Community Healthcare

Mid-Atlantic

Final Report

Kenna Markel
The Pennsylvania State University
Architectural Engineering
Construction Option

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FRAUENSHUH Commercial Real Estate Group

PERKINS + WILL

DPR CONSTRUCTION

2015
2016

Community Healthcare
Mid-Atlantic Region

Kenna Markel
Construction Management
http://kennamarkel.wix.com/kennamarkel

Building Information

Size | 128,000 GSF, 3 Stories

Occupancy | Medical Office

Construction | Sept. 2014 to Jan. 2016

Delivery Method | CM at Risk

Contract Type | Cost Plus Fixed Fee with GMP

Project Team

Owner	Frauenshuh
Primary Tenant	Undisclosed
Architect	Perkins + Will
Contractor	DPR Construction
Structural Engineer	Cagley & Associates
MEP Engineer	AHA Consulting Engineers
Landscape Architect	Fredrick Ward Associates

Architecture

- 3-Story Medical Office and Ambulatory Care Facility
- Includes a clinic, exam rooms, operating suite, Linac Vault, Ultrasound rooms, & physical therapy center
- Brick Veneer with curtain wall entrance and punched windows

Construction

- Ideal site, flat, large, & in a suburban area
- Only 15 month construction duration
- Structure build in three phases: south, north, & main entrance

Structural System

- Spread footings at column bases with a 5" slab on grade
- Structural steel I-beams for beams, girders, and columns with elevated slabs on metal decking

Mechanical System

- Three rooftop air handling units deliver 37K CFM of air each
- Variable Air Volume system delivers air to spaces
- Unit Heaters are used in varying occupancy spaces

Electrical System

- 4#500KCMIL provide 480/277V, #PH, 4W power
- Power from utility enters through the 4000 Amp main switch-board, power steps down per floor by transformers
- Potential for a generator to be added in the future

Acknowledgements:

DPR Construction

Photos Courtesy of:

Perkins + Will

Executive Summary

The Community Healthcare building is located in the Mid-Atlantic region of the country with the intent to bring high quality medical care to local community. This three story medial office facility is being built out for a primary tenant occupying the first level and part of the second and third. The remaining spaces will be finished at a later date by other tenants. This report looked into altering four areas of the project in the hope of providing valuable alternative construction means and methods for future projects. Three of these analyses focused on issues or opportunities that could have improved constructability, accelerated the schedule, or reduced costs. The final analysis researched the critical industry topic of virtual mockups.

Analysis I | Precast Footings

The project experience approximately a five month schedule delay due to litigation, which was further delayed by weather delays pertaining to cold weather concrete. The foundations and structure all had to be completed during the winter months versus the initially planned summer installation. By using precast footings instead of the traditional cast-in-place method, this analysis found that the construction schedule could be accelerated, but the additional cost made this analysis not recommended.

Analysis II | Prefabricate the Building Envelope

With a tight schedule, the project is using temporary enclosure methods to maintain their interiors schedule. This analysis looked at prefabricating the exterior metal framing, sheathing, and insulation into panels in the effort to accelerate building dry-in. This alternative method of panelizing the exterior enclosure is recommended since it was found to minimize risk in damages and record incidents.

Analysis III | Masonry LINAC Vault

The linear accelerator (LINAC) vault was added to the core and shell GMP package fairly late in during design by the primary tenant. The system is a traditional LINAC vault assembly comprised of standard reinforced concrete system. The healthcare industry has been moving away from this system so this analysis looked at the benefits of using a masonry vault instead. However, it was found that the masonry LINAC vault only provided space savings through thinner walls for the same shielding capabilities. Therefore, a LINAC vault is not recommended for this project in its current location, since the vault is not limited by wall thickness or ceiling height, making the current concrete system the cheapest and simplest construction method for a LINAC vault.

Analysis IV | Virtual Mockups

In order to keep cost down, this project chose not to use BIM technologies to coordinate any building systems. Despite these decisions, this project has experienced its fair share of change orders due to constructability issues and late design changes. This analysis looked at potentially using virtual mockup technologies to mitigate change orders of these themes. Research was conducted for virtual mockup usage amongst leading companies in the industry. This research concluded that virtual mockup technologies are being used to identify and solve issues including constructability issues and design review. Therefore, implementing virtual mockups for this project and similar projects are highly recommended for their potential to save projects money.

Acknowledgements

Academic

Construction Advisor | Robert Leicht, PhD.

Penn State Architectural Engineering Faculty and Staff

Industry

DPR Construction | Bill Hahner, Tim Minor, & Ryan Audy
James G. Davis Construction | Julien Bartolo & Christopher Scanlon
Barton Malow | Bill Gamble
Mortenson | Lucas Manos

Special Thanks

PACE Industry Members

Family & Friends

Ladies of 623 S. Allen St

TABLE OF CONTENTS

Section 1 | Project Background

1.1 Project Description

Community Healthcare is a medical office facility under construction in the Mid-Atlantic region. The design intent is to create a three story healthcare project to extend the network of care to the local community. The goal is to create a space where the specialists come to the patients and not the other way around. The primary tenant of this facility has a long standing history of providing exceptional healthcare to this community and has teamed up with Frauenshuh HealthCare Real Estate Solutions, one of the leading developers of medical office and ambulatory care facilities, to create this building.

The flat site in this suburban neighborhood drew attention from other corporations interested in developing the site as well. In fact, Walmart created much controversy in this area as they were ultimately prevented from developing this land due to zoning. Fortunately, the primary tenant of this facility was warmly welcomed by the community and is expected to complete construction in January 2016, just 15 months after the Notice to Proceed.

Frauenshuh brought Perkins +Will on as the architect of record and DPR Construction as the construction manager. This project was split into the Core and Shell (C&S) as one GMP package and the Tenant Interiors (TI) as another, of which both have the same project partners. While Frauenshuh holds both the C&S and TI contracts through their LLC, Frauenshuh is most interested in the C&S and the primary tenant in the TI. This medical office building is set to open in the spring of 2016.

1.2 Client Information

Frauenshuh HealthCare Real Estate Solutions is the owner of the Community Healthcare Building. Frauenshuh is one of the leading developers of medical office and ambulatory care facilities. With over $3 Billion of work in 38 states, Frauenshuh is well experienced in projects such as this one and know exactly what to expect in terms of cost and schedule. Frauenshuh created a LLC for the purpose of this project. All entities are contracted to their LLC instead of Frauenshuh directly in order to mediate risk.

Community Healthcare was bought out into a Core and Shell package and a tenant interiors (TI) package. The primary tenant of this project has requested to be undisclosed. This tenant is contracted with Frauenshuh to build their new medical facility with their preferences in mind. The tenant has a long standing reputation for providing exceptional healthcare to the local community and hopes to expand their network with this project. Their concern will be in the quality of their new faculty with a focus on their end users.

Even though this project was bought out in two separate GMP contracts, this project is not phased and has only one schedule which includes the work for both contracts. In fact there are certain add-ons that were made to Core and Shell contract, supplied by the primary tenant, in order to make the final space best fit their needs. Phased occupancy is still under consideration, but currently is not being implemented.

1.3 Project Delivery Method

As mentioned, Frauenshuh created an LLC for this project. All contracts are tied to the LLC not Frauenshuh directly. Both the Core and Shell work as well as the tenant interiors work are contracted to this LLC and not to the primary tenant. The primary tenant is instead taking advantage of Frauenshuh's experience, using them similar to an owner's representative. Perkins +Will was brought on early and is the architect of record for both the Core and Shell and the TI. They were awarded as lump sum contract and selected their own engineers and consultants by lump sum contract as well. Cagley & Associates were selected as the structural engineers, AHA for MEP, and Fredrick and Ward Associates for civil and landscaping.

DPR Construction was brought on to the project to provide estimates for the Core and Shell as early as the concept plan. Frauenshuh reached out to DPR in 2013. The project was delivered as a construction management at risk, and DPR was selected based on their general conditions, fee, and project team. DPR was selected for the TI package as well after providing pricing for schematic design, design development, and construction documents/GMP.

DPR began awarding bid packages in late September 2014 following Notice to Proceed. The bid packages were awarded to the lowest bidders. The major subcontractors by contract amount include Emjay for mechanical, Windsor Electric for electrical, Hanover for structural steel, and Brightbill Industries, Inc. for casework. Figure 1 shows the organization chart for this project.

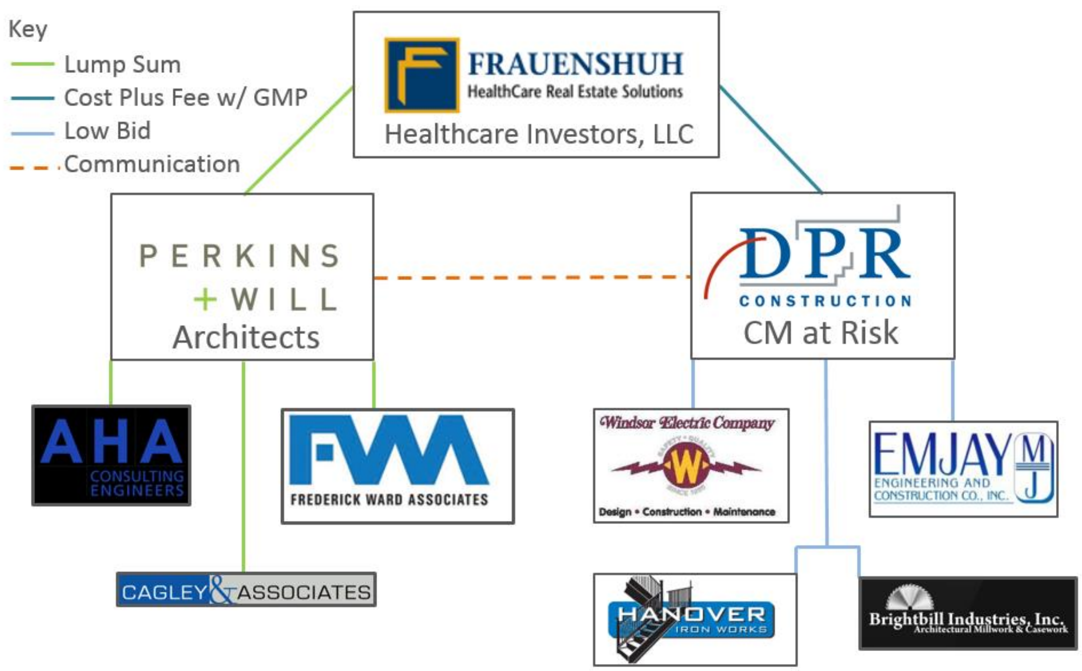


Figure 1 Organizational Chart

1.4 Project Team Staffing Plan

DPR Construction is not structured by job titles, instead, individuals are considered to have roles and responsibilities. The staffing plan in Figure 2 shows the roles that each team member is performing on the Community Healthcare faculty. The DPR team could benefit by adding a project engineer to this role since John Stull the performing PE typically holds the role of project manager. The standing project manager Bill Hahner is working part time on both this project and another project while trying to fulfill PE responsibilities as well. Both Bill and John Anania helped to establish DPR's relationship with this project being that they both have history with the primary tenant. The field team is working full-time on this project at the trailers onsite.

Figure 2 DPR Staffing Plan

1.5 Building Systems

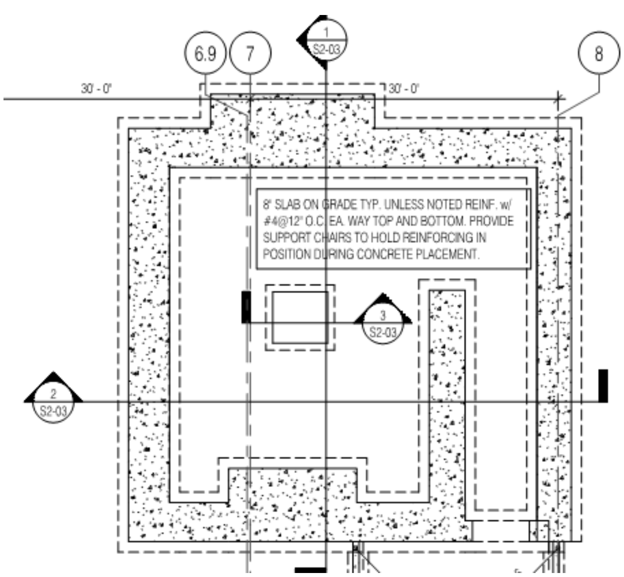


Figure 3 LINAC Structure

1.5.1 Substructure & Superstructure –

The building's foundations are comprised of spread footings at column bases and stepped footing at concrete walls with a 5" slab on grade. In addition to the building foundations, a foundation and concrete vault had to be built for the Linear Accelerator Machine (LINAC) for the primary tenant. This room requires a minimum 4' thick concrete walls and up to 7'-6" thick wall to prevent radiation from leaving the machine's chamber. The LINAC structural plan is shown in Figure 3. The building's structure is structural steel frame with elevated concrete slabs on composite steel floor decking. The elevated slab also includes a cantilever over the main entrance.

1.5.2 Building Enclosure –

The front entrance of the building from the main parking lot is comprised of a curtain wall glazing system and composite metal panels. The Cancer Center entrance in the southwest corner of the building has a similar appearance with a glazed curtain system and composite metal panels. This mimicking of façade creates the two distinct entrances to the building. The first level of the entire building is primarily this curtain wall and composite metal panel system. The second and third levels are brick veneer with windows and some composite metal panels for consistency of design. The details below in Figure 4 show typical details for the curtain wall (A5), metal wall panel (B1), and brick veneer (C4).

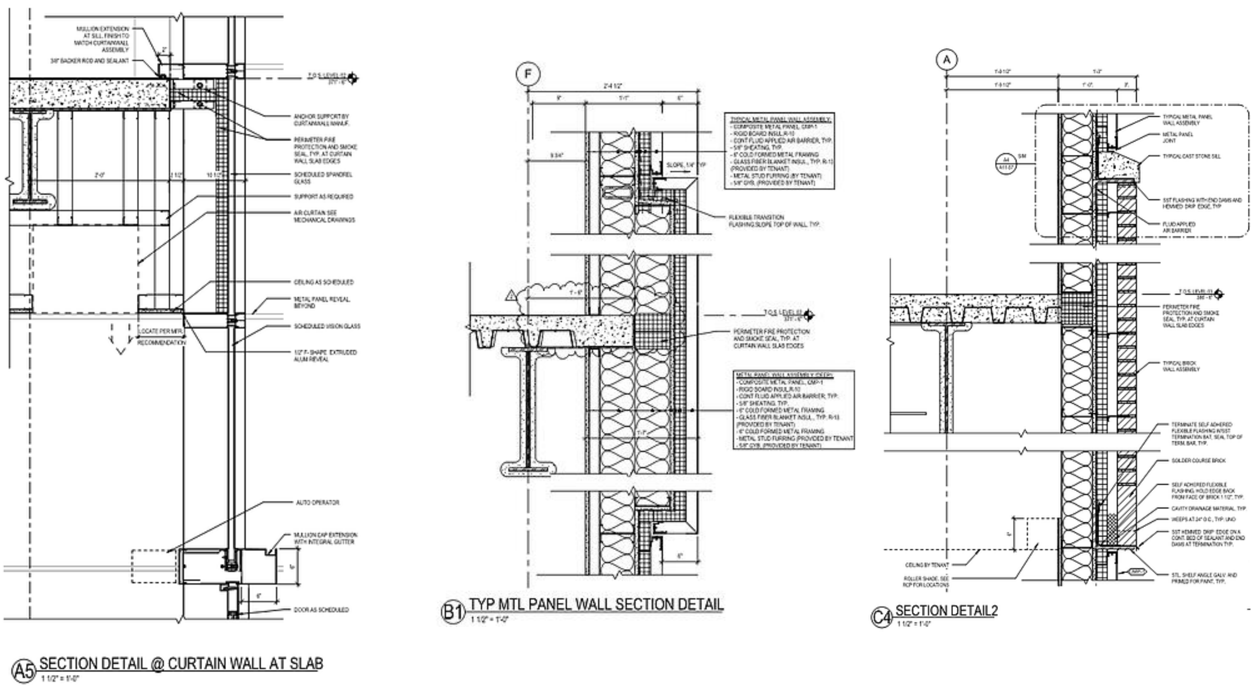


Figure 4 *(from left)* Curtain Wall detail, Metal Panel Wall detail, Brick Veneer detail

1.5.3 Curtain Wall –

The building has three glazing systems including curtain wall, storefront, and ribbon windows. The curtain wall system is incorporated into the main entrance along with decorative metal panels. The storefront windows are located on the first level where the curtain wall is not and some places on the second level on the front of the building. The ribbon windows then appear on the second and third levels. Figure 5 below shows an elevation of these three systems on the front façade.

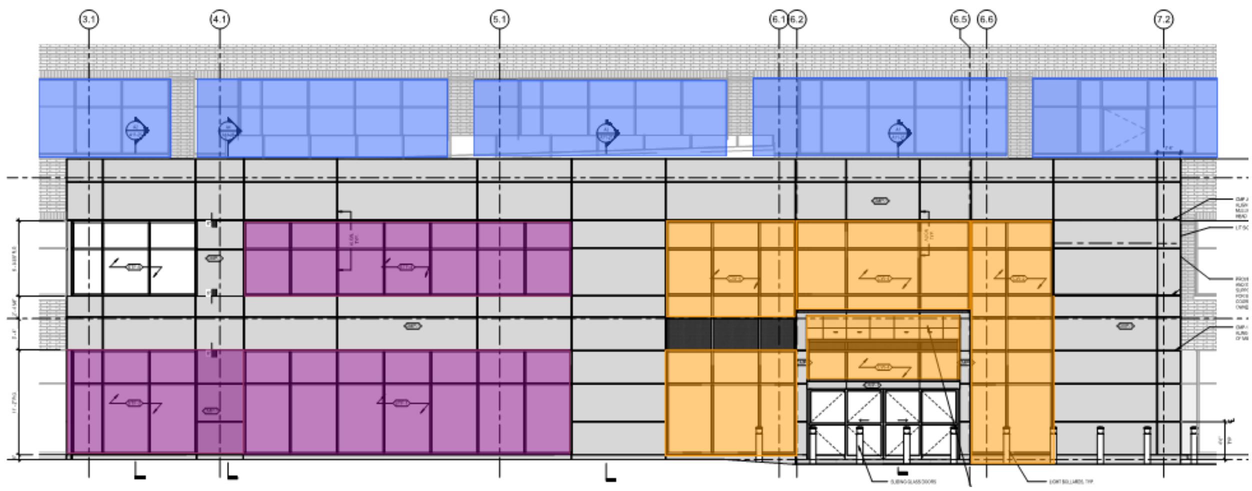


Figure 5 Glazing Systems in Elevation View

1.5.4 Masonry System –

Masonry is one of the three major components of the facade system of this building. The masonry veneer is fairly typical of masonry systems. The veneer ties back to Purple gypsum board that is attached to the cold formed metal framing. A vapor barrier is applied to the Purple board before the veneer is placed. Approximately every ten to twelve brick courses a shelf, which is L-shaped is mounted. The brick sits then on this shelf and ensures that the load in distributed down to ground.

1.5.5 Roofing System –

The roofing system consists of a built-up roofing system utilizing both consistent and tapered insulation for proper drainage and thermoplastic polyolefin (TPO) single-ply roofing membrane. The majority of the roof membrane is white TPO while the roof above the main entrance is a ballasted TPO, meaning that gravel or a small aggregate is placed on top. Also included on the roof above the main entrance is a skylight. Much of the mechanical system is also located on the roof. To support this load, a concrete slab was poured for the equipment in the center of the roof along with larger steel members in area. Additional steel members were also added to frame out the opening for the mechanical shafts. There is also another opening on the north corner of the building's roof surrounded by ceramic tile. This opening is the quench vent for the MRI machine. Another feature of this roof includes a green roof assembly above the LINAC machine on the backside of the building.

1.5.6 Electrical System –

High voltage is provided by the local utility and comes into a transformer. From the transformer power is carried to the 4000 AMP main switchboard by way of eight sets of 4#500KCMIL wires providing 480/277V, 3PH, 4W power. Two transformers step down power from 480/277V to 208/120V to bring power to the first and second levels. There is also a distribution panel located on the third level for future buildout of that space. Additionally, there is a plan for a future generator to be added to the project in years to come.

1.5.7 Lighting System –

The Community Healthcare building utilizes several different fixtures and lamps to meet its various functions. For more critical rooms or highly occupied spaces, including equipment rooms and waiting rooms, LEDs lamps are used for their long lifespan. Recessed and pendent LEDs are primarily used in these spaces. Recessed LEDs are in equipment rooms and elsewhere, while pendent LEDs are tied into the interior design of public spaces. Additionally, there is a specific MRI rated LED downlight in the MRI room. Meanwhile, in less critical spaces, fluorescent lamps are used in all exam rooms. These fluorescents are typically 2'x2' or 2'4' recessed fluorescents. Many to most of the fixtures are on dimmers for occupant comfort.

1.5.8 Mechanical System –

The mechanical system of this building is fairly simple. Three rooftop air handling units (AHU) deliver approximately 37K CFM per unit. Variable air volume terminals (VAV) are located throughout each floor to ensure occupant thermal comfort. Ensuring that there are different zones is especially important in this building since different rooms have varying purposes in the health and treatment of patients. Fan powered terminals are placed to ensure that air is distributed equally throughout large open spaces. Unit heaters can be found in spaces that are not continuously occupied for example stairwells and storage rooms.

1.5.9 Fire Protection –

Due to the low overall square footage and low building height, wall partitions have at maximum only a 1-Hour Fire Rating. Additionally, this facility is only being used for outpatient care; therefore, the wall partitions were allowed by code to have substantially lower fire ratings. These 1-Hour Fire Rated partitions are located around all means of egress including stairwells and elevator banks. While the fire protection and sprinkler systems are delegated design, per IBC 903, an automatic sprinkler system is required; wet-pipe sprinkler systems are specified for this project. Fire alarms, smoke detection, and portable fire extinguishers are all required systems as well. The standpipes, rated for 175-psig, will be located in the two exterior stairwells at the building's edge and will need to be inspected by the local jurisdiction.

1.5.10 Transportation –

Users of the Community Healthcare faculty can make their way through the different levels of the building by means of two elevators, three staircases, and one service elevator, which can be found in Figure 6. Primarily the two elevators will be used by the visitors and patients of this healthcare faculty, while the remaining stairways will mostly be reserved for employee usage only. The service elevator allows for equipment and other maintenance items to be brought up to the second and third level without disrupting daily activities and usage. Additionally, the service elevator will need be utilized to fit out the remaining interiors on the two upper levels.

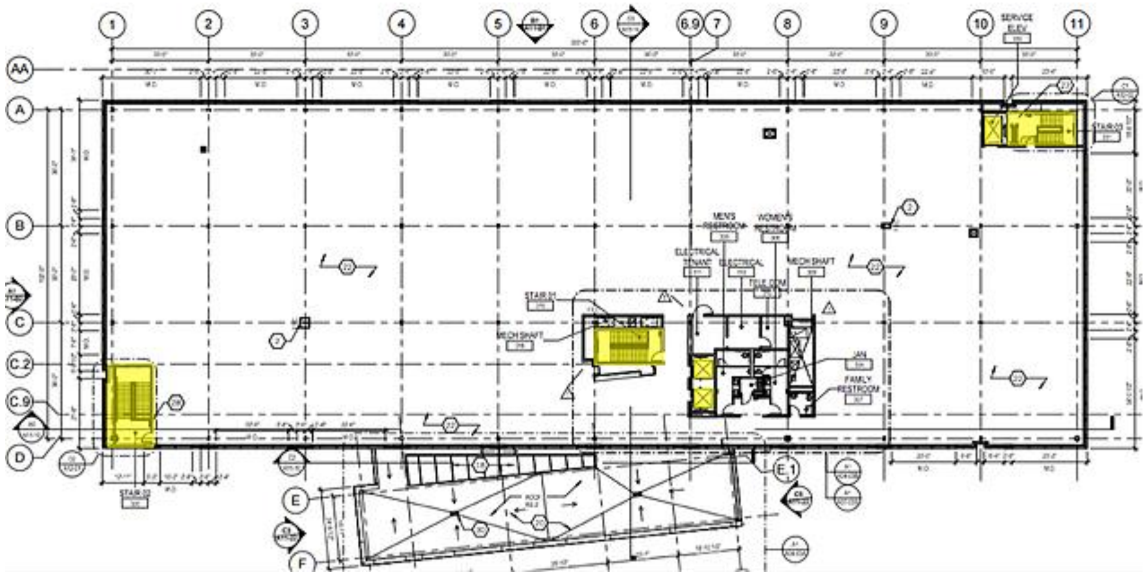


Figure 6 Stairwells and Elevators

1.5.11 Telecommunications –

The majority of the telecommunications for this faculty are for security purposed only. The security for many of the spaces has to be limited to employees with clearance for the safety of the public. Not only do many of the rooms especially equipment rooms have card readers, but there are also fixed position cameras throughout the faculty. Another concern for this faculty is the possibility of intrusion. Therefore, there is a keypad for the instruction detection system along with a panic button on the nurses' station in the case that the safety of the building's staff and patients are under threat. This panic button will notify the local authorities to come immediately. Also for the safety of the patients, there are emergency station pull cords in the toilets and showers in case that a patient needs nurses' assistance.

Section 2 | Construction Overview

2.1 Cost Evaluation –

This project's budget was broken out between the Core & Shell package and the Tenant Interiors package. The Core & Shell package is a fairly standard base build contract including foundations, substructure, superstructure, façade, roofing, fireproofing and basic MEP rough-in. Additionally, included in the Core & Shell package was work related to the tenant specified medical equipment. Some of this work included the Linear Accelerator vault, future backup generator pad and conduit, fume hood exhaust runs, and a quench vent for the MRI. Also, in this package was necessary off-site improvements. This involved access roads to the new facility and public sewer improvements. These improvements are not included in the project cost estimate, since there are not accurate resources available to provide a close estimate, instead the actual cost from the project was carried over. In total, this package makes up sixty-three percent of the total project cost.

The Tenant Interiors package only included fit-out work for a portion of the facility. The primary tenant will only be occupying the first floor and approximately half of the second and third floors. The remaining spaces will be built out at a later date by other tenants. Some of major costs for this package included millwork, which is expected for a medical office space, electrical, for the medical equipment, and the remaining MEP. In total this package is approximately thirty-seven percent of the total project cost.

Table 1 Summary of Project Costs

Summary of Cost Estimate vs. Actual GMP				
	Actual GMP		Estimate	
Total Project Cost	$25,900,000	$244	$32,900,000	$310
Construction Cost	$19,800,000	$187	$22,400,000	$211
Superstructure	$2,550,000	$24	$1,400,000	$13
HVAC	$2,100,000	$20	$2,160,000	$20
Electrical	$3,160,000	$30	$2,650,000	$25

RS Means was used to create the cost estimate for Community Healthcare. The building types provided by RS Mean unfortunately did not fit this building type well. This project is primarily a medical office building; however, it does contain some features of a hospital faculty. RS Means' Medical Office building only goes up to two stories despite this building being three stories. After adjustments were made to the medical office building square foot cost, the unadjusted cost was used for estimating since it was closer to the actual cost. Despite these efforts, the estimate still came in over the actual GMP. Table 1 shows the results from the cost comparison, for the full estimate see Appendix A.1.

One of the sources of variation between the GMP cost and the cost estimate was in the indirect costs. RS Means calls for 9% for Architect Fees and an additional 25% in other indirect costs. These costs are far greater than the costs called out in the GMP because DPR needed to make their bid competitive. Another cost that varies is for the superstructure. Since RS Means could only go up to two stories, it is expected that the superstructure in the GMP would be greater than that in the cost estimate. Once these variations were sorted out the cost estimate came closer to the GMP actual cost.

2.2 Schedule Overview –

The original GMP schedule for the Community Healthcare project had to undergo revisions in October 2014. Construction was delayed by almost five months due to litigation on the land. The original issuance of the Notice to Proceed was set to be May 5, 2014 and was instead revised to be September 29, 2014. Additionally, the finish date was pushed to January 21, 2016 instead of the original completion date of June 2, 2015. The NTP date revision accounts about a five month delay; however, the finish date was pushed about seven months back. This remaining duration was largely attributed to weather days associated with the cold weather concrete of the foundations and the building concrete.

The Core and Shell and TI GMP schedules are actually compiled into one master schedule for both, which was attached to both contracts. Even though there are two separate GMPs packages, the construction is not technically phased. Therefore, when the Notice to Proceed date was pushed for the Core and Shell package, the TI package saw a project delay as well, since both packages shared their Notice to Proceed date.

Site work began following NTP to ensure that the access roads were in place and the sediment and erosion control measures set for the start of building construction. The building is constructed from the south to the north with the main entrance being built last. This sequence is completed for both the foundations and superstructure. Once the south slabs are completed, work can begin on the facades. Work then moves from the west elevation clockwise finishing at the south elevation. Since interiors are on the critical path in this 15 month construction duration, steps needed to be taken to make the building watertight before the roof is complete. Interiors can begin once the building has temporary provisions to make it watertight starting on Level 1. Currently, the project does not have phased occupancy, but the schedule is created to allow this option in the future. The remaining floors follow level one every three weeks. Commissioning is also sequenced similar to the interior finishing by level, once again to keep the possibility of phased occupancy open. Figure 7 shows the project milestones, the full schedule can be found in the Appendix A.2.

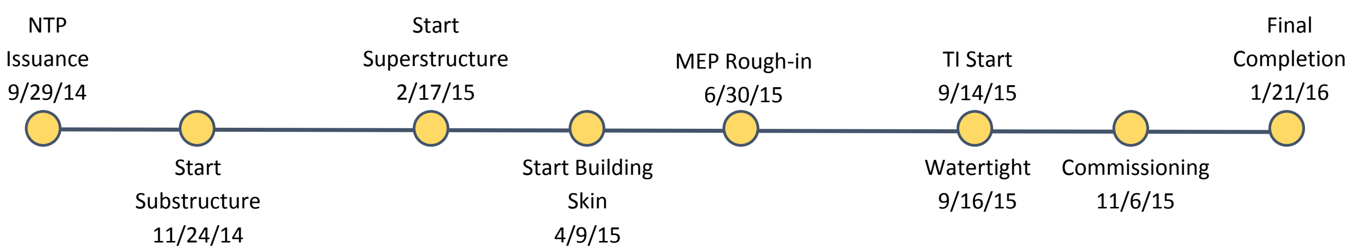


Figure 7 Project Timeline

2.3 Site Logistics Plan –

The site is located in a suburban area of the Mid-Atlantic Region of the country. The site is previously undeveloped but had been cleared previously as seen in Figure 8. The building is adjacent to two neighboring buildings one of which is a pharmacy and the other a fast-food restaurant. The property is ideal and fairly level to begin with. This makes it ideal for ample laydown area and parking. Traffic to and from the site will be made through the intersection on the street approaching the site. The trailer complex will visible from the entrance gate and is located to the left when entering the main gate. Deliveries can enter the site from entrance gate then loop around the laydown and staging area to the exit gate. Mobile cranes will be used along with lifts throughout the duration of the project due to the large size of the site. Additionally, the flat land and decent soils create an ideal crane path. The project will utilize a trash shoot at the corner of the building facing the trailers. The large open area behind the building footprint is owned as well by the developer Frauenshuh. This property will be used for temporary soil relocation from the building excavation that is suitable for backfilling the project later. To see a full site logistics plan for this site, see Appendix A.3.

Figure 8 Project Site

Section 3 | Analysis I – Precast Footings

3.1 Problem Identification –

In the earlier GMP schedule, the foundations were scheduled to begin in mid-July 2014 and finish in early September with a total duration of 39 days. Instead the revised schedule had these same activities beginning in late November 2014 and finishing in late January with the goal of meeting the same 39 day duration. Instead, according to the July 22, 2015 schedule update, the foundations actually took 47 days and occurred from December 15, 2014 to March 10, 2015. Additionally, the building concrete activities including form and pour the slab on grade and elevated decks were originally scheduled to occur from late September 2014 to early December 2014 and last 51 days. The revised GMP had the building concrete occurring from mid-February to late May with a duration of 69 days. However, in the most current schedule update, which showed 51 weather days, the building concrete is now beginning in mid-March 2015 and going until late June 2015 with a duration of 54 days.

With the schedule being a driving factor for the tenants, looking to open their medical suites to the community as soon as possible, the ongoing schedule delays from weather days continue to push this opening day back. While the DPR team is doing their best to complete this project on schedule, they obviously have little control over the weather in their region over the past year. Cast-in-place footers were originally selected since they were the most cost effective foundation system. Additionally the original GMP had the footings being poured in mid to late summer. However, when the GMP schedule was pushed the footings were now being poured during cold weather and into potentially frozen ground.

3.2 Research Goals –

This analysis will focus on investigating whether a precast footing system is a viable alternative to the cast-in-place footing system. The precast system is expected to be more than the current cast-in-place system in terms of cost, but the goal of this analysis is to assess the feasibility of precast footings to accelerate the schedule. Following the completion of this analysis, the additional cost of a precast footing system will be weighed against the resulting schedule or additional benefits this alternative system. Based on these outcomes, a recommendation will be made as to which system possess the best value for this project given the client's drivers and expectations.

3.3 Methodology –

Research

1. Research local vendors in the Mid-Atlantic Region.
2. Research the cost to implement this alternative.
3. Research the time it takes to procure precast footings.
4. Research the limitations and requirements of transporting the footings based on the laws of the road.

Feasibility Study

1. Determine the proximity of the precast warehouse to the site and the transportation costs associated with these deliveries.
2. Determine a delivery sequence for the footings to be brought to site based on the limitations of a truck and laws of the road.
3. Evaluate whether the precast footings could be feasibly transported to site.

Technical Analysis

1. Perform a cost evaluation of the two systems including the total cost of the cast-in-place system with the increased duration and added equipment versus the precast system.
2. Create a schedule for the alternative precast system to determine if the schedule could be accelerated and by how much.
3. Provide recommendations on the system that provides the best value based on cost, schedule, and feasibility.

3.3 Cast-in-Place Foundation System –

The current foundation design for this project is a shallow foundation made up of spread footings. The test borings documented in the geotechnical report revealed that despite boring down over twenty-five feet there was no rock present in the soil. Unfortunately, this lack of rock, swayed the foundation design away from deep foundations. According to the geotechnical report, the soil was found to only have a bearing capacity of 2 ksi. However despite the geotechnical report, ultimately, DPR Construction had to still conduct soil remediation to bring the soil bearing capacity up to 2 ksi. This low bearing capacity led to fairly large spread footings of up to fourteen feet by fourteen feet by two and a half feet thick.

Despite the affordability of this concrete foundation system, the initial project delay took a major toll on the duration of the foundation placement. Not only did the team experience fifty-one weather days, but the project team also had to pull $5,433 out of the winter conditions contingency for the foundation to account for cold weather concrete measures including concrete blankets. The foundation is clearly on the critical path for this project, for everyday that foundation took beyond the initial duration, the DPR team had to either make up the time elsewhere or ultimately push the completion date.

3.4 Precast Foundation System –

Precast concrete is increasingly being used around the world as it continues to be recognized as a major schedule accelerator. Especially useful in simple structures or repetitive structures, precast concrete, if properly installed can not only accelerate the schedule, but also improve safety and quality. The Mid-Atlantic region has an abundance of construction projects, which ultimately puts this project in a location where there are several contractors who would be able to produce precast concrete members. The current footing design calls for fourteen different footing sizes for a total of fifty-seven footings. This large range of variation is not ideal for a precast footing system, since unlike the traditional cast-in-place foundation design, precast footings need to be cast into formwork. Precast in generally is known to be more expensive than cast-in-place; however, due to the added costs needed for the cold weather concrete and extended timeline, the cost variation between the two systems may be less significant.

3.4.1 Constructability –

The location of this project being in the Mid-Atlantic Region, provides many opportunities for affordable concrete construction. This area of the country especially is known for its large quantity of concrete subcontractors. This creates a fairly competitive market for the bidding of concrete projects. On this project, the concrete sub scope is not only minimal but also simple. Dance Brothers were ultimately selected as the lowest bidder for this project, and were awarded the concrete package. While there are several concrete subcontractors in the area who could fabricate these precast footings, this analysis uses pricing and other information from one of the largest concrete subcontractors in the area Miller, Long & Arnold. While Dance Brothers may as well be able to create precast footings, Miller, Long & Arnold has more experience in this area and has a larger project portfolio. After consulting with Mac Ardalan of Miller, Long & Arnold of Baltimore, MD, he confirmed that Miller, Long & Arnold does have the capacity to fabricate these precast footing at their yard at 4701 Washington Blvd, Halethorpe, MD 21227. The footings can be procured in six weeks, two weeks to get the material, and four weeks to form, place, and cure. In consultation with Mac Ardalan, he already began raising concern as to the size of the footing, suggesting that if the footings were smaller and had less variation of sizes, they would be more affordable to build and transport. Additionally, Mac Ardalan explained the importance for having a level surface to place the footings on. The traditional footing method of casting concrete onsite allows for a considerable amount of tolerance for leveling column piers. The precast footing would have to be placed level on compacted gravel to ensure that the column piers could be anchor bolted level then grouted.

3.5 Feasibility Analyses –

The major concern for the feasibility of this study, is whether the precast footings can be transported in accordance with the transportation regulations of the state. While this project's location is to remain undisclosed in this report, the state's or states' regulations that govern the transport of these precast footings were followed for this analysis. Fortunately, interstate roads generally have the same regulations from state to state. Law dictates that semi-trucks can have a maximum length of fifty-three feet and a maximum width of one hundred and two inches, the equivalent of eight feet six inches. The maximum height of the load from the ground to the top of trailer is thirteen feet two inches. With a maximum height that bottom of the trailer can be off the ground at thirty inches or two feet six inches, the worst case scenario would dictate that the load could be a maximum of eleven feet. However, for

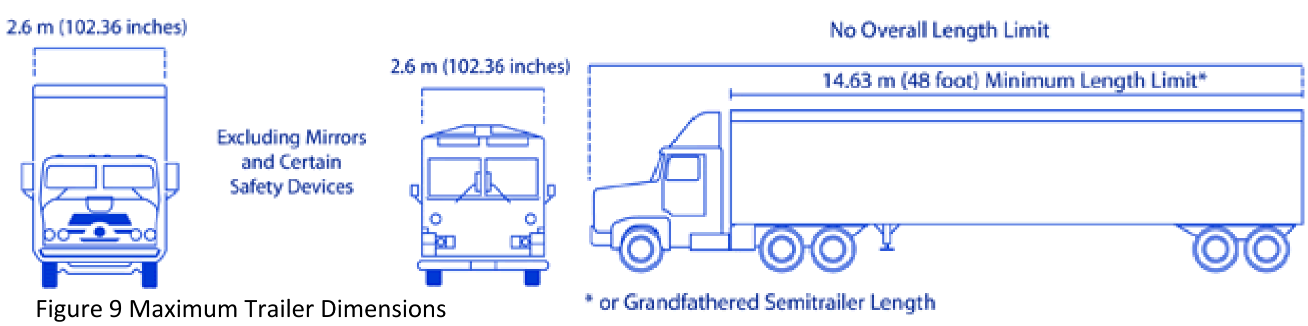


Figure 9 Maximum Trailer Dimensions

http://ops.fhwa.dot.gov/FREIGHT/publications/size_regs_final_rpt/index.htm#length additional precaution, this analysis will only transport foundations with a maximum length and width of ten feet six inches. Figure 9 shows a visual representation of the maximum truck sizing. The road regulations can be found in Appendix B.1.

Not only does the current foundation design have footings that exceed the maximum eleven feet length and width, but under further investigation of the transportation regulations, several footings would also exceed the weight limits for the road. According to state regulation, the gross weight for a five-axle vehicle cannot exceed one hundred and thirty five kips, or twenty-seven kips per axle. The gross weight for a six-axle vehicle cannot exceed one hundred and fifty kips, once again twenty-seven kips per axle. These weight requirements are for the gross weight of the vehicle and load, to get just the maximum load requirements, the weight of the truck and trailer would have to be subtracted from the total. According to EquipmentWatch Intelligence, a provider of analytics on heavy equipment, the top five manufacturers of heavy duty trucks in 2015, were International, Freightliner, Kenworth, Volvo, and Peterbilt. For this analysis, Freightliner's Heavy Haul Truck model 122SD was used for since this model could tow up to ninety-two thousand pounds with a gross vehicle mass ranging from forty-thousand pounds to sixty-thousand pounds. Using the average gross vehicle mass for truck model of fifty-thousand pounds and the maximum over dimensional load, the gross tow load was found to be approximately one hundred pounds. Despite having a potential maximum allowable load of one hundred pounds, the Freightliner model 122SD can only tow up to ninety-two thousand pounds, which will limit each delivery load to ninety-two thousand pounds maximum. The specifications for the Freightliner model 122SD can be found in Appendix B.1. Even though state regulations allow up to a maximum load of one hundred pounds for a six axle load, any load over eighty-thousand pounds is considered an over dimensional load, which requires permit fees, found in Appendix B.1. These permit fees are included later in this analysis for the cost estimate in accordance with the delivery schedule. Unfortunately, not only did the current footing design have footings that would exceed the maximum height requirements of the road, but additionally, the large size of footings twelve feet in length and width or larger had weights that would require them to be transported individually. To transport these footings individually would not only be expensive, but also not especially practical. In order to make this analysis feasible, it became clear that the current foundation design had to be altered to meet the road requirements for transport.

3.6 Foundation Redesign (Structural Breadth) –

During the feasibility study, several footings were found to exceed road regulations for the transport of precast footings to the project site. The maximum height requirements found that all square footings over eleven feet had to be redesigned or altered for transport. For this analysis, square footings will not exceed ten foot six inches for extra precaution. Since footings eleven feet and over would not be able to be transported, the footings could be altered by one of two methods. The footings could either be fabricated in three sections then fabricated into one footing onsite or resized to be transported in one piece. Since the foundation system is fairly simple to begin with, through consultation with Penn State faculty members, it was advised that resizing the footings would be the recommended footing alteration.

In order to be able to downsize the precast footings from the original foundation design, the soil bearing capacity would have to be increased. Unfortunately, there is not a way to calculate exactly how much cement needs to added to the soil to increase the bearing capacity. Instead, this analysis looked at how much the bearing capacity would have to be increased to make precast footings feasible.

In addition to increasing the soil bearing capacity, any square footing eleven feet in length and width or larger, which totaled to be twenty-four footings, had to be redesigned. Fortunately, many of these footings had similar conditions and loading; therefore, only twelve footings had to be recalculated, the remaining footings could be resized from these calculations. All of the footings highlighted in Figure 10 were the footings over eleven feet in length and width that had to be resized, all of the footings highlighted in red were the footings that were recalculated. The footings that were recalculated including footings on the following gridlines: A/2, A/4, A/8, A/11, B/1, B/4, B/5, C/1, C/2, C/4, C/5 and C/11. At glance, these footings were all different in either size, tributary area, or apparent loading. The remaining footings that were not recalculated had to be of the same size, tributary area, and loading as one of these twelve footings.

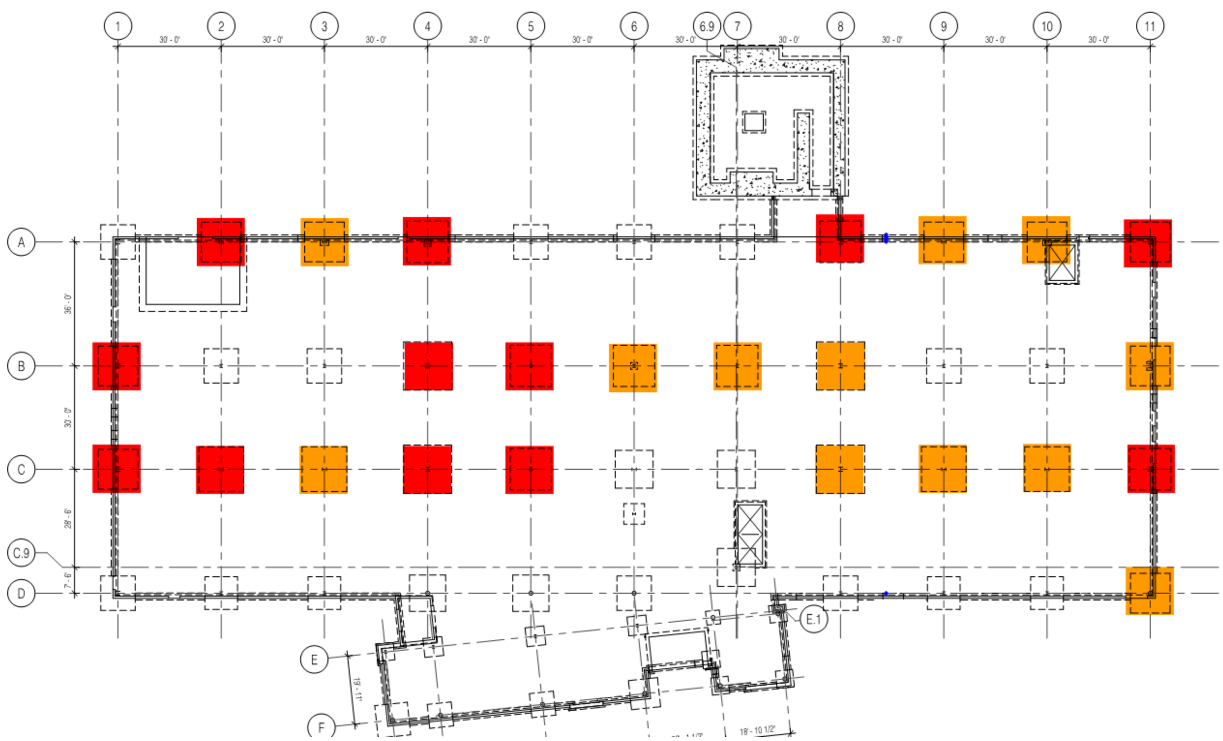


Figure 10 Columns That Require Redesign

3.6.1 Column Loading

To resize these footings, the first step was determining the load that the foundation would have to support. The load had to be calculated and carried through the column down to the spread footing. The following assumptions were made for the loading of this analysis:

- Dead load for the roof:

  - Assume 34psf dead load for the roof including metal deck of 2psf, rigid insulation of 2 psf, built-up roof of 20 psf, and miscellaneous DL 10psf
- Dead load for the elevated slabs:
  - Assume the structural slab is 2 1/2" Lightweight concrete over 3" deep x 20 gage galvanized composite steel deck (total thickness = 5 1/2") in accordance with S1-02 of the structural drawings for the Core & Shell
  - Lightweight concrete weighs from 90-110 pcf, assume worst case for lightweight concrete of 110 pcf:
  - Lightweight concrete 110 pcf x (5.5"/12") thickness of composite deck = 51 psf
  - Add additional 5 psf for dead load of members, for a total dead load per floor of 51 psf + 5 psf = 56 psf
- Live loads are in accordance with ASCE, snow load of 30 psf and a design load of 80 psf for hospitals from Table 4-1

In order to be able to resize the footings later, both the dead and live loads on the columns had to found separately. The following is a sample calculation for finding the dead load for the footing on gridline A/2:

(1) From the Roof to Level 3:

$$\frac{Roof\ Dead\ Load\ (34\ psf)\ x\ Tributary\ Area\ (540\ SF) +\ Wall\ Dead\ Load\ (15\ psf)\ x\ Wall\ Tributary\ Area\ (560\ SF)}{Conversion\ to\ kips\ (1000)} = 22.56\ k$$

(2) From Level 3 to Level 2:

$$\frac{Slab\ Dead\ Load\ (56\ psf)\ x\ Tributary\ Area\ (540\ SF)\ x\ Number\ of\ Floors\ Supported\ (1\ floor)}{Conversion\ to\ kips\ (1000)} = DL\ Floor\ on\ Column\ (30.24\ k)$$

$$\frac{Roof\ Dead\ Load\ (34\ psf)\ x\ Tributary\ Area\ (540\ SF)}{Conversion\ to\ kips\ (1000)} = DL\ Roof\ on\ Column\ (18.36\ k)$$

$$\frac{Wall\ Dead\ Load\ (15\ psf) x\ Tributary\ Area\ (450\ SF)\ x\ (Number\ of\ Floors\ Supported\ (1\ floor) + 0.5)}{Conversion\ to\ kips\ (1000)} = DL\ Wall\ on\ Column\ (10.125\ k)$$

$$DL\ Floor\ (30.24\ k) + DL\ Roof\ (18.36k) + DL\ Wall\ on\ Column\ (10.125\ k) = 58.725\ k$$

(3) From Level 2 to Level 1:

$$\frac{Slab\ Dead\ Load\ (56\ psf)\ x\ Tributary\ Area\ (540\ SF)\ x\ Number\ of\ Floors\ Supported\ (2\ floor)}{Conversion\ to\ kips\ (1000)} = DL\ Floor\ on\ Column\ (60.48\ k)$$

$$\frac{Roof\ Dead\ Load\ (34\ psf)\ x\ Tributary\ Area\ (540\ SF)}{Conversion\ to\ kips\ (1000)} = DL\ Roof\ on\ Column\ (18.36\ k)$$

$$\frac{Wall\ Dead\ Load\ (15\ psf) x\ Tributary\ Area\ (450\ SF)\ x\ (Number\ of\ Floors\ Supported\ (2\ floors) + .05)}{Conversion\ to\ kips\ (1000)} = DL\ Wall\ on\ Column\ (16.875\ k)$$

$$DL\ Floor\ (60.48\ k) + DL\ Roof\ (18.36k) + DL\ Wall\ on\ Column\ (10.125\ k) = 95.715\ k$$

(4) Total Dead Load:

$$DL\ Roof\ to\ 3\ (22.56\ k) + DL\ 3\ to\ 2\ (58.725\ k) + DL\ 2\ to\ 1\ (95.715\ k) = 177\ k$$

The following is a sample calculation for finding the live load for the footing on gridline A/2:

(1) From the Roof to Level 3:

$$\frac{Live\ Snow\ Load\ (30\ psf) x\ Tributary\ Area\ (540\ SF)}{Conversion\ to\ kips\ (1000)} = 16.2\ k$$

(2) From Level 3 to Level 2:

$$0.25 + \frac{15}{\sqrt{Number\ of\ Floors\ Supported\ (1\ floor)\ x\ Tributary\ Area\ (540\ SF) x\ 4}} = LL\ Reducing\ Coefficient\ (0.57)$$

$$LL\ Reducing\ Coefficient\ (0.57)\ x\ Live\ Load\ (80\ psf) = Live\ Load\ Reduced\ (45.8\ psf)$$

$$\frac{Live\ Load\ Reduced\ (45.8\ psf)\ x\ Tributary\ Area\ (540\ SF)\ x\ Number\ of\ Floors\ Supported\ (1\ floor)}{Conversion\ to\ kips\ (1000)} = LL\ Floor\ on\ Column\ (24.7\ k)$$

$$\frac{Live\ Snow\ Load\ (30\ psf) x\ Tributary\ Area\ (540\ SF)}{Conversion\ to\ kips\ (1000)} = LL\ Roof\ on\ Column\ (16.2\ k)$$

$$LL\ Floor\ on\ Column\ (24.7\ k) + LL\ Roof\ on\ Column\ (16.2k) = 40.9\ k$$

(3) From Level 2 to Level 1:

$$0.25 + \frac{15}{\sqrt{Number\ of\ Floors\ Supported\ (2\ floor)\ x\ Tributary\ Area\ (540\ SF) x\ 4}} = LL\ Reducing\ Coefficient\ (0.48)$$

$$LL\ Reducing\ Coefficient\ (0.48)\ x\ Live\ Load\ (80\ psf) = Live\ Load\ Reduced\ (38.3\ psf)$$

$$\frac{Live\ Load\ Reduced\ (38.3\ psf)\ x\ Tributary\ Area\ (540\ SF)\ x\ Number\ of\ Floors\ Supported\ (2\ floor)}{Conversion\ to\ kips\ (1000)} = LL\ Floor\ on\ Column\ (41.3\ k)$$

$$\frac{Live\ Snow\ Load\ (30\ psf) x\ Tributary\ Area\ (540\ SF)}{Conversion\ to\ kips\ (1000)} = LL\ Roof\ on\ Column\ (16.2\ k)$$

$$LL\ Floor\ on\ Column\ (41.3\ k) + LL\ Roof\ on\ Column\ (16.2k) = 57.5\ k$$

(4) Total Live Load:

$$LL\ Roof\ to\ 3\ (16.2\ k) + LL\ 3\ to\ 2\ (40.9\ k) + LL\ 2\ to\ 1\ (57.5\ k) = 114.66\ k$$

The results for the column loading for all twelve redesigned footings can be found in Appendix B.5.

3.6.2 Design Footings

Once the loading was established for each of the critical footings, the footings had to be redesigned. The length, width, and depth, and reinforcing of the footings had to be designed. Using the loading from the steps above, each of the twelve square footings were redesigned. An assumption was made for the rebar bar size according to the original foundation design's reinforcing. In correlation with the original design, any footing under seven feet in length and width uses a #5 bar, any footing between seven feet six inches to and including nine feet six inches uses a #6 bar, and any footing ten feet in length and width or above uses a #7 bar. Additionally, the concrete piers were assumed to square piers 24" x 24". The following sample calculations for the footing on gridlines A/2 show how each of the footings were resized:

(1) $Total\ DL\ (177\ k) + Total\ LL\ (114.66\ k) = Total\ Load\ (291.66\ k)$

(2) $\sqrt{Total\ Load\ (\ 291.66\ k) \div Bearing\ Capacity\ (5\ ksft)}\ = Length\ of\ the\ Square\ Footing\ (7.64\ LF)$

(3) Equation (2) above was repeated with different bearing capacities until the length & width for all of the footing were at a maximum of ten feet six inches or less. The bearing capacity could be at the lowest 4500 psf; however, the bearing capacity was rounded up to the next whole ksf so that the footings could be downsized further.

(4) The length calculated in Equation (2) also has to be rounded up. For this example, 7.64 LF would be rounded up to 8 LF.

(5) ASCE load combinations were used:

$$1.2\ x\ Total\ DL\ (177\ k) + 1.6\ x\ Total\ LL\ (114.66\ k) = Load\ Combination\ (395.8\ k)$$

(6) $\frac{Load\ Combination\ (395.8\ k)}{Footing\ Dimensions\ (8\ LF\ x\ 8\ LF)} = q\ (6.19\ ksf) = q\ (42.95\ psf)$

(7) Concrete Strength (f'c) either 4500 psi for exterior columns or 3000 psi for interior columns according to the current structural drawings.

(8) Solve for the smallest vc value:

$$.75\ x\ 4\ x\ \sqrt{f'c(4500psi)} = vc\ (201.25\ psi)$$

(9) Solve for d:

$$d^2\left[vc\ (201.25) + \frac{q\ (42.95)}{4}\right] + d\left[vc\ (201.25) + \frac{q\ (42.95)}{2}\right] * 24 = \frac{q\ (42.95)}{4}[Footing\ dim.(96 \times 96) - Pier\ dim.(24^2)]$$

$$d = 11.82$$

(10) Solve for the depth of the footing:

$$d\ (11.82){+}3"\ Clr.Cover + Bar\ Diameter\ (\frac{6"}{8}) = Depth\ (15.57\ inches)$$

(11) Round the depth of the footing up to the nearest whole number or in this analysis the nearest footing depth used in the original design. The original design only used the following footing depths 12", 14", 15", 18", 21", 24", 26", 28", and 30". To remain consistent, these were the only depths used in the footing redesign. In this example the footing depth would be rounded up to 18".

(12) The dimension to the center of rebar (d) is then recalculated with the new footing height 18”:

$$h\left((18)\text{ - }3"\ \textit{Clr. Cover - Bar Diameter}\left(\frac{6"}{8}\right)\right) = d\ (14.25\ inches)$$

(13) Solve for *l* and *Mn*:

$$\frac{\textit{Footing Dim.}\,(8')\ x\ \textit{Conversion to inches}\ (12")\text{ - }\textit{Pier}\,(24")}{2} = l\ (36\ inches)$$

$$q\ (6.19\ ksf)x\ \frac{l^2\ (36^2)}{2\ x\ \textit{Conversion to feet}\ (144")} = Mn\ (27.83\ ft-k)$$

(14) Solve for *a*:

$$a = \frac{AsFy}{0.85f'cb}$$

$$a\ for\ f'c\ of\ 4500\ psi:\ \ a = \frac{As(60)}{0.85(4500)(12)} = 1.31As$$

$$a\ for\ f'c\ of\ 3000\ psi:\ \ a = \frac{As(60)}{0.85(3000)(12)} = 1.96As$$

(15) Solve for required rebar area (A_s):

$$Mn\ (27.83)x(12")\ =\ 0.9As(60)[d\ (14.25)\ -\ \frac{a\ (1.31)xAs}{2}]$$

$$As\ \geq\ 0.44$$

(16) Using Table 16.2 Areas of Bars in
Reinforced Concrete Slab per Foot of Width, the bar spacing was found from the calculated As value.

(17) The rebar was then checked for shrinkage and temperature, if the As value does not pass this test, the As value would have to be increased until the test is passed.

The resulting footing calculations for all twelve footings can be found in Appendix B.6 and B.7. Table 2 shows the resulting sizes and rebar for the redesigned square footings.

Table 2 Schedule of Redesigned Footing

Summary of Redesigned Footings				
	L x W	Depth	Bar #	Spacing
A/2	8'x8'	1.5'	#6	9.5"
A/4	8'x8'	1.5'	#6	9.5"
A/8	8'x8'	1.5'	#6	9.5"
A/11	6'x6'	1'	#5	6.5"
B/1	8'x8'	1.5'	#6	9.5"
B/4	10'x10'	2'	#7	12"
B/5	10'x10'	2'	#7	12"
C/1	7.5'x7.5'	1.25'	#6	9.5"
C/2	9.5'x9.5'	2'	#6	9.5"
C/4	9.5'x9.5'	2'	#6	9.5"
C/5	9.5'x9.5'	2'	#6	9.5"
C/11	7.5'x7.5'	1.25'	#6	9.5"

3.6.3 Downsizing Remaining Footings

The remaining footings from the original design, while not critical footings to this analysis, could also be downsized since the soil bearing capacity was increased from 2 ksi to 5 ksi. Despite the remaining original footings are small enough to transport by truck, this analysis would benefit from reducing these footings as well since not only will the cost of footings be reduced, but also more footings could be transported in one delivery if the footings weight less. The twelve redesigned footings were used as precedent for determining how much the remaining footings should be downsized. The total cubic footage of the twelve footings were calculated for before the bearing capacity was reduced and then again for after the bearing capacity was increased. The percentage by which each of the redesigned footings were reduced by was calculated in Appendix B.6. This percentage was then averaged for all of the twelve footing to get a percent reduction for each footing from the 2 ksi bearing capacity to 5 ksi bearing capacity was 64%. The remaining original footings' cubic footage were then reduced by 64% as well.

3.6.4 Structural Breadth – Conclusions and Recommendations

By increasing the bearing capacity significantly, the footing were able to be reduced largely as well. For the goals of this analysis, reducing the footing sizes were critical. Unfortunately, increasing the bearing capacity by so much is by far not a simple process. Not only is the process a lengthy one, but also a very costly one. To remediate a building pad of this size would be expensive; however, since there is no way of knowing how much cement would have to be added to bring up the bearing capacity, therefore, this cost cannot be accurately estimated. Despite these additional costs, something had to be done to be able to get these precast footings delivered to site according to transportation regulations. The footings could either be cut made into sections and assembled onsite. However, increasing the bearing capacity was advised to be the most affective. Additionally, these calculations would better illustrate concepts learned over the course of study in architectural engineering program. The footings redesigned in this breadth are critical to the remainder of this analysis. The sizing determined in this breadth is used for determining the logistics, cost, and schedule for this analysis.

3.7 Delivery and Logistics –

The original plan for the placement of the footings was from west to north, east then south. The foundations were to be constructed in this order since the main building was to go up before the front entrance. However, since the footings would be place significantly quicker than the original plan and would not need curing time, this plan could be slightly alternated without derailing any of the goals that were set by this initial plan. In order to best utilize the concrete subcontractors time, productivity would benefit from being able to pull the footing straight off the truck and placing them immediately. This removes any additional time it would take to unload the footings off the truck, place them in laydown area, only to have to re-rig the footing for placement. Therefore, whenever possible the footings are to be placed straight off the truck from a delivery. To be able to accomplish this, the footings would have to arrive relatively in the order they would be place in the ground. Table 3 shows a summary of the delivery sequence, a full delivery sequence can be found in Appendix B.8.

Table 3 Delivery Schedule for Footing Redesign

Delivery Schedule			
	Footings	**Load Weight**	**Delivery Date**
Truck 1	A/1, B/1, C/1, D/1, D/2, C/2	85000 lbs	11/25/14
Truck 2	B/2, A/2, A/3, B/3, C/3	73000 lbs	11/26/14
Truck 3	D/3, F/3.1, E/3.1, F/4.1, E/4.1, D/4, C/4	74000 lbs	11/29/14
Truck 4	B/4, A/4, A/5, B/5	86000 lbs	12/1/14
Truck 5	C/5, D/5, E/5.1, F/5.1, A/6	63000 lbs	12/1/14
Truck 6	B/6, C/6, C.4/6, D/6, E/6.1, F/6.1, F/6.6, E.7/6.6, E/6.6, F/7.2, E/7.2	81000 lbs	12/2/14
Truck 7	C.9/7, C/7, B/7, A/7, A/8	78000 lbs	12/4/14
Truck 8	B/8, C/8, D/8, D/9	79000 lbs	12/5/14
Truck 9	C/9, B/9, A/9, A/10, B/10	73000 lbs	12/5/14
Truck 10	C/10, D/10, D/11, C/11, B/11, A/11	77000 lbs	12/6/14

This analysis found that the largest footings are primarily interior footings found in the center of the building. The largest footings run along the center gridlines B and C. Since these footings are the largest in dimension, they consequently weight the most. For the delivery of these footings to site, the most effective use of the truck would be to split up the largest footing amongst deliveries, transporting them with smaller footings. To best split up these footings, the placement of the footings would weave through the numbered gridlines instead of following the lettered gridlines. Figure 11 shows the sequence for the placement of the footings. This figure also shows how by using this sequence the largest footings will not have to be delivered all at once. Instead worst case, a truck will have to take three large footings at one time.

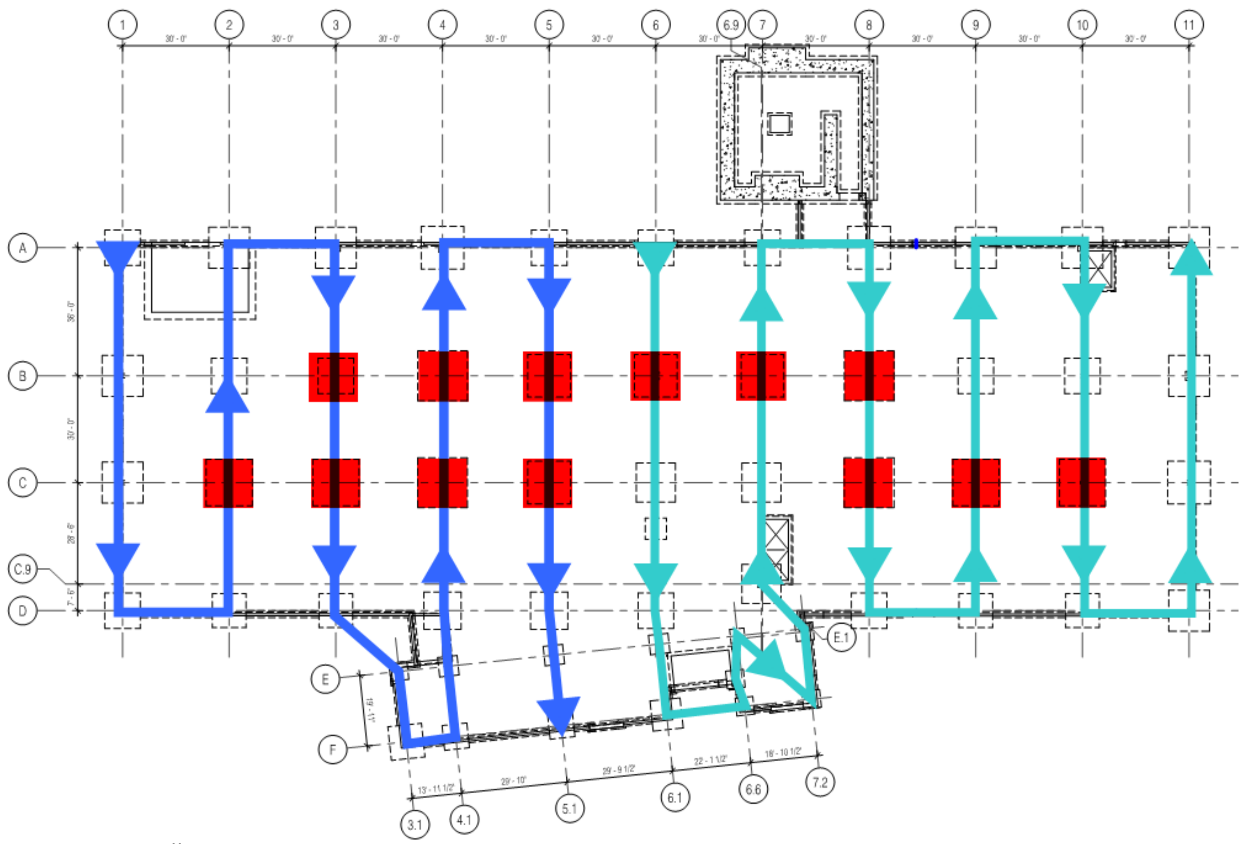


Figure 11 Installation Sequence

In order to be able to place all of the footings, a 150T mobile crane was rented for the site. The crane specifications can be found in Appendix B.3 and the cost in Appendix B.11. This mobile crane is the same type and size that was rented for the steel erection. Using these crane specifications, based on the weight of the precast footings, the crane would have to be moved once during the placement of the footings. This ensures that the crane can safely pick all of the footings. Appendix B.4 shows the two crane locations for the placement of the footings.

3.8 Schedule Comparison –

The GMP schedule following the revisions made for the delayed start, had the foundations beginning to go in November 24, 2014. As mentioned earlier in this analysis, the project team was hopeful that the foundations would take the same duration of 39 days that they were supposed to take in the original GMP schedule when the foundations were being placed in the summer. Unfortunately due to other delays and weather days, the foundations instead took 54 days. The goal of this analysis was to look at a way to accelerate this construction sequence for the placements of the foundation.

The excavation and fill requirements remain fairly consistent between the two systems. Actually since the footings were reduced in size by 64%, there is substantially less excavation and gravel fill needed for each of the footings. According to the DPR project team, since the footing are over half the size they originally were, the excavation duration could be reduced by at least half as well. Excavation and gravel fill could be completed in a week and a half or seven days. Two days for each third of the building's footings excavation and gravel fill. After the first two days, following the completion of a third of the building's footings, the precast footings can begin arriving to site. This way the precast footings in the first third of the building starting from the west wall can be placed while the excavation on the remaining two thirds continue. This excavation duration only includes the time to dig the footings and excludes the duration for the foundation wall. This duration also does not include surveying time since this duration is not included in the foundation line item in the GMP schedule, and it would remain constant for both systems.

By using precast footings, the time constructing the footings onsite should be significantly reduced. Since there is no RS Means cost data for precast footings, the production rates for placing these footings had to be taken from industry experience. In conversations with the project team on the Health Science Facility III in Baltimore, MD, they estimated that could place approximately six footings a day more or less, depending on the size of the footings that day. These estimates are based on their production rates for the installation of their precast system. Arban & Carois, the precast erectors on their project were able to set on average 87000 lbs of precast in an eight hour day. Since each truck load is around this weight, on average a truck load of footings could be placed in day. This is approximately six footings per truck. The schedule shows six footings placed every day, with the exception of four work days that only place five footings, one work day that only places four footings, and one work day that places seven footings. In addition, one day only places three footings, but this is because the crane needs to be moved to the second location on that day as well. The work days with fewer than six footings are mostly due to the large footing sized being place those days. Additionally, having a few days that place less footings than six, leave a buffer for the team to catch up if they fall behind at all. The deliveries also have something to do with production sequence of this activity. If at all possible, there is only one delivery made each day. For the sake of production, some days have up to two deliveries being made, but that is not the preferred method since it hurts productivity as explained either, and therefore, avoided if possible. Following the precast footing placement, the piers would be poured onto stubbed up rebar on the precast footing. The piers are concrete two feet by two feet for all footing sizes to remain consistent. The formwork for the piers could be used up to four times, since all the piers are the same size. The piers are poured consecutively following the placement of a day's worth of footings, allowing for the piers to set and the formwork to be reused on another footing.

With this sequence, the entire schedule for the footing placement is only two weeks, 13 days. The full schedule can be found in Appendix B.13. This includes the two days to start excavation then eleven days for the footing placement. In addition to these two weeks, the DPR project team expressed that an additional two weeks would be needed to conduct the necessary soil remediation. However, since soil remediation to increase the bearing capacity to 2 ksi had to occur already for the original system, the soil remediation to bring the bearing capacity up to 5 ksi could be included in this time and not an additional duration to the project. This timeline is considerably shorter than GMP schedule for this project. Additionally, this construction has a far less likelihood of being interrupted by weather days since the concrete has already cured. The precast footing schedule does not include the duration for the foundation wall placement. The foundation wall was ultimately not precast for this analysis because not only are there far less precedent cases for precast foundation walls, but it would also be far more complex than just constructing the wall onsite. Whereas precast footings are not as difficult in comparison to the traditional cast-in-place footing with the exception of how the footings are transported.

3.9 Cost Comparison –

While the cast-in-place footings were expected from the onset of this analysis to be cheaper than that precast footings, the precast footings surprisingly did not cost excessively more than the cast-in place footings. Table 3 shows the resulting summary for the cost comparison of the cast-in-place footing versus the precast footings, for the full cost comparison see Appendix B.10.

Table 3 Cost Comparison for Footing Types

Summary of Cost Comparison for Analysis I		
	Cast-in-Place Footing	**Precast Footing**
Concrete	$60,000	$29,000
Rebar	$23,000	$23,000
Placement	$8,500	$5,500
Formwork	$0	$45,000
Earthwork & Fill	$7,000	$6,300
Miscellaneous Costs	$11,000	$11,000
Transportation	$0	$1,200
Crane	$0	$41,000
Total System Cost	$110,200	$161,800

The precast footings were ultimately $50,000 more than the cast-in-place footing. With this said, there is a significant cost for the soil remediation to bring the soil up to 5 ksi bearing capacity. This additional cost while critical to this analysis, would ultimately be a random estimation since the initial soil type determines how much cement will need to be added. This process of soil remediation would have to actually occur to determine what that remediation would entail.

In terms of the footings alone, the cost variation between the two systems was reduced since the precast footing would use much less concrete due to the foundation redesign. Since the precast footings were able to be redesigned due to soil remediation to increase the bearing capacity of the soil, the footings were able to be reduced by on average 64%. By reducing the footing size, the quantity of concrete and rebar would be reduced as well. All quantity take-offs can be found in Appendix B.9. Concrete was able to be reduced between the two systems; however, rebar remained the same for two reasons. The first being that getting the exact size of the downsized footings was tricky and not perfectly accurate. Additionally, the second reason the rebar was kept the same is that since the rebar recalculation would not be perfectly accurate, the original number would just be a worst case scenario for the alternative system. Placement was also cheaper for precast footings because once again the footings were smaller, which meant less concrete had to be placed. The miscellaneous costs are consistent between both systems because these costs just include the cost of the base plates and anchor bolts.

The remaining costs including formwork, transportation, and crane rental were just for the precast footings and not for the cast-in-place footings. The formwork and crane were especially costly at over $40,000 each. The crane costs were able to be pulled from the rental costs for this crane used in structural steel erection, as seen in Appendix B.11. Transportation was less expensive. This cost for transportation was found using a research from the American Transportation Research Institute in their study titled “An Analysis of the Operational Costs of Trucking,” found in Appendix B.12. In addition to these transportation costs, there are a three permits for the three overweight deliveries. Despite all of the additions, the precast footing system was only $50,000 more not including soil remediation. For the amount of time the project was able to be accelerated by using precast footings, this added cost seems less significant.

3.10 Conclusions and Recommendations –

While the initial goal to reduce the project schedule was met by utilizing precast footings, using precast footings is not recommended for this project. The major reason this method is not recommended is due to the owner’s project goals. The scope of work for this project is split into Core & Shell and Tenant Interiors, which is extremely common for medical office facilities such as this one. The developer Frauenshuh is funding the Core & Shell not the primary tenant. While the schedule does contribute to the total cost of the project, the Fraeunshuh does not benefit greatly from accelerating the schedule significantly. Their primary goal is keeping the cost of the project down. The primary tenant on the other hand is more interested in opening on time or even earlier in order to start making money as soon as possible. Since Fraeunshuh is most concerned with keep costs low, it would be in their best interest to keep the foundation system cost low. While the costs for the precast footing system is not that much more than the cast-in-place system, Frauenshuh would have to pay a significant amount for the soil remediation to increase the bearing capacity.

Despite not being recommended for this project, precast footings could be extremely beneficial for other projects. For projects with sustainably quick timelines or those that could benefit greatly from being constructed quickly, this analysis shows how quickly a foundation system could be erected. For this project, the footings could be placed in just around two weeks. Unfortunately, this foundation had fairly large footings due to the low bearing capacity of the soil. If the footings were smaller, either because they had less load to carry or the bearing capacity of the soil were higher, precast footings would become far more feasible. As prefabrication construction becomes more common, precast footings are expected to become far more affordable and standardized.

Section 4 | Analysis II – Prefabricate or Preassemble the Building Envelope

4.1 Opportunity Identification –

The façade system for this building was greatly value engineered to determine the most cost effective design. Ultimately, the final façade design had substantially fewer metal panels and curtain wall components than Perkins +Will had originally hoped for. Instead, many of the metal panels were replaced by brick veneer and the curtain wall with storefront windows or ribbon windows. Ultimately to maintain the schedule, temporary weather protection measures had to be put in place for several months so that the project team could install and finish drywall. This sequence is often avoided because installing drywall and electrical equipment in a building before officially watertight is more risky and difficult to maintain. To help remove this risk from the contractor, this analysis will look at the potential to get the building watertight sooner. By accelerating the skin of the Community Healthcare project, this building could continue with interiors without the need of temporary dry-in methods.

4.2 Research Goals –

The traditional method for installing the exterior metal framing and sheathing is not able to dry-in the building in time to meet the project's tight schedule. Instead the project team had to install temporary conditions in order to move forward with construction. This practice is avoided whenever possible because the construction manager has to assume more risk. This analysis instead looks at establishing a quicker method for making the building watertight. The goal of this analysis is to research an alternative method for installing the exterior wall assembly in hopes that the project can be closed in before interior work has to begin.

4.3 Methodology –

Research

1. Research the use of prefabricated exterior wall assemblies.
2. Investigate potential assemblies used in prefabricated skin systems.
3. Research situations preassembly onsite was used over the traditional method of installing directly to the building.
4. Evaluate whether to pursue prefabrication versus preassembly technique.

Technical Analysis

1. Establish a cost comparison of the traditional method being used and the selected alternative method.
2. Develop production plan for panel installation.
3. Investigate the schedule impacts the alternative system would produce.
4. Consider safety of one system over the other.
5. Provide recommendations on which means and methods provide the best value to the project based on the investigated factors.

4.4 Background Research –

Preassembly and prefabrication of exterior framing and sheathing are increasingly being used on projects versus traditional installation methods. The skin for this project includes cold formed metal framing with gypsum sheathing. There are local warehouses that could prefabricate this system, additionally there is ample laydown area onsite for this assembly. By prefabricating this assembly, not only could the enclosure be accelerated, but also the workers could benefit from increased safety by use of this method.

Another potential method for assembling the building's skin is in preassembling sections of metal framing and sheathing onsite then installing these completed sections on the building's perimeter. Since there is ample space onsite to complete this task, the framers could benefit from creating these assemblies since their fall risk would be reduced through this method. Preassembly has also often proven to be quicker than building the assembly directly due to simpler constructability of the assembly since the area would have better accessibly.

The Pennsylvania State University has built a few projects on their University Park campus using a panelized exterior framing method. The Penn State Intramural Building, built by Mortenson, used panelized framing to accelerate the exterior framing. Additionally, DPR Construction will be panelizing the exterior framing and sheathing for the Penn State Agricultural Engineering Building. DPR Construction is implementing this construction method in order to close in the building more quickly. They are using a subcontractor known as Wyatt Incorporated from Pittsburgh, PA to preassemble the panels. Both teams at Penn State acknowledge that these panelized assemblies are more costly upfront, but ultimately save the project money by accelerating the project schedule.

In terms of panelized façade systems, these assemblies can come in many different forms. These panels can come prefabricated as minimal as just the framing or as involved as the full assembly: drywall, framing, insulation, sheathing, air barrier, and façade. Depending on the project, this range of completed assembly gives project teams' different opportunities to implore the best product for their budget and schedule. For the Community Healthcare project, the project schedule was extremely critical to the project's success. It was critical to the primary tenant to open the facility as early as possible. To be able to best meet these goals, the DPR project team decided to provide temporary dry-in conditions for 30% of the building's façade so interior drywall could start being hung earlier.

4.4.1 Literature Review for a Safety Analysis –

In the early 1990s, the construction industry started getting considerable notice and backlash for occupational hazards. This backlash led to a series of case studies into the causes of these construction accidents especially coming out of Europe. A study conducted by the European Foundation in 1991 found that 60% of construction accidents analyzed could have been eliminated or decreased through thoughtful design decisions (Toole M., et al. (2006)) Another study fund that smart design decisions could have lessened the likelihood of 47 out of 100 construction projects examined (Toole M., et al. (2006)). These case studies along with others led to the creation of a new thought process that became known as Designing for Construction Safety (DfCS), also referred to as Prevention through Design (PtD). This method formalized a process for making safety not only everyone's responsibility but also bringing safety to the forefront of design decisions. The United Kingdom has been utilizing this process since 1995; however, the US has been less devoted to the shift in thinking in past years.

According to "The Future of Designing for Construction Safety" by T. Michael Toole and John Gambatese, prefabrication has proven to improve cost, schedule, performance, and safety. It improves safety for two major reasons. The first reason that prefabrication increases safety is by moving the work to a location with a more controlled environment that has a lower risk of hazard. In the case of installing exterior metal framing and sheathing, by assembling the panels offsite, there is less exposure to fall hazards. The other major reason prefabrication is cited for being safer is that factory conditions allow for more controlled use of equipment. When equipment is used in the factory versus onsite, workers are at a lower risk for hazards from regulated equipment safeguards and ventilation. For all of these reasons, prefabrication is expected to increase in usage over the next decade. Safety should always be the most important driver of construction decisions, so why is it not the most important deciding factor during design as well?

4.4.2 Literature Review for Minimizing Construction Waste –

Not only has prefabrication been noted for improving safety of a construction project, but it also has been used to reduce construction waste. In 1998, Hong Kong launched a ten-year Waste Reduction Framework Plan (WRFP), in order to minimize landfill since these areas were limited (Tam, C. M., et al.). Part four of this of the WRFP was focused on reducing construction and demolition waste by better design and construction (Tam, C. M., et al.). Prefabrication was a proposed solution to this waste management plan. Prefabrication is cited in the article "Use of Prefabrication to Minimize Construction Waste – A Case Study Approach" published in the *International Journal of Construction Management* for benefits including waste reduction, shorter construction duration, better quality, overall lower construction cost, and improved safety. This case study looked at the results from Hong Kong implementing their WRFP, also stating that "factory production can reduce wastage and encourage recycling of construction waste, leading to environmental protection and sustainability." This article argues that diligent site management of onsite fabrication is a passive defense for reducing construction waste while prefabrication is "proactive in nature." In fact the prefabrication of façade systems were noted as the "most common prefabricated item." This case study focused on four projects that implemented various forms of prefabrication: a 31-story hotel, a 48-story residential building, an 88-story office building, and a 36-story office building, all in and around China. The study found all of the projects were able to significantly reduce their construction waste through the use of prefabrication.

The journal *Waste Management* published an article about prefabrication in Hong Kong for the reduction of construction was as well, titled "Quantifying the Waste Reduction Potential of Using Prefabrication in Building Construction in Hong Kong." Over the past two decades since the WRFP was instated in Hong Kong, their construction and demolition waste sent to landfill was able to be reduced considerably as shown in Waste Management's chart, Figure 13. With this being said the United States has significant room to grow in their construction and demolition waste management practices as well. Figure 12 shows the average construction and demolition waste by country with the US at 136 million tons in 1996, which is almost 76% of all of construction and demolition waste for all of Europe. With this being said, it is important to note that the construction industry has improved in waste management since the LEED craze in the early 2000s; however, there is still progress that can be made. Prefabrication is proven method that has been shown to reduce construction waste.

Country	C& D Waste (m tonnes)	% Reused/ recycled	% Incinerated/ landfilled
Germany	59	17	83
UK	30	45	55
France	24	15	85
Italy	20	9	91
Spain	13	<5	>95
Netherlands	11	90	10
Belgium	7	87	13
Austria	5	41	59
Portugal	3	<5	>95
Denmark	3	81	19
Greece	2	<5	>95
Sweden	2	21	79
Finland	1	45	55
Ireland	1	<5	>95
Luxembourg	0	n/a	n/a
Europe-15 (Symonds Group Limited, 1999)	180	28	72
US in 1996 (Franklin Associates, 1998)	136	30	70
Hong Kong in 1999	13.55	79	21
Hong Kong in 2005	21.45	89	11
Singapore in 1999 (MEWR, 2006)	0.41	70	30
Singapore in 2005	0.49	94	6

Figure 12 Average Waste by Country

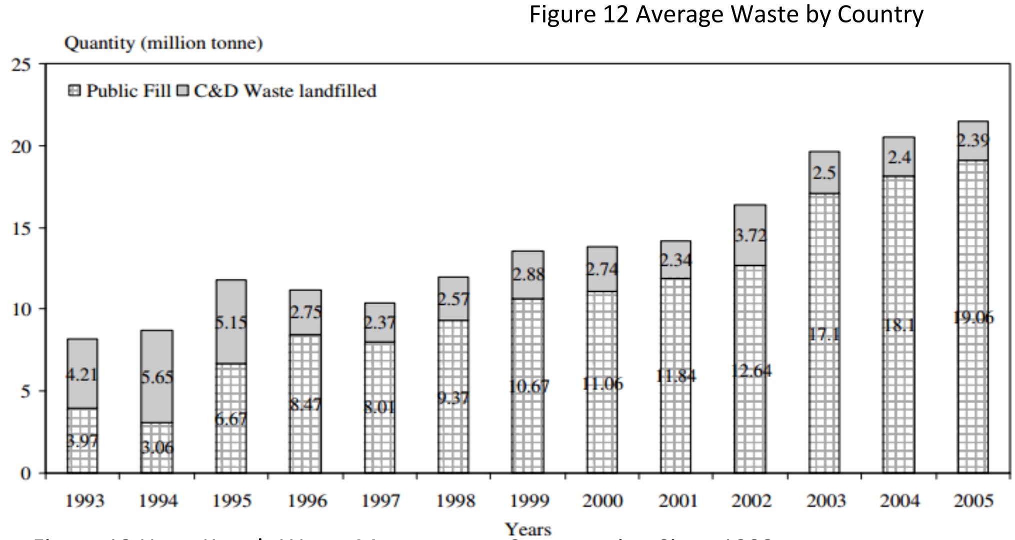


Figure 13 Hong Kong's Waste Management Consumption Since 1993

http://ac.els-cdn.com/S0956053X08000718/1-s2.0-S0956053X08000718-main.pdf?_tid=10150630-f9cd-11e5-b01000000aacb360&acdnat=1459709664_e90b26bec3df7945c79e527b1bfa807a

4.5 Feasibility Study & Panel Layout –

The road regulations for the delivery of the panels were already established in Analysis I, that analysis found that the maximum load width is 8'-6" and a maximum height of 11'. Generally, the panels are designed to be a maximum of ten feet wide to ensure the panels meet the maximum eleven foot height requirement. However, the panels can be a maximum of 15' wide since they can be loaded on an angle and meet the road requirements. Additionally, Wyatt Inc. verified that the panels generally range from 10-15 feet in width. The maximum length of the load is 53', which means that the panels' length cannot exceed 53'.

Knowing these maximum panel sizes, the panels were laid out based on these dimensions and the order in which they would be installed. The widest panel is 11'-9" and is located on the north elevation, the longest panel is 46'-4" and is located on the east elevation. The front entrance is not included in the panel layout since the majority of the metal panel and glazing in that location are part of a curtain wall system. Appendix C.1 shows the panel layout and overall panel dimensions. The panels are color coded by the day they would be installed. According to the project manager of DPR Construction for the Penn State Agricultural Engineering Building, Wyatt Inc. can place on average five panels a day. The panels on the Agricultural Engineering Building are of similar size to the panels on this project.

4.6 Schedule Impacts –

The panels would be installed beginning on the west façade then moving to the north, west, then south, in the same order the framing would be installed. The panels are installed in this order since the west side will take the longest to finish since it has the most glazing due from the curtain wall assembly at the front entrance. There is little framing required for the curtain wall system, so it has been assumed that any framing work in this area can be completed during the seven days it takes to install the panels on the west elevation. Once the panels are placed the remaining façade can be installed in the same order as the dictated in the original project schedule; therefore, all of the durations can be carried over as well from the project schedule. After the panels are installed, the spray on barrier is applied, then the brick and precast sills are installed, followed by the punched windows and curtain wall installed concurrently with the metal panels, and then caulking. Figure 14 summaries the installation sequence of the façade system. All of the building elevations are installed independently of each other once the panels are placed. Appendix C.3 shows the P6 Schedule for the alternative preassembled panel system.

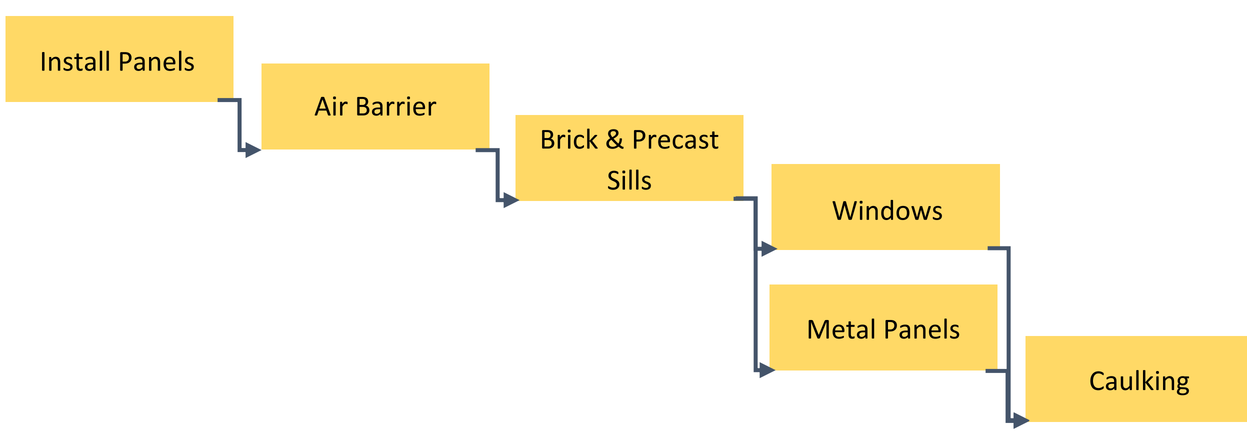


Figure 14 Façade Installation Sequence

The GMP project schedule has a duration of 94 days for the installation of the building façade system and occurs from May 21, 2015 to September 15, 2015. For the proposed preassembled panel system, the alternate schedule would occur from May 21, 2015 to August 12, 2015, for a duration of 60 days. These results are summarized in Table 4 below. Not only does the panel installation save the project 34 days, but also by finishing the exterior façade by August 12, 2015, the building can be dried-in before drywall is hung, which begins on August 4, 2015. The building would be closed in by August 4, 2015 with only final caulking occurring after August 4th. By ensuring the building would be watertight, the project team would be able to reduce their risk of damage to interior finishes specifically finished drywall.

Table 4 Summary of Exterior Framing & Sheathing Installation Schedule

Summary Panelized Façade Schedule		
	Traditional Install	**Preassembled Install**
Start Building Skin Date	May 21, 2015	May 21, 2015
Finish Building Skin Date	September 15, 2015	August 12, 2015
Duration (days)	94	60

4.7 Production Analysis –

To install the exterior metal framing and sheathing in the traditional installation method, the project had ten carpenters working on each side of the building. The carpenters were installing this work via boom lift. By moving the majority of the fabrication of the panels offsite, the manpower onsite was able to be reduced to five carpenters and a foreman per side, for the placement of the panels. This manpower was provided by the panel installers Wyatt Inc. to the DPR team for the Penn State Agricultural Engineering Building. According to Wyatt Inc., the panels would be placed by crane, with two workers rigging, two workers setting and placing the panels, one carpenter foreman, and one crane operator. The remaining manpower would remain consistent with the manpower provided by the superintendent for this project for all of the other activities. This included two roofers installing the air barrier on the north and south sides and three for the west and east sides. Fifteen masons are needed to complete the brick veneer on time for each elevation. The west side needs seven laborers and one foreman for the installation of the curtain wall and windows, while the north and south side have four laborers and one foreman, and the east side five laborers and one foreman. The north and south sides only need three workers installing metal panels, and the east and west sides need five workers for this same task. Finally, three workers are needed to do finish caulking on the long sides, and only two for the short sides.

The manpower curve in Figure 15 displays the man-hours for this alternative construction method. This shows that the manpower peeks the week of June 28, 2015 with 2000 man-hours. The curve looks similar to the manpower curve for the traditional installation method, but this method is saving a considerable amount of man-hours. Not only are less carpenters needed for the installation, but also these carpenters are needed for a shorter duration. Less man-hours results generally in lower labor costs and lower risk for recordable incidents.

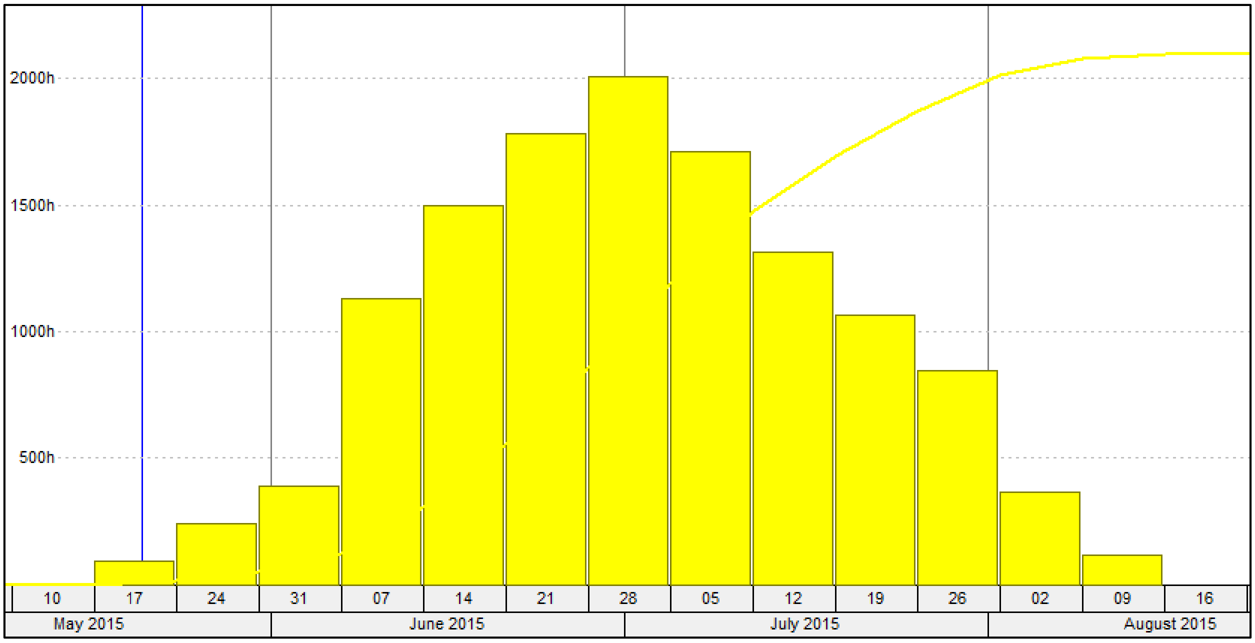


Figure 15 Manpower Loaded Curve

4.8 Cost Comparison –

While the panels were able to accelerate the building enclosure, this alternative construction method was anticipated to cost more based on conversations with both the DPR Construction and Mortenson project teams. The original installation method cost $361,500. Included in this cost was the exterior metal framing and sheathing, the in-wall insulation, and the fluid-applied membrane air barrier. Table 5 uses these system costs to find the cost per square for each of these materials. Square foot costs for the alternative construction method of preassembled panels were carried from the square foot costs provide to the DPR Construction team from Wyatt Inc. Besides the additional cost for the panelized system, the remaining materials and installation of the façade remains constant between both systems. Once the panels are in place, all construction methods are the exact same for both systems, the panels do not require any additional measures to be taken to install the remaining exterior assemblies. Therefore, the remaining façade elements including but not limited to the brick veneer, precast sills, glazing, metal panel, and caulking, would cost the same and were not included in the cost comparison of the two systems as they would cancel each other out. Appendix C.2 has the complete cost comparison of the two systems.

Table 5 shows how the preassembled installation technique for the panels contributes to an additional $10.21 per square foot. This additional cost includes all associated panels cost including but not limited to, the factory yard space, transportation, and delivery fees. In total, this results in a $634,735 cost for the exterior metal framing and sheathing, which is almost a 23% add to the exterior skin cost, but only a 3.8% add to the Core & Shell contract value or 2.5% to the total project cost. The crane used for this project was a 150 Ton mobile crane with a 187 foot boom. This crane has the capacity to place these panels at a cost of $2,600 a day. The crane would be needed for twenty days which is the full panel erection duration for a total crane cost of $52,000. Meanwhile the project team did have to supply temporary enclosures for approximately 30% of the skin which included about $12,000 in labor and materials as well as almost $6,000 for temporary roofing. While this is a small cost, there was risk that DPR could have incurred if the interior work were to get damaged in the event that the temporary enclosure failed. Typically, this is a risk that contractors attempt to avoid by ensuring that the building is watertight; however, due to the quick fifteen month timeline for the project, meeting the schedule was of greater priority.

Table 5 Cost Comparison of Alternative Penalization Method

Square Foot Cost Comparison		
	Traditional Install	**Preassembled Install**
Exterior Metal Framing, Sheathing, & Insulation	$7.18/SF	$17.39/SF
Air Barrier	$2.72/SF	$2.72/SF
Total SF Cost	$9.90/SF	$20.11/SF

The project's traditional installation method while less expensive does take considerably more time to install. There is cost associated with this longer duration however, this value is difficult to quantity in this scenario. However, the schedule was critical enough that the project took on the additional risk of temporarily enclosing the building to keep the project moving forward. This risk was not one that the project team on the Penn State Agricultural Engineering Building is willing to take. For the project team on the Community Healthcare facility, the temporary enclosure paid off and was ultimately a necessary risk; however, this alternative exemplifies the cost required to still meet the schedule and also mitigate risk.

4.9 Conclusions and Recommendations –

Due to the project's short construction schedule of just fifteen months before delays incurred, the project had to use temporary enclosure measures for about 30%. While the cost for these temporary conditions were not a significant amount, the DPR team was taking on some additional risk by installing drywall before the building was permanently watertight. This analysis looked into alternatives that could get this facility dried-in before drywall was hung. By panelizing the exterior framing and sheathing, the building would be closed in before drywall is hung on August 12th.

As expected, this alternative construction method of panelizing the façade would cost additional at 2.5% of the project cost. Despite this cost, prefabricating the exterior framing, sheathing, and insulation would be recommended not only for the schedule savings, but also for the added site safety prefabrication brings to a project. According to OSHA, falls are the leading cause for construction related accidents. The façade installation is an area where fall hazards are especially prevalent. By prefabricating these panels, the manpower for these activities can be shifted offsite, and the fabrication of these panels would be in a low hazard controlled environment. Safety should be the upmost driver of decisions in both design and construction, but the industry is still driven largely by cost and schedule. By panelizing the exterior framing, sheathing, insulation, the project would take a small budgetary hit but would benefit in areas of schedule, safety, and waste management, which makes this construction method recommended.

4.10 Skin Analysis (Lighting Breadth) –

Through this project's various design iterations, the project's exterior façade was value engineered to the current balance of glazing, metal panel, and brick veneer. In order to drive down cost, the project team removed most of the original design's windows on both the north and south facing walls. Figures 16-19 show the façade during schematic design versus final façade design for the construction documents. These designs show how much glazing was valued engineered out especially on the first level. While there is cost savings in the using less glazing material, there may have been daylighting benefits that were discounted due to the ultimate savings. When value engineering a project, weighting all positives and negatives before making a final decision is critical. This study looks at better understanding how the different façade designs contribute to the daylighting of the spaces on the first floor. The first level will be the focus of this study because this level has shown the most change between the schematic design and construction documents.

Daylighting over the past two decades has received significant attention for its effects on occupant health. Outside views and natural light in healthcare buildings "were found to have an important stress-reducing effect, where they can reduce pain and length of stay at hospitals" (Sherif, Ahmed, et al.). Additionally, Ulrich (1991) discovered that natural light and outside views in these facilities have been shown to reduce stress and the effects there of. Then in 2004, Ulrich and his associates found that in a study of 600 cases, patients and staff reported that that these connections to the natural environment reduced stress and fatigue, increased staff effectiveness in providing care, increased patient safety, and overall improved the quality of service provided. As a healthcare facility, this project could greatly benefit from proper daylighting according to the research done by Ulrich and other researchers. This study should prove the importance to proper daylighting to potential tenants of these spaces and in turn to the developer, Frauenshuh.

To better understand the daylighting in the schematic design versus the final design, AGI modeling software was used to simulate daylighting for both designs. Since only the architect, Perkins +Will had access to the design models, the first step in this study involved making simplistic models of the first floor for both design iterations. Once these models were created they were brought into AGI to run daylighting studies on. Table 6 shows the various reflectance assumptions made for the study. Additionally, the glazing had a 0.65 transparency, for the specified Kawneer 1600 glazing system used on project. The calc points were taken for the surface plane that was consistent with the usage of the space. For corridors, lobbies, or waiting spaces, the light level at the floor surface is the most critical to the usage of the space. However, in laboratory, exam, offices, or procedure rooms, light level at the work plane is the most critical; therefore, the daylighting calculations for these spaces were done at 2'-6" off the ground. By defining the task level for each space, the light levels critical to the use of that space could be more accurately calculated.

Figure 16 Schematic Design West Façade *(above),* Construction Documents West Façade *(below)*

Figure 17 Schematic Design East Façade *(above),* Construction Documents East Façade *(below)*

Figure 18 Schematic Design North Façade *(above),* Construction Documents North Façade *(below)*

Figure 19 Schematic Design South Façade *(above),* Construction Documents South Façade *(below)*

Table 6 AGi Material Assumptions

Material Assumptions	
Surface	**Reflectance**
Ceiling	0.8
Floor	0.2
Walls	0.5

In order to evaluate the value of the windows to the interior spaces, at least one space was studied on each face of the building. The main lobby at the front entrance of the building was a major space of interest as it is the first experience many visitors will have when arriving at this facility. Between schematic design and construction documents, this was one of the few locations that glazing was added to the façade versus removed. The additional curtain wall added to the design would have cost the project glazing in other locations; therefore, this study looked at ensuring the solar gain from added curtain wall was worth removing glazing elsewhere.

Table 7 shows the results for the daylighting study for the main lobby. The main lobby's light levels were calculated for both the schematic design and construction documents' design during the summer and winter solstice since these days provide the two daylighting extremes. Since the additional curtain wall was added to the west wall in the construction documents, the lobby saw significantly more illuminance in the current design. Not does the current design have substantially higher light levels, but also the lobby space is actually partially open to the second level, which is not depicted in the model used for the daylighting calculations. With this additional level, the daylighting levels would be expected to be even higher since daylighting from the second floor would also contribute to the light levels in the lobby. The light levels at the summer solstice were so high in some areas that the curtain wall could be actually be providing too much solar gain in the summer months, which would increase the cooling demand.

Table 7 Illuminance Summary for Lobby Daylighting Study

Lobby				
Illuminance (Fc)	**Schematic Design Jun21**	**Construction Documents Jun21**	**Schematic Design Dec21**	**Construction Documents Dec21**
Average	28.51	658.31	212.55	329.74
Maximum	122	9252	1389	4948
Minimum	9.0	21.5	11.6	23.3
Avg/Min.	3.17	30.62	18.32	14.15
Max./Min.	13.51	430.31	119.77	212.36

Another space that was analyzed in this lighting study was the Outpatient Cancer Center located in the southwest corner of the building. This area was particularly critical due to its location and potential for solar gain. In general the storefront windows on both designs are almost the same on the south side, however, there are far more windows on the corridor on the west side leading into the Cancer Center. Table 8 shows the results of this study. Once again this study looked at both the summer and winter solstice. The results were found to have fairly similar light levels in the Cancer Center, but as expected the solar gain in the schematic design's west corridor was significantly higher, acutely double the foot-candles due to the extra windows. However, this higher illuminance is fairly unnecessary because the windows in the construction documents' design still provides enough light for the corridor. Additionally, while the original design for the space provided higher light levels, the redesign was still able to provide enough daylight to open opportunities to install dimmer controls for energy savings. Additionally, the light from the redesign was more uniform than the initial design, with an illuminance average of 293.66 foot-candles in the summer and 271.17 foot-candles in the winter. Overall the redesign provided substantially less daylighting to the corridor, but the storefront windows that remained in the design for the Outpatient Care Center still provided about the same amount of light to lobby of the center. Both spaces however still appear to have high enough light levels in the redesign to offer potential energy saving by reducing the lighting load.

Table 8 Illuminance Summary for Outpatient Cancer Center Daylighting Study

Outpatient Cancer Center				
Illuminance (Fc)	**Schematic Design Jun21**	**Construction Documents Jun21**	**Schematic Design Dec21**	**Construction Documents Dec21**
Average	348.09	293.66	423.57	271.17
Maximum	2733	2728	1411	1405
Minimum	22.2	28.9	22.4	27.8
Avg/Min.	15.68	10.16	18.91	9.75
Max./Min.	123.09	94.40	62.98	50.55

The Infusion Center was another area that was analyzed for its daylighting potential. The Infusion Center is located in the southeast corner of building. Between the original design and current design, the windows on that face of the building were laid out significantly different. The schematic design of the east windows consisted of several punched windows, while in the final design, the windows were changed to ribbon windows to match the window spacing on the second and third floor. The change in design led to far less windows on the north side of the east façade, but around the same amount of glazing remained on the south side of the east wall. This meant that the rooms on the north side including the MRI and CT would see no daylighting in the current design. When the daylighting study was conducted on the two designs, the schematic design was able to achieve higher light levels than the final design, but in general there is substantial solar gain in both designs. The Infusion Center receives so much solar gain especially in the winter months, the space will likely experience the benefit of passive solar throughout the winter. This could potentially reduce the heating load required for this space in the future.

Table 9 Illuminance Summary for Infusion Center Daylighting Study

Infusion Center				
Illuminance (Fc)	**Schematic Design Jun21**	**Construction Documents Jun21**	**Schematic Design Dec21**	**Construction Documents Dec21**
Average	355.21	315.99	2303	2223
Maximum	750	686	4690	4633
Minimum	135	115	165	144
Avg/Min.	2.63	2.75	13.95	15.40
Max./Min.	5.55	5.97	24.40	32.11

The north side of the project was studied as well for daylighting potential since almost all of the windows were removed from this face of the building. However, the daylighting study for the schematic design proved, as expected, that the north facing windows would not produce any significant daylighting that could be utilized in place of lighting fixtures. Therefore, it can be concluded that this project did not lose out on much solar gain from the window redesign.

4.10.1 Lighting Breadth – Conclusions and Recommendations

The goal of this breadth was better understand the benefits that daylighting can provide to occupant health and how the façade redesign affected the solar gain to this facility. Value engineering methods tend to focus around issues of cost and schedule, which can often discredit design decisions. In an effort to make more educated decisions, project teams need to be aware of aspects of the design outside of the cost and schedule implications. The benefits of daylighting for both occupant health and energy savings is a growing topic of interest in the construction industry. This low cost project looked heavily at cutting costs whenever possible, going through several design iterations to get to the final design of the façade system. In doing so, a large portion of glazing was removed along with metal panels and replaced by brick veneer to get to current design. In this redesign, the project was able to save 0.7% of the contract value, or 4.5% of the exterior skin package.

Since the savings were not extremely significant, the daylighting benefits were compared between the original design at schematic design and the final design found in the construction documents. Since the majority of the windows were changed, daylighting studies were taken from all faces of the building. Ultimately, the study found that with the exception of the west façade, the final design produced lower light levels in all of the interior spaces. The west wall was different because more glazing was added to the curtain wall system in the main lobby. Despite the redesign producing lower light levels, the majority of the studied spaces would still receive enough daylighting to potentially benefit from passive solar or a reduced lighting load from dimming controls. The final design created a more consistent window layout and was able to move glazing from the first level to the second and third level. By moving the glazing to the second and third levels, the windows were used to illuminate corridors on the second floor and exam rooms or office spaces on the third floor.

Section 5 | Analysis III – Masonry LINAC Vault

5.1 Problem Identification –

The linear accelerator (LINAC) vault was originally not including in the programming of this facility. However, upon the request of the primary tenant, the LINAC vault was added to the scope of work for the Core and Shell package but paid for and furnished by the tenant. Since this facility would ultimately include a large Outpatient Cancer Care Center, the primary tenant decided that this equipment was necessary to the programming of their new facility. The LINAC vault design along with the design of the other medical equipment rooms were contracted directly to a separate firm instead of Perkins +Will. This specialty firm selected a standard concrete assembly for the vault. This design requires a minimum 4' thick concrete walls and up to 7'-6" thick to prevent radiation from the machine from leaving the chamber. This layout is shown in Figure 20 and in more detail in Appendix D.1.

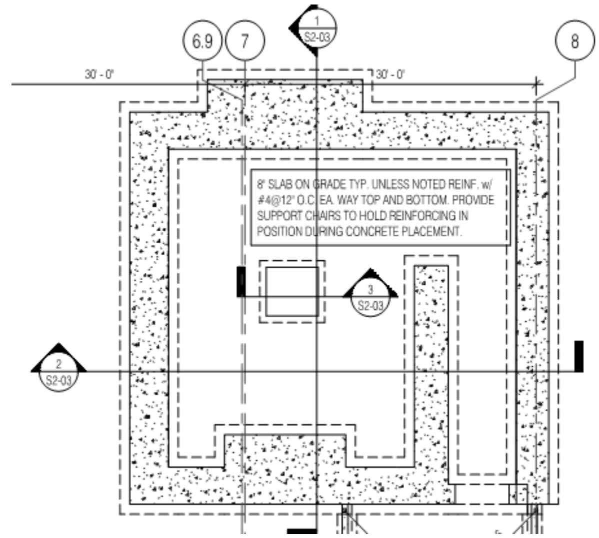


Figure 20 Concrete LINAC Vault Design

While the addition of this equipment does not sound like a major issue, at the time this change was made, the structure of this facility had already been finalized. During early design, a structural steel frame system with elevated concrete decks was selected since this is the cheapest system for this area of the county. However, since this selection was already made the LINAC vault would not be able to tie into the structural system of the main building. Ultimately, this meant that the two facilities would have to be constructed separately of each other and connected by the envelope. If the LINAC vault and the main building could have been built simultaneously, there is some potential to accelerate the schedule or work more efficiently.

According to an article published by the journal *Healthcare Design* titled "Alternative Linear Accelerator Vault Construction," the industry is moving towards using more assemblies of high-density block and lead plate instead of the traditional thick concrete assemblies (Howell). This article sites benefits including thinner walls and ceiling thickness, simplified construction and renovation, and potential cost savings of this alternative masonry system. This system has the potential to work in this area due to the large number of masonry companies in the Mid-Atlantic region of the country. Additionally, this masonry assembly poses a problem for areas of high seismic activity; however, seismic is not a major concern for region this project is located. For all of these reasons, this masonry system could pose as an alternative system to the current concrete LINAC vault.

5.2 Research Goals –

The current concrete LINAC vault design is a fairly traditional method for the shielding of medical equipment radiation. While this method poses few issues for this project, the healthcare market sector has been using more alternatives to this concrete system. These alternatives range greatly in price depending on the material selection, ranging from lead bricks, lead glass, lead lined drywall, and high density concrete block. Currently, high density (HD) concrete block is finding its place in the industry of radiation shielding. This project's LINAC vault was designed as an add-on following much of the completion of the facility's design. This analysis hopes to investigate the potential benefits of utilizing a HD masonry vault system versus a concrete vault system on the basis of cost and schedule. Alternatively, this analysis will attempt to identify when a HD masonry vault system should be substituted for the traditional concrete vault system.

5.3 Methodology –

Research

1. Research masonry versus concrete LINAC vault assembles.
2. Determine why the concrete system was chosen for this project.
3. Understand how the masonry system would have to tie into the building.
4. Investigate the cost, constructability, and production of the associated systems.

Technical Analysis

1. Create a cost comparison of the two systems.
2. Develop a schedule and cost estimate for the alternative system.
3. Determine what modifications need to be made to the site logistics plan.
4. Provide recommendations on whether the original design or the masonry design would be the best assembly for the LINAC vault.

5.4 Cast-in-Place LINAC Vault System –

The current cast-in-place concrete design was designed by Cagley & Associates, the structural engineers of record. They worked jointly with a consulting architectural firm designing the medical equipment rooms to ensure the structural stability of this LINAC vault. The structural engineer of record for this project verified that the structural engineer is in fact only responsible for ensuring the vault can hold structural loads. These loads are provided by the medical equipment providers. Additionally, the thickness of the walls are provided to the structural engineers by way of a consulting physicist. This physicist is responsible for the calculations that determine the thickness of the vault will prevent the escape of radiation.

These calculations and provided information led to the current concrete design from Cagley & Associates. This design includes a small strip footing of varying width and a constant 1'-0" thickness. There is a 0'-8" reinforced slab on grade, which includes a slab depression for the LINAC equipment placement. The walls range in thickness from 3'-6" to 7'-0" thick depending on the location of the wall. The two thickest walls are located in the beam path of the LINAC. The room layout is known as a maze entry categorized by the interior wall that extends almost the entire width of the room. This maze entry requires a lead door to prevent radiation from leaving the vault. The vault lid is generally 3’-6” thick except along the beam path, which proves an additional 3’-6” of concrete in the form of a concrete beam. Metal decking and structural steel were added to this design so that a green roof could be added to the design.

5.5 Alternative System –

Traditionally, concrete cast-in-place systems have been used for the shielding of radiation. Still in new construction, cast-in-place concrete design continues to be the industry choice of shielding materials due to its low cost. However, in renovations and additions, often the space does not allow for the mass concrete system. Therefore alternatives to the cast-in-place systems are available as well. Lead is frequently used in the shielding of radiation because of its extremely high density of 709 pcf, which prevents radiation from passing through it. While lead is effective in shielding radiation, it is substantially more expensive than any concrete product. Despite these costs, lead shielding materials available range from lead blocks, drywall, glass and more. These products are most effective in shielding radiation with the least amount of material thickness. Regardless of these products high costs, often owners had to purchase lead over concrete because they did not have the space needed to accommodate the concrete thickness required for radiation shielding. Fortunately, a fairly recent alternative has come on radiation shielding market, high density (HD) concrete block. This block comes in various sizes and densities based on the design requirements of the space. Additionally, the HD block comes in different shapes including straight brick and different interlocking shapes, which increase constructability and even demolition of these systems.

Despite the Mid-Atlantic region’s reputation for being a concrete town, there are several companies that supply HD block radiation shielding solutions. Ultraray, a provider of radiation shielding products ranging from diagnostic imaging to nuclear plant solutions to security and defense, was selected as the HD block supplier for this analysis. Ultraray has offices in both United States and Canada, with their closest office to this project located in New Jersey. They supply two main shapes of block their Chevron (Interlocking) HD Concrete Blocks and their Flat (Straight) HD Concrete Blocks with HD Grout. Figure 21 *(left)* shows Ultraray’s Chevron block and Figure 21 *(right)* shows the Flat block. Both of these options come in two different sizes, 4”x6”x17” and 6”x6”x12” for the Chevron block and 4”x4”x16” and 4”x8”x16” for the Flat block. More importantly, both shapes come in densities of either 240 pcf or 300 pcf. For this analysis, 240 pcf 6”x6”x12” Chevron (Interlocking) HD Concrete Blocks were chosen.

Figure 21 Interlocking HD Block *(left),* Straight Grouted HD Block *(right)*

A comparable HD masonry vault system had to be established before comparing the two systems. Since a physicist would be needed to finalize a HD masonry vault design, a comparable system had to be made from the current concrete design requirements. The concrete vault design meets the radiation requirements for LINAC equipment selected for this project. The density of the surrounding vault is the critical characteristic that prevents radiation from penetrating out of the containment vault. This project used normal density concrete of 150 pcf. HD masonry ranges in density based on the requirements of the project; however, 240 pcf is fairly standard HD block density. Ultraray is one of many suppliers of HD block and sells both 240 pcf block and matching 240 pcf grout. This analysis is based on Ultraray's 6"x6"x12" 240 pcf block and 240 pcf grout.

To find the thickness of the HD block, a simple calculation was made to compare the concrete system to a HD block system. Since concrete has a density of 150 pcf, this density can be multiplied by the thickness of the wall at the various locations to get the pounds per square foot of wall needed to contain the radiation. Likewise, the HD concrete block for this analysis has a density of 240 pcf, which can then be multiplied by the brick thickness of 0'-6" to get the pounds per square foot of brick. Multiplying 240 pcf by 0'-6", gives a pounds per square foot of brick to be 120 psf. This 120 psf can then be divided by the density of the HD blocks to get the number of bricks needed to get the necessary pounds per square foot to contain the LINAC radiation. This calculation found that all walls ranging in thickness from 3'-4" to 4'-0" needed at least five bricks to meet the radiation requirements, and the thicker sections at 7'-0"

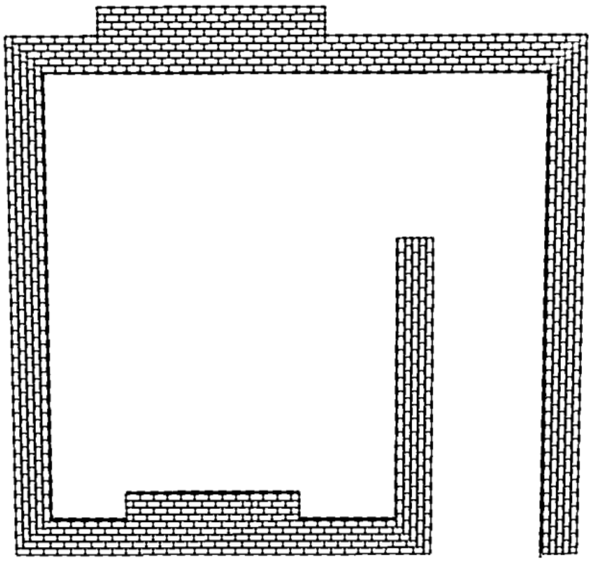


Figure 22 HD Block LINAC Vault Design Plan View

needed at least nine bricks to meet the same requirements. Therefore, the HD concrete block shielding system has the same layout of five bricks thick everywhere except in the two thicker locations in the beam path, which will have an additional four bricks of thickness. Since HD concrete block is denser than concrete, the HD block system can produce the same required density with a thinner wall than concrete. The HD block wall will be approximately 2'-6" thick versus the 4'-0" sections of concrete wall, and 4'-6" in the thicker sections versus the massive 7'-0" concrete walls. Figure 22 shows the redesigned HD block layout and Figure 23 shows the redesign with the foundation and roof.

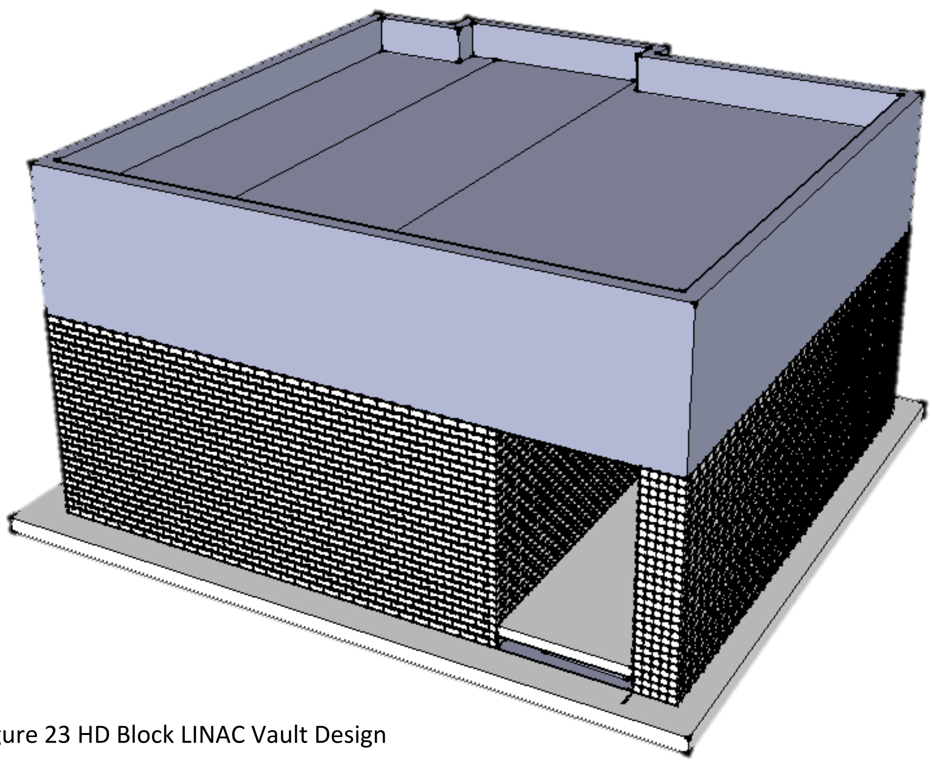


Figure 23 HD Block LINAC Vault Design

Since an official design could not be finalized for a HD block system without a physicist, the remaining LINAC systems were kept constant for this analysis including the concrete foundation and roof. While it is understood that the concrete foundation would potentially have to be modified to hold the additional weight of the HD block, the foundation and roof could essentially also be reduced to meet the new minimized dimensions of the HD block LINAC vault. Since these calculations could not be made without advanced structural analysis, these variations between the systems were considered to counteract the other for the sake of this analysis.

5.6 Cost Comparison –

The LINAC vault was added to the programming of this facility late in design from the primary tenant. This late decision reflects in the odd placement of this additional equipment room behind the main facility. Despite the irregularity of the vault placement, this location provided flexibility for the vault design. There were no space constraints or critical path items for the LINAC. Since there were so few constraints, the concrete vault system was selected not only for its low cost, but also for the project team's familiarity with this system. Even at the start of this analysis, the concrete LINAC vault system was anticipated to be cheaper than any alternative system due to the low cost of concrete especially in the mid-Atlantic region. Regardless, this analysis sought to determine how much more a HD block system would cost since there are various other benefits for this alternative system.

The current LINAC vault system cost $583,000, this includes $326,700 for the concrete and $6,600 for the steel in the LINAC. Since the current system's foundation and roof remain the same in this analysis for both systems, a baseline cost for these items had to be determined. A detailed cost estimate was created for the cast-in-place design using RS Means Construction Costs 2016. Take-off quantities for this estimate can be found in Appendix D.2, and the full estimate in Appendix D.3. This estimate was compared to the actual costs of the structural system of the LINAC. The structural steel cost was lower than the actual cost of $6,600. One of the major reasons for this variation was due to the additional cost the project paid for late ordering the steel package. Several change orders were issued due to the delayed start date, included in these change orders were the additional cost from the steel subcontractor buyout. These costs were ultimately absorbed into contingency from the GMP. The concrete estimate was slightly low as well around ten grand lower than the actual cost. This cost difference can be explained by several factors. One of the sources of variation that RS Means cannot account for is the additional cost for mass concrete. According to the American Concrete Institute (ACI), mass concrete is "any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from hydration of the cement and attendant volume change, to minimize cracking." The ACI recommends that mass concrete considerations should be made for all concrete with a "minimum cross-sectional dimension" of 2'-6". Since all of the concrete walls for this system exceed 2'-6', mass concrete precautions had to be taken especially for the 7'-0" thick sections. These methods may have resulted in the additional cost for concrete. Additionally, this construction is out of this concrete subcontractor's typical scope, which potentially led this contractor to further pad their bid number for precaution. Finally, this estimate does not include indirect costs including contingency (5.0%), Subcontractor Default Insurance and Builder's Risk Insurance (1.10%), Contractor's Insurance (1.10%), and Fee (2.5%). Regardless of these variations, since this number is just the baseline for foundation and roofing system, the cost estimates between cast-in-place vault and the HD block vault are comparable because the variation will remain constant between both estimates.

For the cost estimate of the HD block, many of the line items remained constant from the cast-in-place system. All items related to the placed concrete walls were removed from this estimate including reinforcing, forming, and placing. The quantity of concrete mix was reduced to account for the removal of the walls. Besides these items, all other costs were carried over from the cast-in-place cost estimate. Furthermore, the cost of the HD concrete block wall had to be added to this estimate. Robert Finch, of Ultraray was able to provide pricing for both the 6”x6”x12” 240 pcf interlocking blocks as well as the 240 pcf grout. The HD block take-off was determined from the alternative layout found earlier in this analysis. The grout take-off was estimated from the “Volume of Grout Required in Masonry Walls, Design Aid 15” provided by the Masonry Institute of America. Using the chart (Figure 24) from the Masonry Institute of America, the multiplier of 0.28 was used for a 6” thick wall where the cells are grouted 48” O.C. since there are no cells in the HD block and very little grout is needed for the interlocking design.

Concrete Block Construction

Standard Two Cell Block*	Grouted Cells Vert. Steel Spacing	Cu. Yds. ▲ of Grout Per 100 Sq.Ft. of Wall	Cu.Yds.per ▲ 100 Block (8" High) (16" Long)	Block per Cu. Yd. (8" High) (16" Long)
6" THICK WALLS	All Cells Filled	0.93	0.83	120
	16" O.C.	0.55	0.49	205
	24" O.C.	0.42	0.37	270
	32" O.C.	0.35	0.31	320
	40" O.C.	0.31	0.28	360
	48" O.C.	0.28	0.25	396
8" THICK WALLS	All Cells Filled	1.12	1.00	100
	16" O.C.	0.65	0.58	171
	24" O.C.	0.50	0.44	225
	32" O.C.	0.43	0.38	267
	40" O.C.	0.37	0.33	300
	48" O.C.	0.34	0.30	330
10" THICK WALLS	All Cells Filled	1.38	1.23	80
	16" O.C.	0.82	0.73	137
	24" O.C.	0.63	0.56	180
	32" O.C.	0.53	0.47	214
	40" O.C.	0.47	0.42	240
	48" O.C.	0.43	0.38	264
12" THICK WALLS	All Cells Filled	1.73	1.54	65
	16" O.C.	1.01	0.90	111
	24" O.C.	0.76	0.68	146
	32" O.C.	0.64	0.57	174
	40" O.C.	0.57	0.51	195
	48" O.C.	0.53	0.47	215

*For open end block add 10% more grout
For slumped block deduct 5% grout.
Horizontal bond beams assumed spaced 4'0.C.

Figure 24 Volume of Grout by the Masonry Institute of America

The HD block came out to be substantially more expensive with around five hundred thousand dollars’ worth of material alone. This full estimate for the HD block system can be found in Appendix D.4. The labor unit costs for the both the block and the grout were taken out of RS Means. DPR Construction was able to confirm that the masons for the project, Baltimore Masonry, would be capable of installing the HD block. The labor unit cost for the interlocking block is from RS Means’ concrete block backup, not reinforced since the interlocking blocks do not need to be additionally reinforced due to their mass weight and interlocking joints. The labor cost for HD block would be slightly higher than a 6”x6”x12” 150 pcf CMU block since the 240 pcf block would be heavier at 60 lbs, so to account for this additional cost, the labor cost unit of $3.90 was selected for a slightly larger block of 8”x6”x16”, which weighs around 66 lbs. The labor cost unit for grout remains consistent for all grout types at $2.13. This resulted in labor of close to fifty two thousand dollars. Table 10 shows the final cost comparison between the two structural LINAC vault systems, which proves that a concrete LINAC vault is considerably cheaper than a masonry vault system. Based on these calculations, not only was the concrete LINAC vault clearly less expensive than the masonry system for this project, but it became obvious that when space allows, a cast-in-place concrete LINAC vault will almost always be chosen over a HD concrete block system due to the price alone.

Table 10 Cost Comparison of LINAC Vault Systems

Summary of Cost Comparison for Analysis III		
	Cast-in-Place Concrete	**HD Concrete Block**
Total Structural Cost	$312,000	$715,000
Wall System Cost	$145,180	$549,000

5.7 Schedule Comparison –

Similar to the cost comparison, the schedule remained fairly similar in terms of activities between the two systems with the exception of the construction of the wall. Even the procurement of the HD block was similar to that of the concrete and reinforcing at three weeks of lead time. Unfortunately, the construction of the masonry vault wall is extremely labor intensive since the wall is five to seven blocks thick at any given point. Using the same RS Means line item used for the labor cost estimate of the HD blocks, the daily output was able to give a thirty day duration for this activity, which is three times longer than the time the concrete wall takes to reinforce, form, and place. Additional crews could be added to the HD block construction, but the LINAC vault is not on the critical path, and the HD block system is already substantially more expensive than the concrete wall system.

The current cast-in-place wall system had the LINAC being completed July 28, 2015, while the HD block system pushed the completion of the LINAC back to September 11, 2015. Despite the extended duration, the HD block LINAC would still be completed far before the LINAC equipment would arrive onsite since the delivery date is not until December 17, 2015. In fact, the LINAC vault would still be completed before the first piece of medical equipment was brought onsite on December 7, 2015. Additionally, the masons are already scheduled to be onsite at the beginning of July so Baltimore Masonry would be available to bring bricklayers on a month earlier to complete the LINAC. Baltimore Masonry actually had trouble getting enough workers on the brick façade in their first two weeks in July; therefore, bringing Baltimore Masonry on earlier could in hindsight have prevented this manpower problem on the facade. The full schedule for this alternative system can be found in Appendix D.6.

5.8 Modifications to Site Logistics –

The site for this project is large, which leads to very few site logistics issues. The site is not only massive, but fairly level, which allows for plenty of lay down area. Not only can all of the HD block be delivered and stored onsite, but the HD grout could be mixed onsite. Deliveries could be made through the main entrance through the parking lot and straight to the laydown area by the LINAC. Figure 25 shows the site logistics for the HD block system; this logistics plan can also be found in Appendix D.7. The HD delivery truck would ultimately take the same path as the concrete truck would take for the cast-in-place pours. The only additional equipment that would be needed for the installation of the HD block is scaffolding. Scaffolding could be rented for just one side and then moved, or since a scaffolding rental of this size would not be that expensive, it could be rented for all sides of the LINAC. Ultimately, the site logistics for either LINAC assembly are similar and does not raise any concerns.

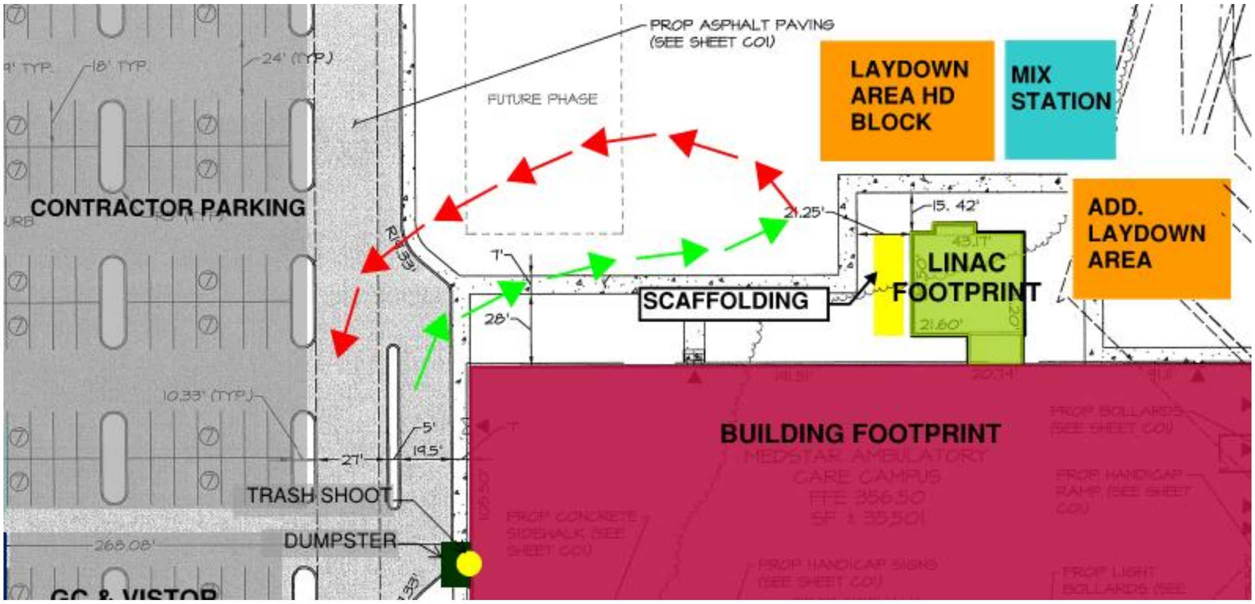


Figure 25 Site Logistics for the Masonry LINAC Vault Installation

5.9 Conclusions and Recommendations –

Since this LINAC vault is of new construction and has few design constraints based on its location, the current cast-in-place system is recommended. Not only is the cast-in-place system significantly cheaper than a masonry vault system, but the construction schedule is approximately a month shorter than the alternative HD block system. In terms of constructability and site logistics for both systems are fairly similar, but the cost and schedule results make the cast-in-place system the obvious choice.

Had the LINAC been incorporated into the design of the facility, the results of this analysis could have gone the other way. For projects with limited space constraints, HD concrete block is one of the best alternatives for radiation shielding. Not only can HD block provide significant radiation shielding, but can also do so for significantly cheaper than lead. If the LINAC was designed into the layout of the main building, HD block could have not only reduced the amount of floor area needed for the LINAC vault, but additionally could have allowed for a higher ceiling height. Despite the benefits a HD block LINAC assembly could provide, for this design, the chosen cast-in-place system is the best system for this project since there are no constraints on the vault design.

Section 6 | Analysis IV – Virtual Mockups | Critical Industry Research Topic

6.1 Problem Identification –

This project is similar to many other medical facilities in that it has experienced a series of change orders related to late design changes initiated by the tenant. The tenant's primary concern is for the best flow for the operation of their new space. As with typical medical facilities, late decisions on medical equipment typically leads a constant anticipation to have some associated change orders for the medical equipment. Despite opting to avoid any other BIM implementations besides the Revit design model, the Revit model is often enough to create virtual mockups.

During the interview with the project manager and superintendent, both highlighted change orders associated with late design changes to be as one of the major issues for this project. However, they would also agree that some of these change orders are to be expected on any healthcare project. Medical equipment is constantly improving, and owners obviously want the most current and up-to-date equipment for their new facilities. Going into a project with the expectation that change orders will occur is an interesting concept to investigate. On this project the tenant's primary concern was the flow of their different clinical spaces and were willing to allot any additional funds to make the space exactly how they want it. However, the question is could these tenants have seen these design issues sooner. By seeing the final design, in a more integrated design review, could the tenants have understood the design better and made requests before they became costly.

6.2 Critical Issues Research Methods–

During the PACE roundtable this semester, Dr. Robert Amor gave a presentation titled "Life after the BIM Revolution," which revolved around his belief that the technology to improve the construction industry is available, but the industry still needs to harness the best methods for implementing these technologies. This presentation not only discussed this issue, but also highlighted some of the many technologies available today including virtual reality, game platforms, augmented reality, and social communication. This topic correlated with the Community Healthcare project since despite DPR Construction's reputation for continuously using BIM technologies and consistently redefining the standard of BIM implementation, BIM was not used on this project by the DPR team. Specifically related to medical room planning, virtual reality has been increasingly used as a design review method for end users. This allows the nurses and doctors to evaluate this spaces and the layout of equipment more effectively, especially having little experience in reading drawings. In today's industry, owners often still struggle to understand the design of their spaces by simply reading drawings, and therefore find themselves contributing to late design changes.

6.3 Research Goals –

The goal of this research is to develop a guide for owners to better understand and illustrate the benefits that virtual mockups can provide to their projects. Just because companies are willing to experiment with new technologies, it is often tricky to convince an owner to fund the usage of these innovative methods on their project. Without previous use of these technologies, owners often struggle to grasp the value that these technologies can bring to their projects. It is difficult to translate potential cost savings into authentic metrics. Instead, researchers on these topics here at Penn State are focusing more on the conversations these technologies can stimulate during design reviews. This research will seek to determine these benefits on a series of selected virtual mockup technologies and create a guide of these technologies for owners to consider the added value versus cost.

6.4 Methodology –

Research

1. Further research the various change orders related to this project.
2. Research the various virtual mockup technologies available today.
3. Research case studies on the benefits of virtual mockups and usage in design reviews.
4. Hold interviews with at least three leading users of virtual reality today.
5. Research the current methods to evaluate the success of the mockup technologies.

Technical Analysis

1. Attempt to define change orders into categories of anticipated versus unpreventable change orders.
2. Select the most feasible virtual mockup technologies for the use of this project.
3. Determine a list of metrics for comparing the selected virtual mockup technologies for the usage on this project.
4. Present recommendations on the benefits and when to utilize of the best virtual mockup technology for this project.
5. Create a guide to determine which technology to implement and implications it would have on the budget.

Resources Required

1. Interviews with companies including but not limited to Barton Malow, DPR Construction, Gilbane, James G. Davis Construction, and Mortenson, who have had experience in virtual mockups.
2. Case study information concerning the use of different technologies.

6.5 Review of Case Studies –

"Comparing Physical and Virtual Mock-ups: A Case Study" by Robert M. Leicht, PhD and John I. Messner, May 29, 2009

This case study was completed for an $11 Million, 34,000 SF Kaiser Permanente medical office building. The focus of this study was to compare physical versus virtual mockups for a better understanding of when one mockup type should be used over the other. Both mockups were conducted for an exam room on the project. For the physical mockup, some equipment including an exam table and computer were brought into the space. Additionally blocking was hung to get a better understanding for the layout of the room. For the virtual mockup, not only was an exam room reviewed but so was the rest of the model. The review was performed at Penn State in the ICon Lab. Unfortunately, far less project team members and end users came to this review session especially in comparison to the twenty people that came to review the physical mockup. The location of the ICon Lab may have proven to be a major deterrent of attendance since the lab is far from the project's location in Virginia.

From these two mockups, the study had several takeaways for the benefits and downfalls of both mockups. Both mockups proved beneficial in providing feedback to the design team. The physical mockup drew more attention of the end users, however, this once again may be attributed the two hundred miles that had to be traveled to attend the virtual mockup. The physical mockup was actually cheaper than the virtual mockup as well since the virtual mockup required licensing of expensive software including 3D Studio Max and VR4Max. The virtual mockup was able to model more spaces in more detail than the physical mockup. Infrastructure proved to be a major contributor to the success of virtual mockups. The ICon Lab was used as the location for review due to its immersive nature. However, this study does not look into using a less immersive space for the review of virtual mockups, potentially one that uses less expensive licensing technology. Another contributor for the success of these mockups ended up being commitment. For virtual mockups to be as successful as the physical mockups for this case study, the virtual mockup review would have benefitted from having end users at that review as the physical mockups had. A benefit that this case study focused on was the added safety of the virtual mockup review over the safety concerns of hosting at an active construction site. Additionally, more areas could be ultimately reviewed during the virtual mockup than at the physical mockup. This case study showed both positives and negatives of physical mockups versus virtual mockups, and also created opportunities for further study of these tools.

<u>Air Barrier and Exterior Wall Construction for the Banner Life Headquarters Project</u> **from James G. Davis Construction, June 23, 2010**

This case study looked at utilizing virtual mockups with a focus on constructability of the exterior façade system. Julien Bartolo was working with James G. Davis Construction on the Banner Life Headquarter Project, a 120,000 SF, $20 Million, 2 story building. According to an interview with Julien Bartolo on March 18, 2016, he had little experience with brick façade buildings up until that point and found himself asking around on the project to better understand how the façade would be built. When he keep finding that no one seemed to know the answers to these questions, he took it upon himself to create a virtual mockup. When he did so, he found that there were actually many areas of concerns. Fortunately, the project team was very receptive to these concerns and held a preconstruction meeting for the air barrier and exterior wall construction. In attendance for this meeting was the DAVIS team, owner and owner's quality control representative, along with several subcontractors.

Addressed in this meeting were several items that showed up as issues in the virtual mockup. Some of these concerns brought up in the meeting include below grade waterproofing requirements, DensGlass installation, and air barrier conditions among others. The issues discussed in this meetings were ultimately applied to the construction of the physical mockup. This actually took place mid-physical mockup construction. Since both physical and virtual mockup were being built and reviewed, these issues that came out from the virtual mockup would have most likely come up during the construction of the physical mockup as well. However, this study shows not only how a virtual mockup can be just as effective at pinpointing constructability concerns, but that virtual mockups are a strong tool in promoting conversion and illustrating the problems across a wide range of people.

In follow-up to this meeting, not only do the meeting minutes from this preconstruction meeting serve as owner approval of construction means and methods, but also these meeting minutes were transformed into an installation guide for everyone working on this system. Using these meeting minutes and the virtual mockup, DAVIS created a step by step guide for how to install the exterior wall assembly. Figure 26 created by James G. Davis Construction in June 2010 for Banner Life Headquarters Project, shows page 3 of their Exterior Wall Construction Mock-up guide as an example of the document made for this assembly. This study shows virtual mockups as a tool for identifying constructability issues, illustrating areas of concern, and depicting construction methods.

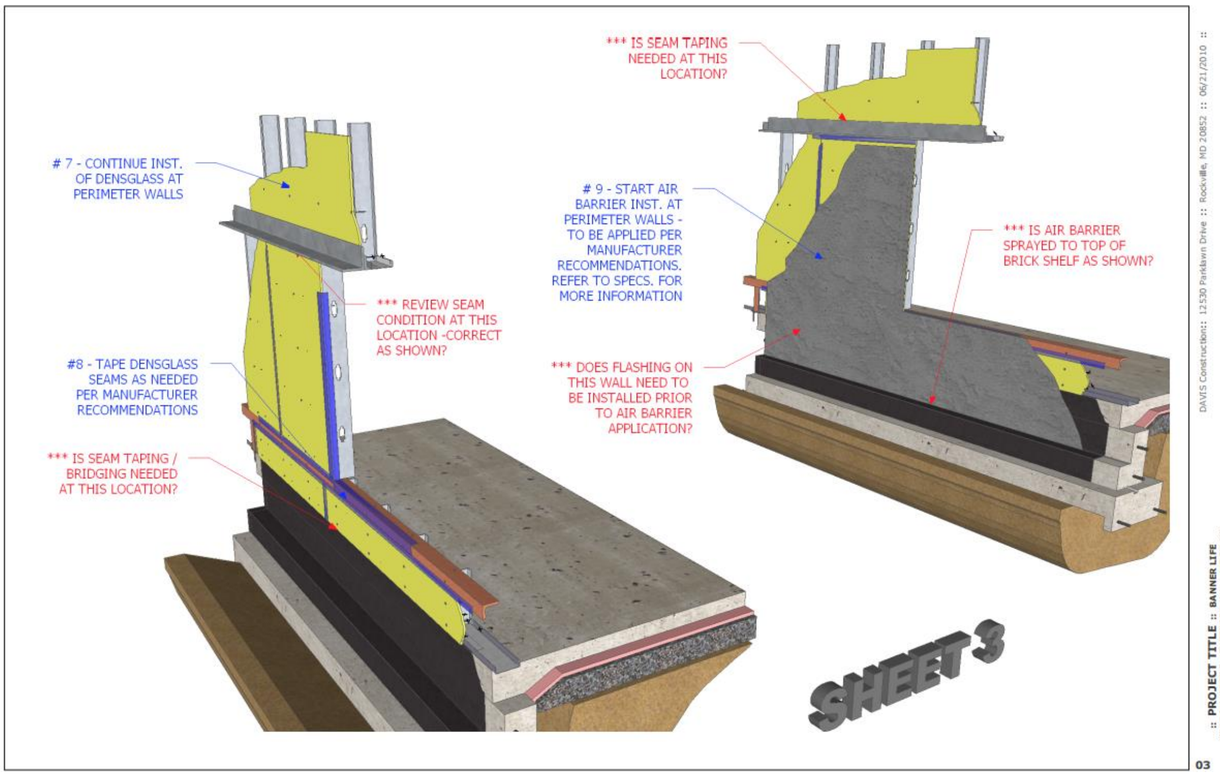


Figure 26 Virtual Mockup from DAVIS Construction

6.6 Industry Research Interviews –

To research how virtual mockups are currently being used in the industry, interviews were conducted with employees of companies that are leading the way in virtual technologies. Companies including Barton Malow, DPR Construction, James G. Davis Construction, and Mortenson provided responses to a series of seven interview questions. The goal of these interviews were to better understand which technologies are on the market, which ones are most used by industry, and what benefits virtual mockups provide. By interviewing employees in various positions from several different companies, the hope was to get a sample of different responses; however, these interview responses led to quite the opposite results. Instead, these responses ended up pointing to a lot of the same technologies and similar responses. While there were responses that varied amongst the different employees, the interviews did have many common themes.

In terms of what kinds of technologies are available on the market, the employees sited many different programs and tools. Some of these technologies include Revit, the Oculus Rift, Trimble and Trimble products especially Sketchup, AutoCAD, Navisworks, Cloudworks, Google Glass, and Cyclone. While many of the companies use some or all of these technologies, interview after interview everyone ultimately chose Sketchup as either one of the best technologies or the best technology for value adding to the project in its usage for virtual mockups. There are two different forms of Sketchup, of which both were mentioned: Google Sketchup the version free to any user and Trimble Sketchup, a licensed software with more capabilities than the free version. Some of the reasons Sketchup was cited as the best software include its affordability, user friendliness, interactive, ability to edit items quickly or “on the fly”, and efficiency. In terms of viewing the models after they were created, Oculus Rift was highlighted as a tool that was effective in providing a walkthrough of a virtual space. A downfall of this same technology was in that only one reviewer could view the model at a time, which reduced the overall collaborative review process. Other more collaborative viewing methods were often less technical including GoToMeeting and even just single-screen projection. These methods are far cheaper and most companies should have access to them already.

While most the employees thought that in general all projects could benefit from some usage of virtual mockups, many of them highlighted different systems or markets that would benefit most. Bill Gamble of Barton Malow thought that any project that has any kind of “complicated details” would benefit from modeling. Lucas Manos of Mortenson construction agreed with Gamble, added that Mortenson hopes encourage the engineers to turn to mockup technologies for a constructability concerns. Julien Bartolo’s response of DAVIS Construction was similar to these responses, believing that every building could benefit, added that above ceiling coordination is one of the best uses of virtual mockups. DPR Construction’s Tim Conroy would agree with other employees that any project could benefit from virtual mockups, but he believes that a critical indicator of success depends upon having enough time to make the necessary design changes from the mockup reviews.

While virtual mockups were defined a little differently in all of the interviews, all of the interviews cited several reasons to implement virtual mockups. One of the major reasons virtual mockups are created are for constructability reviews. This constructability review may be able to identify or fix design conflicts, to check “material compatibility”, understand work sequence, installation means and methods, owner review through visuals, propose alternative systems, and ultimately minimize risk. In all of the interviews, the employees’ position on virtual mockups as a value adding tool to project was very apparent. Not one employee showed any sign of skepticism when talking about virtual mockups. In their experience, virtual mockups were as successful as the project team made them. All interview responses can be found in Appendix E.1.

6.7 Metrics for Classifying Virtual Mockup Technologies –

One of the goals of this analysis was to establish a list of metrics to classify and compare virtual mockup technologies. Through interviews with industry members, there emerged two types of technologies that associated with virtual mockups: one for the creation of virtual mockups and one for the viewing of virtual mockups. The industry members mentioned many different tools to do both create and view virtual mockups this section will look at comparing the technologies mentioned in the industry interviews.

Even before interviews were conducted with industry members, two metrics were easily identified cost and time. These two factors are critical to every project and every market. In interviews with industry three other metrics were identified as critical to virtual mockup technology as well. These three categories are realism, team integration, and ease of use. The technology's ability to show material details can be either a benefit or downfall to that technology. These details could be used to evaluate the aesthetic of the design, but it was cited in interviews with Tim Conroy of DPR Construction, this detail can distract from focus of some design reviews. Team Integration was also a cited metric of Tim Conroy as he valued traditional presentation styles over the Oculus Rift since the traditional method stimulates more discussion. Finally, ease of use was a metric that many of the industry members posed as perk for using Sketchup.

Each of the technologies could be rated against each other based on these metrics. While there are many different technologies that are used for both the creation and viewing of virtual mockups, this comparison will focus specifically on the major technologies reviewed by the industry members interviewed for this analysis. The technology best in that category will be identified with a "1" and the second best with a "2" and so on to "4" being the worst. If the technologies are perform equally in a category, the technologies can be rated with the same performance number. Table 11 looks at the creation technologies, Revit, AutoCad, Sketchup, and Navisworks. Table 12 compares viewing methods including traditional (being an environment that would not be defined as immersive), Oculus Rift, Google Glass, and Fuser.

Table 11 Virtual Mockup Creation Technologies Ranked

Virtual Mockup Creation Technologies				
	Revit	**AutoCad**	**Sketchup**	**Navisworks**
Cost	4	3	1	2
Time to Create	2	2	1	2
Team Integration	1	1	1	1
Ease of Use	3	2	1	4
Realism	1	2	3	3

Table 12 Virtual Mockup Viewing Technologies Ranked

Virtual Mockup Viewing Technologies				
	Traditional	**Oculus Rift**	**Google Glass**	**Fuser**
Cost	1	2	4	3
Time to Review/Edit	1	2	3	4
Team Integration	1	2	2	1
Ease of Use	1	2	2	2
Realism	3	1	2	2

6.8 Change Order Review –

This project is ongoing, but up until March 17, 2016, the project has ten owner approved change orders for the Core & Shell and six owner approved change order for the Tenant Interiors package. While there are some pending potential change items, of the approved owner change orders for both contracts, the changes can be categorized fairly simply into owner driven changes, revisions due to constructability issues, and unforeseen issues based on the project delay from the revised GMP.

Before these categories were decided upon, the project's owner change orders were organized into a change order tracking log. This change order tracking log can be found in Appendix E.2. These change orders are arranged by change order number, the potential change items that were picked up in this change, which contract package the change was made, when it was issued, if there was any cost or time associated with the change, and a description of the change. By classifying each of the change orders in this way, the potential change items that were not picked up yet could be identified. Moreover, the description of the associated changes began showing some similar themes. The first few change orders in the Core & Shell package were heavily contributed to by the project Notice to Proceed date. However when the project got further in construction many of issues that came about had to do with constructability. In early methodology for this analysis, change orders were going to be classified by anticipated versus unforeseen changes. However, as this analysis went on, constructability issues became difficult to classify as foreseen or unforeseen due to Hindsight Bias. Instead, classifying the issues more broadly versus categorizing the changes by an opinionated foreseen versus unforeseen was the method used in this analysis.

The three categories that the change orders were placed into was owner driven changes, constructability, or project delay related changes. The owner driven changes are just considered any issue that was made purely on the basis of owner request. These issues occurred more often in the Tenant Interior package than the Core & Shell package since the primary tenant had more of a vested interest in the functionality of the final space than the developer of the project. The programming of the space by final design already had incorporated all of the requirements of the developer.

Frauenshuh's general goals were to create a facility of minimum square footage, maximum tenant spaces, at the minimum cost. In terms of the actual design, Frauenshuh was not as invested in these aesthetic decisions as long as the space would attract tenants. Even so, once the design was finalized, Frauenshuh's goals were already met and therefore led to fewer owner driven change orders. Despite this, the Core & Shell did have some owner driven change orders including COs #008, 009, and 010. All of these owner driven changes were related to the medical equipment or requirements. However, all of these changes despite being in the Core & Shell package were driven by the primary tenant's request, and would have been paid for by the tenant as well had DPR not taken the cost out of contingency. The first four change orders in the Core & Shell package were related to the delayed project start date. These changes include several revised GMP schedules to reflect the actual Notice to Proceed, building permits, winter conditions, weather days related to the Notice to Proceed delay. While the associated costs were picked up by DPR Construction in contingencies, there were one hundred and twenty five days added to the project schedule. Also as the project got further into construction change orders #006, 007, 008, 009, and 010 included changes related to the constructability issues. Some of these constructability issues include issues with the skylight construction, brick façade and exterior framing issues, waterproofing concerns, steel rework at Prompt Care Canopy, and others. All these changes were ultimately picked up in various contingencies.

The Tenant Interiors package change orders were almost all directly related to owner driven changes. The first change order for the Tenant Interiors package was to update the package's GMP schedule in order to align it with the Core & Shell's delayed GMP schedule. Following this first change order package, the remaining five change order packages were related to owner driven changes primarily for the medical equipment. Change orders related to medical equipment is common theme that exists among projects that call for owner furnished medical equipment. This occurs since owner's want to wait as long as possible to order the latest and greatest medical equipment for their projects since the technology changes so rapidly. Since this equipment is always specified so late in the design and construction process, there is more often than not associated cost with these changes. This project is no different, there has been an added 5% of the contract value in change orders surrounding the medical equipment and other owner changes. Finally, in the tenant interior package there were a few changes related to constructability including coordination issues and above ceiling changes. In total, the Core & Shell package has zero cost added to the contract but 125 days added to the schedule, and the Tenant Interiors package has added 5% cost and 45 days.

6.9 Virtual Mockups Guide –

In an effort to save money, this project did not to use any form of BIM Implementation besides modeling for the construction documents. This fact was surprising since the construction manager on the project, DPR Construction, is a strong advocate for virtual construction. Despite the continuous push in the industry to incorporate virtual construction for efforts including coordination, constructability, and job sequencing, construction projects can be built without any of these technologies. However, the reason these technologies are becoming increasingly popular is due to the added benefits that these techniques can provide. While this project has been very successful in minimizing added cost to the owners, DPR Construction has redirected a substantial portion of cost into contingencies. One category of change orders found as a common theme especially in the Core & Shell package was constructability issues. Unfortunately, there is no way to identify if these constructability issues could have been foreseen by the project team before they came up in the field. However, in interviews with the senior superintendent with DPR Construction on this project, he did emphasize that he wished a constructability review would have been completed for this project.

Two of the major constructability issues identified by the project manager and superintendent that occurred on this project were the skylight and the exterior faming. The skylight located on the front entrance canopy has sloped design. This detail can be seen in Figure 27. According to the project manager, this sloped design has led to major constructability issues to ensure that the skylight connections will be properly waterproofed so that the skylight will not leak. Additionally, the skylight detail is complex, so not only do the details of the skylight's install need to be defined, but this installation method also has to be conveyed to the installer. Fortunately, like many projects today, the same subcontractor is installing both skylight and roofing, this way less coordination had to occur between different trades.

Another major constructability issue that came up during construction was that east and west sides of the building only had a five inch gap between the floor slab edge and exterior wall, but the design called for a standard 6" metal stud. Instead the project had to special order 4" metal studs for both the east and west exterior walls. Another issue found with the brick façade was that the brick lintels were not designed to line up. This issue was found during a physical mockup of the brick façade. The mockup found that the brick lintels at the bottom of the windows were aligned and the brick lintels at the top of the windows were aligned, but the top and bottom lintels were not. While there is no way to determine if any of these assemblies would be picked in a constructability review, both the façade and roofing systems are generally systems that are studied since water penetration is of critical importance to a project especially in these locations.

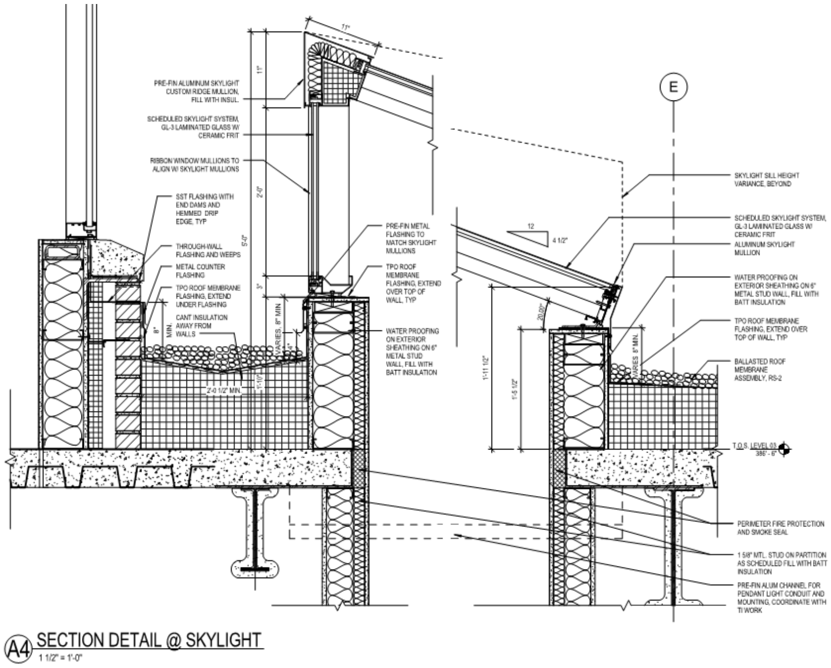


Figure 27 Skylight Detail

These constructability concerns were found when the project was further along in construction. Unfortunately, this meant that the project team had to act in response to address these issues. Since the issues were found as the assemblies were under construction, the potential solutions were limited by the solutions that could go in at that stage in construction. For example, the stud had to be changed to a costly 4" stud, and the brick veneer had to be hung off the building on temporary wood supports until the mortar dried so that the brick courses were in aligned. However, in interviews with DPR Construction as well as other companies, these issues stood out as constructability concerns that could have benefitted from a virtual mockup. Not only did the interviews reveal other projects that used virtual mockups for similar assemblies including exterior walls, but they also showed how easily they mockups could be made.

The Virtual Mockup Implementation Guide that can be found in Appendix E.3 was created for this analysis for the purpose of identifying when a virtual mockup should be pursued and what technologies should be used. The first step of the guide was to establish or identify an issue or area of interest. These issues could be identified by any member of the project team, in fact the project would benefit from having several people with various expertise levels looking at the design and construction plans for the project. Typically these issues would come up in a design review or a constructability review. Once an issue or concern is identified, there are eight topics that the issue could be related to. These eight topics were established in the various interviews with industry as areas that virtual mockups are being implemented. Outside of these topics, industry has less experience using virtual mockups and therefore the benefits of using virtual mockups are less defined making the resources used on creating a mockup for a reason beyond the ones identified in the guide more risky. Once the issue is related to a topic the guide will direct the user to the technology that would provide the best virtual mockup for the issue. After the mockup is created, the user is conveyed to present the mockup under standard presentation styles followed by an immersive environment if the issue is not resolved.

The goal of using this guide is that the project will benefit from working through construction issues earlier in the process before they are identified in the field. This identifying of issues earlier can be assumed to have a cost savings associated with it, based on the well-known impact of changes versus cost of changes curve. This curve found in Figure 28 shows that as the time goes on, changes get more costly; therefore, by catching issues earlier by way of virtual mockup there could be cost savings. Also despite the results from the earlier case study, "Comparing Physical and Virtual Mock-ups: A Case Study" from Robert M. Leicht, PhD and John I. Messner, the associated costs of virtual mockups may be far less than proposed in this study. While the cost for the

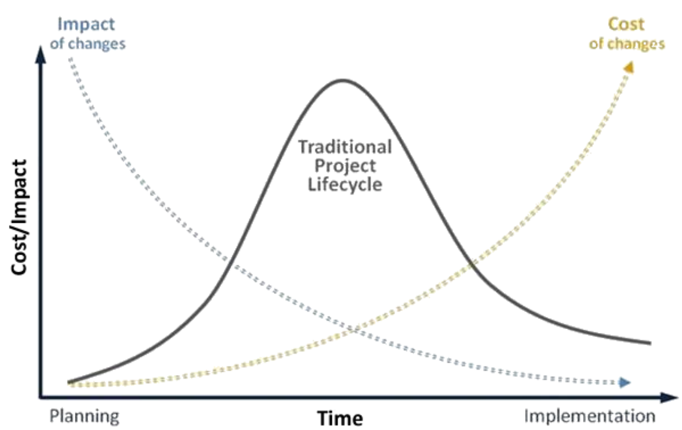


Figure 28 Cost/Impact vs. Tim Curve

http://www.lanner.com/en/blog-entry.cfm?theFqID=F468D245-15C5-F4C0-99E418D64853EDB7 virtual mockups proved to be more than physical mockups in this case study, this study had the cost of the licensing software as a major deterrent for the affordability of virtual mockups. However, this cost is not associated with much of the technologies outlined in the Implementation Guide. For one Sketchup, a mockup creation technology highlighted in the guide, is available online for anyone to download for free. Additionally, the licensing software with the upgraded Sketchup software through Trimble, as pointed out through Lucas Manos of Mortenson, is often licensed to the company as a whole. While the upfront cost of this software is costly, arguably, the more the software is used, the more affordable the software becomes per each model since this cost would be divided by the number of mockups created. Unfortunately, none of these costs can be quantified for the purpose of this analysis. However, the Implementation Guide could have been used for one of these constructability issues had the project team been able to identify the issue during a constructability or design review.

For example, if the skylight detail had been flagged for its potential constructability concerns, the guide would have related this issue to a constructability concern. The guide would then ask if the quick edits would need to be made during the design review. The team would ultimately, have to decide if this issue was critical. For the sake of this example, say that the team would decide that this is critical since the roofing and glazing subcontractors would be sitting in on the review meeting, and the review process would benefit from the team being able to make revisions based on the subcontractor's feedback. The guide would then lead the team to create a Sketchup model of the condition, seen in Figure 29. This model would then be reviewed by standard presentation methods, which based on the scale would probably be sufficient to work out the details of the assembly.

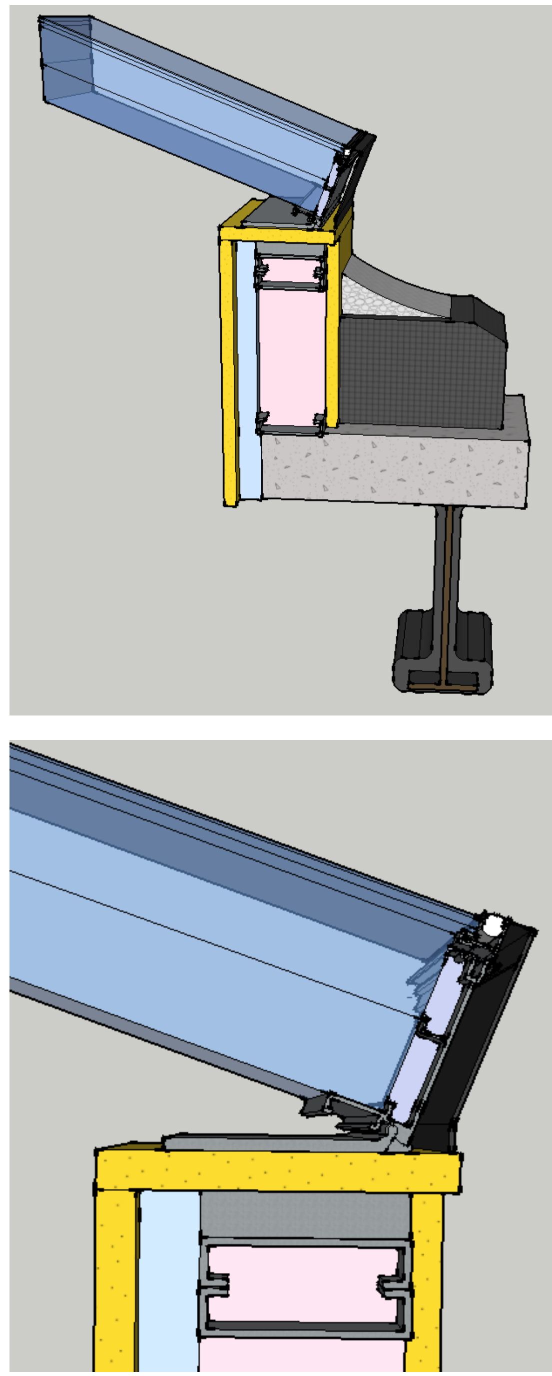


Figure 29 Virtual Mockup of Skylight Detail

This same process can be illustrated by the DAVIS construction case study, ***Air Barrier and Exterior Wall Construction for the Banner Life Headquarters Project***. In this example, Julien Bartolo of DAVIS Construction identified the brick veneer as an issue related to construction means and methods. This would guide him to create a Sketchup model, which he ultimately did. Then the guide would lead him to present the model by way of traditional presentation techniques, which he did via GoToMeeting. These issues would sorted out sufficiently by this presentation technique and the project benefitted by the usage of virtual mockup technology to identify the issues associated with the brick façade assembly.

6.10 Conclusions and Recommendations –

This analysis was focused on researching the use of virtual mockups in the construction industry for design and construction reviews. The goal was to use interviews with industry to produce an implementation guide for use of virtual mockups on a construction project. Research found that virtual mockups involve the combination of two different technologies, one for the creation of the mockup and one for the review of the mockup. While there are many different technologies available on the market, the industry members identified several technologies that are used most often by their companies. These technologies were compared in five categories: cost, time, team integration, ease of use, and realism. By better understanding these technologies and the benefits these can provide to projects, an implementation guide was created to reflect when a virtual mockup should be created and by which technologies.

In addition to the implementation guide, change orders for this project were reviewed. These change orders were organized into three categories: owner driven changes, constructability issues, and changes related to the delayed Notice to Proceed. The change orders that were classified as solutions to constructability issues could be potential items that could have been applied to the implementation guide. Unfortunately, there is no way to directly relate the two items, however, many of the constructability issues that this project had could be related to topics that virtual mockups have been applied to previously. For example in the case study by Julien Bartolo of James G. Davis Construction, a virtual mockup was conducted on the brick veneer on their project. This mockup found several design issues that were solvable due to a virtual mockup design review. This project had several façade review issues of their own that were eventually identified during construction or in a physical mockup. This example shows that a similar method could have been applied to this project for little cost.

This research has provided insight into different technologies available in this growing field in virtual construction. Moving forward this research has provided a better understanding of when virtual mockup technologies could provide benefits to a project including but not limited to work flow, constructability, construction means and methods, and coordination. The cost of implementing virtual mockups continue to become more affordable as virtual mockup software becomes more affordable and as more professionals are trained in these technologies. Virtual mockups have increased in popularity over the years, as more and more companies as well as owners better understand the value they can bring to a project.

Section 7 | Final Recommendations

Community Healthcare is a medical office facility under construction in the Mid-Atlantic region. The design intent is to create a three story healthcare project to extend the network of care to the local community. This report will outline the four depth analyses that will be analyzed for the Community Healthcare project. Three of these analyses will focus on issues or opportunities that could be explored for the construction of this facility that could improve constructability, accelerate the schedule, reduce costs, or value engineer the process. The final analysis will be a critical research issue that will look into virtual mockups.

Analysis I | Precast Footings

A schedule delay, followed by several weather days proved to be a major challenge for the project team. The foundations and structure all had to be completed under cold weather conditions which significantly extended the duration of these activities. This analysis found that the construction schedule could be accelerated by using precast footing, but ultimately the additional cost for this required to implement this change does not correlate well enough with the owner's goals to make this schedule improvement worth the cost.

Analysis II | Prefabricate the Building Envelope

This project is currently utilizing temporary weather protection in order to complete the interior drywall and maintain the tight schedule. The exterior framing and skin are being installed through traditional means and methods. This analysis will focus on altering the construction means and methods to accelerate the installation of the skin and get the building watertight quicker. By prefabricating the exterior metal framing, sheathing, and insulation into panels, this analysis found that the project could minimize risk in damages and record incidents, making this alternative method worth the added cost.

Analysis III | Masonry LINAC Vault

The linear accelerator (LINAC) vault was added to the core and shell GMP package fairly late in during design. The system that was selected was a standard concrete wall and ceiling assembly. By selecting this system, the vault had to follow the completion of the building structure versus being tied in. In the healthcare industry, many owners and medical suite designers are opting for masonry LINAC vaults over concrete. Ultimately the masonry LINAC vault only provided space savings for the system, which makes the current system both cheaper and quicker to build; therefore, a LINAC vault is not recommended for this project in its current location.

Analysis IV | Virtual Mockups

This project has experienced several change orders due to late design changes. Many of these change orders reflected the distinct wishes of the primary tenant, who understood the value these changes would provide to the operation of their facility. This analysis determined that virtual mockup technologies have been used in similar constructability issues that were found on this project; therefore, implementing virtual mockups for areas of concern would have been highly recommended for this facility.

References

"Air Barrier and Exterior Wall Construction for the Banner Life Headquarters Project." James G. Davis Construction. 23 June 2010.

Ardalan, Mac. "Precast Footing Cost." Miller, Long, and Arnold. February 2016.

Bartolo, Julien. "Virtual Mockup Research Interviews: James G. Davis Construction." Telephone Interview. 18 March 2016.

Conroy, Tim. "Virtual Mockup Research Interviews: DPR Construction." Telephone Interview. 18 February 2016.

Finch, Robert. "Ultraray Pricing." Email. February 2016.

Gamble, Bill. "Virtual Mockup Research Interviews: Barton Malow." Telephone Interview. 15 February 2016.

Howell, Mark. "Alternative Linear Accelerator Vault Construction." Alternative Linear Accelerator Vault Construction. Emerald Expositions, n.d. Web. Nov. 2015. <http://www.healthcaredesignmagazine.com/blogs/mark-howell/alternative-linear-accelerator-vault-construction>.

Jaillon, L., C.s. Poon, and Y.h. Chiang. "Quantifying the Waste Reduction Potential of Using Prefabrication in Building Construction in Hong Kong."Waste Management 29.1 (2009): 309-20. Web. <http://ac.els-cdn.com/S0956053X08000718/1-s2.0-S0956053X08000718-main.pdf?_tid=10150630-f9cd-11e5-b010-00000aacb360&acdnat=1459709664_e90b26bec3df7945c79e527b1bfa807a>.

Leicht, Robert M. PhD and Messner, John I. "Comparing Physical and Virtual Mock-ups: A Case Study." The Pennsylvania State University. May 29, 2009

Manos, Lucas. "Virtual Mockup Research Interviews: Mortenson Construction." Telephone Interview. 21 March 2016.

Plotner, Stephen C. *RS Means Building Construction Cost Data 2016*. N.p.: n.d. Print.

Sherif, Ahmed, Hanan Sabry, Rasha Arafa, and Ayman Wagdy. "The Impact of Alternative Window Glazing Types and a Shading System on the Daylighting of Hospital Patient Rooms: Simulation Analysis under a Desert Clear Sky." Energy Procedia 78 (2015): 1805-810. Web. <http://www.ibpsa.org/proceedings/BS2013/p_1427.pdf>.

Tam, C. M., Vivian W. Y. Tam, John K. W. Chan, and William C. Y. Ng. "Use of Prefabrication to Minimize Construction Waste - A Case Study Approach." International Journal of Construction Management 5.1 (2005): 91-101. < http://www.tandfonline.com/doi/pdf/10.1080/1562359 9.2005.10773069>.

"Technical Questions." American Concrete Institute. American Concrete Institute, n.d. Web. 17 Mar. 2016. <https://www.concrete.org/tools/frequentlyaskedquestions.aspx?faqid=650>.

Toole M., and Gambatese J. “The future of Designing for Construction Safety”. Unpublished documents of DFCS. 2007.

Toole M., Hervol N., Hallowell M. (2006) “Designing for Construction Safety”, Modern Steel Construction June 2006.

MAE Integrated Thesis

In order to integrate MAE studies into this thesis, concepts from AE 570 Production Management in Construction and AE 572 Project Delivery Methods were incorporated into these analyses. Analysis II studied prefabrication of the building envelope. In this analysis, production rates were used to create a manpower loaded schedule that was used to track productivity. Using concepts from AE 570, the manpower loaded curve proved that prefabricating the panels would reduce the work hours on the job, thereby, reducing cost and reducing safety risks.

Topics from AE 570 were also applied to Analysis IV, which looked at the best tools for virtual mockups. Using lean decision making tools from AE 570 were used to help determine the best technologies. The process flow map for the Implementation Guide for this analysis was inspired by process flow maps created for AE 570 for lean tool selection. This analysis also used concepts from the Penn State BIM Implementation Guide as a reference for roles and responsibilities for the Virtual Mockup Implementation Guide.

Concepts from AE 572 were used throughout this thesis as it helped to better understand the project contracts and organization, and how that structure affects the project as a whole. The early involvement of the DPR Construction team greatly affected this project and the decisions that were made early on and throughout design.

Appendix A.1

Cost Estimate

Building Parameters		
Gross Area	106,000	SF
Perimeter	910	LF
Story Height	15	Ft

Cost per SF of Floor Area	
Exterior Wall Type	Face Brick with Concrete Block Back-up
Structural System	Steel Frame
Base SF Cost	$231.65/SF

Cost Adjustments		
	Factor	Cost/SF
Perimeter Adjustment	7.75	40.61
Story Ht Adjustment	2.50	7.5
Adjusted Total		279.76
Location Correction	0.93	260.18

Cost Estimate			
Summary	Floor Area	Cost/SF	Total Cost
Cost without Adjustments	106000	231.65	$24,554,900.00
Cost with Adjustments	106000	260.18	$27,578,740.80
		Total	**$27,578,740.80**

Uniformat II - Total Project Costs								
	GMP					Estimate		
System	%	Cost/SF	Core & Shell	Tenant Interior	Total	%	Cost/SF	Cost
A - Substructure	1.88%	$4.22	$447,000	$0	$447,000	4.30%	$9.96	$1,055,861
B - Shell								
B10 - Superstructure	10.73%	$24.09	$2,553,887	$0	$2,553,887	5.70%	$13.20	$1,399,629.30
B20 - Exterior Enclosure	13.41%	$30.12	$2,807,113	$385,375	$3,192,488	10.40%	$24.09	$2,553,709.60
B30 - Roofing	1.92%	$4.30	$451,853	$4,096	$455,949	2.30%	$5.33	$564,762.70
C - Interiors	21.11%	$47.40	$839,778	$4,184,337	$5,024,115	23.80%	$55.13	$5,844,066.20
D - Services								
D10 - Conveying	1.91%	$4.29	$455,190	$0	$455,190	8.70%	$20.15	$2,136,276.30
D20 - Plumbing	3.49%	$7.84	$481,912	$349,600	$831,512	16.50%	$38.22	$4,051,558.50
D30 - HVAC	8.85%	$19.86	$1,075,589	$1,030,020	$2,105,609	8.80%	$20.39	$2,160,831.20
D40 - FP	1.37%	$3.08	$219,800	$106,700	$326,500	3.30%	$7.64	$810,311.70
D50 - Electrical	13.31%	$29.88	$1,458,686	$1,708,125	$3,166,811	10.80%	$25.02	$2,651,929.20
E - Equipment and Furnishing	0.21%	$0.47	$0	$50,000	$50,000	5.40%	$12.51	$1,325,964.60
F - Special Construction	0%	$0.00	$0	$0	$0	0.00%	$0.00	$0.00
G - Site Work	9.38%	$21.05	$2,231,774	$0	$2,231,774	0.00%	$0.00	$0.00
Additional Items Included in GMP								
Demolition	0.34%	$0.76	$80,500	$0	$80,500			
Jobsite Management	2.81%	$6.31	$668,619	$0	$668,619			
Project Requirements	5%	$10.20	$422,794	$658,294	$1,081,088			
TI to be peformed with C/S	5%	$10.65	$1,129,193	$0	$1,129,193			
Total	100%		$15,323,688	$8,476,547	$23,800,235	100%		$24,554,900

Subtotal	$23,800,235.00
Indirect Costs C/S	$1,301,806.00
Indirect Costs TI	$794,341.00
Total	$25,896,382.00
Cost/SF	$244.31

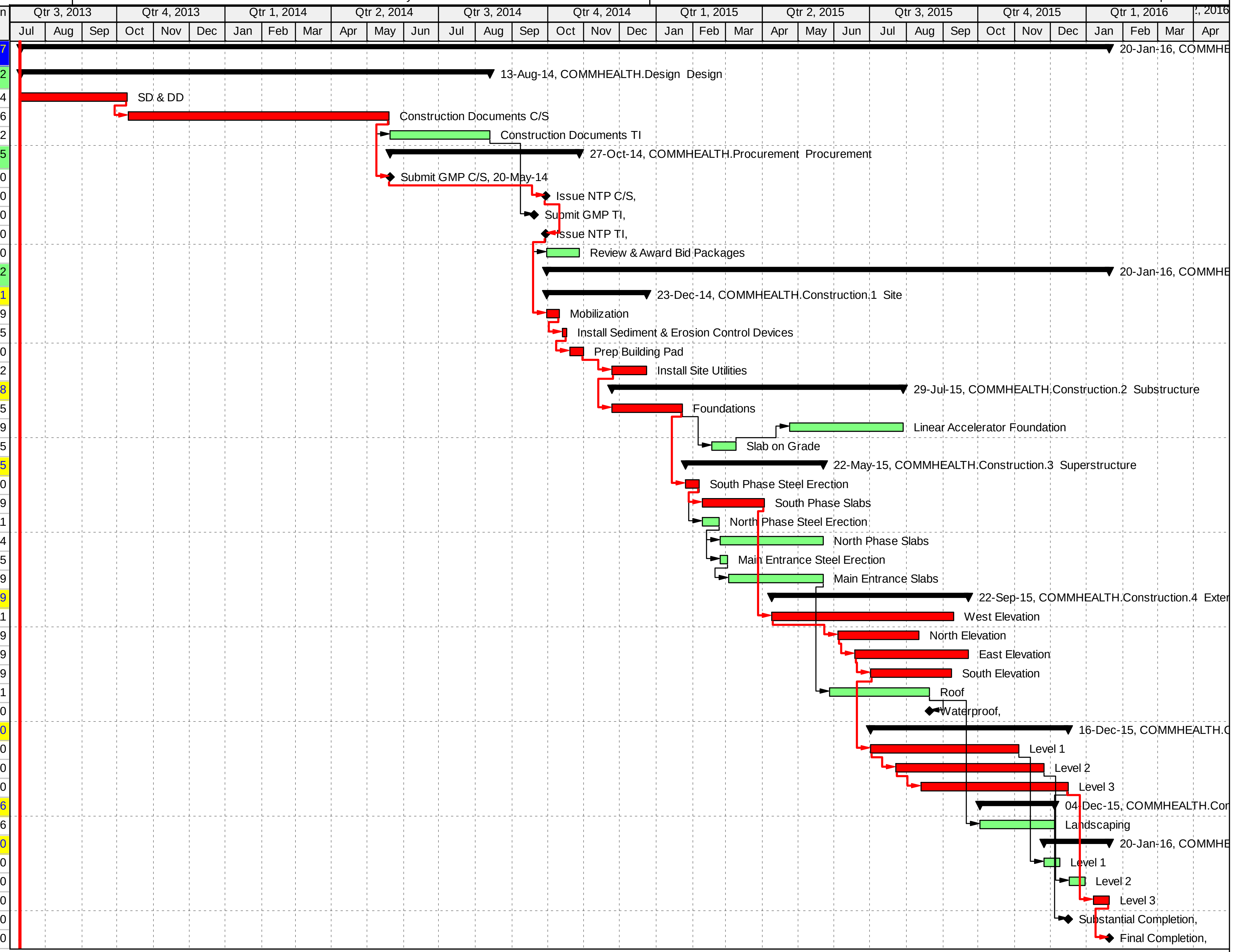
Subtotal		$24,554,900
Architect Fees	9.00%	$2,209,941.00
General Requirements	10.00%	$2,455,490.00
Overhead	5.00%	$1,227,745.00
Profit	10.00%	$2,455,490.00
	Total	$32,903,566
	Cost/SF	$310

Appendix A.2

Schedule Summary

Schedule Summary		Classic Schedule Layout		15-Sep-15 01:16

Activity ID	Activity Name	Start	Finish	Original Duration
COMMHEALTH Schedule Su		11-Jul-13	20-Jan-16	657
COMMHEALTH.Design Design		11-Jul-13	13-Aug-14	282
A1005	SD & DD	11-Jul-13	09-Oct-13	64
A1020	Construction Documents (	10-Oct-13	19-May-14	156
A1060	Construction Documents TI	20-May-14	13-Aug-14	62
COMMHEALTH.Procurement		20-May-14	27-Oct-14	115
A1030	Submit GMP C/S	20-May-14		0
A1050	Issue NTP C/S		29-Sep-14	0
A1070	Submit GMP TI		19-Sep-14	0
A1080	Issue NTP TI		29-Sep-14	0
A1090	Review & Award Bid Packa	30-Sep-14	27-Oct-14	20
COMMHEALTH.Construction		30-Sep-14	20-Jan-16	342
COMMHEALTH.Construction.1 Site		30-Sep-14	23-Dec-14	61
A1100	Mobilization	30-Sep-14	10-Oct-14	9
A1110	Install Sediment & Erosion	13-Oct-14	17-Oct-14	5
A1120	Prep Building Pad	20-Oct-14	31-Oct-14	10
A1130	Install Site Utilities	24-Nov-14	23-Dec-14	22
COMMHEALTH.Construction.2 Sut		24-Nov-14	29-Jul-15	178
A1140	Foundations	24-Nov-14	23-Jan-15	45
A1180	Linear Accelerator Founda	24-Apr-15	29-Jul-15	69
A1190	Slab on Grade	17-Feb-15	09-Mar-15	15
COMMHEALTH.Construction.3 Sup		26-Jan-15	22-May-15	85
A1200	South Phase Steel Erection	26-Jan-15	06-Feb-15	10
A1210	South Phase Slabs	09-Feb-15	02-Apr-15	39
A1220	North Phase Steel Erection	09-Feb-15	23-Feb-15	11
A1230	North Phase Slabs	24-Feb-15	22-May-15	64
A1240	Main Entrance Steel Erecti	24-Feb-15	02-Mar-15	5
A1250	Main Entrance Slabs	03-Mar-15	22-May-15	59
COMMHEALTH.Construction.4 Ext		09-Apr-15	22-Sep-15	119
A1260	West Elevation	09-Apr-15	10-Sep-15	111
A1270	North Elevation	04-Jun-15	11-Aug-15	49
A1280	East Elevation	18-Jun-15	22-Sep-15	69
A1290	South Elevation	02-Jul-15	08-Sep-15	49
A1300	Roof	28-May-15	20-Aug-15	61
A1410	Waterproof		20-Aug-15	0
COMMHEALTH.Construction.5 Inte		02-Jul-15	16-Dec-15	120
A1310	Level 1	02-Jul-15	04-Nov-15	90
A1320	Level 2	23-Jul-15	25-Nov-15	90
A1330	Level 3	13-Aug-15	16-Dec-15	90
COMMHEALTH.Construction.6 Lan		02-Oct-15	04-Dec-15	46
A1340	Landscaping	02-Oct-15	04-Dec-15	46
COMMHEALTH.Construction.7 Cor		26-Nov-15	20-Jan-16	40
A1350	Level 1	26-Nov-15	09-Dec-15	10
A1370	Level 2	17-Dec-15*	30-Dec-15	10
A1380	Level 3	07-Jan-16	20-Jan-16	10
A1390	Substantial Completion		16-Dec-15	0
A1400	Final Completion		20-Jan-16	0



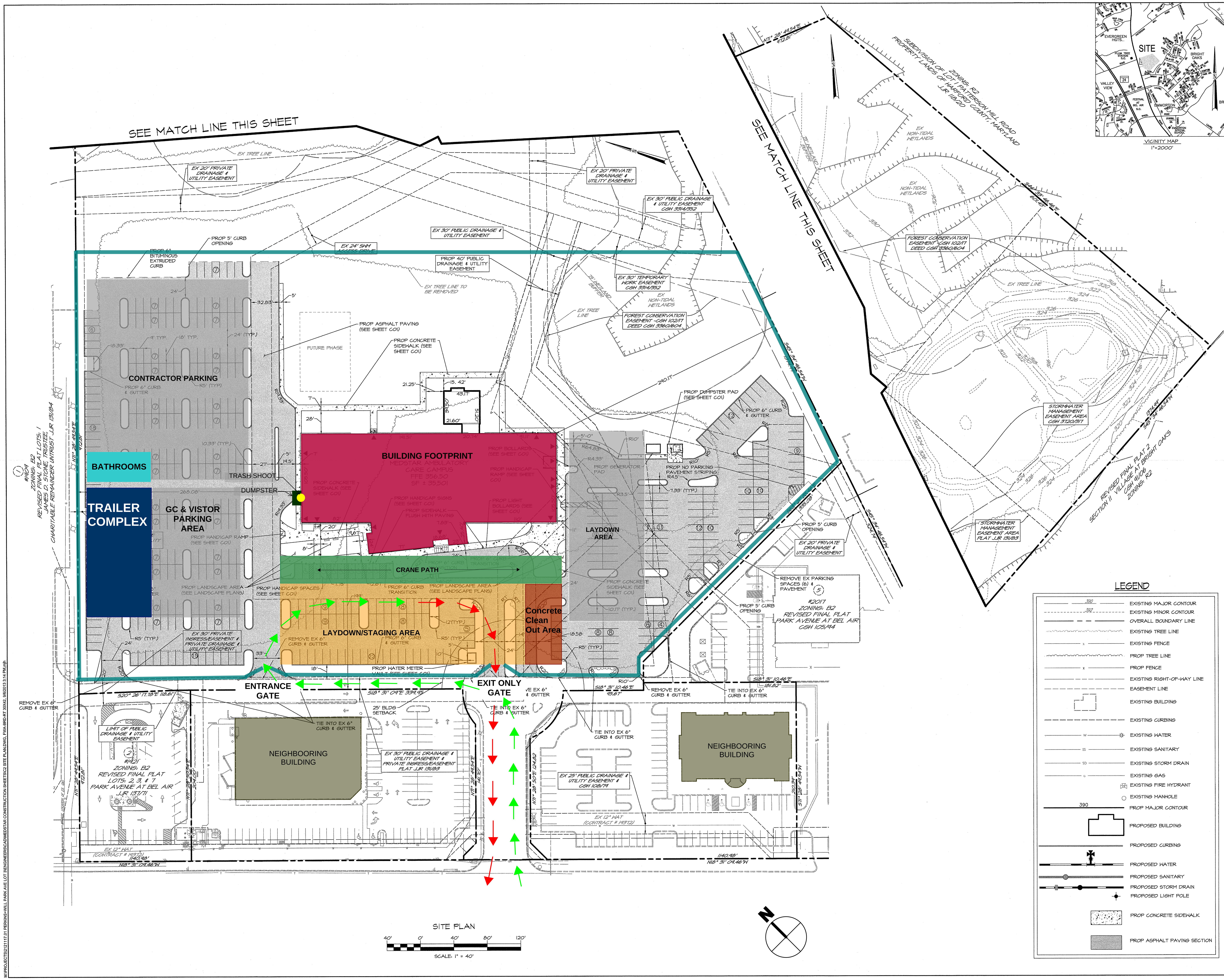
Actual Level of Effort	Remaining Work	Milestone
Actual Work	Critical Remaining Work	summary

Page 1 of 1

TASK filter: All Activities

Appendix A.3

Site Logistics Plan



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Revisions

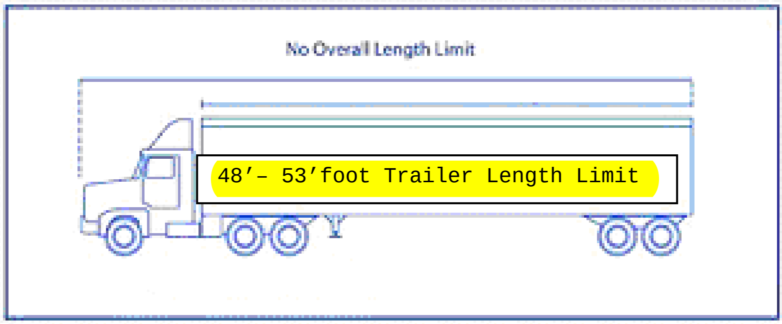
Sheet
C02

APPENDIX B.1

ROAD REGULATIONS

3. SEMI-TRAILERS EXCEEDING 48 FEET IN LENGTH UP TO A LENGTH NOT TO EXCEED 53 FEET – OPERATING RESTRICTIONS

A person may operate a truck tractor in combination with a semi-trailer (single) that exceeds 48 feet in length up to a length not to exceed 53 feet, but travel for this combination is limited to specific routes. Additional restrictions apply.



The following conditions apply:

- **Travel is restricted to the National Network System of Highways and the shortest practical route between a designated highway and a truck terminal, port, or point of origin or destination. Refer to Chapter II for approved routes and additional restrictions.**

- The wheelbase of the semi-trailer, measured as the distance from the kingpin to the center of the rear tandem axles, may not exceed 41 feet in length.

- The kingpin setback, measured as the distance from the kingpin to the front of the semi-trailer may not exceed 4 feet in length.

- The rear overhang, measured as the distance from the center of the rear tandem axles to the rear of the semi-trailer, may not exceed 35 percent of the wheelbase of the semi-trailer.

- The width of the semi-trailer shall be at least 96 inches and not more than 102 inches.

78

CHAPTER XIII

OVERSIZE/OVERWEIGHT HAULING PERMITS

A. LEGAL WEIGHTS

Any vehicle with a gross maximum weight in excess of 73,000 pounds may travel only on State and federal numbered highways, except while making a delivery or pick-up, and then only when traveling by the shortest available legal route to or from the State or federal highway for the purpose of picking up or delivering cargo. In City, the shortest available legal route shall be only on designated truck routes.

B. OVERSIZE/OVERWEIGHT HAULING PERMITS

The State Highway Administration (SHA), Motor Carrier Division (MCD), issues hauling permits to vehicles and loads that are over the allowed size and weight limits established by the ________ *Transportation Article (TA)*. For example, if the vehicle or load exceeds the following limits, you will be required to obtain a hauling permit before moving the vehicle/load

Width:	8 feet 6 inches	Height:	13 feet 6 inches
Length:	See Chapter XII	Weight:	See Chapter XIV

The MCD issues the following types of hauling permits:

- Book permits
- Blanket permits
- Containerized Cargo
- Exceptional Hauling Permit for Agricultural Products
- Exceptional Hauling Permit for Raw Milk*
- Special Hauling Permit
- Test Permit
- Utility Blanket Permit

***October 1, 2014 the will be offering an Exceptional Hauling Permit per House Bill 1246 for milk transporters which allows 88,000 pounds on 5 axles and 95,000 pounds on 6 axles. Refer to the ________ *TA, Title 24, § 113.2*.**

Overweight permits for vehicles carrying manifested international freight as the only load of the vehicle in a sealed seagoing container going to or from the Port of for 24-hour travel on certain designated routes are available by contacting the . Permits issued to 40' containers may not exceed **22,400** pounds gross maximum weight for a single axle, **44,000** pounds gross maximum for two consecutive axles, or **90,000** pounds gross maximum weight with the required axle spacing.

C. POSTED HIGHWAY DETOURS

The provides information on highway restrictions and detours. Refer to the telephone numbers in Appendix C. You may obtain more information on route restrictions by accessing the Motor Carrier Division website at:

D. ESCORT POLICIES

In some cases large loads and vehicles require an escort vehicle or vehicles accompany them during the move for safety. Escort by private personnel or State Police personnel is determined under *_______, Title 11.* If your move requires an escort vehicle or vehicles, call the SHA/HPU telephone numbers listed in Appendix C.

Haz-Mat loads such as flammable gases, liquids, explosives, and corrosives are not allowed in the Tunnel or the Tunnel . For further information contact:

Telephone

website address:

PERMIT FEES

90,000 LBS.	45 TONS	$ 30.00
92,000 LBS.	46 TONS	$ 35.00
94,000 LBS.	47 TONS	$ 40.00
96,000 LBS.	48 TONS	$ 45.00
98,000 LBS.	49 TONS	$ 50.00
100,000LBS.	50 TONS	$ 55.00
102,000LBS.	51 TONS	$ 60.00
104,000LBS.	52 TONS	$ 65.00
106,000LBS.	53 TONS	$ 70.00
108,000LBS.	54 TONS	$ 75.00
110,000LBS.	55 TONS	$ 80.00
112,000LBS.	56 TONS	$ 85.00
114,000LBS.	57 TONS	$ 90.00
116,000LBS.	58 TONS	$ 95.00
118,000LBS.	59 TONS	$100.00
120,000LBS.	60 TONS	$105.00

****

122,000LBS.	61 TONS	$110.00
124,000LBS.	62 TONS	$115.00
126,000LBS.	63 TONS	$120.00
128,000LBS.	64 TONS	$125.00
130,000LBS.	65 TONS	$130.00
132,000LBS.	66 TONS	$135.00
134,000LBS.	67 TONS	$140.00
136,000LBS.	68 TONS	$145.00
138,000LBS.	69 TONS	$150.00
140,000LBS.	70 TONS	$155.00
142,000LBS.	71 TONS	$160.00
144,000LBS.	72 TONS	$165.00
146,000LBS.	73 TONS	$170.00
148,000LBS.	74 TONS	$175.00
150,000LBS.	75 TONS	$180.00

Appendix B.2

Truck Specifications

MENU

Heavy Haul Trucks

Hauling loads or moving equipment, strength, drivability, durability and flat-out bottom line efficiency are all yours. Built to muscle through some of the roughest places on earth, durable Freightliner heavy haul trucks are the ultimate workhorse. Those in heavy haul trucking choose Freightliner not only for our reliable reputation, but also for our reputation of excellence.

122SD >

The flagship vocational model from Freightliner Trucks is tough on the outside, comfortable on the inside and always ready for a hard day of heavy haul trucking, no matter how severe.

122” BBC | 92,000 GVW | 350 to 600 HP | 1,250 to 2,050 lb/ft.

Request Quote > Find Dealer >

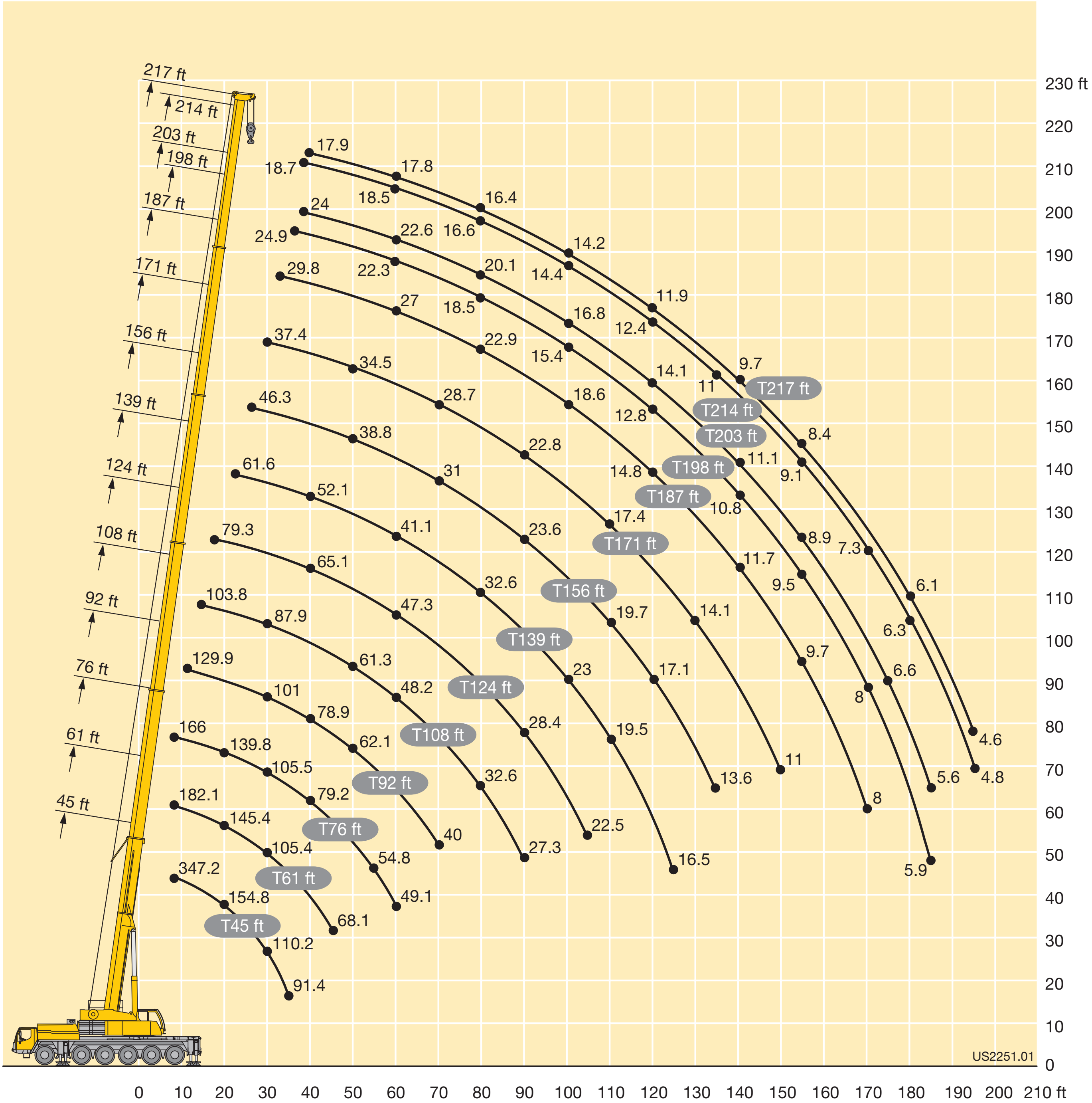
Newsletter Sign Up

Appendix B.3

Crane Specifications

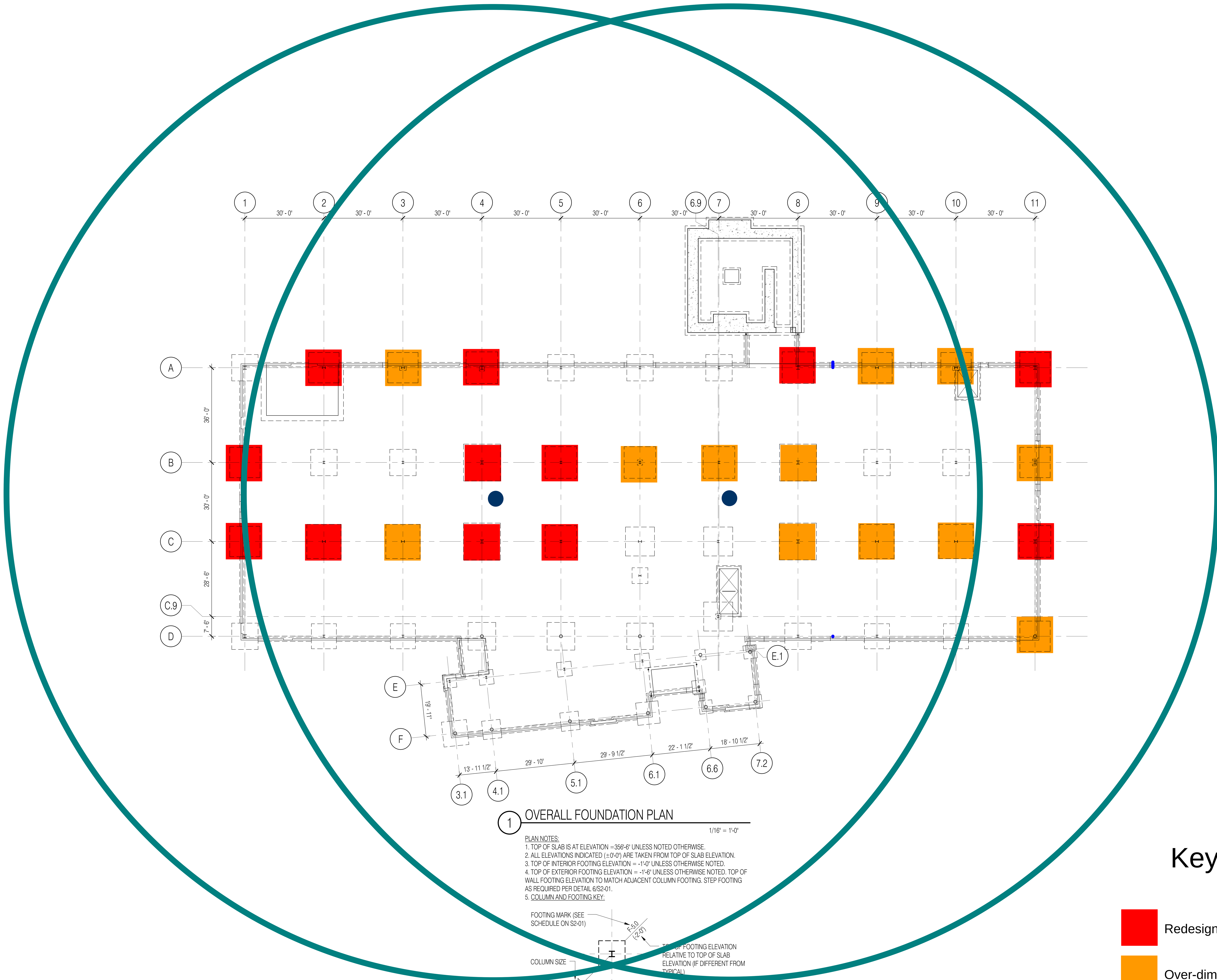
Lifting heights
Hauteurs de levage

T



Appendix B.4

Crane Layout & Footing Redesign



1 OVERALL FOUNDATION PLAN

1/16" = 1'-0"

PLAN NOTES:

1. TOP OF SLAB IS AT ELEVATION =356'-6" UNLESS NOTED OTHERWISE.
2. ALL ELEVATIONS INDICATED (±0'-0") ARE TAKEN FROM TOP OF SLAB ELEVATION.
3. TOP OF INTERIOR FOOTING ELEVATION = -1'-0" UNLESS OTHERWISE NOTED.
4. TOP OF EXTERIOR FOOTING ELEVATION = -1'-6" UNLESS OTHERWISE NOTED. TOP OF WALL FOOTING ELEVATION TO MATCH ADJACENT COLUMN FOOTING. STEP FOOTING AS REQUIRED PER DETAIL 6/S2-01.
5. COLUMN AND FOOTING KEY:

FOOTING MARK (SEE SCHEDULE ON S2-01)
F-5.0
(-2'-0")
TOP OF FOOTING ELEVATION RELATIVE TO TOP OF SLAB ELEVATION (IF DIFFERENT FROM TYPICAL)
COLUMN SIZE
W8x31
BP-1
BASE PLATE MARK (SEE SCHEDULE ON S3-01)

6. ALL PIERS, COLUMNS, AND FOOTINGS SHALL BE CENTERED ON COLUMN LINES UNLESS NOTED.
7. SEE S0-01 FOR GENERAL NOTES.
8. SEE S2-01 AND S2-02 FOR TYPICAL DETAILS.

Key

- Redesigned Footing
- Over-dimensional Footings
- Crane Radius
- Crane Locations

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Rockville, MD 20852
t 301-891-9050
f 301-891-1125

CIVIL
FREDERICK WARD ASSOCIATES
5 South Main Street, P.O. Box 727
Bel Air, MD 21014
t 410-879-2090
f 410-893-1243

Construction Documents

Professional Certification. I hereby certify that these documents were prepared or approved by me, and that I am a duly licensed professional engineer under the laws of the State of Maryland, License No. 19160, Expiration Date: 06-06-2015.

Revisions

NO	ISSUE	DATE
	CDs	04/04/14
	GMP	08/30/13

Sheet Information

Date	08.23.2013
Job Number	2012 082
Drawn	CRW
Checked	CRW
Approved	CRW

Title

OVERALL FOUNDATION PLAN

Sheet

S1-01

Appendix B.5

Load Calculations

Loading Calculation for A2

Start Level	End Level	DL factor	DL	LL factor	LL Reducing Coefficient	LL Reduced	At	n (floors supported)	DL Floor Load on Column (k)	LL Floor Load on Column (k)	DL Roof on Column (k)	LL Roof on Column (k)	Wall Load	Wall At	Wall Load on Column	Pu (DL)	Pu (LL)
3	R	1.2	34	1.6		30	540	0	0	0	18.36	16.2	15	560.1	4.20075	**22.56075**	**16.2**
2	3	1.2	56	1.6	0.57274861	45.81989	540	1	30.24	24.74274	18.36	16.2	15	450	10.125	**58.725**	**40.94274**
1	2	1.2	56	1.6	0.47821773	38.25742	540	2	60.48	41.31801	18.36	16.2	15	450	16.875	**95.715**	**57.51801**
															Total	**177.0008**	**114.6608**

Loading Calculation for A4

Start Level	End Level	DL factor	DL	LL factor	LL Reducing Coefficient	LL Reduced	At	n (floors supported)	DL Floor Load on Column (k)	LL Floor Load on Column (k)	DL Roof on Column (k)	LL Roof on Column (k)	Wall Load	Wall At	Wall Load on Column	Pu (DL)	Pu (LL)
3	R	1.2	34	1.6		30	540	0	0	0	18.36	16.2	15	560.1	4.20075	**22.56075**	**16.2**
2	3	1.2	56	1.6	0.57274861	45.81989	540	1	30.24	24.74274	18.36	16.2	15	450	10.125	**58.725**	**40.94274**
1	2	1.2	56	1.6	0.47821773	38.25742	540	2	60.48	41.31801	18.36	16.2	15	450	16.875	**95.715**	**57.51801**
															Total	**177.0008**	**114.6608**

Loading Calculation for A8

Start Level	End Level	DL factor	DL	LL factor	LL Reducing Coefficient	LL Reduced	At	n (floors supported)	DL Floor Load on Column (k)	LL Floor Load on Column (k)	DL Roof on Column (k)	LL Roof on Column (k)	Wall Load	Wall At	Wall Load on Column	Pu (DL)	Pu (LL)
3	R	1.2	34	1.6		30	540	0	0	0	18.36	16.2	15	560.1	4.20075	**22.56075**	**16.2**
2	3	1.2	56	1.6	0.57274861	45.81989	540	1	30.24	24.74274	18.36	16.2	15	450	10.125	**58.725**	**40.94274**
1	2	1.2	56	1.6	0.47821773	38.25742	540	2	60.48	41.31801	18.36	16.2	15	450	16.875	**95.715**	**57.51801**
															Total	**177.0008**	**114.6608**

Loading Calculation for A11

Start Level	End Level	DL factor	DL	LL factor	LL Reducing Coefficient	LL Reduced	At	n (floors supported)	DL Floor Load on Column (k)	LL Floor Load on Column (k)	DL Roof on Column (k)	LL Roof on Column (k)	Wall Load	Wall At	Wall Load on Column	Pu (DL)	Pu (LL)
3	R	1.2	34	1.6		30	270	0	0	0	9.18	8.1	15	616.11	4.620825	**13.80083**	**8.1**
2	3	1.2	56	1.6	0.7064355	56.51484	270	1	15.12	15.25901	9.18	8.1	15	495	11.1375	**35.4375**	**23.35901**
1	2	1.2	56	1.6	0.5727486	45.81989	270	2	30.24	24.74274	9.18	8.1	15	495	18.5625	**57.9825**	**32.84274**
															Total	**107.2208**	**64.30175**

Loading Calculation for B1

Start Level	End Level	DL factor	DL	LL factor	LL Reducing Coefficient	LL Reduced	At	n (floors supported)	DL Floor Load on Column (k)	LL Floor Load on Column (k)	DL Roof on Column (k)	LL Roof on Column (k)	Wall Load	Wall At	Wall Load on Column	Pu (DL)	Pu (LL)
3	R	1.2	34	1.6		30	495	0	0	0	16.83	14.85	15	616.11	4.620825	**21.45083**	**14.85**
2	3	1.2	56	1.6	0.58709993	46.96799	495	1	27.72	23.24916	16.83	14.85	15	495	11.1375	**55.6875**	**38.09916**
1	2	1.2	56	1.6	0.48836565	39.06925	495	2	55.44	38.67856	16.83	14.85	15	495	18.5625	**90.8325**	**53.52856**
															Total	**167.9708**	**106.4777**

Loading Calculation for B4

Start Level	End Level	DL factor	DL	LL factor	LL Reducing Coefficient	LL Reduced	At	n (floors supported)	DL Floor Load on Column (k)	LL Floor Load on Column (k)	DL Roof on Column (k)	LL Roof on Column (k)	Wall Load	Wall At	Wall Load on Column	Pu (DL)	Pu (LL)
3	R	1.2	34	1.6		30	990	0	0	0	33.66	29.7	15	0	0	**33.66**	**29.7**
2	3	1.2	56	1.6	0.48836565	39.06925	990	1	55.44	38.67856	33.66	29.7	15	0	0	**89.1**	**68.37856**
1	2	1.2	56	1.6	0.41854997	33.484	990	2	110.88	66.29831	33.66	29.7	15	0	0	**144.54**	**95.99831**
															Total	**267.3**	**194.0769**

Loading Calculation for B5

Start Level	End Level	DL factor	DL	LL factor	LL Reducing Coefficient	LL Reduced	At	n (floors supported)	DL Floor Load on Column (k)	LL Floor Load on Column (k)	DL Roof on Column (k)	LL Roof on Column (k)	Wall Load	Wall At	Wall Load on Column	Pu (DL)	Pu (LL)
3	R	1.2	34	1.6		30	990	0	0	0	33.66	29.7	15	0	0	**33.66**	**29.7**
2	3	1.2	56	1.6	0.48836565	39.06925	990	1	55.44	38.67856	33.66	29.7	15	0	0	**89.1**	**68.37856**
1	2	1.2	56	1.6	0.41854997	33.484	990	2	110.88	66.29831	33.66	29.7	15	0	0	**144.54**	**95.99831**
															Total	**267.3**	**194.0769**

Loading Calculation for C1

Start Level	End Level	DL factor	DL	LL factor	LL Reducing Coefficient	LL Reduced	At	n (floors supported)	DL Floor Load on Column (k)	LL Floor Load on Column (k)	DL Roof on Column (k)	LL Roof on Column (k)	Wall Load	Wall At	Wall Load on Column	Pu (DL)	Pu (LL)
3	R	1.2	34	1.6		30	438.75	0	0	0	14.9175	13.1625	15	546.0975	4.095731	**19.01323**	**13.1625**
2	3	1.2	56	1.6	0.60805744	48.64459	438.75	1	24.57	21.34282	14.9175	13.1625	15	438.75	9.871875	**49.35938**	**34.50532**
1	2	1.2	56	1.6	0.50318484	40.25479	438.75	2	49.14	35.32358	14.9175	13.1625	15	438.75	16.45313	**80.51063**	**48.48608**
															Total	**148.8832**	**96.15389**

Loading Calculation for C2

Start Level	End Level	DL factor	DL	LL factor	LL Reducing Coefficient	LL Reduced	At	n (floors supported)	DL Floor Load on Column (k)	LL Floor Load on Column (k)	DL Roof on Column (k)	LL Roof on Column (k)	Wall Load	Wall At	Wall Load on Column	Pu (DL)	Pu (LL)
3	R	1.2	34	1.6		30	877.5	0	0	0	29.835	26.325	15	0	0	**29.835**	**26.325**
2	3	1.2	56	1.6	0.50318484	40.25479	877.5	1	49.14	35.32358	29.835	26.325	15	0	0	**78.975**	**61.64858**
1	2	1.2	56	1.6	0.42902872	34.3223	877.5	2	98.28	60.23563	29.835	26.325	15	0	0	**128.115**	**86.56063**
															Total	**236.925**	**174.5342**

Loading Calculation for C4

Start Level	End Level	DL factor	DL	LL factor	LL Reducing Coefficient	LL Reduced	At	n (floors supported)	DL Floor Load on Column (k)	LL Floor Load on Column (k)	DL Roof on Column (k)	LL Roof on Column (k)	Wall Load	Wall At	Wall Load on Column	Pu (DL)	Pu (LL)
3	R	1.2	34	1.6		30	877.5	0	0	0	29.835	26.325	15	0	0	**29.835**	**26.325**
2	3	1.2	56	1.6	0.50318484	40.25479	877.5	1	49.14	35.32358	29.835	26.325	15	0	0	**78.975**	**61.64858**
1	2	1.2	56	1.6	0.42902872	34.3223	877.5	2	98.28	60.23563	29.835	26.325	15	0	0	**128.115**	**86.56063**
															Total	**236.925**	**174.5342**

Loading Calculation for C5

Start Level	End Level	DL factor	DL	LL factor	LL Reducing Coefficient	LL Reduced	At	n (floors supported)	DL Floor Load on Column (k)	LL Floor Load on Column (k)	DL Roof on Column (k)	LL Roof on Column (k)	Wall Load	Wall At	Wall Load on Column (k)	Pu (DL)	Pu (LL)
3	R	1.2	34	1.6		30	877.5	0	0	0	29.835	26.325	15	0	0	**29.835**	**26.325**
2	3	1.2	56	1.6	0.50318484	40.25479	877.5	1	49.14	35.32358	29.835	26.325	15	0	0	**78.975**	**61.64858**
1	2	1.2	56	1.6	0.42902872	34.3223	877.5	2	98.28	60.23563	29.835	26.325	15	0	0	**128.115**	**86.56063**
															Total	**236.925**	**174.5342**

Loading Calculation for C11

Start Level	End Level	DL factor	DL	LL factor	LL Reducing Coefficient	LL Reduced	At	n (floors supported)	DL Floor Load on Column (k)	LL Floor Load on Column (k)	DL Roof on Column (k)	LL Roof on Column (k)	Wall Load	Wall At	Wall Load on Column (k)	Pu (DL)	Pu (LL)
3	R	1.2	34	1.6		30	438.75	0	0	0	14.9175	13.1625	15	546.0975	4.095731	**19.01323**	**13.1625**
2	3	1.2	56	1.6	0.60805744	48.64459	438.75	1	24.57	21.34282	14.9175	13.1625	15	438.75	9.871875	**49.35938**	**34.50532**
1	2	1.2	56	1.6	0.50318484	40.25479	438.75	2	49.14	35.32358	14.9175	13.1625	15	438.75	16.45313	**80.51063**	**48.48608**
															Total	**148.8832**	**96.15389**

Appendix B.6

Footing Redesign Calculations

Footing Redesign Calculations

Footing	PD (K)	PL (K)	L+D (k)	Bearing capacity (qa) (ksf)	B	B	Size	Load Comb.	q (ksf)	q (psi)	f'c (psi)	vc	vc	vc (controls)	d	h	h (in)	h (ft)	d	l	Mn	a	As	Bar #	As	Spacing (in)	p(s+t)	a	c	ε_s
A2	177.0008	114.6608	291.6615	5	7.64	8.00	8'x8'	395.8581	6.19	42.95	4500	402.4922	2146.625	201.25	11.82	15.57	18	1.5	14.25	36	27.83	1.31	0.44	#6	0.56	9.5	0.001944	0.73	0.86	0.046533
A4	177.0008	114.6608	291.6615	5	7.64	8.00	8'x8'	395.8581	6.19	42.95	4500	402.4922	2146.625	201.25	11.82	15.57	18	1.5	14.25	36	27.83	1.31	0.44	#6	0.56	9.5	0.001944	0.73	0.86	0.046533
A8	177.0008	114.6608	291.6615	5	7.64	8.00	8'x8'	395.8581	6.19	42.95	4500	402.4922	2146.625	201.25	11.82	15.57	18	1.5	14.25	36	27.83	1.31	0.44	#6	0.56	9.5	0.001944	0.73	0.86	0.046533
A11	107.2208	64.30175	171.5226	5	5.86	6.00	6'x6'	231.5478	6.43	44.67	4500	402.4922	1475.805	201.25	7.41	11.035	12	1	8.375	24	12.86	1.31	0.35	#5	0.57	6.5	0.001979	0.75	0.88	0.025601
B1	167.9708	106.4777	274.4485	5	7.41	8.00	8'x8'	371.9293	5.81	40.36	4500	402.4922	2146.625	201.25	11.31	15.06	18	1.5	14.25	36	26.15	1.31	0.42	#6	0.56	9.5	0.0019	0.73	0.86	0.046533
B4	267.3	194.0769	461.3769	5	9.61	10.00	10'x10'	631.283	6.31	43.84	3000	328.6335	2300.435	164.32	19.3	23.175	24	2	20.125	48	50.50	1.96	0.57	#7	0.60	12	0.002083	1.18	1.38	0.040638
B5	267.3	194.0769	461.3769	5	9.61	10.00	10'x10'	631.283	6.31	43.84	3000	328.6335	2300.435	164.32	19.3	23.175	24	2	20.125	48	50.50	1.96	0.57	#7	0.60	12	0.002083	1.18	1.38	0.040638
C1	148.8832	96.15389	245.0371	5	7.00	7.50	7.5'x7.5'	332.5061	5.91	41.05	4500	402.4922	2146.625	201.25	10.3	14.05	15	1.25	11.25	33	22.35	1.31	0.45	#6	0.56	9.5	0.001944	0.73	0.86	0.036105
C2	236.925	174.5342	411.4592	5	9.07	9.50	9.5'x9.5'	563.5647	6.24	43.36	3000	328.6335	2300.435	164.32	17.77	21.645	24	2	20.125	45	43.91	1.96	0.50	#6	0.56	9.5	0.001944	1.10	1.29	0.043755
C4	236.925	174.5342	411.4592	5	9.07	9.50	9.5'x9.5'	563.5647	6.24	43.36	3000	328.6335	2300.435	164.32	17.77	21.645	24	2	20.125	45	43.91	1.96	0.50	#6	0.56	9.5	0.001944	1.10	1.29	0.043755
C5	236.925	174.5342	411.4592	5	9.07	9.50	9.5'x9.5'	563.5647	6.24	43.36	3000	328.6335	2300.435	164.32	17.77	21.645	24	2	20.125	45	43.91	1.96	0.50	#6	0.56	9.5	0.001944	1.10	1.29	0.043755
C11	148.8832	96.15389	245.0371	5	7.00	7.50	7.5'x7.5'	332.5061	5.91	41.05	4500	402.4922	2146.625	201.25	10.3	14.05	15	1.25	11.25	33	22.35	1.31	0.45	#6	0.56	9.5	0.001944	0.73	0.86	0.036105

Average Reduction Percentage

Footing	Bearing capacity (qa) (ksf)	Length/Width @ qa = 2 ksf	Depth @ qa = 2 ksf	CF @ qa = 2 ksf	Bearing capacity (qa) (ksf)	Length/Width @ qa = 5 ksf	Depth @ qa = 5 ksf	CF @ qa = 5 ksf	Reduced
A2	2	11.5	2.17	286.54	5	8.00	1.5	96	66%
A4	2	12	2.33	336.00	5	8.00	1.5	96	71%
A8	2	12	2.33	336.00	5	8.00	1.5	96	71%
A11	2	11.5	2.17	286.54	5	6.00	1	36	87%
B1	2	11.5	2.17	286.54	5	8.00	1.5	96	66%
B4	2	14	2.50	490.00	5	10.00	2	200	59%
B5	2	12	2.33	336.00	5	10.00	2	200	40%
C1	2	11.5	2.17	286.54	5	7.50	1.25	70.3125	75%
C2	2	12	2.33	336.00	5	9.50	2	180.5	46%
C4	2	14	2.50	490.00	5	9.50	2	180.5	63%
C5	2	12	2.33	336.00	5	9.50	2	180.5	46%
C11	2	12	2.33	336.00	5	7.50	1.25	70.3125	79%
								Average	64%

Appendix B.7

Hand Calculations

STRUCTURAL BREADTH CALCULATIONS KENNA MARKEL

A2

$$d^2\left[201.25+\frac{42.95}{4}\right]+d\left[201.25+\frac{42.95}{2}\right](24)=\frac{42.95}{4}\left[(96)(96)-24^2\right]$$

$$211.9875d^2+5345.4d=92772$$

$$d=11.82$$

A4 AND A8 SAME AS A2

A11

$$d^2\left[201.25+\frac{44.67}{4}\right]+d\left[201.25+\frac{44.67}{2}\right](24)=\frac{44.67}{4}\left[(72)(72)-24^2\right]$$

$$212.4175d^2+5366.04d=51459.84$$

$$d=7.41$$

B1

$$d^2\left[201.25+\frac{40.36}{4}\right]+d\left[201.25+\frac{40.36}{2}\right](24)=\frac{40.36}{4}\left[(96)(96)-24^2\right]$$

$$211.34d^2+5314.32d=87177.6$$

$$d=11.31$$

B4

$$d^2\left[164.32+\frac{43.84}{4}\right]+d\left[164.32+\frac{43.84}{2}\right](24)=\frac{43.84}{4}\left[(120)(120)-24^2\right]$$

$$175.28d^2+4469.76d=151511.04$$

$$d=19.3$$

B5 SAME AS B4

C1

$$d^2\left[201.25+\frac{41.05}{4}\right]+d\left[201.25+\frac{41.05}{2}\right](24)=\frac{41.05}{4}\left[(90)(90)-24^2\right]$$

$$211.5125d^2+5322.6d=77215.05$$

$$d=10.3$$

C2

$$d^2\left[164.32+\frac{43.36}{4}\right]+d\left[164.32+\frac{43.36}{2}\right](24)=\frac{43.36}{4}\left[(114)(114)-24^2\right]$$

$$175.16d^2+4464d=134632.8$$

$$d=17.77$$

C3 AND C5 SAME AS C2

C11 SAME AS C1

A2

$$27.83(12) = .9A_s(60)(14.25 - \frac{1.31A_s}{2})$$

$$6.18 = 14.25A_s - .655A_s^2$$

$$A_s \geq .44$$

A4 AND A8 SAME AS A2

A11

$$12.86(12) = .9A_s(60)(8.375 - \frac{1.31A_s}{2})$$

$$2.85 = (8.375A_s - .655A_s^2)$$

$$A_s \geq .35$$

B1

$$26.15(12) = .9A_s(60)(14.25 - \frac{1.31A_s}{2})$$

$$5.81 = 14.25A_s - .65A_s^2$$

$$A_s \geq .42$$

B4

$$50.50(12) = .9A_s(60)(20.125 - \frac{1.96A_s}{2})$$

$$11.22 = 20.125A_s - .98A_s^2$$

$$A_s \geq .57$$

B_5 SAME AS B4

C1

$$22.35(12) = .9A_s(60)(11.25 - \frac{1.31A_s}{2})$$

$$4.96 = 11.25A_s - .655A_s^2$$

$$A_s \geq .45$$

C2

$$(43.91)(12) = .9A_s(60)(20.125 - \frac{1.96A_s}{2})$$

$$9.7578 = 20.125A_s - .98A_s^2$$

$$A_s \geq .5$$

C4 AND C5 SAME AS C2

C11 SAME AS C1

Appendix B.8

Delivery Sequence Footings

Delivery Sequence

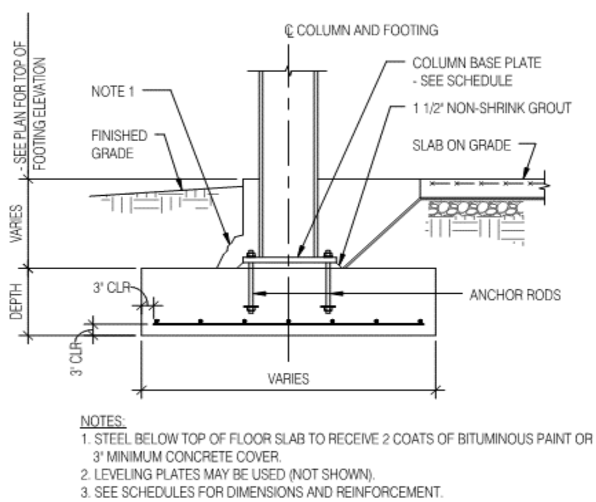
Delivery Day	Footing	Length (LF)	Width (LF)	Depth (LF)	Total (CF)	Reduced (64%)	Reduced L & W	Rounded L & W (LF)	Weight (lbs)	Weight (kips)
1	A/1	10.0	10.0	2	200	72	6	6	10800	10.8
1	B/1	8.0	8.0	1.5	96	-	-	8	14400	14.4
1	C/1	7.5	7.5	1.25	70.3125	-	-	7.5	10546.88	10.54688
1	D/1	10.0	10.0	2	200	72	6	6	10800	10.8
1	D/2	9.5	9.5	2	180.5	64.98	5.7	6	10800	10.8
1	C/2	9.5	9.5	2	180.5	-	-	9.5	27075	27.075
								Delivery Weight	84421.88	84.42188
2	B/2	10.0	10.0	2	200	72	6	6	10800	10.8
2	A/2	8.0	8.0	1.25	80	-	-	8.0	12000	12
2	A/3	8.0	8.0	1.25	80	-	-	8.0	12000	12
2	B/3	10.0	10.0	2	200	72	6	6	10800	10.8
2	C/3	9.5	9.5	2	180.5	-	-	9.5	27075	27.075
								Delivery Weight	72675	72.675
3	D/3	9.5	9.5	2	180.5	64.98	5.7	6	10800	10.8
3	F/3.1	9.5	9.5	2	180.5	64.98	5.7	6	10800	10.8
3	E/3.1	5.0	5.0	1.17	29.25	10.53	3	4	2808	2.808
3	F/4.1	7.0	7.0	1.5	73.5	26.46	4.2	4	3600	3.6
3	E/4.1	5.5	5.5	1.17	35.3925	12.7413	3.3	4	2808	2.808
3	D/4	10.5	10.5	2.17	239.2425	86.1273	6.3	7	15949.5	15.9495
4	C/4	9.5	9.5	2	180.5	-	-	9.5	27075	27.075
								Delivery Weight	73840.5	73.8405
4	B/4	10.0	10.0	2.17	217	-	-	10.0	32550	32.55
4	A/4	8.0	8.0	1.25	80	-	-	8.0	12000	12
4	A/5	10.0	10.0	2	200	72	6	6	10800	10.8
4	B/5	10.0	10.0	2	200	-	-	10.0	30000	30
								Delivery Weight	85350	85.35
4	C/5	9.5	9.5	2	180.5	-	-	9.5	27075	27.075
5	D/5	10.5	10.5	2.17	239.2425	86.1273	6.3	7	15949.5	15.9495
5	E/5.1	5.5	5.5	1.17	35.3925	12.7413	3.3	4	2808	2.808
5	F/5.1	7.0	7.0	1.5	73.5	26.46	4.2	5	5625	5.625
6	A/6	10.0	10.0	2	200	72	6	6	10800	10.8
								Delivery Weight	62257.5	62.2575
5						MOVE CRANE				
6	B/6	10.0	10.0	2	200	-	-	10.0	30000	30
6	C/6	11.0	11.0	1.5	181.5	65.34	6.6	7	11025	11.025
6	C.4/6	6.0	6.0	1.25	45	16.2	3.6	4	3000	3
6	D/6	10.0	10.0	2	200	72	6	6	10800	10.8
7	E/6.1	5.5	5.5	1.17	35.3925	12.7413	3.3	4	2808	2.808
7	F/6.1	8.5	8.5	1.75	126.4375	45.5175	5.1	6	9450	9.45
7	F/6.6	5.0	5.0	1.17	29.25	10.53	3	4	2808	2.808
7	E.7/6.6	5.0	5.0	1.17	29.25	10.53	3	4	2808	2.808
7	E/6.6	4.0	4.0	1	16	5.76	2.4	4	2400	2.4
7	F/7.2	5.0	5.0	1.17	29.25	10.53	3	4	2808	2.808
7	E/7.2	5.0	5.0	1.17	29.25	10.53	3	4	2808	2.808
								Delivery Weight	80715	80.715
8	C.9/7	10.0	10.0	2	200	72	6	6	10800	10.8
8	C/7	11.0	11.0	1.5	181.5	65.34	6.6	7	11025	11.025
8	B/7	10.0	10.0	2.17	217	-	-	10.0	32550	32.55
8	A/7	10.0	10.0	2	200	72	6	6	10800	10.8
8	A/8	8.0	8.0	1.25	80	-	-	8.0	12000	12
								Delivery Weight	77175	77.175
9	B/8	10.0	10.0	2	200	-	-	10.0	30000	30
9	C/8	9.5	9.5	2	180.5	-	-	9.5	27075	27.075
9	D/8	10.0	10.0	2	200	72	6	6	10800	10.8
9	D/9	9.5	9.5	2	180.5	64.98	5.7	6	10800	10.8
								Delivery Weight	78675	78.675
10	C/9	9.5	9.5	2	180.5	-	-	9.5	27075	27.075
10	B/9	10.0	10.0	2	200	72	6	6	10800	10.8
10	A/9	8.0	8.0	1.25	80	-	-	8.0	12000	12
10	A/10	8.0	8.0	1.25	80	-	-	8.0	12000	12
10	B/10	10.0	10.0	2	200	72	6	6	10800	10.8
								Delivery Weight	72675	72.675
11	C/10	10.0	10.0	2	200	-	-	10.0	30000	30
11	D/10	9.5	9.5	2	180.5	64.98	5.7	6	10800	10.8
11	D/11	6.0	6.0	1.25	45	-	-	6.0	6750	6.75
11	C/11	7.5	7.5	1.25	70.3125	-	-	7.5	10546.88	10.54688
11	B/11	8.0	8.0	1.25	80	-	-	8.0	12000	12
11	A/11	6.0	6.0	1.25	45	-	-	6.0	6750	6.75
								Delivery Weight	76846.88	76.84688

Appendix B.9

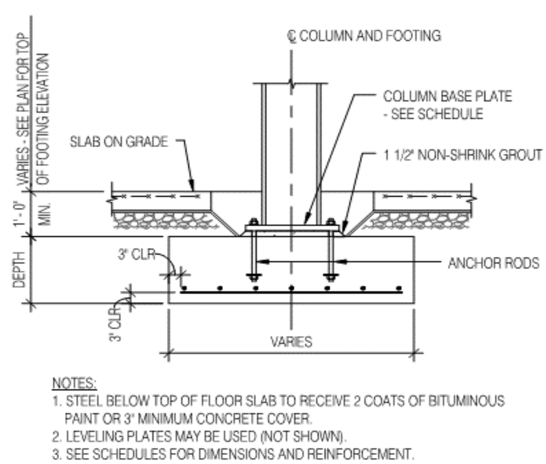
Footing Take-offs

Cast-in-Place Concrete Take-off							
Footing Type	Quantity	Width (LF)	Length (LF)	Fill (SF)	Depth (LF)	Subtotal (CF)	Subtotal (CY)
F-4.0	1	4	4	16	1.00	16.0	0.592593
F-5.0	5	5	5	125	1.17	145.8	5.401235
F-5.5	3	5.5	5.5	90.75	1.17	105.9	3.921296
F-6.0	1	6	6	36	1.25	45.0	1.666667
F-7.0	2	7	7	98	1.50	147.0	5.444444
F-8.5	1	8.5	8.5	72.25	1.75	126.4	4.68287
F-9.5	5	9.5	9.5	451.25	2.00	902.5	33.42593
F-10.0	11	10	10	1100	2.00	2200.0	81.48148
F-10.5	2	10.5	10.5	220.5	2.17	477.8	17.69444
F-11.0	3	11	11	363	2.17	786.5	29.12963
F-11.5	9	11.5	11.5	1190.25	2.17	2578.9	95.51389
F-12.0	7	12	12	1008	2.33	2352.0	87.11111
F-13.0	4	13	13	676	2.33	1577.3	58.41975
F-14.0	4	14	14	784	2.50	1960.0	72.59259
			Total Fill (SF)	6231		Total (CY)	497.0779
			Excess (10%)	6854.1		Excess (5%)	521.9318

S2-01 Details 1 & 2



1 EXTERIOR COLUMN FOOTING (STEEL COLUMN) 1/2" = 1'-0"



2 INTERIOR COLUMN FOOTING (STEEL COLUMN) 1/2" = 1'-0"

Excavation For Cast-in-Place Footings							
Footing Type	Quantity	Width (LF)		Depth (LF)	Top of Footing (LF)	Subtotal (CF)	Subtotal (CY)
F-4.0	1	4	4	1.00	1.50	40.0	1.5
F-5.0	5	5	5	1.17	1.50	333.3	12.3
F-5.5	3	5.5	5.5	1.17	1.50	242.0	9.0
F-6.0	1	6	6	1.25	1.50	99.0	3.7
F-7.0	2	7	7	1.50	1.50	294.0	10.9
F-8.5	1	8.5	8.5	1.75	1.50	234.8	8.7
F-9.5	5	9.5	9.5	2.00	1.50	1579.4	58.5
F-10.0	11	10	10	2.00	1.50	3850.0	142.6
F-10.5	2	10.5	10.5	2.17	1.50	808.5	29.9
F-11.0	3	11	11	2.17	1.50	1331.0	49.3
F-11.5	9	11.5	11.5	2.17	1.50	4364.3	161.6
F-12.0	7	12	12	2.33	1.50	3864.0	143.1
F-13.0	4	13	13	2.33	1.50	2591.3	96.0
F-14.0	4	14	14	2.50	1.50	3136.0	116.1
					Total (CY)		843.245
					Excess (10%)		927.569

Excavation For Precast Footings								
Footing Type	Quantity	Width (LF)		Depth (LF)	Top of Footing (LF)	Subtotal (CF)	Additional Depth	Total (CF)
F-4.0	1	4	4	1.00	1.50	10.1	24.0	34.1
F-5.0	5	5	5	1.17	1.50	91.9	187.5	279.4
F-5.5	3	5.5	5.5	1.17	1.50	66.7	136.1	202.8
F-6.0	1	6	6	1.25	1.50	28.4	54.0	82.4
F-7.0	2	7	7	1.50	1.50	92.6	147.0	239.6
F-8.5	1	8.5	8.5	1.75	1.50	79.7	108.4	188.0
F-9.5	5	9.5	9.5	2.00	1.50	568.6	676.9	1245.5
F-10.0	11	10	10	2.00	1.50	1386.0	1650.0	3036.0
F-10.5	2	10.5	10.5	2.17	1.50	301.0	330.8	631.7
F-11.0	3	11	11	2.17	1.50	495.5	544.5	1040.0
F-11.5	9	11.5	11.5	2.17	1.50	1624.7	1785.4	3410.1
F-12.0	7	12	12	2.33	1.50	1481.8	1512.0	2993.8
F-13.0	4	13	13	2.33	1.50	993.7	1014.0	2007.7
F-14.0	4	14	14	2.50	1.50	1234.8	1176.0	2410.8
								Total (CY)
								Excess (10%)

Precast Concrete and Formwork													
Footing Type	Quantity	Reduction	Reduction	Width (LF)	Length (LF)	Fill (SF)	Depth (LF)	Original Subtotal (CF)	Reduced Subtotal (CF)	Per Footing Reduced (CY)	Reduced Subtotal (CY)	Subtotal Surface Area (SF)	Reduced SA (SF)
F-4.0	1	37%	72%	4	4	7.71	1.00	16.0	10.1	0.4	0.37	32.00	20.16
F-5.0	5	37%	72%	5	5	60.20	1.17	145.8	91.9	0.7	3.40	148.33	93.45
F-5.5	3	37%	72%	5.5	5.5	43.71	1.17	105.9	66.7	0.8	2.47	116.42	73.34
F-6.0	1	37%	72%	6	6	17.34	1.25	45.0	28.4	1.1	1.05	66.00	41.58
F-7.0	2	37%	72%	7	7	47.20	1.50	147.0	92.6	1.7	3.43	140.00	88.20
F-8.5	1	37%	72%	8.5	8.5	34.80	1.75	126.4	79.7	3.0	2.95	131.75	83.00
F-9.5	5	37%	72%	9.5	9.5	217.32	2.00	902.5	568.6	4.2	21.06	527.25	332.17
F-10.0	11	37%	72%	10	10	529.76	2.00	2200.0	1386.0	4.7	51.33	1180.00	743.40
F-10.5	2	37%	72%	10.5	10.5	106.19	2.17	477.8	301.0	5.6	11.15	311.50	196.25
F-11.0	3	37%	72%	11	11	174.82	2.17	786.5	495.5	6.1	18.35	458.33	288.75
F-11.5	9	37%	72%	11.5	11.5	573.22	2.17	2578.9	1624.7	6.7	60.17	1289.92	812.65
F-12.0	7	37%	72%	12	12	485.45	2.33	2352.0	1481.8	7.8	54.88	1120.00	705.60
F-13.0	4	37%	72%	13	13	325.56	2.33	1577.3	993.7	9.2	36.80	797.33	502.32
F-14.0	4	37%	72%	14	14	377.57	2.50	1960.0	1234.8	11.4	45.73	924.00	582.12
					Total Fill (SF)	3000.85				Total (CY)	313.159097	Total (SFCA)	4562.985
										Excess (5%)	328.817052	Excess (10%)	5019.2835

Rebar Take-off

Footing Type	Quantity	Reinforcement		Width (LF)	Length (LF)	Rebar Width (LF)	Subtotal Rebar Width-wise (LF)	Rebar Length (LF)	Subtotal Rebar Length-wise (LF)	Subtotal for Footers (LF)	Subtotal (LF)		Weight Conversion (lb/LF)	Quantity (lbs)	Quantity (tons)
F-4.0	1	4	#4 EWB	4	4	3.75	15	3.75	15	30	#4	30	0.668	20.04	0.01002
F-5.0	5	4	#5 EWB	5	5	4.75	19	4.75	19	190	#5	659.5	1.043	687.8585	0.343929
F-5.5	3	5	#5 EWB	5.5	5.5	5.25	26.25	5.25	26.25	157.5	#6	1073.5	1.502	1612.397	0.806199
F-6.0	1	6	#5 EWB	6	6	5.75	34.5	5.75	34.5	69	#7	10498.5	2.044	21458.93	10.72947
F-7.0	2	9	#5 EWB	7	7	6.75	60.75	6.75	60.75	243			Total #4-#7 (tons)		11.88961
F-8.5	1	9	#6 EWB	8.5	8.5	8.25	74.25	8.25	74.25	148.5			Excess (5%)		12.4841
F-9.5	5	10	#6 EWB	9.5	9.5	9.25	92.5	9.25	92.5	925					
F-10.0	11	9	#7 EWB	10	10	9.75	87.75	9.75	87.75	1930.5					
F-10.5	2	9	#7 EWB	10.5	10.5	10.25	92.25	10.25	92.25	369					
F-11.0	3	10	#7 EWB	11	11	10.75	107.5	10.75	107.5	645					
F-11.5	9	11	#7 EWB	11.5	11.5	11.25	123.75	11.25	123.75	2227.5					
F-12.0	7	13	#7 EWB	12	12	11.75	152.75	11.75	152.75	2138.5					
F-13.0	4	14	#7 EWB	13	13	12.75	178.5	12.75	178.5	1428					
F-14.0	4	16	#7 EWB	14	14	13.75	220	13.75	220	1760					

Base Plate Takeoff

	Quantity	W	L	SF	Total SF
BP -1	5	1.42	1.42	2.01	10.03
BP -2	11	1.42	1.42	2.01	22.08
BP -3	8	1.58	1.58	2.51	20.06
BP -4	3	1.75	1.75	3.06	9.19
BP -5	4	1.75	1.75	3.06	12.25
BP -6	16	1.50	2.08	3.13	50.00
BP -7	5	1.50	2.08	3.13	15.63
BP -8	2	1.50	2.50	3.75	7.50
BP -9	4	1.42	1.83	2.60	10.39
				Total	157.1181

Appendix B.10

Footing Redesign
Cost Comparison

Cast-in-Place Footings Estimate															
Cost Code		Item		Units	Crew	Daily Output	Labor Hours	Quantity	Mat'l Unit Cost	Mat'l Cost	Labor Unit Cost	Labor Cost	Equip Unit Cost	Equip Cost	Total
Concrete															
03 31 13.35	0350	Heavyweight Concrete, Ready Mix, delivered	4500 psi	CY	C-30	135	0.059	522	$ 116.00	$ 60,552.00	$ -	$ -		$ -	$ 60,552.00
Rebar															
03 21 11.60	0500	Reinforcing in Place	Footings, #4 to #7	Ton	4 Rodm.	2.1	15.238	13	$ 960.00	$ 12,480.00	$ 810.00	$ 10,530.00		$ -	$ 23,010.00
Placement															
03 31 13.70	2600	Placing Concrete	Footings, spread, over 5 C.Y., direct chute	CY	C-6	120	0.4	522	$ -	$ -	$ 15.80	$ 8,247.60	$ 0.53	$ 276.66	$ 8,524.26
Anchor Bolts															
03 015 19.1	0130	Anchor Bolts	3/4" diameter x 8" long	Set	1 Carp	20	0.4	31	$ 10.81	$ 335.11	$ 19.40	$ 601.40		$ -	$ 936.51
03 15 19.1	0420	Anchor Bolts	1-1/4" diameter x 18" long	Set	1 Carp	18	0.444	27	$ 30.00	$ 810.00	$ 21.50	$ 580.50		$ -	$ 1,390.50
Base Plates															
05 12 23.65	0500	Plates	1" thick (40.8 lb/S.F.)	SF	E-4			158	$ 54.00	$ 8,532.00	$ -	$ -		$ -	$ 8,532.00
Excavation															
31 23 16.42	0200	Excavating, Bulk Bank Measure	Excavator, hydraulic, crawler mtd., 1 C.Y. cap. = 100 C.Y/hr.	BCY	B-12A	800	0.02	930	$ -	$ -	$ 0.90	$ 837.00	$ 1.92	$ 1,785.60	$ 2,622.60
Fill															
31 23 23.17	0500	General Fill	Gravil fill, compacted, under floor slab, 4"	SF	B-37	10000	0.005	7,000	$ 0.44	$ 3,080.00	$ 0.19	$ 1,330.00	$ 0.02	$ 140.00	$ 4,550.00
Total										$ 85,789.11		$ 22,126.50		$ 2,202.26	$ 110,117.87

Precast Footings Estimate															
Cost Code		Item		Units	Crew	Daily Output	Labor Hours	Quantity	Mat'l Unit Cost	Mat'l Cost	Labor Unit Cost	Labor Cost	Equip Unit Cost	Equip Cost	Total
Concrete															
03 31 13.35	0350	Heavyweight Concrete, Ready Mix, delivered	4500 psi	CY				250	$ 116.00	$ 29,000.00	$ -	$ -		$ -	$ 29,000.00
									$ -	$ -	$ -	$ -		$ -	$ -
Rebar															
03 21 11.60	0500	Reinforcing in Place	Footings, #4 to #7	Ton	4 Rodm.	2.1	15.238	13	$ 960.00	$ 12,480.00	$ 810.00	$ 10,530.00		$ -	$ 23,010.00
									$ -	$ -	$ -	$ -		$ -	$ -
Formwork															
03 11 13.45	0050	Forms in Place, Footings	Plywood, 2 use	SFCA	C-1	440	0.073	6,340	$ 3.74	$ 23,711.60	$ 3.33	$ 21,112.20		$ -	$ 44,823.80
									$ -	$ -	$ -	$ -		$ -	$ -
Placement															
03 31 13.70	2600	Placing Concrete	Footings, spread, over 5 C.Y., direct chute	CY	C-6	120	0.4	329	$ -	$ -	$ 15.80	$ 5,195.31	$ 0.53	$ 174.27	$ 5,369.58
									$ -	$ -	$ -	$ -		$ -	$ -
Anchor Bolts															
03 015 19.1	0130	Anchor Bolts	3/4" diameter x 8" long	Set	1 Carp	20	0.4	31	$ 10.81	$ 335.11	$ 19.40	$ 601.40		$ -	$ 936.51
03 15 19.1	0420	Anchor Bolts	1-1/4" diameter x 18" long	Set	1 Carp	18	0.444	27	$ 30.00	$ 810.00	$ 21.50	$ 580.50		$ -	$ 1,390.50
									$ -	$ -	$ -	$ -		$ -	$ -
Base Plates															
05 12 23.65	0500	Plates	1" thick (40.8 lb/S.F.)	SF	E-4			158	$ 54.00	$ 8,532.00	$ -	$ -		$ -	$ 8,532.00
Excavation															
31 23 16.42	0200	Excavating, Bulk Bank Measure	Excavator, hydraulic, crawler mtd., 1 C.Y. cap. = 10(	BCY	B-12A	800	0.02	730	$ -	$ -	$ 0.90	$ 657.00	$ 1.92	$ 1,401.60	$ 2,058.60
Fill															
31 23 23.17	0500	General Fill	Gravil fill, compacted, under floor slab, 4"	SF	B-37	10000	0.005	6,500	$ 0.44	$ 2,860.00	$ 0.19	$ 1,235.00	$ 0.02	$ 130.00	$ 4,225.00
Transportation															
		Truck Costs		Mile				650	$ -	$ -	$ 0.62	$ 403.00	$ 1.09	$ 708.50	$ 1,111.50
		Permit Fees	92,000 lbs					0	$ 35.00	$ -	$ -	$ -		$ -	$ -
		Permit Fees	90,000 lbs					3	$ 30.00	$ 90.00	$ -	$ -		$ -	$ 90.00
Crane															
		Mobile Crane Rental	Liebherr-LTM1150-6.1	Day				12	$ -	$ -	$ -	$ -	$ 2,600.00	$ 31,200.00	$ 31,200.00
		Mobile Crane Move Charges	Liebherr-LTM1150-6.1	1 Way				1	$ -	$ -	$ -	$ -	$ 10,000.00	$ 10,000.00	$ 10,000.00
Total										$ 77,818.71		$ 40,314.41		$ 43,614.37	$ 161,747.49

Appendix B.11

Cost Information For 150T Crane

4. LABOR RATES:

Unless provisions of the Prime Contract provide for other methods of determining Subcontractor labor rates, the rates listed below will be used as the basis for determining reimbursable costs and for calculating the value of any labor changes to the Subcontract Price. These rates apply for the duration of the project and include all labor burdens, fringes, benefits, taxes, and insurance allowed by the Subcontract but shall not include markups for overhead and profit.

	STRAIGHT TIME	OVER TIME (TIME + ½)	DOUBLE TIME
Foreman	$89.00	$133.50	N/A
Welder	$89.00	$133.50	N/A
Ironworker	$89.00	$133.50	N/A
Crane Operator	$89.00	$133.50	N/A

5. UNIT PRICES

The Unit Prices listed below include all labor, material, equipment, overhead, profit and any other costs required to perform the work described and shall be used to calculate the Subcontract Price adjustment for all changes in the work performed under a Unit Price compensation basis.

UNIT PRICE #	UNIT PRICE DESCRIPTION	$/UNIT	UNIT
001	50T Crane	$1,150	/ Day
002	65T Crane	$1,600	/ Day
003	85T Crane	$1,950	/ Day
004	100T Crane	$2,200	/ Day
005	150T Crane	$2,600	/ Day
006	50T Crane	$143	/ Hour
007	65T Crane	$200	/ Hour
008	85T Crane	$243	/ Hour
009	100T Crane	$275	/ Hour
010	150T Crane	$325	/ Hour
011	Move Charges – 65T Crane	$2,000	2 way
012	Move Charges – 85T Crane	$7,000	1 way
013	Move Charges – 100T Crane	$2,500	1 way
014	Move Charges – 150T Crane	$10,000	1 way
015	Crew Remobilization fee for all cranes	$1,800	Mob.
016	Ingersol Rand 8,000 lbs	$265	/ Day
017	Ingersol Rand 8,000 lbs	$700	/ Week
018	Ingersol Rand 8,000 lbs	$1,700	/ Month
019	Large Scissor	$125	/ Day
020	Large Scissor	$300	/ Week
021	Large Scissor	$575	/ Month
022	60’ JLG	$300	/ Day
023	60’ JLG	$750	/ Week
024	60’ JLG	$1,900	/ Month

Appendix B.12

Cost Information For Trucking

The outlook for 2012 points to a continued increase in industry costs. The two key cost centers, fuel and driver wages, are expected to increase in 2012. Fuel prices have risen nearly 10 percent in the first eight months of 2012, which will almost certainly increase multiple cost centers, including (petroleum-based) tire purchases. For driver wages, the truck driver shortage is expected to become increasingly worse over time, likely translating to higher wages and higher industry costs. According to ATRI's 2011 "Top Industry Issues" survey of industry stakeholders,[2] the driver shortage and fuel costs ranked third and fifth on the list, respectively. The driver shortage issue rose from number five in 2010 to number three in 2011, indicating that the economy was improving. Other factors are likely amplifying the shortage however, including an aging workforce, new government regulations and driver quality-of-life challenges.

Table ES1. Average Carrier Costs per Mile, 2008, 2009, 2010 and 2011

Motor Carrier Costs	2008	2009	2010	2011
Vehicle-based				
Fuel & Oil Costs	$0.633	$0.405	$0.486	$0.590
Truck/Trailer Lease or Purchase Payments	$0.213	$0.257	$0.184	$0.189
Repair & Maintenance	$0.103	$0.123	$0.124	$0.152
Truck Insurance Premiums	$0.055	$0.054	$0.059	$0.067
Permits and Licenses	$0.016	$0.029	$0.040	$0.038
Tires	$0.030	$0.029	$0.035	$0.042
Tolls	$0.024	$0.024	$0.012	$0.017
Driver-based				
Driver Wages	$0.435	$0.403	$0.446	$0.460
Driver Benefits	$0.144	$0.128	$0.162	$0.151
TOTAL*	**$1.653**	**$1.451**	**$1.548**	**$1.706**

Table ES2. Average Carrier Costs per Hour, 2008, 2009, 2010 and 2011

Motor Carrier Costs	2008	2009	2010	2011
Vehicle-based				
Fuel & Oil Costs	$25.30	$16.17	$19.41	$23.58
Truck/Trailer Lease or Purchase Payments	$8.52	$10.28	$7.37	$7.55
Repair & Maintenance	$4.11	$4.90	$4.97	$6.07
Truck Insurance Premiums	$2.22	$2.15	$2.35	$2.67
Permits and Licenses	$0.62	$1.15	$1.60	$1.53
Tires	$1.20	$1.14	$1.42	$1.67
Tolls	$0.95	$0.98	$0.49	$0.69
Driver-based				
Driver Wages	$17.38	$16.12	$17.83	$18.39
Driver Benefits	$5.77	$5.11	$6.47	$6.05
TOTAL*	**$66.07**	**$58.00**	**$61.91**	**$68.21**

[2] Critical Issues in the Trucking Industry – 2011. ATRI. Arlington, VA. 2011.

* Line items may not sum to total shown due to rounding.

Table ES3. Share of Total Average Cost, 2008, 2009, 2010 and 2011

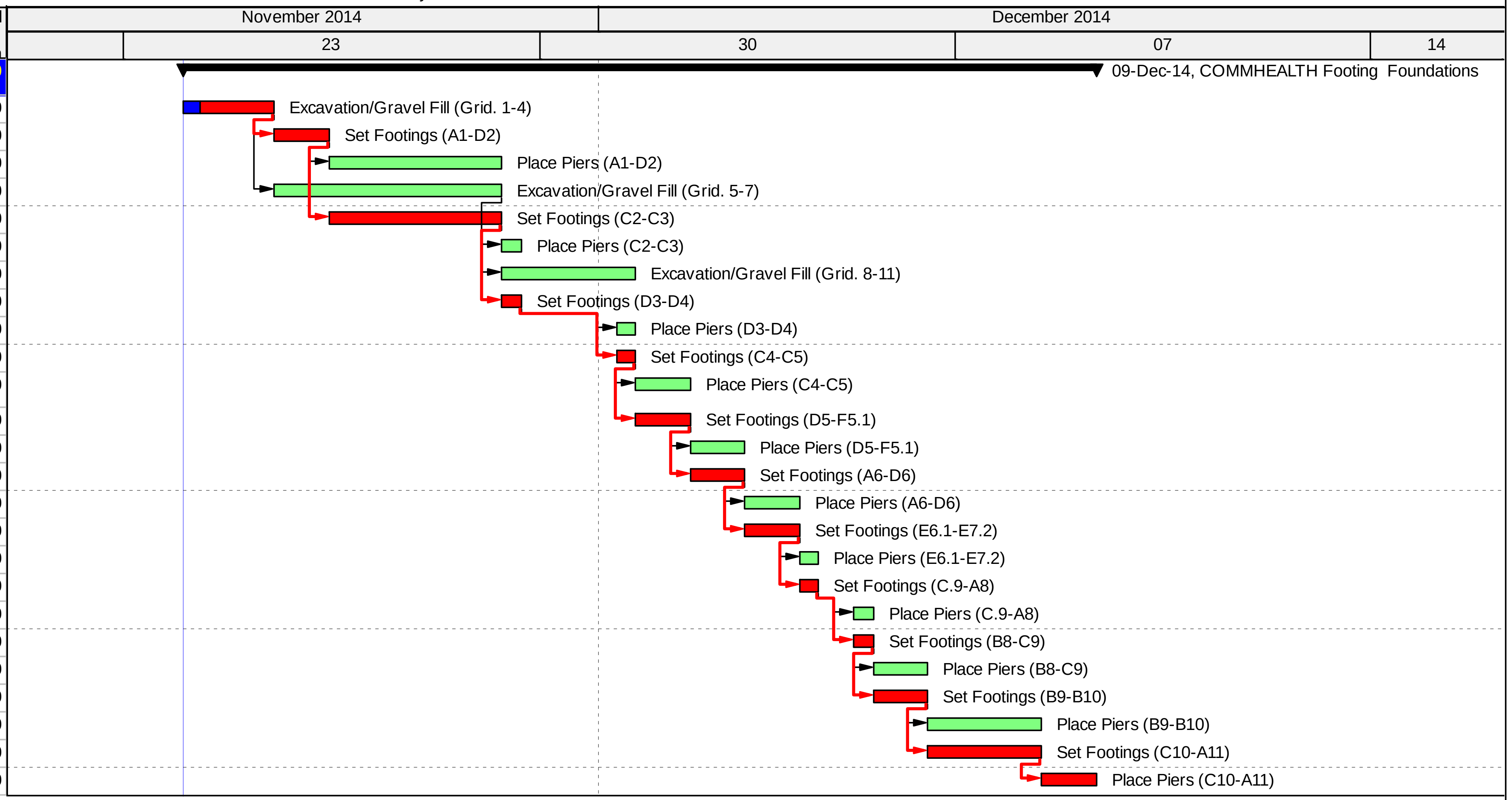
Motor Carrier Costs	2008	2009	2010	2011
Vehicle-based				
Fuel & Oil Costs	38%	28%	31%	35%
Truck/Trailer Lease or Purchase Payments	13%	18%	12%	11%
Repair & Maintenance	6%	8%	8%	9%
Truck Insurance Premiums	3%	4%	4%	4%
Permits and Licenses	1%	2%	3%	2%
Tires	2%	2%	2%	2%
Tolls	1%	2%	1%	1%
Driver-based				
Driver Wages	26%	28%	29%	27%
Driver Benefits	9%	9%	10%	9%
TOTAL*	100%	100%	100%	100%

* Line items may not sum to total shown due to rounding.

Appendix B.13

Precast Footing Schedule

Activity ID	Activity Name	Start	Finish	Original Duration	Actual Duration
COMMHEALTH Footing Foundat		24-Nov-14 A	09-Dec-14	510	0
A1000	Excavation/Gravel Fill (Grid. 1	24-Nov-1	25-Nov-14	2	0
A1010	Set Footings (A1-D2)	25-Nov-14	26-Nov-14	1	0
A1020	Place Piers (A1-D2)	26-Nov-14	29-Nov-14	1	0
A1030	Excavation/Gravel Fill (Grid. 5	25-Nov-14	29-Nov-14	2	0
A1040	Set Footings (C2-C3)	26-Nov-14	29-Nov-14	1	0
A1050	Place Piers (C2-C3)	29-Nov-14	29-Nov-14	1	0
A1060	Excavation/Gravel Fill (Grid. 8	29-Nov-14	01-Dec-14	2	0
A1070	Set Footings (D3-D4)	29-Nov-14	29-Nov-14	1	0
A1080	Place Piers (D3-D4)	01-Dec-14	01-Dec-14	1	0
A1090	Set Footings (C4-C5)	01-Dec-14	01-Dec-14	1	0
A1100	Place Piers (C4-C5)	01-Dec-14	02-Dec-14	1	0
A1110	Set Footings (D5-F5.1)	01-Dec-14	02-Dec-14	1	0
A1120	Place Piers (D5-F5.1)	02-Dec-14	03-Dec-14	1	0
A1130	Set Footings (A6-D6)	02-Dec-14	03-Dec-14	1	0
A1140	Place Piers (A6-D6)	03-Dec-14	04-Dec-14	1	0
A1150	Set Footings (E6.1-E7.2)	03-Dec-14	04-Dec-14	1	0
A1160	Place Piers (E6.1-E7.2)	04-Dec-14	04-Dec-14	1	0
A1170	Set Footings (C.9-A8)	04-Dec-14	04-Dec-14	1	0
A1180	Place Piers (C.9-A8)	05-Dec-14	05-Dec-14	1	0
A1190	Set Footings (B8-C9)	05-Dec-14	05-Dec-14	1	0
A1200	Place Piers (B8-C9)	05-Dec-14	06-Dec-14	1	0
A1210	Set Footings (B9-B10)	05-Dec-14	06-Dec-14	1	0
A1220	Place Piers (B9-B10)	06-Dec-14	08-Dec-14	1	0
A1230	Set Footings (C10-A11)	06-Dec-14	08-Dec-14	1	0
A1240	Place Piers (C10-A11)	08-Dec-14	09-Dec-14	1	0

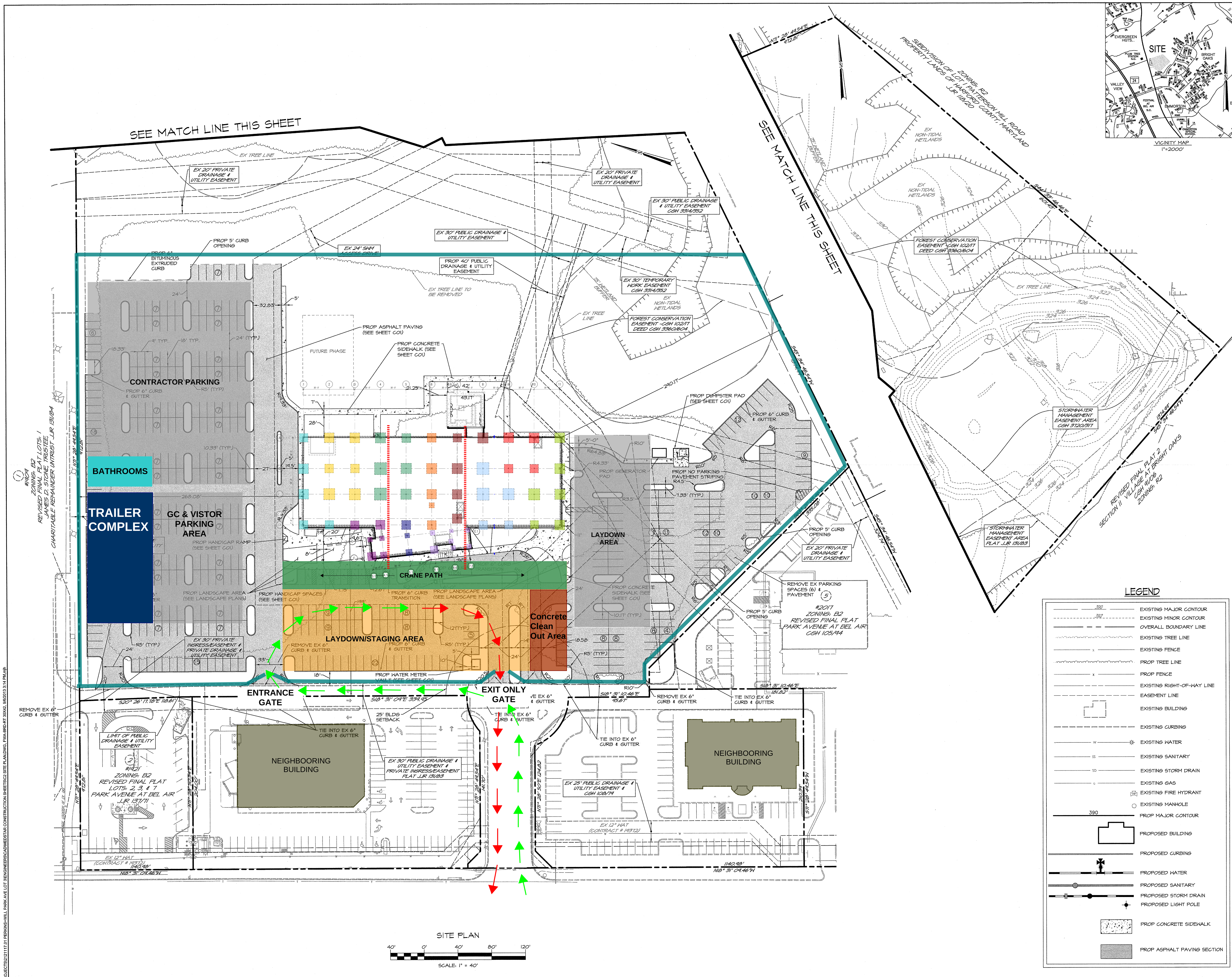


Legend: Actual Level of Effort; Actual Work; Remaining Work; Critical Remaining Work; Milestone; summary

TASK filter: All Activities

Appendix B.14

Site Logistics For Precast Footings



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DESIGN DRAWINGS
August 30, 2013

Revisions

BID DOCUMENTS NOT FOR CONSTRUCTION

ISSUE	DATE

Sheet Information

Date	08.30.13
Job Number	2121117.01
Drawn	MJH
Checked	GGP
Approved	

Title
SITE PLAN

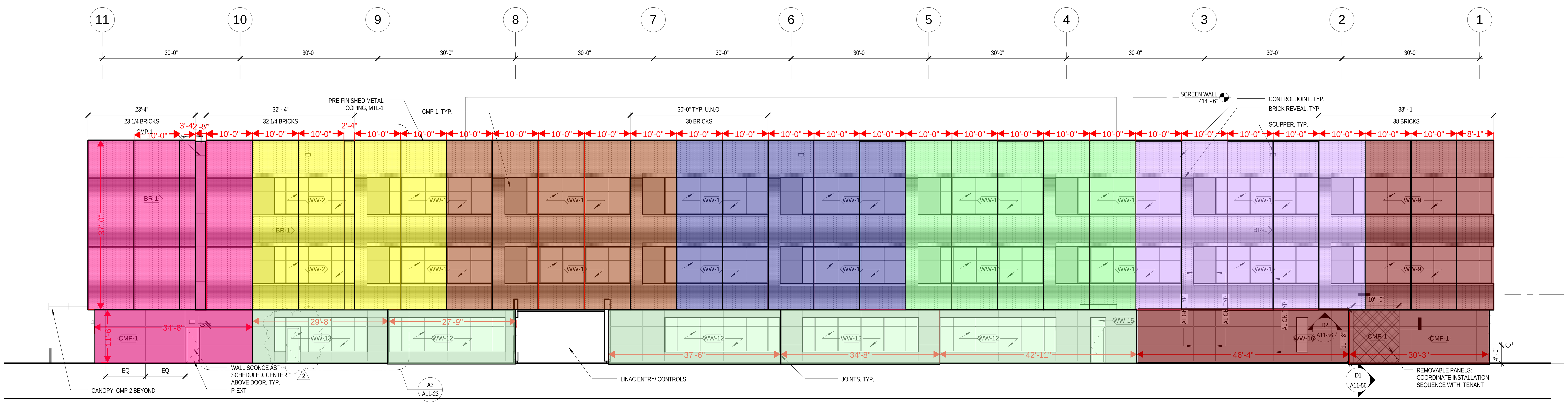
Sheet
C02

Appendix C.1

Panel Layout

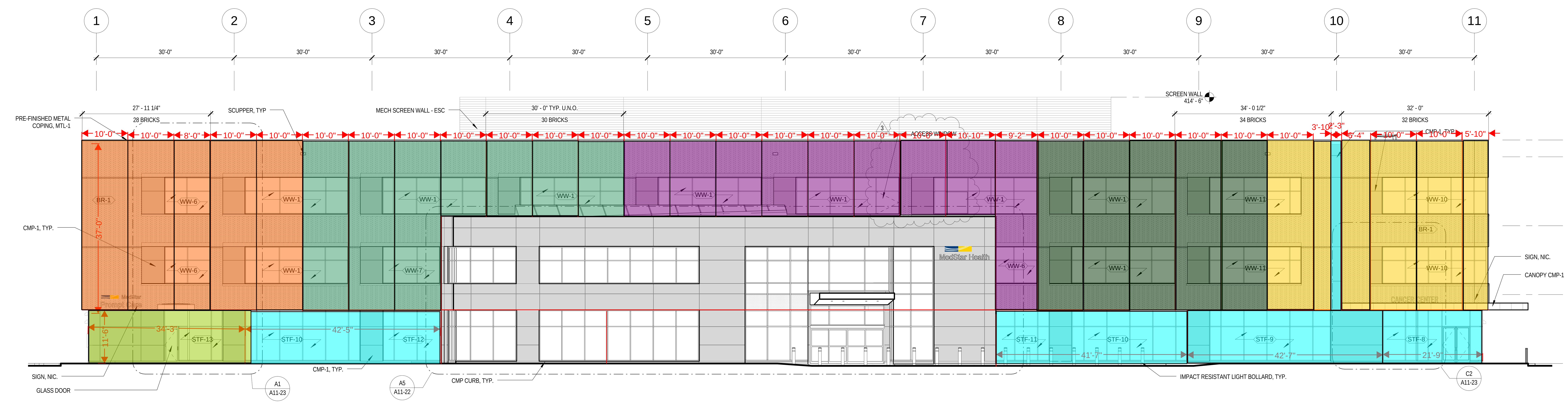
MATERIALS LEGEND

ABBREVIATION	DESCRIPTION
WW	WINDOW WALL SYSTEM: KAWNEER TRIFAB 451 T 4 1/2" SYSTEM, CLEAR ANODIZED ALUMINUM FINISH
STF	STOREFRONT SYSTEM: KAWNEER TRIFAB 601T 6" SYSTEM, CLEAR ANODIZED ALUMINUM FINISH
CW	CURTAIN WALL SYSTEM: KAWNEER 1600 SYSTEM 1, CLEAR ANODIZED ALUMINUM FINISH
GL-1	VISION GLASS - 1" REFLECTIVE LOW-E IGU, VIRACON VRE1-59 W/ GRAY GASKETING
GL-2	SPANDREL GLASS - 1" REFLECTIVE LOW-E IGU, VIRACON VRE1-59 W/ GRAY GASKETING, APPLY COATING ON 4TH SURFACE, COLOR # VIRASPAN "MEDIUM GRAY"
GL-3	LAMINATED INSULATED GLASS - 1" LOW-E IGU VIRACON VRE1-46 W/ GRAY GASKETING, APPLY CERAMIC FRIT VIRACON V175 HIGH OPACITY WHITE SCREEN #5006, 40% COVERAGE ON 3RD SURFACE, VIRACON VRE1-46, CLEAR PVB INTERLAYER, 1/4" CLEAR GLASS, TOTAL THICKNESS 1 1/4"
BR-1	BRICK VENEER (NORMAN BRICK - 4" X 2 2/3" X 12" NOM, 1/3 RUNNING BOND TYP.) OPTION 1: MANUFACTURE: TAYLOR, COLOR: #5 AUBURN, SIZE: MODULAR, TEXTURE: WIRECUT OPTION 2: MANUFACTURE: TAYLOR, COLOR: #5 AUBURN, SIZE: MODULAR, TEXTURE: SMOOTH OPTION 3: MANUFACTURE: TAYLOR, COLOR: #317 RED, SIZE: MODULAR, TEXTURE: WIRECUT
CMP-1	COMPOSITE METAL PANEL ROUT AND RETURN, DRY JOINT SYSTEM, COLOR: ARCHITECT TO SELECT FROM MANUFACTURER'S FULL RANGE
ESC	EQUIPMENT SCREEN LOUVER SYSTEM
GSS	B.O.D. GREEN SCREEN SYSTEM, ADD ALTERNATE CONCRETE FORMLINER
MTL-1	PRE-FINISHED METAL COPING, COLOR TO MATCH CMP-1
RS-1	WHITE TPO ROOF MEMBRANE ASSEMBLY
RS-2	BALLASTED ROOF MEMBRANE ASSEMBLY
RS-3	GREEN ROOF ASSEMBLY



B1 EAST ELEVATION

3/32" = 1'-0"



A1 WEST ELEVATION

3/32" = 1'-0"

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Revisions

NO	ISSUE	DATE
3	ASI 6	05/04/15
2	ASI 5	05/04/15
	CDs	04/04/14
1	DD/GMP REVISIONS	09/06/13
	GMP	08/30/13

Sheet Information

Date	04/04/2014
Job Number	860342.000
Drawn	TS
Checked	NP
Approved	DM

Title

EXTERIOR BUILDING ELEVATIONS

Sheet

A11-01

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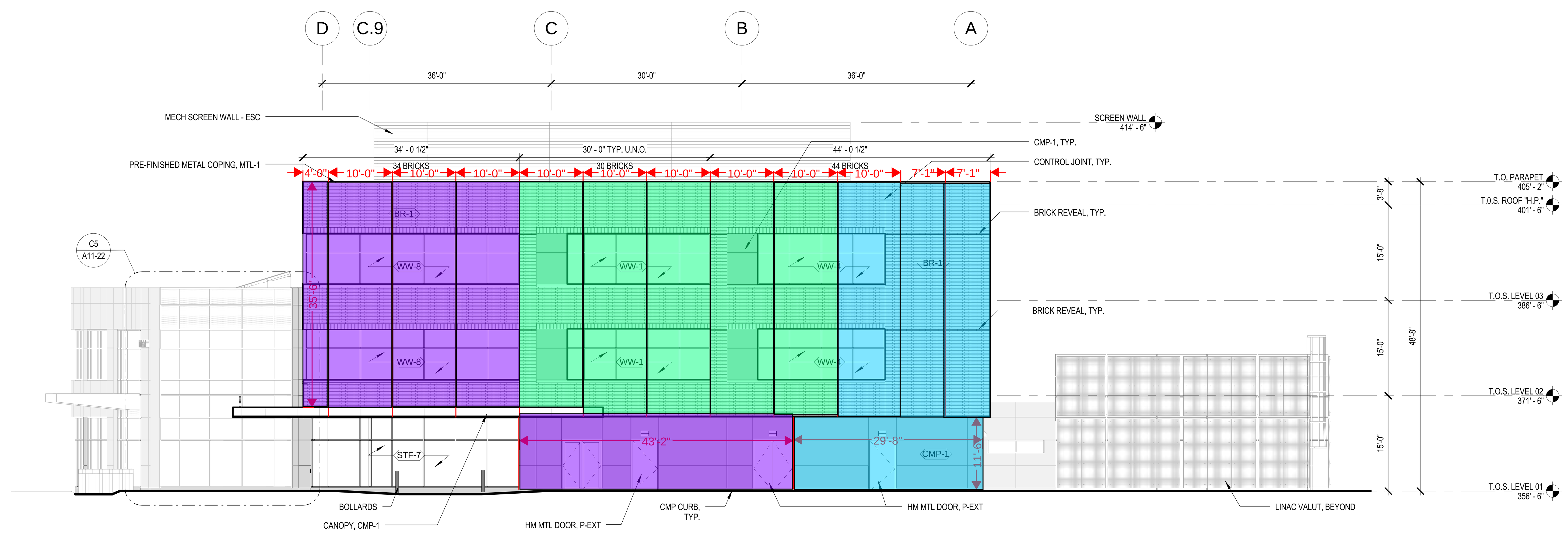
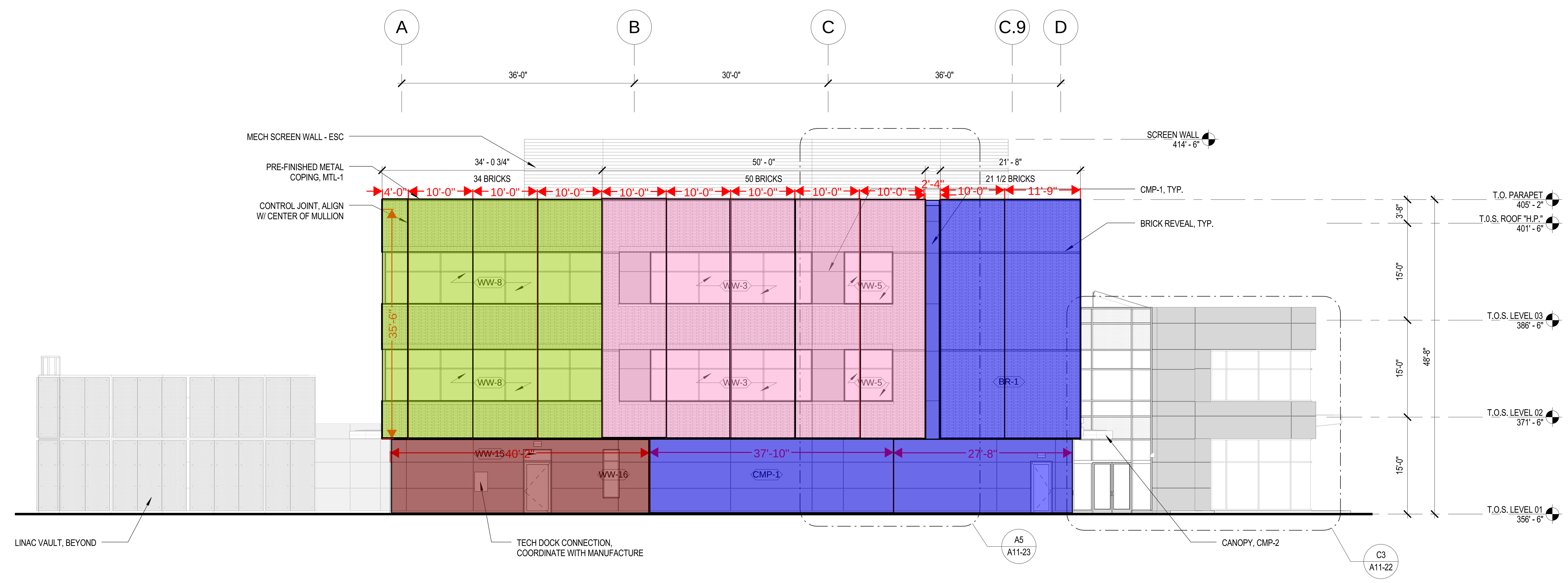
MATERIALS LEGEND

ABBREVIATION	DESCRIPTION
WW	WINDOW WALL SYSTEM: KAWNEER TRIFAB 451 T 4 1/2" SYSTEM, CLEAR ANODIZED ALUMINUM FINISH
STF	STOREFRONT SYSTEM: KAWNEER TRIFAB 601T 6" SYSTEM, CLEAR ANODIZED ALUMINUM FINISH
CW	CURTAIN WALL SYSTEM: KAWNEER 1600 SYSTEM 1, CLEAR ANODIZED ALUMINUM FINISH
GL-1	VISION GLASS - 1" REFLECTIVE LOW-E IGU, VIRACON VRE1-59 W/ GRAY GASKETING
GL-2	SPANDREL GLASS - 1" REFLECTIVE LOW-E IGU, VIRACON VRE1-59 W/ GRAY GASKETING, APPLY COATING ON 4TH SURFACE, COLOR # VIRASPAN "MEDIUM GRAY"
GL-3	LAMINATED INSULATED GLASS - 1" LOW-E IGU VIRACON VRE1-46 W/ GRAY GASKETING, APPLY CERAMIC FRIT VIRACON V175 HIGH OPACITY WHITE SCREEN #5006, 40% COVERAGE ON 3RD SURFACE, VIRACON VRE1-46, CLEAR PVB INTERLAYER, 1/4" CLEAR GLASS, TOTAL THICKNESS 1 1/4"
BR-1	BRICK VENEER (NORMAN BRICK - 4" X 2 2/3" X 12" NOM, 1/3 RUNNING BOND TYP.) OPTION 1: MANUFACTURE: TAYLOR, COLOR: #5 AUBURN, SIZE: MODULAR, TEXTURE: WIRECUT OPTION 2: MANUFACTURE: TAYLOR, COLOR: #5 AUBURN, SIZE: MODULAR, TEXTURE: SMOOTH OPTION 3: MANUFACTURE: TAYLOR, COLOR: #317 RED, SIZE: MODULAR, TEXTURE: WIRECUT
CMP-1	COMPOSITE METAL PANEL ROUT AND RETURN, DRY JOINT SYSTEM, COLOR: ARCHITECT TO SELECT FROM MANUFACTURER'S FULL RANGE
ESC	EQUIPMENT SCREEN LOUVER SYSTEM
GSS	B.O.D. GREEN SCREEN SYSTEM, ADD ALTERNATE CONCRETE FORMLINER
MTL-1	PRE-FINISHED METAL COPING, COLOR TO MATCH CMP-1
RS-1	WHITE TPO ROOF MEMBRANE ASSEMBLY
RS-2	BALLASTED ROOF MEMBRANE ASSEMBLY
RS-3	GREEN ROOF ASSEMBLY



B2 SOUTH ELEVATION
3/32" = 1'-0"



A1 NORTH ELEVATION
3/32" = 1'-0"

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Revisions

NO	ISSUE	DATE
	CDs	04/04/14

Sheet Information

Date	04/04/2014
Job Number	860342.000
Drawn	Author
Checked	Checker
Approved	Approver

Title

EXTERIOR BUILDING ELEVATIONS

Sheet

A11-02

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Appendix C.2

Cost Comparison For Façade Installation Method

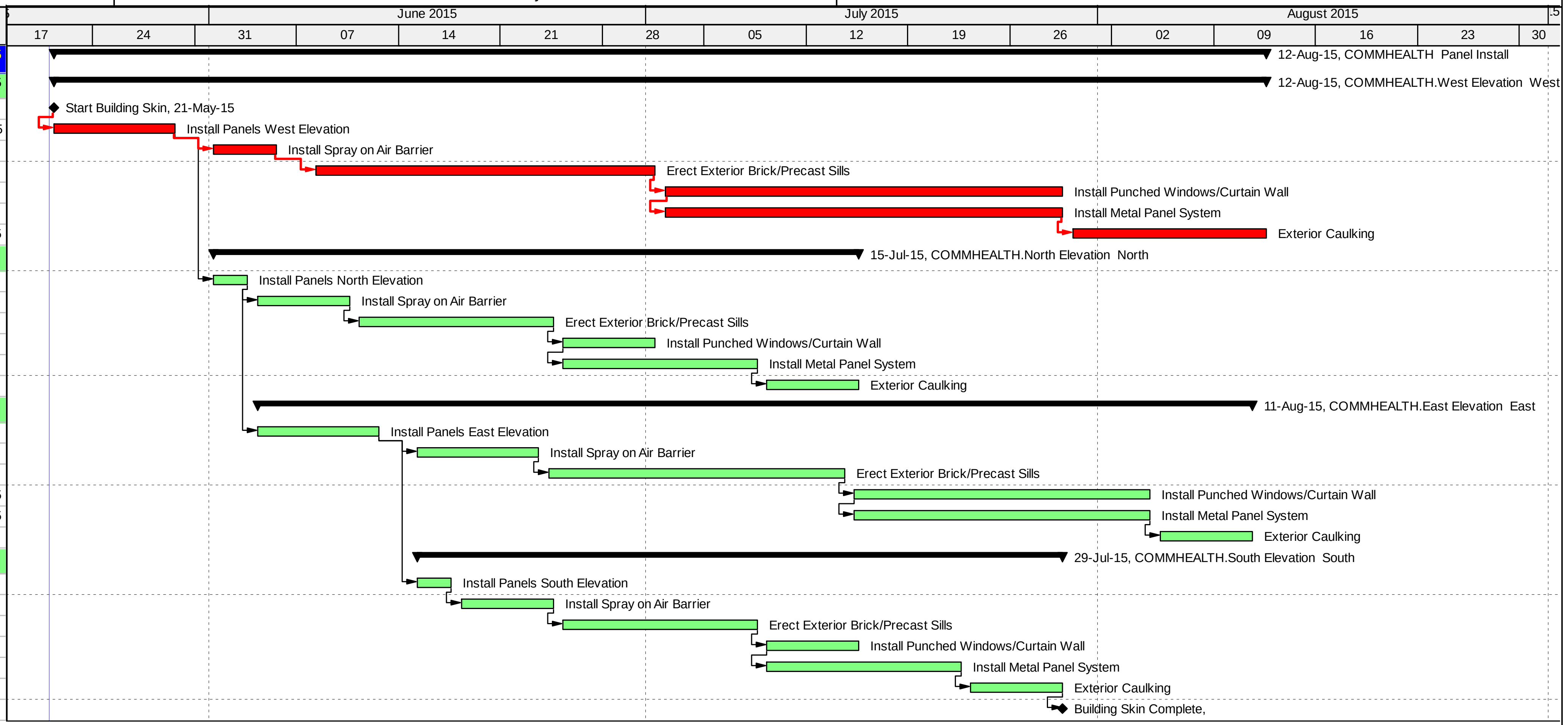
Prefabricated Panel Estimate						
Item	SF	Traditional System Cost		Panelized System Cost		
		$/SF	Total	$/SF	Total	
Exterior Metal Framing and Sheathing	36500	$ 6.74	$ 246,050.00	$ 17.39	$ 634,735.00	
Insulation	36500	$ 0.44	$ 16,100.00	Incl.		
Fluid-Applied Membrane Air Barrier	36500	$ 2.72	$ 99,268.00	$ 2.72	$ 99,280.00	
Total	36500	$ 9.90	$ 361,418.00	$ 20.11	$ 734,015.00	

Appendix C.3

Panelized Façade Schedule

Panel Install | Classic Schedule Layout | 29-Mar-16 19:45

Activity ID	Activity Name	Original Duration	Start	Finish
COMMHEALTH Panel Install		60	21-May-15	12-Aug-15
COMMHEALTH.West Elevation West		60	21-May-15	12-Aug-15
A1000	Start Building Skin	0	21-May-15	
A1010	Install Panels West Elevation	7	21-May-15	29-May-15
A1020	Install Spray on Air Barrier	5	01-Jun-15	05-Jun-15
A1030	Erect Exterior Brick/Precast Sills	18	08-Jun-15	01-Jul-15
A1040	Install Punched Windows/Curtain Wall	20	02-Jul-15	29-Jul-15
A1050	Install Metal Panel System	20	02-Jul-15	29-Jul-15
A1240	Exterior Caulking	10	30-Jul-15	12-Aug-15
COMMHEALTH.North Elevation North		33	01-Jun-15	15-Jul-15
A1060	Install Panels North Elevation	3	01-Jun-15	03-Jun-15
A1070	Install Spray on Air Barrier	5	04-Jun-15	10-Jun-15
A1080	Erect Exterior Brick/Precast Sills	10	11-Jun-15	24-Jun-15
A1090	Install Punched Windows/Curtain Wall	5	25-Jun-15	01-Jul-15
A1100	Install Metal Panel System	10	25-Jun-15	08-Jul-15
A1110	Exterior Caulking	5	09-Jul-15	15-Jul-15
COMMHEALTH.East Elevation East		49	04-Jun-15	11-Aug-15
A1120	Install Panels East Elevation	7	04-Jun-15	12-Jun-15
A1130	Install Spray on Air Barrier	7	15-Jun-15	23-Jun-15
A1140	Erect Exterior Brick/Precast Sills	15	24-Jun-15	14-Jul-15
A1150	Install Punched Windows/Curtain Wall	15	15-Jul-15	04-Aug-15
A1160	Install Metal Panel System	15	15-Jul-15	04-Aug-15
A1170	Exterior Caulking	5	05-Aug-15	11-Aug-15
COMMHEALTH.South Elevation South		33	15-Jun-15	29-Jul-15
A1180	Install Panels South Elevation	3	15-Jun-15	17-Jun-15
A1190	Install Spray on Air Barrier	5	18-Jun-15	24-Jun-15
A1200	Erect Exterior Brick/Precast Sills	10	25-Jun-15	08-Jul-15
A1210	Install Punched Windows/Curtain Wall	5	09-Jul-15	15-Jul-15
A1220	Install Metal Panel System	10	09-Jul-15	22-Jul-15
A1230	Exterior Caulking	5	23-Jul-15	29-Jul-15
A1250	Building Skin Complete	0		29-Jul-15



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

Page 1 of 1

TASK filter: All Activities

Appendix C.4

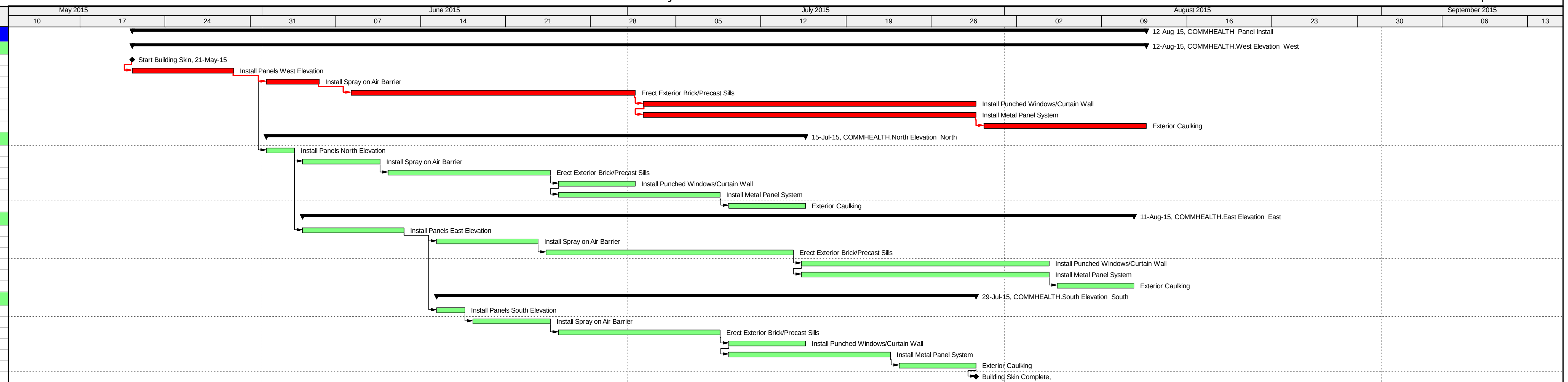
Panelized Schedule & Manpower Curve

Panel Install

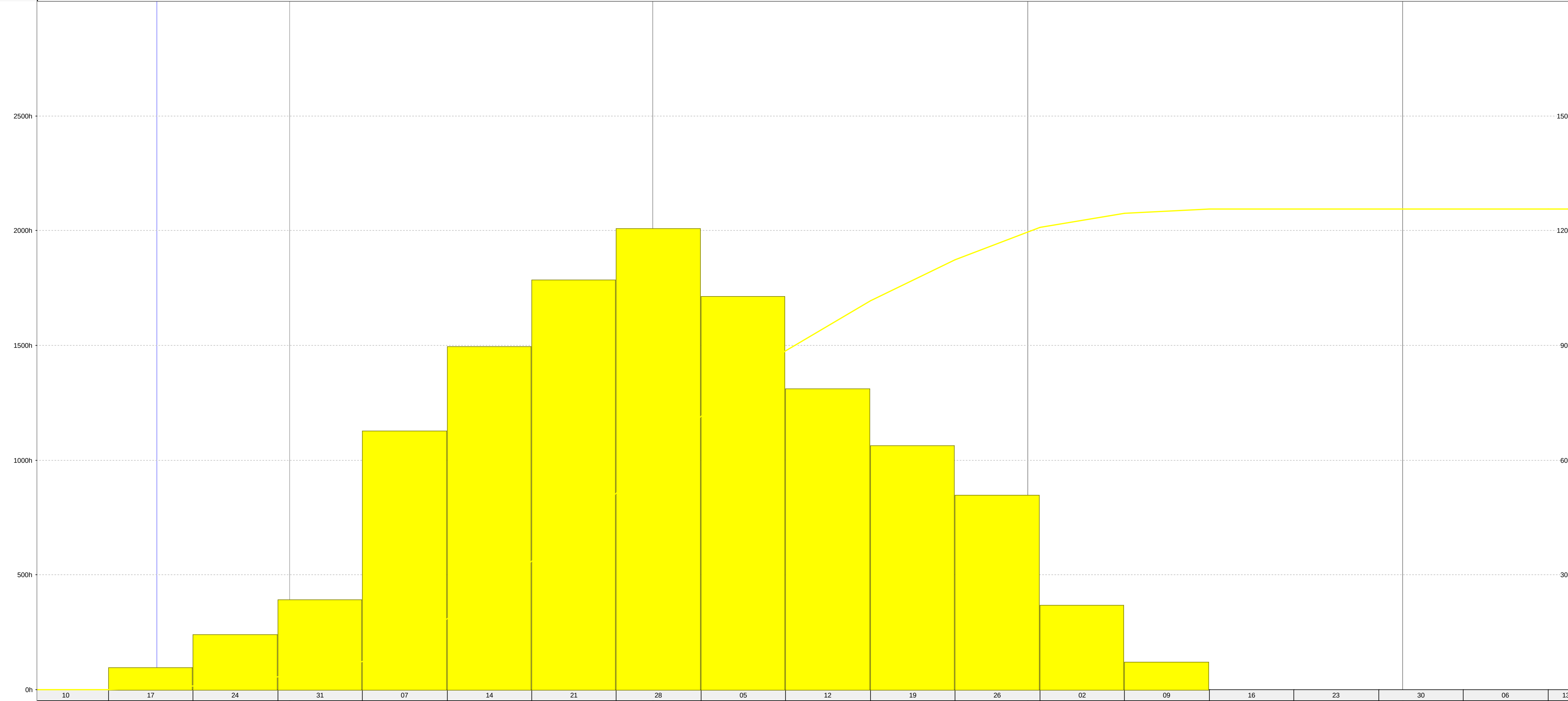
Classic Schedule Layout

03-Apr-16 18:47

Activity ID	Activity Name	Original Duration	Start	Finish
COMMHEALTH Panel Install		60	21-May-15	12-Aug-15
COMMHEALTH.West Elevation West		60	21-May-15	12-Aug-15
A1000	Start Building Skin	0	21-May-15	
A1010	Install Panels West Elevation	7	21-May-15	29-May-15
A1020	Install Spray on Air Barrier	5	01-Jun-15	05-Jun-15
A1030	Erect Exterior Brick/Precast Sills	18	08-Jun-15	01-Jul-15
A1040	Install Punched Windows/Curtain Wall	20	02-Jul-15	29-Jul-15
A1050	Install Metal Panel System	20	02-Jul-15	29-Jul-15
A1240	Exterior Caulking	10	30-Jul-15	12-Aug-15
COMMHEALTH.North Elevation North		33	01-Jun-15	15-Jul-15
A1060	Install Panels North Elevation	3	01-Jun-15	03-Jun-15
A1070	Install Spray on Air Barrier	5	04-Jun-15	10-Jun-15
A1080	Erect Exterior Brick/Precast Sills	10	11-Jun-15	24-Jun-15
A1090	Install Punched Windows/Curtain Wall	5	25-Jun-15	01-Jul-15
A1100	Install Metal Panel System	10	25-Jun-15	08-Jul-15
A1110	Exterior Caulking	5	09-Jul-15	15-Jul-15
COMMHEALTH.East Elevation East		49	04-Jun-15	11-Aug-15
A1120	Install Panels East Elevation	7	04-Jun-15	12-Jun-15
A1130	Install Spray on Air Barrier	7	15-Jun-15	23-Jun-15
A1140	Erect Exterior Brick/Precast Sills	15	24-Jun-15	14-Jul-15
A1150	Install Punched Windows/Curtain Wall	15	15-Jul-15	04-Aug-15
A1160	Install Metal Panel System	15	15-Jul-15	04-Aug-15
A1170	Exterior Caulking	5	05-Aug-15	11-Aug-15
COMMHEALTH.South Elevation South		33	15-Jun-15	29-Jul-15
A1180	Install Panels South Elevation	3	15-Jun-15	17-Jun-15
A1190	Install Spray on Air Barrier	5	18-Jun-15	24-Jun-15
A1200	Erect Exterior Brick/Precast Sills	10	25-Jun-15	08-Jul-15
A1210	Install Punched Windows/Curtain Wall	5	09-Jul-15	15-Jul-15
A1220	Install Metal Panel System	10	09-Jul-15	22-Jul-15
A1230	Exterior Caulking	5	23-Jul-15	29-Jul-15
A1250	Building Skin Complete	0		29-Jul-15



Budgeted Labor Units

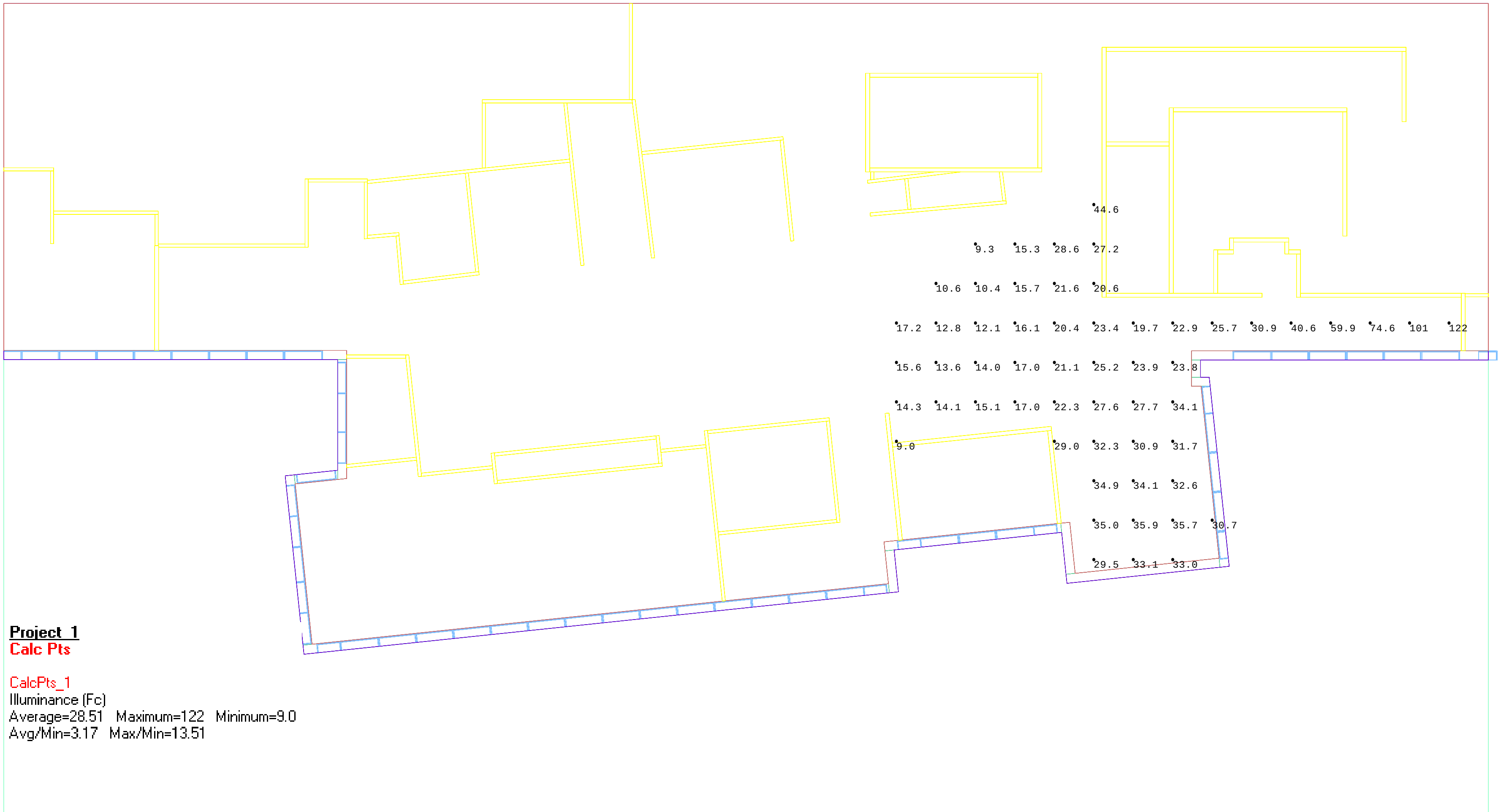


Actual Level of Effort	Remaining Work	Milestone	Page 1 of 1	TASK filter: All Activities	
Actual Work	Critical Remaining Work	summary			© Oracle Corporation

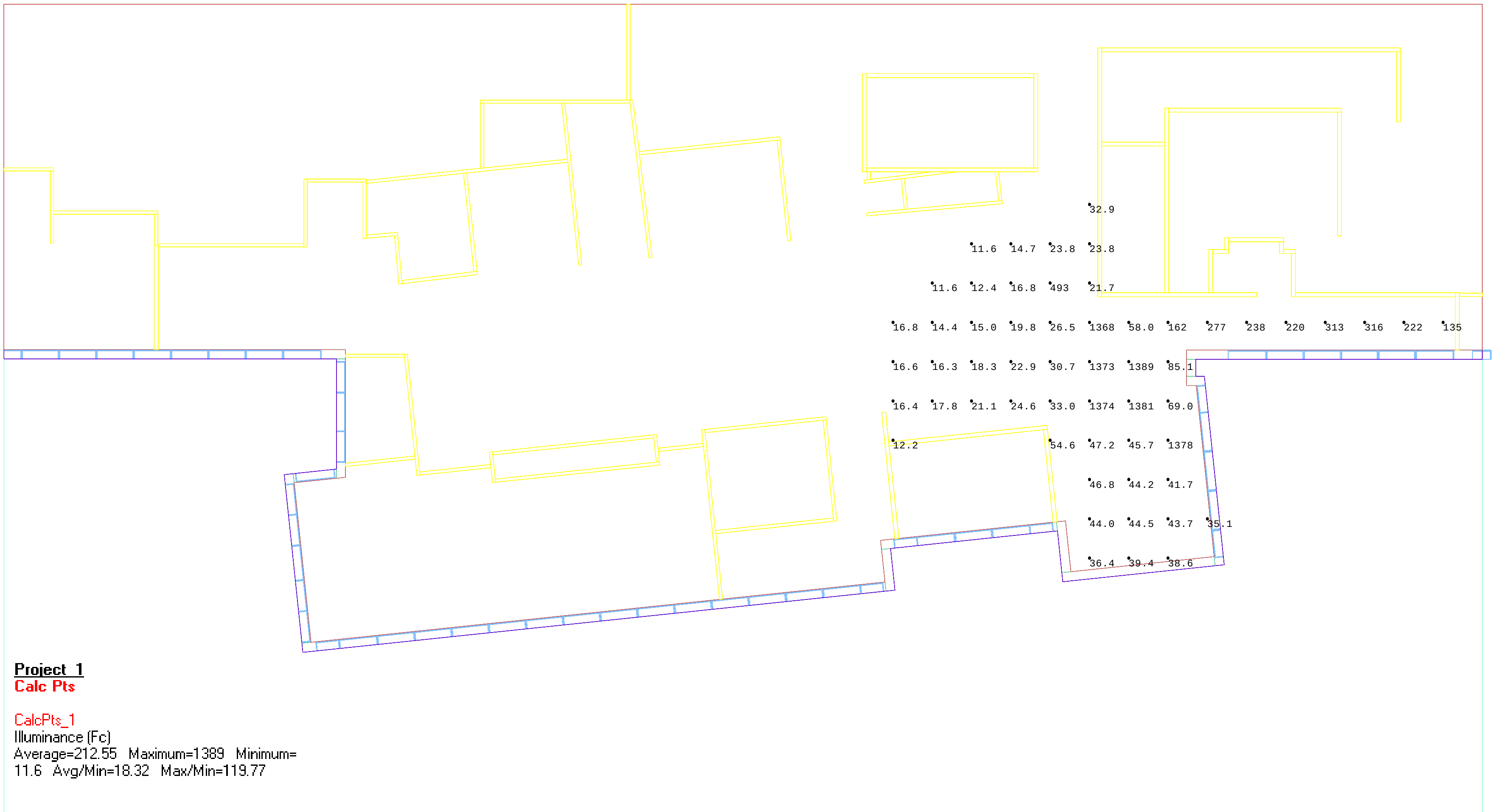
Appendix C.5

AGI Outputs

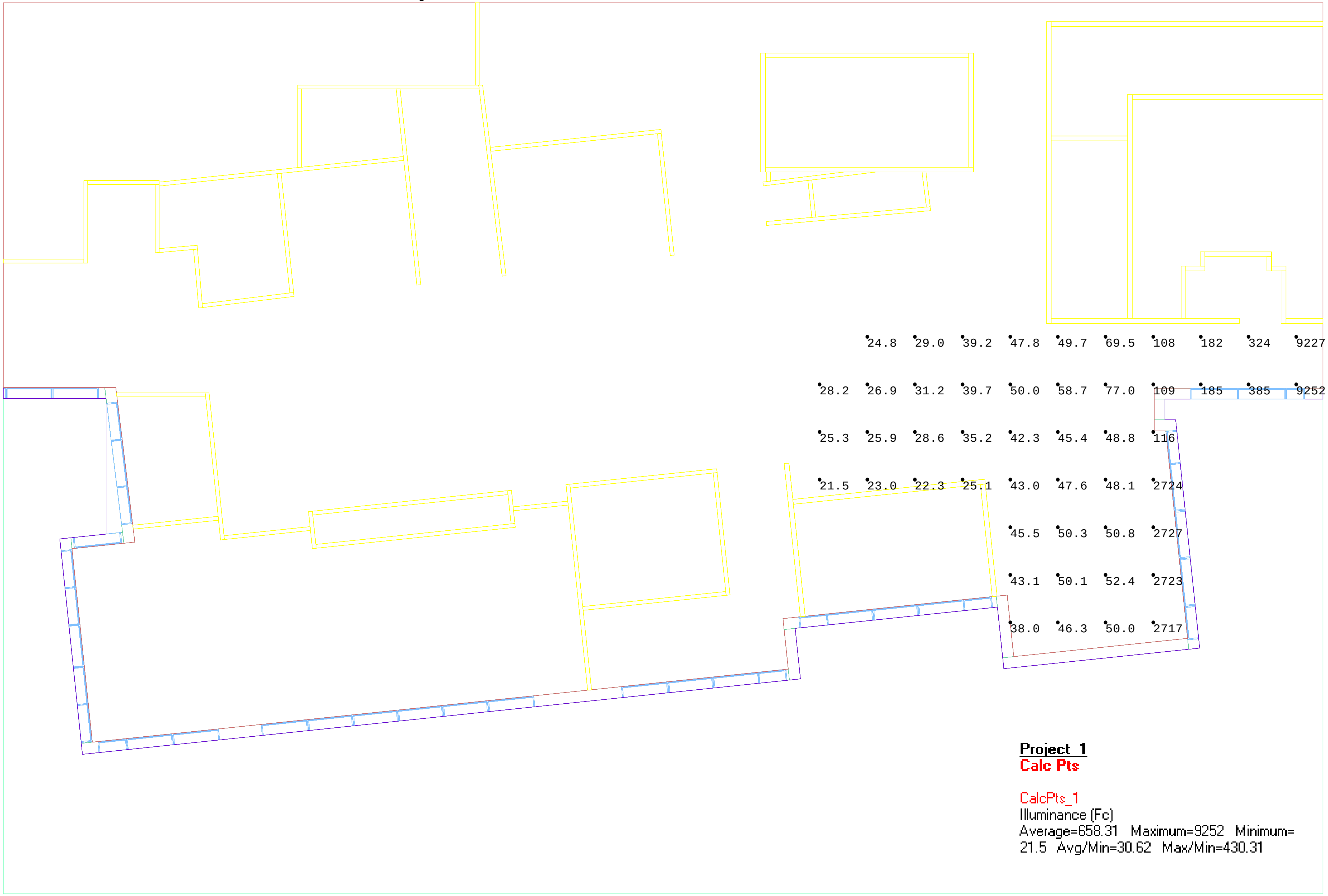
Schematic Design Lobby June 21



Schematic Design Lobby December 21



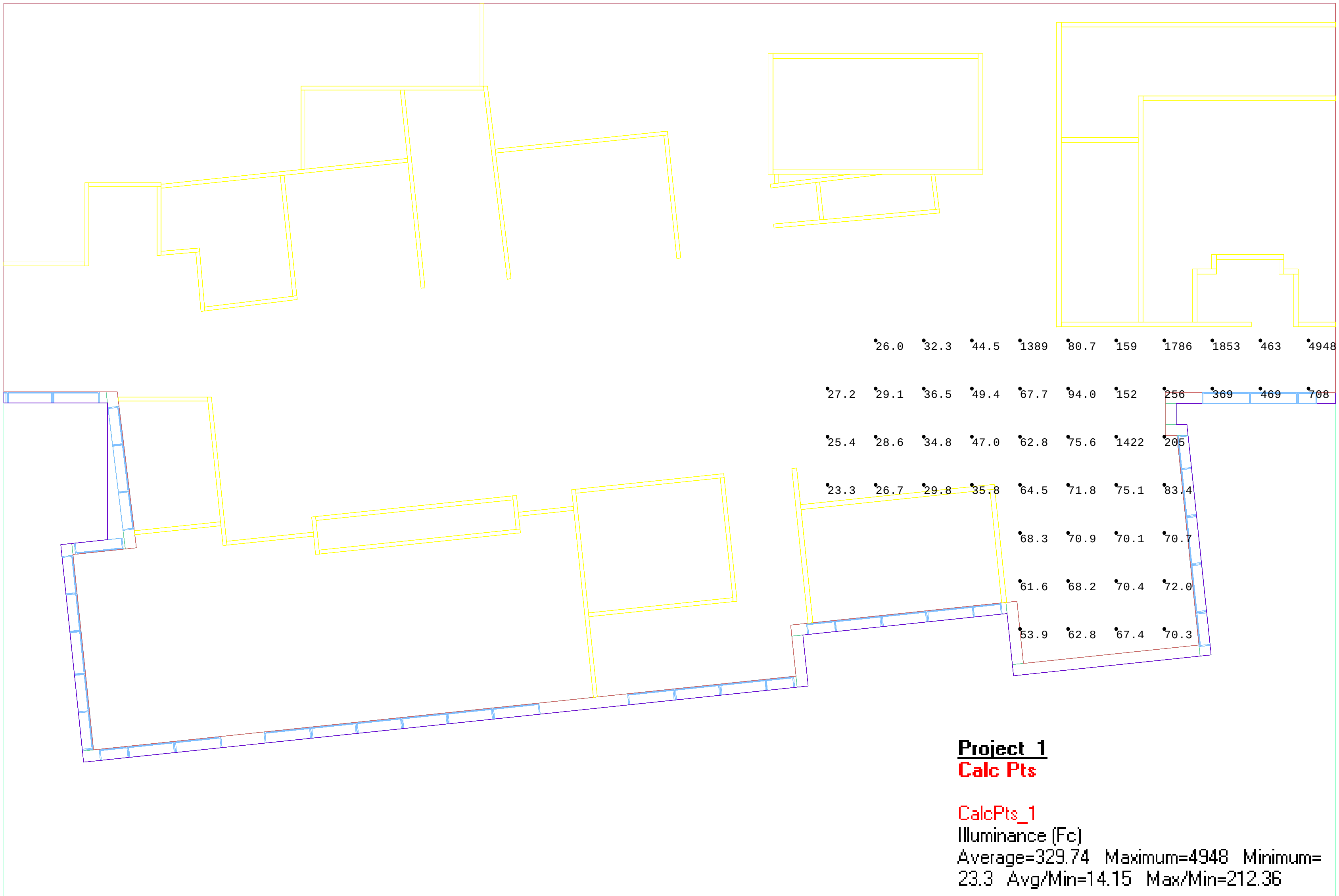
Construction Documents Lobby June 21



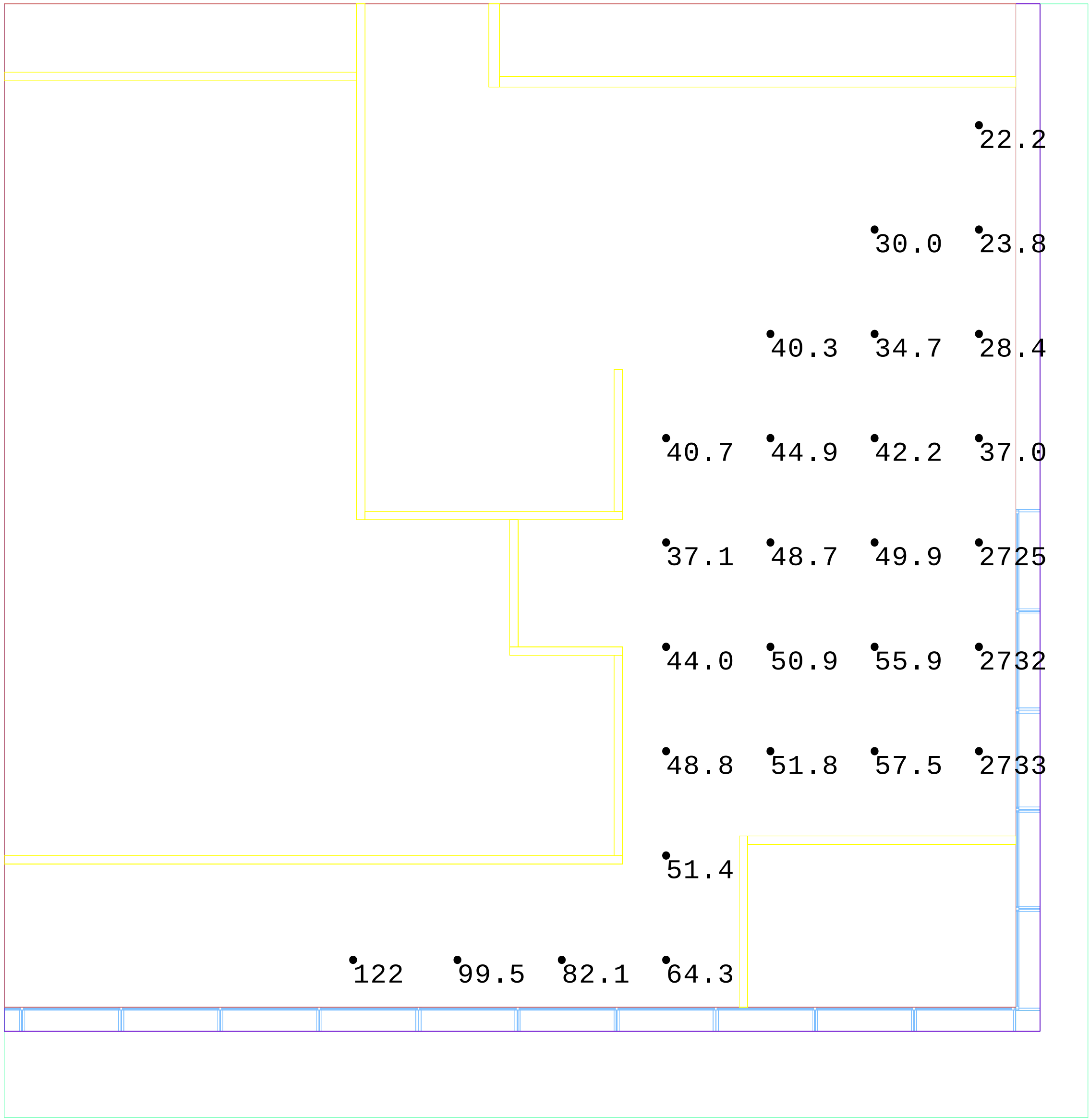
Project_1
Calc Pts

CalcPts_1
Illuminance (Fc)
Average=658.31 Maximum=9252 Minimum=21.5 Avg/Min=30.62 Max/Min=430.31

Construction Documents Lobby December 21



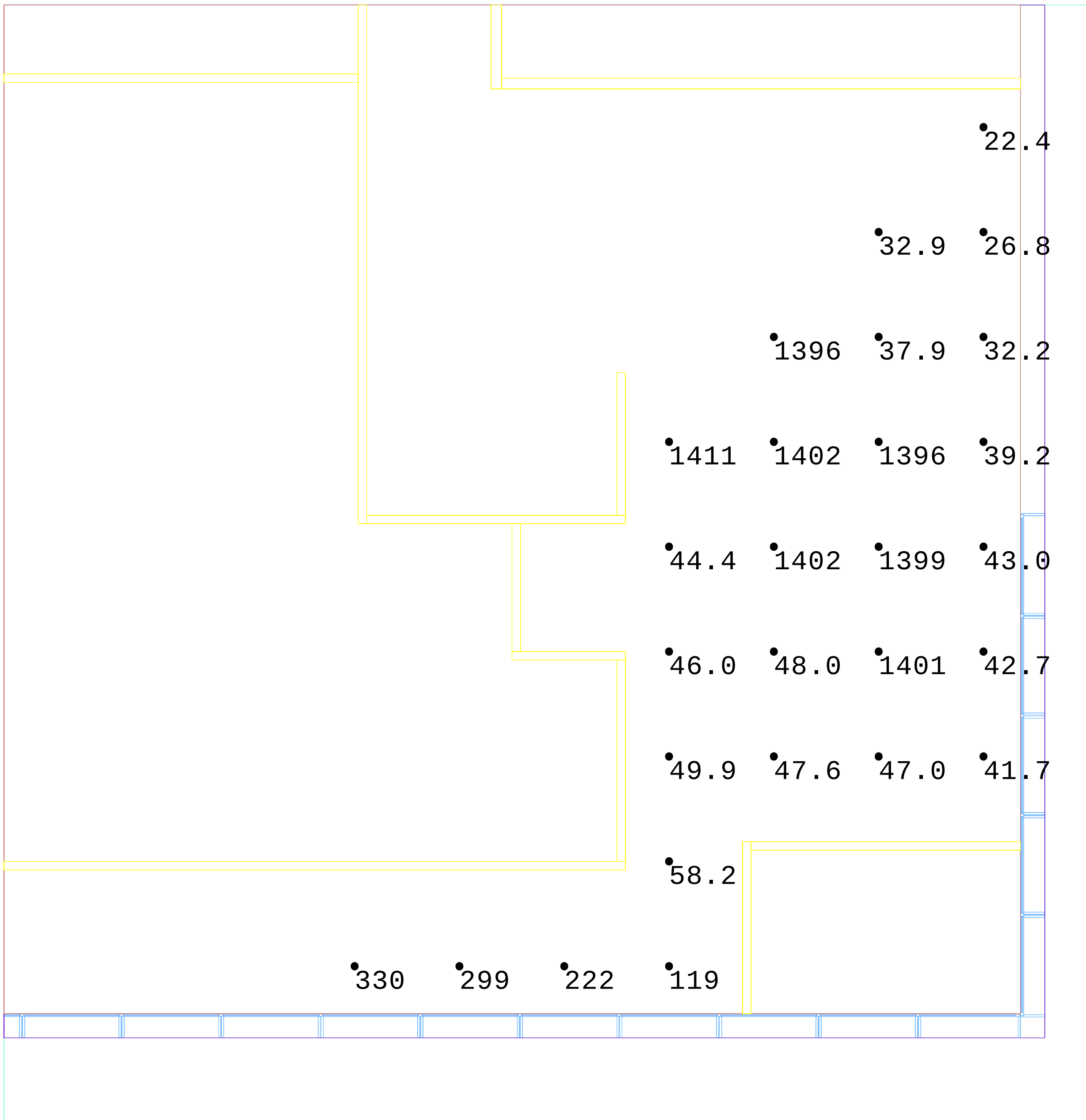
Schematic Design Outpatient June 21



Project_1
Calc Pts

CalcPts_1
Illuminance (Fc)
Average=348.09 Maximum=2733 Minimum=22.2 Avg/Min=15.68 Max/Min=123.09

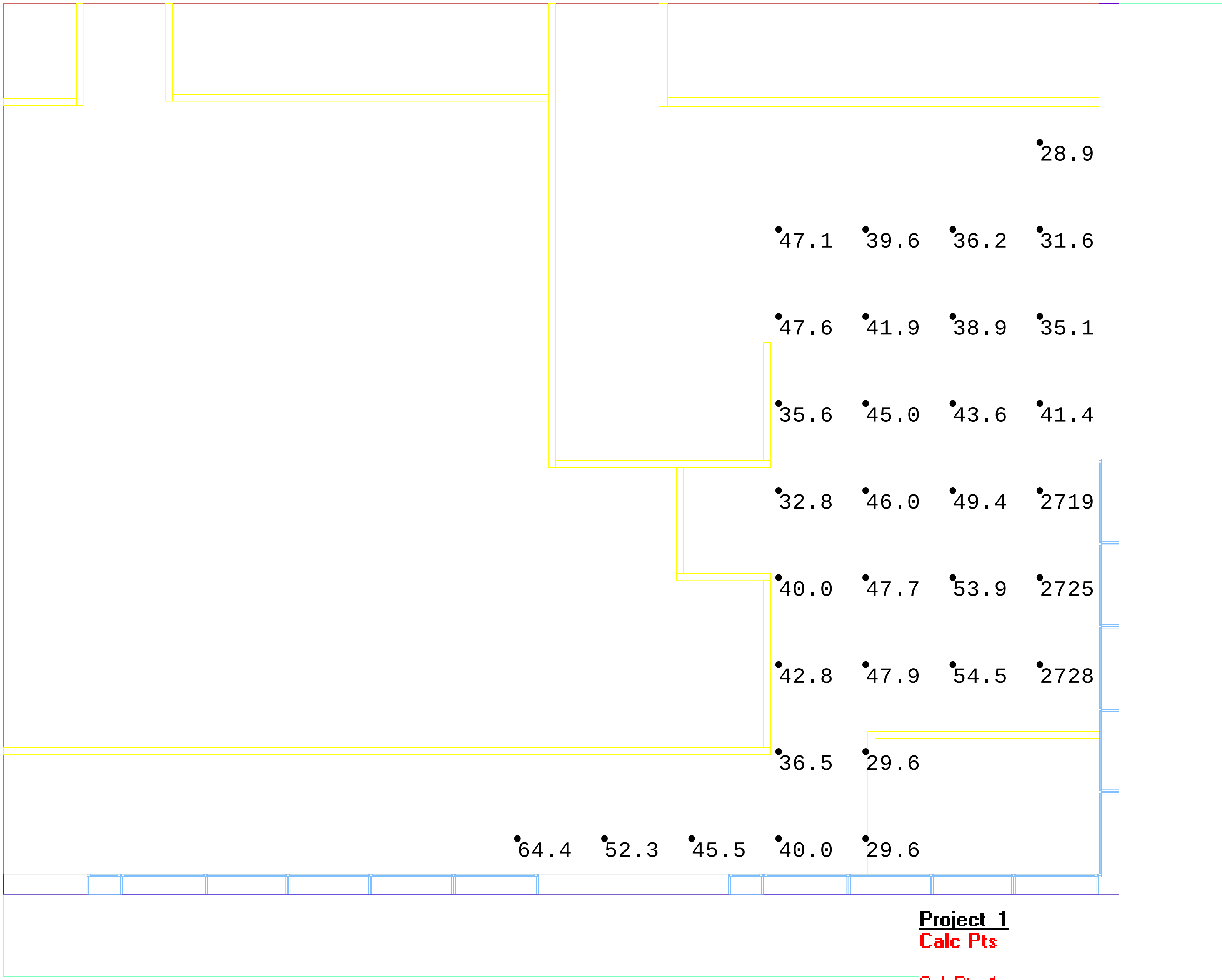
Schematic Design Outpatient December 21



Project 1
Calc Pts

CalcPts_1
Illuminance (Fc)
Average=423.57 Maximum=1411 Minimum=22.4 Avg/Min=18.91 Max/Min=62.98

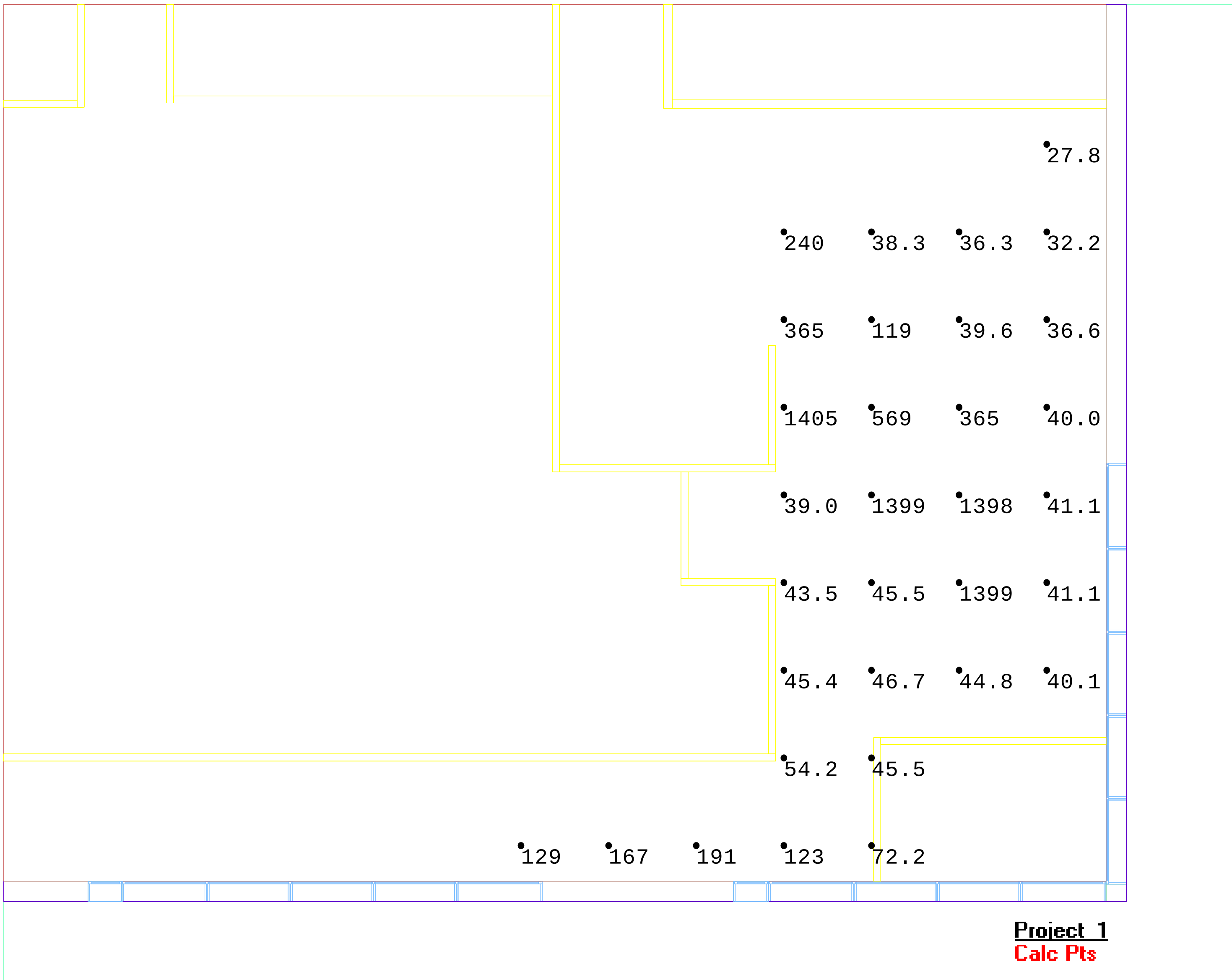
Construction Documents Outpatient June 21



Project 1
Calc Pts

CalcPts_1
Illuminance (Fc)
Average=293.66 Maximum=2728 Minimum=
28.9 Avg/Min=10.16 Max/Min=94.40

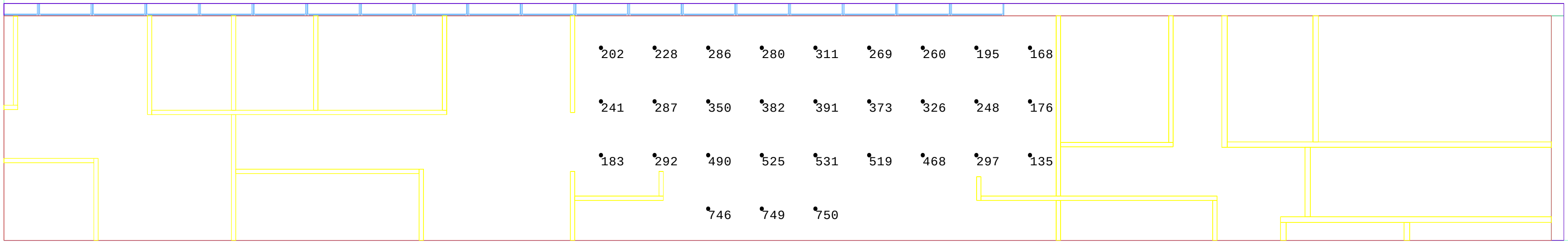
Construction Documents Outpatient December 21



Project_1
Calc Pts

CalcPts_1
Illuminance (Fc)
Average=271.17 Maximum=1405 Minimum=27.8 Avg/Min=9.75 Max/Min=50.55

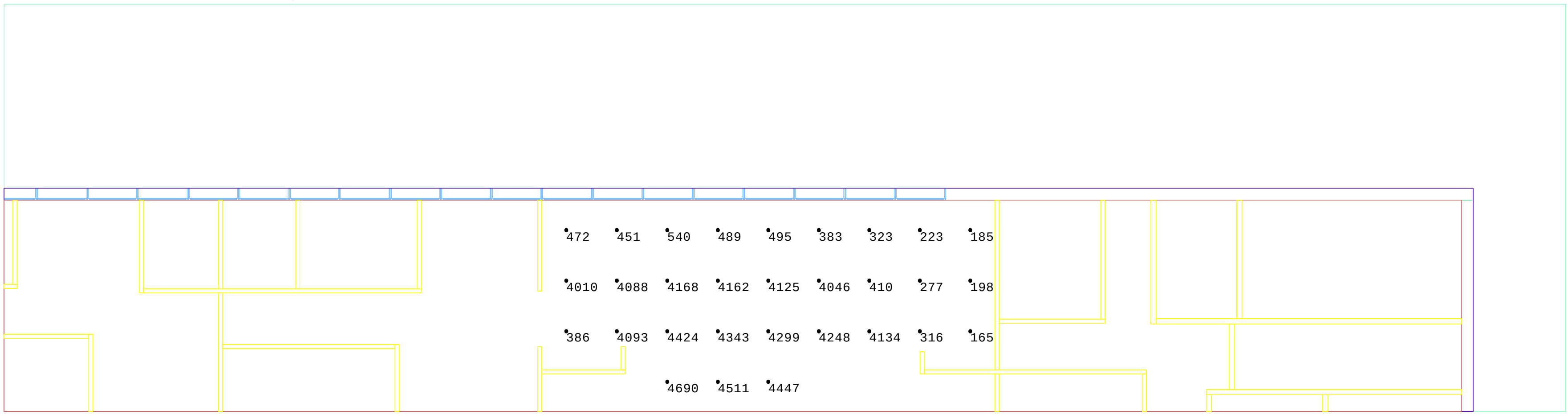
Schematic Design Infusion Center June 21



Project_1
Calc Pts

CalcPts_1
Illuminance (Fc)
Average=355.21 Maximum=750 Minimum=135
Avg/Min=2.63 Max/Min=5.55

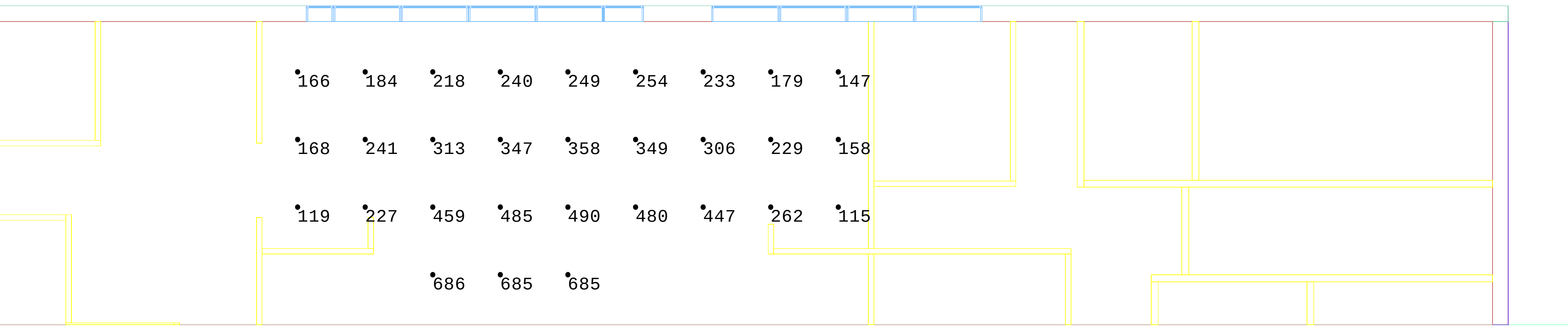
Schematic Design Infusion Center December 21



Project_1
Calc Pts

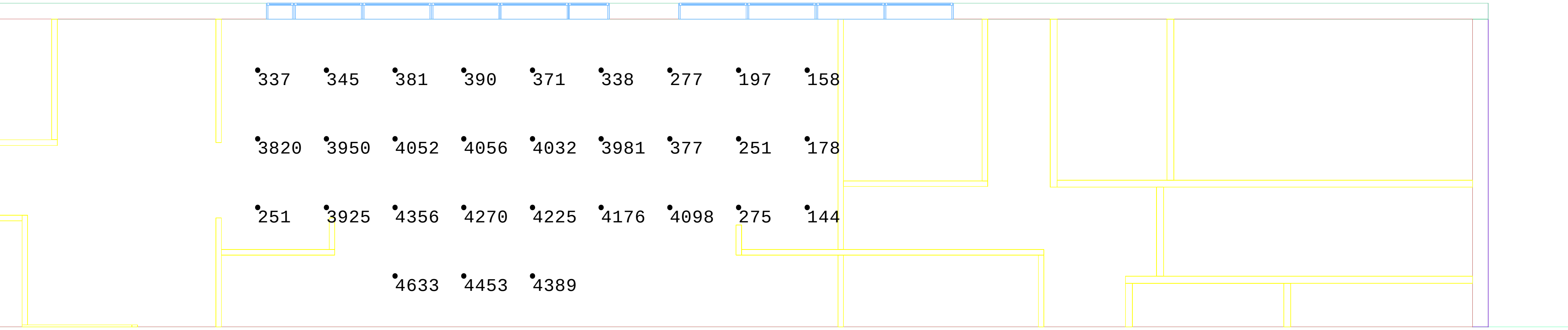
CalcPts_1
Illuminance (Fc)
Average=2303 Maximum=4690 Minimum=165
Avg/Min=13.95 Max/Min=28.40

Construction Documents Infusion Center June 21



CalcPts_3
Illuminance (Fc)
Average=315.99 Maximum=686 Minimum=115 Avg/Min=2.75 Max/Min=5.97

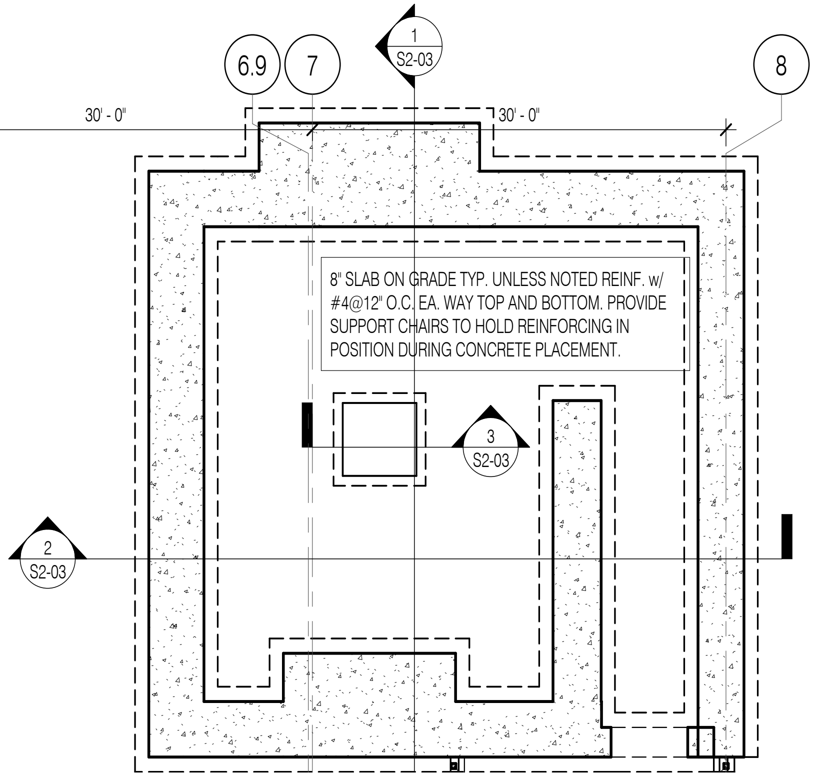
Construction Documents Infusion Center December 21



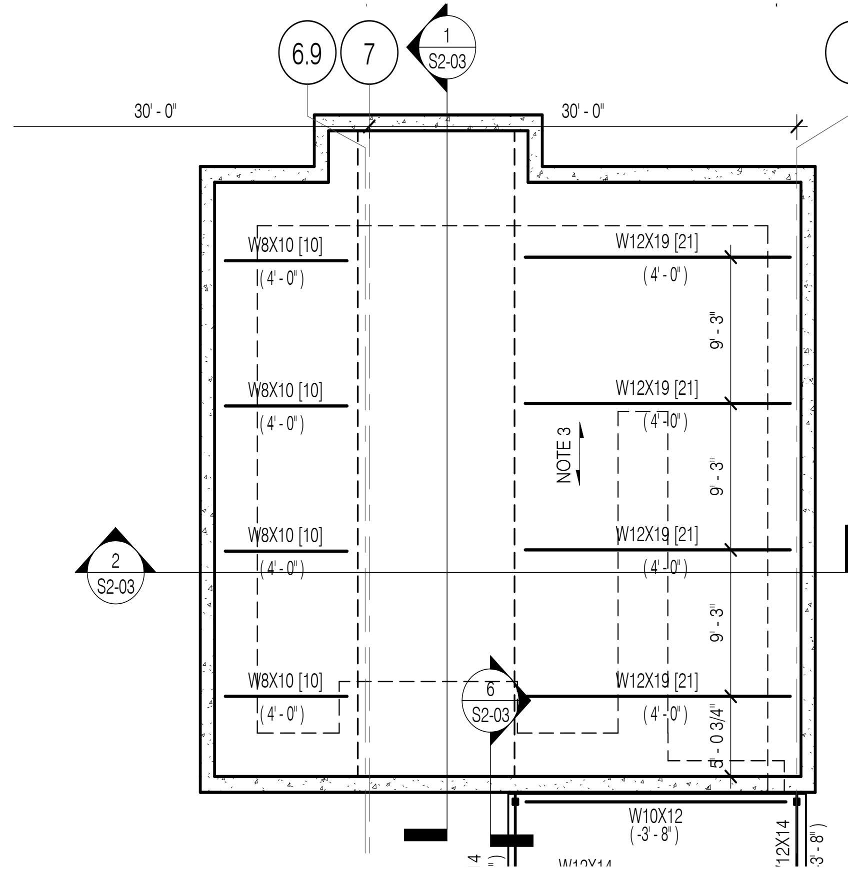
CalcPts_3
Illuminance (Fc)
Average=2223 Maximum=4633 Minimum=144 Avg/Min=15.40 Max/Min=32.11

Appendix D.1

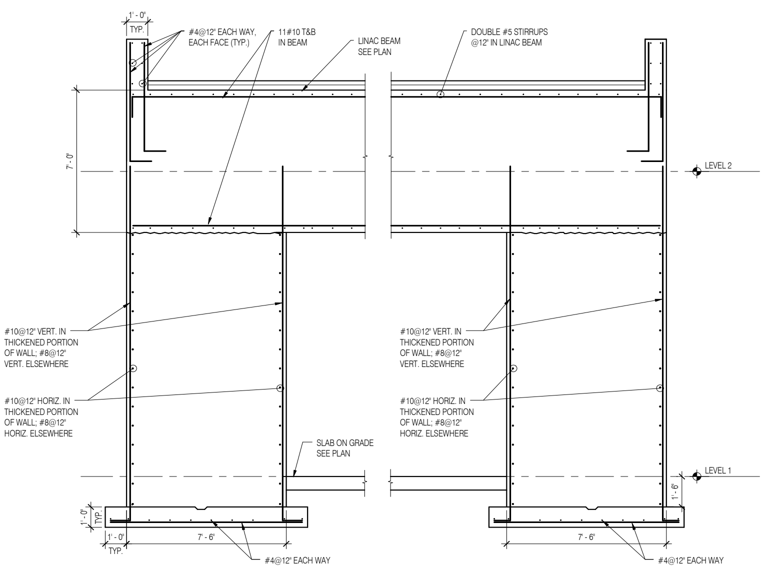
LINAC Vault Concrete Design



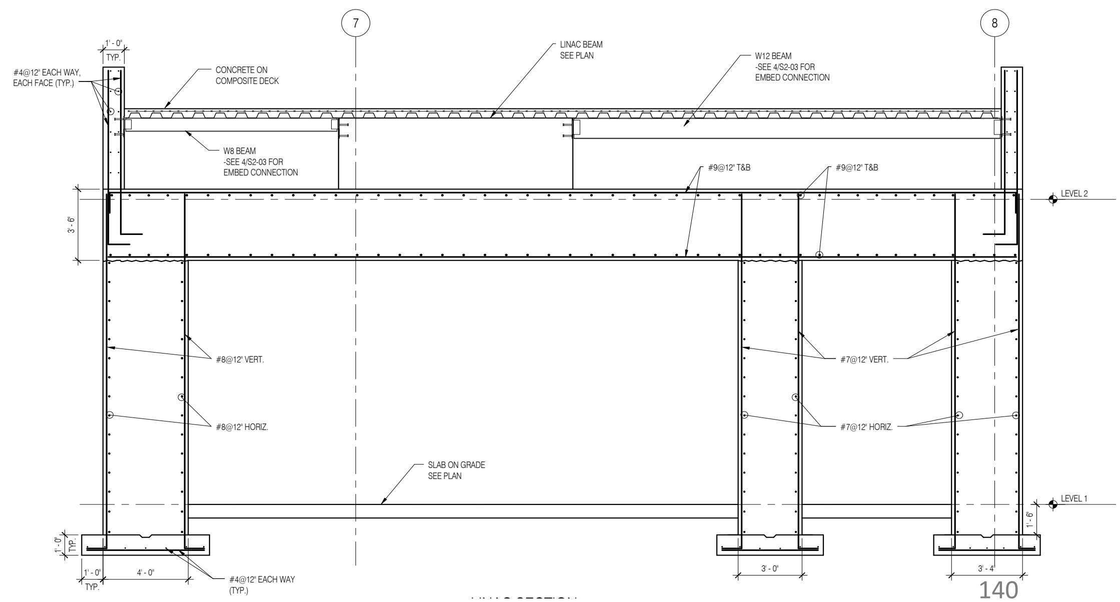
6.9
7
1
S2-03
8
30' - 0"
30' - 0"
8" SLAB ON GRADE TYP. UNLESS NOTED REINF. w/ #4@12" O.C. EA. WAY TOP AND BOTTOM. PROVIDE SUPPORT CHAIRS TO HOLD REINFORCING IN POSITION DURING CONCRETE PLACEMENT.
3
S2-03
2
S2-03



6.9
7
1
S2-03
8
30' - 0"
30' - 0"
W8X10 [10]
(4' - 0")
W12X19 [21]
(4' - 0")
9' - 3"
NOTE 3
2
S2-03
6
S2-03
3' - 0 3/4"
W10X12
(-3' - 8")



1' - 0"
TYP.
#4@12" EACH WAY, EACH FACE (TYP.)
11#10 T&B IN BEAM
LINAC BEAM SEE PLAN
DOUBLE #5 STIRRUPS @12" IN LINAC BEAM
7' - 0"
LEVEL 2
#10@12" VERT. IN THICKENED PORTION OF WALL; #8@12" VERT. ELSEWHERE
#10@12" HORIZ. IN THICKENED PORTION OF WALL; #8@12" HORIZ. ELSEWHERE
SLAB ON GRADE SEE PLAN
LEVEL 1
1' - 6"
7' - 6"
#4@12" EACH WAY



7
8
1' - 0"
TYP.
#4@12" EACH WAY, EACH FACE (TYP.)
CONCRETE ON COMPOSITE DECK
LINAC BEAM SEE PLAN
W12 BEAM -SEE 4/S2-03 FOR EMBED CONNECTION
W8 BEAM -SEE 4/S2-03 FOR EMBED CONNECTION
#9@12" T&B
LEVEL 2
3' - 6"
#8@12" VERT.
#8@12" HORIZ.
#7@12" VERT.
#7@12" HORIZ.
SLAB ON GRADE SEE PLAN
LEVEL 1
1' - 6"
4' - 0"
3' - 0"
3' - 4"
#4@12" EACH WAY (TYP.)

Appendix D.2

LINAC Vault Take-offs

Rebar Takeoffs For LINAC Vault

Location		Horizontal							Vertical						
		Bar Size	Height (LF)	Bar Spacing (LF)	Quantity of Bars (calc.)	Quantity of Bars (act.)	Bar Length (Horz.)	Subtotal Length (LF)	Bar Size	Length (LF)	Bar Spacing	Quantity of Bars (calc.)	Quantity of Bars (act.)	Bar Length (Vert.)	Subtotal Length (LF)
Wall	North Wall	#8	13.67	1	13.67	28	39.17	1096.67	#8	39.17	1	39.17	80	18.50	1480.00
	East Wall	#8	13.67	1	13.67	28	7.83	219.33	#8	7.83	1	7.83	16	18.50	296.00
	East Wall	#8	13.67	1	13.67	28	19.00	532.00	#8	19.00	1	19.00	40	18.50	740.00
	East Wall	#10	13.67	1	13.67	28	15.75	441.00	#10	15.75	1	15.75	32	18.50	592.00
	South Wall	#7	13.67	1	13.67	28	39.17	1096.67	#7	39.17	1	39.17	80	18.50	1480.00
	West Wall	#8	13.67	1	13.67	28	11.08	310.33	#8	11.08	1	11.08	24	18.50	444.00
	West Wall	#8	13.67	1	13.67	28	9.58	268.33	#8	9.58	1	9.58	20	18.50	370.00
	West Wall	#10	13.67	1	13.67	28	12.25	343.00	#10	12.25	1	12.25	26	18.50	481.00
	Maze Wall	#7	13.67	1	13.67	28	20.17	564.67	#7	20.17	1	20.17	40	18.50	740.00
							Subtotal (#7)	1661.33						Subtotal (#7)	2220.00
							Subtotal (#8)	2426.67						Subtotal (#8)	3330.00
							Subtotal (#10)	784.00						Subtotal (#10)	1073.00

Location		Bar Size	Height (LF)	Bar Spacing (LF)	Quantity of Bars (calc.)	Quantity of Bars (act.)	Bar Length (Horz.)	Subtotal Length (LF)	Bar Size	Length (LF)	Bar Spacing	Quantity of Bars (calc.)	Quantity of Bars (act.)	Bar Length (Vert.)	Subtotal Length (LF)
Slab on Grade		#4	44.00	1	44.00	44.00	43.50	1914.00	#4	42.00	1.00	42.00	42.00	41.50	1743.00

Location		Horizontal (Longways, Short Bars)							Vertical (Short-side, Long Bars)						
		Bar Size	Height (LF)	Bar Spacing (LF)	Quantity of Bars (calc.)	Quantity of Bars (act.)	Bar Length (Horz.)	Subtotal Length (LF)	Bar Size	Length (LF)	Bar Spacing	Quantity of Bars (calc.)	Quantity of Bars (act.)	Bar Length (Vert.)	Subtotal Length (LF)
Foundation	North Wall	#4	41.00	1	41.00	41.00	5.50	225.50	#4	5.50	1	5.50	6	41.00	246.00
	East Wall	#4	7.75	1	7.75	8	5.50	44.00	#4	5.50	1	5.50	6	7.75	46.50
	East Wall	#4	19.00	1	19.00	19	5.50	104.50	#4	5.50	1	5.50	6	19.00	114.00
	East Wall	#4	16.00	1	16.00	19	9.00	171.00	#4	9.00	1	9.00	9	16.00	144.00
	South Wall	#4	41.00	1	41.00	41	4.83	198.17	#4	4.83	1	4.83	5	41.00	205.00
	West Wall	#4	11.00	1	11.00	11	5.50	60.50	#4	5.50	1	5.50	6	11.00	66.00
	West Wall	#4	12.50	1	12.50	13	5.50	71.50	#4	5.50	1	5.50	6	12.50	75.00
	West Wall	#4	9.75	1	9.75	10	9.00	90.00	#4	9.00	1	9.00	9	9.75	87.75
	Maze Wall	#4	20.33	1	20.33	21	4.50	94.50	#4	4.50	1	4.50	5	20.33	101.67
							Subtotal (#4)	1059.67						Subtotal (#4)	1085.92

Location		North to South							East to West						
		Bar Size	Height (LF)	Bar Spacing (LF)	Quantity of Bars (calc.)	Quantity of Bars (act.)	Bar Length (Horz.)	Subtotal Length (LF)	Bar Size	Length (LF)	Bar Spacing	Quantity of Bars (calc.)	Quantity of Bars (act.)	Bar Length (Vert.)	Subtotal Length (LF)
Roof	Primary Roof - N	#9	42.83	1	42.83	86.00	10.75	924.50	#9	10.75	1	10.75	22	42.83	942.33
	Primary Roof - S	#9	42.83	1	42.83	86.00	20.75	1784.50	#9	20.75	1	20.75	42	42.83	1799.00
	Linac Beam	#10	11.00	1	11.00	22	10.67	234.67	#5	25.00	1	25.00	50	35.34	1767.00
							Subtotal (#9)	2709.00						Subtotal (#5)	1767.00
							Subtotal (#10)	234.67						Subtotal (#9)	2741.33

Location		Vertical							Horizontal						
		Bar Size	Height (LF)	Bar Spacing (LF)	Quantity of Bars (calc.)	Quantity of Bars (act.)	Bar Length (Horz.)	Subtotal Length (LF)	Bar Size	Length (LF)	Bar Spacing	Quantity of Bars (calc.)	Quantity of Bars (act.)	Bar Length (Vert.)	Subtotal Length (LF)
Parapet	Primary Roof - N	#4	39.17	1	39.17	160	9.42	1506.67	#4	5.83	1	5.83	24	39.17	940.00
	Primary Roof - V	#4	31.83	1	31.83	108	9.42	1017.00	#4	5.83	1	5.83	24	31.83	764.00
	Linac Beam	#4	10.67	1	10.67	44	6.58	289.67	#4	2.17	1	2.17	12	10.67	128.00
							Subtotal (#4)	2813.33						Subtotal (#4)	1832.00

Summary of Rebar Quantities

Location	Bar Size	Subtotal (LF)	Conversion (lbs/ft)	Weight (lbs)	Tons (T)	Excess (5%)
Walls	#4	4645.33	0.668	3103.08267	1.55	1.63
Slab	#4	3657.00	0.668	2442.876	1.22	1.28
Foundation	#4	2145.58	0.668	1433.24967	0.72	0.75
Roof	#5	1767.00	1.043	1842.981	0.92	0.97
Walls	#7	3881.33	2.044	7933.44533	3.97	4.17
Walls	#8	5756.67	2.670	15370.3	7.69	8.07
Roof	#9	5450.33	3.400	18531.1333	9.27	9.73
Walls	#10	1857.00	4.303	7990.671	4.00	4.20
Roof	#10	234.67	4.303	1009.77067	0.50	0.53

Concrete Takeoff For LINAC Vault

	Plan (SF)	f'c (PSI)	Thickness (LF)	Subtotal (CY)	Excess (5%)
Foundation	1070	4500	1	39.62962963	41.6111111
Slab on Grade	1060	3500	0.67	26.17283951	27.4814815
Wall	700	4500	13.5	350	367.5
Roof	1590	4500	3.5	206.1111111	216.416667
Beam	450	4500	3.5	58.33333333	61.25
Parapet	170	4500	6	37.77777778	39.6666667
				Subtotal (3500 psi)	27.4814815
				Subtotal (4500 psi)	753.925926

Appendix D.3

Concrete LINAC Vault Estimate

Concrete LINAC Vault Estimate

Cost Code		Item		Units	Crew	Daily Output	Labor Hours	Quantity	Mat'l Unit Cost	Mat'l Cost	Labor Unit Cost	Labor Cost	Equip Unit Cost	Equip Cost	Total
Excavation															
31 23 16.13	0090	Excavating, Trench	4' to 6' deep, 1/2 C.Y. excavator	B.C.Y	B11-M	200	0.08	400	$ 3.56	$ 1,424.00	$ 1.98	$ 792.00	$ 5.54	$ 2,216.00	$ 4,432.00
									$ -	$ -	$ -	$ -		$ -	$ -
Miscellaneous Cast-in-Place Concrete															
03 30 53.40	3300	Concrete in Place	Lightweight, 110# per C.F., 2-1/2" thick floor infill	S.F.	C-8	2582	0.22	1,800	$ 1.48	$ 2,664.00	$ 0.92	$ 1,656.00	$ 0.28	$ 504.00	$ 4,824.00
Heavyweight Structural Concrete															
03 31 13.35	0200	Heavyweight Concrete, Ready Mix, delivered	3500 psi	CY				30	$ 110.00	$ 3,300.00	$ -	$ -		$ -	$ 3,300.00
03 31 13.35	0350	Heavyweight Concrete, Ready Mix, delivered	4500 psi	CY				800	$ 116.00	$ 92,800.00	$ -	$ -		$ -	$ 92,800.00
Rebar															
03 21 11.60	0500	Reinforcing in Place	Footings, #4 to #7	Ton	4 Rodm.	2.1	15.238	2	$ 960.00	$ 1,563.95	$ 810.00	$ 1,319.59		$ -	$ 2,883.54
03 21 11.60	0700	Reinforcing in Place	Walls, #3 to #7	Ton	4 Rodm.	3	10.667	6	$ 960.00	$ 5,568.00	$ 565.00	$ 3,277.00		$ -	$ 8,845.00
03 21 11.60	0750	Reinforcing in Place	Walls, #8 to #18	Ton	4 Rodm.	4	8	12	$ 960.00	$ 11,779.20	$ 425.00	$ 5,214.75		$ -	$ 16,993.95
03 21 11.60	0600	Reinforcing in Place	Slab on grade, #3 to #7	Ton	4 Rodm.	2.3	13.913	2	$ 960.00	$ 1,920.00	$ 735.00	$ 1,470.00		$ -	$ 3,390.00
03 21 11.60	0400	Reinforcing in Place	Elevated slabs, #4 to #7	Ton	4 Rodm.	2.9	11.034	12	$ 960.00	$ 11,779.20	$ 585.00	$ 7,177.95		$ -	$ 18,957.15
									$ -	$ -	$ -	$ -		$ -	$ -
Concrete Placement															
03 31 13.70	1900	Placing Concrete	Footings, continuous, shallow, direct chute	CY	C-6	120	0.4	42	$ -	$ -	$ 15.80	$ 657.46	$ 0.53	$ 22.05	$ 679.51
03 31 13.70	4300	Placing Concrete	Slab on grade, up to 6" thick, direct chute	CY	C-6	110	0.436	28	$ -	$ -	$ 17.25	$ 483.00	$ 0.58	$ 16.24	$ 499.24
03 31 13.70	4900	Placing Concrete	Walls, 15" thick, pumped	CY	C-20	110	0.582	408	$ -	$ -	$ 23.50	$ 9,588.00	$ 7.20	$ 2,937.60	$ 12,525.60
03 31 13.70	1500	Placing Concrete	Elevated slabs, over 10" thick, pumped	CY	C-20	180	0.356	278	$ -	$ -	$ 14.50	$ 4,031.00	$ 4.39	$ 1,220.42	$ 5,251.42
									$ -	$ -	$ -	$ -		$ -	$ -
Concrete Forming															
03 11 13.65	2000	Forms in Place, Slab on Grade	Curb forms, wood, 6" to 12" high, on grade, 1 use	SFCA	C-1	215	0.149	160	$ 2.64	$ 422.40	$ 6.80	$ 1,088.00	$ -	$ -	$ 1,510.40
03 31 13.85	2400	Forms in Place, Walls	Over 8' to 16' high, 1 use	SFCA	C-2	280	0.171	5,700	$ 2.96	$ 16,872.00	$ 8.05	$ 45,885.00	$ -	$ -	$ 62,757.00
03 11 13.20	2000	Forms in Place, Beams and Girders	Interior beam, job-built plywood, 12" wide, 1 use	SFCA	C-2	300	0.16	485	$ 3.62	$ 1,755.70	$ 7.50	$ 3,637.50	$ -	$ -	$ 5,393.20
03 31 13.70	4900	Forms in Place, Elevated Slabs	Flat plate, job-built plywood, to 15' high, 1 use	S.F.	C-2	770	0.102	1,210	$ 3.76	$ 4,549.60	$ 4.80	$ 5,808.00	$ -	$ -	$ 10,357.60
03 31 13.70	8000	Forms in Place, Elevated Slabs	Perimeter deck and rail for elevated slabs, straight	L.F.	C-1	90	0.356	400	$ 12.80	$ 5,120.00	$ 16.30	$ 6,520.00	$ -	$ -	$ 11,640.00
Concrete Finishing															
03 35 13.30	0250	Finishing Floors, High Tolerance	Bull Float, machine float & machine trowel (walk-behind)	S.F.	C-10C	1715	0.014	1,800	$ -	$ -	$ 0.60	$ 1,080.00	$ 0.03	$ 54.00	$ 1,134.00
Anchor Bolts															
03 15 19.1	0030	Anchor Bolts	J-type, incl. hex nut & washer, 1/2" dia x 96" long	Set	1 Carp	21	0.981	16	$ 5.55	$ 88.80	$ 18.45	$ 295.20		$ -	$ 384.00
									$ -	$ -	$ -	$ -		$ -	$ -
Steel Members															
05 12 23.75	0300	Structural Steel Members	W 8 x 10	L.F.	E-2	600	0.093	35	$ 14.60	$ 511.00	$ 4.88	$ 170.80	$ 2.53	$ 88.55	$ 770.35
05 12 23.75	1300	Structural Steel Members	W 12 x 22	L.F.	E-2	880	0.064	73	$ 32.00	$ 2,336.00	$ 3.33	$ 243.09	$ 1.73	$ 126.29	$ 2,705.38
									$ -	$ -	$ -	$ -		$ -	$ -
Metal Decking															
05 31 23.50	3350	Roof Decking	3" deep, Type N, 20 ga., 50-500 squares	S.F.	E-4	3600	0.009	1,800	$ 14.60	$ 26,280.00	$ 4.88	$ 8,784.00	$ 2.53	$ 4,554.00	$ 39,618.00
									$ -	$ -	$ -	$ -		$ -	$ -
										$ 190,733.85		$ 109,178.33		$ 11,739.15	$ 311,651.34

Appendix D.4

HD Block LINAC Vault Estimate

HD Block LINAC Vault Estimate

Cost Code		Item		Units	Crew	Daily Output	Labor Hours	Quantity	Mat'l Unit Cost	Mat'l Cost	Labor Unit Cost	Labor Cost	Equip Unit Cost	Equip Cost	Total
Excavation															
31 23 16.13	0090	Excavating, Trench	4' to 6' deep, 1/2 C.Y. excavator	B.C.Y	B11-M	200	0.08	400	$ 3.56	$ 1,424.00	$ 1.98	$ 792.00	$ 5.54	$ 2,216.00	$ 4,432.00
									$ -	$ -	$ -	$ -		$ -	$ -
Miscellaneous Cast-in-Place Concrete															
03 30 53.40	3300	Concrete in Place	Lightweight, 110# per C.F., 2-1/2" thick floor infill	S.F.	C-8	2582	0.22	1,800	$ 1.48	$ 2,664.00	$ 0.92	$ 1,656.00	$ 0.28	$ 504.00	$ 4,824.00
Heavyweight Structural Concrete															
03 31 13.35	0200	Heavyweight Concrete, Ready Mix, delivered	3500 psi	CY				30	$ 110.00	$ 3,300.00	$ -	$ -		$ -	$ 3,300.00
03 31 13.35	0350	Heavyweight Concrete, Ready Mix, delivered	4500 psi	CY				430	$ 116.00	$ 49,880.00	$ -	$ -		$ -	$ 49,880.00
Rebar															
03 21 11.60	0500	Reinforcing in Place	Footings, #4 to #7	Ton	4 Rodm.	2.1	15.238	2	$ 960.00	$ 1,563.95	$ 810.00	$ 1,319.59		$ -	$ 2,883.54
03 21 11.60	0600	Reinforcing in Place	Slab on grade, #3 to #7	Ton	4 Rodm.	2.3	13.913	2	$ 960.00	$ 1,920.00	$ 735.00	$ 1,470.00		$ -	$ 3,390.00
03 21 11.60	0400	Reinforcing in Place	Elevated slabs, #4 to #7	Ton	4 Rodm.	2.9	11.034	12	$ 960.00	$ 11,779.20	$ 585.00	$ 7,177.95		$ -	$ 18,957.15
									$ -	$ -	$ -	$ -		$ -	$ -
Concrete Placement															
03 31 13.70	1900	Placing Concrete	Footings, continuous, shallow, direct chute	CY	C-6	120	0.4	42	$ -	$ -	$ 15.80	$ 657.46	$ 0.53	$ 22.05	$ 679.51
03 31 13.70	4300	Placing Concrete	Slab on grade, up to 6" thick, direct chute	CY	C-6	110	0.436	28	$ -	$ -	$ 17.25	$ 483.00	$ 0.58	$ 16.24	$ 499.24
03 31 13.70	1500	Placing Concrete	Elevated slabs, over 10" thick, pumped	CY	C-20	180	0.356	278	$ -	$ -	$ 14.50	$ 4,031.00	$ 4.39	$ 1,220.42	$ 5,251.42
									$ -	$ -	$ -	$ -		$ -	$ -
Concrete Forming															
03 11 13.65	2000	Forms in Place, Slab on Grade	Curb forms, wood, 6" to 12" high, on grade, 1 use	SFCA	C-1	215	0.149	160	$ 2.64	$ 422.40	$ 6.80	$ 1,088.00	$ -	$ -	$ 1,510.40
03 11 13.20	2000	Forms in Place, Beams and Girders	Interior beam, job-built plywood, 12" wide, 1 use	SFCA	C-2	300	0.16	485	$ 3.62	$ 1,755.70	$ 7.50	$ 3,637.50	$ -	$ -	$ 5,393.20
03 31 13.70	4900	Forms in Place, Elevated Slabs	Flat plate, job-built plywood, to 15' high, 1 use	S.F.	C-2	770	0.102	1,210	$ 3.76	$ 4,549.60	$ 4.80	$ 5,808.00	$ -	$ -	$ 10,357.60
03 31 13.70	8000	Forms in Place, Elevated Slabs	Perimeter deck and rail for elevated slabs, straight	L.F.	C-1	90	0.356	400	$ 12.80	$ 5,120.00	$ 16.30	$ 6,520.00	$ -	$ -	$ 11,640.00
Anchor Bolts															
03 15 19.10	0030	Anchor Bolts	J-type, incl. hex nut & washer, 1/2" dia x 96" long	Set	1 Carp	21	0.981	16	$ 5.55	$ 88.80	$ 18.45	$ 295.20		$ -	$ 384.00
04 05 19.05	0060	Anchor Bolts	3/4" diameter, 8" long	Each	1 Bric	127	0.063		$ 3.81	$ -	$ 2.91	$ -		$ -	$ -
High Density Concrete Block															
04 22 10.14	0300	Interlocking HD Block	6x6x12 240 pcf	Each	D-8	440	0.091	28,000	$ 17.50	$ 490,000.00	$ 3.90	$ 51,121.20	$ -	$ -	$ 541,121.20
04 05 13.30	0000	HD Grout	240 pcf	C.F.	1 Brhe	143	0.056	120	$ 60.00	$ 7,200.00	$ 2.13	$ 255.60	$ -	$ -	$ 7,455.60
Steel Members															
05 12 23.75	0300	Structural Steel Members	W 8 x 10	L.F.	E-2	600	0.093	35	$ 14.60	$ 511.00	$ 4.88	$ 170.80	$ 2.53	$ 88.55	$ 770.35
05 12 23.75	1300	Structural Steel Members	W 12 x 22	L.F.	E-2	880	0.064	73	$ 32.00	$ 2,336.00	$ 3.33	$ 243.09	$ 1.73	$ 126.29	$ 2,705.38
									$ -	$ -	$ -	$ -		$ -	$ -
Metal Decking															
05 31 23.50	3350	Roof Decking	3" deep, Type N, 20 ga., 50-500 squares	S.F.	E-4	3600	0.009	1,800	$ 14.60	$ 26,280.00	$ 4.88	$ 8,784.00	$ 2.53	$ 4,554.00	$ 39,618.00
									$ -	$ -	$ -	$ -		$ -	$ -
Total										$ 610,794.65		$ 95,510.38		$ 8,747.55	$ 715,052.59

Appendix D.5

Grout Requirements
Masonry Institute
Of America

Volume of Grout Required in Masonry Walls

Design Aid 15

GROUT REQUIREMENTS

UNIFORM BUILDING CODE 1973 EDITION
SECTION 2403

Materials

(s) Grout. 1. General. Grout shall be proportioned by volume and shall have sufficient water added to produce consistency for pouring without segregation. Aggregate shall conform to the requirements set forth in U.B.C. Standard No. 24-24.

2. Type. Fine grout shall be composed of one part portland cement, to which may be added not more than one-tenth part hydrated lime or lime putty, and two and one-fourth to three parts sand.

Coarse grout shall be composed of one part portland cement to which may be added not more than one-tenth part hydrated lime or lime putty, and two to three parts sand, and not more than two parts gravel.

Coarse grout may be used in grout spaces in brick masonry 2 inches or more in horizontal dimension and in grout spaces in filled-cell construction 4 inches or more in both horizontal dimensions.

3. Strength. Grout shall attain a minimum compressive strength of 2000 pounds per square inch at 28 days. The Building Official may require a compressive field strength test of grout made in accordance with U.B.C. Standard. No. 24-23

Concrete Block Construction

Standard Two Cell Block*	Grouted Cells Vert. Steel Spacing	Cu. Yds. ▲ of Grout Per 100 Sq.Ft. of Wall	Cu.Yds.per ▲ 100 Block (8" High) (16" Long)	Block per Cu. Yd. (8" High) (16" Long)
6" THICK WALLS	All Cells Filled	0.93	0.83	120
	16" O.C.	0.55	0.49	205
	24" O.C.	0.42	0.37	270
	32" O.C.	0.35	0.31	320
	40" O.C.	0.31	0.28	360
	48" O.C.	0.28	0.25	396
8" THICK WALLS	All Cells Filled	1.12	1.00	100
	16" O.C.	0.65	0.58	171
	24" O.C.	0.50	0.44	225
	32" O.C.	0.43	0.38	267
	40" O.C.	0.37	0.33	300
	48" O.C.	0.34	0.30	330
10" THICK WALLS	All Cells Filled	1.38	1.23	80
	16" O.C.	0.82	0.73	137
	24" O.C.	0.63	0.56	180
	32" O.C.	0.53	0.47	214
	40" O.C.	0.47	0.42	240
	48" O.C.	0.43	0.38	264
12" THICK WALLS	All Cells Filled	1.73	1.54	65
	16" O.C.	1.01	0.90	111
	24" O.C.	0.76	0.68	146
	32" O.C.	0.64	0.57	174
	40" O.C.	0.57	0.51	195
	48" O.C.	0.53	0.47	215

*For open end block add 10% more grout
For slumped block deduct 5% grout.
Horizontal bond beams assumed spaced 4'0.C.

2 Wythe Brick Wall Construction

Width of Grout Space (Inches)	Cubic Yards of Grout per 100 Sq. Ft. of Wall ▲	Sq. Ft. of Wall per Cubic Yard of Grout ▲
2.0	0.64	157
2.5	0.79	126
3.0	0.96	105
3.5	1.11	90
4.0	1.27	79
4.5	1.43	70
+ 5.0	1.59	63
5.5	1.75	57
6.0	1.91	52
6.5	2.07	48
7.0	2.23	45
8.0	2.54	39

▲A 3% allowance has been included for loss and job conditions.
+It is recommended that floaters be used in low lift grouting when the grout space is 5" or more wide.

For Engineering Information and Details contact

MASONRY INSTITUTE OF AMERICA

386 Beech Ave., Suite #4 · Torrance, CA 90501-6202
Tel: (310) 328-4400 – Fax: (310) 328-4320

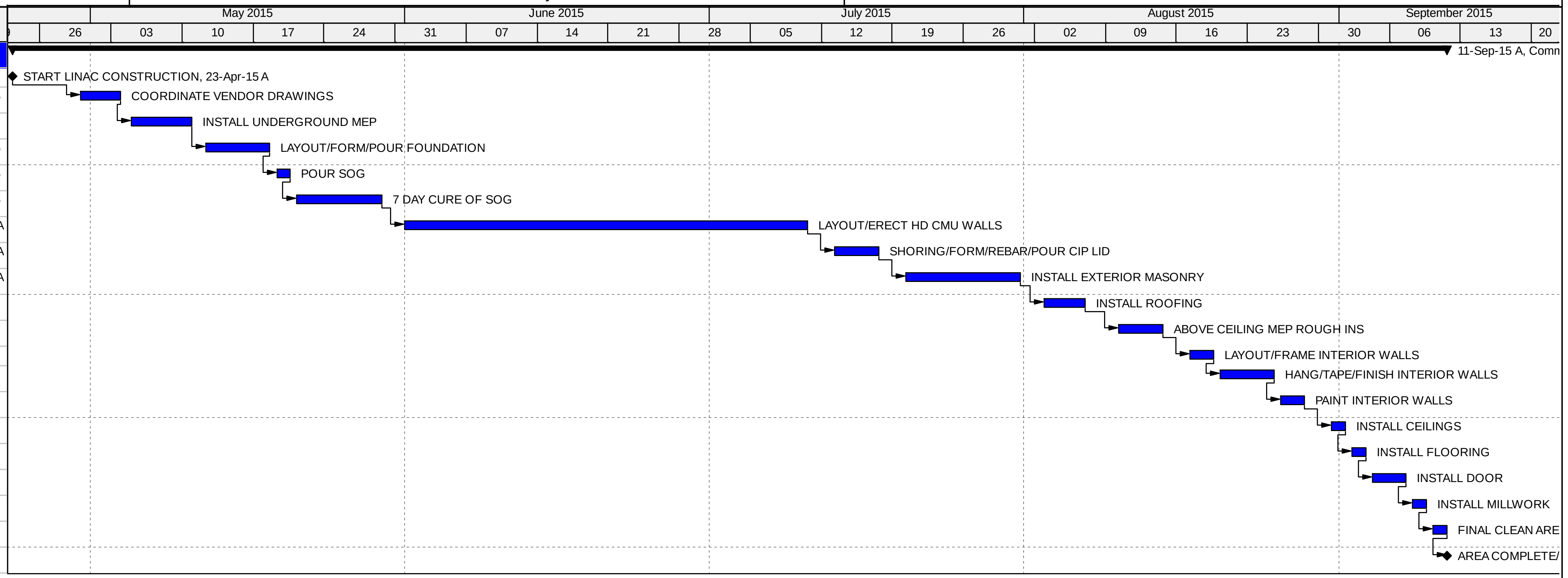
3M1-75MIA115

Appendix D.6

HD Block LINAC Vault Schedule

Comm Health LINAC	Classic Schedule Layout	16-Mar-16 14:43

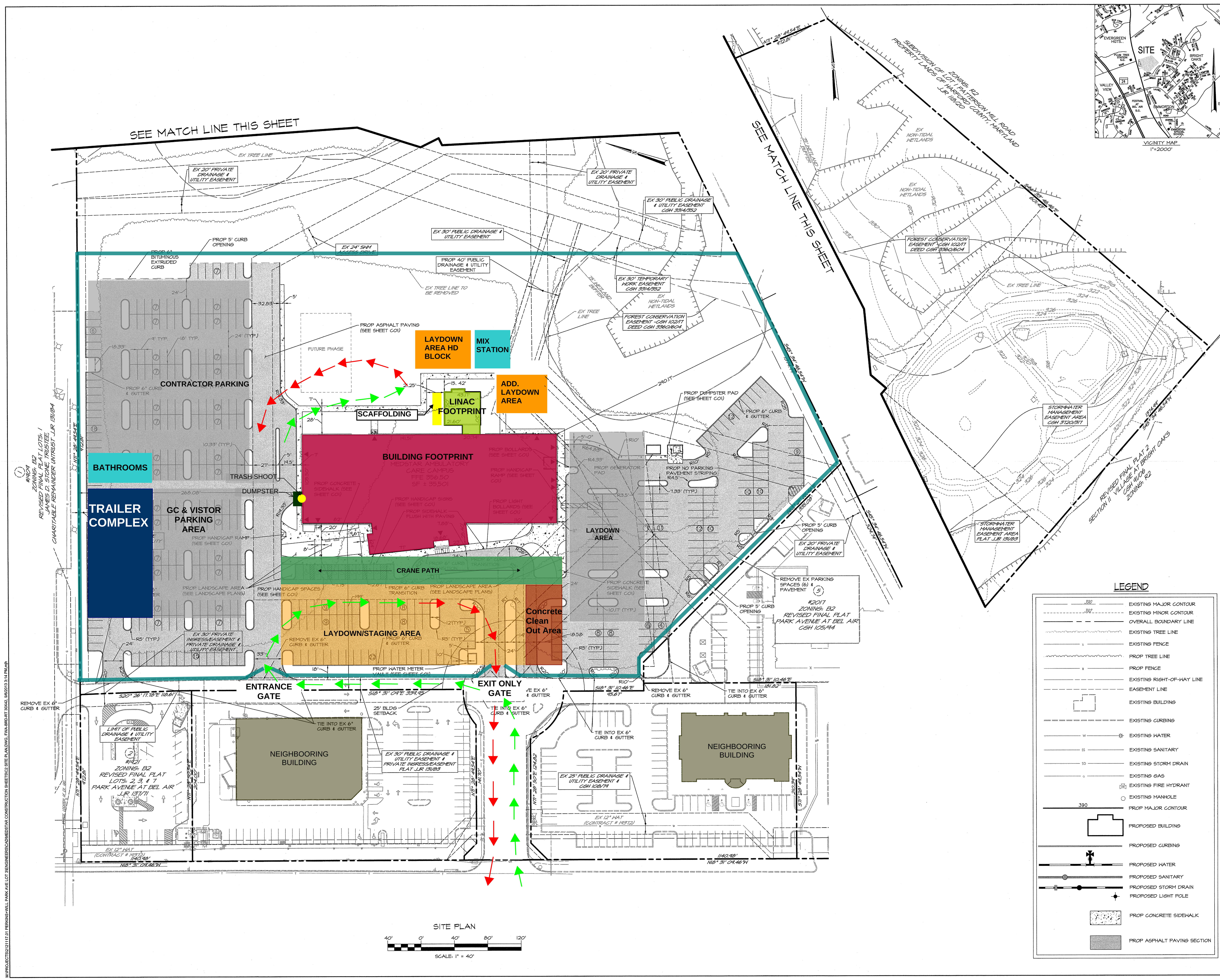
Activity ID	Activity Name	Original Duration	Remaining Duration	Start	Finish
Comm Health LINAC Comm Health		291	0	23-Apr-15 A	11-Sep-15 A
A1000	START LINAC CONSTRUCTION	0	0	23-Apr-15	
A1010	COORDINATE VENDOR DRAWINGS	3	0	30-Apr-15 A	04-May-15 A
A1020	INSTALL UNDERGROUND MEP	5	0	05-May-15 A	11-May-15 A
A1030	LAYOUT/FORM/POUR FOUNDATION	5	0	12-May-15 A	18-May-15 A
A1040	POUR SOG	2	0	19-May-15 A	20-May-15 A
A1050	7 DAY CURE OF SOG	7	0	21-May-15 A	29-May-15 A
A1060	LAYOUT/ERECT HD CMU WALLS	30	0	01-Jun-15 A	10-Jul-15 A
A1070	SHORING/FORM/REBAR/POUR CIP LID	5	0	13-Jul-15 A	17-Jul-15 A
A1080	INSTALL EXTERIOR MASONRY	10	0	20-Jul-15 A	31-Jul-15 A
A1090	INSTALL ROOFING	5	0	03-Aug-15 A	07-Aug-15 A
A1100	ABOVE CEILING MEP ROUGH INS	5	0	10-Aug-15 A	14-Aug-15 A
A1110	LAYOUT/FRAME INTERIOR WALLS	3	0	17-Aug-15	19-Aug-1
A1120	HANG/TAPE/FINISH INTERIOR WALLS	4	0	20-Aug-15 A	25-Aug-15 A
A1130	PAINT INTERIOR WALLS	3	0	26-Aug-15 A	28-Aug-15 A
A1140	INSTALL CEILINGS	2	0	31-Aug-15 A	01-Sep-15 A
A1150	INSTALL FLOORING	2	0	02-Sep-15 A	03-Sep-15 A
A1160	INSTALL DOOR	2	0	04-Sep-15 A	07-Sep-15 A
A1170	INSTALL MILLWORK	2	0	08-Sep-15 A	09-Sep-15 A
A1180	FINAL CLEAN AREA	2	0	10-Sep-15 A	11-Sep-15 A
A1190	AREA COMPLETE/TURN OVER TO VENDOR	0	0		11-Sep-15 A



Legend		Page 1 of 1	TASK filter: All Activities
Actual Level of Effort	Remaining Work		
Actual Work	Critical Remaining Work		
Milestone	summary		

Appendix D.7

HD Block LINAC Vault
Site Logistics



PERKINS + WILL

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DESIGN DRAWINGS

August 30, 2013

Revisions

BID DOCUMENTS NOT FOR CONSTRUCTION

ISSUE	DATE

Sheet Information

Date	08.30.13
Job Number	2121117.01
Drawn	MJH
Checked	GGP
Approved	

Title

SITE PLAN

Sheet

C02

Appendix E.1

Industry Interviews

The interview below was conducted 2/15/2016 with Bill Gamble of Barton Malow. The answers below are paraphrased from the responses of the Bill Gamble and are not directly quoted from the subjects, however, they do reflect the intended content of their answers.

DATE: 2/15/2016
NAME: Bill Gamble
COMPANY ROLE: Project Engineer
YEARS OF EXPERIENCE IN POSITION: 2 Years

Q1: Have you, your company, or your studies utilized virtual mockup tools? How would you define a virtual mockup?

A1: Yes, both Barton Malow and the project team heavily use virtual mockups. I would define a virtual mockup as any tool that can visually create an interpretation of what is or will be happening on a project to establish clarification on a detail, layout, etc. The key is that the visual aid is not only vetted in the planning stages, but also with the personnel in the field.

Q2: How do you believe these technologies have improved your design review process? Could you provide an example of a time your company has utilized a form of virtual mockup technology on a project (building type, SF, cost), and how that technology affected the project?

A2: These technologies have allowed a team to sit down and basically build the entire building on the computer, where safety concerns can clearly be seen, where sequencing must be redone because the CPM has items in the incorrect order, or even help prefabricate some items on the job. At Health Sciences Facility III (Biomedical research facility, 430,000 GSF, $217M), we used virtual mockups to re sequence our schedule looking at the safety of having crews on top of one another - specifically the skin, we looked at the best possible location for the man hoist (tight site), and looked at the sequencing of the complicated skin through the use of virtual mockups. By doing these mockups and planning ahead, Barton Malow has saved thousands of dollars and the job is only half completed.

Q3: What kinds of projects (building type, SF, cost, contact type, etc.) do you think would benefit most from these technologies?

A3: The projects that would benefit the most from virtual mockups are projects with complicated details (skin, structure, etc.), intricate site layouts, and difficult sequencing of trades. In the end any job over $50,000 could benefit from virtual mockups. Although the models can be large upfront costs, the payback in the long run is far worth the time and money to create the models. The reason I chose $50k was because the smaller jobs are typically 'cookie cutter' jobs, where there is no need to create virtual mockups because of their simplistic design

Q4: What are some of the technologies your group have looked at?

A4: Some of the technologies Barton Malow uses are Google Sketchup, Navisworks Manage, AutoCad, Oculus Rift Glasses, 360 Heros (GoPro), Trimble, and BIM 360 Field/ Glue

Q5: Which technologies have proven most effective in conveying virtual mockups?

A5: Google Sketchup and Navisworks are by far the two we use most on the job here at Barton Malow. Sketchup is used almost weekly to take a look at the details in the drawings and show what they should look like when constructed. From there, RFIs are written before the material is even delivered or installed, along with the safety and sequencing concerns. Navisworks is used on the iPads and computers to view the model to ensure systems are being installed correctly and help mitigate augments on sequencing and location the material is to be installed in the field. After the mockups are created, the Oculus Rift glasses are used to basically provide a real life experience 'walking' through the model

Q6: What resources are needed to implement and use these technologies on a project?

A6: To implement these programs, Sketchup must be downloaded and someone with some basic knowledge of both the program and the installation of the material must create the virtual mockup. For Navisworks, a license must be provided to create the model, but one is not needed to view the model. To view in the field on a desktop, Navisworks Freedom is used, or on an iPad, BIM 360 Glue is used. The Oculus Rift glasses must be purchased by the company, where there must be the understanding that leading technology costs money in the beginning but will pay its dividends in the end.

Q7: What technology do you believe provides the best value?

A7: I believe the technology that provides the best value is anything that allows the team to leave with more information than what they came into the meeting with. After viewing the model in a program such as Sketchup, Navisworks, or AutoCad, any information that can be extracted and used to prevent a safety concern or help save time/ money, has proved that the model (whatever program it is in) is 'worth its weight in gold'.

The interview below was conducted 3/18/2016 with Julien Bartolo of James G. Davis Construction. The answers below are paraphrased from the responses of the Julien Bartolo and are not directly quoted from the subjects, however, they do reflect the intended content of their answers.

DATE: 3/18/2016
NAME: Julien Bartolo
COMPANY ROLE: Senior Virtual Construction Coordination Manager
YEARS OF EXPERIENCE IN POSITION: 6+ years performing VC, 14+ in the industry

Q1: Have you, your company, or your studies utilized virtual mockup tools? How would you define a virtual mockup?

A1: Yes, virtual mock-up design tools are used often in our industry. I personally interpret a virtual construction mock-up as a full-size model representation of a design condition(s) which is typically built well ahead of physical construction taking place in order to review, question and understand design constructability details.

Q2: How do you believe these technologies have improved your design review process? Could you provide an example of a time your company has utilized a form of virtual mockup technology on a project (building type, SF, cost), and how that technology affected the project?

A2: Technology has improved our design review process by allowing us the opportunity to quickly and efficiently analyze complex 3D representations of a proposed design. Technology allows us to review issues, propose alternatives, save time and reduce risk. We can assist with design and constructability concerns well ahead of actual construction. Banner Life Headquarters - 120,000 SF, $20 million - typical facade mock-up, poor design, and numerous issues discovered/addressed.

Q3: What kinds of projects (building type, SF, cost, contact type, etc.) do you think would benefit most from these technologies?

A3: I personally feel every single building type benefits tremendously from the use of this technology whether it be an isolated study of a new element coming into an existing condition or new construction. The bulk of our coordination efforts relate to Mechanical, Electrical, Plumbing and Fire Protection systems scheduled to be installed above finished ceilings.

Q4: What are some of the technologies your group have looked at?

A4: The technologies we have implemented within our group are numerous and used by different individuals on a daily basis. Software includes Autodesk products such as Revit, AutoCAD and Navisworks. We also own a Leica laser scanner which is used mainly to capture existing conditions which can then be converted into 3D models. A few other technologies we use include robotic total stations and APL (for layout), Cyclone (modeling software), Cloudworks and Trimble Sketchup.

Q5: Which technologies have proven most effective in conveying virtual mockups?

A5: If we are talking strictly about virtual mock-ups I would personally lean towards Trimble Sketchup as the preferred technology. This software is affordable, quick and easy to learn, extremely efficient and very interactive. Within minutes one can put together full scale model conditions which can then be adjusted and modified as needed when needed. The software can very quickly create a very powerful 3D visualization model everyone can review and easily understand.

Q6: What resources are needed to implement and use these technologies on a project?

A6: As with any other type of investment, there is always an upfront cost associated with new technologies. Our industry is no different however it is important to state that the return on investment is truly remarkable in most cases. Spending upfront time and money with the use of technology typically results in a more efficient project (less waste) and more efficient material installation due to prefabrication (saved time). Combined, this results in reduced cost and reduced risk for the owner.

Q7: What technology do you believe provides the best value?

A7: With regards to technology and 3D coordination, I personally feel the best value is found in 3D MEP/FP plenum coordination. When properly implemented and executed by all parties everyone wins. The end results consist of the ability to identify and address design issues early, increased field productivity, prefabrication opportunities, less field rework, reduction in RFI's related to field conflicts, improved efficiency and field installation. Owners appreciate these combined benefits (happy client).

The interview below was conducted 2/18/2016 with Tim Conroy of DPR Construction. The answers below are paraphrased from the responses of the Tim Conroy and are not directly quoted from the subjects, however, they do reflect the intended content of their answers.

DATE: 2/18/2016
NAME: Tim Conroy
COMPANY ROLE: N/A
YEARS OF EXPERIENCE IN POSITION: 6 Years

Q1: Have you, your company, or your studies utilized virtual mockup tools? How would you define a virtual mockup?

A1: Yes

Q2: How do you believe these technologies have improved your design review process? Could you provide an example of a time your company has utilized a form of virtual mockup technology on a project (building type, SF, cost), and how that technology affected the project?

A2: Virtual Mockups can have a huge impact on the design review process especially for owners. The medical/healthcare market has one of the greatest opportunities to provide benefits since there are many end users who have a say in the functionality of the space. There are so many decision makers in this field including board members, surgeons, doctors, and nurses. Many of these users can really benefit from seeing the space in the built environment to better understand the space.

My first project, a Kaiser Project approximately 244k SF, 7 story med office, $44 million, 16 month project schedule that grew in cost over its duration. The project designed had fairly standard room layouts; however, the owner wanted to mockup all a-typical rooms, but instead realized how easily a virtual mockup could be created for that space. The impact on design process could have been phenomenal. The project reviewed key spaces with many nurses and doctors set up all day meetings with the design team including the architect, DPR, end users (nurses, surgeons) on a three screen in sketch up so that things could be moved on the fly. One of the surgeons was heavily involves, pointing to things and had the DPR team move items. These design changes were then screenshotted and sent to architect. Unfortunately, the architect did not capture all of the revisions in the virtual mockup to the design/drawings. Ultimately, I consider this a huge opportunity missed.

Q3: What kinds of projects (building type, SF, cost, contact type, etc.) do you think would benefit most from these technologies?

A3: All projects could benefit if they have the time to review and make the changes, but if the project has too quick of a pace to really make these changes and have proper review time then not as beneficial. Team coordination is crucial to the success. In terms of contact type, IPD is the best, Design-Build can still benefit, and Design-Bid-Build still benefit as well but is more difficult. These technologies could be applied everywhere, they just need the time and commitment to be a success.

Q4: What are some of the technologies your group have looked at?

A4: Photorealistic programs either have to be dead on or don't do at all. Especially when showing the design team, they tend to get hung up on visual details. I would recommend keeping everything shades of grays to show the shape, size, and relative proximity. Sketchup is great, one of the best programs to move things quickly. Revit not so great, it is not as easy to move items around, can clunky. Oculus Rift is okay, but the downside to this is its small scale. You cannot have the collective group discussions, which could be value adding. Oculus Rift could be used for final review after Sketchup, but should not be the first step from 2-D to Oculus Rift. Fuser and other technologies are making it easier for Oculus to use.

Q5: Which technologies have proven most effective in conveying virtual mockups?

A5: Sketchup seems to be the most effective for design review and discussion. Easiest technology to make quick changes and move things around in a review.

Q6: What resources are needed to implement and use these technologies on a project?

A6: Drawings, design, a little from revit model, dimensions of rooms, created library of furniture. Additionally there needs to be buy in from team. In terms of employees for the Kaiser project, it 1 BIM guy for 6-8 weeks for modeling, for review1 BIM guy, 1 Project Engineer, at least 2 end users, and one day for everyone to review.

Q7: What technology do you believe provides the best value?

A7: Sketchup

The interview below was conducted 3/21/2016 with Lucas Manos of Mortenson. The answers below are paraphrased from the responses of the Lucas Manos and are not directly quoted from the subjects, however, they do reflect the intended content of their answers.

DATE: 3/21/2016
NAME: Lucas Manos
COMPANY ROLE: Field Engineer for the National Projects Group
YEARS OF EXPERIENCE IN POSITION: 2 Years

Q1: Have you, your company, or your studies utilized virtual mockup tools? How would you define a virtual mockup?

A1: We use VM's for many different purposes. Some of our most predominant uses would be for owner visualization of the design prior to construction. We also use VM's for constructability review, phasing/sequencing, preliminary physical mock-up review.

Q2: How do you believe these technologies have improved your design review process? Could you provide an example of a time your company has utilized a form of virtual mockup technology on a project (building type, SF, cost), and how that technology affected the project?

A2: VM's have greatly benefited our design review. Owner visualization VM's significantly reduce if not eliminate late design changes due to owner approval. VM's used for constructability review have allowed us to determine dimensional, material compatibility, or other design conflicts that might not have been discovered until the physical construction otherwise.

Q3: What kinds of projects (building type, SF, cost, contact type, etc.) do you think would benefit most from these technologies?

A3: We use VM's on virtually every project regardless of the SF, cost, or type. We push our engineers to leverage tools like Sketchup as needed to build VM's that can be used for analysis and construction. Creating VM's early in the construction process allows us to catch issues as sated above. This greatly reduces potential schedule and cost problems later as material is not ordered incorrectly, and therefore find it useful for all of our projects.

Q4: What are some of the technologies your group have looked at?

A4: We primarily leverage Trimble Sketchup for the basis of both our owner visualization VM's (both virtual and augmented reality) as well as our constructability VM's, as it is simple and easy to modify as needed. We are transitioning our engineers to be able to build their own VM's and found sketch-up has the lowest barrier to entry. To eliminate the duplication of work we also pull a lot of information from design models.

Q5: Which technologies have proven most effective in conveying virtual mockups?

A5: We have leveraged everything from Google Glass, Oculus Rift, HTC Vive, to iPads and other mobile devices to convey owner visualization VM's. Our constructability VM's are generally conveyed through a Go-To Meeting or other web conference call with those who may be affected.

Q6: What resources are needed to implement and use these technologies on a project?

A6: Due to our enterprise agreement with Trimble every Mortenson Team member has access to Sketchup, and due to its simplistic nature we found virtually anyone can get started using it with very little training or outside help.

Q7: What technology do you believe provides the best value?

A7: Sketchup has constituently proven to be the best value both from a software license price and in cost to train team members in its use.

Appendix E.2

Change Order Tracking Log

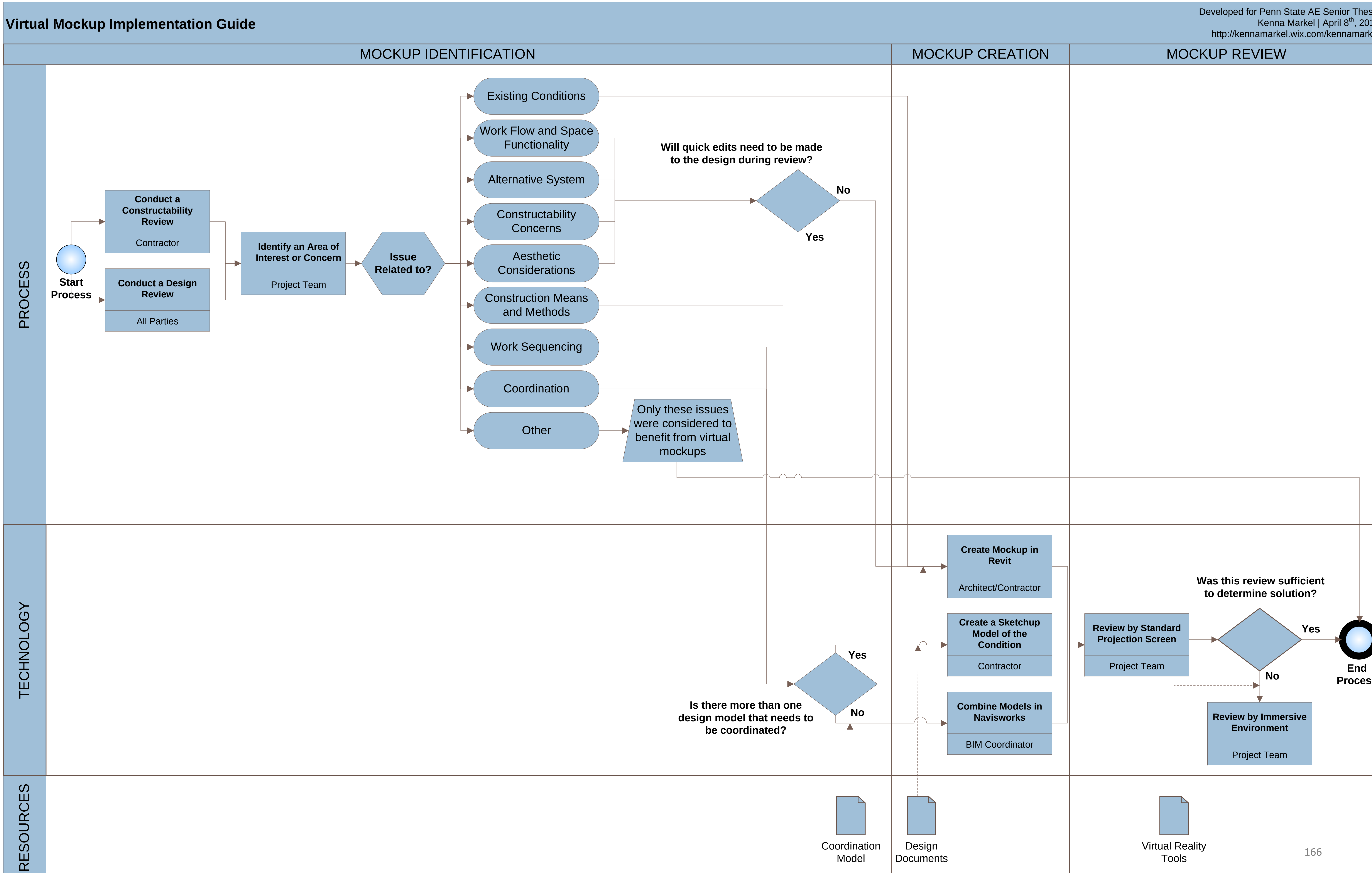
Change Order Tracking

CO #	PCI #	C & S	TI	Issued	Driver	Cost	Days	Description	Owner Driven Chang	Constructability	GMP Related
001	0006	X		10/29/14		$ -	99	Revised GMP schedule to include the Stormwater Management Conversion in lie of the Public Sanitary work and reflect the actual NTP.			X
002	0002 0004 0005 0008 0010 0012	X		10/22/15		$ -	13	Updated GMP schedule based on receiving the building permit to support beginning concrete on 11/24/14 but the permit was delayed until 12/10/14, allowing work to begin 12/15/14.			X
003	0001 0003 0009 0011 0013 0014 0017 0018 0019 0020 0021	X		02/18/15		$ -	0	Addendum #2, ASI #2, minor changes to scope, and winter conditions due to NTP delay. Various cost absorbed by contingencies, no delays.			X
004	0007 0015 0016 0022 0023 0024 0025 0026 0028 0032	X		05/06/15		$ -	13	ASI #1, ASI #3, ASI #4, RFI #0028, minor changes to scope, and revised completion date for weather days. GMP called for 12 weather days, but up to 25 weather days.			X
005	0027 0029 0030 0031 0039 0042	X		06/12/15		$ -	0	Tube Steel Revision, Winter Concrete Costs/Lost Productivity, Unsuitabale Soils at Building Pad, Soil Cement at Parking Lot, Expedite Door Frames, Add Platform at Linac Roof Access, Changes absorbed by contingencies.	X		
006	0035 0036 0040 0041 0043	X		07/15/15		$ -	0	RFI #0053 added CUH at Vestibule 100, #0060 Eliminate Drainage Board at Foundation Waterproofing, #061 Reivsed Exterior Control Joints, #063 Steel Angle for Precast Sill at 3rd Floor West, #064 Steel Framing at Skylight Support Wall, absorbed by contingencies.		X	
007	0033 0034 0045	X		09/15/15		$ -	0	ASI #5 Revisions to Service Area, #06 Finish and Heater Changes, RFI#0072 Issues at Spandrel Framing		X	
008	0038 0043 0044 0048 0054 0057 0058 0059 0062	X		10/14/15		$ -	0	RFI #064 Revision due to Skylight, #0087 Steel at Linac Roof Perimeter, ASI #7 Linac Equipment Coordination, #08 Finish Changes, temporary conditions, SOF patching, extend conduit for IT	X	X	

009	0051 0053 0055 0062 0066 0068 0070 0075	X		12/11/15		$ -	0	RFI #0074 & #0092 Fire/Smoke Dampers, #0088 Column Conflict with Slab Edge, SOF Patching, ASI #10 Access Hatches and Linac Coaling, Security Contractor Allowance, Sod at East Side Slope per Inspector, Add Rebar at tech dock concrete	X	X	
010	0050 0067 0074 0076 0077 0078 0083 0089 0091 0093	X		02/15/16		$ -	0	RFI #083 Brick Shelf at West Elevation, #101 Re-Work Steel at Prompt Care Canopy, #104 Re-Work Curb to Account for Incorrect Grades, ASI #11 Security Changes, Base Paving Repair at Wheel Road, Re-Orient Elevator Hoist Beam, Add Sod at SWM Pond Slopes, Fireman's Key (Knox) Box, Extra Keys by Owner's Request, Traffic Signal Work at Wheel Road	X	X	
001	0001 0002		X	06/15/15		$ -	26	Schedule alignment to progress delay of C & S and preconstruction rebate.			X
002	0005 0010 0011 0013 0017		X	08/15/15		$ -	0	RFI #0017 Additional Framing Around Duct Conflicts, ASI#01 Telecomm Changes, Increast RTU-4 Size, Split System AC Submittal Review Comments, Security Cameras and Monitoring System	X		
003	0006 0007 0014 0015 0019 0022 0023		X	10/14/15		$ -	0	ASI #01 Storage/Med Gas Room Layout Revisions, #02 Coordination Changes, #03 Linac Equipment Drawings, #05 Door & Frame Changes, #06 Pharmacy and Lab Changes, #09 Exterior Signage, RFI #0039 Water Closet Location	X	X	
004	0012 0016 0020		X	12/11/15		$ -	0	CT Sim, Linac, & MRI Chillers - Rig, Store, & Set, ASI #04 CT Simulator Med Equipment Drawings, #07 Revised CT and MRI Layout	X		
005	0016 0021 0026 0028 0029 0031 0034 0036 0037 0038 0048 0053		X	01/20/16		$ 24,672.99	0	ASI #04 CT Simulator Med Equipment Drawings, #08 Miscellaneous Changes, #10 Shielding, #12 Millwork Paper Towel Detail/Flooring/Cubicle Curtain Changes, #13 MRI/CT Control Room & Linac Equipment Room Revisions, RFI#0060 Lighting Fixture Credit FT-12, #0074 IT Room Drip Pan, #0093 Added Bulkheads in Infusion, Re-Work Openings for Door Frame Installation, Overtime Related to MRI/CT Rooms, Moisture Mitigation	X		
006	0030 0041 0044 0057 0059 0060 0061 0062 0063		X	02/15/16		$ 362,725.00	0	ASI #11 Owner Furnished X-Ray Changes, #14 Radiology Changes & Equipment Coordination, #15 Security Grille and Owner Requested Changes, RFI #0107 Bulkheads for Ceiling Changes, Concrete Pour/Patch for Med Equipment, Moisture Mitigation, Infill MRI Depression, Roof Patching for Med Equipment, Extra Keys Requested by Owner.	X	X	
007	0047 0056 0064 0074 0075		X	03/16/16		$ 86,710.41	19	ASI #17 Misc. Electrical Changes to Coordinate with IT, RFI #0112 Added Corner Guards, Additional DPR Staffing for LINAC Install, ASI#22 Smoke Dampers at Lobby, Pneumatic MRI Door	X		

Appendix E.3

Virtual Mockup Implementation Guide



Virtual Mockup Implementation Guide
Developed for Penn State AE Senior Thesis
Kenna Markel | April 8th, 2016
http://kennamarkel.wix.com/kennamarkel
MOCKUP IDENTIFICATION
MOCKUP CREATION
MOCKUP REVIEW
PROCESS
TECHNOLOGY
RESOURCES
Start Process
Conduct a Constructability Review
Contractor
Conduct a Design Review
All Parties
Identify an Area of Interest or Concern
Project Team
Issue Related to?
Existing Conditions
Work Flow and Space Functionality
Alternative System
Constructability Concerns
Aesthetic Considerations
Construction Means and Methods
Work Sequencing
Coordination
Other
Only these issues were considered to benefit from virtual mockups
Will quick edits need to be made to the design during review?
No
Yes
Is there more than one design model that needs to be coordinated?
Yes
No
Create Mockup in Revit
Architect/Contractor
Create a Sketchup Model of the Condition
Contractor
Combine Models in Navisworks
BIM Coordinator
Review by Standard Projection Screen
Project Team
Was this review sufficient to determine solution?
Yes
No
Review by Immersive Environment
Project Team
End Process
Coordination Model
Design Documents
Virtual Reality Tools