	16-Aug-10	07-Sep-10
A2910	Phase 2 Complete	0		07-Sep-10
A2920	Phase 3 - Campus Drive Alignment	13	08-Sep-10	24-Sep-10
A2930	Phase 3 Complete & All Roads Open to Traffic	0		24-Sep-10
TUNNEL WORK		172	07-Jun-10	08-Feb-11
A2770	Develop, Submit & Approve Tunnel Construction Plan	30	07-Jun-10	19-Jul-10
A2940	Expose Tunnel for Foundation Work	5	17-Jun-10	23-Jun-10
A2950	Intall Waterproofing at Tunnel & Test	10	20-Sep-10	01-Oct-10
A2960	Cut Opening in Tunnel	2	27-Dec-10	28-Dec-10
A2970	Secure Tunnel Entrance	1	28-Dec-10	28-Dec-10
A2980	IT Conduit, Cabling Inside Tunnel & BMR	30	29-Dec-10	08-Feb-11
A2990	Tunnel Work Commplete	0		08-Feb-11
SHELL & ENCLOSURE		242	01-Jul-10	10-Jun-11
A2780	Micropile Testing	5	01-Jul-10	08-Jul-10
A3000	Micropiles (SE to NW)	24	06-Jul-10	06-Aug-10
A3010	Pile Caps (SE to NW)	20	26-Jul-10	20-Aug-10
A3020	Complete Deep Foundations	0		06-Aug-10
A3030	Grade Beams (SE to NW)	30	09-Aug-10	20-Sep-10
A3040	Foundation Walls	25	30-Aug-10	04-Oct-10
A3050	Backfill Foundations	30	30-Aug-10	11-Oct-10
A3060	Underslab Plumbing	15	27-Sep-10	15-Oct-10
A3070	Prep, Form, & Pour Concrete Slab-On-Grade	10	18-Oct-10	29-Oct-10



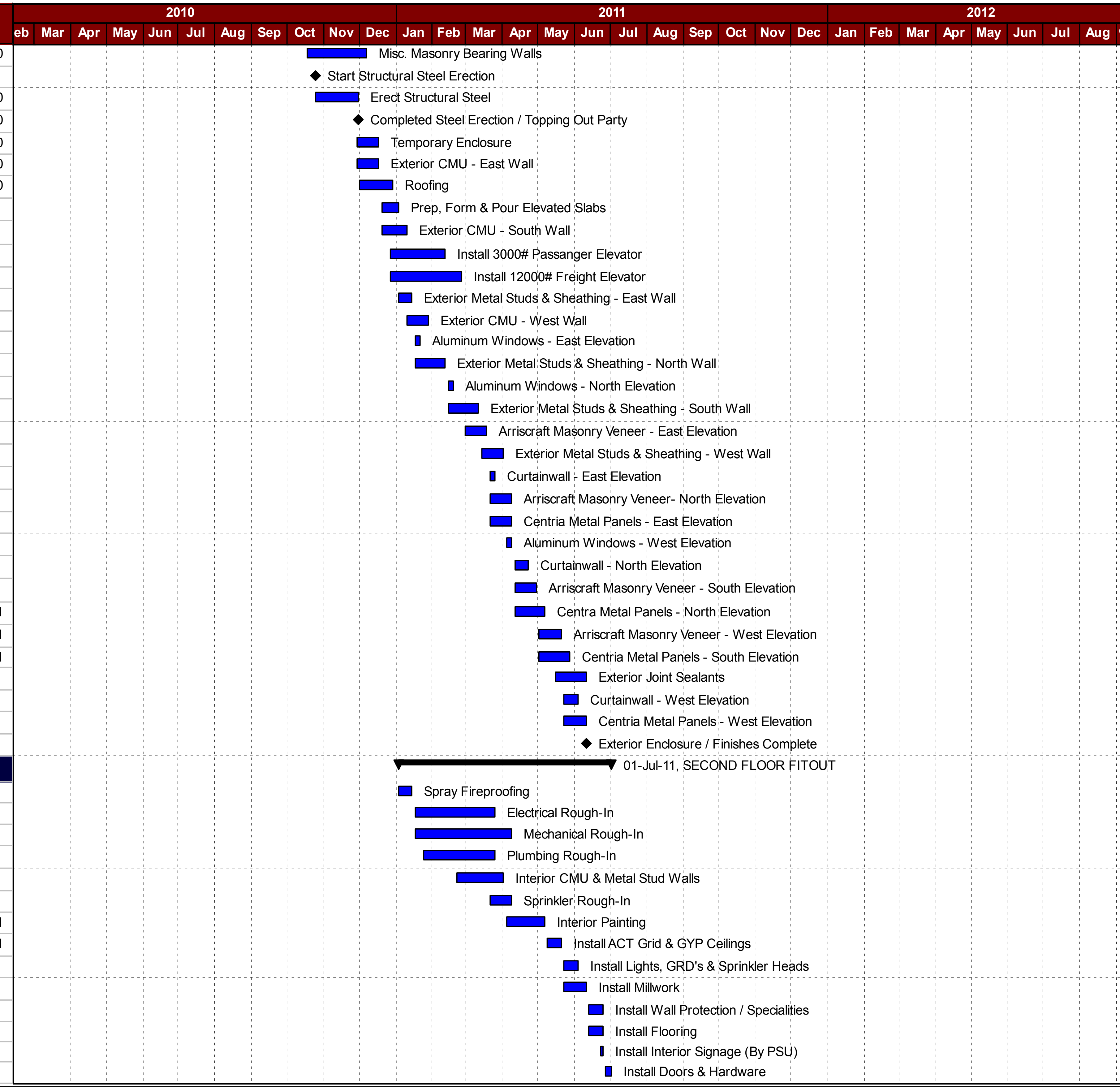
Actual Work | Critical Remaining Work | Summary
Remaining Work | Milestone

SUPPORT SERVICES BUILDING
PENN STATE MILTON S. HERSHEY MEDICAL CENTER - HERSHEY PA

WILL LAZRATION
CONSTRUCTION MANAGEMENT

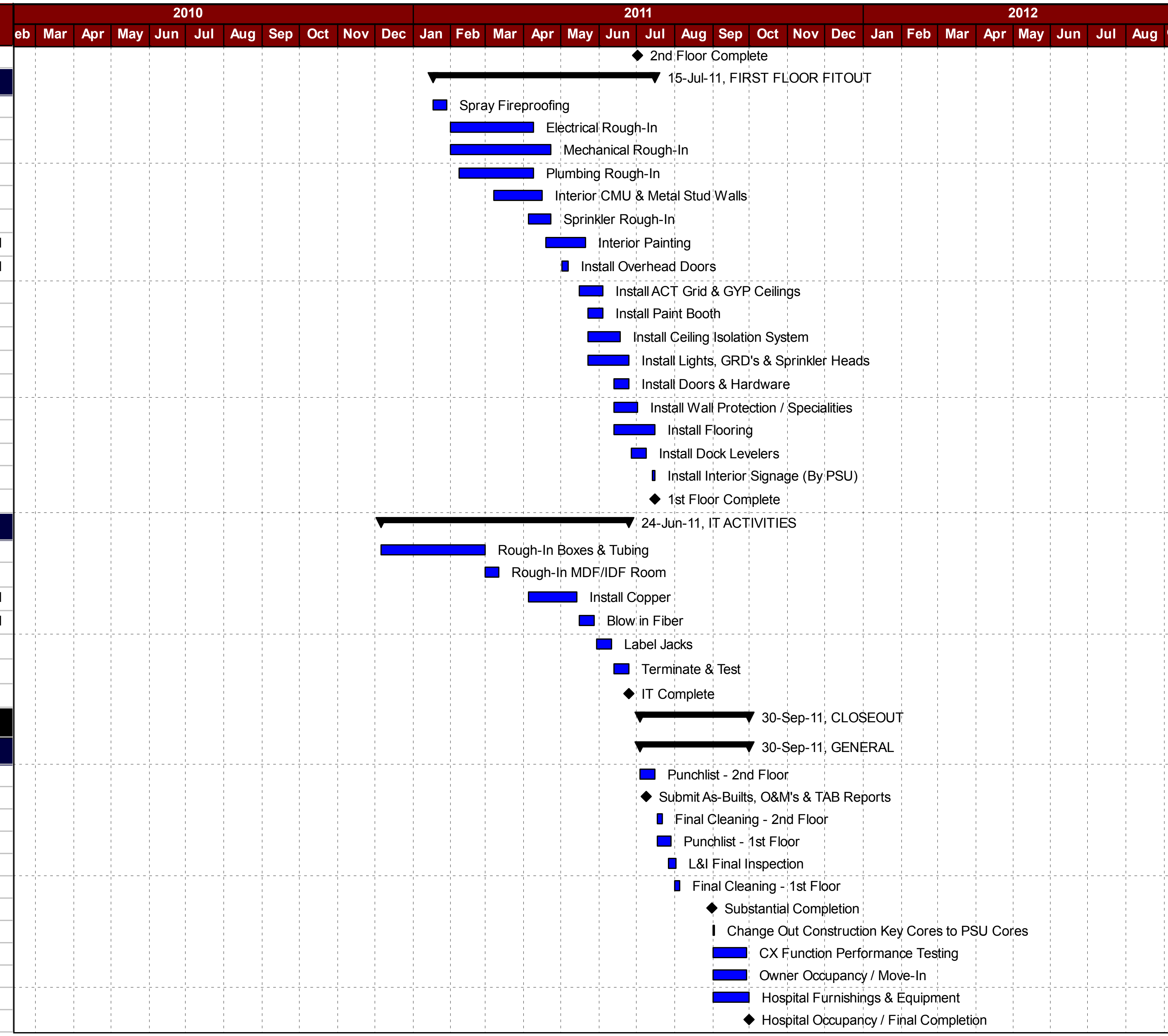
DETAILED PROJECT SCHEDULE
TECHNICAL ASSIGNMENT 2

Activity ID	Activity Name	Original Duration	Start	Finish
A3080	Misc. Masonry Bearing Walls	35	18-Oct-10	07-Dec-10
A3090	Start Structural Steel Erection	0	25-Oct-10	
A3100	Erect Structural Steel	25	25-Oct-10	30-Nov-10
A3110	Completed Steel Erection / Topping Out Party	0		30-Nov-10
A3120	Temporary Enclosure	15	29-Nov-10	17-Dec-10
A3130	Exterior CMU - East Wall	15	29-Nov-10	17-Dec-10
A3140	Roofing	20	01-Dec-10	29-Dec-10
A3150	Prep, Form & Pour Elevated Slabs	10	20-Dec-10	03-Jan-11
A3160	Exterior CMU - South Wall	15	20-Dec-10	10-Jan-11
A3170	Install 3000# Passanger Elevator	35	27-Dec-10	11-Feb-11
A3180	Install 12000# Freight Elevator	45	27-Dec-10	25-Feb-11
A3190	Exterior Metal Studs & Sheathing - East Wall	10	03-Jan-11	14-Jan-11
A3200	Exterior CMU - West Wall	15	10-Jan-11	28-Jan-11
A3210	Aluminum Windows - East Elevation	5	17-Jan-11	21-Jan-11
A3220	Exterior Metal Studs & Sheathing - North Wall	20	17-Jan-11	11-Feb-11
A3230	Aluminum Windows - North Elevation	5	14-Feb-11	18-Feb-11
A3240	Exterior Metal Studs & Sheathing - South Wall	20	14-Feb-11	11-Mar-11
A3250	Arriscraft Masonry Veneer - East Elevation	15	28-Feb-11	18-Mar-11
A3260	Exterior Metal Studs & Sheathing - West Wall	15	14-Mar-11	01-Apr-11
A3270	Curtainwall - East Elevation	5	21-Mar-11	25-Mar-11
A3280	Arriscraft Masonry Veneer- North Elevation	15	21-Mar-11	08-Apr-11
A3290	Centria Metal Panels - East Elevation	15	21-Mar-11	08-Apr-11
A3300	Aluminum Windows - West Elevation	5	04-Apr-11	08-Apr-11
A3310	Curtainwall - North Elevation	10	11-Apr-11	22-Apr-11
A3320	Arriscraft Masonry Veneer - South Elevation	15	11-Apr-11	29-Apr-11
A3330	Centra Metal Panels - North Elevation	20	11-Apr-11	06-May-11
A3340	Arriscraft Masonry Veneer - West Elevation	15	02-May-11	20-May-11
A3350	Centria Metal Panels - South Elevation	20	02-May-11	27-May-11
A3360	Exterior Joint Sealants	20	16-May-11	10-Jun-11
A3370	Curtainwall - West Elevation	10	23-May-11	03-Jun-11
A3380	Centria Metal Panels - West Elevation	15	23-May-11	10-Jun-11
A3390	Exterior Enclosure / Finishes Complete	0		10-Jun-11
SECOND FLOOR FITOUT		130	03-Jan-11	01-Jul-11
A2790	Spray Fireproofing	10	03-Jan-11	14-Jan-11
A3400	Electrical Rough-In	50	17-Jan-11	25-Mar-11
A3410	Mechanical Rough-In	60	17-Jan-11	08-Apr-11
A3420	Plumbing Rough-In	45	24-Jan-11	25-Mar-11
A3430	Interior CMU & Metal Stud Walls	30	21-Feb-11	01-Apr-11
A3440	Sprinkler Rough-In	15	21-Mar-11	08-Apr-11
A3450	Interior Painting	25	04-Apr-11	06-May-11
A3460	Install ACT Grid & GYP Ceilings	10	09-May-11	20-May-11
A3470	Install Lights, GRD's & Sprinkler Heads	10	23-May-11	03-Jun-11
A3480	Install Millwork	15	23-May-11	10-Jun-11
A3490	Install Wall Protection / Specialities	10	13-Jun-11	24-Jun-11
A3500	Install Flooring	10	13-Jun-11	24-Jun-11
A3510	Install Interior Signage (By PSU)	2	23-Jun-11	24-Jun-11
A3520	Install Doors & Hardware	5	27-Jun-11	01-Jul-11



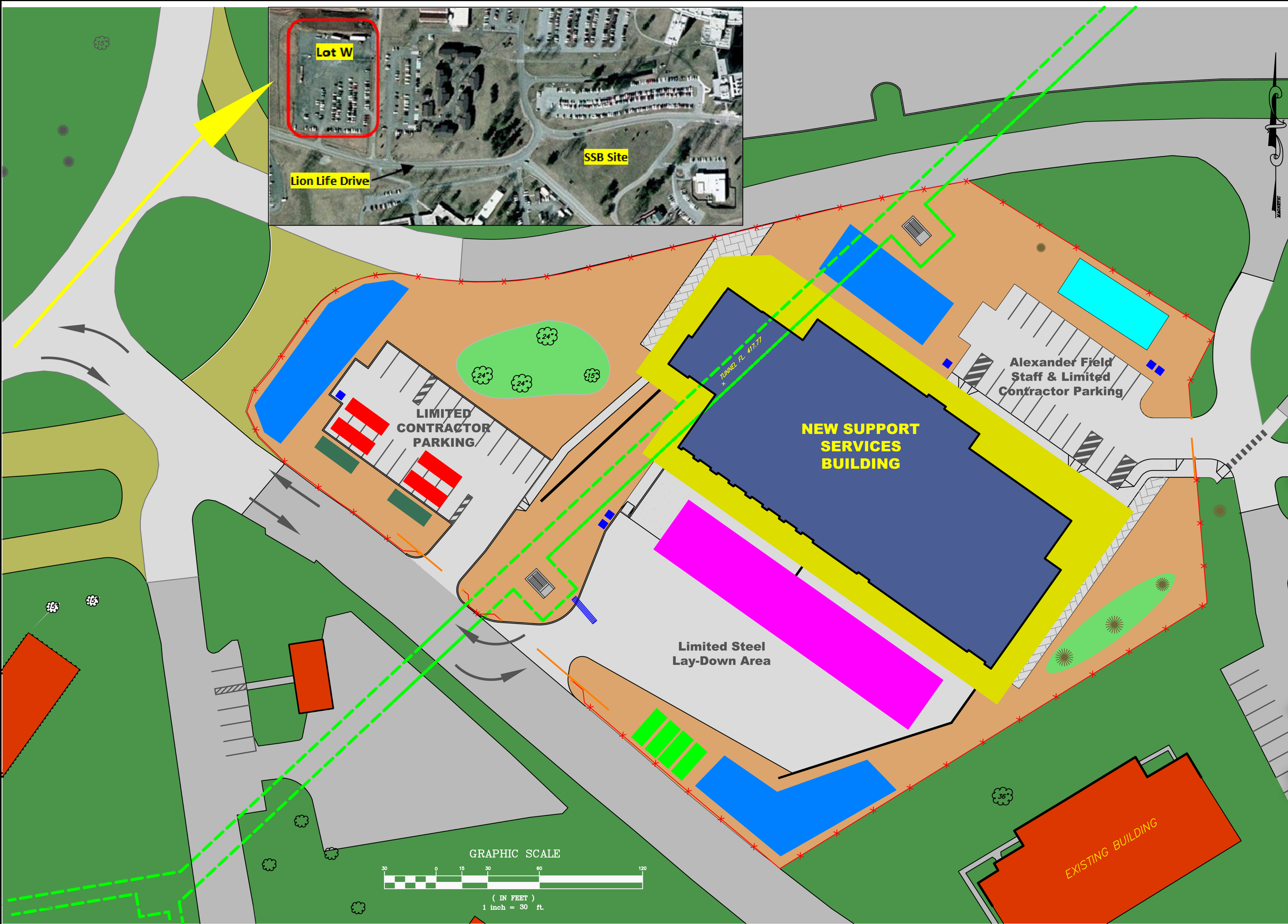
Actual Work
Remaining Work
Critical Remaining Work
Milestone
Summary

Activity ID	Activity Name	Original Duration	Start	Finish
A3530	2nd Floor Complete	0		01-Jul-11
FIRST FLOOR FITOUT		130	17-Jan-11	15-Jul-11
A2800	Spray Fireproofing	10	17-Jan-11	28-Jan-11
A3560	Electrical Rough-In	50	31-Jan-11	08-Apr-11
A3570	Mechanical Rough-In	60	31-Jan-11	22-Apr-11
A3580	Plumbing Rough-In	45	07-Feb-11	08-Apr-11
A3590	Interior CMU & Metal Stud Walls	30	07-Mar-11	15-Apr-11
A3600	Sprinkler Rough-In	15	04-Apr-11	22-Apr-11
A3610	Interior Painting	25	18-Apr-11	20-May-11
A3620	Install Overhead Doors	5	02-May-11	06-May-11
A3630	Install ACT Grid & GYP Ceilings	15	16-May-11	03-Jun-11
A3640	Install Paint Booth	10	23-May-11	03-Jun-11
A3650	Install Ceiling Isolation System	20	23-May-11	17-Jun-11
A3660	Install Lights, GRD's & Sprinkler Heads	25	23-May-11	24-Jun-11
A3661	Install Doors & Hardware	10	13-Jun-11	24-Jun-11
A3670	Install Wall Protection / Specialities	15	13-Jun-11	01-Jul-11
A3671	Install Flooring	25	13-Jun-11	15-Jul-11
A3681	Install Dock Levelers	10	27-Jun-11	08-Jul-11
A3691	Install Interior Signage (By PSU)	2	14-Jul-11	15-Jul-11
A3701	1st Floor Complete	0		15-Jul-11
IT ACTIVITIES		144	06-Dec-10	24-Jun-11
A3540	Rough-In Boxes & Tubing	60	06-Dec-10	28-Feb-11
A3680	Rough-In MDF/IDF Room	10	28-Feb-11	11-Mar-11
A3690	Install Copper	30	04-Apr-11	13-May-11
A3700	Blow in Fiber	10	16-May-11	27-May-11
A3710	Label Jacks	10	30-May-11	10-Jun-11
A3720	Terminate & Test	10	13-Jun-11	24-Jun-11
A3730	IT Complete	0		24-Jun-11
CLOSEOUT		65	04-Jul-11	30-Sep-11
GENERAL		65	04-Jul-11	30-Sep-11
A3550	Punchlist - 2nd Floor	10	04-Jul-11	15-Jul-11
A3740	Submit As-Builts, O&M's & TAB Reports	0		08-Jul-11
A3750	Final Cleaning - 2nd Floor	5	18-Jul-11	22-Jul-11
A3760	Punchlist - 1st Floor	10	18-Jul-11	29-Jul-11
A3761	L&I Final Inspection	5	27-Jul-11	02-Aug-11
A3770	Final Cleaning - 1st Floor	5	01-Aug-11	05-Aug-11
A3780	Substantial Completion	0		31-Aug-11
A3790	Change Out Construction Key Cores to PSU Cores	2	01-Sep-11	02-Sep-11
A3800	CX Function Performance Testing	20	01-Sep-11	28-Sep-11
A3810	Owner Occupancy / Move-In	20	01-Sep-11	28-Sep-11
A3820	Hospital Furnishings & Equipment	22	01-Sep-11	30-Sep-11
A3830	Hospital Occupancy / Final Completion	0		30-Sep-11



Actual Work | Critical Remaining Work | Summary
Remaining Work | Milestone

APPENDIX D – SHELL & ENCLOSURE SITE PLAN



LEGEND

SITE FENCE	
CONSTRUCTION GATE	
ALEXANDER FIELD OFFICE	
SUBCONTRACTOR TRAILERS	
STORAGE TRAILERS	
BUILDING FOOTPRINT	
CRANE TRACKING AREA	
MATERIAL LAY-DOWN AREA	
BUILDING ENVELOPE AREA	
DUMPSTERS	
TEMPORARY TOILETS	
OLD CAMPUS DRIVE	
NEW CAMPUS DRIVE	
TREE PROTECTION AREA	
CONSTRUCTION TRAFFIC	
EXISTING BUILDING	
EXISTING UTILITY TUNNEL	
NEW PAVING PER PROJECT	
EXISTING PAVEMENT	
TIRE WASH	

NOTES:

- Limited onsite parking and storage available to all contractors. Contractors to utilize Lot W just off Lion Life Drive for additional parking and storage.
- A limited number of Office and Storage trailers were be permitted onsite. Contractor to coordinate with Construction Manager for availability before bringing onsite.
- Onsite storage/lay-down areas (except for trailers) is limited to one week's work of material unless approval by Construction Manager.
- Construction access to site is from the west via Bull Frog Road and Lion Life Drive.
- Per the medical center's request, ABSOLUTELY NO deliveries will be permitted onsite between the hours of 6:30-8:30 A.M. and 3:30-5:30 P.M. However, deliveries to Lot W are permitted during this time.
- All vehicles onsite must exit through tire wash station prior to returning to main road.

Support Services Building

Penn State
Hershey Medical Center
500 University Drive Hershey, PA 17033

PENNSTATE HERSHEY
Milton S. Hershey Medical Center

SHELL & ENCLOSURE PHASE PLAN

OCTOBER 25, 2010

WILL LAZRATION
Construction Management

APPENDIX E – GENERAL CONDITIONS ESTIMATE

PERSONNEL				
DESCRIPTION	**Weeks on Project**	**Hours/Week**	**UNIT RATE**	**COST**
Senior Project Manager	65	16	$100.00	$104,000.00
Project Manager	65	25	$88.00	$143,000.00
Superintendent	65	40	$93.00	$241,800.00
MEP Coordinator	40	8	$75.00	$24,000.00
Project Engineer	60	40	$61.00	$146,400.00
Project Assistant	65	40	$30.00	$78,000.00
Intern	15	40	$20.00	$12,000.00
Corporate Safety Director	40	4	$86.00	$13,760.00
Carpenter Foreman	20	40	$55.00	$44,000.00
	Total Manhours	12,145	**Total Staff Costs**	$806,960.00

CONSTRUCTION FACILITIES & EQUIPMENT				
DESCRIPTION	UNIT	QUANTITY	UNIT RATE	COST
Field Office Setup	LS	1	$2,000.00	$2,000.00
Field Office Rental	Month	15	$600.00	$9,000.00
Field Office Removal	LS	1	$2,000.00	$2,000.00
Field Office Furniture & Equipment	Month	15	$450.00	$6,750.00
Field Office Telephone Install	LS	1	$750.00	$750.00
Field Office Internet Connection Installation	LS	1	$1,500.00	$1,500.00
Temporary Power/Water Installation	LS	1	$10,000.00	$10,000.00
Dumpsters	Each	25	$600.00	$15,000.00
Fire Extinguishers	Month	15	$100.00	$1,500.00
Expendable Small Tools	Month	15	$250.00	$3,750.00
Tire Wash Station	Month	10	$1,900.00	$19,000.00
Total Construction Facilities & Equipment Costs				$71,250.00

TEMPORARY UTILITIES /SERVICES				
DESCRIPTION	UNIT	QUANTITY	UNIT RATE	COST
Temporary Toilets	Month	15	$400.00	$6,000.00
Field Office Cleaning	Week	65	$200.00	$13,000.00
Field Office Telephone Usage	Month	15	$200.00	$3,000.00
Field Office Internet Usage	Month	15	$90.00	$1,350.00
Mobile Phones	Month	15	$175.00	$2,625.00
Submittal Exchange	LS	1	$5,500.00	$5,500.00
Professional Surveying	LS	1	$4,500.00	$4,500.00
Temporary Power/Water Usage	By Owner			$0.00
Total Temporary Utilities/Services Costs				$35,975.00

MISCELLANOUS COSTS				
DESCRIPTION	UNIT	QUANTITY	UNIT RATE	COST
Travel/Mileage	Mile	5,000	$0.45	$2,250.00
Job Signage	LS	1	$1,500.00	$1,500.00
Office Supplies	Month	15	$200.00	$3,000.00
Document Printing	Month	15	$150.00	$2,250.00
Postage & Courier Service	Month	15	$250.00	$3,750.00
Safety	LS	1	$2,000.00	$2,000.00
Incidentals	LS	1	$1,500.00	$1,500.00
Total Miscellanous Costs				$16,250.00

APPENDIX F – COLUMN LOADS & FOOTING SIZES CALCULATIONS

FOOTING SIZE PER COLUMN LOADS

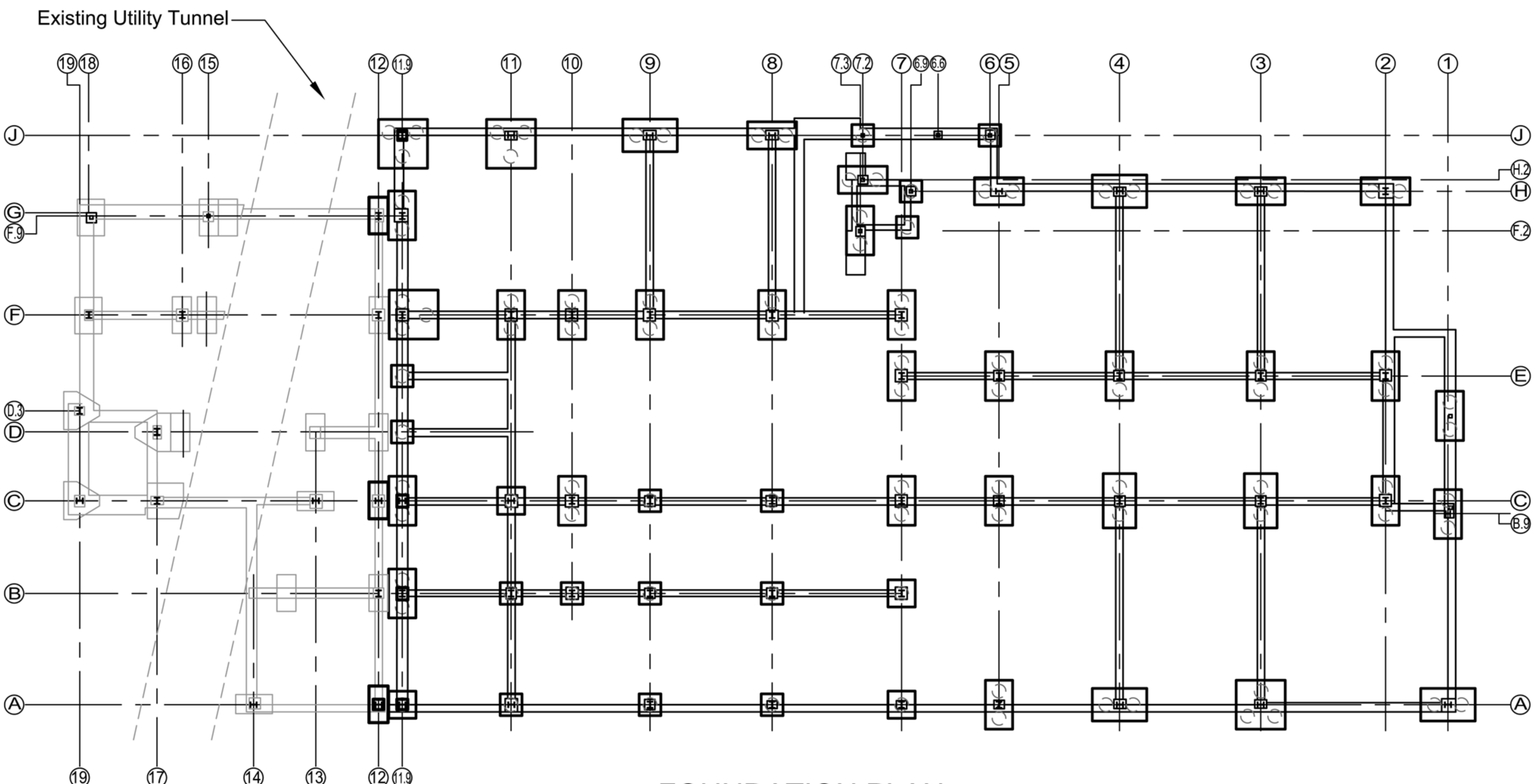
Column Number	Column Load (k)				Total Column Load (k)	Min. Spread Footing Area per 2000 PSF Bearing Capacity (SF)	Min. Square Spread Footing Size per 2,000 PSF Soil	Min. Spread Footing Area per Geopier® Soil Improvement to 5,000 PSF (SF)	Min Square Spread Footing Size per Soil Improvement to 5,000 PSF	Design Footing Size per 5' Center to Center Geopier® Spacing	Design Footing Area (SF)
	North Pile	South Pile	East Pile	West Pile							
A-1	-	-	81	63	144	72	8'-6" x 8'-6"	36	6'-0" x 6'-0"	6'-0" x 10'-0"	60
A-3	-	-	98	98	196	98	9'-11" x 9'-11"	49	7'-0" x 7'-0"	10'-0" x 10'-0"	100
A-4	-	-	73	67	140	70	8'-5" x 8'-5"	35	5'-11" x 5'-11"	6'-0" x 10'-0"	60
A-6	48	64	-	-	112	56	7'-6" x 7'-6"	28	5'-4" x 5'-4"	5'-0" x 9'-0"	45
A-7	45	29	-	-	74	37	6'-1" x 6'-1"	18.5	4'-4" x 4'-4"	5'-0" x 5'-0"	25
A-8	35	19	-	-	54	27	5'-1" x 5'-1"	13.5	3'-8" x 3'-8"	4'-0" x 4'-0"	16
A-9	35	19	-	-	54	27	5'-1" x 5'-1"	13.5	3'-8" x 3'-8"	4'-0" x 4'-0"	16
A-11	-	-	27	27	54	27	5'-1" x 5'-1"	13.5	3'-8" x 3'-8"	4'-0" x 4'-0"	16
B-7	33	31	-	-	64	32	5'-8" x 5'-8"	16	4'-0" x 4'-0"	5'-0" x 5'-0"	25
B-8	20	20	-	-	40	20	4'-6" x 4'-6"	10	3'-2" x 3'-2"	4'-0" x 4'-0"	16
B-9	18	18	-	-	36	18	4'-3" x 4'-3"	9	3'-0" x 3'-0"	4'-0" x 4'-0"	16
B-10	24	24	-	-	48	24	4'-11" x 4'-11"	12	3'-6" x 3'-6"	4'-0" x 4'-0"	16
B-11	11	11	-	-	22	11	3'-4" x 3'-4"	5.5	2'-4" x 2'-4"	4'-0" x 4'-0"	16
B.9-1	57	57	-	-	114	57	7'-7" x 7'-7"	28.5	5'-4" x 5'-4"	5'-0" x 9'-0"	45
C-2	44	44	-	-	88	44	6'-8" x 6'-8"	22	4'-8" x 4'-8"	5'-0" x 9'-0"	45
C-3	71	71	-	-	142	71	8'-5" x 8'-5"	35.5	5'-11" x 5'-11"	6'-0" x 10'-0"	60
C-4	70	70	-	-	140	70	8'-5" x 8'-5"	35	5'-11" x 5'-11"	6'-0" x 10'-0"	60
C-5	58	58	-	-	116	58	7'-8" x 7'-8"	29	5'-5" x 5'-5"	5'-0" x 9'-0"	45
C-7	58	54	-	-	112	56	7'-6" x 7'-6"	28	5'-4" x 5'-4"	5'-0" x 9'-0"	45
C-8	23	23	-	-	46	23	4-10" x 4'-10"	11.5	3'-6" x 3'-6"	4'-0" x 4'-0"	16
C-9	23	23	-	-	46	23	4-10" x 4'-10"	11.5	3'-6" x 3'-6"	4'-0" x 4'-0"	16
C-10	45	45	-	-	90	45	6'-9" x 6'-9"	22.5	4'-9" x 4'-9"	5'-0" x 9'-0"	45
C-11	32	32	-	-	64	32	5'-8" x 5'-8"	16	4'-0" x 4'-0"	5'-0" x 5'-0"	25
D.3-1	50	50	-	-	100	50	7'-1" x 7'-1"	25	5'-0" x 5'-0"	5'-0" x 9'-0"	45
E-2	50	50	-	-	100	50	7'-1" x 7'-1"	25	5'-0" x 5'-0"	5'-0" x 9'-0"	45
E-3	67	67	-	-	134	67	8'-2" x 8'-2"	33.5	5'-9" x 5'-9"	5'-0" x 9'-0"	45
E-4	65	65	-	-	130	65	8'-1" x 8'-1"	32.5	5'-8" x 5'-8"	5'-0" x 9'-0"	45
E-5	56	56	-	-	112	56	7'-6" x 7'-6"	28	5'-4" x 5'-4"	5'-0" x 9'-0"	45
E-7	54	59	-	-	113	56.5	7'-7" x 7'-7"	28.25	5'-4" x 5'-4"	5'-0" x 9'-0"	45
F-7	55	60	-	-	115	57.5	7'-7" x 7'-7"	28.75	5'-5" x 5'-5"	5'-0" x 9'-0"	45
F-8	54	54	-	-	108	54	7'-5" x 7'-5"	27	5'-3" x 5'-3"	5'-0" x 9'-0"	45
F.8-6.9	20	-	-	-	20	10	3'-2" x 3'-2"	5	2'-3" x 2'-3"	4'-0" x 4'-0"	16
F.8-7.3	50	50	-	-	100	50	7'-1" x 7'-1"	25	5'-0" x 5'-0"	5'-0" x 9'-0"	45
F-9	48	48	-	-	96	48	6'-11" x 6'-11"	24	4'-11" x 4'-11"	5'-0" x 9'-0"	45
F-10	54	59	-	-	113	56.5	7'-6" x 7'-6"	28.25	5'-4" x 5'-4"	5'-0" x 9'-0"	45
F-11	65	65	-	-	130	65	8'-1" x 8'-1"	32.5	5'-8" x 5'-8"	5'-0" x 9'-0"	45
H-2	44	33	-	-	77	38.5	6'-3" x 6'-3"	19.25	4'-5" x 4'-5"	5'-0" x 9'-0"	45
H-3	-	-	58	73	131	65.5	8'-1" x 8'-1"	32.75	5'-8" x 5'-8"	5'-0" x 9'-0"	45
H-4	-	-	70	70	140	70	8'-5" x 8'-5"	35	5'-11" x 5'-11"	6'-0" x 10'-0"	60
H-5	-	-	53	56	109	54.5	7'-5" x 7'-5"	27.25	5'-3" x 5'-3"	5'-0" x 9'-0"	45
H-6.9	20	20	-	-	40	20	4'-6" x 4'-6"	10	3'-2" x 3'-2"	4'-0" x 4'-0"	16
H.2-7.2	50	50	-	-	100	50	7'-1" x 7'-1"	25	5'-0" x 5'-0"	5'-0" x 9'-0"	45
J-6	20	20	-	-	40	20	4'-6" x 4'-6"	10	3'-2" x 3'-2"	4'-0" x 4'-0"	16
J-7.2	20	20	-	-	40	20	4'-6" x 4'-6"	10	3'-2" x 3'-2"	4'-0" x 4'-0"	16
J-8	-	-	50	44	94	47	6'-10" x 6'-10"	23.5	4'-10" x 4'-10"	5'-0" x 9'-0"	45
J-9	-	-	64	64	128	64	8'-0" x 8'-0"	32	5'-8" x 5'-8"	5'-0" x 9'-0"	45
J-11	122	52	-	-	174	87	9'-4" x 9'-4"	43.5	6-7" x 6'-7"	10'-0" x 9'-0"	100

APPENDIX G – ESTIMATED SETTLEMENTS

Foundation Settlements

Column Number	Total Column Load (k)	Min Spread Footing Size per 2,000 PSF Soil	Original Settle-ment (in)	Footing Size w/ Geopier® Improvement to 5,000 PSF Soil	New Settlement with Geopier® Soil Improvement (in)	Column Number	Total Column Load (k)	Min Spread Footing Size per 2,000 PSF Soil	Original Settle-ment (in)	Footing Size w/ Geopier® Improvement to 5,000 PSF Soil	New Settlement with Geopier® Soil Improvement (in)
A-1	144	8'-6" x 8'-6"	1.70	6'-0" x 10'-0"	0.62	E-2	100	7'-1" x 7'-1"	1.28	5'-0" x 9'-0"	0.49
A-3	196	9'-11" x 9'-11"	1.79	10'-0" x 10'-0"	0.64	E-3	134	8'-2" x 8'-2"	1.71	5'-0" x 9'-0"	0.69
A-4	140	8'-5" x 8'-5"	1.71	6'-0" x 10'-0"	0.60	E-4	130	8'-1" x 8'-1"	1.60	5'-0" x 9'-0"	0.68
A-6	112	7'-6" x 7'-6"	1.47	5'-0" x 9'-0"	0.57	E-5	112	7'-6" x 7'-6"	1.47	5'-0" x 9'-0"	0.57
A-7	74	6'-1" x 6'-1"	1.02	5'-0" x 5'-0"	0.39	E-7	113	7'-7" x 7'-7"	1.42	5'-0" x 9'-0"	0.57
A-8	54	5'-1" x 5'-1"	0.90	4'-0" x 4'-0"	0.35	F-7	115	7'-7" x 7'-7"	1.45	5'-0" x 9'-0"	0.59
A-9	54	5'-1" x 5'-1"	0.90	4'-0" x 4'-0"	0.35	F-8	108	7'-5" x 7'-5"	1.31	5'-0" x 9'-0"	0.54
A-11	54	5'-1" x 5'-1"	0.90	4'-0" x 4'-0"	0.35	F.8-6.9	20	3'-2" x 3'-2"	0.50	4'-0" x 4'-0"	0.13
B-7	64	5'-8" x 5'-8"	0.99	5'-0" x 5'-0"	0.37	F.8-7.3	100	7'-1" x 7'-1"	1.28	5'-0" x 9'-0"	0.49
B-8	40	4'-6" x 4'-6"	0.80	4'-0" x 4'-0"	0.24	F-9	96	6'-11" x 6'-11"	1.10	5'-0" x 9'-0"	0.48
B-9	36	4'-3" x 4'-3"	0.71	4'-0" x 4'-0"	0.22	F-10	113	7'-6" x 7'-6"	1.48	5'-0" x 9'-0"	0.57
B-10	48	4'-11" x 4'-11"	0.90	4'-0" x 4'-0"	0.30	F-11	130	8'-1" x 8'-1"	1.60	5'-0" x 9'-0"	0.68
B-11	22	3'-4" x 3'-4"	0.51	4'-0" x 4'-0"	0.13	H-2	77	6'-3" x 6'-3"	1.02	5'-0" x 9'-0"	0.38
B.9-1	114	7'-7" x 7'-7"	1.43	5'-0" x 9'-0"	0.58	H-3	131	8'-1" x 8'-1"	1.61	5'-0" x 9'-0"	0.67
C-2	88	6'-8" x 6'-8"	1.24	5'-0" x 9'-0"	0.44	H-4	140	8'-5" x 8'-5"	1.71	6'-0" x 10'-0"	0.60
C-3	142	8'-5" x 8'-5"	1.69	6'-0" x 10'-0"	0.61	H-5	109	7'-5" x 7'-5"	1.49	5'-0" x 9'-0"	0.55
C-4	140	8'-5" x 8'-5"	1.67	6'-0" x 10'-0"	0.60	H-6.9	40	4'-6" x 4'-6"	0.80	4'-0" x 4'-0"	0.24
C-5	116	7'-8" x 7'-8"	1.56	5'-0" x 9'-0"	0.59	H.2-7.2	100	7'-1" x 7'-1"	1.28	5'-0" x 9'-0"	0.49
C-7	112	7'-6" x 7'-6"	1.47	5'-0" x 9'-0"	0.57	J-6	40	4'-6" x 4'-6"	0.80	4'-0" x 4'-0"	0.24
C-8	46	4-10" x 4'-10"	0.83	4'-0" x 4'-0"	0.29	J-7.2	40	4'-6" x 4'-6"	0.80	4'-0" x 4'-0"	0.24
C-9	46	4-10" x 4'-10"	0.83	4'-0" x 4'-0"	0.29	J-8	94	6'-10" x 6'-10"	1.09	5'-0" x 9'-0"	0.47
C-10	90	6'-9" x 6'-9"	1.22	5'-0" x 9'-0"	0.45	J-9	128	8'-0" x 8'-0"	1.59	5'-0" x 9'-0"	0.67
C-11	64	5'-8" x 5'-8"	0.99	5'-0" x 5'-0"	0.37	J-11	174	9'-4" x 9'-4"	1.69	10'-0" x 10'-0"	0.56
D.3-1	100	7'-1" x 7'-1"	1.28	5'-0" x 9'-0"	0.49						

APPENDIX H – FOUNDATION PLAN



FOUNDATION PLAN

SCALE: NTS

NOTES:

- Items that appear lighter near tunnel are apart of the original micropile foundation that was unchanged from column lines 12-19.
- Pilecaps A-12, C-12, & G-12 were rotated 90° from original design to allow for addition of column line 11.9

PENN STATE
AE SENIOR
THESIS

SUPPORT SERVICES BUILDING

PROJECT #:

DATE: 3/31/2011

SCALE: NTS

S-1

APPENDIX I - Detailed Estimate for New Foundation Design

ADDED ITEM ESTIMATE						
Item	**Description**	**Unit**	**Quantity**	**Unit Price**	**Total Inc. 15% O&P Markup**	**Total Cost**
Geopiers®						**$199,796.70**
	Design/Engineering	EA	1	$25,000.00	-	$25,000.00
	Mobilization	EA	1	$25,000.00	-	$25,000.00
	Pier Strength Tests	EA	2	$12,500.00	-	$25,000.00
	Aggregate Piers	EA	93	$1,278.00	$1,341.90	$124,796.70
Spread Footings						**$93,820.78**
	4,000 PSI Concrete	CY	394	$101.14	$116.31	$45,826.53
	Reinforcing	Ton	8.66	$1,811.10	$2,082.77	$18,036.74
	Excavation	EA	53	$350	$402.50	$21,332.50
	Misc. Form Materials	EA	1	$7,500	$8,625.00	$8,625.00
Added Gradebeam & Piers						$20,467.06
	4,000 PSI Concrete	CY	30.31	$101.14	$116.31	$3,525.39
	Reinforcibng	Ton	0.91	$1,811.10	$2,082.77	$1,893.86
	Formwork	SFCA	458	$28.57	$32.86	$15,047.82
Expansion Joint						**$14,240.45**
	Floor Plates	LF	185	$34.50	$39.68	$7,339.88
	Interior Joints	LF	198	$6.75	$7.76	$1,536.98
	Exterior Joints	LF	82	$9.50	$10.93	$895.85
	Joint at Roof	LF	92.5	$42	$48.30	$4,467.75
Structural Steel						**$32,065.51**
	W10x33 x 16'-7"	EA	2	$910.10	$1,046.62	$2,093.23
	W10x33 x 33'-7"	EA	1	$1,844.88	$2,121.61	$2,121.61
	W12x79 x 35'-11"	EA	3	$3,650.54	$4,198.12	$12,594.36
	W12x14 x 18'-4"	EA	1	$429.47	$493.89	$493.89
	W12x14 x 17'-0"	EA	2	$398.31	$458.06	$916.11
	W12x14 x 20'-6"	EA	2	$480.32	$552.37	$1,104.74
	W12x94 x 34'-2"	EA	1	$3,564.96	$4,099.70	$4,099.70
	W16x31 x 18'-4"	EA	1	$733.38	$843.39	$843.39
	W18x35 x 34'-2"	EA	1	$1,567.38	$1,802.49	$1,802.49
	Connections/Misc. Details	20%	1	$5,213.90	$5,995.99	$5,995.99
CMU Lateral Support Walls						**$30,000.00**
	Added Reinforcing/Grouting	EA	1	$30,000	-	$30,000.00
Contingency						**$18,019.53**
	Contingency in Design	5%	1	$18,019.53	-	$18,019.53
					Total Cost of New Design	**$408,410.03**

DELETED ITEM ESTIMATE						
Item	**Description**	**Unit**	**Quantity**	**Unit Price**	**Total Inc. 15% O&P Markup**	**Total Cost**
Micropiles						**$460,500.86**
	7" Micropiles	EA	101	$4,559.41	-	$460,500.86
Pilecaps						**$27,214.29**
	4,000 PSI Concrete	CY	164.5	$101.14	$116.31	$19,133.16
	Reinforcing	Ton	3.88	$1,811.10	$2,082.77	$8,081.13
Moment Connections						**$15,000.00**
	Eliminated Moment Con.	LS	1	$15,000.00	-	$15,000.00
					Total Cost of Eliminated Items	**$502,715.05**

APPENDIX J- CLIMATEMASTER TRANQUILITY TVL SERIES SALES BROCHURE

TRANQUILITY TLV SERIES

CLIMATEMASTER®

Water-Source Heat Pump Systems

TRANQUILITY LARGE (TLV) SERIES

The award-winning Tranquility Large (TLV) Series raises the bar for water-source heat pump efficiencies, features and application flexibility. Not only does the Tranquility Large Series exceed ASHRAE 90.1 efficiencies, but it also uses EarthPure® (HFC-410A) zero ozone depletion refrigerant, making it an extremely environmentally-friendly option. Tranquility Large Series is eligible for additional LEED® (Leadership in Energy and Environmental Design) points because of the “green” technology design.

UNIT FEATURES

- Vertical sizes 084 (7 tons, 24.6 kW) through 300 (25 tons, 87.9 kW)
- Unit configuration can be ordered with, or converted to front or back return and top, front, or back discharge. Field conversion uses all existing parts including panels and belts
- Electrical box can be field converted to be on front or back of unit
- Electric power can enter from any side of unit
- Water and drain can be connected to either side
- Dual refrigeration circuits (TL168, 192, 240, 300)
- Exceeds ASHRAE 90.1 efficiencies
- TXV metering device
- Extended range (20 to 120°F, -6.7 to 48.9°C operation)
- Microprocessor controls standard (optional DXM and/or DDC controls)
- LonWorks, BACnet, Modbus and Johnson N2 compatibility options for DDC controls
- Unit Performance Sentinel performance monitoring system

Condensate overflow is one of the 8 standard safeties provided by the microprocessor controls in all TLV Series units

Belt drive blowers with high efficiency motors and multiple pulley adjustments

Wide variety of vertical configurations

Large capacity (up to 25 tons, 87.97 kW)

Galvanized steel cabinet with baked-on epoxy powder finish on all access panels

Optional insulated water/refrigerant circuits allow extended range operation (ground loop applications)

Dual compressor refrigeration circuit in TLV 168-300 equipment single compressor refrigeration circuit in TLV 084-150

PERFORMANCE AND SPECIFICATIONS

AHRI/ISO/ASHRAE 13256-1 Data (English (I-P) Units & Metric (S-I) Units)

Model	Refrigerant	Water Loop Heat Pump				Ground Water Heat Pump				Ground Loop Heat Pump			
		Cooling 86°F [30°C]		Heating 68°F [20°C]		Cooling 59°F [15°C]		Heating 50°F [10°C]		Cooling 77°F [25°C]		Heating 32°F [0°C]	
		Capacity Btuh [kW]	EER Btuh/W [W/W]	Capacity Btuh [kW]	COP	Capacity Btuh [kW]	EER Btuh/W [W/W]	Capacity Btuh [kW]	COP	Capacity Btuh [kW]	EER Btuh/W [W/W]	Capacity Btuh [kW]	COP
TLV-084	HFC-410A	82,000 [24.03]	15.2 [4.5]	101,000 [29.60]	4.8	87,500 [25.65]	21.0 [4.3]	83,500 [24.33]	4.3	83,000 [24.33]	16.5 [4.8]	65,500 [19.20]	3.6
TLV-096	HFC-410A	94,000 [27.55]	15.0 [4.4]	118,000 [34.58]	4.7	102,500 [30.04]	20.5 [4.2]	96,500 [28.58]	4.2	97,500 [28.58]	16.5 [4.8]	76,500 [22.42]	3.6
TLV-120	HFC-410A	118,000 [34.58]	15.0 [4.4]	144,000 [42.20]	5.0	133,000 [38.98]	21.0 [4.2]	118,000 [34.58]	4.2	120,000 [35.17]	16.5 [4.8]	93,000 [27.26]	3.7
TLV-150	HFC-410A	150,000 [43.96]	14.0 [4.1]	186,000 [54.51]	4.7	170,000 [49.82]	20.0 [4.2]	155,000 [45.43]	4.2	156,000 [45.72]	15.8 [4.6]	122,000 [35.76]	3.6
TLV-168	HFC-410A	166,000 [48.65]	15.5 [4.5]	204,020 [59.80]	4.9	177,000 [51.87]	21.4 [4.4]	169,000 [49.53]	4.4	168,000 [49.24]	16.8 [4.9]	132,500 [38.83]	3.7
TLV-192	HFC-410A	190,000 [55.69]	15.3 [4.5]	238,360 [69.86]	4.8	207,000 [60.67]	20.9 [4.3]	195,000 [57.15]	4.3	197,000 [57.74]	16.8 [4.9]	155,000 [45.43]	3.7
TLV-240	HFC-410A	238,500 [69.90]	15.3 [4.5]	291,000 [85.29]	5.1	269,000 [78.84]	21.4 [4.3]	238,000 [69.90]	4.3	242,500 [71.07]	16.8 [4.9]	188,000 [55.10]	3.8
TLV-300	HFC-410A	300,000 [87.93]	14.0 [4.1]	372,000 [109.03]	4.7	340,000 [99.65]	20.0 [4.2]	310,000 [90.86]	4.2	312,000 [91.44]	15.8 [4.6]	244,000 [71.51]	3.6

Cooling capacities based upon 80.6°F [27°C] DB, 66.2°F [19°C] WB entering air temperature.
Heating capacities based upon 68°F [20°C] DB, 59°F [15°C] WB entering air temperature.
All ratings based upon operation at the lower voltage of dual voltage rated models.

Dimensional Data

Vertical Model		Overall Cabinet W	D	H
084 -150	in. cm	53.1 134.9	34.0 86.4	79.0 200.7
168 -300	in. cm	106.7 270.9	34.0 86.4	79.0 200.7

Voltage Options

Vertical Model	Volts	Hz	Phase
084 - 300	208/230 460 575	60 60 60	3 3 3

UNIT FEATURES

Product Series	EarthPure® (HFC-410A) Refrigerant	Microprocessor CXM Controls*	Standard Entering Water Temperature Range (60 to 95°F)	Copper Water Coil**	TXV	Dual Level Compressor Vibration Isolation	Field Convertible Discharge (Horizontal Units)	Multiple Access Panels for Installation and Service Ease	Scroll Compressors	Factory Installed Hanger Brackets (Horizontal Units)	Remote Reset at Thermostat	Condensate Overflow Protection	Cupro-Nickel Coil	High Static Blower	UltraQuiet (Mute) Package	Extended Entering Water Temperature Range (20 to 120°F) ‡	Auto-Flow Water Regulation	Two-Way Control Valve	Downflow Configuration	Desuperheater Coil	DDC Controller	Deluxe DXM Controller	Coated Air Coil	Internal Secondary Pump	Fan Motor***	ClimaDry Reheat	Internal Service Disconnect
	Standard Features												**Factory Installed Options**														
Tranquility 27® Two-Stage (TT)	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•
Tranquility 20 Single-Stage (TS)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Tranquility High Efficiency (TR)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•		•	
Tranquility 16 Compact (TC)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•					•	•	•				
Tranquility Vertical Stack (TRM)	•	•	•	•	•	•			•		•	•	•		•	•	•	•			•	•	•	•			•
Tranquility Vertical Stack (TRW)	•		•		•	•			•		•	•			•		•				•	•	•				•
Tranquility Console (TRC)	•	•	•	•	•						•	•	•		•	•	•	•			•	•	•	•			•
Tranquility Compact Horizontal (TCH)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•					•	•	•				
Tranquility Large Vertical (TLV)	•	•	•	•	•			•	•		•	•	•	•	•	•	•	•			•	•	•	•		•	
Tranquility Water-to-Water (TMW)	•	•	•	•	•	•		•	•		•		•		•	•				•	•	•					
Rooftop (TRE)	•	•	•	•	•	•		•	•		•	•	•	•		•	•	•	•		•	•	•	•		•	
Rx Energy Recovery Ventilator (ERV)			•					•																			
Vertical Dedicated Outdoor Air (TOV)	•		•	•	•			•	•						•	†					•		•				
Horizontal Dedicated Outdoor Air (TOH)	•		•	•	•			•	•					•		†			•		•		•				

Some exceptions may apply to standard features and options, consult product submittal materials to determine availability.
* Standard control for TO Series is DDC with modulating HGR.
** Standard water coil construction for TO Series is stainless steel.
*** Standard on TT Series
‡ Standard on TMW Series
† Extended Range = 35°F–95°F EWT

CLIMATEMASTER®
Water-Source Heat Pump Systems

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Oklahoma City, OK 73179
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Fax: 405-745-6058
climatemaster.com

APPENDIX K- SUNPOWER E19-320 DATA SHEET

SUNPOWER

E19 / 320 SOLAR PANEL

MAXIMUM EFFICIENCY AND PERFORMANCE

BENEFITS

Highest Efficiency
SunPower™ Solar Panels are the most efficient photovoltaic panels on the market today.

More Power
Our panels produce more power in the same amount of space—up to 50% more than conventional designs and 100% more than thin film solar panels.

Reduced Installation Cost
More power per panel means fewer panels per install. This saves both time and money.

Reliable and Robust Design
Proven materials, tempered front glass, and a sturdy anodized frame allow panel to operate reliably in multiple mounting configurations.

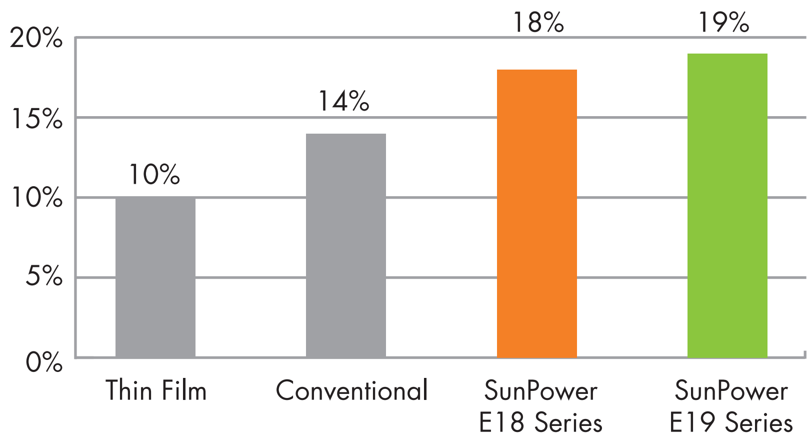
SPR-320E-WHT-D

E19 SERIES

The planet´s most powerful solar panel.

The SunPower™ 320 Solar Panel provides today's highest efficiency and performance. Utilizing 96 back-contact solar cells, the SunPower 320 delivers a total panel conversion efficiency of 19.6%. The 320 panel's reduced voltage-temperature coefficient, anti-reflective glass and exceptional low-light performance attributes provide outstanding energy delivery per peak power watt.

SunPower's High Efficiency Advantage



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SUNPOWER™

E19 / 320 SOLAR PANEL

MAXIMUM EFFICIENCY AND PERFORMANCE

Electrical Data

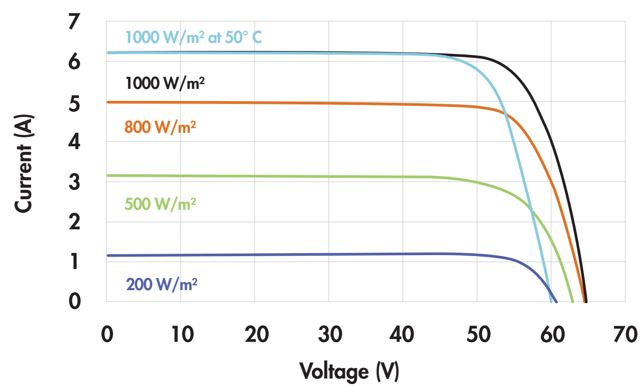
Measured at Standard Test Conditions (STC): irradiance of 1000W/m², AM 1.5, and cell temperature 25° C

Peak Power (+5/-3%)	P_{max}	320 W
Efficiency	η	19.6 %
Rated Voltage	V_{mpp}	54.7 V
Rated Current	I_{mpp}	5.86 A
Open Circuit Voltage	V_{oc}	64.8 V
Short Circuit Current	I_{sc}	6.24 A
Maximum System Voltage	UL	600 V
Temperature Coefficients	Power (P)	-0.38% / K
	Voltage (V_{oc})	-176.6mV / K
	Current (I_{sc})	3.5mA / K
NOCT		45° C +/-2° C
Series Fuse Rating		15 A

Mechanical Data

Solar Cells	96 SunPower all-back contact monocrystalline
Front Glass	High transmission tempered glass with anti-reflective (AR) coating
Junction Box	IP-65 rated with 3 bypass diodes Dimensions: 32 x 155 x 128 (mm)
Output Cables	1000mm length cables / MultiContact (MC4) connectors
Frame	Anodized aluminum alloy type 6063 (silver); stacking pins
Weight	41.0 lbs (18.6 kg)

I-V Curve



Current/voltage characteristics with dependence on irradiance and module temperature.

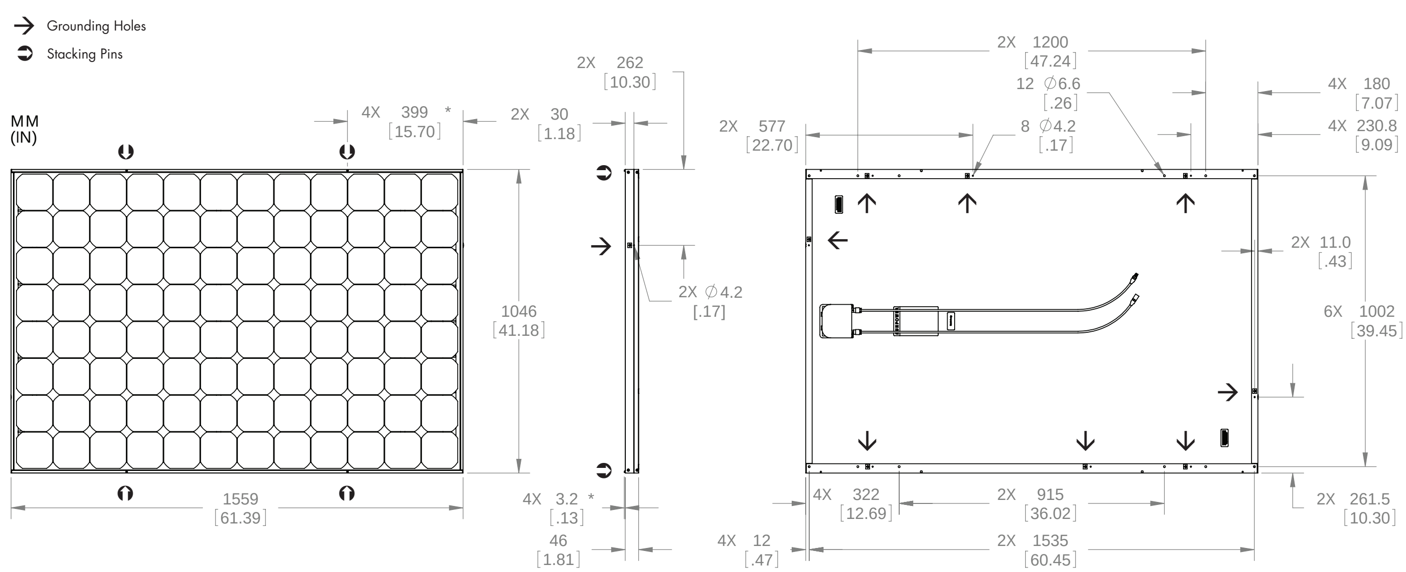
Tested Operating Conditions

Temperature	-40° F to +185° F (-40° C to + 85° C)
Max load	113psf 550 kg/m² (5400 Pa), front (e.g. snow) w / specified mounting configurations 50 psf 245 kg/m² (2400 Pa) front and back – e.g. wind
Impact Resistance	Hail 1 in (25 mm) at 51mph (23 m/s)

Warranties and Certifications

Warranties	25 year limited power warranty
	10 year limited product warranty
Certifications	Tested to UL 1703. Class C Fire Rating

Dimensions



CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

Visit sunpowercorp.com for details

APPENDIX L- SATCON POWERGATE PLUS 75KW INVERTER DATA SHEETS

Satcon™

PowerGate Plus 75 kW

PVS-75 (208 V)
PVS-75 (240 V)
PVS-75 (480 V)

Unparalleled Performance

With their advanced system intelligence, next-generation Edge™ MPPT technology, and industrial-grade engineering, PowerGate® Plus inverters maximize system uptime and power production, even in cloudy conditions.

Power Efficiency

Power Level	Output Power[1]	Efficiency[2]
10%	7.5 kW	92.6%
20%	15 kW	95.6%
30%	22.5 kW	96.3%
50%	37.5 kW	96.7%
75%	56.25 kW	96.6%
100%	75 kW	96.3%

[1] 315V minimum [2] 240V model

Edge MPPT

Provides rapid and accurate control that boosts PV plant kilowatt yield

Provides a wide range of operation across all photovoltaic cell technologies

Printed Circuit Board Durability

Wide thermal operating range: -40° C (-40° F) to 85° C (185° F)

Conformal coated to withstand extreme humidity and air-pollution levels

Proven Reliability

Rugged and reliable, PowerGate Plus PV inverters are engineered from the ground up to meet the demands of large-scale installations.

Low Maintenance

Modular components make service efficient

Safety

UBC Seismic Zone 4 compliant

Built-in DC and AC disconnect switches

Integrated DC two-pole disconnect switch isolates the inverter (with the exception of the GFDI circuit) from the photovoltaic power system to allow inspection and maintenance

Built-in isolation transformer

Protective covers over exposed power connections

PV Inverters | PowerGate Plus 75 kW

PowerGate Plus 75 kW Specifications			UL/CSA
Input Parameters			
Maximum Array Input Voltage	600 VDC		•
Input Voltage Range (MPPT; Full Power)	315–600 VDC		•
Maximum Input Current	248 ADC		•
Output Parameters			
Output Voltage Range (L-L)	183–229 VAC	208 VAC	•
	211–264 VAC	240 VAC	•
	422–528 VAC	480 VAC	•
Nominal Output Voltage	208 VAC		•
	240 VAC		•
	480 VAC		•
Output Frequency Range	59.3–60.5 Hz		•
AC Voltage Range (Standard)	-12%/+10%		•
Nominal Output Frequency	60 Hz		•
Number of Phases	3		•
Maximum Output Current per Phase	208A	208 VAC	•
	181A	240 VAC	•
	91A	480 VAC	•
CEC-Weighted Efficiency	96%		•
Maximum Continuous Output Power	75 kW (75 kVA)		•
Tare Losses	65.36 W	208 VAC	•
	71.84 W	240 VAC	•
	69.5 W	480 VAC	•
Power Factor at Full Load	>0.99		•
Harmonic Distortion	<3% THD		•

• Standard ○ Optional

Satcon™

PowerGate Plus 75 kW

Output Options

PowerGate Plus 75 kW	
UL/CSA	208 VAC Output
	240 VAC Output
	480 VAC Output

Streamlined Design

With all components encased in a single, space-saving enclosure, PowerGate Plus PV inverters are easy to install, operate, and maintain.

Single Cabinet with Small Footprint

Convenient access to all components

Large in-floor cable glands make access to DC and AC cables easy

Rugged Construction

Engineered for outdoor environments

Output Transformer

Provides galvanic isolation

Matches the output voltage of the PV inverter to the grid

PowerGate Plus 75 kW Specifications		UL/CSA
Temperature		
Operating Ambient Temperature Range (Full Power)	-20º C to +50º C	●
Storage Temperature Range	-30º C to +70º C	●
Cooling	Forced Air	●
Noise		
Noise Level	<65 dB(A)	●
Combiner		
Number of Inputs and Fuse Rating	5 (100 ADC)	○
	6 (80 ADC)	○
Inverter Cabinet		
Enclosure Rating	NEMA 3R	●
Enclosure Finish (14-Gauge, Powder-Coated G90 Steel)	RAL-7032	●
Cabinet Dimensions (Height x Width x Depth)		80" x 57" x 30.84"
Cabinet Weight		2,150 lbs.
Transformer		
Integrated Internal Transformer		●
Low Tap Voltage[1]	20%	●
Testing and Certification		
UL1741, CSA 107.1-01, IEEE 1547, IEEE C62.41.2, IEEE C62.45, IEEE C37.90.1, IEEE C37.90.2		●
UBC Zone 4 Seismic Rating		●
Warranty		
Five Years		●
Extended Warranty (up to 10, 15, or 20 years)		○
Extended Service Agreement		○
Intelligent Monitoring		
Satcon PV View® Plus		○
Satcon PV Zone®		○
Third-Party Compatibility		●

● Standard
○ Optional

[1] The 20% boost tap on the isolation transformer increases the AC voltage output range for applications where the solar array DC operating voltage is at or near the lower end of the DC input range. This boost allows for continued inverter operation at lower DC voltage input levels.

Note: Specifications are subject to change.

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