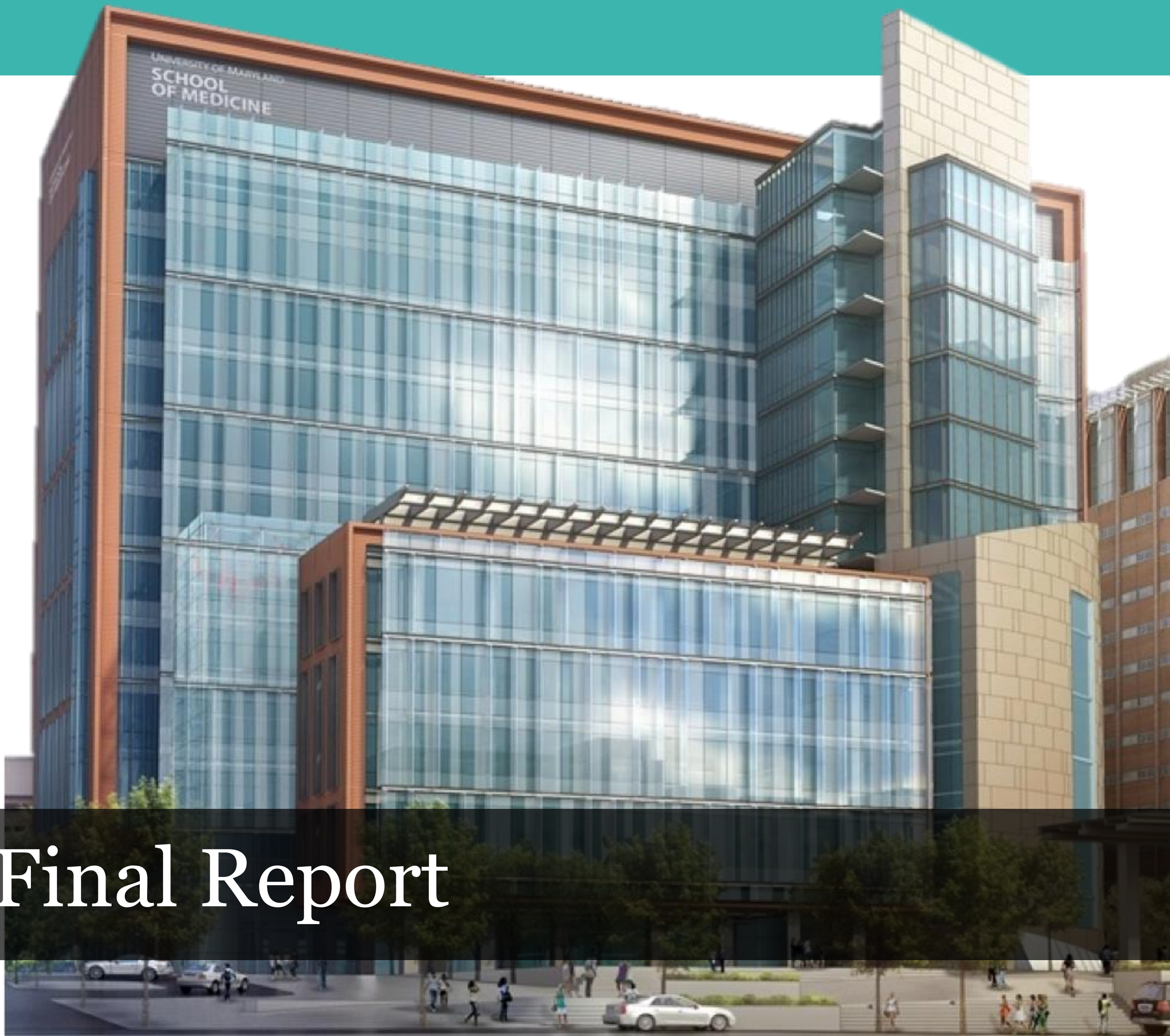

Final Report

Penn State

Construction Management

Advisor: Somayeh Asadi
Health Sciences Facility III
Baltimore, Maryland
April 8, 2015

Executive Summary

This thesis report outlines the research of the construction of Health Sciences Facility III in Baltimore, Maryland. Throughout the year, the building as a whole was analyzed to understand and identify avenues of research in areas like constructability, schedule acceleration, or challenges on the project. These avenues of research developed into specific analyses to investigate based on specific goals in each analysis. All of the analyses cover a wide range of construction topics and are related to understanding value and how to improve value on the project, from the value of a product to the value of time spent performing certain tasks or using certain equipment on a job. This thesis presents the findings of three specific areas of research: alternative support of excavation methods on this project, motivation and its correlation to team performance and resource leveling for cash flow.

Analysis 1: Design of Shoring System

One major challenge on the project included the dewatering system paired with the pile and lagging support of excavation surrounding the site. The project required dry soil in order to both achieve bearing capacity for the pours and to install the waterproofing membrane. Through the investigation of two alternative shoring methods, it was decided that sheet piles would be the best alternative method based on its schedule and overall cost. At $1,640,040 and 90 days of construction, this method is $490,000 cheaper than the pile lagging system and will save 24 days compared to the original system.

Analysis 2: Motivation and Team Performance

Taken from the PACE roundtable, this critical industry research revolves around defining elements that motivate people to do work and how that correlates with team performance on a project. Literature reviews of research done in this area as well as a survey sent to construction managers in the industry paint a picture of how broad of an opinion people have on their motivators to work as well as how their team performance is affected by positive or negative motivators.

Analysis 3: Resource Leveling for Cash Flow

Another challenge on this project involves cash flow. With the project spanning several years, there is only a certain amount of state funding given to the project each fiscal year. Through an analysis of the cash flow for the mechanical trade, a manipulation of the manpower on the project helped move $2.5 million dollars out of fiscal year 2016 into other fiscal years on the project, but it delayed the mechanical rough-in and testing and balancing in the upper floors at least one month. This means that the interior trades that were originally delayed a month could start as originally scheduled and this would accommodate the month delay of the overhead and in-wall installation on the upper floors without compromising the critical path of the project. Overall, it is recommended to use this alternative manpower schedule for the project.

Table of Contents

Acknowledgements

Academic

Advisor: Dr. Somayeh Asadi
Dr. Rob Leicht
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Industry

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THE FOUNDING CAMPUS

Barton Malow

Southland

HSFIII Team
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Health Sciences Facility III
Baltimore, MD

South Elevation Rendering*

BUILDING INFORMATION

Size: 435,000 GSF
Stories: 11 above grade, 2 below
Occupancy: mixed-use lab/office/assembly
Construction Cost: $206 million
Construction: July 2013-Sept 2017
Delivery Method: Fast Track Construction
Contract Type: CM at Risk with GMP

PROJECT TEAM

Owner: University of Maryland
Architect: HOK
MEP Engineer: AEI
Structural Engineer: Cagley & Associates
Civil Engineer: Site Resources
Construction Manager: Barton Malow

*Images courtesy of HOK

North Elevation Rendering*

CONSTRUCTION

- Placement of concrete is pumped from the foundations to the 5th floor, crane and bucket for the remaining floors
- Tower crane will stay throughout the construction of the super-structure and façade
- Material hoist on west wall will have two cages to transport both material and workers

ARCHITECTURE

- Open lab layout to promote collaboration
- Offices mainly along the south wall of each floor
- Primary occupants include the School of Medicine, Pharmacy and Dentistry
- Main exterior façade elements of brick, precast, and curtain wall
- Multiple green roofs located on the atrium and south tower roof
- LEED silver qualified

STRUCTURE

- 44" mat foundation
- Concrete superstructure, 5000 psi, 8"-10" elevated slabs
- Steel framing in atrium, hollow tube steel trusses
- Average span of CIP columns is 21 feet

MECHANICAL

- Mechanical penthouse holds main equipment
- 100% DOAS AHUs—(4) service labs and (2) service vivariums
- (2) AHUS are 35% outside air to service the office spaces
- All systems have airside economizer controls, reheat coils, chilled beams and VAV units
- Process cooling water system in the lab spaces
- Glycol heat exchangers and cooling towers service the chillers and fin tube radiators around the perimeter

ELECTRICAL

- Skylights along atrium roof to promote daylighting
- Main electrical room in basement to receive dual redundant 13.2 KV feeders
- Anticipated load of building is 7,447 KVA
- (4) main switchgears at 100 KAIC, 5000A, 480/277 Wye, two of which are backup switchgears
- (2) electrical rooms per floor to service half of the floor
- Distribution panels are divided into lighting, receptacle, lab, equipment, and emergency panels

Barton Malow

University of Maryland The Founding Campus

Kathryn Gonzales | Construction Option
Advisor: Dr. Asadi
http://www.engr.psu.edu/ae/thesis/portfolios/2015/keg5247/index.html

Project Information

Project Background

As the third phase in the master plan for the University of Maryland, Baltimore (UMB), Health Sciences Facility III is a ten-story lab and office space that will be constructed on the existing site of Hayden Harris Hall, previously occupied by the Dental school. This building will be used primarily by the School of Medicine to further research developments for the university. At 435,000 GSF, this is the largest project to date that the UMB has undertaken. The guaranteed maximum price contract amounts to $216 million dollars and is expected to finish in September of 2017. One unique element of the design by HOK is the glass atrium that acts as a communal and transition space between distinct areas of the building. The construction manager, Barton Malow, came on board to the project early, around the schematic design phase, and has both the preconstruction and construction contracts. They plan to attain LEED Silver for HSFIII.

Client Information

The University of Maryland, Baltimore chose to move forward with the Health Sciences Facility III building for several reasons. Housing mainly the School of Medicine, it is designed to promote collaboration among researchers across disciplines with an open lab layout. As leaders of research in their fields, this building will allow UMB to grow in research activity and bring more funding to the university. The design has more of a generic layout to accommodate future tenants that the owner has not yet procured. This does not apply to floors 3 and 4, both of which have an identified tenant.

The main drivers of the project are cost and safety, partly because UMB prefers a more traditional method for the construction process. As for safety, the construction manager Barton Malow is working on a partnership with Maryland OSHA that will help improve the safety standards on the project. Another main element that UMB has prioritized throughout design is the facility maintenance. Many systems in the building mimic those in other buildings that they service.

One requirement of the project is to attain 30% MBE participation, with an emphasis on 4% Asian-American participation. Also, this project is moving toward a LEED Silver certification. HSF III is the largest that UMB has undertaken to date, so there are high expectations for the success of this building.

Architecture

Health Sciences Facility III is located in downtown Baltimore, less than a mile from inner harbor. The ten-story facility has a penthouse for mechanical equipment and two levels in the basement that host service spaces as well as special lab spaces such as an MRI suite and radiochemistry lab. All floors accommodate a host of offices, lab spaces, and multi-purpose conference rooms. Most of the lab spaces have an open layout to promote collaboration among students and professors. The offices are mainly along the south wall to take advantage of the direct sunlight into the space. The fifth and sixth floors will be left as a core and shell space. The building is divided up into four main areas, as seen in Figures 1 and 2 below. In the core there are 4 elevators, one of the main mechanical shafts and a stair tower. The south end of the core also holds conference room space up to level 4. The north and south tower include the main program space while the atrium serves as a bridging point between the two towers.

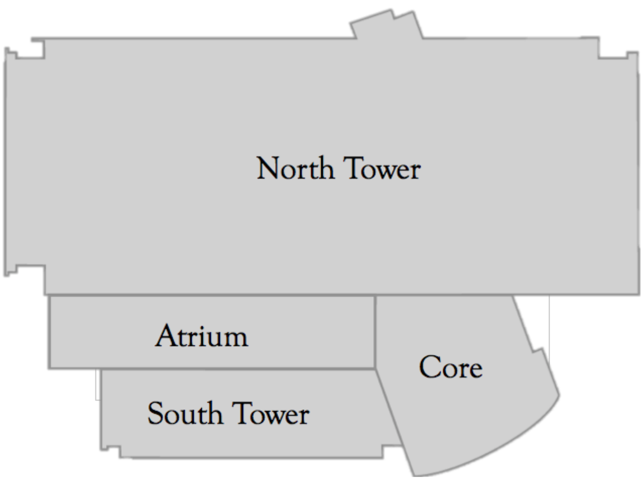


Figure 2: Plan View of Floors 1-6

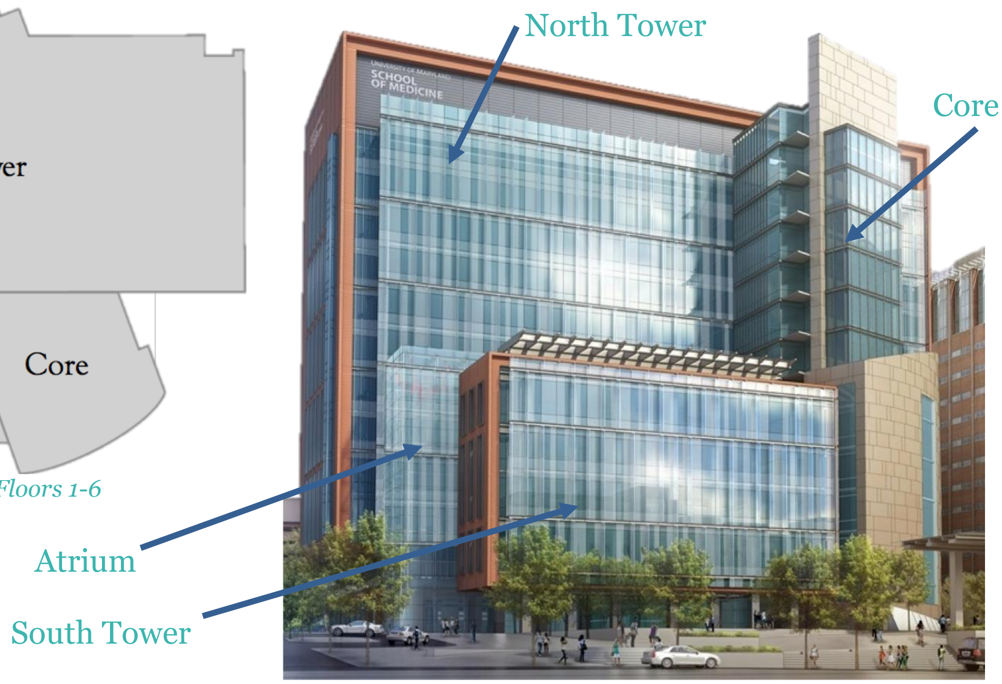


Figure 1: South view of HSFIII

Structural

HSF III has a mat foundation because of the high water table present on this site. The 44"-60" mat slab acts as a massive weight to anchor the rest of the building to the soil, allowing water to freely pass around it. The waterproof membrane that wraps around the building must be dry when applied, which makes the dewatering efforts critical for this process. This extends all the way up the foundation walls whose forms are built on site with a mix of plywood and reusable forms. There are several shear walls in this building, mostly located near shafts, elevators or stairs, which act as a stiffening agent to the building. The pour schedule of the mat slab is in eight sections and the forms are built in such a way that each joint between pours fits together like a puzzle piece.

The entire superstructure is cast in place concrete that span on average about 21 feet. The elevated slabs are primarily 8" in thickness at 5000 psi with the exception of the 10" slab within the core on all floors. Most of the stairs are made of precast or miscellaneous metal. From the foundations to the 5th floor, the placement method of the concrete will be pumped, while the higher floors will be crane and bucket due to pumping height limitations. It is preferred that many of the major pours will be conducted on a Saturday due to less traffic in the downtown area as well as more availability from the batching plant. Reusable forms will be used on almost all of the columns and shear walls. Re-shoring of the slab is a host of scaffolding to support the weight of the structure while it gains in strength over time.

There is a unique moment of steel framing at the intersection of two curtain walls in the atrium. Hollow metal steel is used to create this horizontal truss to brace the glass, specifically HSS6x4x1/4. A massive HSS6x6 mega column supports each truss in the atrium. There is also a mix of W8x10 and W18x40 steel beams around the atrium skylights on the seventh floor.

Envelope

The design of the envelope for HSF III includes 5 main elements: brick, precast, curtain wall, granite, and punched windows. The roofing system is a mixture of green roof and traditional IRMA roofing, as discussed in the next section. The brick façade located mainly on the east and west walls is intended to blend this building with the existing structures that embody UMB's campus, while the precast on the north elevation, seen in figure 3, also encases the core section of the building. Most of the south façade has curtain wall along with granite surrounding the first floor. The north elevation also has a metal panel fin extending on the bump out.

Figure 3: North Elevation of HSFIII

There is a small relationship between the brick and the precast on the north façade, but the main integration of materials is seen through the curtain-wall and precast on the south façade. Curtain wall takes advantage of the natural sunlight that comes from the south. All of the windows throughout the exterior of the building are made of a low-e insulating glass, and the punched openings will have a louver shading system where needed.

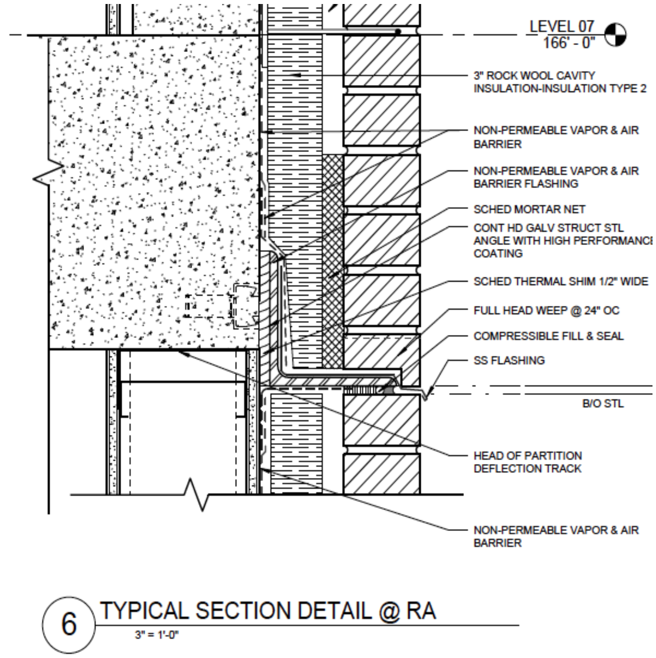


Figure 4 courtesy of the contract documents

The makeup of the brick façade includes the brick, a 2" air barrier, insulation, vapor barrier, sheathing and 6" metal stud backup, shown in figure 4. One noticeable difference of the precast detail compared to the brick wall is its elimination of the air barrier replaced with a cementitious thermal barrier. The precast is also thicker than the brick at 6". Above the roof level, the envelope extends as a parapet forty-three feet to hide the mechanical equipment located on the roof. This is concealed with louvers encased with precast and brick.

Roof

As previously mentioned, there are two types of roofing systems on this building. The main type is an IRMA system that consists of a hot fluid applied asphalt membrane followed by insulation, a fabric mat and ballast stone. The figure below shows an 8" thick slab of concrete that supports the roof.

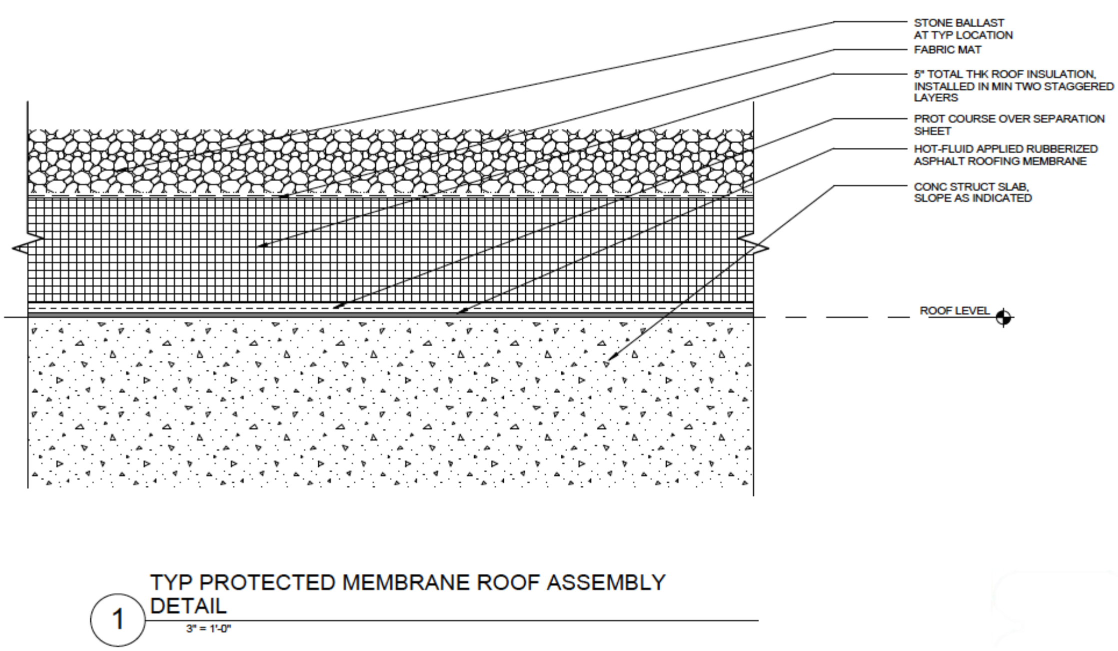


Figure 5: Typical Roof Section

The figure to the right explains the makeup of the green roof. There are multiple locations and levels that this green roof exists such as the south tower, atrium and 7th floor core roof. Its main purpose is to collect rainwater and divert it into the appropriate systems as well as provide thermal insulation. Most of the green roofs have 8" of soil separated by a fabric and a water retention panel. Underneath the retention panel, the roof follows the same makeup as the IRMA roofing system.

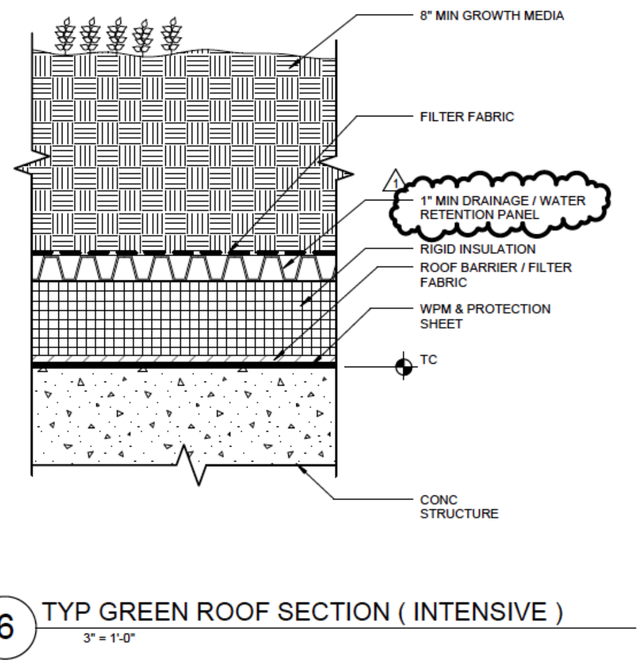


Figure 6: Green Roof Section

Mechanical

There are three major categories for the mechanical systems located in the penthouse of the building. Four air-handling units service the lab spaces with a 100% DOAS system at 64000 CFM. Two air-handling units service the vivarium with the same type of DOAS system that the labs have at 63000 CFM. Finally, the last two air-handling units service the offices space in a mixed air system with 35% outside air at 38000 CFM. All of these systems have airside economizer controls, reheat coils, chilled beams and VAV units. For the vivarium space, the source of energy is a humidification steam generator that also services the booster humidifiers. The existing chilled water system is not sufficient for the capacity of the new building, but the new building will tie into that system as for redundancy and as an emergency loop. The four chilled water systems are electrical driven, water cooled, and variable flow. They service the air-handling units. Due to the program of a lab space, there are several other systems that are involved in the mechanical space. For example, a process cooling water system is used for the water-cooled equipment in the lab spaces in addition to the cold room compressors. For the reheat system, HSFIII has glycol heat exchangers and reheat coils in the fin tube radiators around the perimeter and the chilled beams. Four fiberglass cooling towers on the roof exist to service the chillers and are double cell, counter flow and induced draft.

Electrical

The main electrical room is located in the basement where it receives the dual redundant 13.2KV feeders. For construction related power requirements, a temporary switch on N Fayette will be located. Based on the design information, the anticipated load of the building is 7,447 KVA. There are four main switchgears at 100 KAIC, 5000A and 480/277 wye. Two serve as backup generators and the other two service the entire building. Each distribution panel for the lab spaces has an emergency distribution panel on the same floor. The main distribution of power throughout the building comes from two electrical rooms on each floor. They act somewhat like a shaft up the center of the building on each side that it services.

There are multiple distribution panels on each floor. These panelboards service each of the following items: receptacles, lab receptacles, equipment, lighting, and emergency power. Most of these panels are 100A with the exception of the lab power supply panelboards at 225A and 120/208 wye. For the lighting and the equipment panelboards, their voltage is 480/277 wye.

Lighting

With a high surface area of curtain wall on the south end as well as the use of skylights in the atrium space, natural light is an important feature to the project team at HSFIII. Many of the offices face the south curtain wall and can take advantage of that direct light while the open spaces in the labs are located in the north allow indirect light into the space. Recessed grid mounted fluorescent lights will be used in the open lab spaces because those spaces need a high concentration of light. A typical office space has one pendant hung fluorescent light. The conference rooms match a similar layout to the open lab spaces. Emergency lighting in the space is generally small square recessed fixtures or linear fluorescent fixture mounted on the wall.

Fire Protection

Some of the two hour rated spaces include the shafts, stairs, elevators, and the main switchgear room. Many of these types of spaces span most all the floors and are most likely to spread a fire. One hour rated partitions are for all of the electrical and mechanical rooms, the firs command center in the building, and chemical waste storage. The oil tank room is a hazardous space and requires three hour partitions around it. Within the atrium there are storefront windows that separate the atrium from the north tower. They will be serviced by a water curtain with sprinkler heads spanning no greater than 6 feet. Floors 5 and 6 are shell spaces and will have upright sprinkler heads where the ceiling is exposed all the way up to the metal deck. This is in anticipation of the future use of the space. The lab spaces are considered ordinary hazard, group 2 while the rest fall under the group 1 category, according to NFPA 13. The stairs are a mix of wet and dry standpipes, depending on the location of the stair tower in the building; there is also a dry standpipe at the loading dock. To connect to the water system in the building, the fire department can access connections both at the southwest corner and northeast side. Copper piping and fittings are located in the shielded imaging rooms because these spaces imitate requirements for an MRI suite. An 8" pipe of incoming fire service located on the southwest corner of basement includes a double check backflow preventer on the building side. Standard piping is required at pressure less than 175 psi, while high pressure piping will be used when greater than 175 psi.

Transportation

Figure 7 shows the layout of transportation in the building. There are 6 elevators located in the building and four of them serve as the main core of movement. The two north elevators are the service elevators that access all floors, and the elevator in the southwest corner of the building only stops at the lower basement and the first floor. There are also stairs scattered throughout the building that service all of the floors. There is a difference in elevation at the north entrance of the building, which requires a small set of stairs as well as a wheelchair lift.

Figure 7: Layout of Stairs and Elevators

Telecommunications

All of the data routes back to two IT rooms per floor, each one servicing either the west or east wing of the building. There are plenty of outlets and data connections within all of the office and lab spaces. With the location of the building in downtown Baltimore, the University of Maryland has an on-site security guard that monitors traffic in and out of the building during normal business hours. At all other times the building must be card accessed. There are various security cameras on both the exterior and interior of the building to enhance the safety of the students and faculty. Security closets are on each floor that house the related data and security information. Many of the service rooms in the building as well as lab spaces require card access to those rooms.

Construction Information

Project Delivery System

The main delivery system used in this project is a CM at Risk with a maximum GMP. This type of contract is held with the construction manager as well as 4 design-assist subcontractors. They include the concrete, curtain wall, mechanical and electrical contractors. Barton Malow, the construction manager, was brought on board shortly around the schematic design phase after which the design assist subcontractors soon followed. Their main purpose is to provide expertise on schedule, cost, and constructability at each design stage. They also participate in the coordination of drawings. All other subcontractors for the job are competitively bid.

The design team has a traditional fixed fee contract structure. The project is also considered fast-track construction because the demolition and excavation began before the design was completed. Below is an outline of the contract structure on the project.

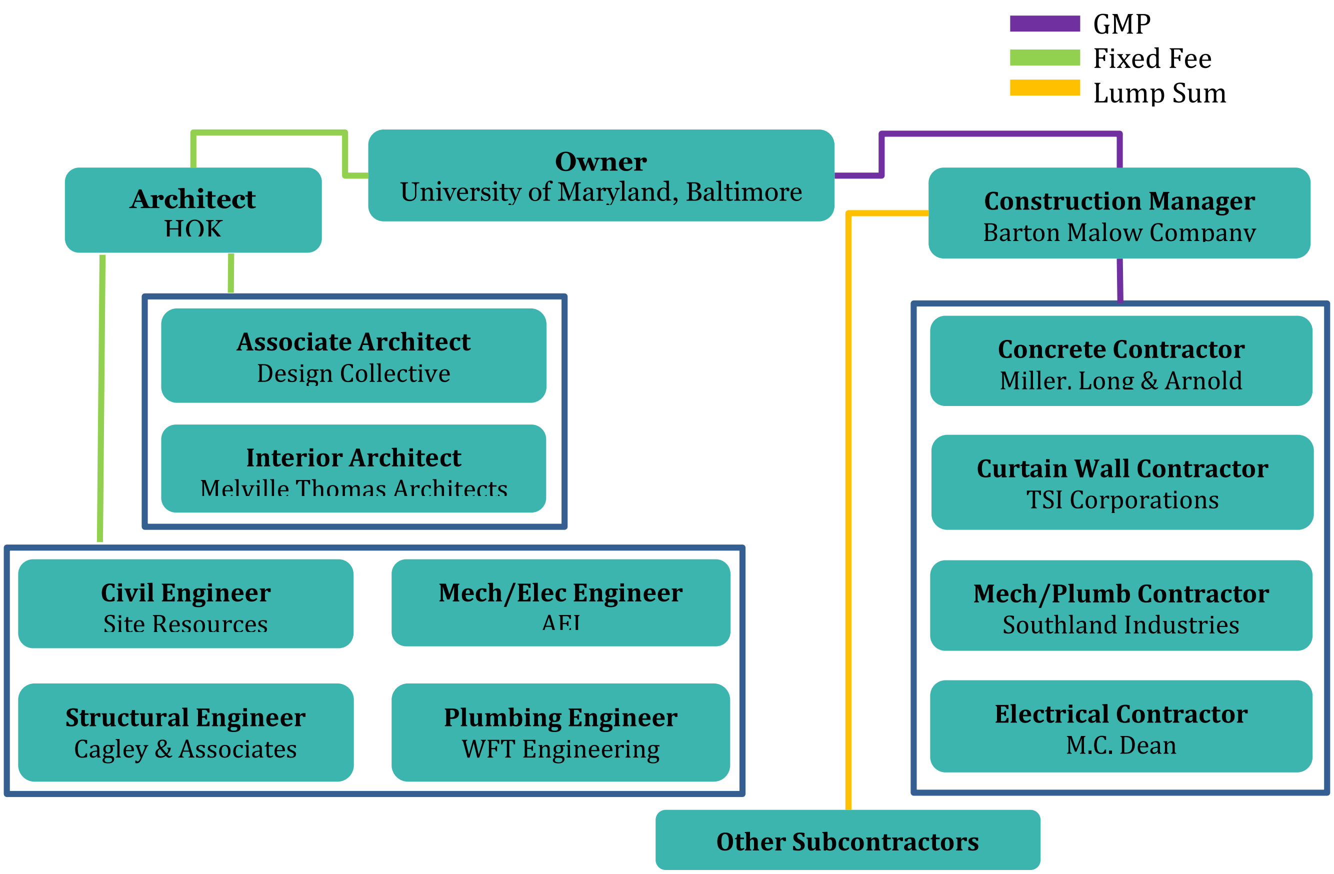


Figure 8: Contract Structure on HSFIII

Staffing Plan

One interesting feature of this project is the colocation of the design assist subcontractors with the CM. The designer representatives and owners also have work spaces available to them at the colocation, which is convenient for when they are attending day long meetings. This promotes collaboration among the various representatives within the company as well as between the contractors. The senior project manager is involved in managing the budget and has a direct relationship with the owner representatives. The second project manager is more responsible for the schedule and some project management work for subcontractors.

There are three project engineers in charge of various subcontractors as well as two superintendents. One of the superintendents oversees the entire site while the other is in charge of the MEP work. The administrative assistant as well as safety coordinator are only on site part-time.

Existing Conditions

A major area of concern is the high water table. With the site approximately one mile from the inner harbor, the dewatering effort is a crucial element to keeping this project on schedule and safe working environment. Based on the geotechnical report, the subsurface conditions are mostly poorly graded sand with silty sand and a layer of silty clay with sand. This plays a large role in what type of dewatering methods can be used. Jet wells work better for the clay layer because it pinpoints the specific location of the water while drilled wells around the perimeter can take care of most of the water before it reaches the site. Due to the tight site shown in figure 9, there is no contractor parking allowed on site. Major utility lines are located on all of the streets surrounding the building site, which means all work must be monitored closely for both marked and potentially unmarked utility lines.

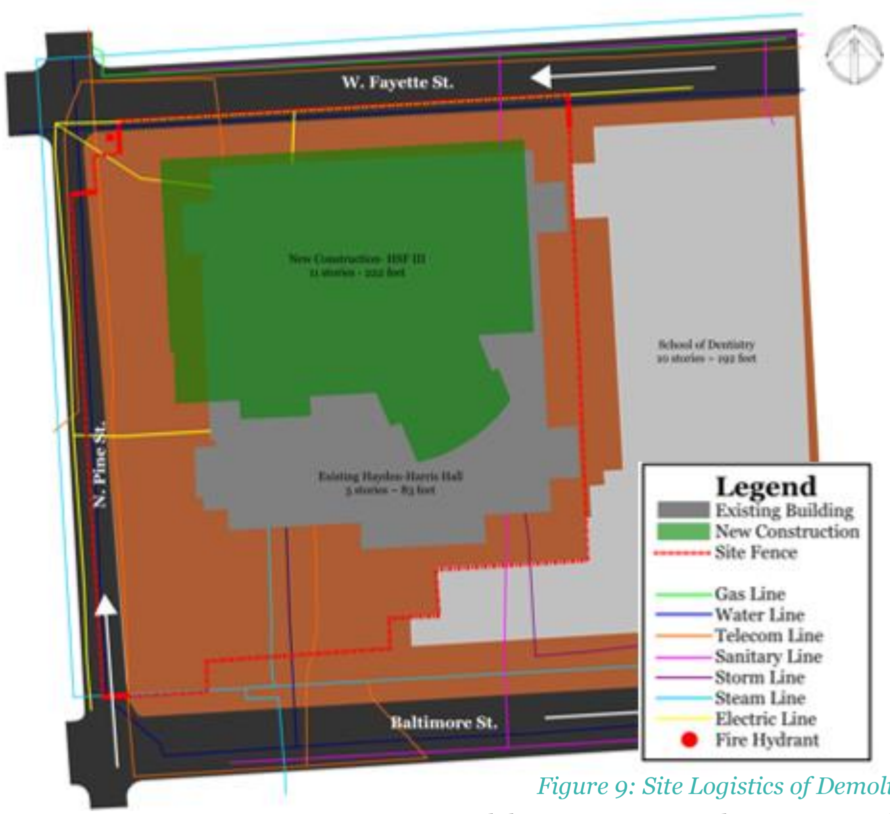


Figure 9: Site Logistics of Demolition

Demolition of the existing building includes the removal of the caissons at least 2 feet past the plan bottom of the new building. Most of the pedestrian traffic is from the University of Maryland and only half of Pine Street was taken for construction to allow access to between W. Fayette and Baltimore St. There is a covered walkway on the south end of the School of Dentistry building to help with the safety of pedestrians at that entrance. Entrances to the site help promote flow within the site for the trucks to easily enter and exit.

Major Equipment

The tower crane is located in the atrium space and fits within the hole of two designated skylights for the space. It is planning on staying in action throughout the erection of the exterior envelope. Once the building reaches the eighth floor, it will have to be raised another eighty feet to reach its final height. During peak times of crane usage, there is potential for two shifts to work with the crane. This plays out when the concrete is using the crane on the upper floors while the precast and curtain wall have started on multiple faces of the building. One material hoist will be located on the west side of the building, obstructing about a third of the façade. There will be a temporary loading dock beside it to allow for material deliveries.

Site Logistics Plan

The first phase of this project includes the demolition of the existing structure, seen in the site logistics plans in appendix A.1. There needs to be as much open space as possible to allow for this movement in dismantling the existing building. With a tight site, the construction management trailer is located 2 blocks off site in the University of Maryland's administrative building. This is a colocation room that is shared with the design assist subcontractors. The subcontractors also have trailers located on site for material and foreman use. The wheel wash stations are crucial to the erosion and sediment control portion of this project that is in an urbanized area. Finally, covered walkways allow for safe access to both entrances to the School of Dentistry that are adjacent to the project boundaries.

The excavation and foundation phase of this project causes more congestion on site due to the large mat foundation and basement. There are two ramp designations because the ramp needs to move at some point in the project to build the lagging behind the ramp area. As the excavation reaches plan bottom, the bottom of the hole can be appropriately used as material storage for the concrete foundation. There needs to be ample space above the hole to accommodate, potentially, multiple cranes during the sequencing of the concrete placement. Port-a-johns are located inside of the building or in the excavation hole. Also, the dewatering station located in the southwest corner of the site will remain there until the building passes the 4th floor and has enough weight to keep the high water table at bay without damage to the structure. Parking is not on site and is the responsibility of the contractor to find parking. The material staging areas will also host the dumpsters because they are in line with the truck path on and off site.

The final stage involves the superstructure, skin and interiors. The main differences in this site logistics plan are the appearance of the material hoist and tower crane. There are more site trailers to account for more subcontractors on site. With more open space for layout of material, there should also be a clear path around the building for cranes and other machinery to move around to perform various tasks.

Cost Evaluation

Although the actual construction cost is $206 million, the table below distinguishes the calculated RS Means cost to the actual construction cost on the project. At $184 million, this number is attributed to the hybrid assemblies and detailed estimate of the MEP systems as well as a detailed quantity takeoff of the structural system.

Table 1: Total Cost Comparison

Actual Building Systems Cost

System	Amount	% Project
Demolition/Excavation	$ 7,616,000	3.69
Structure	$ 21,297,000	10.31
Envelope	$ 34,726,000	16.82
Mechanical/Plumbing	$ 62,903,000	30.46
Electrical	$ 32,357,000	15.67
Fire Protection	$ 1,965,000	0.95
Sitework	$ 2,672,800	1.29
Other	$ 42,956,200	20.80
General Conditions	$ 10,130,300	4.91
Total	**$ 206,493,000**	

RS Means Building Systems Cost

System	Amount	% Project
Demolition/Excavation	$ 5,750,000	3.11
Structure	$ 20,729,700	11.22
Envelope	$ 14,416,100	7.80
Mechanical/Plumbing	$ 54,860,900	29.69
Electrical	$ 22,357,600	12.10
Fire Protection	$ 1,621,400	0.88
Sitework	$ 2,672,800.00	1.45
Other	$ 47,171,200	25.53
General Conditions	$ 15,175,500	8.21
Total	**$ 184,755,200**	

For the detailed structural estimate, every beam, column and shear wall was taken off from the drawings in Bluebeam and input into an original excel file. The slabs are generally repetitive in HSFIII, not including the basement and first floor. A detailed quantity takeoff of the reinforcing in the second floor slab was calculated and then extrapolated from the upper basement to the roof based on the percentage of SF compared to floor 2. The multiple elevations of level 1 called for a multiplier of 1.05 to make up for the added rebar on that floor. The miscellaneous steel in the building is mainly located in shafts, specifically elevator shafts. There is also steel on the atrium roof and a horizontal truss at the joining of the two curtain walls in the atrium that does not have a slab for reinforcement. Appendix A.2 includes the takeoff information as well as overall estimate information.

With a lab and research building, there are multiple mechanical assemblies that RS Means does not cover. Despite this limitation, cost data was acquired from the subcontractors to aid in the understanding of the breakout of the MEP trades and to act as a comparison to the assemblies estimate. For piping, ductwork, wiring and other elements that ran through the entire building, a $/SF value from the contractor was used against the square foot estimate found from a quantity takeoff of the concrete slabs. This also applies to lighting fixtures to accommodate the volume of LED fixtures that are not represented in RS Means. Large equipment from the other systems was determined using the detailed RS Means cost data. This helps account for all of the special systems that come along with this type of building. Overall, all estimates are lower than the actual estimate. This may be partially represented in the lack of temporary facilities quantities in the RS Means estimates because the real MEP estimates include a line item for each subcontractor's contribution to temporary facilities. Also, there is a large volume of miscellaneous smaller equipment not found in RS Means that is in the actual building. Finally, there is no markup, bonding, insurance, escalation, allowances or general conditions within the RS Means estimate that all contribute to the actual building estimate.

The general conditions estimate for the project is considerably higher than the actual estimate. Two drivers to this is the inclusion of temporary facilities and the tower crane in this estimate. The tower crane rental in the actual estimate is divided up by the subcontractors and their frequency of use. Also, the temporary facilities are carried by the subcontractor that installed the work, i.e. the electrical subcontractor carries the pricing for temporary power. Some unknown contingencies and allowances are not included in the RS Means cost but can be seen in the actual estimate. In the staffing plan, not all of the members are full-time or through the whole project. This is specific to the BIM manager and the accountant, who are charged to the job less than 50% of their work week.

Summary Schedule

This lab and research building is a 55 month preconstruction/construction duration with 50 months of construction. There are two core and shell floors whose fit-out portion not in the scope of this project. Preconstruction for the construction manager and the design began in April 2013 and continued through July 2014. During this time, demolition of the existing building began in July 2013. The design reached 100% construction documents while the project was pouring the mat foundation. Table 2 is a summary of the durations of the main project phases and the detailed schedule can be found in appendix A.3.

Table 2: Summary Project Schedule

Health Sciences Facility III Project Summary Schedule

Phase	Begin	End	Duration (Days)
Procurement/Preconstruction	April 15, 2013	October 1, 2015	639
Demolition/Excavation	July 31, 2013	July 11, 2014	245
Substructure	July 4, 2014	September 24, 2014	59
Superstructure	August 25, 2014	February 18, 2016	389
Envelope	February 11, 2015	October 28, 2016	448
Interiors	January 22, 2015	March 7, 2017	554
Sitework	January 11, 2016	July 1, 2016	125
Building Closeout	January 18, 2017	September 29, 2017	183

An abridged version of the critical path can be seen in figure 10. First, the schematic design, site mobilization, demolition and excavation of the project all fall within the critical path. This is a common item within the critical path because the next stages of the project must wait for these steps to be fully complete before initiating sequencing. One exception to this rule is the top-down method, which is not a chosen method on this project. The design and construction of this building is considered fast- track because only 5 months of preconstruction had occurred before the notice to proceed was issued and the contractors broke ground to demolish the existing structure. The fast-track element on this project removes some stages of design from the critical path; however, it could become an issue if the designs were delayed in some way. The beginning of schematic design to the completion of excavation took about four months to complete. Also, the dewatering system needed to be operational until the structure reached at least the fourth floor to sufficiently weigh down the potential uplift and structural problems that would occur from the water infiltration. This led to a decision to provide perimeter wells around the site and jet wells in the most crucial areas with the most water present.

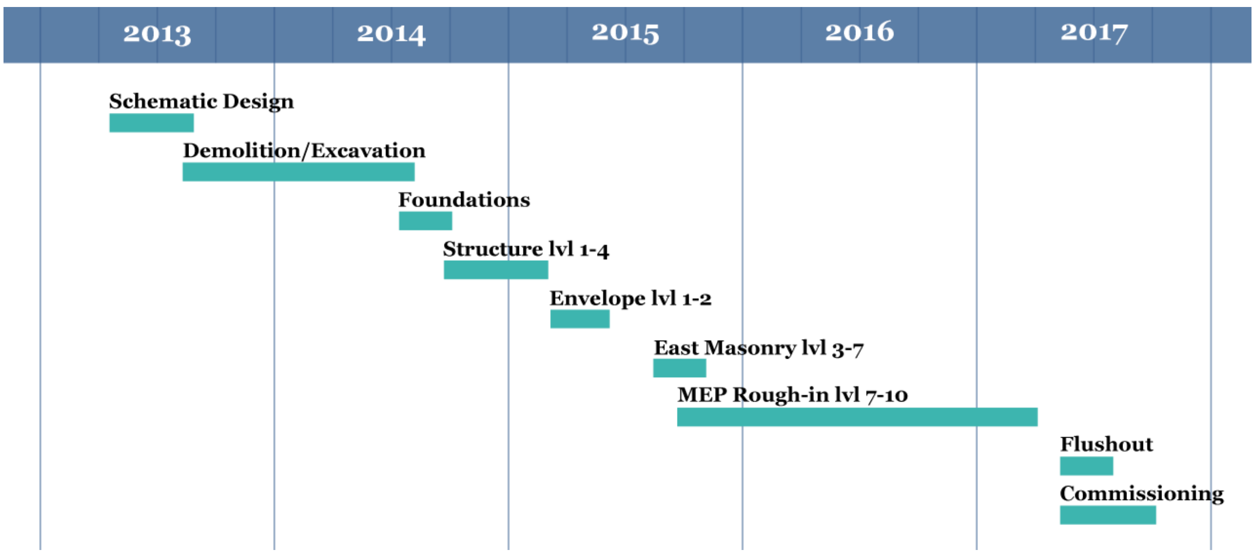


Figure 10 Critical Path of HSFIII

Succeeding the excavation stage in the critical path are the concrete pours for the foundation and structure up to the fourth floor. The entire concrete package is slated to take approximately nineteen months, from foundations to topping out. After the fourth floor, exterior work begins on the first floor. This work must wait until after the fourth floor is poured to both allow the safety nets to be erected on the fourth floor and give sufficient lead-time for the concrete contractor. This ensures that multiple trades are not in the same spaces slowing production. Several parts of the façade on the north tower fall on the critical path. Among those include the first floor granite, the second floor storefront, and the east masonry. This is because the interior finishes must wait for those floors to be dried in to begin installing temperature dependent items. In general, installation of the envelope starts on the west elevation of the north tower where the material hoist is located and works clockwise. The material hoist makes the west elevation the last to be completed, but the east elevation of masonry from floors three through seven is a critical item to close up each floor for the interior work.

The breakout of the interiors for the purpose of this exercise is by floor. Floors 1-10 are highly repeatable, not including the two core and shell floors. The detailed schedule in appendix A.3 captures the main trades and a high level view of the overall duration it will take for a trade to complete one floor. Next on the critical path is the overhead rough-in of floors seven through nine. Generally the MEP overhead rough in is linked from one floor to the next in a start to start fashion with a lag because the MEP trades can sequence themselves so that they are able to be on multiple floors at once. For example, the mechanical piping contractors can be on the fourth floor while the ductwork laborers are working in the same areas on the third and the plumbing contractors on the second, etc. Most of the interior work on the tenth floor also lies on the critical path. Other work in the mechanical spaces have enough float that don't land them on the critical path; this helps with the long lead items and major equipment that needs to be installed for the building commissioning.

Sitework does not fall on the critical path because the interior work and building commissioning have a longer duration both before and after this phase. Also, it is not tied to the interior work and has some freedom as to when it can be performed, preferably in good weather. Although not at the most ideal time, the sitework is to be completed from January 2016 to July 2016. Much of it can be moved around to accommodate weather in this schedule because the project is not complete until September of that following year. The buffer space can be taken advantage of when working on the new utility lines as well as the restoration of the adjacent streets. This type of work is ideally done as close to the end of the project as possible to avoid any damages from construction. Due to the large size of this project, ample time is left for commissioning and flushout of the building. Extra commissioning for the building, including the building envelope, helps with the LEED accreditation process. The building reaches substantial completion at the end of September 2017.

MAE Requirements

All analyses used information from graduate classes to both frame the topics and guide the direction of each analysis. For example, the overarching idea behind this thesis is to investigate what elements provide value on a project and how that can be formed and changed depending on the goals and priorities of the project team. This comes from AE 570, also known as Production Management. This class taught about lean practices and how to create the optimal amount of production based on the resources of the project or team. With this in mind, each analysis looked at how to provide the best value to the project. It also formed the strategies and working patterns throughout the creation of this thesis.

CE 543, better known as Prestressed Concrete helped identify opportunities for a structural breadth and the content used in this class proved to be greatly effective to the steps in design of the alternative shoring systems. Finally, AE 572 on Project Delivery Methods aided greatly in the understanding of the contract structure of this project. Since there are multiple types of contracts on this project as well as a fast-track element, this class helped understand how to identify the different contracts and how that plays into the whole of the project.

Analysis 1: Shoring System

Problem Identification

Over the summer, the excavation phase of the project ran into issues with excessive water in the hole, delaying the project and creating cost over-run in remedial efforts to further dewater the site. This analysis will investigate multiple shoring options to decide on the optimal support of excavation methods for this project. Included in this analysis is a structural breadth that designs the alternative shoring systems.

Background Research

During the excavation phase of HSF III, problems arose with the high water table in the last few feet of excavation to plan bottom. The current pile and lagging shoring method allowed water and mud to ooze from the walls and seep up from the ground. This was problematic to the project because the soil needed adequate bearing to pour the mud mat and the waterproofing required a dry surface during application. The mud that was coming through the walls was a great concern because it caused the shafts between the piles to slowly empty, creating voids behind the lagging. At first, the cranes and other heavy machinery were directed to stay at least ten feet away from the walls as a safety precaution. There were a few occasions where sinkholes formed on the north side between the lagging and the construction fence. This was solved by pouring concrete in the hole to prevent more mud and water from entering the hole. The concrete in these sinkholes was concerning because of the utility lines located in that same general area below grade, making it potentially more difficult to perform the work at a later date.

The dewatering system kept the water table down significantly, but not enough for the bottom of the hole to stay dry. The original documents did not call for any gravel under or surrounding the mat slab and foundation walls, but after several attempts to keep the site dry, gravel was used in some areas of the site to keep the water at bay for the mud mat to be poured. This issue caused delays in the completion of excavation as well as the beginning of the foundation work. Because of this, the first analysis will focus on exploring other shoring methods that could increase the ability to contain the water.

Analysis Goals

The three different shoring systems will be reviewed based on the following parameters:

- Availability
- Constructability
- Cost
- Schedule

While cost and schedule are quantitative values, availability and constructability are qualitative. These will be weighted less than the cost and schedule to install different systems. The following list includes the steps that will be taken to perform this analysis.

1. Research the cost and installation time of the pile and lagging system. Estimate an approximate value for the dewatering system.
2. Research the two alternative systems and evaluate the advantages/disadvantages of both.
3. Design the alternative systems.
4. Compare the three systems based on criteria above.
5. Recommend the most appropriate system for the project.

A design of the alternative systems will help spec a specific product for this analysis and make a more informative decision on the best system to use for this project.

Execution

Each of the three systems will be assessed thoroughly with the four criteria above in mind. With a base understanding of the installation method mentioned, the alternative systems will be designed to satisfy the structural breadth and a there will be a final decision from the research done in this report.

Investigation of Current System

Soldier pile and lagging is arguably the most common type of shoring system used in construction today. Its advantages and disadvantages are shown in figure 11. This is mainly due to the ease of installation, cost effectiveness, and availability of the product. First, the H piles are driven into the ground at specific intervals. In the case of HSFIII, the spacing between piles is 8 feet. Next, the contractor excavates the soil in small lifts of about five feet and installs the lagging boards until the excavation has reached plan bottom.

Advantages	Disadvantages
• Versatile to adjustments in the field	• Difficult to use with high water tables
• Fast to Construct	• Poor backfilling can lead to settlement
• Cheaper installation compared to other systems	• Not as stiff as other shoring methods
• Does not require advanced construction techniques	

Figure 11: Pile and Lagging Advantages and Disadvantages

With the depth of excavation at 32 feet for HSFIII, two lifts tiebacks are used at an interval of 8 feet to help with the static loads induced on the support of excavation. Tieback design will determine the angle to install the tendon, number of tendons, length of tendon, and bond length. A hole is drilled to place the tendon followed by grout to anchor the tendon in the wall. Tiebacks can be designed as temporary or permanent anchors to the foundation wall design. It is important to consider the location of utilities when determining the location of tendons because it could potentially be a major cost to the project if a tieback disturbs a utility line.

At HSFIII, the bottom of excavation for most of the site is at an elevation of +36 feet with a total excavation depth of 32 feet. Two areas of the foundation require a thicker mat foundation slab of 60” instead of the typical 44” slab.

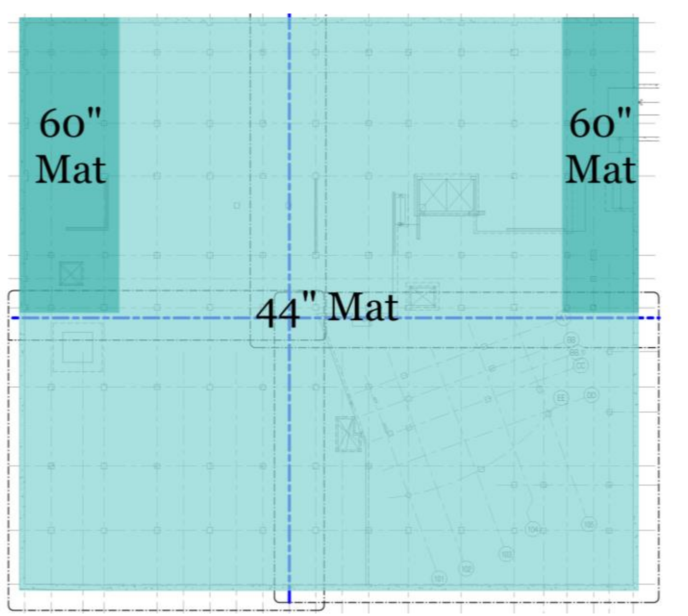


Figure 12: Basement Foundation Plan

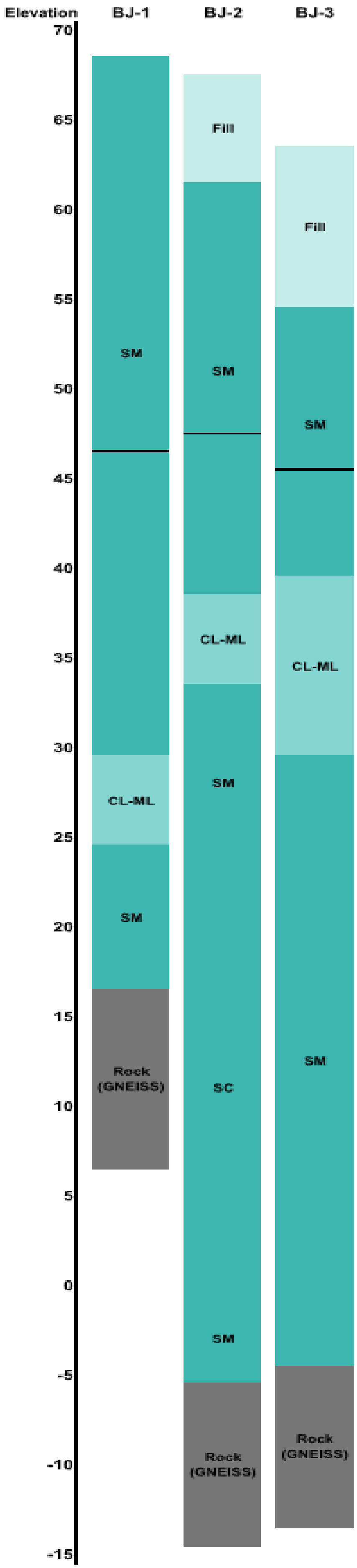


Figure 13: Boring Test Results

Figure 12 on the previous page shows the layout of the mat slab. The foundation design calls for bentonite waterproofing underneath the mat slab to protect the foundation below the water table. Once the soil reaches a bearing capacity of 5000 psf, a mud mat is poured to level out the surface for the waterproofing. Following the mud mat, the waterproofing must be installed on a dry surface to prepare for the mat slab. This is a crucial step to the installation of the foundation system. After the waterproofing, contractors install the bottom rebar, mechanical, plumbing and electrical work. Finally, the completion of the top layer indicates it is time to pour the concrete for the mat slab. It is critical that water does not delay or inhibit this process.

Soil Analysis

Because HSFIII included a complete demolition of the existing building on site, there was limited access for placement of the soil borings. Three boring tests were conducted and analyzed in the geotechnical report[1], seen in figure 13 on the left. The elevation at grade between the north and south borings only differ by five feet, which indicates a small and insignificant difference of grade on the project for the purposes of this soil analysis. Based on the results from the test borings, the majority of the soil is SM, or silty sand. There is a small CL-ML, or silty clay layer, but the bottom of excavation will encounter this layer only in the last few feet of excavation. Figure 14 below shows a comparison between the borings and how they relate to the groundwater found in the boring and the expected plan bottom of excavation.

Figure 14: Location of Boring Tests [1]

Groundwater was found between 19 and 22 feet below the surface level of the boring logs at the time of drilling. The elevation in which groundwater was encountered is consistent among each boring within two feet of one another, but these values can change throughout the project based on rainfall and other related factors. Due to the high groundwater table, the project requires a dewatering system throughout the excavation and foundation stage of the project. The site is located less than one mile from the Baltimore Inner Harbor as seen in the figure below and is less than 100 feet above sea level, indicating that groundwater would be encountered at a shallow depth during excavation.

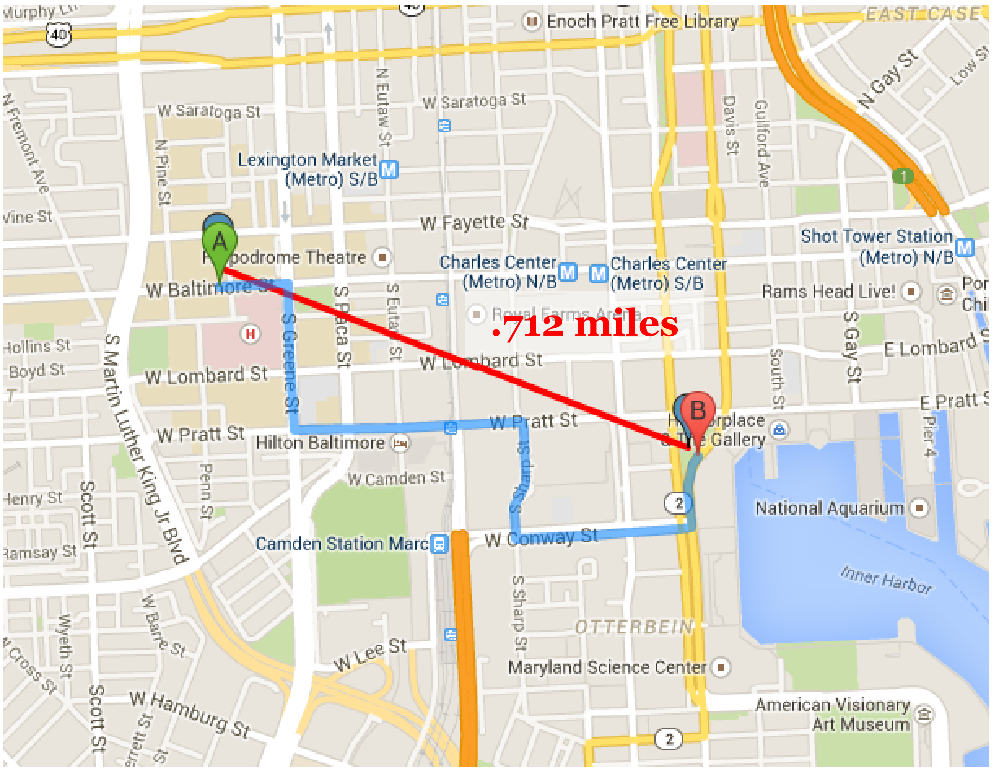


Figure 15: Distance from Site to Inner Harbor[2]

Dewatering Methods

With this knowledge of the high water table on site, a dewatering contractor was brought on board to design a dewatering system capable of handling the heavy amount of water penetrating into the site. Due to the high permeability of the soil, a perimeter deep well system was designed with 19 wells embedded to a depth of 60 feet around the outside of the pile and lagging. All wells are about 60 feet deep and feed into the same header pipe to a discharge station on the southeast corner of the site where the water is filtered and sifted from the soil. Each well is expected to pump about 660 gallons per minute to successfully keep the anticipated water out of the hole.

Challenges with Excavation

As the project progressed, the excavation continued without delay until the contractor reached the last few feet of excavation. Around elevation +39 feet, the perimeter wells could not successfully keep the water out of the hole. Heavy rain complicated the investigation of the source of the dewatering problem, but it was not the main cause for delay. Wet soil seeped through the lagging boards on the north face of the site, causing voids in the shafts between the two lagging boards and increasing the risk of a cave-in. A sinkhole was discovered on the north end of the site, which led to enhanced monitoring of the shafts and seepage of soil.

In an effort to control the excessive water, many other types of well systems were used on the project. Battered wells were drilled from inside of the hole about halfway down the excavation on the northwest corner to address the heaviest area of water penetration. Also, jetted wells were installed in the same corner below the mat slab once the excavation reached plan bottom to help the soil achieve the proper bearing capacity for the mud mat. The contractor installed a French drain on the northeast corner of the site to avoid the same dewatering issues on the northwest corner. Most of the site was also excavated an additional foot and backfilled with gravel to help control the water.

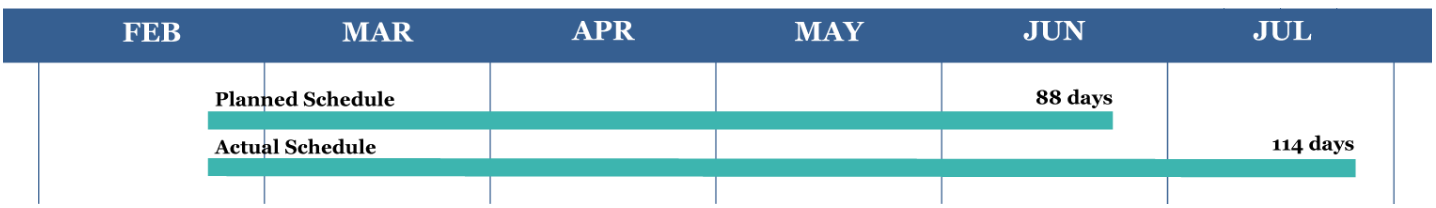


Figure 16: Pile and Lagging Planned vs Actual Duration

Figure 16 above is a comparison of the planned versus actual schedule of the excavation. As seen in the image, the project was delayed 26 days from excessive water on site that caused a variable amount of issues. Not only did the water reduce productivity of removing soil from the site, cost also accrued from the additional gravel and wells required to aid the dewatering problem as well as labor to investigate the issue. This added roughly $650,000 to the base shoring price on the project.

Shoring	$1,480,000
Dewatering Issues	$650,000
New Total	**$2,130,000**

Based on the original price for the shoring system and the delay from dewatering the site, the total cost for the shoring system is $2,130,000. This is a 44% increase from the original contract price. Two alternative systems will be examined based on the criteria previously mentioned to determine the optimal solution for this project. For consistency in the values among the various systems, excavation of the soil is not included. Also, the original dewatering system price of $600,000 is not included because it is assumed that this perimeter well system must stay in place for any shoring system to act as a secondary line of defense against the penetration of water into the hole.

Investigation of Alternative Systems

Based on the given information for the current shoring system on the project, this analysis will investigate sheet piles and a slurry wall system as alternatives mainly due to their common applications in places with high water tables.

Sheet Piles

Traditional sheet piles, shown in the figure below, are manufactured in a Z or U configuration from a variety of materials like aluminum, treated timber, vinyl, fiberglass reinforced polymer, and steel. Among these material choices for sheet piles, the most common material used is steel. While steel may have a higher corrosion and generally weighs more than other materials, they are more cost-effective for the same strength requirements than the other options. The ends of each sheet act as a tongue and groove that interlock multiple sheets together and come in various lengths and strengths. Maximum manufacturing lengths can be upwards of 100 feet depending on the manufacturer. Using the sheet pile design for HSFIII shown later in this report, this shoring method only requires sheet piles between 50 and 60 feet. They can also be used in conjunction with anchors and tiebacks to reduce the overall length of the pile and increase the strength of the system.

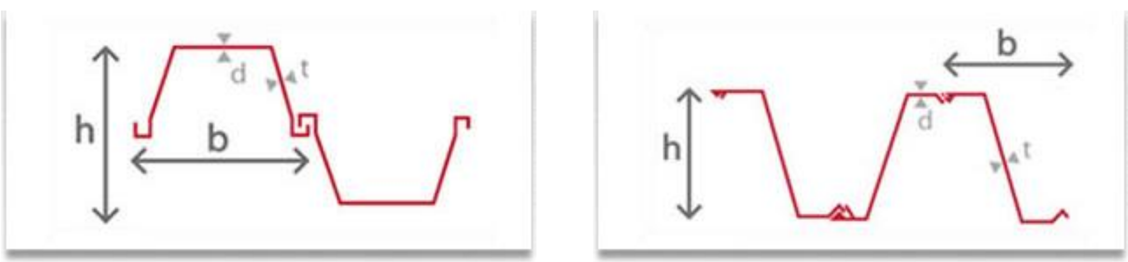


Figure 17: Z and U Sheet Pile Configuration[3]

Typically sheet piles are used as retaining structures in water or to control chemical seepage. This is often seen in the construction of bridges or dams. There are several advantages and disadvantages to using sheet piles as a shoring system for building construction as defined in figure 18. Although HSFIII would use these sheet piles in a permanent application, there are many types of coatings that prevent corrosion to the steel over time. Also, the vibration impact on other buildings is something to consider here in the urban setting of downtown Baltimore.

Advantages	Disadvantages
• High resistance to driving stress	• Difficult to use in permanent application
• Quick installation	• Soil type greatly affects the cost and schedule
• Long service life when properly protected	• Installation method could disturb neighboring buildings
• Can be reused on multiple projects	

Figure 18: Sheet Pile Advantages and Disadvantages

Two main methods to drive sheet piles into the soil is either through impact or vibration. Impact driving uses a machine that performs a series of hammer blows on the sheet piles to successfully dig into the ground. The type of soil determines the most effective equipment needed to drive the piles. For cohesive soils, diesel or drop hammers have fewer strikes per minute to allow for the pressure from the hammer to dissipate in the soil between blows. Generally the hammer is raised to a certain height and freely dropped onto the pile to drive it into the ground. One important thing to consider is the stress induced on the top of the pile from the hammer. A pile cap is commonly used to help reduce this stress, but the hammer force or soil resistance can increase the stress on the top of the pile and potentially damage it. Some tips to consider when driving piles into the ground include:

- Drive with ball end leading to prevent damage to the pile
- Drive pile in stages to help reduce deflection
- Alternate sheets to prevent driving them out of interlock
- Keep sheets plumb

Vibration driving uses counter-rotating eccentric weights with hydraulic motors that translate the vibrations into the pile. They are best used in sandy soil and also have the ability to extract piles if used for temporary shoring. Clamped to the pile, the hammer is set to a specific frequency based on the type of soil uses this frequency to drive the pile into place.

Slurry Wall

A slurry wall, also known as a diaphragm wall, is a non-structural vertical wall that uses a slurry trench installation system. The purpose of this method is to reduce the flow rate of groundwater on site. A variety of mixtures such as soil bentonite, soil-cement-bentonite and cement bentonite are common to this system. A specified narrow trench is excavated while one mixture mentioned above is pumped into the hole to keep the integrity of the soil wall. These mixtures, also called bentonite slurry or just slurry, keep the trench stable from collapsing. They enter the trench in a semi-fluid mix and harden to various strengths depending on the degree of cement present in the mix, seen in the figure below.

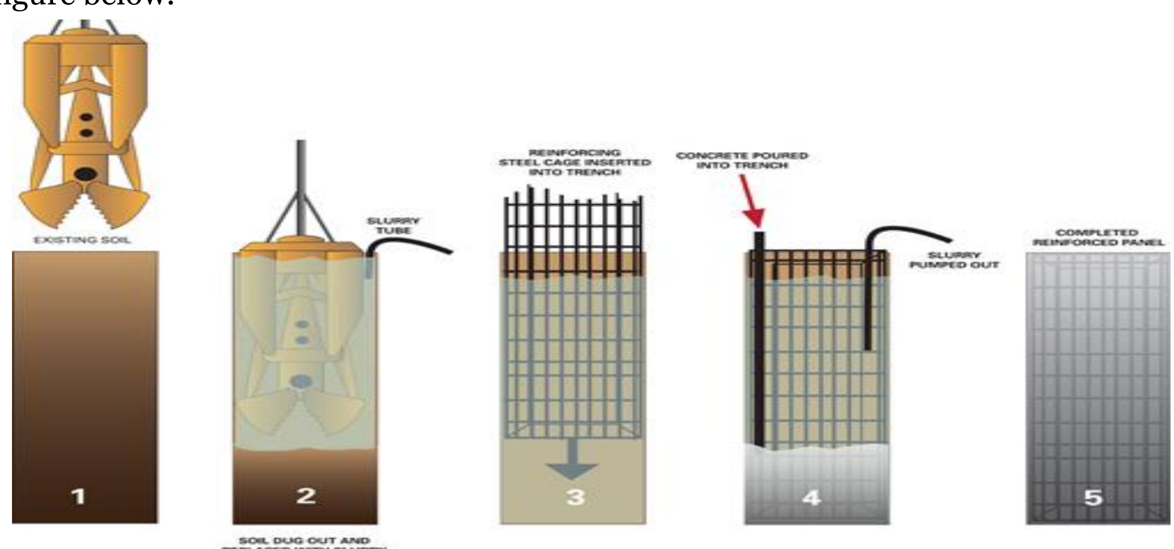


Figure 19: Slurry Wall Sequence[4]

Typically the mixture is prepared on site if there is room for the slurry plant or nearby to the project if the site does not have adequate on-site space. The soil-cement-bentonite mix has the highest strength and stability among the three options. Bentonite is important to this mixture because it absorbs a considerable amount of water and increases the viscosity of the mixture to reduce the amount of water flowing through the wall.

Advantages	Disadvantages
• Good for applications with high water table	• More expensive
• High stiffness	• Requires more working space than other systems
• Does not need backfill	• Longer installation time

Figure 20: Slurry Wall Advantages and Disadvantages

One of the major disadvantages to a slurry wall system is the high mobilization costs, seen in figure 20, making this system one of the most expensive to use. Equipment required to install a slurry wall include a slurry mix plant, pumping equipment to place the slurry in the trench, and an excavator to remove soil from a narrow trench. A clamshell bucket is a smart equipment choice for excavation in a tight site or deep foundation. Other excavators with extended booms work well when there is more room on site to follow the line of excavation. Stop end pipes allow for the trenches to be excavated and poured in sections.

Structural Breadth: Design of Shoring Systems

The purpose of this breadth is to design both a sheet pile and a slurry wall for more accurate cost and schedule information. They both share the same loading properties and can use the same data to determine total depth of wall and maximum shear and moment. The slurry wall requires more design for reinforcement and thickness of the wall. With SM soil and recommendations from the geotechnical report, the following assumptions concerning soil properties that can be made are shown in table 3.

Table 3: Geotechnical Information and Assumptions

Soil Property	**Amount**	**Unit**
Water Table	20	ft
Angle of Friction, ϕ	35	Degrees (°)
Moist Unit Weight, γ	125	pcf
Saturated Unit Weight, γ_{SAT}	145	pcf
\`Construction surcharge, q	250	psf
Allowable bearing, q_a	5000	psi
Soil Type	SM	--

This information given above helps fill in other constants required for the completion of a retaining wall design, shown below.

$$\gamma' = \gamma_{SAT} - \gamma_w = 125\text{-}62.4 = 82.6 \text{ pcf}$$

$$Ka = \tan^2\left(45 - \frac{\phi}{2}\right) = \tan^2\left(45 - \frac{35}{2}\right) = .271$$

$$Kp = \tan^2\left(45 + \frac{\phi}{2}\right)$$

$$= \tan^2\left(45 + \frac{35}{2}\right)$$

$$= 3.69$$

The figure on the right shows the distribution of forces on the wall. The water table shown at 20 feet greatly affects the loading on the lower part of the wall above the foundation grade. The rectangular loads 1 and 3 are from the construction surcharge on the top of the wall while the triangular loads 2, 4, 5, and 6 are from the soil or water. Load 6 is where the wall moves from active pressure to passive pressure. With the given information from the depth of excavation, L_1 and L_2 are known while the L_3 and H must be calculated. Below is a list of the resulting forces from the loads described in the image.

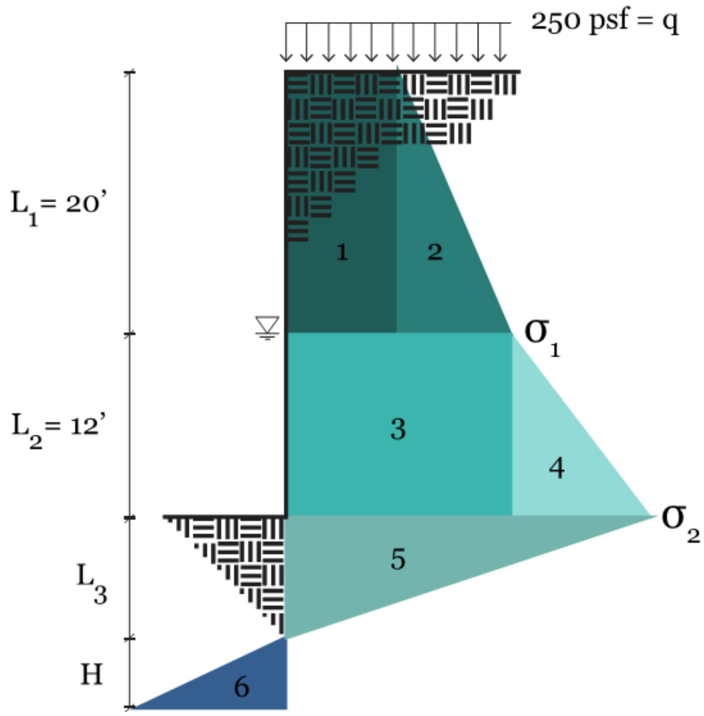


Figure 21: Retaining Wall Load Diagram

Active Forces

$$P_1 = k_a q L_1$$
$$= .271(250)(20) = \mathbf{1355}\ \boldsymbol{lbs}$$

$$P_2 = \frac{1}{2} k_a \gamma L_1^2$$
$$= .5(.271)(125)(20)^2 = \mathbf{6775}\ \boldsymbol{lbs}$$

$$P_3 = k_a(q + \gamma L_1)L_2$$
$$= .271\big(250 + 125(20)\big)12 = \mathbf{8943}\ \boldsymbol{lbs}$$

$$P_4 = \frac{1}{2} k_a(\gamma_{SAT} - \gamma_W)L_2^2 + \frac{1}{2}\gamma_W L_2^2$$
$$= .5(.271)(145 - 62.4)(12)^2 + .5(62.4)(12)^2 = \mathbf{6105}\ \boldsymbol{lbs}$$

The forces that occur from the soil and surcharge up to the bottom of the mat slab help to determine L_3, which ends at the point where the active pressures become passive pressures.

$$L_3 = \frac{\sigma_2}{\gamma'\big(k_p - k_a\big)}$$
$$= \frac{1763}{82.6(3.69 - .271)} = \mathbf{6.24}\ \boldsymbol{ft}$$

$$P_5 = \frac{1}{2}\sigma_2 L_3$$
$$= .5(1763)(6.24) = \mathbf{5501}\ \boldsymbol{lbs}$$

Passive Forces

$$P_6 = \frac{1}{2} k_p \gamma' H^2$$
$$= .5(3.69)(82.6)H^2 = \mathbf{152}\boldsymbol{H^2}$$

Summing moments about the bottom of the retaining wall will get H, the final length needed to determine the total height of the wall. The first calculations do not include the tieback to determine whether or not a tieback is needed.

Sum of Moments (without tieback)

$$\sum M_O = P_1\left(H + L_3 + L_2 + \frac{L_1}{2}\right) + P_2\left(H + L_3 + L_2 + \frac{L_1}{3}\right) + P_3\left(H + L_3 + \frac{L_2}{2}\right) + P_4\left(H + L_3 + \frac{L_2}{3}\right) + P_5\left(H + \frac{2L_3}{3}\right)$$

$$= 1355\left(H + 6.24 + 12 + \frac{20}{2}\right) + 6775\left(H + 6.24 + 12 + \frac{20}{3}\right) + 8943\left(H + 6.24 + \frac{12}{2}\right) + 6105\left(H + 6.24 + \frac{12}{3}\right) + 5501\left(H + \frac{2(6.24)}{3}\right)$$

$$= \mathbf{401869 + 28659}\boldsymbol{H}$$

$$\sum M_R = P_6\frac{H}{3}$$

$$= 152H^2\frac{H}{3} = \mathbf{50.7}\boldsymbol{H^3}$$

$$F.S. = 1.5 \quad --\rightarrow \frac{M_o}{M_R} = 1.5 \quad --\rightarrow M_O = 1.5M_R$$

$M_O = 1.5M_R$
$401869 + 28659H = 1.5(50.7)H^3$
$-76H^3 + 28659H + 401869 = 0$
$\boldsymbol{H = 24.4\, ft}$

Total height = L1 + L2 + L3 + H
=20+12+6.24+24.4=**62.64ft**

Although it is feasible for sheet piles to be manufactured to this length, from a constructability standpoint it makes more sense to add a tieback and reduce the overall length of the member. The length of the sheet piles also affects the transportation method. With this project being located in an urban setting, it is prudent to restrict the transportation of the piles to the length of a truck bed, which is about 53 feet maximum. The following calculations include a tieback at an assumed height of 10 feet from the surface.

Sum of Moments (with tieback)

$$\sum F_X = P_1 + P_2 + P_3 + P_4 + P_5 - P_T - P_6$$
$$= 1355 + 6775 + 8943 + 6105 + 5501 - P_T - 152H^2$$
$$= 28659 - P_T - 152H^2$$
$$P_T = 28659 - 152H^2$$

$$M_T = P_T(H + L_3 + L_2 + L_1 - 10')$$
$$= P_T(H + 6.24 + 12 + 20 - 10)$$
$$= P_T(H + 28.24)$$

$$M_O = M_R - M_T$$
$$401869 + 28659H = 76H^3 - P_T H + P_T 28.24$$
$$401869 + 28659H = 76H^3 - (28659 - 152H^2)H + (28659 - 152H^2)28.24$$
$$H = \mathbf{5.5\,ft}$$

Total height = L1 + L2 + L3 + H
=20+12+6.24+5.5=43.74ft~**44ft**

$$P_T = 28659 - 152(5.5)^2 = 24061\ lbs = \mathbf{24k/ft}$$

These calculations indicate that the length of the shoring system only needs to be a total of 44 feet. Shaving almost 20 feet off the total length is a significant amount to the weight of the system, and decreasing crane size requirements as well as reducing installation time frames.

Using a structural software tool called Risa to find the maximum shear and moment, a factor of 1.64 per LRFD standards was multiplied to get the ultimate shear and moment on the member. Risa software results can be found in appendix B.1.

$$M_a = 145.6ft \cdot k$$
$$M_u = 1.64M_a$$
$$M_u = 1.64(145.6) = \mathbf{239ft \cdot k}$$

$$V_a = 14.2k$$
$$V_u = 1.64V_a$$
$$V_u = 1.64(14.2) = \mathbf{23.3k}$$

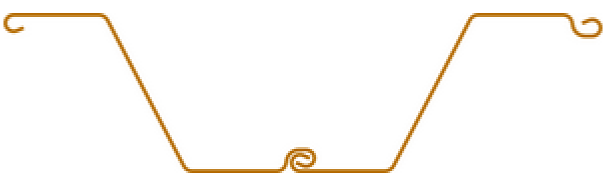
Sheet Pile Design Choice

Using the maximum bending moment, a suitable sheet pile was picked, seen below in figure 22. With grade 50 steel, the bending moment capacity is 259.6 ft·k and exceeds the ultimate moment of 239 ft·k. The perimeter of the shoring is 948 feet with 4 corners which means it only requires 4 bends in the system. More product data for this sheet pile can be found in appendix B.2.

Solution Estimate

SKZ 38

Skyline Steel



Z-Sheet Pile	
name	SKZ 38
units	400
height	44.00 ft
weight per ft	88.95 lb/ft
total weight	782.747 short tons

Summary

wall height	44.00 ft
target wall length	948.00 ft
actual wall length	950.00 ft
panel quantity	400
pieces to install	400
WADIT® sealant	17,600.00 ft
choose WADIT® sealant	
wall area	41,800.00 ft^2
panel weight	88.95 lb/ft
weight per ft^2	37.45 lb/ft^2
section modulus	62.32 in^3/ft
moment of inertia	560.85 in^4/ft
total weight	782.747 short tons

Figure 22: Sheet Pile Specifications[5]

Slurry Wall Design

A design for the slurry wall can use the maximum shear and moment value from the previous calculations, shown below. Checks for bearing, overturning and sliding are all taken care of in previous calculations.

Assumptions	Value	Notes
h	24"	thickness
d_o	20"	
b	12"	Unit strip method
$f'c$	5000 psi	
Clear cover	3"	

$M_u = 1.64(145.6) = \mathbf{239 ft \cdot k}$ $\quad V_u = 1.64(14.2) = \mathbf{23.3k}$

Calculate Shear on Wall

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

$\phi V_n = .9 * 2\sqrt{5000}(12)(20)$

$\phi V_n = \mathbf{30.5k} > 23.3k \quad ok$✓

Calculate Moment on Wall

$a = \frac{A_s * f_y}{.85 f'c\, b}$

$a = \frac{A_s * 60}{.85(5)(12)} = 1.18 A_s$

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

$239 = .9(A_s)(60)(20 - \frac{1.18 A_s}{2})$

$A_s = 2.90\ in^2$

Use (2 layers) #8 @6" -> $A_s = 3.14\ in^2$

New d = 24"-3"-1"-.5"=19.5"

Check Shear and Moment

$\phi V_n = \mathbf{29.8k} > 23.3k \quad ok$✓

$\phi M_n = .9(3.14)(60)(19.5 - \frac{1.18 * (3.14)}{2})$

$\phi M_n = 2992\ in \cdot k = \mathbf{249 ft \cdot k} > \mathbf{239 ft \cdot k} \quad ok$✓

Check Steel

$\beta = .85 - .05(f'c - 4) = .85 - .05(5 - 4) = .80$

$c = \frac{a}{\beta} = \frac{3.71}{.8} = 4.63$

$\varepsilon = \frac{.003}{c}(d - c)$

$\varepsilon = \frac{.003}{4.63}(19.5 - 4.63) = \mathbf{.0096 > .005 \dashrightarrow\ \phi = 0.9}$

Horizontal Reinforcement

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

$A_s = \rho bd = .002(12)(12) = .288$

A_s = (2 layers) #4@12”=.40in²

A_s = .40>.288 ok✓

Vertical Reinforcement

As seen above:

A_s = (2 layers) #8@6”= 3.14 in²

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

$\rho = \frac{3.14}{(12)(19.5)}$

$= .013 > .0033$ ok✔

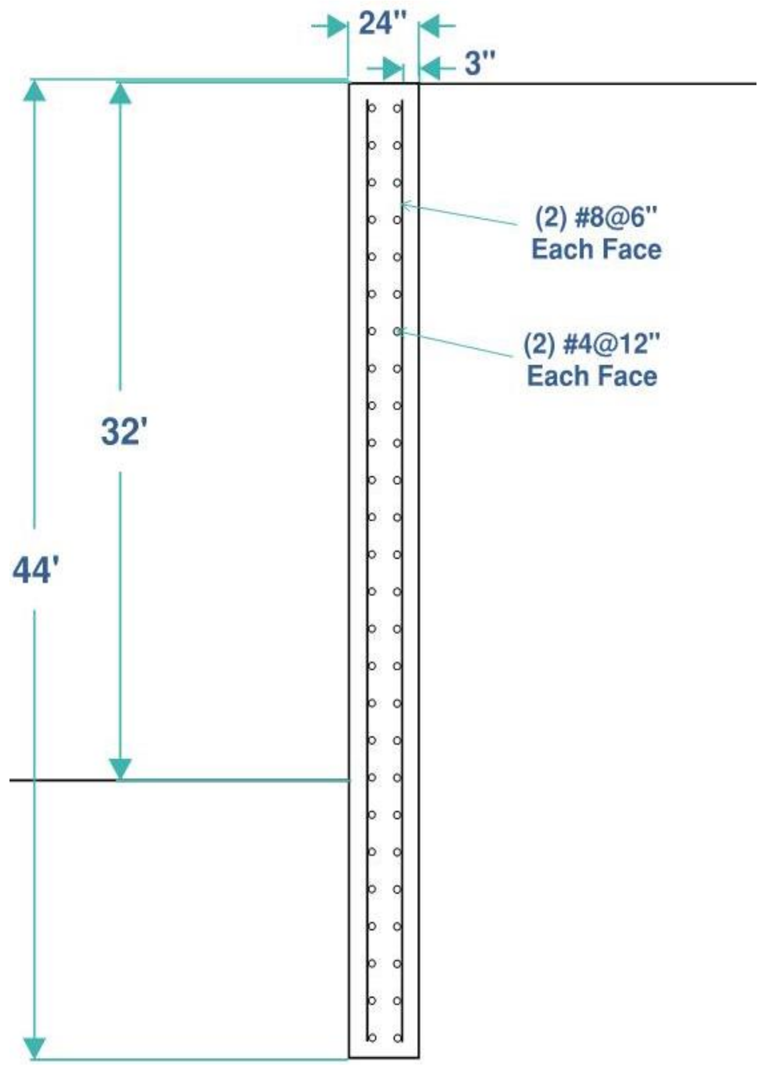


Figure 23: Slurry Wall Detail

Comparison of Three Systems

Looking at all three systems together, the most appropriate system for this application will be decided based on the cost, schedule, availability and constructability of the system.

Availability

The current shoring contractor is capable of installing a pile and lagging system as well as sheet piles, but they do not have experience in slurry walls. This means a slurry wall design would require a different installation contractor. There are at least 3 alternative contractors found with offices within an hour of the site that are capable of installing slurry walls, shown in the figure below.

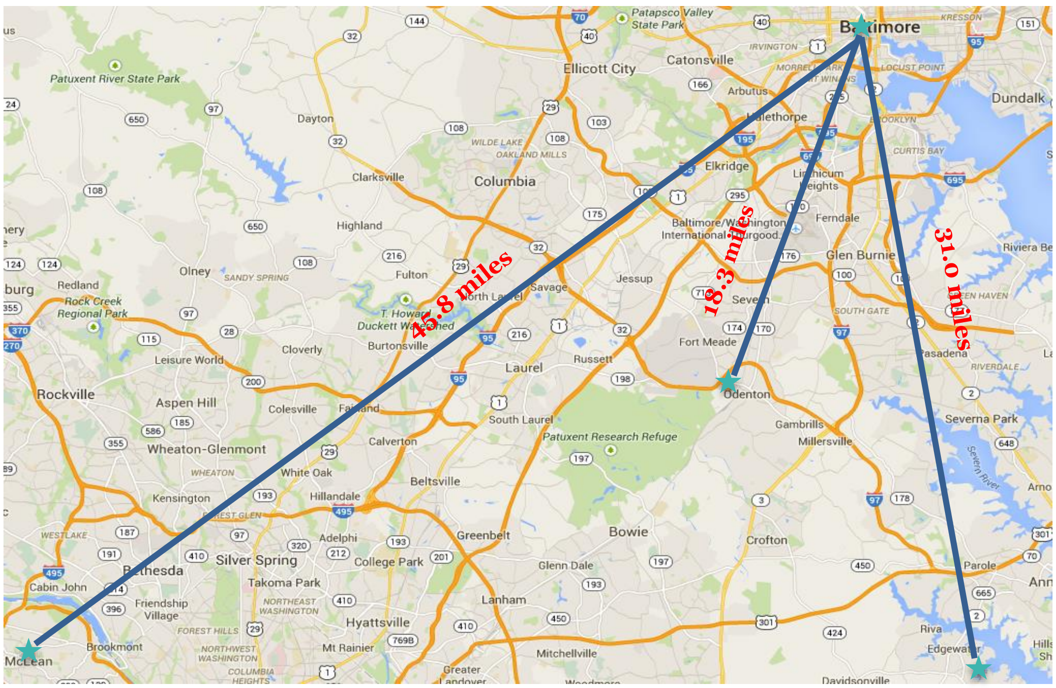


Figure 24: Alternative Shoring Contractor Locations[6]

Potential limitations for the sheet pile installation include the 8 week lead time for the specified product. Luckily, the overall depth of the pile is shorter than the length of a truck bed, which allows for the piles to be easily transported to the site. One location for the manufacturer specified is in Springfield, Virginia, just over an hour away from the job site. This means the specified product is well within driving distance to acquire and install.

Some factors to consider for the slurry wall system are the location of the slurry batch plant and the availability of trenching equipment for the slurry wall. Many projects have a place on site to mix the bentonite slurry mix with the existing soil. This allows for easy reuse of the slurry as the trenching progresses through the site. The size of the batch plant is based on the size of the slurry wall and the speed of installation. There must be enough slurry mix to keep up with the excavation on the leading end of the wall while also waiting for the concrete to be poured on the other end. For HSFIII, there is not enough room on site to keep a slurry plant during installation, so a suitable place near the site is required. This will also create price increases in transportation of materials from the batch plant to the site. Figure 25 shows the limited space on site and the lighter green square is the excavation footprint where the shoring wall surrounds. The east side of the site is inaccessible due to the grade difference from the site fence to the edge of excavation, and the south west corner is used for mobile cranes, material laydown, site trailers and traffic on site.

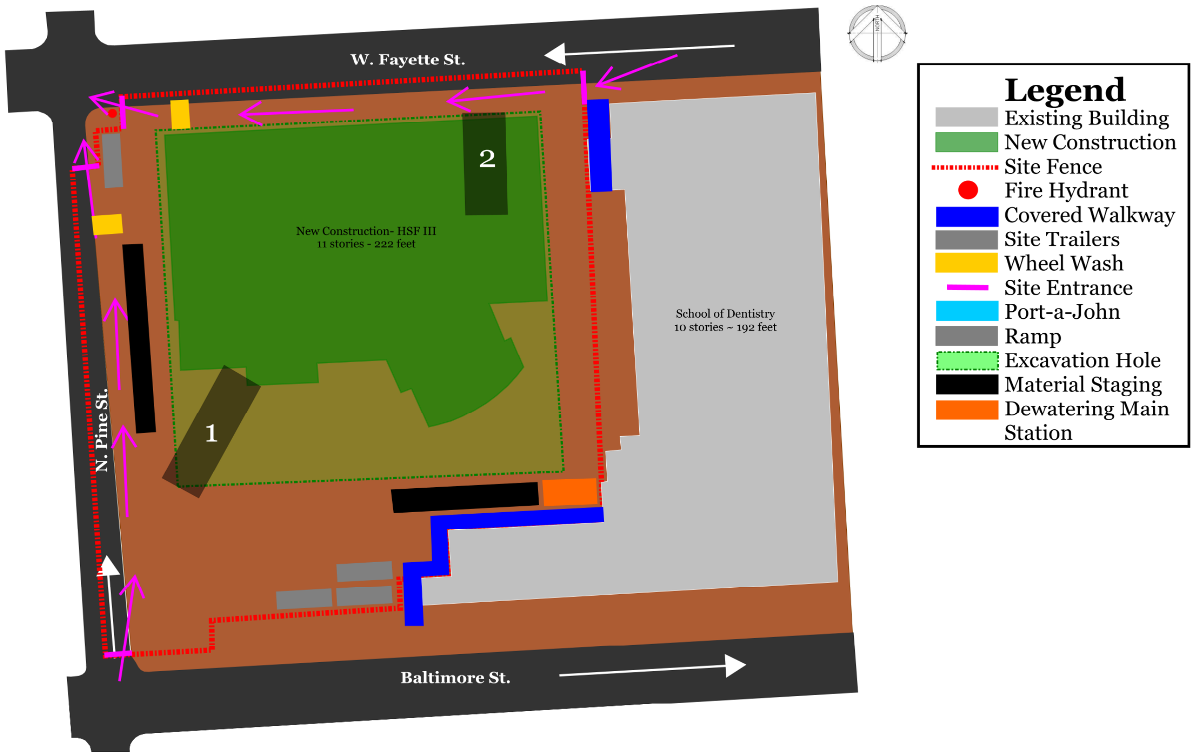


Figure 25: Site Logistics of HSFIII

Constructability

Looking at the constructability of the pile and lagging, the excess water coming into the site compromised the soil in the shafts and the integrity of the lagging boards. Many shafts were replaced with concrete or soil and boards covered with bracing to prevent a blowout. Complications arise when the soil is too hard and cause difficulties in pile driving. Also, the piles should be within driving tolerances.

Sheet pile construction is much like pile and lagging. The sheet pile driving has similar tolerances and limitations to H piles. Two main areas to look at the constructability are the interlocking of the piles and the corners. The method of driving piles into the soil can greatly affect the connection between piles. Too much friction at the interlock of the two piles can cause the two to fuse together. This sometimes happens when the pile is driven with the socket end leading. When the socket end leads, the socket becomes filled with soil and requires the ball joint to force out the extra soil, causing excessive friction on the members. Also, pile caps should be used to reduce warping of the top of the pile and to help the pile to remain straight as it is driven. Finally, the angle in which a pile is driven can affect adjacent piles, so piles driven in at an angle should be corrected immediately. At the corners, there are many types of sheet piles interlocking designs to allow for a change in direction. The final two corners where the driving starts and ends are crucial to meet and cause a tight connection to prevent water from entering the site.

Slurry walls have many more stages throughout the process that need to be monitored compared to the other two systems. First, trenching equipment needs adequate space to excavate the trench, specifically in the corners where the trench changes direction. This is problematic on the site of HSFIII. Second, the slurry mix should be monitored so it is sufficient according to the design specifications. It is important to keep the integrity of the walls to install the rebar cage, remove and slurry and place the concrete. Concrete mixes shall be tested also according to design specifications. Overall, the offsite slurry batch plant and space requirement for a slurry wall does not make this a feasible option from a constructability standpoint.

Cost

As mentioned before, the original pile and lagging price plus the delays to the project amount to $2,130,000. The list below shows the cost comparison between the three systems. The sheet pile and slurry wall cost data came from RS Means 2015. A detailed breakout of the pricing can be found in appendix B.3.

Pile and Lagging	$2,130,000
Sheet Piles	$1,640,040
Slurry Wall	$3,029,810

Without the dewatering issues, pile and lagging would be the cheapest option for HSFIII; however, the other two options are designed to better contain or keep out fluids, reducing the risk of leakage found on the site. Both the sheet piles and slurry wall include a mobilization cost, but the slurry wall mobilization is much higher and more elaborate than the sheet piles. One source found estimated a conservative mobilization and demobilization cost at 5% of the total price, which can be found in the current slurry pricing. As mentioned earlier, these prices do not include excavation of the hole, which was an entirely different contractor on this project.

For the slurry wall pricing, a range of values were investigated from different sources, but most of them only included the materials and did not include equipment, labor and mobilization. This is also true of the early production rates discovered. One source used in this report was a case study in California that happened to be about an average of all the other prices investigated. A comparison of the RS Means values for the slurry wall helps understand where this source falls in pricing. Concerning the sheet piles, RS means helped with the bulk of the pricing and other sources were used for the tiebacks as well as mobilization costs.

Schedule

Using both production information from RS Means as well as contractor pricing, the following durations helped compare the three systems, seen in figure 26.

Figure 26: Schedule Matrix

It is obvious that the slurry wall takes the most time to install because there are inherently more steps than the other system options. Slurry walls require digging the trench, placing the slurry, inserting the rebar cage, and then simultaneously pouring the concrete while pumping out the slurry. This requires more equipment such as a clam and shell bucket for excavation, a crane for the rebar cage, a pump for both the slurry and concrete, and a station for the slurry to mix while it is not being used. Compared to the other options of piles that only require pile driving equipment, this is much more extensive and takes longer to install.

If the pile and lagging was not delayed, it would also be an optimal solution, but again the sheet piles takes the gold in its efficiency and ability to keep water out in areas with a high water table. The pile and lagging is technically not complete until the excavation finishes because the lagging boards are installed as the excavators dig deeper into the hole while the sheet piles do not have this restriction, so they should be inherently faster than the pile and lagging system.

Recommendations

The table below outlines the performance of each shoring system and clearly shows that sheet piles is the recommended system to use for HSFIII. Because the pile and lagging was unable to keep the water at bay, it does not receive a check mark in the constructability category. Although there are contractors available to install the slurry wall, it is the most expensive system as well as takes significantly longer than other systems to install, making it the least optimal system to use for HSFIII. The sheet piles satisfy all of the needs of this project, making it the optimal solution.

	Pile and Lagging	**Sheet Piles**	**Slurry Wall**
Availability	✓	✓	✓
Constructability		✓	
Cost	✓	✓	
Schedule	✓	✓	

With sheet piles as the optimum choice, this system would only cost $1,640,040 to install and would take about 90 days. This is not only 24 days faster than the pile and lagging system, but would also cost about $490,000 less than the pile and lagging.

Analysis 2: Motivation and Team Performance

Problem Identification

Motivation is crucial to the overall performance and lifestyle of an individual in all facets of life. This critical industry research will investigate the drivers that motivate individuals and how this affects construction projects.

Background Research

At the PACE roundtable, the most interesting topics were related to innovative design and incentivizing team performance. The first breakout session was about innovative design. The discussion took a different direction than was originally anticipated: it was focused more on how innovation is born and the drivers behind innovation. The second breakout session discussed many types of incentives that contribute to team performance. Among those listed included organizational culture, peer pressure, recognition, personal price and potential for repeat work. Motivations to perform work differ between people, which allow for various methods to have different degrees of success on projects.

These two topics are closely related to how motivation drives performance and innovation. The research topic that sounds the most intriguing to pursue is identifying intrinsic motivators and how they relate to team performance. The construction industry is saturated with challenges and a variety of individuals from the tradesman level up through the owner. They all play a large role in the overall success of the project. Problems arise when the challenges start to negatively affect the performance on the project. This research is intended to outline the drivers of motivation on project and how that correlates to team performance.

Analysis Goals

The major goals of this research fall under two categories: discovering what motivates people to work and how it correlates to team performance. There are several variables that revolve around understanding how people are motivated to work. The audience of this research area will be primarily construction management companies. This is intended to narrow the scope and find consistencies among the research with one specific group within the construction process. A survey will be the main source of information from industry professionals to gather statistically relevant data and better understand how people are currently motivated to perform work. From there, literature review on ways to motivate people to perform work will help understand how motivation relates to team performance. These two avenues of research will help discover the following analysis goals:

1. Evaluate the main drivers of motivation.
2. Investigate the correlation between different drivers of motivation.
3. Identify if there is a relationship between motivation and team performance.
4. Evaluate the effects of negative motivation on a project.
5. Study previous research in the area of motivation and team performance.
6. Compare this research to construction practices and drivers of motivation.

Execution

As mentioned above, the two avenues of this research include literature review and a survey analysis. These are intended to help connect research done in the field of motivation to construction practices to better understand project motivators.

Literature Review

From the seminal research of *Maslow on the Hierarchy of Needs* to the new research findings of What Millennials Want from Work, these four literature reviews give an overview of motivation to understand what motivation is and how this can be applied to construction.

Maslow's Hierarchy of Needs[1]

Abraham Maslow's theory on motivation and the hierarchy of needs has been widely used in the areas of higher education and management training. He suggests five levels of needs that build on each other (seen in figure 27). This means that one level of need must be satisfied in order to advance up the pyramid of needs. He also mentions that the lowest four levels of needs must be met to be satisfied as an individual; meaning if one or more elements were missing it would cause unrest and anxiety. Below is an explanation of each level of need with a relevant example to how these needs can be satisfied.

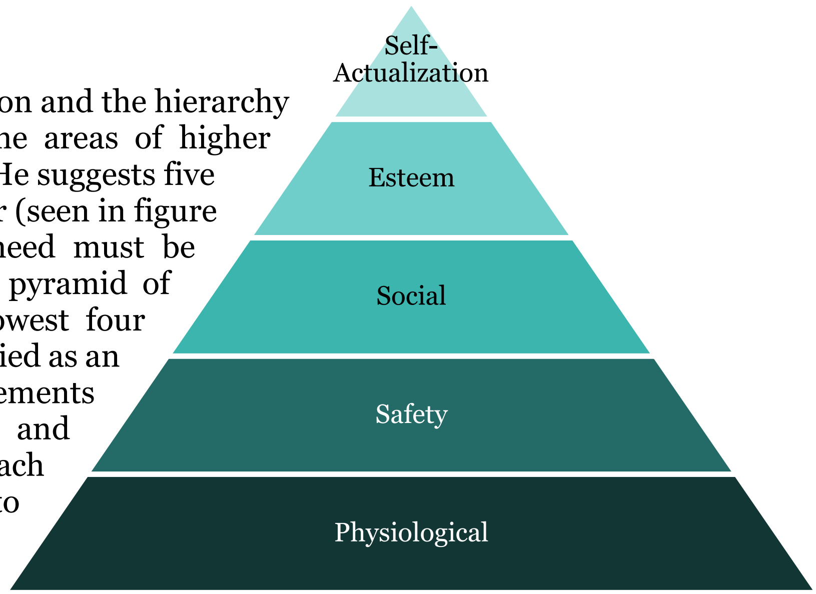


Figure 27: Maslow's Hierarchy of Needs

- *Physiological Needs* relate to basic needs of survival like food, water and shelter. These items provide nourishment to the body and protection from the elements.
- *Safety Needs* refer to areas like finances, health, freedom from fear and others. They provide security and comfort to the individual.
- *Social Needs* stem from the branches of emotions and relationships. It encompasses all types of relationships from work to intimacy and gives the person a sense of belonging.
- *Esteem Needs* focus more on the events and accomplishments of an individual that promote feelings of respect and self-achievement.
- *Self-actualization* is the highest need on the list and is not required for satisfaction; rather it represents the full potential of an individual and the process toward realizing this potential.

The highest level, self-actualization, is dependent on the person, but it is a need that signifies growth in an individual[2]. It may materialize in different ways, like an engineer desiring to invent a life changing device or musician composing a masterpiece. For Maslow, the main purpose is to climb the ladder and reach the self-actualization phase of life.

This relates to motivation because different individuals on a project will be motivated by a variety of factors depending on what level of the pyramid they identify with. The levels are not indicative in the sense that it can predict one's motivation to work to satisfy multiple needs, or have different motivations to satisfy the same need, this structure from Maslow simply helps with a basic understanding of the overall satisfaction of an individual and how it relates to motivation.

Frederick Herzberg- Theory of Motivation[3]

Similarly, Herzberg recommended a two-needs system to successfully promote satisfaction in the workplace. These two are Hygiene Factors and Motivators, as listed below:

Hygiene Factors

- Company Policy
- Supervision
- Relationship with Boss
- Work Conditions
- Salary
- Relationship with Peers

Motivators

- Achievement
- Recognition
- The work itself
- Responsibility
- Advancement
- Growth

While the facilitation of all hygiene factors does not guarantee a cohesive workplace, one or more elements left unfulfilled might cause dysfunction. These, as described by Herzberg, are more important than the motivators because they accomplish the basic physiological needs of the individual. Motivators focus more on the growth and personal development. They will nurture a positive work environment when fulfilled, but they are not primary reasons for dysfunction when unfulfilled.

Compared to Maslow's hierarchy of needs, the hygiene factors relate to the lower four levels of needs while the motivators fall under the self-actualization category. Herzberg weights the categories much differently than Maslow but the ideology behind dissatisfaction if one of more of the elements is not present remain consistent between both theories. Maslow connects motivators to general needs within society while Herzberg specifically mentions motivators within the workplace that could cause dissatisfaction.

One thing that Herzberg concludes from his research on satisfaction is the idea of job enrichment. The company should be providing opportunities and responsibilities that match the employee's full abilities for maximum satisfaction from the employee. Dissatisfaction arises when a person is performing a majority of tasks well below their ability level. This dissatisfaction can lead to a serious problem in motivation because they do not feel adequately challenged in their job.

What Millennials Want from Work, Charted Across the World[4]

A recent study conducted last summer focused on the millennial generation from age 18 to 30 and aimed to understand the goals of the millennial generation and how that is shaped by culture around the world. As the future leaders in construction, this is a pivotal study that is planned to continue annually to understand trends in different cultures. Although it is not focused on construction, this information can easily be translated to the construction millennials. This analysis will focus on the data taken from North America and what that means for motivation in construction. The two sections below are only pieces of this vast study that applies to this research on motivation.

Importance of Leadership and Drivers to Become Leaders

Understanding why millennials want to work will help a team customize the goals of the group to hopefully maximize the motivation of the group. Over 70% of millennials from North America said it was important for them to become leaders, but their reasoning compared to the world was shockingly diverse. According to figure 28, the most important driving factor toward becoming a leader is for the opportunity to influence a company or organization. While this is the highest reason from the pool of participants, other reasons still had high responses. This is potentially a good question to ask on a team to best align the goals of the project to the team or personal goals.

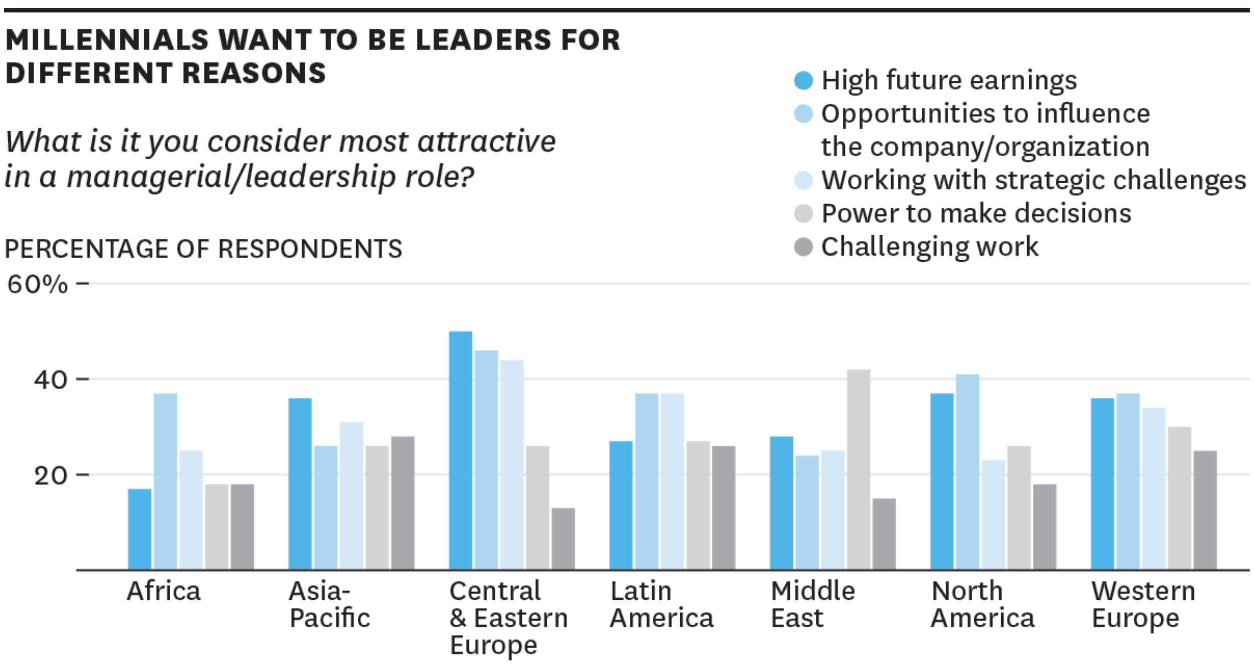


Figure 28: Reasons behind becoming a leader[4]

How Millennials Want to Be Managed

If the majority of millennials are striving to become leaders, then their idea of good management is closely related to their ability to perform and satisfaction in the job. For North America, almost 50% of participants indicated that the most important trait in a manager would be to empower their employees. Universum made a point to note that "Millennials responding to the survey seem to connect the term empowerment with the ability to make independent decisions and chart their own course (based on additional interviews conducted to probe deeper into this topic). This suggests empowerment is less about being empowered in day-to-day work life, and more about having personal freedom and autonomy." Two other ways millennials want in their managers is for them to be experts in their technical field as well as role models to the millennials.

Clear expectations in what millennials want in their leadership can drive decisions in the team goals and approach on the project. This is helpful for managers to use a leadership style that best fits the team and to increase team cohesiveness. Some of the research found in the survey isolates the millennial generation and compares its tendencies to older generations which is an important distinction to understand how the trends and drivers of motivation change with age. Construction is no exception to working in teams and having supervisors that delegate work to their employees, and are historically known to work more than a 40 hour work week; this is what makes this data extremely useful to see the future of a company and how to address the needs of the younger generation.

The Five Dysfunctions of a Team[5]

One of the participants in the open ended survey mentioned the book The Five Dysfunctions of a Team by Patrick Lencioni. When investigating the drivers behind motivation and in what way it correlates to team performance, this is a great resource that outlines five interconnected areas limiting the success of a team. These are as follows:

- *Absence of trust*—unwilling to be vulnerable within the group
- *Fear of conflict*—seeking artificial harmony over constructive passionate debate
- *Lack of commitment*—feigning buy-in for group decision creates ambiguity throughout the organization
- *Avoidance of accountability*—ducking the responsibility to call peers on counterproductive behavior which sets low standards
- *Inattention to results*—focusing on personal success, status and ego before team success[6]

Patrick makes a point to emphasize that these five reasons are not independent from one another. Rather, they build on each other and the absence of one of these characteristics causes a detrimental domino effect of the other characteristics. Figure 29 shows how these traits start from the foundation of trust all the way up to the attention to results. Much like the visual for Maslow's hierarchy of needs, this is an easy way to emphasize that these needs or elements of team cohesiveness are not independent.

Figure 29: 5 Dysfunctions of a Team

Concerning construction managers, this team dysfunction is easily relatable. One of the more obvious roadblocks in the success of a construction project is the lack of trust among the involved parties. When an owner does not trust a construction manager, there is constant tension related to keeping the project on schedule and within budget. A lack of trust easily waterfalls into conflict, causes the team commitment to falter and so forth. When this happens, morale on the team plummets and production on the project visibly reduces. Becoming aware of the importance of trust to the success of the project across all professions is crucial to the satisfaction of the project quality.

Survey Results

The survey prepared was sent to construction managers in the industry and included a mix of open ended responses and Likert scale questions. From a pool of 30 participants, the responses came from a range of experience in the industry as well as varied levels of education. Also, six of the responses came from women, representing 20% of the data. A copy of the survey and the responses can be found in appendix C.1.

Multiple Choice Questions

The likert scale questions had a list of drivers of motivations where participants ranked on a 1 to 5 scale how much they agreed with the reason. The main question asked in the survey was "to what degree does each of these items motivate you" and included the following options:

- A respectable leader
- Formal recognition
- Promotional opportunities
- Time off
- A challenging project
- Money
- A complex project
- Negative consequences
- Team reputation
- Negative feedback
- An unmotivated team leader

The subjects could rank according to the scale of:

Not at All	Very Little	Somewhat	Significantly	Very Significantly

There were a few more questions related to motivation and its connection to team performance. They are included in the correlation analyses. For clarification, the likert scale questions concerning belief in the cause means that the subject feels motivated when they can stand behind the mission of the project, and the team means the subject feels motivated by their team. With a data set of 30 individuals, a correlation analysis used the average of each question to see what drivers were negatively or positively correlated to each other. The correlation between questions can be seen in appendix C.2.

Correlation between Drivers of Motivation

The data shows the top 5 positively correlated drivers in table 4. This means that if a subject considers a complex project to be of greater significance as a driver to motivation, they are more likely to think the same thing of a challenging project. Similarly, if they think that a complex project is little to no significance on a project, they tend to think the same of a challenging project.

Table 4: Positively Correlated Drivers of Motivation

Driver #1	Driver #2	Degree of Correlation
A complex project	A challenging project	.70
When believe in the cause	The team	.58
The team	Motivated leader influences team performance	.54
Formal recognition	Promotional opportunities	.51
Promotional opportunities	Time off	.45

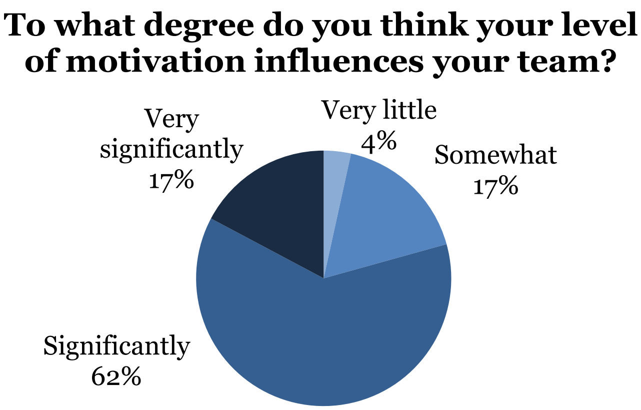
The second highest correlation from this date is between feeling motivated when the subject believes in the cause and by their team. This positive correlation would make sense if teams were put together based on not only their strengths, but their passion to work on specific projects. Thirdly, the participants responded positively toward feeling both motivated by their team as well if a motivated leader influences team performance.

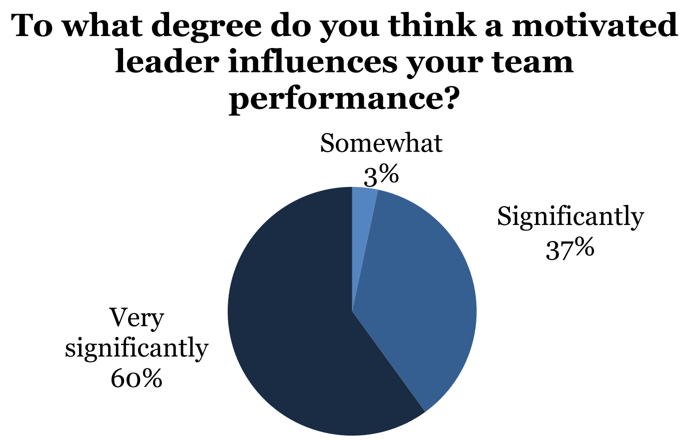
The top 5 negatively correlated drivers are shown in table 5. Money and the questions related to team performance showed up the most in the top selections from this data. This means that if the subjects said that money was less significant as a driver of motivation, then their opinion toward how much motivation relates to team performance was high. Because money is a major part of a construction project, the reasoning why money motivates could definitely be a contributor to this correlation. For example, if money motivates an individual for personal gain, than they would care less about how to motivate the team to perform better.

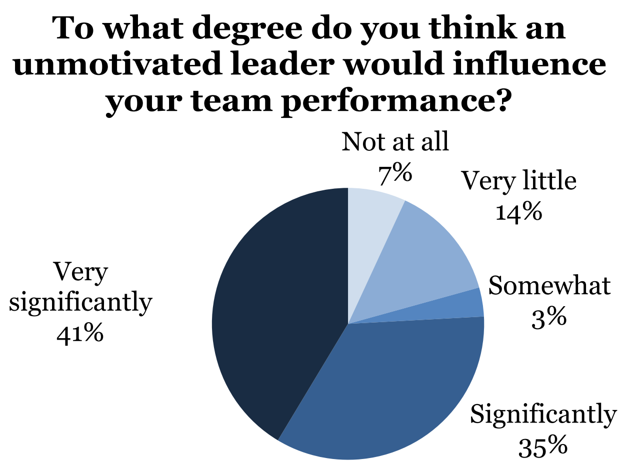
Table 5: Negatively Correlated Drivers of Motivation

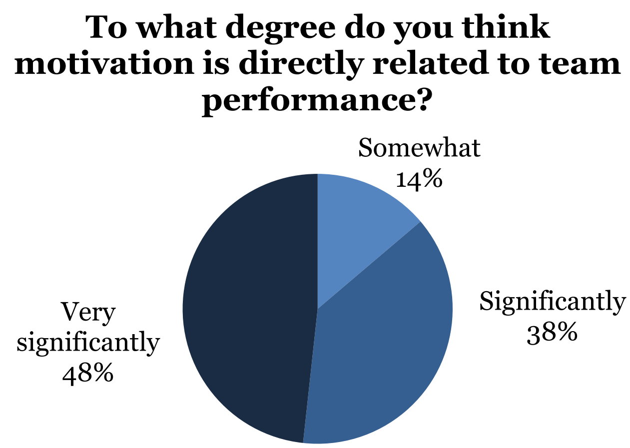
Driver #1	Driver #2	Degree of Correlation
Money	Degree motivation related to team performance	-.44
A complex project	Motivated leader influences team performance	-.43
Money	Assuming a leadership position	-.40
A complex project	Unmotivated leader influences team performance	-.39
Money	Motivated leaders influences team performance	-.38

Relationship between Motivation and Team Performance
A few questions asked about the relation between motivation and team performance. These were more qualitative questions related to participant's perception on the relationship between the two. The four main questions were as follows with their corresponding graphs below:









The only question that the participants varied in their opinion was the question on the bottom left chart related to how much an unmotivated leader would influence team performance. This is different than the other questions that had strong opinions on how much motivation and team performance correlated. The data shows the wide scope of how something negative, like lack of motivation from a leader, does not negatively affect everyone. Some people may be able to perform their jobs independent of this leadership while others may have more trouble functioning. Tasks that require multiple participants to complete might have more trouble if their leader is unmotivated. It is common on construction projects to require information and collaboration among multiple parties, and without clear direction, the end goal can be adversely affected.

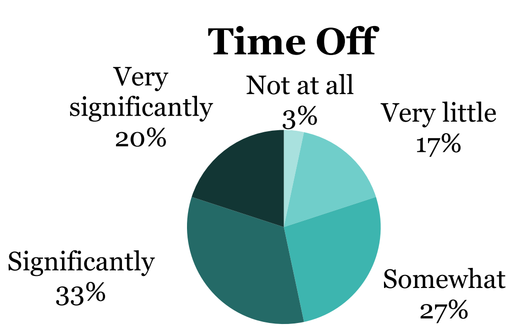
Degree of Significance for each Driver of Motivation

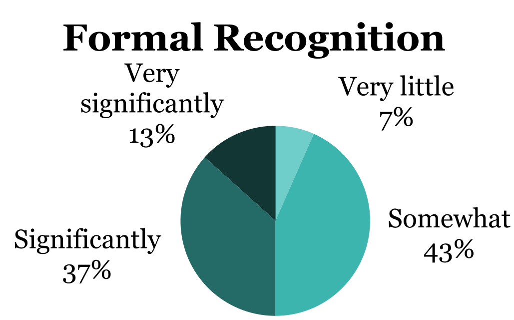
In conjunction with the correlation analysis from the drivers of motivation, the responses were ranked to see how significant or insignificant they perceived a specific driver to be. This ranking is shown below in table 6. The percent significant includes both people that responded very significant and significant while the percent insignificant includes those that responded very little to not at all on the likert scale. It is not surprising that these two tables are opposite of one another; the only factor that would change this data around is the percentage of participants who responded 'somewhat' to any question because that is not represented in this table.

Table 6: Drivers of motivation and their levels of significance

Driver	% Significant	Driver	% Insignificant
Believe in Cause	100	Unmotivated Team Member	60
Respectable Leader	97	Negative Consequences	43
A Challenging Project	83	Negative Feedback	27
Team reputation	80	Time Off	20
Assuming Leadership Position	77	Formal Recognition	7
A Complex Project	73	Promotional Opportunities	7
The Team	63	Team Reputation	7
Promotional Opportunities	60	Money	3
Money	57	A Complex Project	3
Time Off	53	The Team	3
Formal Recognition	50	Respectable Leader	0
Negative Consequences	37	A Challenging Project	0
Negative Feedback	27	Assuming Leadership Position	0
Unmotivated Team Member	10	Believe in Cause	0

Not unlike the question related to how an unmotivated leader affects team performance, respondents answered that over 60% of individuals thought an unmotivated team member motivates them very little or not at all. This is due to the teamwork heavy nature of construction. There is only a small level of autonomy



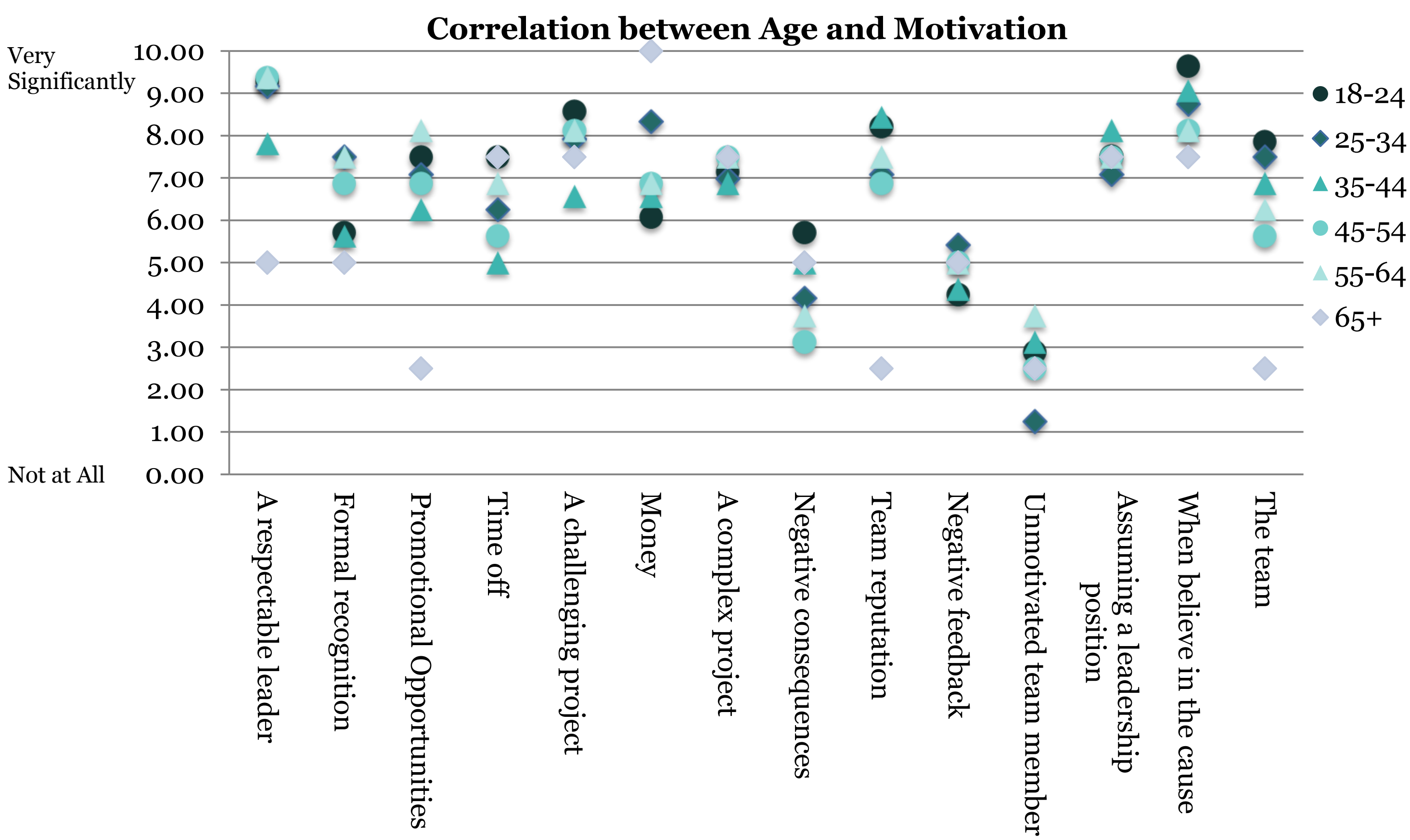


because many challenges and problems require multiple to participate in. Not surprisingly, subjects were less likely to be motivated by negative experiences like feedback and consequences. Some of the questions such as formal recognition and time off had a larger degrees of influence on the subject's motivation, seen in the graphs below.

Correlation between Age and Motivation

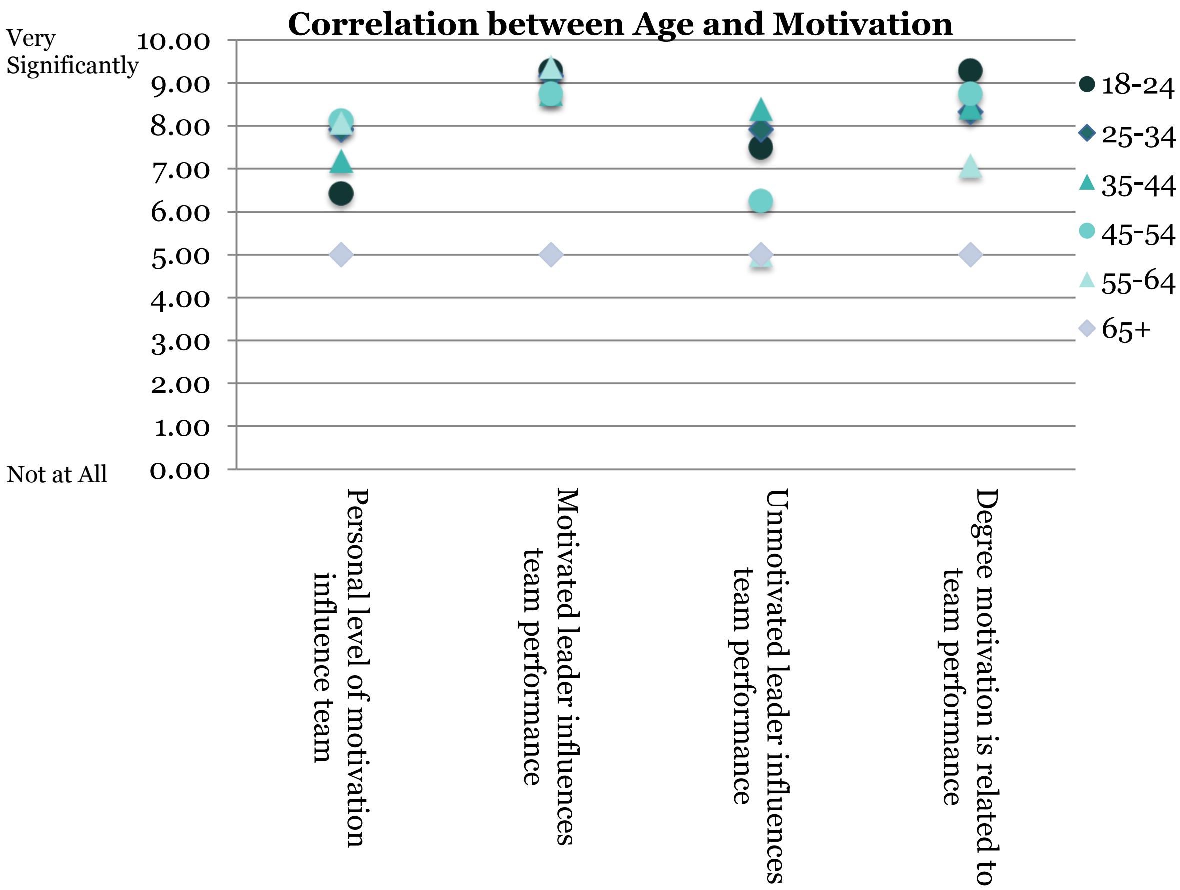
Another analysis done with this survey was to see if age affected how significantly the participant's felt motivated. The table on the right shows the number of responses per age group from the thirty participants. The age group least represented is 65+, so this data in the graph below is slightly skewed based on one response. The written responses were turned into numerical values, seen on the left of the graph. Then an average for each age group was calculated and plotted against the other age groups. The lighter colors on the chart indicate an increase in age.

Age Range	# Responses
18-24	7
25-34	6
35-44	8
45-54	4
55-64	4
65+	1



These questions above relate to the drivers of motivation. One of the more obvious drivers of motivation that changes with age is the how much the team affects personal motivation as seen in the last question on the right. This may potentially be the case because employees that are younger and with less experience rely on the team more for wisdom and direction while more seasoned members of the team have a better understanding of their roles and are more autonomous. Two drivers that seem to have little impact with age is a complex project and assuming a leadership position. The subjects generally ranked these two items in the significant (7.5) range, meaning they find these two to be significant in their personal motivation on a job, but the opinion does not seem to change with age. One of the questions that was across the board depending on age is formal recognition. This implies that not only is the driver of formal recognition not affected by age, but people have varying opinions on how much that personally motivates them.

The next questions below follow the same format as the graph above, but these questions relate to team performance. Based on this information, it looks like the degree that a motivated team leader affects team performance does not vary significantly with age, but the degree motivation is related to team performance does.



Its level of influence decreases as age or experience increases.

The survey included not only likert style questions, but a series of open ended questions as well. This was intended to better understand the reasoning why participants ranked the drivers or questions about team performance a certain way. The next section of this report gives an overview of those responses.

Open Ended Questions

The most fruitful information from this survey was the open-ended questions. They ranged from asking about personal experiences of motivated or unmotivated teams to what the most effective way to motivate the team is. This report walks through those questions and comments on their responses.

What type of project did you work on that particularly motivated you?
There was a wide interpretation of this question from naming specific types of projects to the type of people that were the most motivating. People felt most motivated by leadership, a motivated owner, a challenging project, responsibility, or a team desire to deliver a quality product. As seen in other questions, these reasons continued throughout the responses. This question prompted answers highly related to specific people on the project, including the owner, the team and the contractors; even those responses that named specific projects were more related to repeat work through a specific owner.

What type of project were you on that you did not feel motivated to work? Explain what did not work.
While some people may be motivated by strict deadlines or challenging projects, the interpretation of the word challenging greatly changes the perspective of motivation. If the participant saw challenging as an ability to use problem solving skills with the team to improve the quality of the project, then they felt more motivated. If different teams or people on the project proved to be challenging or difficult to work with, then their idea of motivation decreased. This is seen through this question where multiple subjects explained situations involving people that caused them to not feel motivated to work. Some of those responses included answers such as a specific unmotivated leader, negative relations to an owner, lack of trust between multiple parties. Many responses mentioned the importance of a leader and how their attitude greatly affects motivation. Animosity, disrespect, negative critique, and a lack of acknowledgement of work all contributed to the participants' loss of motivation.

What do you think is the most effective way to motivate your team?
The most common answer to this question was communication. Some answers layered communication with other responses, but it was clear that many individuals found this to be the most important way to motivate the team. Good communication is the backbone that makes the other reasons to motivate the team effective. Other reasons included respect, positive reinforcement, clear goals, working hard, accountability and leading by example. A few people also mentioned including the team to solve problems and being part of the solution. These forms of motivation seem to break down when there is a miscommunication somewhere in the chain.

What do you think is the least effective way to motivate your team?
These responses were similarly aligned to the question that asked about an experience where the participant did not feel motivated. Many of the same answers such as disrespect, criticism, negative feedback, unprofessional actions and a lack of

communication came up in this section. While the last question like this one prompted answers that focused more on the team and the project, this one elicited answers much more focused on specific individuals on a team such as the manager. Some of these individual focused answers include poor incentives, not recognizing unique strengths in people, poor conflict management, laziness and a negative attitude.

What makes an effective/efficient team?
This is the first question where trust was mentioned among one of the reasons behind an effective or efficient team. There was also an emphasis on work-life balance as well as identifying and building on the strengths of individual team members. Some of the same answers such as clear goals, communication and accountability also popped up in these answers. This is also an area where personal motivation was mentioned to making an effective team.

Do you think team or personal motivation affects overall job quality? Explain.
There was a resounding yes to this question. This shows the significance on how much motivation relates to job satisfaction and the overall quality of a product. One participant specifically mentioned that "Construction is a people business. Unmotivated people do a poor job and this affects quality." A few mentioned that personal motivation has a higher effect on job quality than team motivation.

How does conflict affect motivation or team performance?
Compared to the last question, this response had varied results. Although there was a heavy emphasis that conflict has a negative effect on motivation, a few participants actually felt more motivated to resolve the conflict. One response specifically clarified that constructive conflict is a good thing on a project, but when this spirals out of control it reduces team performance. Another mentioned that conflict is healthy and helps team members "get aligned when working together to develop the most effect solution. There are two parts to this question. Based on the responses here, one could argue that conflict overall slows team performance because it detracts from the normal tasks at hand, but it varies on how it affects the motivation of the team members. This might be due to how they personally feel motivated or handle different types of conflict.

Would you consider yourself client driven, cost driven, team driven, or other?
The purpose of this question was to see if there was an array of answers among construction managers and whether they prioritized different aspects of construction. The majority of the answers actually discussed the significance of having a balance of all three drivers and a few people mentioned other drivers such as time or personal reasoning.

It is evident through the participant's responses that leadership style is essential to the level of motivation of the team. Not only is it the responsibility of the construction manager to lead the efforts in conflict management between different parties on the project, but the project managers also have a responsibility to effectively manage their team and motivate them to work. A better understanding of how their team is personally motivated will help maximize their potential and build them up as an individual.

Without quantifying the degree in which motivation relates to team performance, these responses indicate that a correlation exists between the two. There were multiple instances in which participants explained a perceived lower performance on a project from a mismanagement of conflict or an inability for leaders to communicate their goals clearly.

Participants mentioned several items correlative to the literature reviews. For example, the Five Dysfunctions of a Team were saturated in the individual responses. This shows a strong correlation between the importance of building trust and communication within a team to improve the success of a team. Also, Frederick Herzberg's motivational factors of achievement, recognition, the work itself, responsibility, advancement and growth were mentioned at least once in all of the questions asked in the survey. There is definite correlation between Frederick's study and the responses from construction managers.

Recommendations

Also this research is more qualitative, some conclusions based on the survey can be drawn. First, the survey participants most strongly agreed with each other on their opinion of how much the two drivers of belief in the cause and a respectable leader affects motivation. They were much more varied on their opinion of negative motivators such as negative feedback or and unmotivated leader. Some drivers of motivation showed a correlation between age and their responses like how much the team affects personal motivation while others like assuming a leadership position did not have a correlation to age.

Based on the questions relating to team performance, there was a similar reaction among the participants of their strong agreement that a motivated leader affects team performance as well as a varied response on how much an unmotivated leader affects team performance. This shows that there is a correlation, but the extent of its correlation greatly depends on varied factors such as leadership style and satisfaction of employees.

The open ended responses greatly showed how much the literature review related to the participant's responses. Two of the most prominent responses revolved around trust and communication on a project and how much that greatly influences motivation and team performance. This directly correlates with the *5 Dysfunctions of a Team* research which states that the most important element in a team environment is trust and that trust is the foundation of success on a team.

Overall, it was found that not only is there was a correlation between motivation and team performance, but these drivers behind motivation can change with age, roles and responsibilities in life, and with the team dynamic. It is recommended to try and understand these motivators on a job to best craft the team's goals and responsibilities.

Analysis 3: Resource Leveling for Cash Flow

Problem Identification

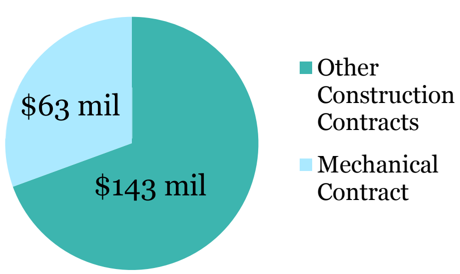
The construction portion of this project spans multiple years and with some state funding involved in the project and there are limitations concerning the amount of money awarded to the project per year. This analysis will look at the mechanical budget and investigate how much a manipulation of manpower affects the overall project schedule.

Background Research

Construction spans 50 months from July 2013 to September 2017, a lengthy project in which a project manager must manage cash flow. Because this building is a laboratory for the University of Maryland, Baltimore, state funding is heavily involved in the project budget. This limits the amount of funding awarded each year from the state. The table on the right shows this funding breakout based on the fiscal year from July to June. This limitation presents cash flow challengers with this project.

Fiscal Year	Funding (million)
FY 2014	$18
FY 2015	$59
FY 2016	$91.5
FY 2017	$53
FY 2018	$9.5
Total	$231

The total funding during this time period amounts to $231 million. With the construction budget at $206 million and the project total budget at $216 million, this means there is $15 million dollars from the state allocated elsewhere and are not within the scope of this analysis. This state funding restriction requires the project to carefully look at how cash is distributed throughout tendency of this project. To accommodate this cash flow limitation, the project team delayed some purchasing of major equipment as well as the start of interior work to push off major expenses into a fiscal year with more funding.



This analysis will look at the cash flow of the mechanical contractor due to their duration on site and contract size. An attempt to level out the manpower from the mechanical trade on the project will help create a steady flow of production and delay some funding to later fiscal years. The mechanical and plumbing contracts were awarded to the same contractor; combined, they amount to $63 million of the $206 million budget. As seen in the graph on the left, this is about 31% of the entire budget. As the largest trade contract on the project, the mechanical trade also spends the longest amount of time on site compared to other trades. Figure 30 shows the

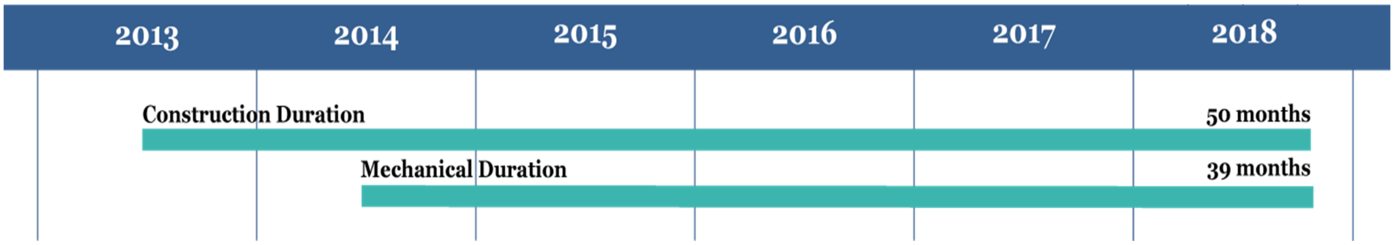


Figure 30: Construction Durations

overall time frame of the project and how long the mechanical contractor will remain on site. With this longevity on site, there is opportunity to manipulate the cash flow in the mechanical trade and make a large financial impact on the project.

Analysis Goals

With the project in a unique position of being not interested in accelerating the project schedule, the purpose of this analysis is to see how the manipulation of manpower on the project affects the mechanical schedule. Below is a list of goals for this analysis to better understand this situation.

- Research the funding on the project
- Understand the relationship between the current schedule and the monthly manpower allocation
- Review first assumptions with the mechanical contractor
- Manipulate the manpower for a more consistent number of crews across the length of the project
- Assess the schedule implications with this shift in manpower
- Assess the change in monthly billing due to this change
- Assess how this affects the critical path of the project

Ultimately, it is assumed that leveling the manpower will delay some of the floors, but hopefully it will not delay the entire project.

Execution

Based on the information from the original cost and schedule data provided by the project team, the cash flow was initially assessed to understand the mechanical billing on the project. From there, a preliminary man-loaded schedule helped illustrate how the monthly billing for labor related to the schedule of different mechanical and plumbing tasks. This original schedule was reviewed by the mechanical contractor and corrected with the most current information. The contractor corrected some outlier assumptions made in the first pass and added missing information into the schedule. Finally, this updated schedule was used to level the manpower curve and assess the impacts on both the mechanical and overall project schedules.

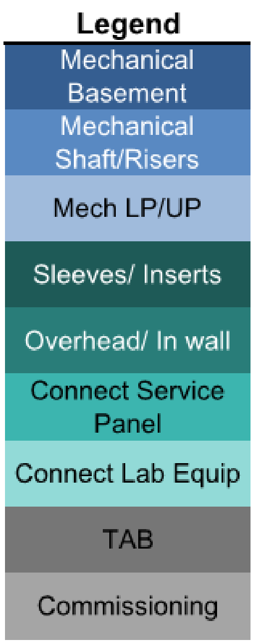


Figure 31: Schedule Legend

Study of Original Cash Flow

Using the original project schedule given at the beginning of the year, a high level mechanical schedule was created to understand the relationship between the cash flow and the schedule items. A Gantt chart style mechanical schedule for all iterations of this analysis can be found in appendix D.1 and a summary of major tasks is shown in figure 32 below. One important difference to distinguish is between repeatable tasks and non-repeatable tasks. For example, the basement and penthouse equipment is unique compared to the installation of ductwork on every floor. For the man-loaded schedule, it was important to include both types of tasks because of the crews allocated across all types of tasks in a given week. The color coordination in the schedule follows the same format as the man-loaded schedule. On the left, figure 31 shows the breakout of each major task on the project. The shades of blue tasks are unique to the space and the teal or gray indicate work that repeats throughout the building.

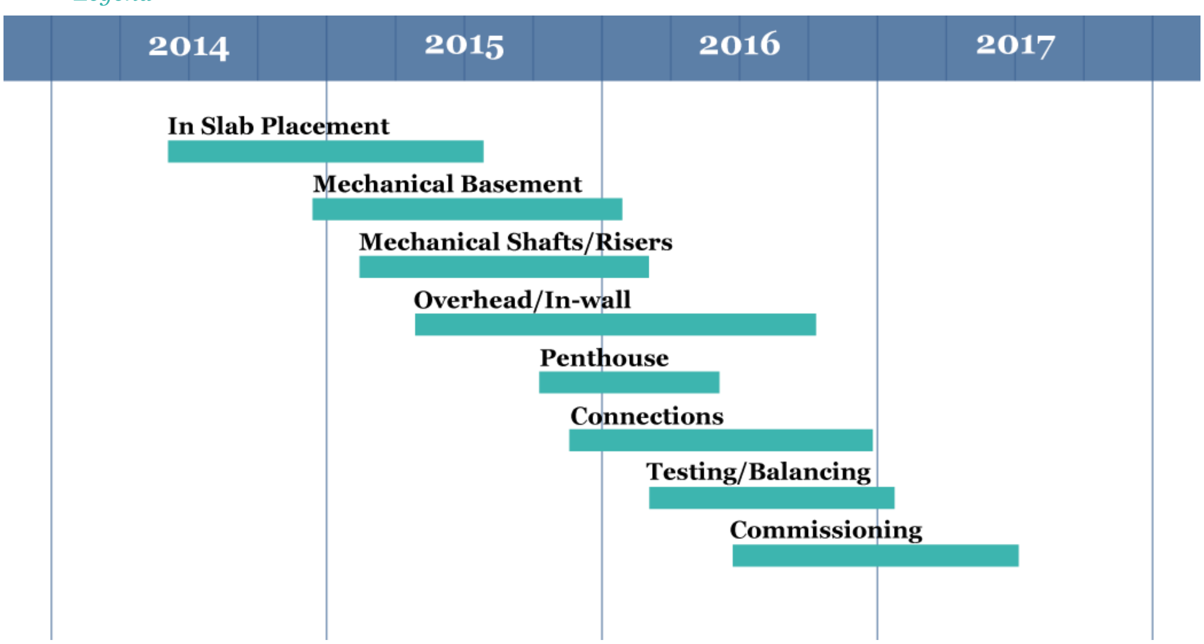
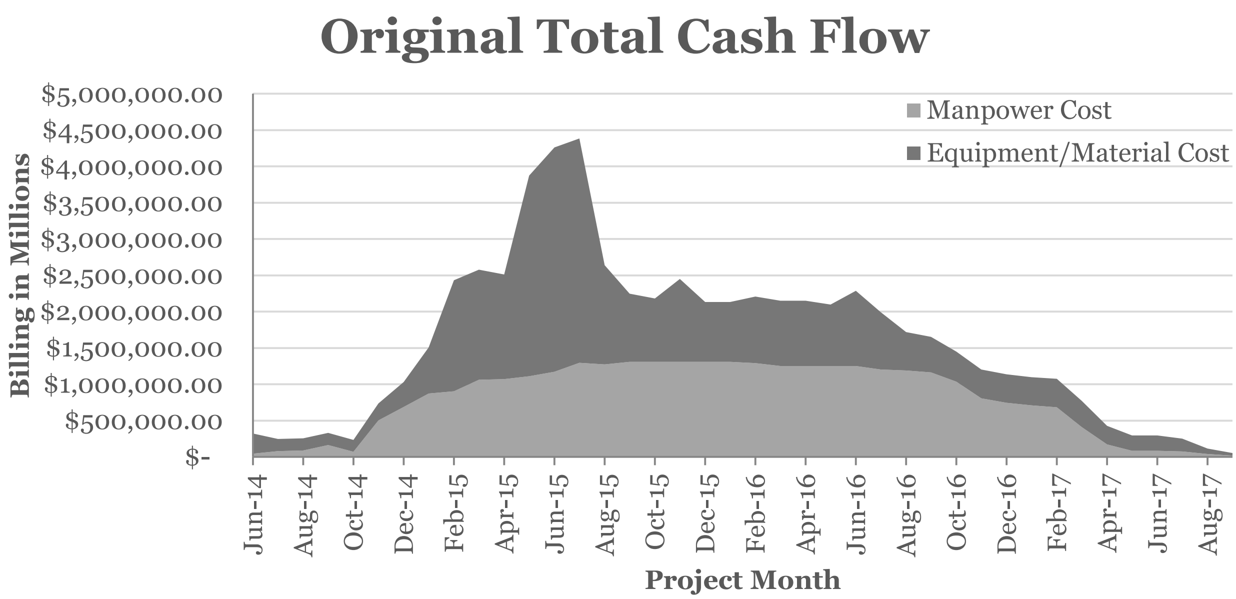


Figure 32: Mechanical Summary Schedule

Levels 5 and 6 are currently designed as core and shell spaces, so the duration for these floors is considerably shorter than the other floors. This is why the logic of starting a new floor every two months jumps from floor 4 to 7. As the mechanical work in the risers and the basement end, both floors 7 and 8 start at the same time; this is done in the same way for floors 9 and 10.

The first attempt to understand how the manpower is divided through the project closely aligned with the planned schedule of major activities. For example, it was noticed that from December 2014 to January 2015 there was the first jump in the number of crews on site. This directly correlates to the start of work in the basement. Also, the repeatable elements for the most part were able to have a consistent crew size per month, which also translated to each floor. There is a line item designated for miscellaneous crews. This pertains to work that is not indicated on the list such as utility work or performance mockups. With the projected monthly billing information, this was broken into two sections: labor and materials/equipment. This breakout identifies where the big equipment purchases occur and how that affects the monthly billing. With the labor billing as a separate item, the iterations identify how the manipulation of manpower changes the monthly billing. These findings are shown in the graph below.



The bulk of equipment purchases occur between fiscal years 2015 and 2016. This correlates to state funding of $59 million in FY2015 and $91.5 million in FY 2016. At that stage in construction, the mechanical trade is in the middle of work in the basement, mechanical shafts, first floor overhead and second floor overhead. With at least three months before the mechanical penthouse starts, this is an opportunity to purchase long lead items such as the air handling units and cooling towers located on the roof.

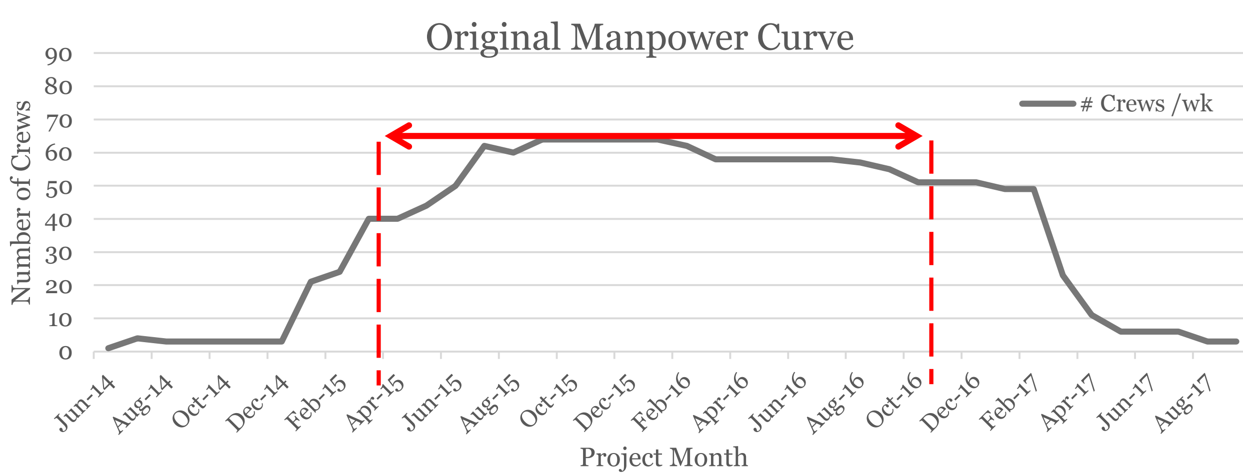
As mentioned previously, the information given on number of crews per month helped create a man-loaded schedule. A snapshot of this can be found in figure 33, while the entire schedule is located in appendix D.2. The line between the blue tasks and teal or gray tasks separate the unique work from the repeatable work on different floors. One important thing to note is that the number of crews only changes monthly to help with the simplicity of the exercise. For a smaller project size, it would be wiser to break out this work by week or even day. To read this table, 18 in the box under April-15 and the mechanical basement indicates that for the month of April 2015, there will be 18 crews working per day. Realistically, the number of crews from day to day will vary, but this average helps calculate a monthly estimate of work to bill to the owner.

Original Man-Loaded Schedule	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
Mechanical Basement	18	12	18	20	20	20	18	15												
Mechanical Shafts/Risers	19	19	19	19	19	19	19	19	19	19	19									
Mechanical Penthouse/Roof							7	7	15											
Basement																		10	10	
Level 1		10	10	10	10	10									5		10	10	10	
Level 2				10	11	10	10	10								5		10	10	10
Level 3						5	10	10	15	10						5	10	10	10	
Level 4								3	15	15	10	10						5	5	10
Level 5													10	5					6	10
Level 6														5	10					10
Level 7										10	10	10	10	10						5
Level 8	3									10	10	10	10	10						
Level 9		2										10	10	10	10	10	10			
Level 10		1										10	10	10	10	10	10			
Penthouse			3										4	4	9	9				
Roof				3									4	4	9	9				
Miscellaneous											13	8			5	10	17	10		6
Total Number of Crews	40	44	50	62	60	64	64	64	64	64	62	58	58	58	58	58	57	55	51	51
	40	44	50	62	60	64	64	64	64	64	62	58	58	58	58	58	57	55	51	51
	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Legend
Mechanical Basement
Mechanical Shaft/Risers
Mech LP/UP
Sleeves/ Inserts
Overhead/ In wall
Connect Service Panel
Connect Lab Equip
TAB
Commissioning

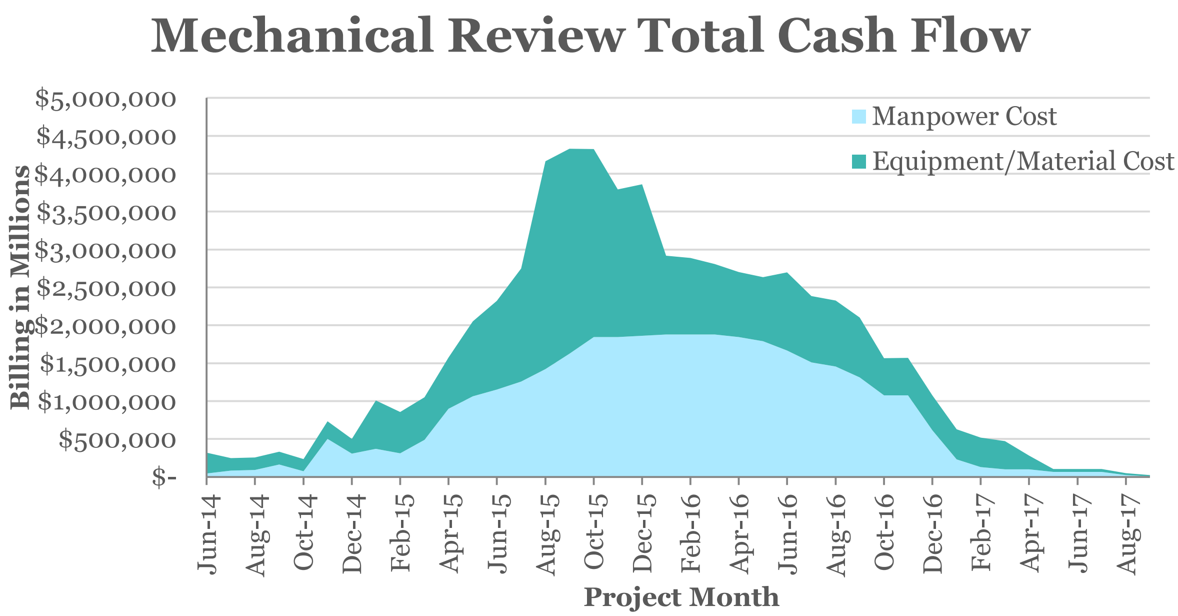
Figure 33: Snapshot of Original Man-loaded Schedule

At the bottom of the table, there is a line for the total number of crews. This is done by adding all of the crews in a given column. A crew size in this exercise is considered one laborer, whether a journeyman or apprentice. An average price per laborer is used for the monthly billing process. From there, the number of supervisors on site is dependent on the number of crews working. They are not counted for in the man-loaded schedule but they are included in the overall manpower price per month. Below is a graphical representation of the total number of crews per month. Highlighted is the focus time seen in the man-loaded schedule.

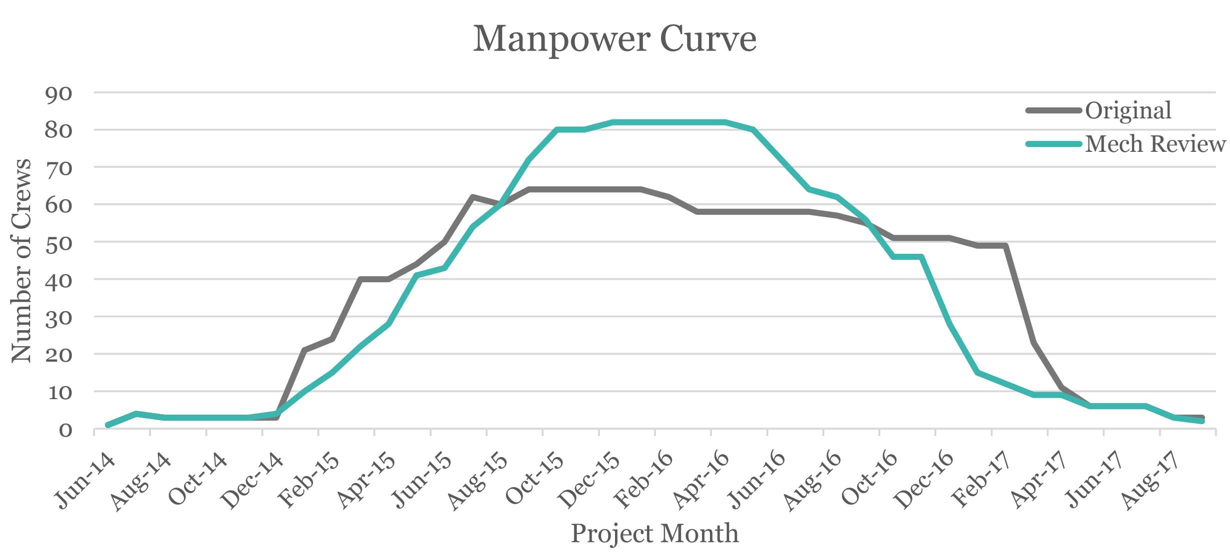


Mechanical Review of Cash Flow

This original man-loaded schedule was discussed with the mechanical contractor and the feedback given gave more accurate assumptions and billing information. After this meeting, the updated cash flow became the new baseline of information to manipulate and modify. In this new graph below, the manpower curve is noticeably larger. Also, the peak equipment billing occurs over a larger span of months rather than sharply dropping off after July 2015. The information given from the contractor also shows an increase in contract price from $63 million to $64.4 million. The reasoning behind this change in price is not necessary to understand to continue through this analysis, so a new baseline of $64.4 million was used in further modifications.



Peak manpower from the original assumptions to the schedule review grew from 64 crews to 82, seen in the teal line on the graph below. This is due to a more accurate analysis of the manpower demands on the project between the original receiving of information in August to this review in March.



The two figures below show the same schedule snapshot from April 2015 to November 2016 to emphasize minor changes made in the man-loaded schedule. For example, the original assumptions for overhead installation were shorter than the true project schedule. This longer duration accounts for plumbing tasks previously missed in the first pass at the schedule. Also, the work in the penthouse and roof is slated to last longer than anticipated. Finally, the crew sizes for the mechanical shafts and commissioning were inflated. This new man-loaded schedule looks much more repeatable and accurate. From here, the new baseline was used to modify the schedule and investigate how the leveling of manpower on a project affects the schedule.

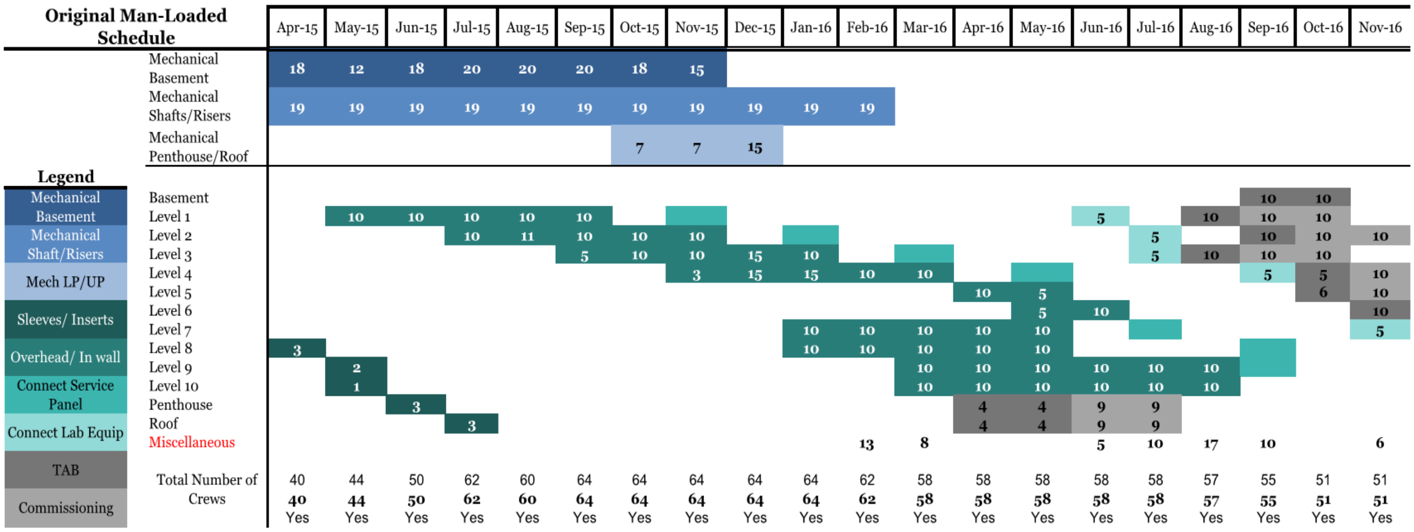


Figure 34: Snapshot of Original Man-Loaded Schedule

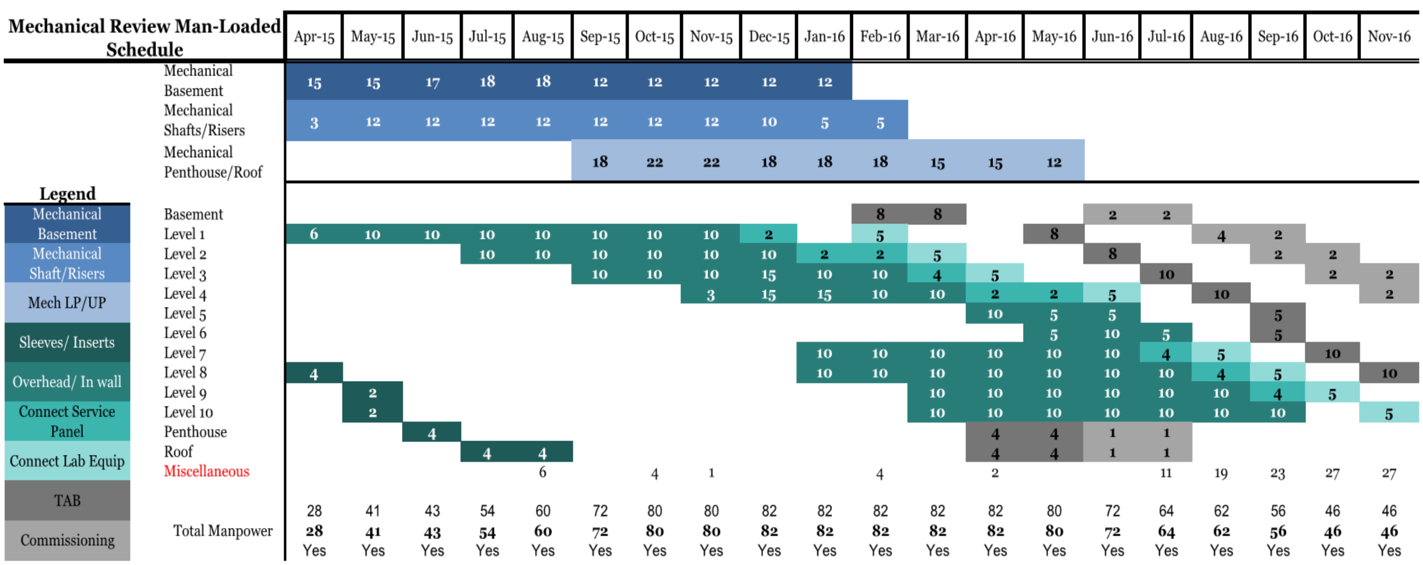
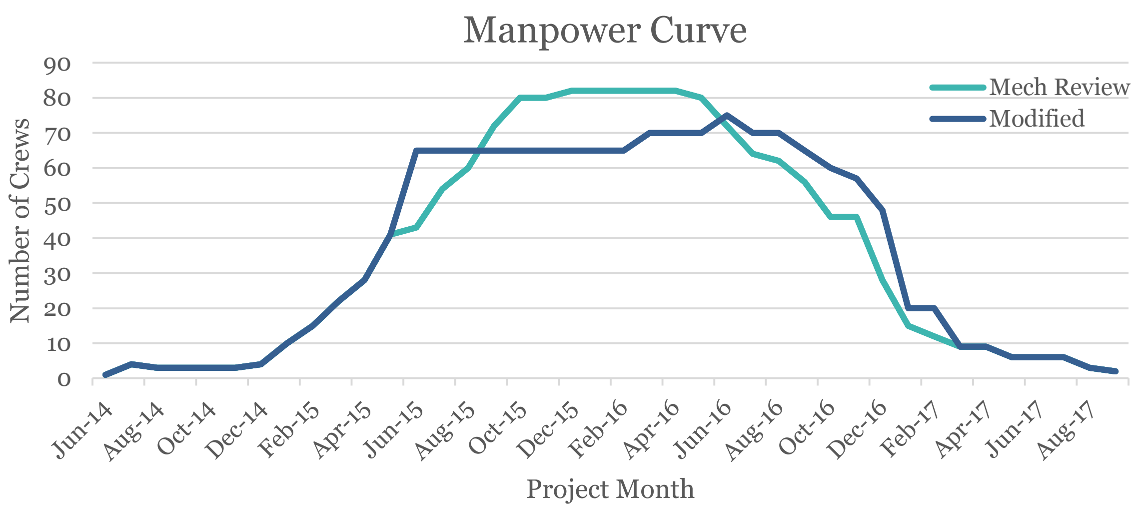


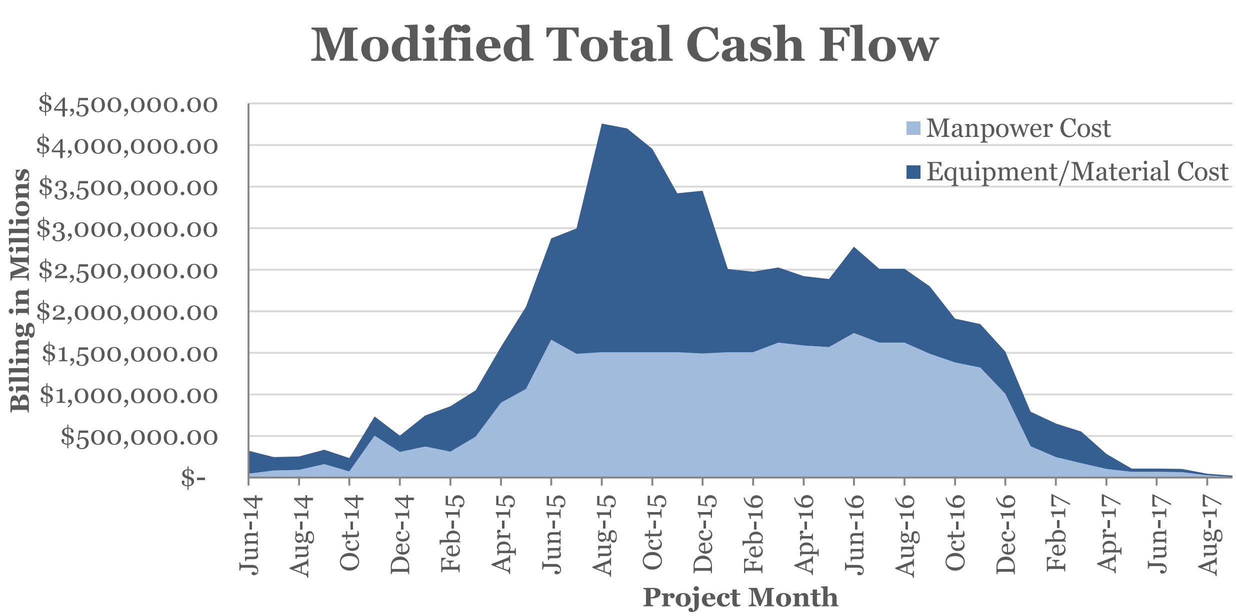
Figure 35: Snapshot of Mechanical Review Man-loaded Schedule

Modified Cash Flow

Armed with the new cost information, the man-loaded schedule was manipulated to show a more consistent crew size for more months. First, the total number of crews per month was adjusted, shown in the graph below. The peak manpower on the project reduced from 82 crews to 75; however, the months from June 2015 to February 2016 consistently have 65 crews per month. This adjusted crew distribution translates to the total monthly cost data in the second graph on the bottom of the page. It took several iterations to balance the total number of crews with a reasonable distribution of crews across different tasks per month.



In order to successfully level this manpower, it was assumed that a total number of crews across the job would stay the same no matter what month they landed because the scope of the job remained the same from the new baseline to the modified version. Once the total number of crews across the project was calculated, then they were divided up based on the goal of reducing the peak manpower and being aware of the schedule affects and major milestones on the project. The following graph translates this leveling information paired with the equipment and material monthly cost.



Looking at the critical path compared to this man-loaded schedule reviewed by the contractor, the mechanical items on the critical path include overhead installation for levels 7-9, all installation for level 10 and commissioning. Because of this, most of the commissioning crew sizes and durations were not moved. Also, the overhead/in wall line item in the man-loaded schedule includes tasks for both plumbing and mechanical. This means in order to meet the critical path on the project, those crew sizes for the mechanical overhead should stay the same while the other tasks in this line item such as in-wall rough-in for mechanical and plumbing should adjust accordingly. Figures 36 and 37 show the alterations from the new baseline to the modified schedule.

Mechanical Review Man-Loaded Schedule	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
Mechanical Basement	15	15	17	18	18	12	12	12	12	12										
Mechanical Shafts/Risers	3	12	12	12	12	12	12	12	10	5	5									
Mechanical Penthouse/Roof						18	22	22	18	18	18	15	15	12						
Basement											8	8			2	2				
Level 1	6	10	10	10	10	10	10	10	2		5			8			4	2		
Level 2				10	10	10	10	10	10	2	2	5			8			2	2	
Level 3						10	10	10	15	10	10	4	5			10			2	2
Level 4								3	15	15	10	10	2	2	5		10			2
Level 5													10	5	5			5		
Level 6														5	10	5		5		
Level 7										10	10	10	10	10	10	4	5		10	
Level 8	4									10	10	10	10	10	10	10	4	5		10
Level 9		2										10	10	10	10	10	10	4	5	
Level 10		2										10	10	10	10	10	10	10		5
Penthouse			4										4	4	1	1				
Roof				4	4								4	4	1	1				
Miscellaneous					6		4	1			4		2			11	19	23	27	27
Total Manpower	28	41	43	54	60	72	80	80	82	82	82	82	82	80	72	64	62	56	46	46
	28	41	43	54	60	72	80	80	82	82	82	82	82	80	72	64	62	56	46	46
	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Legend: Mechanical Basement; Mechanical Shaft/Risers; Mech LP/UP; Sleeves/ Inserts; Overhead/ In wall; Connect Service Panel; Connect Lab Equip; TAB; Commissioning

Figure 36: Snapshot of Mechanical Review Man-Loaded Schedule

Modified Man-Loaded Schedule	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
Mechanical Basement	15	15	18	18	18	12	12	12	12	10	3									
Mechanical Shafts/Risers	3	12	13	13	12	12	12	12	8	5	5									
Mechanical Penthouse/Roof						11	11	22	18	18	16	15	15	13	15	4				
Basement												6	5	5	2	2				
Level 1	6	10	15	15	10	10	10		2		5				8		4	2		
Level 2			15	15	15	10	10	5		2	2	5				8		2	2	
Level 3						10	10	10	10	10	10	4	5				10		2	2
Level 4								3	15	10	10	10	5	4	5			10		2
Level 5																10	5	5		5
Level 6																	5	5	10	5
Level 7										5	5	10	10	10	10	10	4	5		10
Level 8	4									5	5	10	10	10	10	10	10	4	5	
Level 9		2										5	10	10	9	10	10	5	4	5
Level 10		2										5	10	10	8	8	10	10	10	
Penthouse			4											4	4	1	1			
Roof				4	4									4	4	1	1			
Miscellaneous					6			1			4					6	10	17	27	28
Total Manpower	28	41	65	65	65	65	65	65	65	65	65	70	70	70	75	70	70	65	60	57
	28	41	65	65	65	65	65	65	65	65	65	70	70	70	75	70	70	65	60	57
	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Legend: Mechanical Basement; Mechanical Shaft/Risers; Mech LP/UP; Sleeves/ Inserts; Overhead/ In wall; Connect Service Panel; Connect Lab Equip; TAB; Commissioning

Figure 37: Snapshot of Modified Man-Loaded Schedule

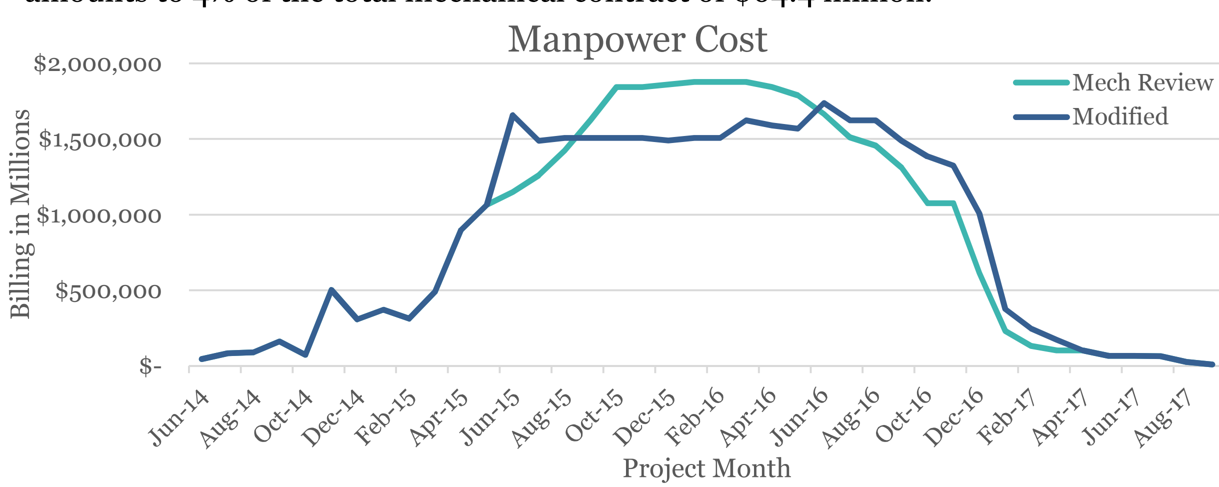
Shown in the snapshot on the previous page, testing and balancing for most of the floors were pushed back one month and the commissioning for the penthouse and roof was also delayed one month. The only main tasks following testing and balancing is punchlist items, building flushout and commissioning. There is 100 days for building flushout, giving some wiggle room for both testing and balancing as well as punchlist items. The work for levels 5 and 6 were delayed 3 months since they serve as core and shell spaces. Levels 7 through 10 extended one month in the overhead line item, pushing back the connections line items one month. Again, a Gantt chart of the original, mechanical review and modified versions of the mechanical schedule can be found in appendices D.1 and D.2.

Cumulatively, this manipulation of the manpower saved at most $400,000 per month in the months of December 2015-February 2016. This is a significant amount of money that can be used for things such as purchasing long lead items at critical times to keep the project moving. Below is table 7 describing the overall change per fiscal year and how that relates to funding on the project. A comparison of the manpower cost monthly is shown in the graph at the bottom of the page.

Table 7: Fiscal Cost Comparison

Fiscal Year	Funding	Mechanical Review Billing	Modified Billing	Difference from Baseline
FY 2014	$18,000,000	$ 321,700	$321,700	--
FY 2015	$59,000,000	$10,910,600	$11,463,500	$552,900
FY 2016	$91,500,000	$39,874,100	$37,377,100	($2,497,000)
FY 2017	$53,000,000	$13,141,800	$15,086,200	$1,944,500
FY 2018	$9,500,000	$173,900	$174,000	$100

There is a variance of about $500 between the reviewed and modified total project price; this is from rounding in the labor excel file used to move around the manpower crews and determine monthly billings. Fiscal year 2016 is where the majority of the savings is realized. This is also the source of the most funding in a fiscal year for the project. Over an entire year, this is a significant amount of money that could be allocated to other equipment purchases or to start other trades sooner on the project like the exterior façade. If the building becomes dried in faster, the interior work could start earlier and at a more constant pace throughout the building. This money saved in fiscal year 2016 amounts to 4% of the total mechanical contract of $64.4 million.



Recommendations

This exercise of manipulating the manpower in hopes of transferring cost into other fiscal years was valuable because it helped define how much a reduction of manpower affects not only the mechanical trade itself but other trades that depend on the completion of mechanical work as well. Based on moving solely manpower, this project transferred almost $2.5 million dollars out of fiscal year 2016 where the most funding as well as the most work is happening. This comes at the risk of delaying the top floors from 7 to 10 an entire month as well as delaying testing and balancing one month. Although there is some buffer room in the building flushout phase of the project, it is a risk to delay this work and sandwich other phases on the critical path. If the situation on this project required more money in fiscal year 2016, Because this project planned on delaying the interior work one month, they could use this new manpower schedule and start the interior trades at the original intended start date without detrimentally affecting the tasks on the critical path later in the project. With this in mind, it is recommended to suggest this modified cash flow system for the mechanical trade and the success of the project.

Architectural Breadth

Problem Identification

Originally this breadth was embedded in the fourth analysis, discussed in the next section; however, it was decided to keep this breadth but remove that analysis from the scope of this thesis. This architectural breadth acknowledges that the east side of the precast on the north elevation cannot be installed with a tower crane because the precast is either too heavy or the tower crane cannot reach the last few panels on the east side. Because of this issue, the precast contractor plans to bring in a mobile crane to install about half of the precast panels on the north elevation. This architectural breadth will analyze how an alternative material may change the appearance of the building but reduce the amount of time needed for a secondary crane to assemble the precast installation. This analysis will also comment on the material change's potential impacts on other systems.

Execution

First, a model of the original building was created to analyze the current architectural north façade. There are many materials on this façade. Figures 38 and 39 below give both a large scale perspective of the current materials and a close up perspective as a person would encounter the building. Since this building is so massive, the material choice makes a bold statement in how it interacts both with the other materials on this building but also the surrounding structures.

Figure 38: North View of HSFIII

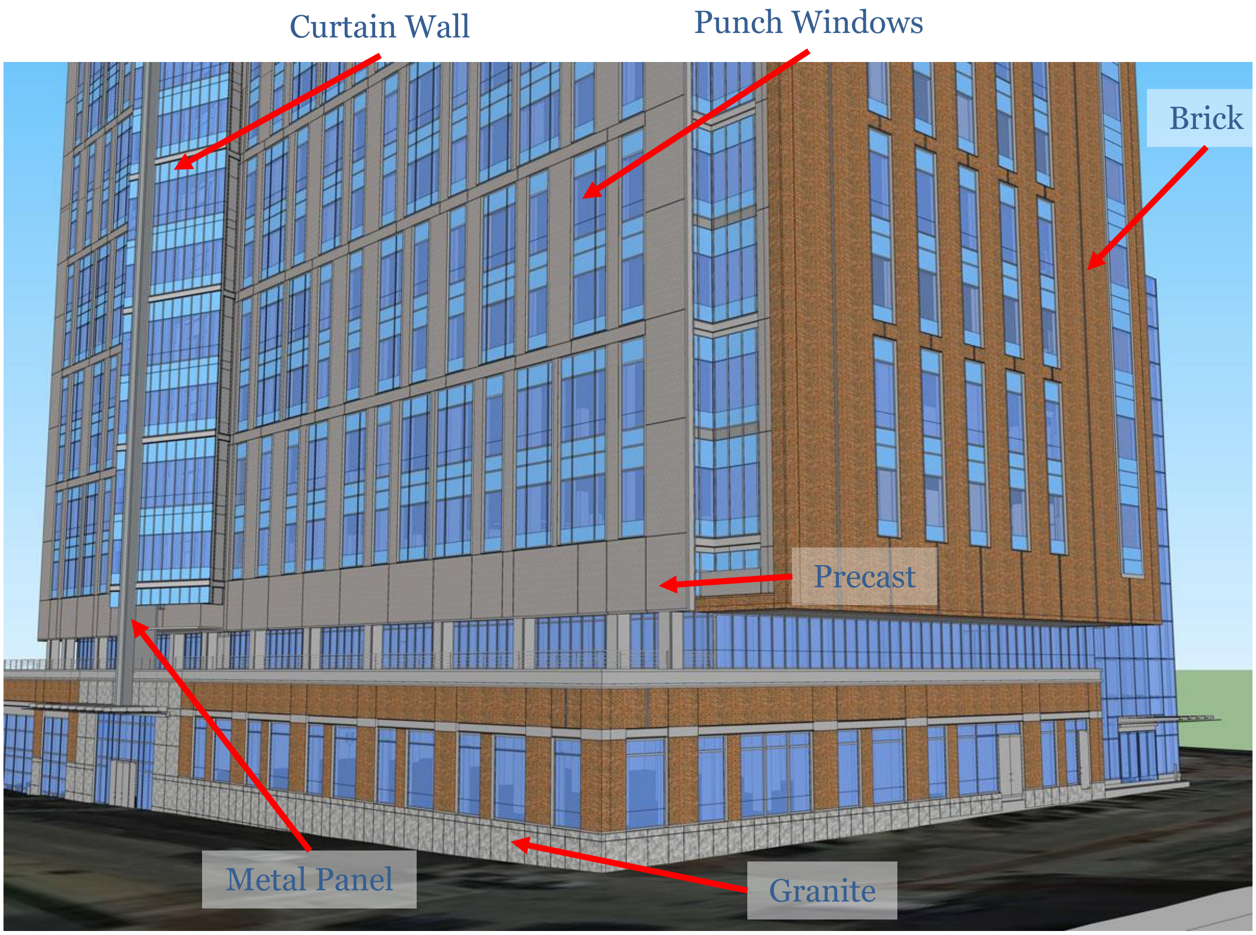
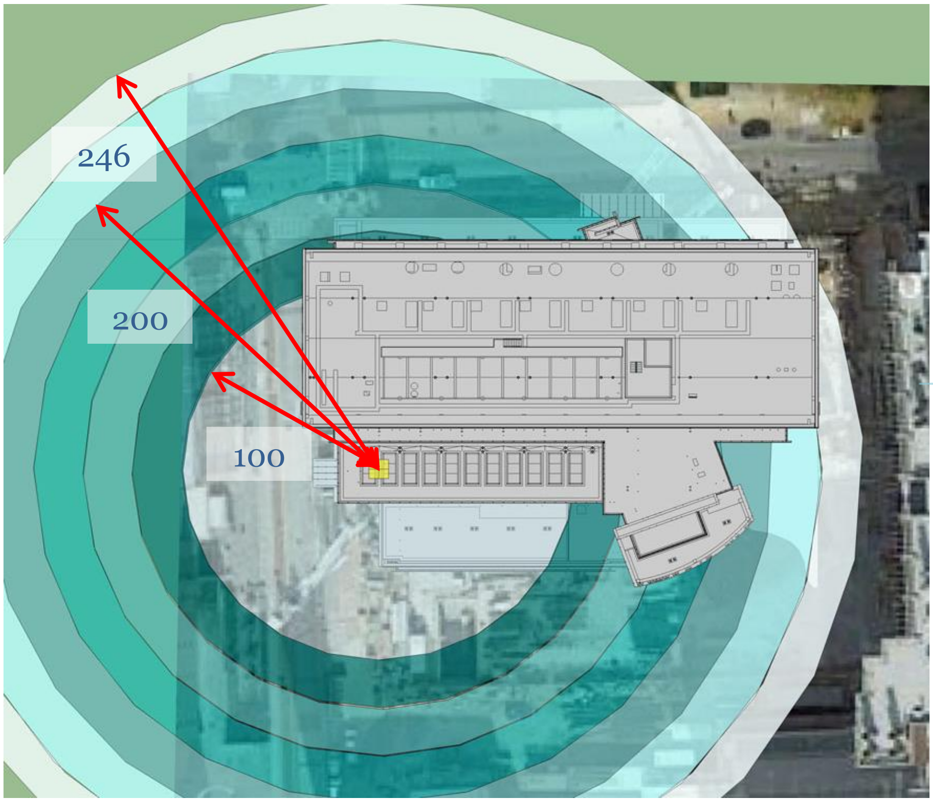


Figure 39: Close up of HSFIII

The image above identifies the main components of the façade system in the building. This closer view shows more of their interactions with each other. The store front on the second floor acts as a divider between the first floor program and the upper levels that have labs and offices. Also, the bump out on the north façade is designated as the collaboration tower and hosts collaboration or meeting spaces on every other floor.

The panels are deceptively large. The middle precast panels next to the punch windows span two levels, about 27 feet. On the east side, the heaviest panel falls just east of the collaboration tower and weighs approximately 16,000 pounds. The easternmost panels where the tower crane barely reaches average at about 8000-9000 pounds, which exceeds the capacity of the tower crane at that distance. Figures 40 and 41 on the next page show the tower crane capacity as the distances increases from the base and how that interacts with the precast system.



Distance from Base (feet)	Capacity (kips)
100	22
125	17
150	13.5
175	11.3
200	9.5
225	8
246	7

Figure 40: Tower Crane Load Capacity

Precast panels located 175 feet to 246 feet away from the tower crane base exceed the load capacity of the tower crane and require a mobile crane for installation. This breadth will investigate a new material that will keep the integrity of the design while simultaneously designing a lighter system for the tower crane to install.

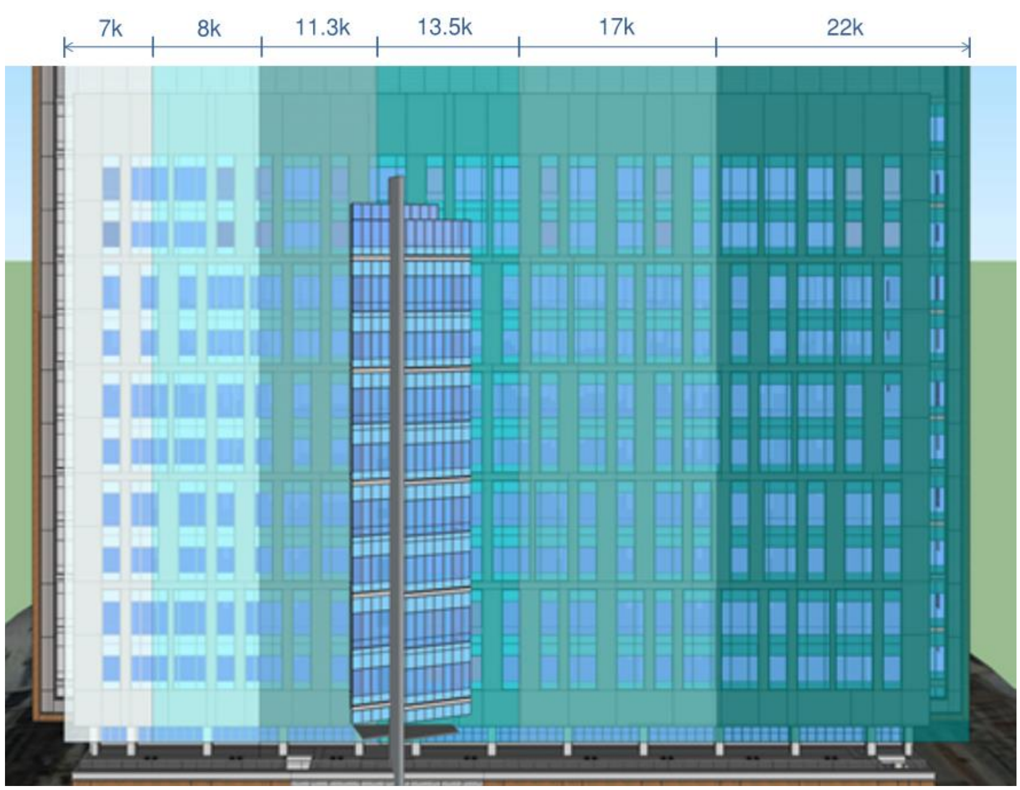
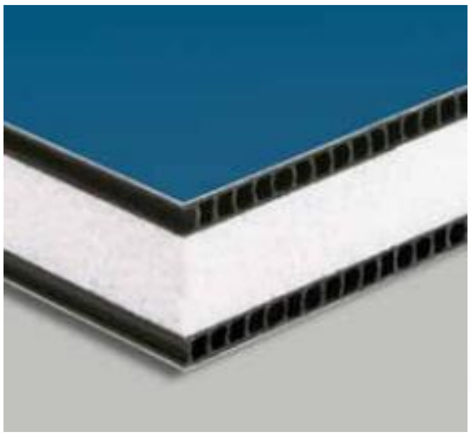


Figure 41: North Elevation of Tower Crane Load Capacity

Material Selection

When looking at material choices, the 6” of precast at 75 psf is one of the heavier façade systems. Metal panel is the strong contender for alternative material selection. It is already located on the fin on the north collaboration tower, so the same manufacturer could be used for this material change. Below is some product information for the existing metal panel on the fin. This product comes from the manufacturer Laminators Inc, seen in appendix E.1.

Thermolite™



Energy-saving insulating properties and a great look rolled into one—that's the magic of our Thermolite panels used for exterior wall applications.

- Constructed of an insulating foam core sandwiched between two corrugated polyallomer stabilizers and finished aluminum sheets
- Water-resistant, virtually maintenance-free for up to 20 years
- Available in smooth or stucco-embossed finishes
- Fit into standard 1 in. insulating glass and glazing pockets and storefront extrusions

Another product from the same manufacturer is better suited for the precast replacement based on its color options and typical applications, seen below.

Omega-Lite®

When you're looking for a highly decorative yet durable solution for exterior wall surfaces, choose Omega-Lite panels—they will not rot, swell, corrode, or delaminate. Best of all, with our installation systems they make total installed costs extremely competitive.

- Composed of a polyallomer corrugated core between two finished aluminum sheets
- Non-absorbent, water-resistant, and easy to maintain
- Custom color panels and caulks available to meet any corporate need

Two limitations with this manufacturer are that one dimension can be no wider than 60”, and it only comes in certain colors. This champagne color fortunately comes in this dimension and is being used on the fin for the collaboration tower. It has a metallic look that compliments the color. Because of this width restriction, the panel sizes need to be reconfigured into smaller units. The panels themselves are only .99lb/sf, making them significanly lighter than precast. A comparison of the old and new layout can be found on the next page.

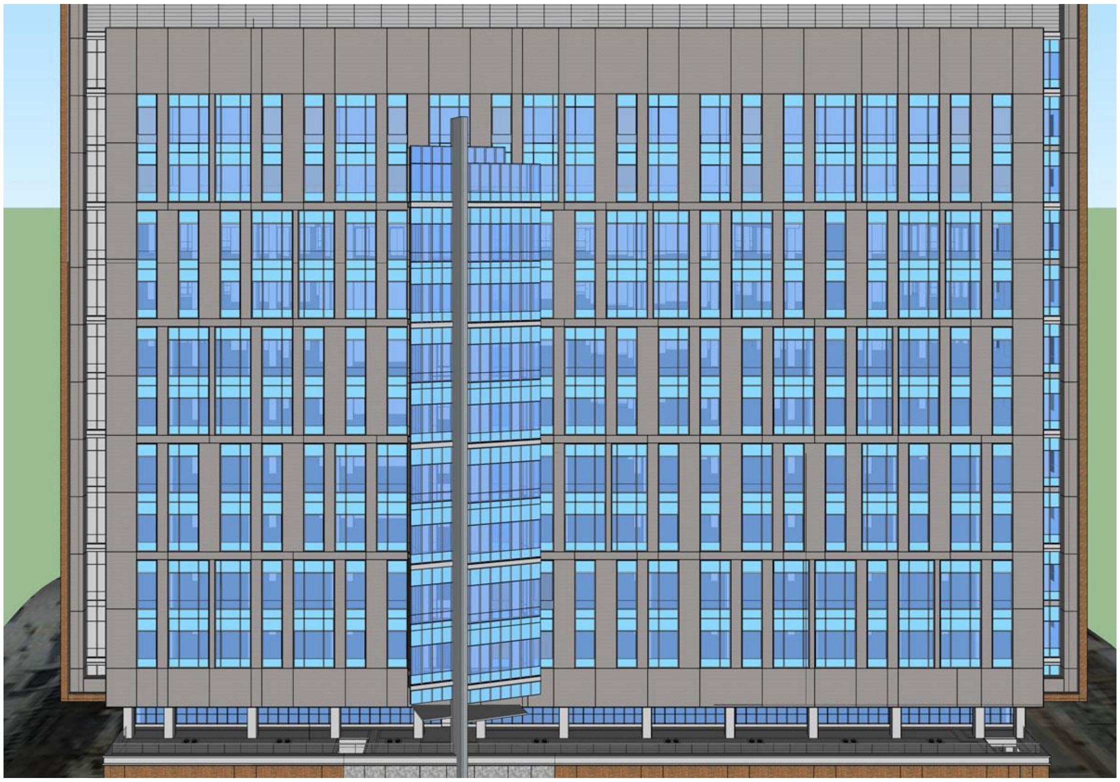


Figure 43: Original Precast Layout

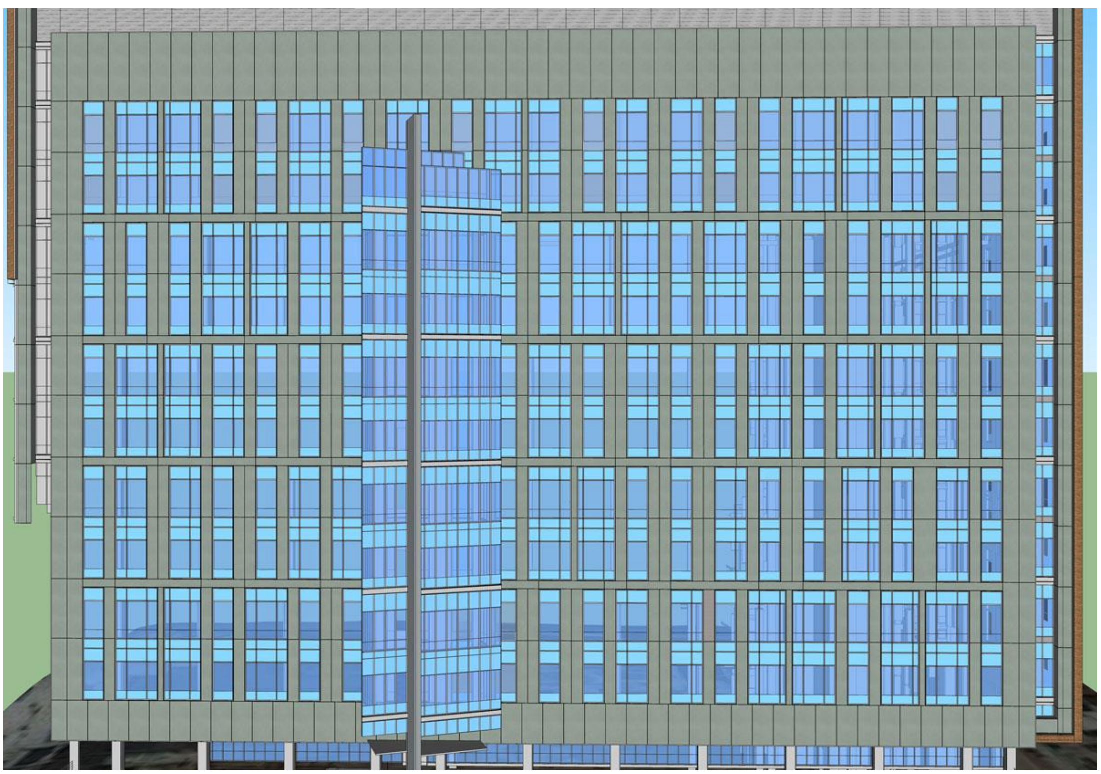


Figure 42: Modified Metal Panel Layout

The most noticeable place where the metal panel differs from the precast is in the north and south precast that frames the building. Here, uniform panels accommodate the width restriction of 60". Also, the widest panels woven in between the windows were over 60" which prompted a redesign of these panels. Although the redesign is small, the texture from the precast to the metal panel is significant and greatly changes the impression of the building.

Effect on Other Systems

With a lighter facade, one major system affected is the mechanical system. The new metal panel has an R-value of 2.63, surprisingly higher than 6" precast which has an R-value of about 1.22[1]. This means that the other components of the wall such as the insulation and air barrier can be adjusted accordingly to get the same heating and cooling on the spaces in the building. Secondly, the structural system is greatly affected by this new system. This specific metal panel is significantly smaller than the precast, weighing in at .99lb/sf rather than the 6" precast at 75 lb/sf. This means that the structural backing for the system can be greatly reduced, similar to the curtain wall loading requirements.

Cost Analysis

The metal panels are also significantly cheaper than the precast. Based on existing cost information from the glazing and precast contractor, the table below shows the average cost per square foot for each system, indicating that the metal panel is less than half the cost of precast per square foot. A detailed takeoff of the precast and existing metal panel to obtain this cost information can be found in appendix E.2.

Precast	$103/SF
Metal Panel	$44/SF

Recommendations

With a higher R-value, a cheaper cost per square foot and similar panel layout to the current system, it is recommended to switch the precast to a metal panel system.

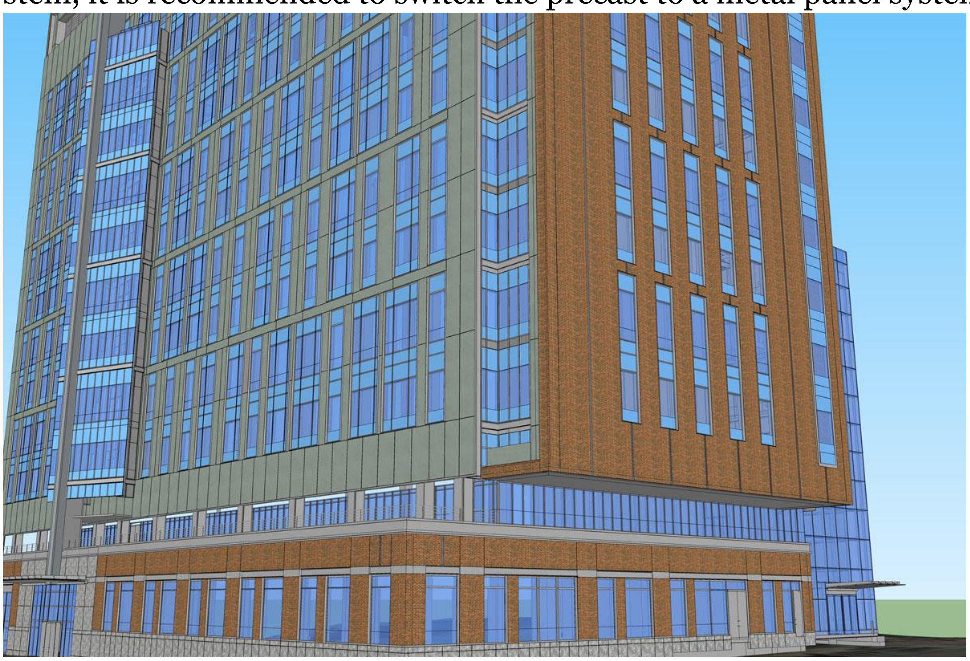


Figure 44: Closeup of Metal Panel System

Analysis 4: Remarks on Tower Crane Optimization

Problem Identification

There are multiple times during the installation of the exterior façade where the tower crane will be at its peak usage. This analysis was originally intended to investigate alternative solutions to help with the tower crane usage.

Background Research

Some of the first discussions over the summer concerning this tower crane included using the crane in two shifts to be used by different trades. The only trade that does not need the tower crane is the masonry contractor and they only have the east and west façade to erect. Apart from that, the concrete, windows, curtain wall, and precast contractor all require use of the tower crane.

With no interest in accelerating the schedule, this analysis will focus on how the re-sequencing of the exterior façade will affect the project schedule and the overall construction cost. The curtain wall and the precast will be the two major trades bargaining for crane usage throughout their time on site, and they each have a substantial amount of work that spans all of the floors.

When the first two floors of the façade begin, there is more structural concrete to pour on the upper floors. This overlap means the façade needs to be aware of the pathway that the crane is taking to transport concrete up to the top floors. The concrete has a high chance of spilling out of the bucket and could potentially damage the façade, specifically the storefront windows on the second floor. Also, the concrete contractor requires the tower crane for erection.

One important element to consider in this is how the interior trades are affected by this façade re-sequencing. If it is drawn out too long, then there will be potential delays in the interior work which will not benefit the project. 4D modeling such as Synchro will be used to help visualize and understand this relationship between the structure, exterior façade contractors, and interior trades.

Potential Solutions

With the tower crane as the element that limits production on the project, the following potential solutions will address how to best use the tower crane. Overall, the design variables that will help make the decision include the tower crane, the manpower, and the cost of installation.

The first option is to remove the two shifts of the precast and curtain wall. The overtime of the tower crane operator would not be necessary here. This option will investigate how this affects the overall project schedule. Also, with the assumed additional cranes that will be on site when the tower crane is at its peak usage, this solution will evaluate the cost of the additional cranes and the best balance between double shifts and multiple cranes on site. The mindset behind removing the two shifts is to potentially flatten out the cash flow curve in this year, since the funding for the project comes in certain amounts every year.

Second, this analysis could investigate supplementary equipment to aid the tower crane in the erection of the façade. For example, a gantry could be used to erect the punch windows and other smaller elements, which would free up the tower crane. Also, there might be some other equipment that could erect the curtain wall or precast. This may take the responsibility of erection off the tower crane, but the cost of the equipment and impact on the schedule and other trades will be evaluated.

Finally, the third potential solution could consider sequencing the project in sections rather than clockwise. The building is broken into four sections, the north tower, south tower, atrium, and core, seen in the figure on the right. They are disproportionally sized, but it might help with the tower crane production. This could free up those areas inside to perform interior work sooner in areas like the atrium or south tower. If the interior trades start earlier and with a smaller sized manpower, they might be able to better level out the fluctuations of manpower throughout the project. This will also allow the tower crane to focus on specific areas and specific trades at a time.

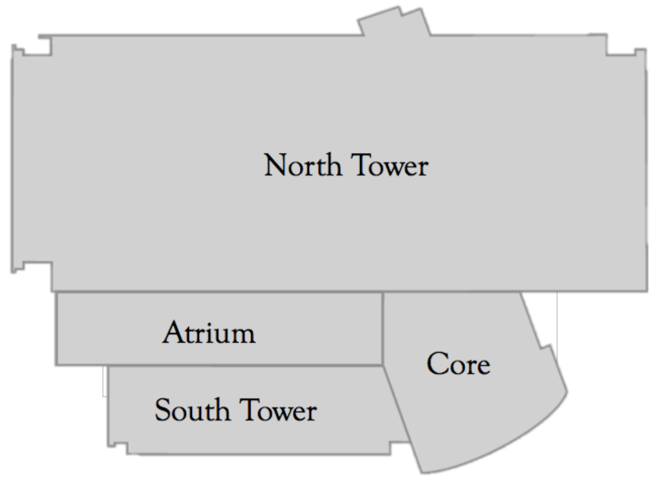


Figure 45: Breakout of HSF III

Remarks

After puzzling through this analysis and discussions with the construction manager, it was decided to remove the tower crane analysis from this thesis. By the time the conversation took place with the construction manager, many of the things originally proposed in this thesis were either shot down or implemented on the project. Below is a recap of the potential solutions I planned to investigate:

Option 1: double shift removal (based on assumption that they were moving forward with two shifts for precast/concrete or precast/curtain wall)
Option 2: supplementary equipment
Option 3: re-sequencing the project

The discussion with the project engineer outlined their current plan with the façade. Since the relationship between the precast and concrete is the most crucial to requiring the tower crane, this is where the most time was spent in solving how to use the tower crane. The concrete contractor has priority over the tower crane for its last pours on the upper floors, so the precast will be using a mobile crane to erect floors 1 through 4. This limitation is also because of the safety nets surrounding the concrete on levels 4 and 7. These must come down before the precast can use the tower crane. Once the nets are gone, the precast will use the tower crane during a night shift while it is used for other purposes during the day. The tower crane cannot set the northeast precast due to weight limits on the crane, so it will be erected completely by a mobile crane. There is some precast in the southeast that will also be erected during off-hour shifts.

Concerning the other façade types, the masonry never needed the crane and will be using a hydraulic lift to build the masonry façade. The curtain wall on the south end as well as any punch windows plan to use a deck crane, which is a small crane set up on the 9th floor that can move around the floor and hang the panels as needed. The tower crane will only be used in this case to stock the deck crane of material during off hours. Both the storefront and metal panel will be stick built on site, while the granite on the first floor will be hung by from the scaffolding.

With this new information, the use of a mobile crane and a deck crane used many of the potential solutions I intended to look into. This made the analysis obsolete and I did not think it was a wise use of time to research the same potential solutions implemented on site. Because the final presentation only required three analyses, I chose to spend my time focusing intently on the first three for the presentation. I plan to keep the architectural breadth originally connected to this thesis in order to fulfill the requirement of having two breadths for my thesis.

Conclusion

Each analysis in this thesis is intended to research and better understand construction issues while utilizing the resources and knowledge gained through the pursuits of an architectural engineering degree. The breadths are designed to showcase the talents and knowledge of other disciplines that take this program to the next level. All three analysis investigated value and its effect on construction, from the value of motivation and team performance to deciding on the best value in a shoring system to understanding the value of manpower's effect on the cost and schedule of a project.

Analysis 1 considered multiple shoring systems for the project and proved that although pile and lagging is a better system when there are no complications, it is more advantageous to the project to pick sheet piles as the support of excavation method. This would greatly reduce the amount of dewatering issues on the site and is cheaper for the project at $1,640,040, about $490,000 less than the final pile and lagging price. It will also take 24 days less than the delayed pile and lagging system. The structural breadth for this analysis designed the alternative systems to give better content in the decision making process.

Analysis 2 researched motivation and team performance within construction managers on a construction project. Overall, it was found that not only is there was a correlation between motivation and team performance, but these drivers behind motivation can change with age, roles and responsibilities in life, and with the team dynamic. It is recommended to try and understand these motivators on a job to best craft the team's goals and responsibilities. The literature review greatly helped identify and categorize the responses of the individuals on how they perceived motivation and team performance.

Analysis 3 focused on cash flow of the mechanical trade and manipulated the manpower crew sizes throughout the project to understand how it affected cash flow on a project. It was discovered that the reduction in peak manpower saves almost $2.5 million dollars in fiscal year 2016. This means that the interior trades that were originally delayed a month could start as originally scheduled and this would accommodate the month delay of the overhead and in-wall installation on the upper floors without compromising the critical path of the project.

Finally, the architectural breadth that was not woven into any analysis examined an alternative material to the precast on the north elevation based on the tower crane load capacity. With a higher R-value and a lighter system, it was recommended to use metal panel as a substitute to the precast on the north.

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Appendix B

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