Final Report

900 16th Street

Douglas W. Watson | 08 April 2016
Construction Management | Leicht

900 16th Street

PROJECT TEAM:

Owner - Undisclosed
General Contractor - James G. Davis Construction
Design Architect - Robert A.M. Stern Architects, LLP
Architect of Record - Cooper Cary
Structural Engineer - Thornton-Tamasetti
MEP Engineer - Dewberry
Civil Engineer - Wiles Mensch Corporation

BUILDING INFORMATION:

Construction Dates - February 2014 - March 2016
Gross SF Area - 201,481 SF
Total Levels - 12
Delivery Method - CM at Risk
Contract - Negotiated Cost + Fee with GMP
GMP Value - $38,000,000

Image courtesy of Robert A.M. Stern and Cooper Cary

MECHANICAL SYSTEM:

- Central utility plant located on first parking level
- Two main water chillers to provide cooling
- AHU's and VAV boxes used for distribution

ARCHITECTURE:

- 9 levels of Office/Retail space above 3 levels of subgrade parking
- Precast concrete façade with limestone and marble inlays
- 3D structural curtain wall at North entrance
- Penthouse with views of the Washington Monument
- Design follows the rules set forth by DC Historic Preservation

CONSTRUCTION:

- Demolition of an existing church and its monitor building
- Support of Excavation systems used include; walers, rakers, tie-backs, and bracket piles

STRUCTURAL SYSTEM:

- Cast-in-place concrete with two way and post tensioned slabs
- Concrete spread footing foundations
- Above grade levels poured in 3 phases moving North to South

ELECTRICAL SYSTEM:

- 277/480V power supplied to two 2000 Amp switchboards
- 800A switchboard designated to retail space
- Two separate bus ducts supply power to levels 1-4 and 5-9

Image courtesy of Robert A.M. Stern and Cooper Cary

DOUGLAS WATSON
[CONSTRUCTION MANAGEMENT]

http://dqw5120.wix.com/aethesis

EXECUTIVE SUMMARY

The 900 16th Street NW is a nine story building, primarily office space, located in the heart of Washington DC. The project began with the demolition of two existing buildings on site in the beginning of February 2014 and the core and shell construction was set to reach substantial completion in November 2016. The purpose of this thesis project is to document the construction of a project from start to finish. This report in particular will highlight areas of the project that have an opportunity for improvement, recommend a possible improvement, and analysis its impacts. Topics in the following pages will focus on topics that include value engineering, schedule acceleration scenarios, and alternative methods of construction. The four analyses that will be highlighted shall provide a description of the opportunity, the potential solutions or alternate methods, the methodology behind the analysis, the expected outcome, and the analysis.

Analysis I:

The first technical analysis will be focused on the utilization of modular concrete formwork for the cast-in-place concrete structure. Throughout construction the team used traditional stick built formwork, which lends to longer durations between pours. This labor intensive process also requires a larger amount of man hours then its modular counterpart. Included within this analysis will be research as to how modular formwork compares to stick built, possible schedule, cost, and man hour savings associated with the implementation of modular formwork, and the transportation and storage of forms on site.

Analysis II:

This second technical analysis will focus on an alternate exterior façade to the precast concrete panels that were used. Included within this analysis will be a cost and schedule comparison between the current system and the alternate system. In addition the mechanical and structural properties of the alternate façade system will be analyzed. This will lead to a structural breadth to ensure that the current design of the cast-in-place structure can support the new system and what connection changes must be made. It will also contain a mechanical breadth to analyze the thermal efficiency of the new façade system. The purpose of this analysis is to provide an alternate façade system that will increase the thermal efficiency of the exterior wall while providing similar quality to the original system a minimal impact to the project schedule. I will also conduct an analysis on to see if the overall amount of man hours can be reduced by implementing a new system.

Analysis III:

The third technical analysis will focus on value engineering the glazing for the 3D structural curtainwall based upon a risk analysis of its supply chain. Within this analysis the cost of the glazing, cost of delivery to the project, delivery distance, delivery method, delivery duration will be conducted. A comparison between the alternate product and the current product will be conducted will be completed. A risk analysis between the possible delays and changes to the above topics will be conducted as well. The main purpose of this analysis is to provide a similar product that is manufactured closer to the jobsite to reduce the risk of unforeseen costs associated with possible delays.

Analysis IV:

The focus of the final analysis will be a research based topic that will look into driving collaboration in the field through implementing lean construction principles. Driving collaboration is an issue that most all construction projects have. The lean construction tools of last planner and collocation create an extremely collaborative atmosphere by nature which will assist in furthering the collaboration between trades in the field day to day.

Acknowledgements

Academic

Penn State AE Faculty and Staff

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Industry

DAVIS

PENNSTATE PACE

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Tim Jones, Project Manager at Massaro CM Services

Alex Brown, Assistant Project Manager at Mortenson Construction

900 16th Street NW Project Owner

Friends and AE classmates

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NOTE: Any and all figures containing images of floor plans, wall sections, or elevations come directly from the 900 16th Street NW project documents unless otherwise stated. All building renderings are courtesy of Cooper Carry and Robert A.M. Stern.

| Project Background |

Project Description:

900 16th Street is a feature office building under construction on the corner of 16th Street NW and I Street NW in Washington DC. This building was chosen to be studied as a part of the Penn State Architectural Engineering Senior Thesis course. The purpose of the AE Senior Thesis course is to analyze the construction of a structure in every aspect from preconstruction to completion.

The building is comprised of nine above grade stories and three below grade stories. While the majority of the space within the structure is slated to be office space, a portion of the ground level will be retail space. Along with the retail space, a portion of the North most area of the building will be a replacement space for the church that had existed on the site prior to construction of 900 16th Street. The structure of the building is mainly cast-in-place concrete with a mixture of two-way slabs and post-tensioned slabs. Precast concrete panels with limestone and marble veneer are used as the main component of the façade. Along with the precast façade a system of aluminum punched windows and a feature 3D curtainwall make this structure stand out from the buildings surrounding it.

Client Information:

NOTE: This building is Base Building project with a separate contractor for Interiors.

As per request of the owner, the specific name of the owners of 900 16th Street is not to be released. However, the owner of this building is one of the largest real estate developers in the DC area. The purpose behind this new office building is to provide showcase space to clients in a historic district of Washington DC. Located only a few blocks away from Lafayette Square and The White House, the space has already attracted several high value clients including the law firm of Miller & Chevalier. They will occupy over half of the available office space including the 9th floor penthouse which has a spectacular view of the national mall.

There are several expectations for the schedule of this project. Due the fact that a majority of the space already has planned occupants it is key that the project be completed by the time the leases of the respective parties are set to begin. If there is a schedule delay preventing this then the Owner and the general contractor, DAVIS, will be responsible for the costs associated for the future tenants to remain in their current spaces.

Project Delivery Method:

The delivery method that this project utilizes is a Construction Manager at Risk with a GMP. The general contractor for 900 16th Street is James G. Davis Construction Corporation (DAVIS) and they hold a Cost + Fee with a Guaranteed Maximum Price with the owner. Although this project was intended to go out to bid, DAVIS was able negotiate a contract with the owner before the bid process was initiated. All subcontractors on the job are contracted to DAVIS and were selected by method low-bid.

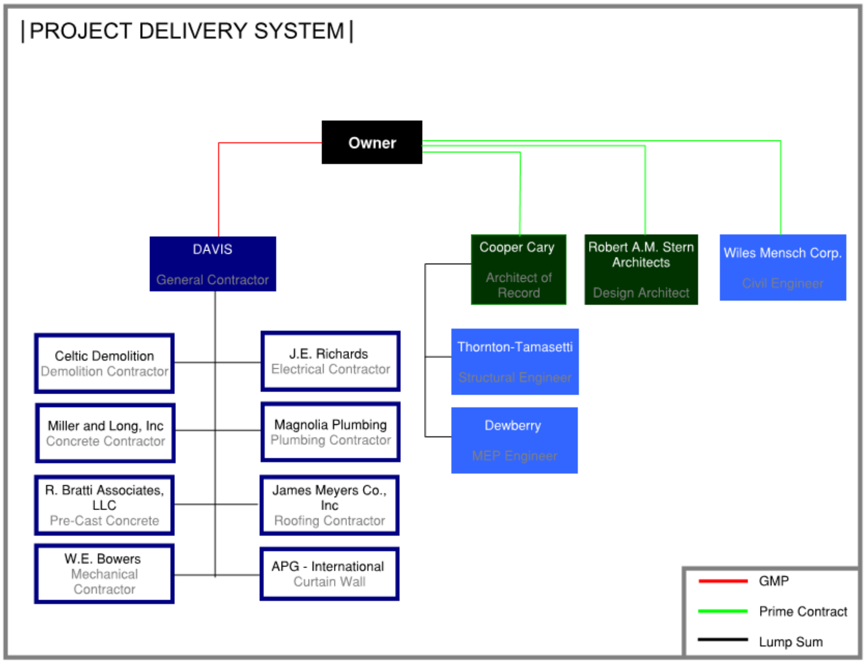


Figure 1: Project Delivery System

Project Team Staffing Plan:

To complete this project in the most efficient manner as possible the general contractor, DAVIS, utilizes a number of employees at all levels and all disciplines. The entire office and field staff is housed in a building adjacent to the site. DAVIS was allowed, with permission of the owner, to use the mezzanine level of the building North of the site as the field office for the project. The project team consists of multiple project managers and project engineers to ensure that all the complex systems have proper attention.

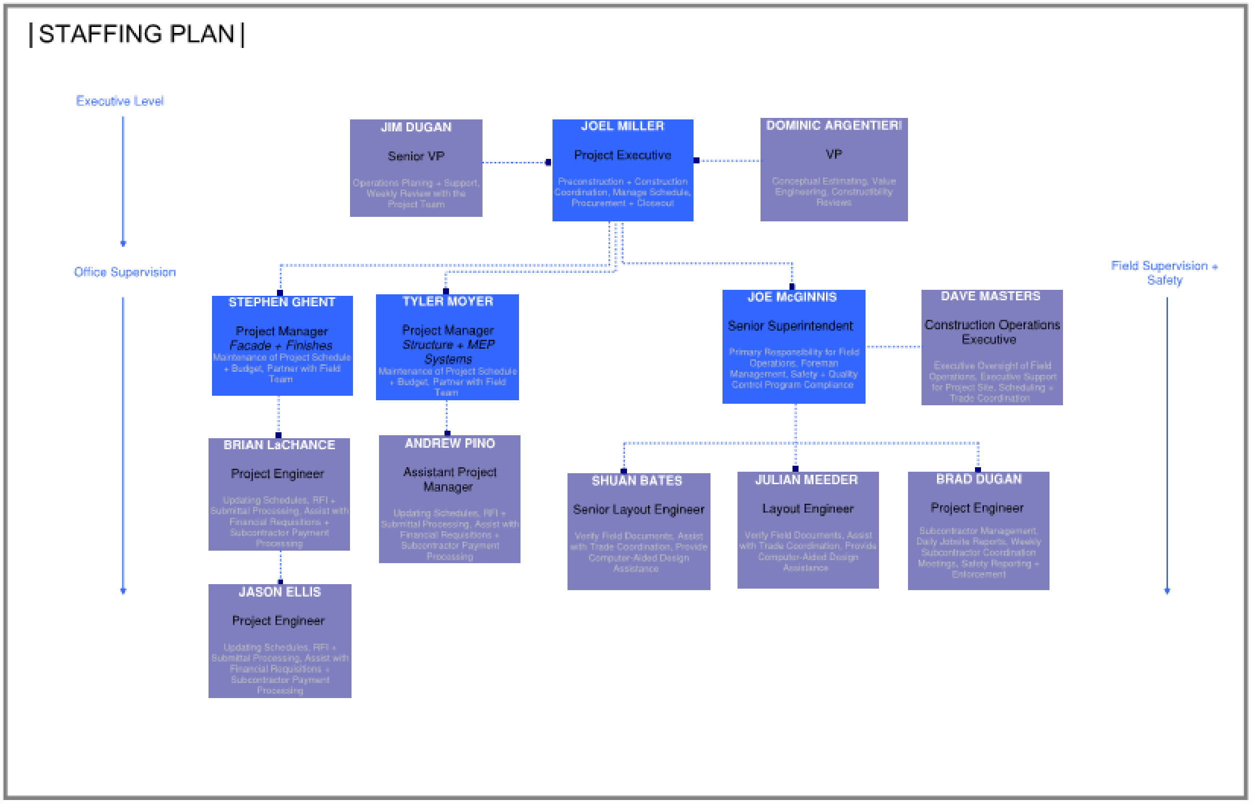


Figure 2: DAVIS Team Staffing Plan

Site Logistics & Existing Conditions:

Reference **Appendix A for a sample logistics plan**

The project site is located in the heart of Washington DC on the corner of 16th Street NW and I Street NW. In this case the site was occupied by a church and a monitor building that needed to be demolished before the new building could begin. Because the site is located on the corner of two streets it is neighbored by buildings on both the North and West. 10' from the property line to the South is an active tunnel of the DC metro system.

During construction the site is commonly occupied by several pieces of equipment. The site plan, which can be seen in **Appendix A**, shows the typical layout for a concrete pour. At the end of each pour the pump truck was taken off site immediately to reopen the site access and laydown area. As soon as the building reached the second level overhead protection was put into place on the pedestrian walkway located on the South side of the site fence along I Street NW. The lack of available space on site eventually lead to moving the subcontractors trailer to above the pedestrian walkway on the South side of the site.

Project Cost Evaluation:

A square foot estimate was completed using the 2015 RS Means Square Foot Cost Data. After calculating the proper adjustment factors the estimated cost and cost per square foot of the total project.

Total Cost:	$201.15/SF	-	$40,528,189
Construction Cost:	$167.60/SF	-	$33,768,110
RS Means Estimate:	$140.93/SF	-	$28,394,779

The value obtained from the RS Means estimate are considerably lower than the actual costs reported by the job. There are many reasons why the numbers came out so low. This structure features a lot of high end façade types that RS Means does not take into account when compiling their estimation information. The project also requires a number of different excavation systems that require special attention in an estimate. RS Means provided an over estimate of the electrical system that is being installed on 900 16th Street because the actual contract only includes a limited scope of work for this trade.

Project Schedule Summary:

Reference **Appendix B for full project summary schedule**

The owner gave the notice to proceed with construction on February 7th of 2014. Immediately following the NTP site mobilization and installation of perimeter controls occurred. Construction began with the abatement and demolition of two existing buildings. The project experienced a 3 month delay due to the demolition of a firestop and structural component of 1600 K St. Existing condition drawings improperly depicted the function of a brick wall which separated the monitor building and 1600 K St. Following the completion of demolition and excavation the structure of 900 16th began with foundations on October 6th, 2014. After the structure reached grade, the construction of the floors one to nine began to fall into a three phase sequence. All sequences accounted for approximately one third of the floor area on each level. The sequences moved North to South and the formwork for the columns to the next level began the day following each slab pour. The main structure was just over a month from being completed when the precast façade began being set on May 11th, 2015. In November of 2015 the process of constructing the core and shell of 900 16th Street is predicted to reach substantial completion after a 22 month duration.

Building Systems:

Demolition:

To create the new office building at 900 16th Street NW two existing buildings needed to first be demolished. On site there existed both a church and the churches monitor building. Initial demolition of these structures first being with abatement to remove all hazardous materials from them. Following abatement a Brokk was used to demolish the monitor building, which had shared a wall with the building North of the site, and an excavator with a jack hammer attachment was used to demo the main church building.

Support of Excavation:

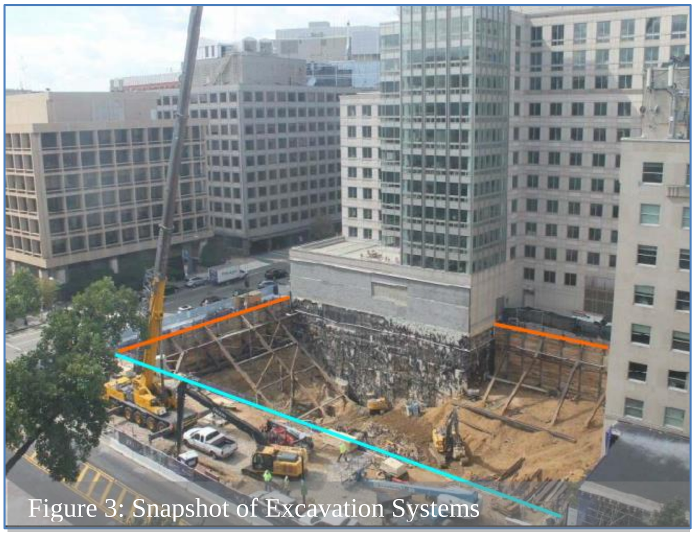


Figure 3: Snapshot of Excavation Systems

With the variety of obstacles that this project provides there were three main support of excavation systems that were used during the excavation for the sublevel parking garage. Figure 1 shows a real time image of the excavation of 900 16th Street. Extra care needed to be taken place on the South said of the excavation due to the underground metro line being located at little over 10’ from the edge of the property line. The South and West edges of excavation (highlighted in orange in the above figure) used a system of walers, rakers, and heel blocks as the support of excavation. The East edge of the excavation (highlighted in blue) was able to receive the standard piles and lagging with tie-back system because there was nothing located underneath 16th street that would impede them from being used. The North edge of the excavation, along the 1600 K Street building, was supposed to use underpinning but after further investigation of the neighboring buildings foundations a bracket pile system was implemented.

Cast-in-Place Concrete Structure:

The main structural system of 900 16th Street is cast in place concrete and implements a mixture of both two-way normal weight concrete slabs with drop panels and post-tensioned concrete slabs with drop panels. Levels P2 through the ground level utilize two-way flat slab systems with drop panels while levels 2 to the penthouse are constructed with post-tensioned slabs with drop panels. The typical slab dimension for the upper levels is 7” thick with 8” drop panels at the columns.

There were two methods of concrete placement used in the construction of the cast-in-place structure. Once the tower crane was erected a crane and bucket method was utilized for smaller pours. As the slabs began to be poured a pump truck was the main method of concrete placement. After the 9th floor slab was poured, the crane and bucket method was used to complete the concrete pour on the roof. The main form work used was job built lumber forms and metal shoring to support uncured concrete.

Building Façade:

The façade of this structure is unique because a majority of it is precast concrete panels that have limestone or marble cast within them. Each panel was cast off site and picked into place off directly off the flat beds they were delivered on. The typical connection detail is shown in Figure 2 to the left. Embed panels are cast into each floor slab and precast panels as shown in detail 3A. Once each panel is set into place by the track crane on site they are secured to the floor slab with steel angle and a welded connection. The north most entrance on 16th street features a prismatic curtainwall system made of custom, triangular glazing units.

Mechanical System:

The main building mechanical system is a chilled water system with a central plant. The central plant is located on the first parking level and is home to 2 water chilling units and their respective pumps. Both of the cooling towers are located in the Northwest corner of the penthouse level.

Electrical System:

The primary electrical system of the building is run from 2 separate 2000 amp, three phase, 4 wire switchgears running at 265/460 V. Power is transported to the rest of the building using two bus ducts, one which supplies floors one to four while the other supplies floors five to nine.

Sustainability Features:

900 16th Street was designed to receive a LEED Gold rating. The designers maximized the amount of green roof area by also incorporation green areas into the terrace space. Nearly the entire roof is a green roof while on the terrace there are two smaller green areas. Access and egress points to the terrace push occupants around the green areas and allow for the flow of foot traffic to be uninhibited. Many of the other LEED practices that are being utilized on this project involve waste management of construction materials, using materials with recycled content and utilizing regional suppliers and manufacturers to provide building materials.

TECHNICAL ANALYSIS I – Modular Concrete Formwork

Problem Identification:

It is typical for Washington DC the projects to feature a cast-in-place concrete structure. In this type of construction the schedule relies heavily on the completion of the concrete slabs, beams, and columns. The formwork needed to support this type of structure is extensive. On the 900 16th Street project traditional stick built formwork was when completing the cast-in-place structure. This type of formwork was used to allow for the drop panels surrounding the columns. Due to the intensive labor needed to construct the formwork, the total number of man hours and duration of construction was higher than if an alternate system would have been used.

Since stick-built formwork is labor intensive it creates a longer duration for the pours of the concrete structure. The price for material, labor, and equipment required to construct the cast-in-place structure was $6.9 million. The structure uses a mixture of 2-way slabs, on the subgrade levels, and post tensioned slabs for the nine above grade levels. All types of concrete slabs that make up the structural system contain drop panels at the columns. Drop panels in the subgrade parking levels are 5” thick while the above grade levels feature 8” drop panels. Throughout the structure the sizes of the bays vary greatly but the most common bay measures approximately 30’ by 30’.

Research Goals:

The purpose of this analysis is to identify a formwork system for the cast-in-place concrete structure of 900 16th Street. Because the structure of this project features drop panels at each of the columns it will be a requirement that any system to be considered must be able to easily be modified to accept these drop panels.

Methodology:

In order to complete the analyses that I plan to conduct, the following steps will be taken:

- *Research*
    - Research modular formwork systems that are popular throughout the industry and select three possible options
    - Conduct a feasibility analysis of each of the three systems chosen in order to select the one that best fits the project
    - Interview several industry professionals on the impacts using said system would have on the current design of the structure

- *Technical Analysis*
    - Determine the cost associated with the current formwork system used
    - Determine the cost associated of the modular formwork system

    - Conduct a cost comparison of the two systems based upon the estimated reduction in man hours required per day
    - Estimate the installation time of the new system and compare with the pours and sequencing that the current formwork system allowed for
    - Compare the costs and schedule duration for both systems
- *Recommendations*
    - Make recommendation based upon cost savings, schedule logistics, and the impact that modular formwork would have on the structure

Expected Outcomes:

It is expected that the introduction of modular formwork, in lieu of traditional stick built formwork, will have a positive impact on the overall project schedule. Even though the structure is not a flat slab system, the integration of two modular systems will still have a positive impact on the project schedule. With a schedule acceleration it is probable that the total number of man hours required to construct the cast-in-place structure will also decrease, resulting in a reducing of labor costs.

Analysis:

Potential Replacement Systems:

The cast-in-place concrete structure of 900 16th Street poses a unique challenge to implementing a modular formwork system. This challenge is the 10' X 10' drop panels located at each of the columns and the 4" perimeter beam. During preliminary investigations of several types of formwork systems it was determined that a modular system that has the ability to incorporate drop panels was not possible without extreme difficulty. However, it was determined after speaking with professionals from various formwork companies that this is not a problem because of the ease in which a secondary system can be integrated to form the drop panels.

Dokamatic S Tables with Dokaflex S

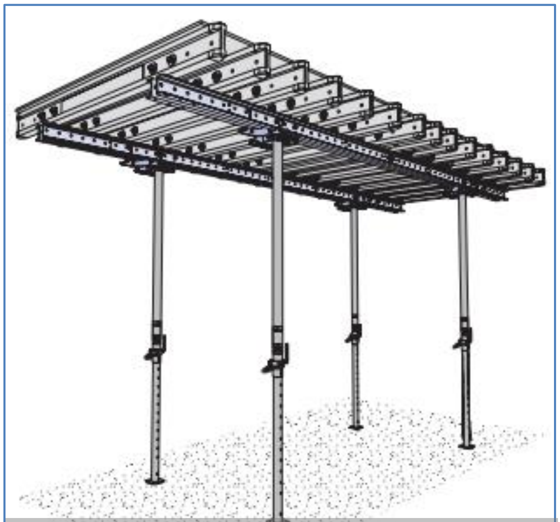


Figure 4: Doka S Table – Source: Doka

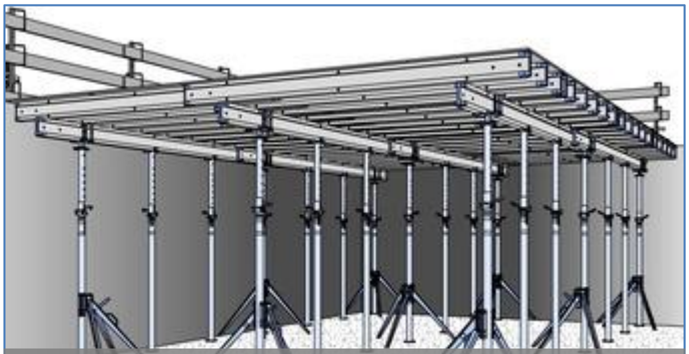


Figure 5: Dokaflex S – Source: Doka

The Dokamatic S Table system is a preassembled formwork system that comes in several standard sizes. These tables only require the addition of the props and when using the shifting device these table forms are able to be set by a single individual, allowing for a possible reduction in the total labor cost. Each of the props is to attach to the tables uses a simple connection method consisting of a clamping swivel head. The large Dokamatic tables have the ability to form large spans of flat slab area, but a secondary system, Dokaflex, is needed to around the drop panels. The Dokaflex system is similar to a stick built formwork system where you first set the floor props followed by Doka beams and plywood. While the Dokamatic tables would allow for a single worker to erect a form, that can only be done with the use of a DoKart table shifting device. The number of tables that could be erected in a day is dependent on the number of DoKart's on site, which would only be another added cost to the system. Another disadvantage of this system is that the tables come in preset standard sizes which may not lend to the layout of the cast-in-place structure.

Peri SKYDECK with Peri Multiflex

Figure 6: Peri Sky Deck – Source: Peri Formwork

The second formwork system that could provide cost and schedule savings is the Peri Sky Deck. This system features a main structural beam which allows the system to utilize fewer floor props. Once the main beams are in place the panels are dropped into place, where they are secured by projecting teeth on the top of the beams. The panels and main beams are covered in a powder coat and have self-draining edges to ensure that minimal cleaning is needed after the forms are stripped. The Peri Sky Deck system is the simplest system out of the three that have been investigated. Along with extremely light and strong aluminum parts, each of the floor props features a drop head system. When these drop heads are stuck with a hammer the Sky Deck panels and main beams drop approximately 2-1/4” to allow for easy removal. Once removed the panels and beams can be transferred to another area of the structure to begin a new forming a new component of the structure. This system seems to hold the most promise as an alternate system.

MevaDec with MevaFlex

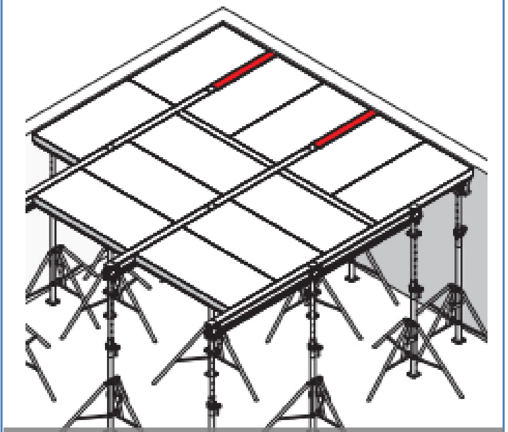


Figure 7: MevaDec – Source:Meva Forms

The final system that was investigated during this preliminary analysis was the MevaDec. This system is very similar to the Peri SKYDECK system previously discussed. Much like that system it features drop head props that allow for earlier stripping of the formwork. However the method that the panels are placed is very different. While the Peri panels sit on top of the main beams the MevaDec panels sit inside the main beams and are installed from below. Although this aspect is safer it’s more complicated installation method could add a significant amount of time to the erection of the slab formwork because of the learning curve. Another drawback with this system is that the drop heads need to be attached to the props with nuts and bolts, which only increases the time required to erect the formwork.

Selected Alternative Formwork System:

After completion of research on the alternative formwork systems discussed above, the Peri SKYDECK and Peri Multiflex systems were chosen as the best fit for 900 16th Street NW. Although the Dokamatic tables cover more surface area the size of the system does not lend itself to work properly at this site location. Also, a main reason why this system was not chosen is that it requires the use of Dokarts to maneuver and set each table, which is only an added project cost and could ultimately slow down the entire process. Even though the MevaDec system is nearly exactly the same as Peri Sky Deck, the added duration from mechanical fasteners on system components makes it unfavorable. The benefits that Peri Sky Deck provides over the other systems investigated above include:

- Ability to use fewer floor props because of the main beam design
- Lightweight components made of aluminum allow for a single individual to install and move system across a slab
- Earlier striking equates to faster turnover rates
- Drop heads attach to floor props with an easy self-locking coupling, which results in a reduction in erection duration

Even though the Peri Sky Deck provides many things that the 900 16th Street project could benefit from there are still drawbacks that may have a large impact on the project. One of those drawbacks is that the aluminum based system will be more expensive because of rental costs for the props and panels. With any new system there will be a learning curve involved, which could create an instance in which the full benefits of Peri Sky Deck are not attained. It will be important that a workforce be employed that has experience with the system so the project can experience the full benefits.

When comparing the benefits and drawbacks of the Peri Sky Deck system it has been determined that the systems benefits with vastly over weigh the drawbacks. The hope of the system is that the schedule will be reduced enough so that the added costs are reasonable.

Slab Forming Sequence:

To optimize the erection of the cast-in-place structure floor was broken into three separate sequences, as shown in Figure 8 below. Out of the three sequences, sequences 2 is the most labor intensive as it is the largest at roughly 7,600 SF. Sequence 1 and 3 are approximately 4,500 SF and 5,100 SF respectively. The sequences will move from North to South across the slab, the areas of which are defined by the dark blue lines. The light blue signifies areas that Sky Deck will be used as the primary formwork system. Green and orange both represent areas of the concrete slabs that have drop panels or a thickened slab. In those areas the primary formwork system will be the Peri Multiflex system, a post and beam formwork system that requires the addition of plywood after erection.

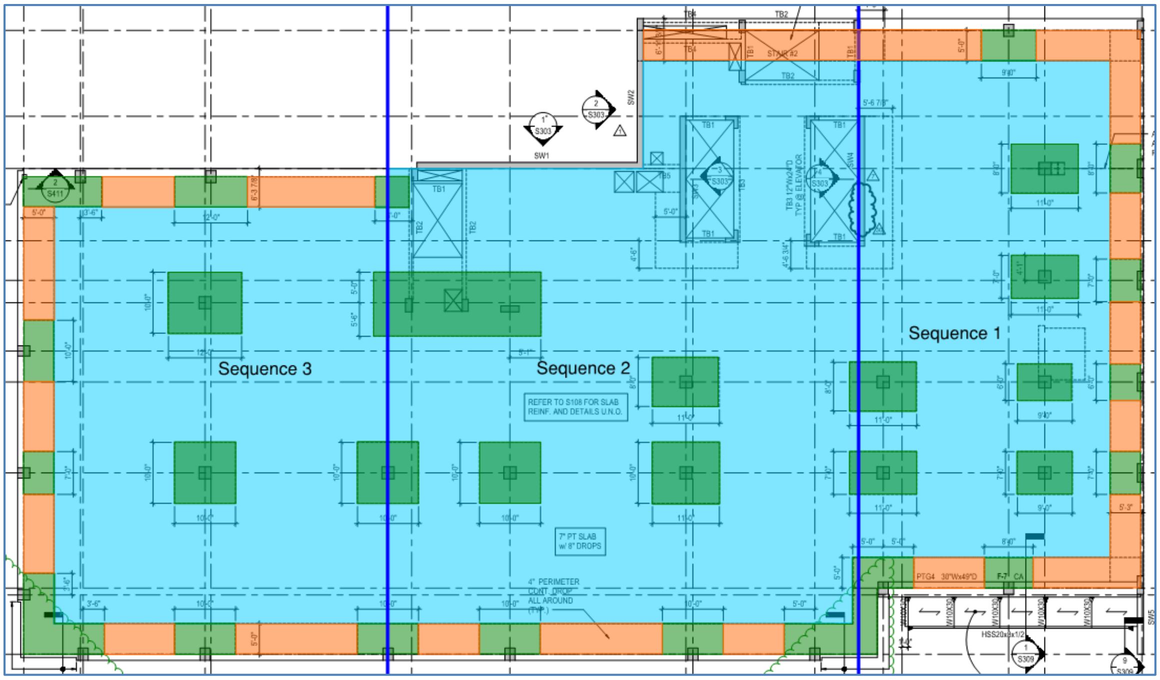


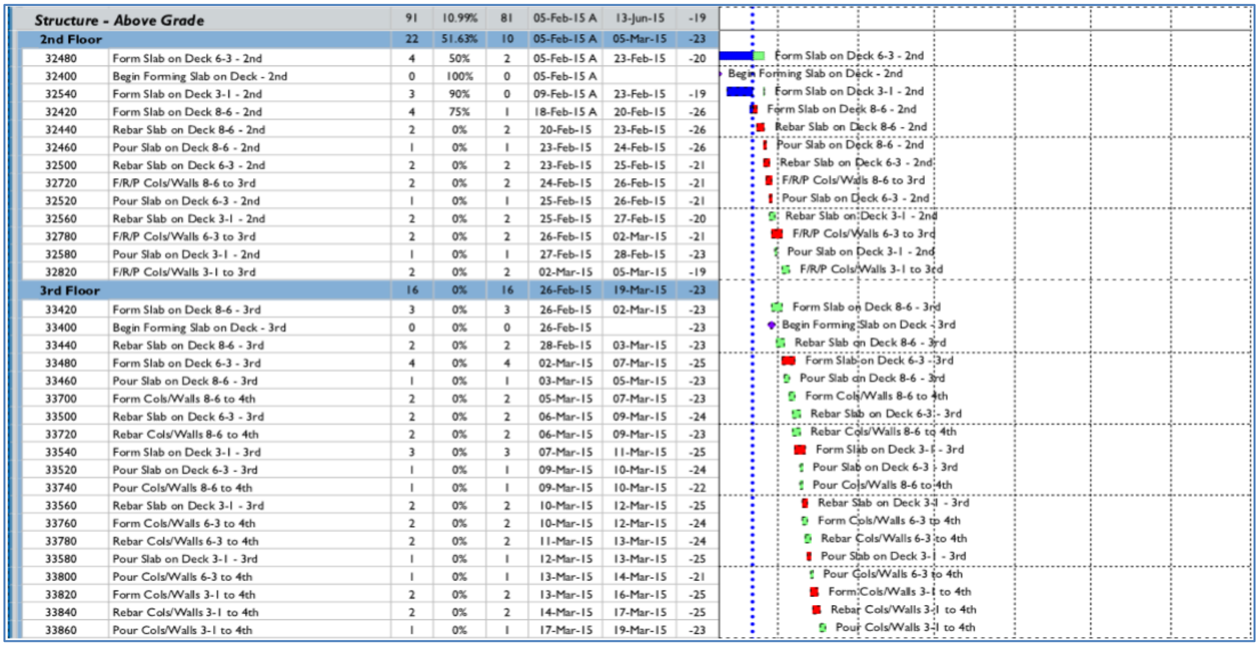
Figure 8: Typical Cast-in-Place Concrete Pour Sequence

Schedule Impact Analysis:

Refer to **Appendix C for a complete schedule and man hour summary of modular formwork**

Stick-Built Formwork:

The schedule for the stick built formwork system is outlined in Figure 9. To maintain the durations that the schedule shows a significant size work force of 47 was used. This work force was deployed on site 10 hours a day, 6 days a week.

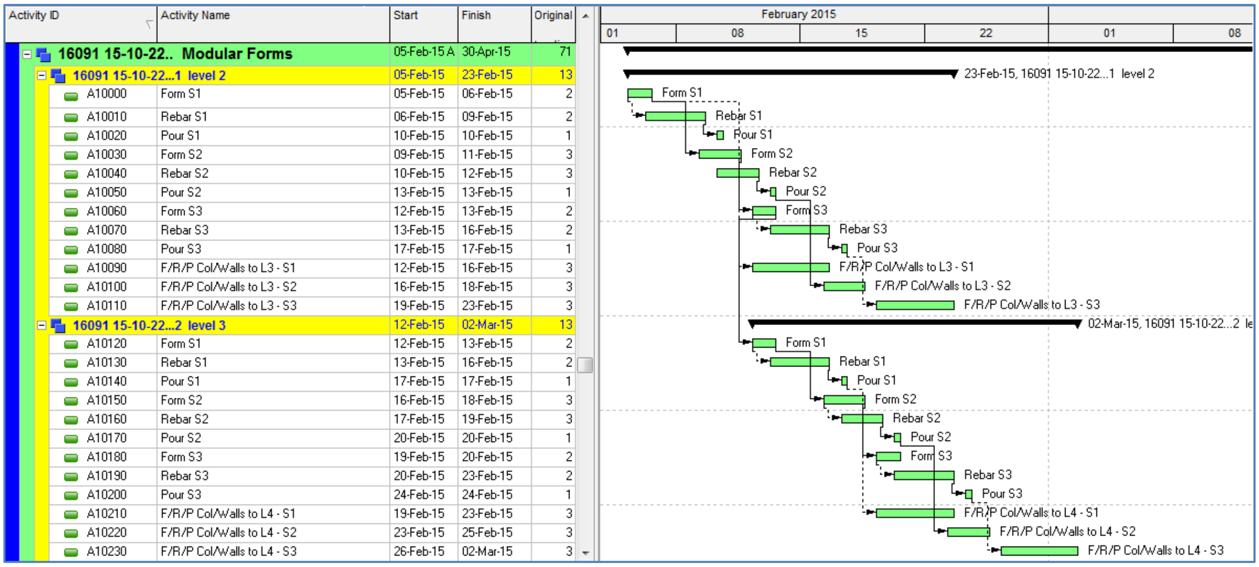


Structure - Above Grade		91	10.99%	81	05-Feb-15 A	13-Jun-15	-19
2nd Floor		22	51.63%	10	05-Feb-15 A	05-Mar-15	-23
32480	Form Slab on Deck 6-3 - 2nd	4	50%	2	05-Feb-15 A	23-Feb-15	-20
32400	Begin Forming Slab on Deck - 2nd	0	100%	0	05-Feb-15 A		
32540	Form Slab on Deck 3-1 - 2nd	3	90%	0	09-Feb-15 A	23-Feb-15	-19
32420	Form Slab on Deck 8-6 - 2nd	4	75%	1	18-Feb-15 A	20-Feb-15	-26
32440	Rebar Slab on Deck 8-6 - 2nd	2	0%	2	20-Feb-15	23-Feb-15	-26
32460	Pour Slab on Deck 8-6 - 2nd	1	0%	1	23-Feb-15	24-Feb-15	-26
32500	Rebar Slab on Deck 6-3 - 2nd	2	0%	2	23-Feb-15	25-Feb-15	-21
32720	F/R/P Cols/Walls 8-6 to 3rd	2	0%	2	24-Feb-15	26-Feb-15	-21
32520	Pour Slab on Deck 6-3 - 2nd	1	0%	1	25-Feb-15	26-Feb-15	-21
32560	Rebar Slab on Deck 3-1 - 2nd	2	0%	2	25-Feb-15	27-Feb-15	-20
32780	F/R/P Cols/Walls 6-3 to 3rd	2	0%	2	26-Feb-15	02-Mar-15	-21
32580	Pour Slab on Deck 3-1 - 2nd	1	0%	1	27-Feb-15	28-Feb-15	-23
32820	F/R/P Cols/Walls 3-1 to 3rd	2	0%	2	02-Mar-15	05-Mar-15	-19
3rd Floor		16	0%	16	26-Feb-15	19-Mar-15	-23
33420	Form Slab on Deck 8-6 - 3rd	3	0%	3	26-Feb-15	02-Mar-15	-23
33400	Begin Forming Slab on Deck - 3rd	0	0%	0	26-Feb-15		-23
33440	Rebar Slab on Deck 8-6 - 3rd	2	0%	2	28-Feb-15	03-Mar-15	-23
33480	Form Slab on Deck 6-3 - 3rd	4	0%	4	02-Mar-15	07-Mar-15	-25
33460	Pour Slab on Deck 8-6 - 3rd	1	0%	1	03-Mar-15	05-Mar-15	-23
33700	Form Cols/Walls 8-6 to 4th	2	0%	2	05-Mar-15	07-Mar-15	-23
33500	Rebar Slab on Deck 6-3 - 3rd	2	0%	2	06-Mar-15	09-Mar-15	-24
33720	Rebar Cols/Walls 8-6 to 4th	2	0%	2	06-Mar-15	09-Mar-15	-23
33540	Form Slab on Deck 3-1 - 3rd	3	0%	3	07-Mar-15	11-Mar-15	-25
33520	Pour Slab on Deck 6-3 - 3rd	1	0%	1	09-Mar-15	10-Mar-15	-24
33740	Pour Cols/Walls 8-6 to 4th	1	0%	1	09-Mar-15	10-Mar-15	-22
33560	Rebar Slab on Deck 3-1 - 3rd	2	0%	2	10-Mar-15	12-Mar-15	-25
33760	Form Cols/Walls 6-3 to 4th	2	0%	2	10-Mar-15	12-Mar-15	-24
33780	Rebar Cols/Walls 6-3 to 4th	2	0%	2	11-Mar-15	13-Mar-15	-24
33580	Pour Slab on Deck 3-1 - 3rd	1	0%	1	12-Mar-15	13-Mar-15	-25
33800	Pour Cols/Walls 6-3 to 4th	1	0%	1	13-Mar-15	14-Mar-15	-21
33820	Form Cols/Walls 3-1 to 4th	2	0%	2	13-Mar-15	16-Mar-15	-25
33840	Rebar Cols/Walls 3-1 to 4th	2	0%	2	14-Mar-15	17-Mar-15	-25
33860	Pour Cols/Walls 3-1 to 4th	1	0%	1	17-Mar-15	19-Mar-15	-23

Figure 9: Stick-Built Formwork Schedule

Modular Formwork:

Figure 10 on the following page is a summary of the projected schedule for the completion of the cast-in-place concrete structure using the Peri formwork systems. After speaking with representatives from Peri it was discovered that the production rate of the Sky Deck and Multiflex systems are 25 and 18 square feet per man hour respectively. Using this information and the areas for each pour sequence on a typical floor it was determined that the appropriate crew size would be 18. Eight of those are responsible for the installation of the Sky Deck system, while the remaining ten are to erect the Multiflex system. The total man hours required to form each floor are broken out in **Appendix C**.



Activity ID	Activity Name	Start	Finish	Original
16091 15-10-22.. Modular Forms		05-Feb-15 A	30-Apr-15	71
16091 15-10-22...1 level 2		05-Feb-15	23-Feb-15	13
A10000	Form S1	05-Feb-15	06-Feb-15	2
A10010	Rebar S1	06-Feb-15	09-Feb-15	2
A10020	Pour S1	10-Feb-15	10-Feb-15	1
A10030	Form S2	09-Feb-15	11-Feb-15	3
A10040	Rebar S2	10-Feb-15	12-Feb-15	3
A10050	Pour S2	13-Feb-15	13-Feb-15	1
A10060	Form S3	12-Feb-15	13-Feb-15	2
A10070	Rebar S3	13-Feb-15	16-Feb-15	2
A10080	Pour S3	17-Feb-15	17-Feb-15	1
A10090	F/R/P Col/Walls to L3 - S1	12-Feb-15	16-Feb-15	3
A10100	F/R/P Col/Walls to L3 - S2	16-Feb-15	18-Feb-15	3
A10110	F/R/P Col/Walls to L3 - S3	19-Feb-15	23-Feb-15	3
16091 15-10-22...2 level 3		12-Feb-15	02-Mar-15	13
A10120	Form S1	12-Feb-15	13-Feb-15	2
A10130	Rebar S1	13-Feb-15	16-Feb-15	2
A10140	Pour S1	17-Feb-15	17-Feb-15	1
A10150	Form S2	16-Feb-15	18-Feb-15	3
A10160	Rebar S2	17-Feb-15	19-Feb-15	3
A10170	Pour S2	20-Feb-15	20-Feb-15	1
A10180	Form S3	19-Feb-15	20-Feb-15	2
A10190	Rebar S3	20-Feb-15	23-Feb-15	2
A10200	Pour S3	24-Feb-15	24-Feb-15	1
A10210	F/R/P Col/Walls to L4 - S1	19-Feb-15	23-Feb-15	3
A10220	F/R/P Col/Walls to L4 - S2	23-Feb-15	25-Feb-15	3
A10230	F/R/P Col/Walls to L4 - S3	26-Feb-15	02-Mar-15	3

Figure 10: Modular Formwork Schedule

After analyzing the projected schedule of completion it was determined that the contractor would only need to rent two full floors of formwork. With the early shuttering times the formwork can be recycled quickly, so that it can be used in another sequence of the structure. The costs outlined in a future section of this report reflect the rental of both Sky deck and Multiflex for the appropriate square footage of two full levels.

Schedule Comparison:

When comparing the two formwork systems it is evident that Peri Sky Deck and Multiflex would have a positive impact on the completion of the cast-in-place structure. As it can be seen in Table 1, the average duration to form a concrete pour sequence decreases by 1.7 days. The average duration to complete a floor from beginning of formwork to pouring the slabs and columns decreased a total of 5 work days. Saving such a large amount of time per floor equates to a total possible savings of 20 work days.

Table 1: Formwork Schedule Comparison

Summary of Projected Schedule Savings			
Formwork System	*Sequence Duration*	*Floor Duration*	*Total Duration*
Stick-Built	4	18	91
Peri Systems	2.3	13	71
Difference	1.7	5	20

Cost Impact Analysis:

Reference **Appendix D for a complete cost estimate of both formwork systems**

The following assumptions have been made during the analysis of the cost of both the original stick-built system and the implementation of Peri Sky Deck:

- Cost of stick-built system, Plywood for Multiflex system, and labor costs are attained from RS Means 2016
- Miller & Long own stick-built formwork system so their only material cost would be plywood
- Multiflex system is only required in the exact SF coverage of the drop panels and perimeter beam

There are several costs that will change between the use of a stick-built form work system and Peri Sky Deck and Multiflex. The main factors that will change are the costs from both materials and labor. The labor required to install a traditional stick built system is far greater then what is required of the Peri Sky Deck and Multiflex systems. The ease of which the Peri Sky Deck system can be installed allows for a large reduction in the total labor force required to form the structural slabs. To drive the schedule as it has been planned in the previous section it would be required that an average of 114 man hours be needed each day for forming activities, opposed to the average 458 daily man hours to keep the stick-built formwork on schedule. After analyzing the two average daily man hours it was determined that the implementation of the Peri system would generate a labor savings of 75% (refer **Appendix C** for production rate and total man hours per floor).

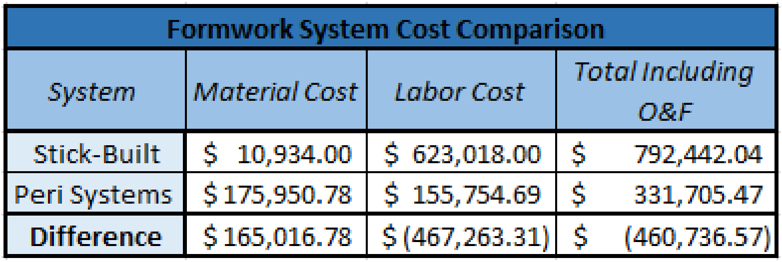
Table 2: Formwork Rental Costs

Rental Cost Per Month	
System	*Cost per SF*
Sky Deck	$ 1.85
Multiflex	$ 1.15

To best complete the schedule reflecting the modular formwork, it was determined that the contractor would need to rent enough of the Peri forms to complete two floors at once. Upon contacting a representative from Peri, the rental costs per square foot per month were obtained. These costs are summarized in Table 2 to the right. It is important to note that the plywood required for the Multiflex system will be an additional one time cost. As stated previously the structure is projected to be completed in 71 working days, which would require the formwork rental fee to be charged on three occasions. Four use plywood was priced out for both the stick-built and modular systems. In order to complete the structure it is required that the equivalent of three floors of plywood needs to be purchased.

All of the costs discussed on the previous page are shown in full in **Appendix D**. Below, in Table 3, is a summary of the total costs for both of the formwork systems.

Table 3: Cost Comparison



Formwork System Cost Comparison			
System	*Material Cost*	*Labor Cost*	*Total Including O&F*
Stick-Built	$ 10,934.00	$ 623,018.00	$ 792,442.04
Peri Systems	$ 175,950.78	$ 155,754.69	$ 331,705.47
Difference	$ 165,016.78	$ (467,263.31)	$ (460,736.57)

Recommendation:

Stick-built formwork used on 900 16th Street did not provide the project schedule with optimal durations. It is understandable that it was used because the drop panels in the slab lend themselves better to a stick-built system. However due to the versatility of Peri Sky Deck and the use of Peri Multiflex at the drop panels, modular formwork is just as feasible. The Sky Deck system with its light weight panels and props make the formwork much easier and faster to install then a stick-built system.

After taking into account the benefits of the modular formwork systems and how their implementation into the project impacts the schedule, I recommend that this system be used on 900 16th Street. According to the daily reports from Miller & Long and the calculated man hours to complete erection of the formwork a labor reduction of 75% could be achieved. Even though the initial cost of the system is high because of the need to rent the forms directly from Peri the final cost savings generated through the reduction of labor outweigh the initial cost premium. It total it has been projected that the savings would be equal to $461,000.

The schedule savings that the implementation of modular forms would reflect is considerable at 20 days. This value could be effected by the time it takes for the tradesmen to learn how to install the system. After studying this system and speaking with individuals at Peri, it was determined that the impact of the learning curve for the alternative systems would be minimal. The results of this analysis confirm the expected results that modular forms would benefit the project therefore the use of modular formwork on 900 16th Street is recommended.

|TECHNICAL ANALYSIS II – Exterior Façade System Redesign|

Problem Identification:

The 900 16th Street project features a variety of façade systems. The main facade system used on this building is precast concrete panels. The panels themselves vary from a typical precast panel that one may see on a project because these feature high end finishes (limestone, granite, and marble) inlayed within them. These high end stones added a significant amount of weight to the panels therefore the connections to the cast-in-place structure needed to be strengthened to ensure they would be supported. These connections required extra care in the field upon installation and a number of the connections were overly complex taking hours to complete. One main issue that arose of delays of materials to site, some of which were created by lack of material and others were shut down by the secret service for special events occurring in the area. Delays were created on several circumstances because there was no material on site to erect. Also delays incurred when the cranes erecting the panels needed to be used to fly in materials for other trades.

In its entirety the precast façade system features over 250 individual precast panels, and cost just over $2.3 million for both the material and labor. The erection of the panels began on May 5th 2015 and erection was completed, not including broken panels, on the 14th of July. In total the duration for the erection of the precast panels was 7 weeks and 4 days. Conducting research on an alternative system could create a great value engineering opportunity, while also helping to reduce the load the façade will have on the structure and increase the thermal performance of the façade system. Because this building was design to be a trophy class office building with various high end finishes it is imperative alternative must give similar visual appeal and lifespan.

Research Goals:

The purpose of this analysis is to analysis the current precast concrete façade system and suggest an alternative system. Overall the goal is to propose an alternate system that will allow for an acceleration in the schedule and decrease the overall cost without compromising the architectural appeal of the finished product.

Methodology:

In order to complete the analyses that I plan to conduct, the following steps will be taken:

- *Research*
    - Research innovative façades that provide similar aesthetics, durability, and lifespan to the façade system that is in use
    - Select the system that best fits the needs of the clients requirements and the goals of this analysis

- *Technical Analysis*
    - Determine the cost of the system in use (material, labor, equipment)
    - Conduct a constructability analysis of the alternate system chosen
    - Estimate the cost of the alternate system (material, labor, equipment)
    - Determine the estimated installation duration of the alternate system and how it impacts the overall project schedule
    - Compare the cost and schedule of the façade system in place to the alternate system chosen
    - Conduct a structural breadth analysis by ensuring the structure can support the loads of the alternate system
        - If the system in place does not work with the current connection method design a typical connection for the alternate system
    - Conduct a mechanical breadth analysis by assessing the thermal performance of the alternate façade system
    - Evaluate the aesthetic appeal of the alternate system selected with the requirements of the client
- *Recommendations*
    - Make recommendation based on the overall impact of cost, project schedule, and aesthetic appeal of the alternate system

Expected Results:

Overall the results of this analysis are expected to be positive. There is a fantastic opportunity to reduce the cost of the project by utilizing an alternative façade system to the precast concrete system in place. It is also possible that the schedule can be accelerated. In addition, the overall impact the alternate system will have on the structure will be decreased and more simple connections will be created. Moreover the thermal efficiency of the exterior façade will increase with an alternate system.

Analysis:

Original Façade System:

System Description:

The façade system that is currently in place on this structure consists of a precast concrete panels with stone veneer, various curtainwalls, bronze finished storefronts, and StoTherm Next EIFS (Reference figure 11 below for a breakdown of the façade composition). For the purpose of this analysis the only system that will be analyzed is the precast concrete panels. Each of the panels features either a 3” limestone or marble veneer on the exterior face, depending on the location of the panel. The size of each of these panels varies throughout the entirety of the façade. In total the entire façade is comprised of 308 different precast panels covering roughly 17,000 square feet, with an average panel covering 93 square feet.

LEGEND
Yellow – Limestone Precast
Red – Marble Precast
Green – Curtainwall/Storefront
Orange – Structural Curtainwall
White – Window Units

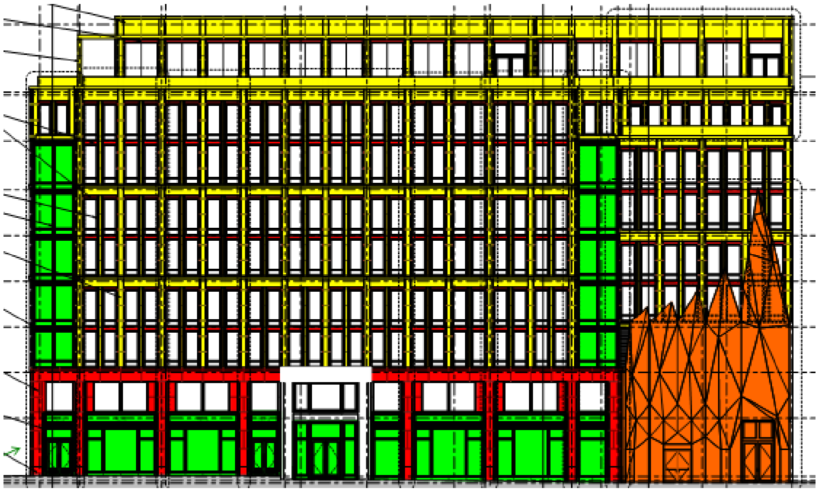


Figure 11: Façade Types on East Elevation

Each of these panels were transported to site on a flat-bed truck and lifted directly into place by one of the two cranes on site. The tower crane was used to erect the panels on both the West and South elevations, while an additional track crane was delivered to site to erect the precast panels on the East elevation.

Issues with Original Facade System:

It is typical to see a precast concrete panel façade in downtown DC but the limestone and marble veneers brought with them extra precautions. Care needed to be taken that none of the finish stone was cracked when the panels were lifted from the flat bed they were delivered on and set into place. As stated earlier most of the façade is a fairly simple system but what did provide challenges were the number of various connections and the added weight of the precast panels from the limestone and marble. While a majority of the connections between the panels and the structure were quite typical there were many that required special attention due to their complexity. These welded connections took a considerable amount of time to complete compared to their typical counterparts

Besides the varying variety and complexity of the connections, the marble and limestone cast into the concrete created a whole new challenge. This challenge was the added weight to the panels from these dense stones. The increase in weight required larger cranes and extra care in maneuvering each panel into place. To best take these challenges out of the picture the DAVIS team held many preconstruction meetings with all parties involved to choose the cranes to be delivered to site. This ensured that the entire process would run as smoothly as possible.

Alternative Façade System:

Required Characteristics:

The owner's vision for this structure was to create a trophy class office building with extremely high end finishes. For that reason, among others, a precast concrete façade with limestone and marble veneer was chosen.

One challenge the design team was presented with came from the location of the building. Located within the historic sixteenth street district, the design team had to abide by the design criteria set forth by the Historic Preservation Board. The guidelines laid forth revolve around the ability for the new structure to blend in with the buildings that neighbor it. Key proponents to achieving this include façade materials, exterior color, and ornamentation.

Many buildings neighboring 900 16th Street feature ornamental storefronts at the street levels with limestone covering the rest of the structure. The current façade system in place at 900 16th Street consists of bronze capped aluminum storefronts and precast concrete faced with limestone and marble covering the rest of the building. This current system uses the materials that are similar in nature and appearance to the buildings around it. It is imperative that any alternative system chosen incorporate limestone or be able to mimic its appearance. In giving the appearance of limestone it is also important that the material can closely match the color of neighboring structures.

Another area of concern that needs to be addressed is the weight and thermal performance of the wall system. The current system of precast concrete panels with stone veneer does not provide optimal thermal protection for the interior spaces. Also, this system, which is up to 15" thick, exerts a significant amount of stress on the buildings cast-in-place concrete structure. Providing a system with improved thermal performance would cut down on the operating costs of the structure. A more lightweight system has the ability to use less complex and time consuming connection methods.

Lastly it is important to consider the costs and schedule impacts an alternative system would have on the project. While this particular owner was more concerned with the overall quality of the project it is still important that the new system fits within the projects budget. It is also imperative that the new system selected be able to have the building effectively closed in within the 7 weeks it took to erect the precast panels.

Alternate Systems Investigated:

As stated previously in this report, any alternative façade system that is to be considered must have a finish that is extremely close to true limestone. This obstacle immediately narrowed the number of alternatives to the precast panels already in place. Under the constraints it was determined that there were three available options that could be a possibility. The first option that was researched was a system that was comprised of cement fiber panels. This system has great qualities that make it a good candidate to replace the current system in place. Each of the individual fiber cement panels are completely detached from the structural wall of the façade, allowing each panel to act as a rain screen, protecting the actual wall system from being exposed to water. The air gap that is present between each of the fiber cement panels and the rest of the façade system creates a ventilated moisture management system, helping to prevent water vapor from getting trapped within the wall system.

Cement Fiber Board lends itself well to the requirements set forth previously, defining the design criteria for an alternative façade system. However construction of such a façade may prove to be difficult. This system features a series of individual panels that are attached to a previously constructed substrate. Each panel would need to be lifted into place and mechanically attached to the face of the building. While the process of attaching the panels is quite simple, when using the quick clip system, it is a system that would require much more time to complete then a panelized system. The height of the structure would provide another issue surrounding the attachment of the panels as well. A simple man lift would not allow for the panels on the upper most level to be installed therefore a system of suspended scaffolding would have to be used. In either system it would be dangerous because of the close proximity to that of the tower crane.

The design of the façade itself poses an issue to the use of cement fiber panels as well. Panels are manufactured in set widths and lengths. Although it is possible to cut and shape cement fiber panels to meet the needs of a project the number of large windows would make it highly time consuming to cut and refinish each panel. Also, another main downfall with this system is that it is not possible to get a panel that matches close enough to that of limestone that would be acceptable.

The next system that was evaluated was StoTherm Next EIFS. The reason for investigating the possibility of using such a system was because it is currently used in a portion of the West façade that is in an ally way behind the structure. EIFS systems are favorable in certain circumstances because, as the name leads one to believe, it wraps the building in an extra layer of insulation, increasing the overall thermal performance. One of the purposes of this analysis is to increase the thermal performance of the exterior façade system to decrease heating and cooling loss. If such a system were to be implemented it would certainly decrease the amount of heating and cooling lost through the exterior wall system.

Although this system will allow the thermal resistance of the wall to be increased it does have significant drawbacks that would turn the owner away from using it on the 900 16th Street project. The first issue that would raise a flag to the owner is the systems inability to resist impact damage. The thin base coat of the StoTherm Next EIFS system is prone to cracking under direct impacts. If the façade is riddled with cracks then the status of a trophy class office building will be compromised. Along with the system inability to resist impact damage, when an EIFS system is subjected to cracking over its lifespan.

Selected Alternative System:

Table 4: System Selection Summary

Alternative Façade System Evaluation				
Criteria	Importance	*Possible Alternative Systems*		
		Cement Fiberboard Panels	*StoTherm NExT EIFS*	*Thermocromex*
Thermal Resistance	2	1	2	2
Asethetics	3	1	1	3
Lifespan	3	3	3	3
Weight	2	1	2	2
Ease of Installation	2	1	2	2
Maintenance	2	2	1	1
Durability	3	3	1	2
Summary	17	12	12	15

As it can be seen in the table above the specific system chosen to replace the precast concrete façade on the 900 16th Street NW project consists of prefabricated panels with a Thermocromex finish. While this particular system is similar in nature to that of a traditional EIFS system the one main benefit this system has is its finish quality. Thermocromex initially began to be used throughout the United Kingdom and other European countries before being introduced to the market in the United States. Having been introduced to the market place in 1985 the material is still relatively new. Although it has not been around as long as several other façade types the use of this system is growing due to its wide array of finished available and exceptional performance characteristics.

As stated earlier in this report, that due to its location, this building posed a unique set of criteria when it comes to the façade. The building footprint sits with the historic district of Sixteenth Street and its design requires the approval of the Historic Preservation Board. One of the main points that is laid forth in the design guidelines is states that new buildings should mimic the materials that have been used on the neighboring buildings so that the appearance of the buildings are compatible. Thermocromex is manufactured in a mixture that provides an exact match to natural limestone (Reference the image below for a comparison of limestone to Thermocromex limestone finish).

Along with the high quality of finish, the weight and mechanical properties of the material are exemplary. The material weighs 3lbs per square foot at a thickness of 3/8”, which is a significant difference than that of the 150 lbs per cubic foot concrete panels. Due to this decrease in overall weight it is possible that the panels will be able to be larger, cutting down on the overall time on erection. Besides the extreme reduction in weight, Thermocromex also adds an incredible amount of thermal resistance to a wall system. At a thickness of 3/8” Thermocromex will add 0.94 to the total R-Value of the wall system.

Alternative System Installation:

There are several ways in which the alternative Thermocromex façade system can be installed on the 900 16th Street project. One way to install this alternative system would be by using a scaffolding system, whether it be stick-built, suspended scaffolding, or hydro-mobile, to install the system components one by one until the finish coat is applied. The issue with this method of installation is the scaffolding itself. The project location and site size would make it extremely difficult to bring in numerous pieces of scaffolding for a stick-built system. Although hydro-mobiles would have considerably less parts, they would still envelope a significant amount of lay down area which is already small. Lastly suspended scaffolding creates a significant safety hazard because they would be in close proximity to the tower crane and the materials that it is flying in to various levels of the structure.

For the reasons stated above it was decided that the alternative façade system would be installed much like the original system, in prefabricated panels. While the original precast panels were cumbersome and required numerous, time consuming, welded connections, these new panels will be much lighter and easier to install.

Following a meeting with Alex Brown of Mortenson Construction, it was decided that to allow for the shortest duration to complete the system that all components should be included on the panels prior to erection. The composition of the panels can be seen on the following page in

Figure 12. Figure 13 on the following page show the South elevation prefabricated panel breakdown. The red panels span 8’-6” across and are 24’ in length. The green below them represent panels that are dimensioned at 8’-6” by 44’- 6”. The blue and purple measure 2’-2” by 24’ and 2’-2” by 44’-6” respectively. Each of the panels described above will feature a limestone Thermocromex finish so as to match the limestone veneer of the original system. Both the orange and red panels on the ground levels of the elevation will be finished to match marble.

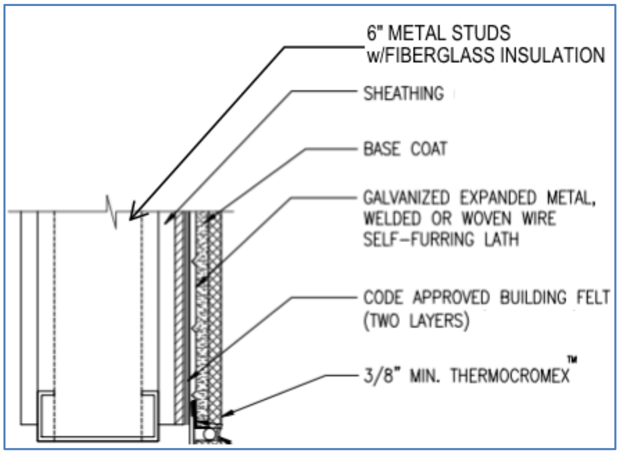


Figure 12: Panel Composition

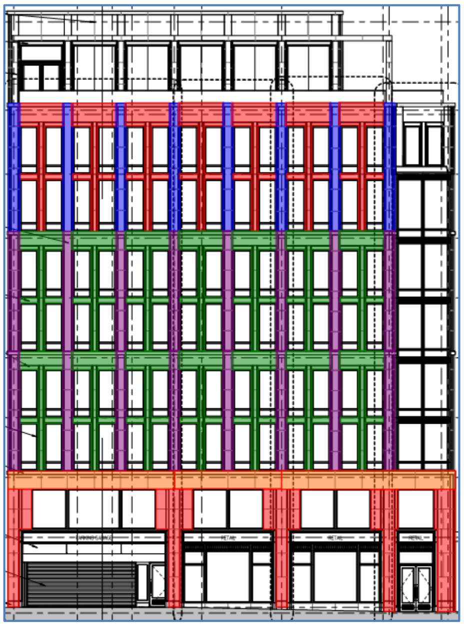


Figure 13: Panel Breakdown

The panel sizes mentioned above were chosen because they create a natural break in the façade and will allow for the joints between the panels to be less noticeable. The size of the panels were confirmed as possible after it was discovered that Pegula Ice Arena featured 50’ prefabricated panels. Even though some of the panels are quite large they fit perfectly on a flatbed truck (dimensioned 8’-6” x 48”). Under the direction of Alex Brown of Mortenson, it was determined that the panels can be stacked 6 high on a flatbed. With a continuous flow of deliveries this façade system has a possibility of accelerating the project schedule.

These the largest panels that will need to be erected have an area of approximately 125 square feet. The following calculation was done to determine the weight of the largest panel:

$$(125 \text{ SF} \times 12 \text{ lbs/SF}) \times 1.10 = 1650 \text{ lbs}$$

To take into account any errors in area take off or variance in the weight of materials a factor of safety was added. The weight of this panel is significantly less than that of the original façade system. This decrease in weight allows for the secondary panel erection crane to be downsized from a 100 ton crane to a 40 ton crane (**Appendix E** shows the load charts and calculations to support this). The reflected cost savings can be found in the cost analysis portion of this report. This 40 ton crane would be dedicated to the erection of the panels on the East elevation of the building. Both the West and South Elevations will be erected using the tower crane. The tower crane needs to also be used to fly in materials for the other trades completing work on site. After consulting the project team it was decided that the tower crane on average spent 60% of the day focused on erecting façade panels.

Unlike the original façade system which required multiple fully welded connections per panel, the Thermocromex panels feature a much simpler connection as shown in figure 14. The first step to creating this connection is to cast steel angle into the edge of the concrete slabs. Once the formwork is stripped welding teams can be sent into the field to install the connection clips to the steel slab edge with a welded connection. These connection clips feature a 5 point mechanical connection to attach the prefabricated panels. Once lifted into place by a crane the panels are received by the clips and then connected with 5 TEK-H fasteners and the erection team would move on two erecting the next panel.

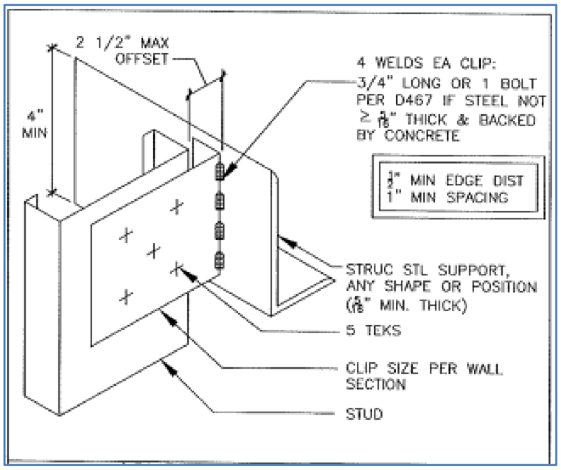


Figure 14: Connection Detail – Source: Pegula Shop Drawings

Structural Breadth Analysis: Structural Load Analysis

Reference **Appendix F for calculations to support structural investigation**

One of the considerations when choosing the alternative façade system was the effect that it would have on the structure of 900 16th Street. Altering the composition and materials in the exterior façade will exert a completely different force on the columns of the building. Much like the precast concrete panels, the prefabricated Thermocromex finished panels are not self-supporting, so their weight needs to be transferred through the connections and down through the columns to the foundations. In order to ensure that the designed columns can support the new load introduced by the change in façade, a load analysis must be completed. To complete this investigation thoroughly the weight per square foot of the prefabricated panels needed be calculated. To do this information was attained from the Thermocromex manufacturer and from online resources. The results of this load analysis concluded that the structural system in place has the capability to support the load exerted by the alternative façade system.

Technical Investigation:

To begin this analysis the structural plans were analyzed to locate the exterior column which would carry the largest amount of loading. After looking at a typical column layout it was determined that the column with the largest tributary area is column G-3, located on the East façade. Figure 15 below highlights the location and tributary area of column G-3.

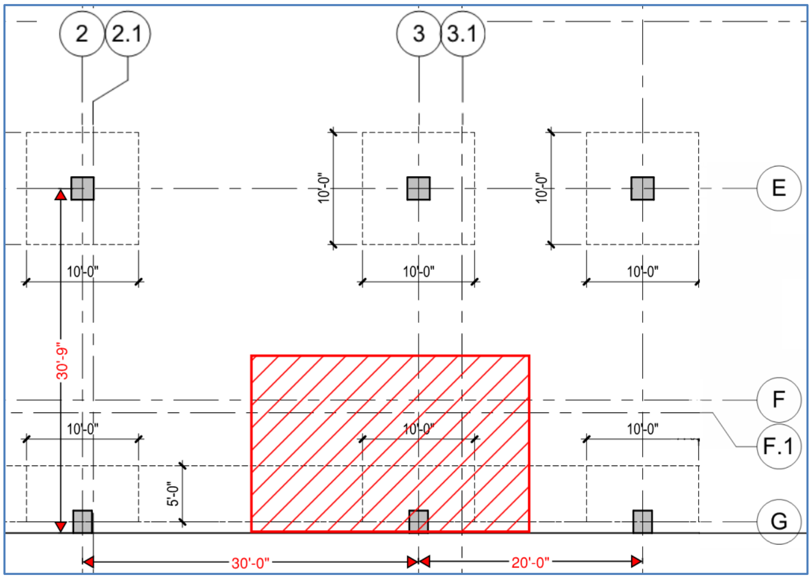


Figure 15: Area of Investigation

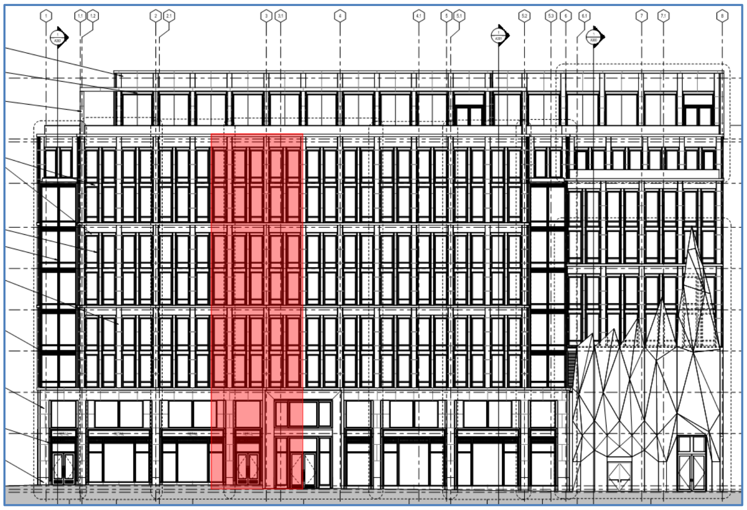


Figure 16: Tributary Area of Structural Analysis

The figure directly above highlights the area of the East façade that influences the loads experienced by column G-3. In this area of the façade there is both the prefabricated panels, aluminum punched window units, and storefront. Column G-3 was selected for this investigation because it represents the worst case scenario for the entire building. The dimensions of the column are 20” X 24” with 8#8 rebar evenly spaced and #4’s at 16” for stirrups.

The total calculated weight per square foot of the panels is 12 lbs/SF, 3 of which come directly from the Thermocromex finish at 3/8” thickness. Consulting the design loads the in the project specifications it was discovered that the design load for the punched windows and storefront were both 15 lbs/SF. Taking these values and the weight of the concrete slab within the tributary area is was determined that the total axial load on the column through to the foundation would be 1,132 kips. Note that the loads on this column is not affected by the façade system on the 9th floor because its loads are transferred through column line E because of the setback in the façade. After completing the column strength analysis it was calculated that the maximum axial load the column can support is 1,453 kips. A spot check of the maximum moment that the column can withstand was completed at a typical floor. This analysis yielded a maximum imposed moment of 187 in-kips. The maximum moment, according to CRSI tables, that this column can withstand is 2204 in-kips. Since the maximum imposed values are less than the absolute maximum moment and axial load it is confirmed that the structure in place can support the alternative faced system.

Mechanical Breadth Analysis: Thermal Performance of Alternative Façade System

Reference **Appendix G for full reports from thermal performance analysis**

As this analysis focuses on changing the exterior façade of the structure it is important to consider how such a change would impact the thermal efficiency and cooling loads throughout the building. Below shows a typical wall section of the original façade system and the table accompanying it depicts the R-values of the materials that it is composed of.

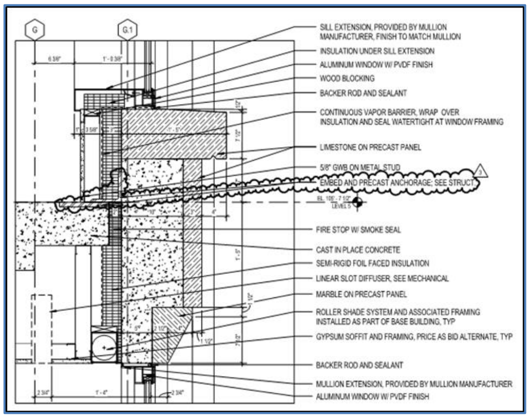


Figure 17: Precast Concrete Facade Section

Table 5: Precast Façade R-value Summary

Precast Concrete with Stone Veneer	
Material	*R-Value*
5/8" GWB	0.57
3-5/8" Metal Stud	0.01
Vapor Barrier	0.12
3" Semi-Rigig Insulation	10.68
11" Precast Concrete	1.44
3" Limestone Veneer	0.18
TOTAL	13

The original precast concrete façade system provides a thermal resistance of 13, which is typical for a concrete based wall system. As it is seen in the section above the panels themselves are comprised of 3” limestone and 11” of concrete. Following the concrete is the interior wall system. The precast panel offers very little thermal resistance while the interior wall makes up a large majority of the systems thermal resistivity.

Upon selection of the alternative exterior façade system it was expected that the total thermal resistance would be significantly higher than the original system. The figure and table below show a typical section of the alternative façade system and a summarization of the R-values that it is composed of.

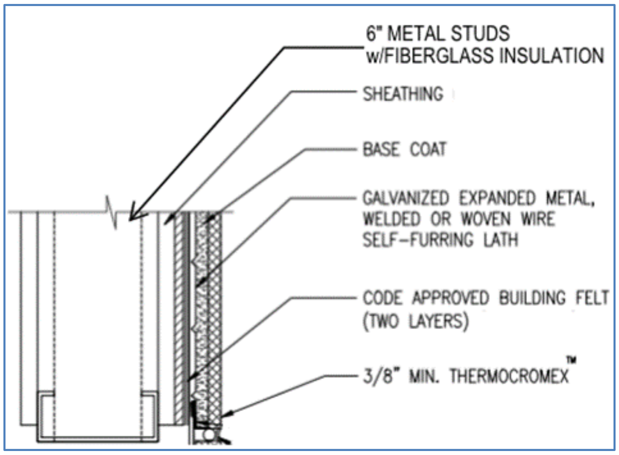


Figure 18: Alternative Facade Section

Table 6: Alternative Façade R-value Summary

Prefabricated Thermocromex Panels	
Material	*R-Value*
5/8" GWB	0.57
3-5/8" Metal Stud	0.01
Vapor Barrier	0.12
3" Semi-Ridig Insulation	10.68
6" Steel Studs (16 ga.)	0.02
1/2" GWB	0.56
Weather Barrier	0.17
Adhesive	0
2" EPS Insulation Board	10
Building Felt	0.06
Metal Lath	0
Base Coat	0.94
Thermocromex Finish Coat	
TOTAL	23.13

The spaces that will be analyzed include two corner office spaces located on the 5th floor. These offices were chosen because they are included within the portion of the building that is undergoing interior construction. Much of the space within the structure remains unleased and has yet to have plans for interior construction. While a majority of spaces that have an exterior wall share similar features these two spaces differ because of the percentage of window coverage. The spaces that will be the focus of this mechanical study are shown on the following page. Office 0557 has a total window coverage of 50% and Office 0546 has a total window coverage of 78%.

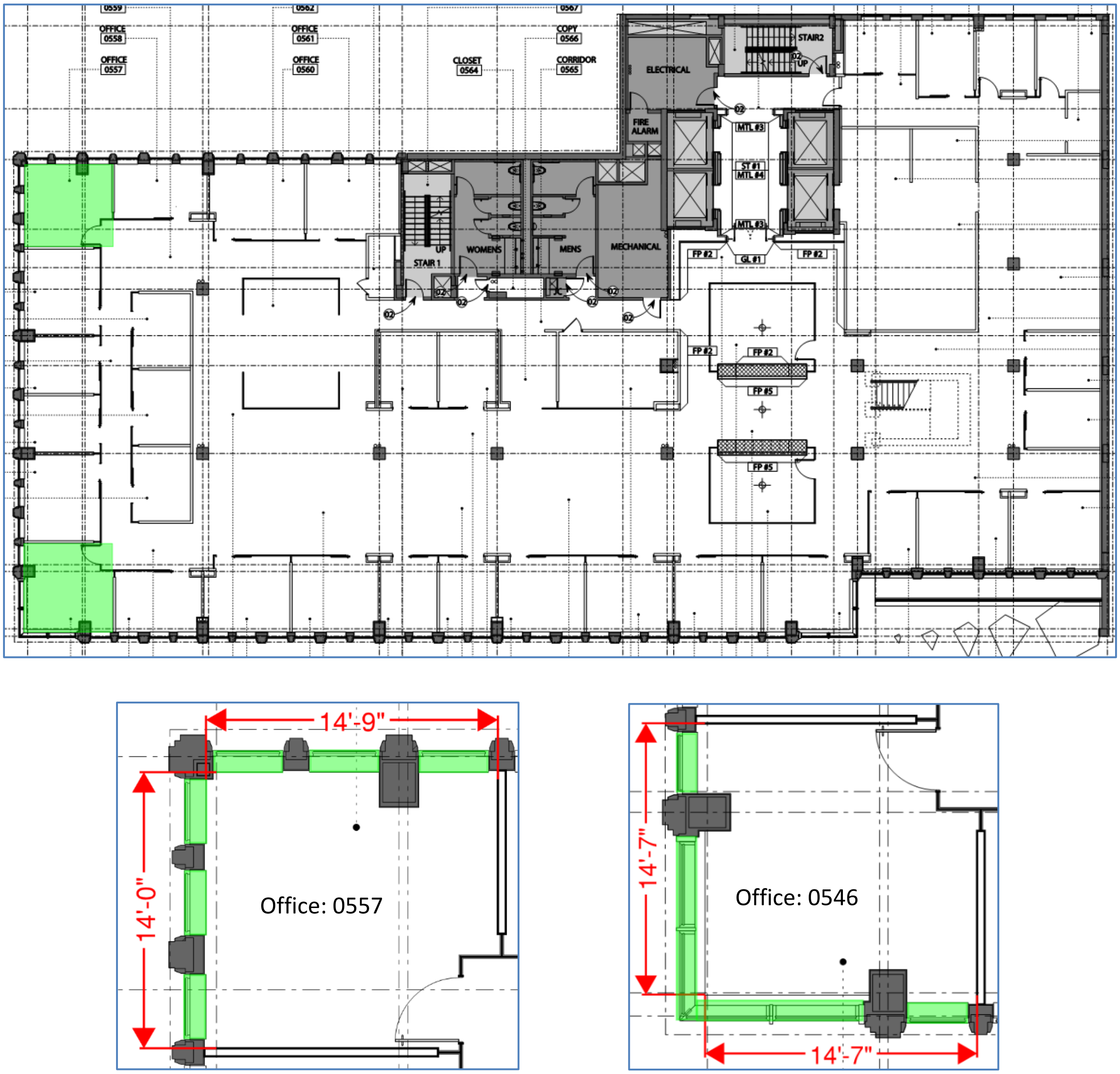


Figure 19: Mechanical Analysis Spaces

Evaluation:

To evaluate the differences in thermal performance of each wall system the program Trace 700 was used. The goal of the simulations run through this program was to measure the change in the cooling load of the spaces to see if altering the exterior façade system would have an impact on the performance of the building. Table 7 summarizes the results of the simulation that was conducted. The alternative façade system resulted in a decrease of 286 BTU/hr of cooling load. It was not expected that the introduction of a different exterior wall system would have a large impact because more than 50% of the wall is comprised of glazing. The impact that the large area of glazing has on the performance can easily be seen in the table below. Although the overall impact ended up being marginal, the analysis was still highly successful because the performance of the facade was increased by 56% when the alternative system was introduced.

This decrease in the required cooling load for the spaces is not significant enough to consider the reduction in the size of the air handling units suppling these spaces. Also, the office space in this building is being leased so there is a chance that the layout of the interior could change over the buildings lifespan. With that in mind it would be best to leave the air handling units as designed so they can serve a wide array of spaces and occupancy types.

Table 7: Comparison of Cooling Loads

Cooling Load Comparison		
Applicable Loads	*Cooling Coil Peak Load (BTU/hr)*	
	Precast Concrete w/Stone Veneer	*Prefabricated Thermocromex Panels*
Envelope Loads		
Glass Solar	6831	6831
Glass/Door	436	436
Wall	654	368
Internal Loads		
Lights	701	701
People	500	500
Total	9122	8836

Table 8: Monthly Utility Cost Comparison

Monthly Utility Cost Comparison		
Month	*Total Costs*	
	Precast Concrete w/Stone Veneer	*Prefabricated Thermocromex Panels*
Janurary	$91.00	$90.00
February	$83.00	$79.00
March	$86.00	$85.00
April	$85.00	$84.00
May	$88.00	$88.00
June	$88.00	$88.00
July	$92.00	$92.00
August	$92.00	$92.00
September	$90.00	$90.00
October	$88.00	$87.00
November	$86.00	$85.00
December	$87.00	$87.00
Total	**$1,056.00**	**$1,047.00**

In addition to analyzing the loads required to condition the spaces a secondary analysis of the monthly utility costs was completed. After discovering that the cooling loads of the spaces had decreased with the implementation of the alternative façade system it was expected that the utility costs would decrease as well. The outcome of this analysis is summarized in Table 8 on the previous page. As it is shown the utility costs per year, for the spaces analyzed, were reduced by $9.00. This is not a large savings but if it is extrapolated throughout the entire area of occupied space within the structure it results in nearly $3,000 in savings per year.

Schedule Analysis:

Original Façade System:

Reference **Appendix H for the original façade system schedule**

The original façade of 900 16th Street took a total of 141 days to complete. This duration includes all window, storefronts, and curtainwall installations. The construction of the façade began on the 11th of May 2015 and completed on the 3th of November that same year.

Alternative Façade System:

Reference **Appendix I for the full alternative façade system schedule**

After consulting with industry members it was estimated that the panels would be able to be erected at a rate of 1 panel per hour (this rate includes the large 44’-6” panels). Crews would be working 10 hour work days, which would mean that a total of 9 panels could be erected per day. As stated previously the tower crane will only dedicate 60% of its time per day (6 hours) to the erection of the façade, meaning that it is only capable of erecting 6 panels per day.

Using the same initial start date as the original system, the installation of the alternative façade is projected to be completed on the 20th of October. These dates reflect a duration of 127 days from start to completion.

Comparison:

The implementation of the alternative façade system reflects a total schedule savings of 14 days, which is a 10% reduction. This schedule savings is mostly impart to the increased ease of installation that the Thermocromex finished panels provides. Also, their significant decrease in overall weight provided the opportunity to enlarge the panels and erect a larger area of façade in a single lift. This is a significant reduction because an earlier completion of the façade allows the building to be essentially dried in. Once this milestone is met the interior can be released so as to move the completion of the building along.

Cost Analysis:

Original System Cost Breakdown:

Table 9 to the right summarizes the costs associated with material and labor involved in making the precast concrete panels with stone veneer. The $2,000,000 cost for this façade system is largely due to the stone veneer which accounts for 58% of the total system cost. In addition to the costs outlined in table 9, there was an additional $270,000 charged by the contractor to erect the panels.

Table 9: Original Façade Cost Summary

Precast Panel Façade Cost Summary	
Item	*Cost (Material & Labor)*
Marble Veneer	$ 1,181,000.00
Limestone Veneer	$ 143,000.00
Anchors	$ 37,500.00
Panel Fabrication	$ 712,000.00
Total	$ 2,073,500.00

Prefabricated Thermocromex Panel Cost Breakdown:

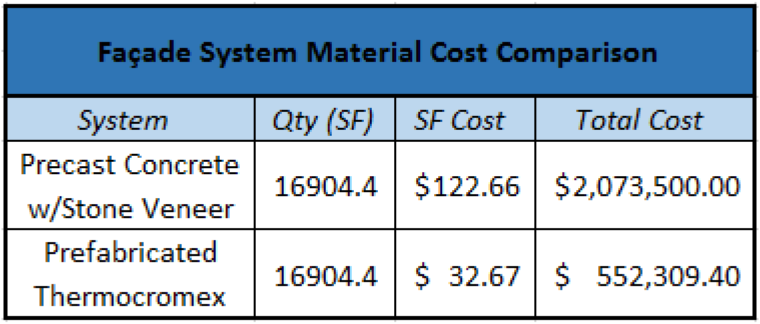
Refer to **Appendix J for a complete summary of the cost estimation**

To attain an accurate cost of the prefabricated Thermocromex panels RS Means Building Cost Data 2016 was used to estimate material, labor, and equipment costs. Upon completion of the estimation it was determined that the alternative façade system would have an estimated overall cost of $552,309. While this estimated number does not included the cost of the additional crane and manpower to install the panels, it does however reflect a cost reduction of 74%. Based upon the weights of the materials and the breakdown of the panels on the façade, it was determined that the crane needed to erect the façade could be much smaller.

System Cost Comparison and Evaluation:

It is evident that the alternate façade system proposed creates an extremely large reduction in overall cost of the project. The alternative system much cheaper because it does not include the expensive cost of the stone veneer. As stated before removal of these materials accounts for 58% of the total cost of the original system. Table 10 below highlights the comparison of the costs of both the original façade, precast concrete with stone veneer, and the alternative system, prefabricated Thermocromex panels.

Table 10: Façade System Material Comparison

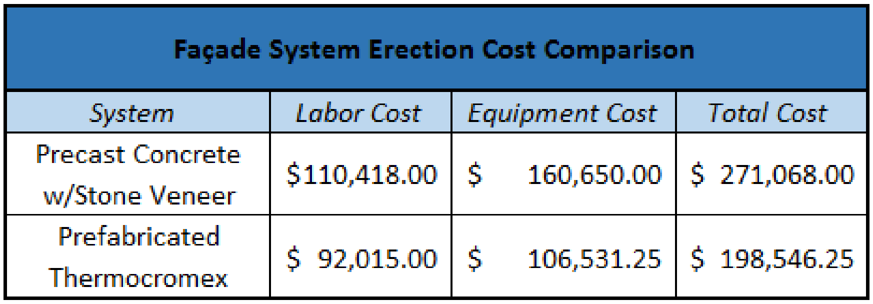


Façade System Material Cost Comparison			
System	*Qty (SF)*	*SF Cost*	*Total Cost*
Precast Concrete w/Stone Veneer	16904.4	$122.66	$2,073,500.00
Prefabricated Thermocromex	16904.4	$ 32.67	$ 552,309.40

The alternative system proposed will have a total savings of $1,521,190.60. This equates to nearly a 74% reduction in the material costs of the façade system.

As stated previously in this report the change in the façade system allowed for the secondary erection crane to be downsized from a 100 ton crawler crane to a 40 ton hydraulic truck crane (refer to **Appendix E** for supporting calculations and load charts). The table below compares the cost of installation of both the original and alternative façade systems. As you can see there is approximately $74,000 in savings in erection costs when the alternative façade system is implemented.

Table 11: Erection Cost Comparison



Façade System Erection Cost Comparison			
System	*Labor Cost*	*Equipment Cost*	*Total Cost*
Precast Concrete w/Stone Veneer	$110,418.00	$ 160,650.00	$ 271,068.00
Prefabricated Thermocromex	$ 92,015.00	$ 106,531.25	$ 198,546.25

Taking into account both erection and material costs, the prefabricated Thermocromex panels generates $1,593,712 in savings and a 4% reduction in the overall contract cost.

Recommendation:

Following the investigation of an alternative façade system, I recommend that the prefabricated Thermocromex panels be used in lieu of precast concrete panels. Not only does their implementation generate a 10% reduction in duration for the construction of the entire façade, but they also make the installation process much easier. The decrease in the weight of the panelized façade system allows for the creation of larger panels, which would generate a reduction in the number of deliveries to the job site.

Although the analysis of the thermal performance of the alternative wall system yielded positive results, this was not a deciding factor in the final recommendation. The simulations run show that new system increases the performance by 50%, but because the window coverage in each of the perimeter spaces is above 50% the only way a large change in the cooling load can be generated is by altering the design or window glazing.

Along with schedule savings, increased thermal performance, and structural benefits the system generates a significant cost savings of just under $1.6 million. This reduction in cost translates to a 4% decrease in the overall cost of the project. A large majority of this cost savings is generated by the removal of the stone veneer. Since the owner wants to create an office building with numerous high end finishes it would be understandable if they chose to remain with the original system. For the purpose of this senior thesis project it would still have to be recommend that this alternative façade system be used because of the significant increase in constructability, cost savings, and schedule reduction.

|TECHNICAL ANALYSIS III – VE of Prismatic Curtainwall Glazing Units|

Problem Identification:

The main goal of owner in constructing the 900 16th Street building is to create trophy class office space in downtown Washington DC. For that reason the building features a variety of extremely high end finishes on both the interior and exterior. Take for instance the entrance to the church located on the North end of the building (see Building Statistics I for more detail on the floor area designated to the church). This entrance features a 3 dimensional structural curtainwall system which happened to be designed by a company based in Germany. It was a decision that the highly customized glazing units be manufactured in a facility located within the United Arab Emirates. Because of the degree of uniqueness the system was riddled with delays throughout the design phase which began to push back the planned completion date of the curtainwall. Furthermore there were delays during the fabrication period of the 128 individual glazing units. With delays in both the design and fabrication process the delivery date of the glazing material was pushed so far from the planned start date of installation that two of the three shipments were delivered by means of air freight. Seeing as this curtainwall system sits on the critical path of the project this expedited shipping method was deemed necessary to keep the project on schedule.

The system in its entirety was bid at $1.8 million. This value includes the metal frame, glazing, installation, delivery of materials, and other incurred costs. Of the total contract value mentioned previously approximately $283,000 is associated directly with the custom glazing units. This cost of material vastly changed over the course of the project due to the changes discussed above.

Research Goals:

The purpose of this particular analysis is to derive and alternate supply chain for the curtainwall glazing units and determine if that procurement method would have resulted in cost and schedule savings.

Methodology:

In order to complete the analysis that I plan to conduct, the following steps will be taken:

- *Research*
    - Conduct research to find a comparable type of glazing and a manufacturer that will provide that glazing
        - Plan to contact DAVIS team to attain the contact information of well trusted glazing contractors

  - Conduct research on supply chain risk management techniques that could have helped mitigate the risks associated with the procurement of the curtainwall glazing
  - Use the collected information to choose a different manufacturer to provide the glazing
- *Technical Analysis*
  - Calculate the cost of the glazing of the structural curtainwall currently used
  - Calculate the initial cost to ship the material to the job site and the upcharge associated with air-freighting said material
  - Estimate the cost of the new type of glazing and the shipping costs associated with it
  - Create a weighted system based on the different risks associated with the procurement of the material
  - Provide in depth analysis on the cost associated with each risk to support or oppose the new glazing and supply chain
- *Recommendations*
  - Recommend a supply chain of the material based upon the weight of each risk and the potential costs and delays associated with each

Analysis:

Advantages and Disadvantages to Procuring Material Overseas:

To fully understand why it is that a large majority of architects and subcontractors look to manufacturers overseas a representative from Guardian, the glazing unit manufacturers, was contacted. Upon speaking with a sales representative it became very clear as to why it is not uncommon for glazing to come from Europe, or in the case of this specific curtainwall system, the UAE.

Advantages:

One reason in particular is related directly to the abundance of glazing available they fact that the market place in other countries does not currently have a large need for large curtainwall panels. Also the plants in many foreign countries have the means to create larger panels than many of the fabricators located within the boundaries of the United States. So while a company may want to utilize a fabricator in closer proximity to the site, depending on the size of the glazing units required they may not be able to. In many circumstances a contractor may be able to get the exact same material it could from a supplier within the United States as it could from a supplier in a different country. The difference between the two of them would be the upfront cost of the material. In a majority of cases an owner or contractor is not willing to pay more for a material even though there may be less risk attached to it.

Disadvantages:

When on looks at the procurement of materials from a risk analysis prospective, it makes all the sense in the world to attain materials from places as close to the project as possible. What a construction manager sees when they find out various material are being brought in from all over the globe is the increased possibility of large delays and the costs associated with them. On any construction site material is what drives the schedule, and without the material on site the day it is needed that particular work cannot be done. In circumstances such as this curtainwall system a delay would cause the critical path to slide, pushing following trades back with it.

While locating a supplier that will supply the glazing units at a marked up price may not be ideal in the eyes of an owner at first, after explaining the risks involved they may see the situation differently. All the buried risks that an owner does not think about all have a dollar value and schedule delay that can be associated with them. If enough of the highlighted risks occur it may turn out to have been in the owner's best interest to use a supplier within the United States.

Definition of Risk Factors and Potential Impacts:

There are several reasons as to why material may not arrive on site at the expected time or need to be reordered. Again this analysis looks to pick out the main procurement issues, or possible issues, with the glazing units for the structural curtainwall system and assign them a level of risk to justify choosing a manufacturer located closure to the project site. The following paragraphs will outline four risk factors which may have an effect on both the schedule and the cost of the project.

Design/Fabrication Delays ~ High Risk

Many construction projects experience delays in the development of the system design. As a system becomes more complex the risk of a delay occurring becomes higher. Figure 20 to the right shows the prismatic curtainwall system that this analysis focuses on. It is easy to see that a system as unique as this requires special care in the design to ensure that no issues arise when it is being installed. It would be expected that the design team would take longer than anticipated to create such a marvel. Any delay in this phase would push back the start of fabrication and furthermore the start date of the system's construction. These delays would bring about additional costs associated with general conditions.

Figure 20: Prismatic Curtainwall

In addition to delays in the design of the glazing units, there is also a large chance that the fabrication process will experience delays. This expectance is due to the nature of the curtainwall itself. The multitude of variations in the size and shape of the units will only make the fabrication process more difficult.

Broken Glazing Unit ~ High Risk

The first risk that this analysis begins to investigate is when one of the glazing units it broken either in transit to the jobsite or during the installation process. In construction projects it is not uncommon for materials to be damaged to the point in which they are unable to be used. Often contractors order extra material so instead of having to wait for more material to arrive, they are able to continue their work. In the case of this custom curtainwall system, or any curtainwall system for that matter, it is impossible to predict which glazing panel may be the one that will break. For that reason, and the fact that it would be completely unfeasible to make multiples of each panel, glazing panels are never made in excess rather they are made when needed.

At the end of the day how often is this an issue on a jobsite? According to one industry member it is expected that a glazing unit will be broken accidentally in approximately one third of all construction projects. Another industry member goes further to approximate that about one in every 100 glazing units will break and need to be replaced. In this curtainwall in particular there are 128 different glazing units that had to be installed. By the standards outlined previously that would guarantee that one of the 128 units would be damaged and need to be remanufactured. It is for the reasons outlined above that “high risk” has been given to this category.

In the event of a broken panel remanufacturing at the current supplier’s location, within the United Arab Emirates, could cause a large impact. This particular activity is on the critical path of the project, so any damaged material would push the completion of the job. The distance that the material would need to travel to get to site requires that it is either delivered by boat or plane. Each delivery method is not cheap and only continues to add cost to the project. While the schedule delay to manufacture a new panel is unavoidable the cost of delivery and duration of delivery may be able to be reduced significantly if the manufacture was located within the United States.

Poor or Improper Fabrication of Glazing Units ~ Moderate to High Risk

Quality is extremely important on any construction project. A high quality of work and materials will ensure that a system is less likely to fail and is more likely to meet the expectations of both the owner and the architect. This particular system demands near perfect construction and materials because of its level of uniqueness. However, it is perhaps because this system is so unique and custom that raises the bar in how exact the glazing units need to be.

These curtainwall panels feature a variety of specialty coatings which give the glazing units its mechanical and more importantly aesthetic appeal. If the various layers of special coating or custom frit patterns are not applied correctly the performance of the system could be compromised entirely.

International Incident ~ Very Low Risk

A factor that is not as expected as the ones previously mentioned above is that of an international incident. Under certain circumstances it is possible that the shipping lanes from Abu Dhabi could be closed. The impact that such a situation would have is strictly dependent on the severity of the incident that has occurred and it highly unlikely to occur. According to The Economist, the shipping lanes out of Abu Dhabi "seem immune to the conflict that is occurring in the area." In the recent past threats have been reported to shut down the Strait of Hormuz, the shipping channel which all vessels leaving the UAE must pass through. Thankfully there has not been an incident that has led to the closure of these shipping lanes in recent history, however with the continuing turmoil in that part of the globe the chance of that happening is still somewhat existent. For the reason stated this situation is being regarded as a very low risk factor. The impact of a situation in this category would result in an increase of the general conditions cost for the project and could lead to the need to order materials from another manufacturer all together.

Risks that Occurred:

As stated previously delays on any project are expected to occur. Table 12 to the right summarizes which of the previously defined risks had actually occurred during the procurement or installation of the glazing units. Nearly all of the defined risks that this analysis took into account had occurred with the exception of an international incident which would have shut down shipping lanes.

Table 12: Delays Experienced

Summary of Delays Experienced	
Risks	*Occurrence (Y/N)*
Broken Glazing Unit	Yes
Design/Fab Delays	Yes
Improper Fabrication	Yes
International Incident	No

One of the risks present during material procurement and installation of the prismatic curtainwall was broken glazing units. During either the installation or delivery process the project team noted that a total of seven glazing units had been broken. After speaking with industry professionals about the possibility of a curtainwall glazing unit it was not surprising to find that this was an issue on the 900 16th Street project. During the fabrication process the manufacturer experienced delays. These delays were not reflected in the project schedule but in order to not impact the schedule two of the three glazing shipments where sent by air-freight. This change added a significant cost to the project, which can be seen in the cost analysis portion of this report.

A quality review done by the owner and architect following the completion of the prismatic curtainwall resulted in the discovery that a number of the units had been fabricated incorrectly. When considering how meticulous and complicated this prismatic curtainwall is it was not surprising to find that a number of panels were not up to the expectation of the owner and architect. As per the request of the project team the exact number of glazing units that needed to be replaced will not be disclosed.

Alternative Fabricator Analysis:

Following a conversation with Chris Randisi of Guardian Industries it was pointed out that a manufacturer named JE Berkowitz has the capability to produce the glazing units that are required. JE Berkowitz is a glazing manufacturer based out of New Jersey which utilizes its 250,000 square foot manufacturing facility to produce high quality architectural glazing for projects around the country. Their in house capabilities allow them to produce irregular shaped glazing units, which is key for the prismatic curtainwall system that this analysis focuses on. Also located within the fabrication shop are several convection heat treating ovens which allow for the application of solar films, such as Guardian Sunguard HP-Silver 35. In addition they have the ability to create laminated glass with PVB layers in their oversized autoclaves. The last production capability that JE Berkowitz has which is key to the fabrication of the glazing units is their ability to apply custom frit to the units.

The manufacturing location is only 116 miles from the 900 16th Street project and theoretically has the capability of delivering glazing units in one day. The distance between the original manufacturer in Abu Dhabi and the site is roughly 7,100 miles. Because of this vast distance the expected delivery duration is between 6 to 8 weeks. After speaking with industry professionals about the possibilities of a panel being broken, the benefits of using an alternative manufacturer become clear.

JE Berkowitz is also familiar with the project because they were contracted through ECP to fabricate the glazed units for the aluminum framed curtainwall systems located in both the North East and South East corners of the façade.

Schedule Impact Analyses:

After speaking with an industry professional it was determined that production rate of both the original manufacturer and alternative manufacturer would be nearly equivalent. Without a significant difference in the duration it takes to manufacture the glazing the schedule savings come into play when looking at the duration it takes to deliver the materials to site. Using the information provided to me from the project team it was determined that it takes just under a day to fabricate a glazing unit.

Table 13 on the following page summarizes the schedule impacts associated with a broken glazing unit.

Table 13: Impact Comparison of Broken Glazing Units

Schedule Impact of Broken Glazing Units							
Manufacturer	*Units Effected*	*Duration of fabrication*	*Delivery Method*	*Delivery Duration*	*Installation Rate*	*Installation Duration*	*Total Duration*
Original	7	9	Sea Freight	35	6	3	47
Alternative	7	9	Truck	5	6	3	17

As it can be seen in Table 13 above there is a significant decrease in the duration to fabricate and delivery new glazing units to site. While the original manufacturer could provide new panels to site in 47 days the alternative manufacturer has the capability to deliver the same units in 17 days. The difference between the two is the equivalent to 5 or 6 weeks of work. The release of interior trades in this area of the building is completely dependent on the completion of the prismatic curtainwall. That being said a difference of 5 to 6 weeks would have enormous impact on the completion of the project.

Table 14: Impact Comparison of Improperly Fabricated Glazing Units

Schedule Impact of Improperly Fabricated Glazing Units							
Manufacturer	*Units Effected*	*Duration of fabrication*	*Delivery Method*	*Delivery Duration*	*Installation Rate*	*Installation Duration*	*Total Duration*
Original	35	30	Sea Freight	35	6	6	71
Alternative	35	30	Truck	5	6	6	41

Table 14 summarizes the impacts that both manufactures will have on the project due to improper fabrication of glazing units. Again the schedule savings are in the speed of delivery. While it may take the same amount of time to fabricate and install each of the glazing units, the 30 day difference in delivery duration still exists. If the units came from the alternate manufacturer they could be installed before the units from the original manufacturer even arrived on site.

Cost Analysis:

**Reference Appendix K* for a full cost estimate of alternate manufacturer*

The following assumptions have been made during the evaluation of costs associated with the original supply chain and alternate supply chain:

- RS Means cost data was used to estimate the cost of the glazing units from the alternate manufacturer
- Costs associated with various delivery methods were attained from the project team and industry professionals

- Under direction of industry professional 6% of material cost used for cost of delivery to jobsite from alternative manufacturer

Below is a summary of the initial costs associated with the fabrication and delivery of the glazing units in the prismatic curtainwall system.

Table 15: Initial Cost Summary

Initial Cost Summary						
Manufacturer	*Delivery Method*	*Cost of Delivery*	*# of Shippments*	*Total Delivery Costs*	*Cost of Material & Labor*	*Total Cost*
Original	Sea Freight	$ 12,000.00	3	$ 36,000.00	$ 282,295.00	$ 318,295.00
Alternative	Truck	$ 19,577.58	3	$ 19,577.58	$ 326,293.00	$ 345,870.58
Difference	-	-	-	$ (16,422.42)	$ 43,998.00	$ 27,575.58

Although the material cost is approximately $44,000 more expensive through the alternative manufacturer, it creates a $16,500 savings in the delivery of the material. Overall the initial cost, without the impact of delays, of the alternative manufacturer would be a $27,500 increase.

Initially each of the three shipments of glazing units were to be delivered by means of sea freight. After speaking with the project team it was discovered that two of the three shipments needed to be air freighted to the job site because of delays in the fabrication and design process. This change in delivery method added a total of $300,000.

Below, Table 16 outlines the costs associated with the risks factors that had occurred on the project.

Table 16: Cost Summary of Actual Impacts

Impact Cost Summary			
Delays	Cost		
	Original	Alternate	Difference
Design/Fabrication	$276,000.00	$ 13,000.00	$ (263,000.00)
Broken Glazing Units	$ 58,125.00	$ 49,603.58	$ (8,521.42)
Improper Fabricaton	$119,865.00	$ 125,257.00	$ 5,392.00
Total	$453,990.00	$ 187,860.58	$ (266,129.42)

With all cases of risk occurrences taken into account an alternative manufacturer could have saved the project $266,129. When the initial up charge of $27,500 is taken into account the project would have been saved a total of $238,554. In conjunction with the direct cost savings that were mentioned above the project would also save 60 days (the difference in shipping duration) in general conditions costs. The total cost per day for the general conditions of the site is $4,861. This means that an additional $291,660 would be saved if the alternative manufacturer would be used. With the inclusion of the projected savings in general conditions costs the total savings generated by using the alternative manufacturer is $530,214.

Recommendation:

This analysis provided a large amount of insight into why materials such as glazing units are procured from manufacturers or fabricators located overseas. While the initial material costs are lower there are several risks that could lead to significant increases in cost. For this particular instance, I would highly recommend procuring the glazing units from the alternative fabricator, JE Berkowitz.

A curtainwall system that is as unique as this is almost certain to run into one of the risks that were outlined previously in this report. In the case of this particular system, three of the four just so happened to actually occur. In any of the instances the duration to design new units and fabricate them would be the same. The main difference between the two manufacturers is the duration of delivery to the jobsite. The alternative manufacturer is able to have the glazing units on site and ready to install 30 days sooner than the original manufacturer in both instances. Upon completion of the cost analysis it was determined that a total savings of $530,214 could be generated. Although there will be an additional cost to the project with the use of either manufacturer the use of the alternative manufacture reflects a 50% reduction in cost.

|TECHNICAL ANALYSIS IV – Driving Collaboration with Lean Construction|

Critical Industry Issue:

One of the difficulties of the construction industry is getting individuals within a project team to collaborate to achieve a common goal. Collaboration on a construction project creates teamwork and understanding among the various trades. Furthermore, this atmosphere increases the quality of communication on the project and will result in a high quality final project. The issue that the industry is presented with is how exactly a management team supposed to drive collaboration in the field. This question was one of the breakout discussions at the 24th Annual PACE Roundtable. During this breakout it was discussed that one of the main things needed to drive collaboration in field is contractor buy in and creating a sense of accountability. Some of the best ways to do just that are to implement lean construction principles on the job site. The most important of these principles include last planner and collocation.

The areas within lean construction in which the research will focus on include the use of last planner and collocation. Collocation entails bringing the entire project team into a single site office so as to create the most collaborative atmosphere as possible. By bringing the team together in a collaborative atmosphere issues that would normally have to travel through several lines of communication to resolve can be solved face to face and confirmed with a confirming RFI. This shortened problem resolution allows work to continue at a more rapid rate. The last planner system and in turn pull planning is a great way to mitigate coordination issues that would typically arise in the field. This lean construction tool allows for contractor involvement in creating the schedule by taking milestones and working backwards to identify the tasks that need to get done to complete them. Contractor involvement in creating the schedule creates more accurate timeline of construction because they are more aware of the duration a particular task will take then the general contractor is.

Research Goals:

Identify the effects, positive or negative, that using last planner and collocation have on a project. Using that information, develop a plan that the 900 16th Street project team could have used to benefit the project.

Methodology:

In order to complete the analysis of lean construction tools the following steps will be taken:

- Research
    - Conduct further research on leading practices concerning collocation and last planner
        - Focusing on how these practices increase collaboration and coordination

  - Review academic studies previously completed on the positive and negative effects of lean construction tools
  - Create an interview containing questions related to the effectiveness of last planner and collocation
  - Conduct an interview with the project manager of the Penn State HHD project
    - Reference **Appendix L** for a full transcript of the interview conducted
  - Analyze the possible issues regarding implementation of lean principles on jobs where a contractor is only scoped for the interiors or the base building
  - Use the information attained to determine in what ways the 900 16th Street project could have benefitted from using last planner and collocation

Expected Outcome:

It is expected that the research and analysis of said research will show that the lean construction tools of last planner and collocation provide the drive behind collaboration in the field. These tools create a sense of accountability and open a line of communication between contractors that would not have previously existed. In general, the level of collaboration that these lean construction tools create will lead to a significant decrease in RFI's and rework. Although I expect these tools to be useful to the project I believe that collocation may not be feasible for this particular project.

Analysis:

Collocation:

Defining Colocation:

Almost each company that uses this tool has a different way of putting it into practice on a job site. For some they use a large open space where no one has their own office. While this has the benefit of easy communication between all parties on the job it takes away from the privacy that a majority of contractors have come accustom to. To get a better understanding of how companies might define colocation I conducted an interview with Tim Jones of Massaro Construction Management Services. After speaking with him it about the system that they used on the Penn State HHD project, he described collocation as any circumstance where key members of the project team are brought together under a single roof. Instead of a wide open space they used two double wide trailers, joined by a breezeway, with both private offices and joined spaces. Figure 21 on the following page shows the layout of the collocation trailer used by the HHD project team. As it is shown, the perimeter of the trailer contains offices for all the main contractors on site while the center is joint space. The blue represents the desks for those who did not fit in the offices, while the white space is open area with tables to hold meetings or eat lunch.

The red lines represent a series of white boards that the Massaro team used as a pivotal part of the last planner system. Their specific purpose will be explained later in this report as a part of the analysis of last planner.

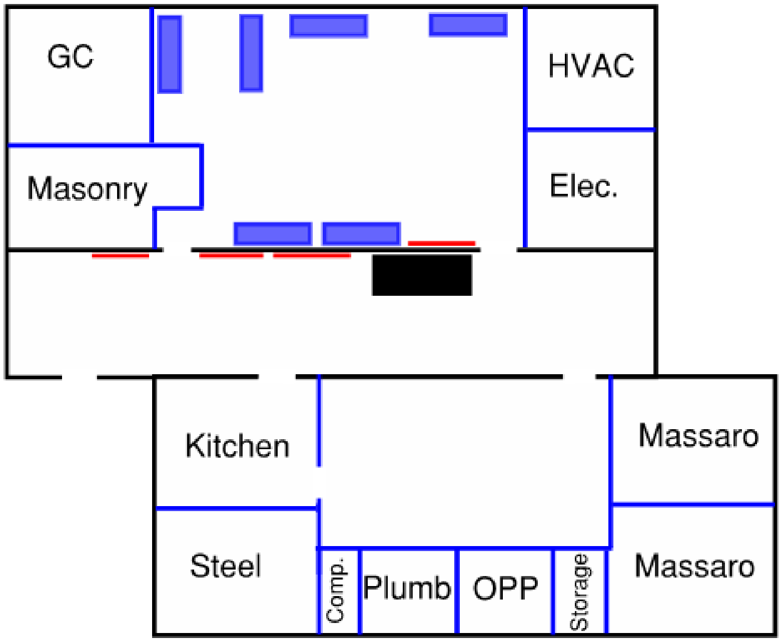


Figure 21: Collocation Trailer on PSU HHD project

Key Parties to Include in Collocation:

Determining the correct parties to include within the collocation space is one of the most difficult parts of using a collocation space. In the instance of the Penn State HHD project the contractors who were located within the colocation trailer changed the job moved through each phase. In the start of the project the trades included inside the trailer where; excavation, blasting, foundations, and plumbing. As the project progress the steel erectors, masons, electricians, and HVAC. Although every project may not require these trades the bottom line is still clear, all key parties should be based out of the colocation trailer. After speaking with Tim I found that it is a huge benefit to the project to include the architect in the colocation trailer as well. While it may not be as important to have them on site every day, their presence two days a week really helped to cut down the number of RFI's and amount of turnaround time for them.

Another characteristic that Tim pointed out was any company with a "non-working" superintendent should be involved in colocation. The reason being is that their jobs tend to revolve more around solving problems that arise throughout the completion of their scope rather than being directly involved in doing the work. Having those individuals in close proximity to the other key trades and construction manager makes it much easier to solve issues or prevent them from occurring in the first place.

Benefits:

One of the most difficult things on any construction project is getting each of the separate contractors to work together to produce a high quality project for the owner. Most of this stems from that fact that, to a large number of contractors, this concept is still new. While on many projects contractors tend to but-heads with each other, the Penn State HHD project was not the case. Having interned with Massaro Construction Management Services from May 2014 to May 2015 on the HHD project, I could easily see the collaborative environment that was created within the collocation trailer. A key point that Tim noted was that while the job has several companies on it they are all coworkers. Having everyone in the same space each and every day allowed for each of the superintendents or project managers to get to know each other better throughout the course of the project. Countless times a day contractors would drop by each other's offices and ask when certain work would be completed so they could plan their own accordingly. The perfect example of this was when the general contractor needed to start closing in interior walls but all of the outlets and switch boxes where yet to be roughed in. Instead of sending a team out to just start putting up drywall he walked across the trailer to the electrician to see what rooms he was complete with so work could at least begin. Each day following that the electrician would tell the general contractor what rooms were ready for drywall.

In summarization the key benefit of collocation is that it creates the atmosphere that encourages collaboration and communication between trades. The increase in trade communication helps to decrease the total amount of rework that may occur and in turn number of change orders on a job.

Limitations:

The obvious limitation for the use of collocation is space. A project site must contain the room necessary to house a collocation trailer or office space. Even if a site does not have the space for such an area outside then it would be possible to be placed within the structure itself. In some cases, like on the 900 16th Street project, the owner will provide a space in a neighboring building to house the project team during the duration of the project. Also, if the project has a short duration it is most likely not worthwhile to put the extra costs into collocation.

Feasibility Analysis for Implementation on 900 16th Street:

After my involvement in the HHD project it is evident that the implementation of collocation benefits a job. The question that needs to be asked is, is it able to be implemented on 900 16th Street? A requirement of its implementation is that a site has the space to accommodate the collocation trailer. Below is a site plan of 900 16th Street when it was the most congested. Take note that the mobile crane is required to travel the entire face of the building to install the façade system. After analyzing how congested the site was at various points throughout the construction process it was determined that, if a collocation space was used, it would have to be within the structure or in the office space that the DAVIS was given. This space is represented by the red area in the neighboring building.

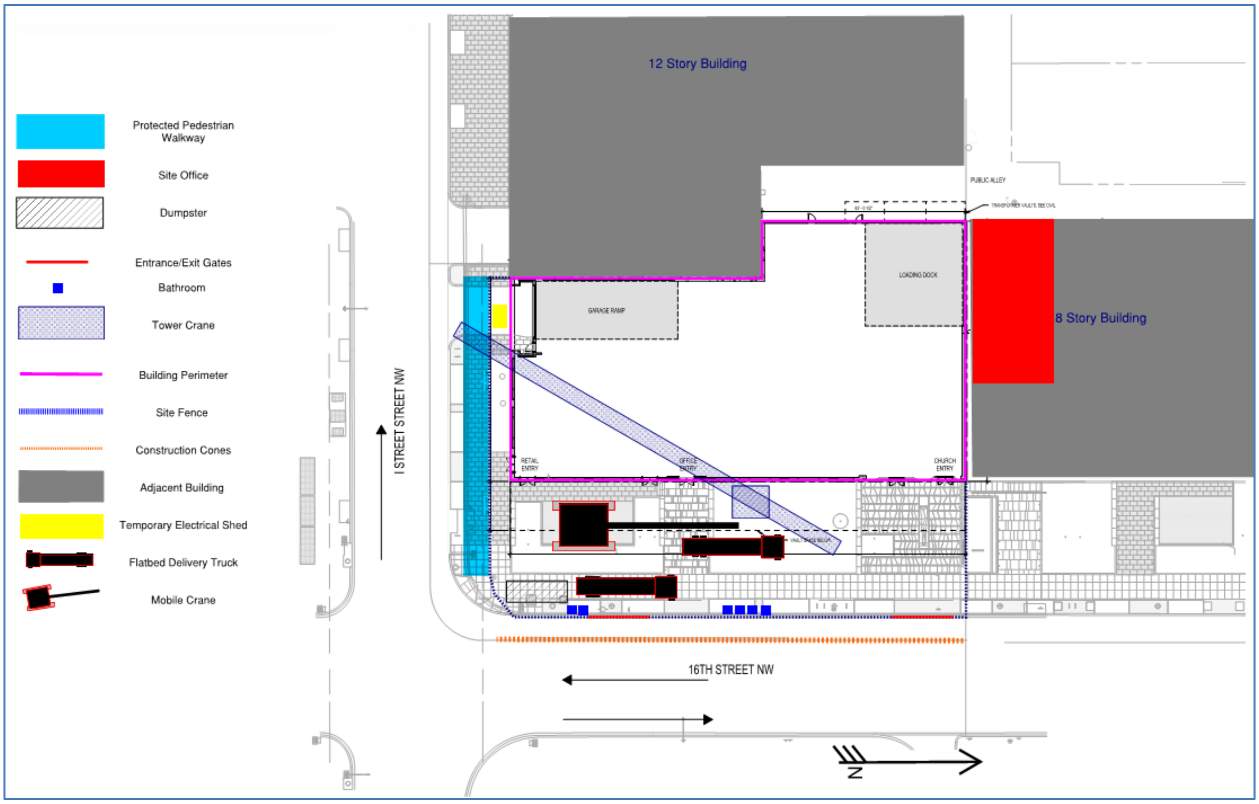


Figure 22: Site Plan

The office space provided by the owner was nearly ¾'s of the neighboring buildings second floor, certainly a large enough space to support a collocation space. While this office space is not directly on site, it is not a key factor of collocation to be located on the job site. According to the information collected from Tim Jones the following contractors would be key parties within a collocation space; Demolition, Foundations, Cast-in-Place Concrete, HVAC/Plumbing, Electrical, and Church Façade (prismatic curtainwall).

Although the office space provided by the owner has ample room to support the creation of a collocation space it is being shared with the team from another DAVIS project located nearby. The final option would be to create a collocation space within the structure. This option would not be beneficial to the project because the contract is only for the completion of the core and shell. By the time the project got to a point that the space could be created many of the parties that would be involved would be well into their respective scopes of work. The use of collocation would certainly benefit the project but the site and project scope do not support its implementation.

Last Planner:

Defining Last Planner:

Each and every construction project has the challenging task of defining all of the tasks and tying them together in a way that allows for the project to be completed in the most efficient manner possible. In many circumstances it is easy to lose track of tasks and the order they may need to be done in. Last Planner was created to ease the burden of creating and managing a project schedule as well as to create a collaborative job site with early contractor involvement. The key steps to implementing Last Planner are the master schedule, phase planning, look-ahead schedules, weekly work planning, and daily huddles.

To first begin the process the team creates a **master schedule** of the major milestones and their relationships. Following the creation of the master schedule is the **phase planning**, also known as pull planning. Pull planning is the first step in breaking the schedule into individual activities that will lead to the completion of the milestone activities. These sessions bring each of the contractors involved in a milestone completion together in a single room to plan out the activities and their expected durations. Pull planning allows the team to highlight, or even fix, possible areas of concern in the construction process. Once pulling planning is complete the process turns to look ahead planning.

Figure 23: Pull Planning Session from DAVIS

Look ahead planning should occur constantly on the job once it has begun so the team can be aware of tasks that are in the near future. Typically each look ahead planning session will look at the next 6 weeks of the project. Using this block of a schedule the team is able to get accurate estimates from the trades on if the planned work can be completed or not. Early acknowledgement of this schedule activities gives the team more time to plan and ensure all involved parties are on the same page. In addition, this portion of the last planner process highlights future constraints so they can be removed before they become an issue. From the look ahead schedule and the project progress, the team works collectively to create the **weekly work plans** that are to be distributed and discussed at a weekly job wide meeting. These plans highlight the activities that each contractor on site will plan to complete in a specific week and on which day. The key to the success of the weekly work plans is revisiting them at the end of the week to see what was completed and what was not completed. This process of tracking the completion of the schedule activities is referred to as **percent plan complete**. When activities do not meet the intended goal the superintendent and project manager need to look at the reason why. This allows contractors the opportunity to explain why goals were not met so that the entire project team understands. The result of these interactions between the members of the project team are documented through a **plus/delta chart**. Anything that requires improvement is placed underneath the delta while anything good that the team did is placed underneath the plus. The purpose of this part of last planner is not to point out mistakes or wrong doings, rather its purpose is to highlight good areas and areas of improvement to ensure continued success of the project.

Implementation on Penn State HHD Project:

While on that particular project I realized that the Massaro team implemented last planner in a different method than what I had been previously exposed to. After speaking with the project manager, Tim Jones, he explained they used it more heavily as an execution tool rather than an initial planning tool. The project team was given a master schedule that was created by the company’s schedulers rather than large pull planning sessions with the contractors. As the project began they used look ahead planning to develop and drive the weekly work plans.

Throughout the previous week the site managers track the progress of the trades and on Fridays lay out the following weeks work based upon what is completed on site and what needs to be done by the end of the following week to stay on track with the 6 week look ahead. During the weekly contractor meetings the site manager, Jim Kephart, would bring the team into the breezeway of the collocation trailer where there were a series of white boards. Jim first looked at the previous week’s milestones and determined if each of them were met. If one was not met then the entire team would be informed as to why and what is going to be done to get the task complete. This step in particular created a large amount of accountability for each of the trades because they had to explain to everyone why their work was behind. Although this process was never specifically called this it acted as an informal way to track the percent plan complete and to create the plus/delta chart for the previous week. Next Jim would set the project milestones and individual contractor milestones for the week. Once that was complete each superintendent would step to the white boards and plan out their weeks day by day. After watching this process multiple times it was easy to see the positive impact it had on the flow of work. While writing down their activities, contractors would all be interacting with each other to see when predecessor activities would be complete or if work they were doing in an area would affect each other.

After much discussion with Tim he believes that the use of these white boards is a key to the success of Last Planner. Not only is it a way that all trades can continually check where work is being done on specific day, but it is a huge tool is creating accountability and collaboration throughout the project team.

Benefits of Last Planner:

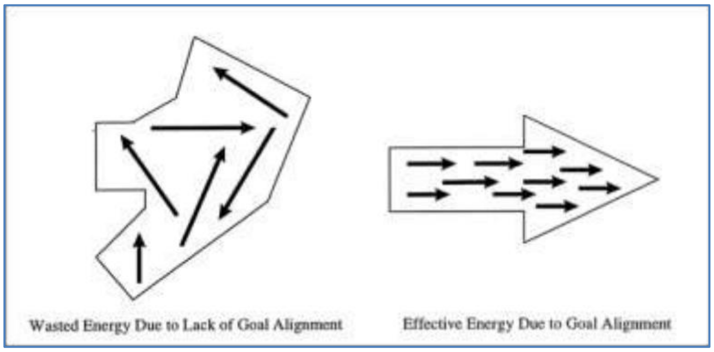


Figure 24: Goal Alignment with Last Planner

The implementation of Last Planner can provide a vast amount of benefits to a job. First and foremost it creates a collaborative atmosphere between all of the contractors on the job site. This way all of the individuals on the project will be more willing to work together to achieve the delivery of a high quality product to the owner instead of working against each other. Figure 24, from the DAVIS Last Planner Implementation Guide, shows how contractors act on a job without Last Planner and how they act on a job using Last Planner. The left side represents a job without Last Planner where all parties usually work in separate directions, acting with their own interests in mind. On the other hand the right represents how Last Planner gets everyone moving in the same direction with a common goal in mind.

On any jobsite there is nobody who knows the durations and sequencing of activities better than those who are completing the work. By bringing those individuals to help create the master schedule through pull planning sessions the project has a more reliable and accurate schedule. Also, pull planning sessions give the contractors an early look at the scopes of other trades so they can try to avoid clashes between systems. Look ahead planning, weekly work plans, and weekly contractor meetings on further increase the ability to highlight issues before they have an impact on the project.

Drawbacks of Last Planner:

The main issue with the use of last planner is that in many circumstances there is only partial deployment of the last planner process. This stems mostly from the lack of training and emphasis on the importance of full buy in to ensure the last planner's tools have a positive impact on the project. Research and my own experiences with last planner has brought the conclusion to light that there is not an industry standard on how exactly last planner should be used on a project. When I had been a part of the Penn State HHD project I noticed that there was more of a focus on developing the weekly work plans and look ahead planning while the initial steps of creating the master schedule through pull planning were not as important.

On the other hand the DAVIS project that I was involved in during the summer of 2015 used the front end of last planner (milestone scheduling and pull planning) more heavily then look ahead planning and weekly work plans. While the project had weekly meetings to discuss the plan for the week and what would be coming in the future I felt as if they were largely unsuccessful. This was mostly due to the variance in the understanding how important the entire process was. Also it was a weekly occurrence that key members of the project team would not attend the meeting, which is another issue all in itself. The success of the system lays in the hands of the management staff on the project but it is largely affected by the willingness for all parties to fully participate in all parts of last planner.

Implementation on 900 16th Street:

Seeing as the 900 16th Street project did not use last planner in any capacity, implementing the last planner system would only benefit the project. To best benefit the project I recommend that the team use the tools of last planner in both planning and project execution. After bringing on board all of the main contractors the team should conduct a series of pull planning sessions. This way they could have better estimated the durations of schedule activities by receiving feedback from the experts in the field. The scheduling department at DAVIS can the work with the DAVIS project staff to create the master schedule for the project.

Following the creation of the master schedule the focus of the project team should shift to ensuring successful execution of the project. The first step in doing so would be to use a 6 week look ahead and determine weekly milestones to ensure the schedule stays on track. These milestones should be extremely specific and measureable. For example, the HHD project had a handset brick with CMU backup as the façade system. The weekly milestones for the masonry contractor were not broad such as “complete face brick to level 3 East”. Rather they were extremely specific and included the elevation, area of elevation, and two which level the brick needed to be completed. The more specific the milestone, the easier it will be for the DAVIS team to notice a foreseeable delay in the construction of a system. Catching a lack in productivity early allows the team to add additional man power before the schedule begins to suffer from it.

Each Monday morning at 9 am the staff should hold a site wide contractors meeting. All subcontractors and a representative from the owner should be required to attend. This meeting serves to make everyone aware of upcoming schedule activities, reflect on the past weeks work, and plan the work of the current week. A change to the prescribed DAVIS plan for implementing last planner would be to use white boards like the HHD project. After the look ahead schedule is discussed, the superintendent should lead the group to the area which the previous weeks work was planned. Next they should walk through the milestones from that week and if they were or were not completed and why. This aspect of the weekly planning process worked as a great tool to create accountability for uncompleted work because no one wants to have to explain why they are delaying the project. Following the discussion of the previous week the superintendent should set the milestones for that week and then the subcontractors should approach the boards and fill in their work for each day of the week. As explained previously this process is integral to contractor collaboration.

Recommendation:

Collocation:

After analyzing collocation the conclusion has been drawn that it should not be implemented on the 900 16th Street project. While it is believed that the project could have benefitted from the use of collocation as an additional tool, a look at the feasibility of its implementation proves that it would be not possible. The size of the site would simply not allow for a collocation trailer to be placed on it. Also the office space that the DAVIS team uses as its base of operations it not suitable because they are required to share it with another project. The only reasonable way to implement this on the job would be to place the collocation space within the building itself. Since DAVIS is only contracted to complete the core and shell, outfitting the interior space with joint office space would not provide the team with a significant amount of time to adjust to the system for it to become useful.

Last Planner:

After completing research on the benefits and drawbacks of the last planner system I fully recommend that it should be implemented on the 900 16th Street project. Having been emerged in the process for over a year with past internships it is difficult to see why all projects are not using parts of last planner to ensure excellence on their job.

Even though the project is only a core and shell, the benefits of Last Planner can still have a huge impact. Milestone and pull planning sessions early in the project can really help to set the tone for the job by providing accurate durations and activity sequences. The early involvement of various contractors would create a better understanding of the complex systems that will be used on the project. While I think keeping track of each contractors planned percent complete is important because of the HHD project I do not think that it is an integral part of the last planner process. I still recommend it be used but it should be tracked by the management staff and only displayed to each individual contractor if issues with production begin to occur. The use of the weekly contractor meeting as explained in the report is a perfect way to track the plus/delta of each week.

Throughout all of the processes within Last Planner there is a reoccurring theme of using visuals to aid the process. Another recommendation is to implement white boards that contractors use to plan out their daily tasks for the week to the contractor meetings. This way everyone can see the work being planned and coordinate tasks to ensure trades do not hinder each other's work.

Final Conclusions

Analysis I - Modular Concrete Formwork:

Stick-built formwork used on 900 16th Street did not provide the project schedule with optimal durations. It is understandable that it was used because the drop panels in the slab lend themselves better to a stick-built system. However due to the versatility of Peri Sky Deck and the use of Peri Multiflex at the drop panels, modular formwork is just as feasible. The Sky Deck system with its light weight panels and props make the formwork much easier and faster to install then a stick-built system.

After taking into account the benefits of the modular formwork systems and how their implementation into the project impacts the schedule, I recommend that this system be used on 900 16th Street. According to the daily reports from Miller & Long and the calculated man hours to complete erection of the formwork a labor reduction of 75% could be achieved. Even though the initial cost of the system is high because of the need to rent the forms directly from Peri the final cost savings generated through the reduction of labor outweigh the initial cost premium. It total it has been projected that the savings would be equal to $461,000.

The schedule savings that the implementation of modular forms would reflect is considerable at 20 days. This value could be effected by the time it takes for the tradesmen to learn how to install the system. After studying this system and speaking with individuals at Peri, it was determined that the impact of the learning curve for the alternative systems would be minimal. The results of this analysis confirm the expected results that modular forms would benefit the project therefore the use of modular formwork on 900 16th Street is recommended.

Analysis II - Exterior Façade Redesign:

Following the investigation of an alternative façade system, I recommend that the prefabricated Thermocromex panels be used in lieu of precast concrete panels. Not only does their implementation generate a 10% reduction in duration for the construction of the entire façade, but they also make the installation process much easier. The decrease in the weight of the panelized façade system allows for the creation of larger panels, which would generate a reduction in the number of deliveries to the job site.

Although the analysis of the thermal performance of the alternative wall system yielded positive results, this was not a deciding factor in my recommendation. The simulations run show that new system increases the performance by 50%, but because the window coverage in each of the perimeter spaces is above 50% the only way a large change in the cooling load can be generated is by altering the design or window glazing.

Along with schedule savings, increased thermal performance, and structural benefits the system generates a significant cost savings of just under $1.6 million. This reduction in cost translates to a 4% decrease in the overall cost of the project. A large majority of this cost savings is generated by the removal of the stone veneer. Since the owner wants to create an office building with numerous high end finishes I could understand if they chose to remain with the original system. From the viewpoint of a construction manager, I would still have to recommend that this alternative façade system be used because of the significant increase in constructability, cost savings, and schedule reduction.

Analysis III - VE of Prismatic Curtainwall Glazing Units:

This analysis provided a large amount of insight into why materials such as glazing units are procured from manufacturers or fabricators located overseas. While the initial material costs are lower there are several risks that could lead to significant increases in cost. For this particular instance, I would highly recommend procuring the glazing units from the alternative fabricator, JE Berkowitz.

A curtainwall system that is as unique as this is almost certain to run into one of the risks that were outlined previously in this report. In the case of this particular system, three of the four just so happened to actually occur. In any of the instances the duration to design new units and fabricate them would be the same. The main difference between the two manufacturers is the duration of delivery to the jobsite. The alternative manufacturer is able to have the glazing units on site and ready to install 30 days sooner than the original manufacturer in both instances. Upon completion of the cost analysis it was determined that a total savings of $530,214 could be generated. Although there will be an additional cost to the project with the use of either manufacturer the use of the alternative manufacture reflects a 50% reduction in cost.

Analysis IV - Driving Collaboration with Lean Construction:

Collocation:

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Appendix A:

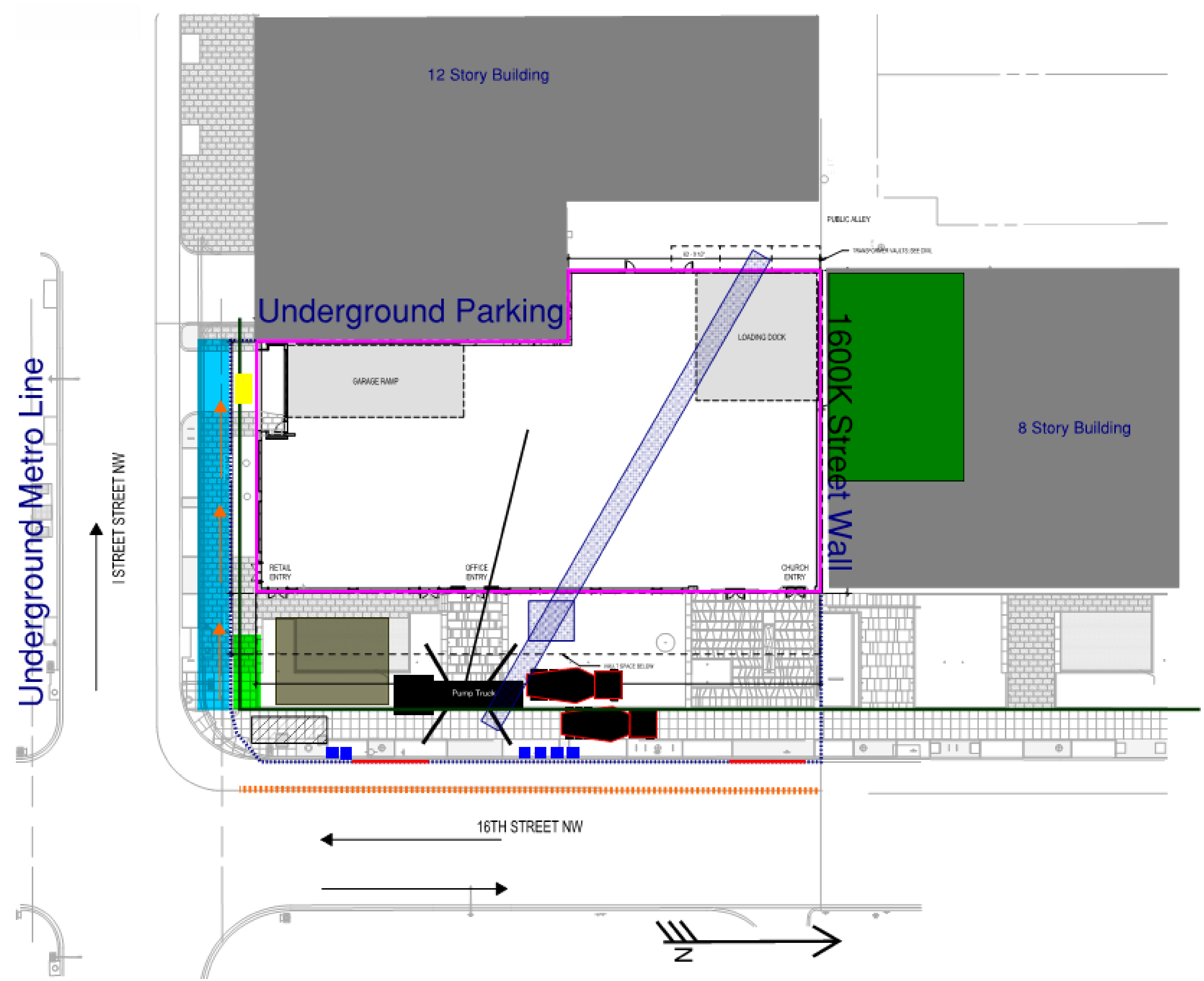
Existing Conditions Site Plan

|SITE LOGISTICS|

Typical Cast-In-Place Pour Layout

LEGEND

🟦	Protected Pedestrian Walkway
🟫	Material Lay down
🟩	GC/Sub Office
▨	Dumpster
—	Entrance/Exit Gates
■	Bathroom
▦	Tower Crane
—	Building Perimeter
┄	Site Fence
┄	Construction Cones
⬛	Adjacent Building
→	Pedestrian Traffic
🟨	Temporary Electrical Shed
—	Existing Sanitary Line



Appendix B:

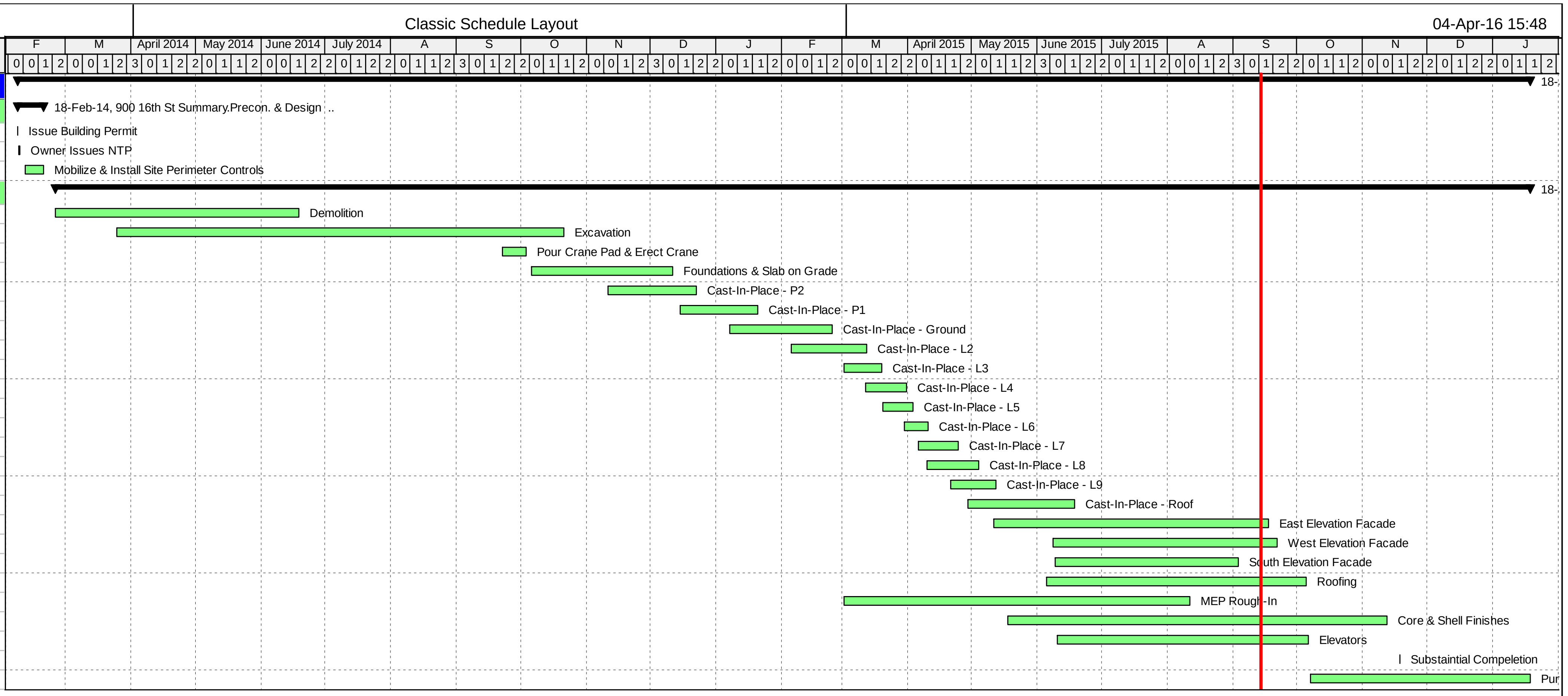
Project Summary Schedule

900 16th St Summary Schedule

Classic Schedule Layout

04-Apr-16 15:48

Activity Name	Remaining Duration	Start	Finish
900 16th St Summary 900 16th St Summ	511	06-Feb-14	18-Jan-16
900 16th St Summary.Precon. & Design ..	9	06-Feb-14	18-Feb-14
Issue Building Permit	1	06-Feb-14	06-Feb-14
Owner Issues NTP	1	07-Feb-14	07-Feb-14
Mobilize & Install Site Perimeter Controls	7	10-Feb-14	18-Feb-14
900 16th St Summary.Base Building .	499	24-Feb-14	18-Jan-16
Demolition	83	24-Feb-14	18-Jun-14
Excavation	151	25-Mar-14	21-Oct-14
Pour Crane Pad & Erect Crane	10	22-Sep-14	03-Oct-14
Foundations & Slab on Grade	49	06-Oct-14	11-Dec-14
Cast-In-Place - P2	30	11-Nov-14	22-Dec-14
Cast-In-Place - P1	27	15-Dec-14	20-Jan-15
Cast-In-Place - Ground	35	07-Jan-15	24-Feb-15
Cast-In-Place - L2	26	05-Feb-15	12-Mar-15
Cast-In-Place - L3	14	02-Mar-15	19-Mar-15
Cast-In-Place - L4	14	12-Mar-15	31-Mar-15
Cast-In-Place - L5	11	20-Mar-15	03-Apr-15
Cast-In-Place - L6	10	30-Mar-15	10-Apr-15
Cast-In-Place - L7	15	06-Apr-15	24-Apr-15
Cast-In-Place - L8	17	10-Apr-15	04-May-15
Cast-In-Place - L9	16	21-Apr-15	12-May-15
Cast-In-Place - Roof	37	29-Apr-15	18-Jun-15
East Elevation Facade	94	11-May-15	17-Sep-15
West Elevation Facade	76	08-Jun-15	21-Sep-15
South Elevation Facade	63	09-Jun-15	03-Sep-15
Roofing	87	05-Jun-15	05-Oct-15
MEP Rough-In	117	02-Mar-15	11-Aug-15
Core & Shell Finishes	129	18-May-15	12-Nov-15
Elevators	85	10-Jun-15	06-Oct-15
Substaintial Compeletion	1	18-Nov-15*	18-Nov-15
Punchlist	74	07-Oct-15*	18-Jan-16



▬ Actual Level of Effort

🟦 Actual Work

🟩 Remaining Work

🟥 Critical Remaining Work

◆ ◆ Milestone

▼▬▼ summary

Page 1 of 1

TASK filter: All Activities

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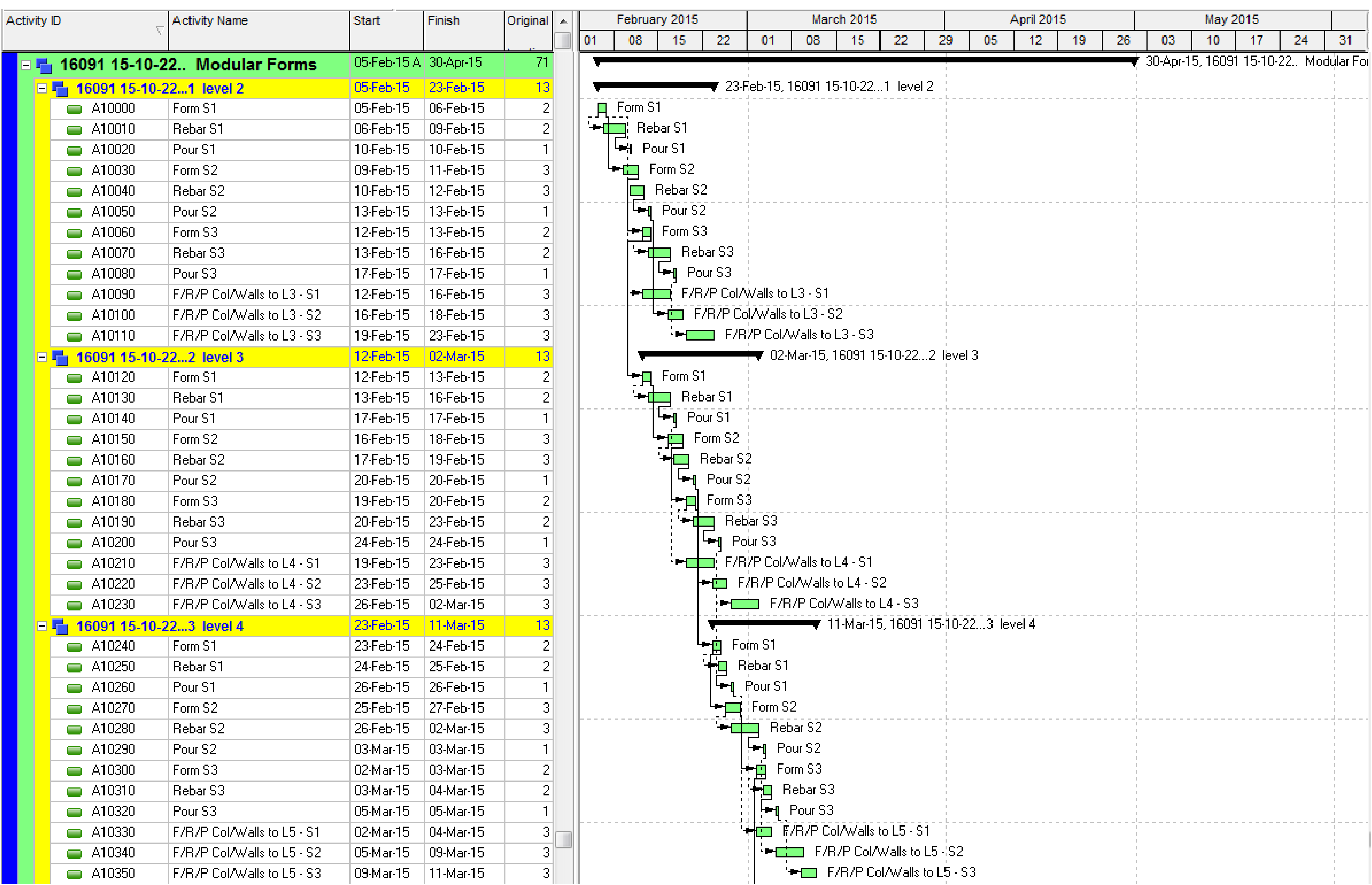
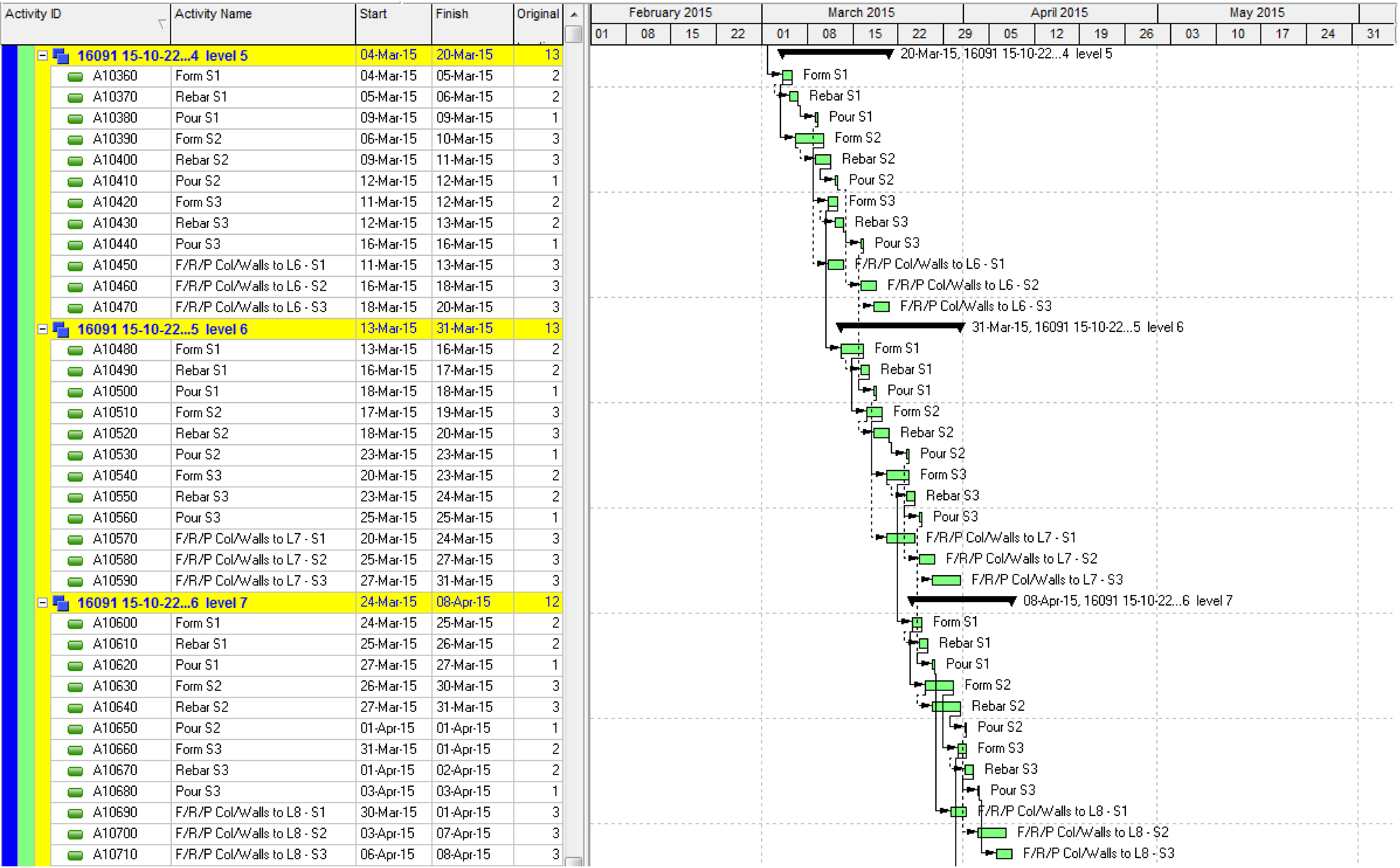
Appendix C:

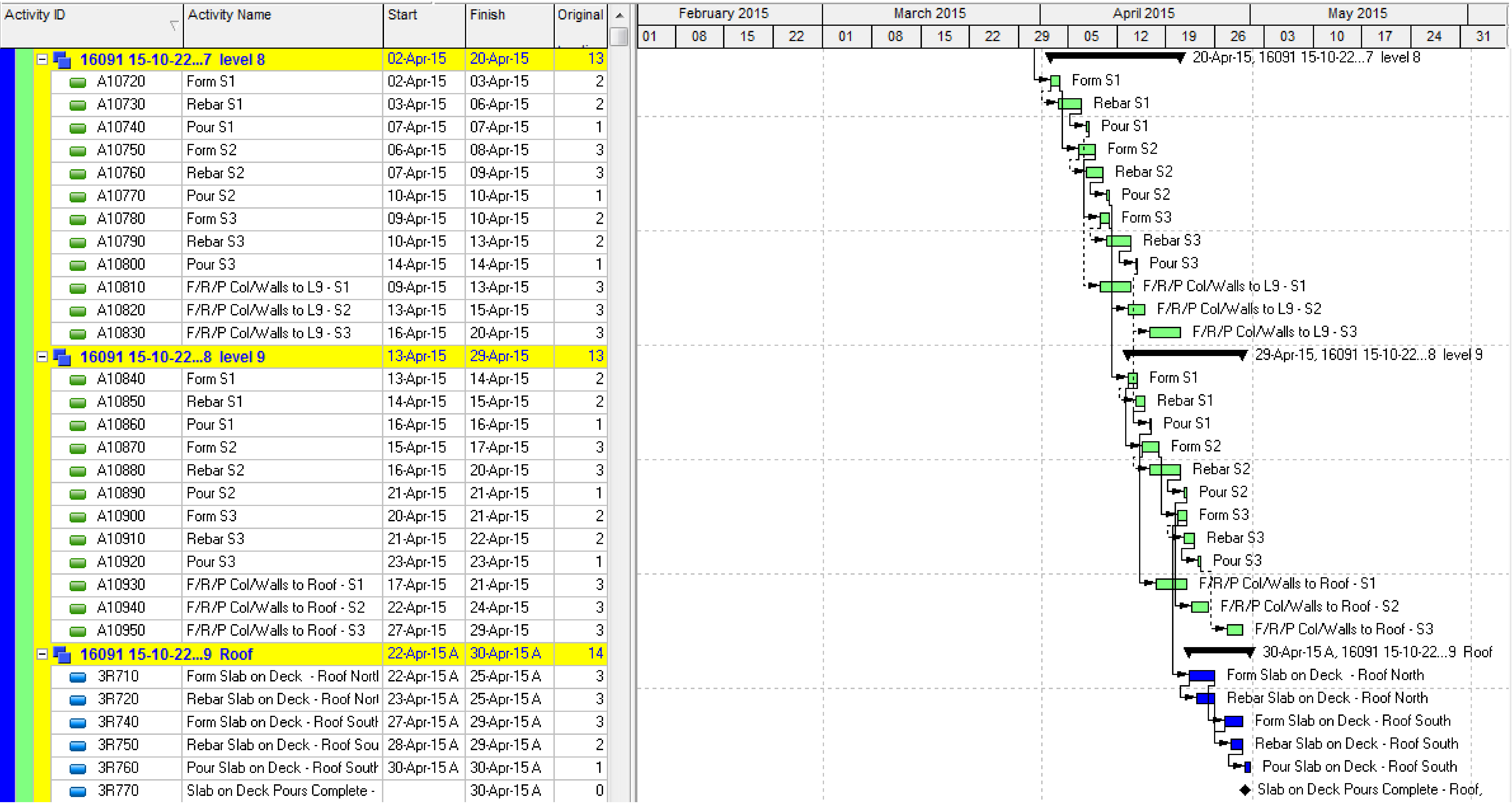
Modular Formwork Schedule



Activity ID	Activity Name	Start	Finish	Original
16091 15-10-22..	**Modular Forms**	05-Feb-15 A	30-Apr-15	71
16091 15-10-22...1	**level 2**	05-Feb-15	23-Feb-15	13
A10000	Form S1	05-Feb-15	06-Feb-15	2
A10010	Rebar S1	06-Feb-15	09-Feb-15	2
A10020	Pour S1	10-Feb-15	10-Feb-15	1
A10030	Form S2	09-Feb-15	11-Feb-15	3
A10040	Rebar S2	10-Feb-15	12-Feb-15	3
A10050	Pour S2	13-Feb-15	13-Feb-15	1
A10060	Form S3	12-Feb-15	13-Feb-15	2
A10070	Rebar S3	13-Feb-15	16-Feb-15	2
A10080	Pour S3	17-Feb-15	17-Feb-15	1
A10090	F/R/P Col/Walls to L3 - S1	12-Feb-15	16-Feb-15	3
A10100	F/R/P Col/Walls to L3 - S2	16-Feb-15	18-Feb-15	3
A10110	F/R/P Col/Walls to L3 - S3	19-Feb-15	23-Feb-15	3
16091 15-10-22...2	**level 3**	12-Feb-15	02-Mar-15	13
A10120	Form S1	12-Feb-15	13-Feb-15	2
A10130	Rebar S1	13-Feb-15	16-Feb-15	2
A10140	Pour S1	17-Feb-15	17-Feb-15	1
A10150	Form S2	16-Feb-15	18-Feb-15	3
A10160	Rebar S2	17-Feb-15	19-Feb-15	3
A10170	Pour S2	20-Feb-15	20-Feb-15	1
A10180	Form S3	19-Feb-15	20-Feb-15	2
A10190	Rebar S3	20-Feb-15	23-Feb-15	2
A10200	Pour S3	24-Feb-15	24-Feb-15	1
A10210	F/R/P Col/Walls to L4 - S1	19-Feb-15	23-Feb-15	3
A10220	F/R/P Col/Walls to L4 - S2	23-Feb-15	25-Feb-15	3
A10230	F/R/P Col/Walls to L4 - S3	26-Feb-15	02-Mar-15	3
16091 15-10-22...3	**level 4**	23-Feb-15	11-Mar-15	13
A10240	Form S1	23-Feb-15	24-Feb-15	2
A10250	Rebar S1	24-Feb-15	25-Feb-15	2
A10260	Pour S1	26-Feb-15	26-Feb-15	1
A10270	Form S2	25-Feb-15	27-Feb-15	3
A10280	Rebar S2	26-Feb-15	02-Mar-15	3
A10290	Pour S2	03-Mar-15	03-Mar-15	1
A10300	Form S3	02-Mar-15	03-Mar-15	2
A10310	Rebar S3	03-Mar-15	04-Mar-15	2
A10320	Pour S3	05-Mar-15	05-Mar-15	1
A10330	F/R/P Col/Walls to L5 - S1	02-Mar-15	04-Mar-15	3
A10340	F/R/P Col/Walls to L5 - S2	05-Mar-15	09-Mar-15	3
A10350	F/R/P Col/Walls to L5 - S3	09-Mar-15	11-Mar-15	3



Activity ID	Activity Name	Start	Finish	Original
16091 15-10-22...4 level 5		04-Mar-15	20-Mar-15	13
A10360	Form S1	04-Mar-15	05-Mar-15	2
A10370	Rebar S1	05-Mar-15	06-Mar-15	2
A10380	Pour S1	09-Mar-15	09-Mar-15	1
A10390	Form S2	06-Mar-15	10-Mar-15	3
A10400	Rebar S2	09-Mar-15	11-Mar-15	3
A10410	Pour S2	12-Mar-15	12-Mar-15	1
A10420	Form S3	11-Mar-15	12-Mar-15	2
A10430	Rebar S3	12-Mar-15	13-Mar-15	2
A10440	Pour S3	16-Mar-15	16-Mar-15	1
A10450	F/R/P Col/Walls to L6 - S1	11-Mar-15	13-Mar-15	3
A10460	F/R/P Col/Walls to L6 - S2	16-Mar-15	18-Mar-15	3
A10470	F/R/P Col/Walls to L6 - S3	18-Mar-15	20-Mar-15	3
16091 15-10-22...5 level 6		13-Mar-15	31-Mar-15	13
A10480	Form S1	13-Mar-15	16-Mar-15	2
A10490	Rebar S1	16-Mar-15	17-Mar-15	2
A10500	Pour S1	18-Mar-15	18-Mar-15	1
A10510	Form S2	17-Mar-15	19-Mar-15	3
A10520	Rebar S2	18-Mar-15	20-Mar-15	3
A10530	Pour S2	23-Mar-15	23-Mar-15	1
A10540	Form S3	20-Mar-15	23-Mar-15	2
A10550	Rebar S3	23-Mar-15	24-Mar-15	2
A10560	Pour S3	25-Mar-15	25-Mar-15	1
A10570	F/R/P Col/Walls to L7 - S1	20-Mar-15	24-Mar-15	3
A10580	F/R/P Col/Walls to L7 - S2	25-Mar-15	27-Mar-15	3
A10590	F/R/P Col/Walls to L7 - S3	27-Mar-15	31-Mar-15	3
16091 15-10-22...6 level 7		24-Mar-15	08-Apr-15	12
A10600	Form S1	24-Mar-15	25-Mar-15	2
A10610	Rebar S1	25-Mar-15	26-Mar-15	2
A10620	Pour S1	27-Mar-15	27-Mar-15	1
A10630	Form S2	26-Mar-15	30-Mar-15	3
A10640	Rebar S2	27-Mar-15	31-Mar-15	3
A10650	Pour S2	01-Apr-15	01-Apr-15	1
A10660	Form S3	31-Mar-15	01-Apr-15	2
A10670	Rebar S3	01-Apr-15	02-Apr-15	2
A10680	Pour S3	03-Apr-15	03-Apr-15	1
A10690	F/R/P Col/Walls to L8 - S1	30-Mar-15	01-Apr-15	3
A10700	F/R/P Col/Walls to L8 - S2	03-Apr-15	07-Apr-15	3
A10710	F/R/P Col/Walls to L8 - S3	06-Apr-15	08-Apr-15	3



Activity ID	Activity Name	Start	Finish	Original
16091 15-10-22...7 level 8		**02-Apr-15**	**20-Apr-15**	**13**
A10720	Form S1	02-Apr-15	03-Apr-15	2
A10730	Rebar S1	03-Apr-15	06-Apr-15	2
A10740	Pour S1	07-Apr-15	07-Apr-15	1
A10750	Form S2	06-Apr-15	08-Apr-15	3
A10760	Rebar S2	07-Apr-15	09-Apr-15	3
A10770	Pour S2	10-Apr-15	10-Apr-15	1
A10780	Form S3	09-Apr-15	10-Apr-15	2
A10790	Rebar S3	10-Apr-15	13-Apr-15	2
A10800	Pour S3	14-Apr-15	14-Apr-15	1
A10810	F/R/P Col/Walls to L9 - S1	09-Apr-15	13-Apr-15	3
A10820	F/R/P Col/Walls to L9 - S2	13-Apr-15	15-Apr-15	3
A10830	F/R/P Col/Walls to L9 - S3	16-Apr-15	20-Apr-15	3
16091 15-10-22...8 level 9		**13-Apr-15**	**29-Apr-15**	**13**
A10840	Form S1	13-Apr-15	14-Apr-15	2
A10850	Rebar S1	14-Apr-15	15-Apr-15	2
A10860	Pour S1	16-Apr-15	16-Apr-15	1
A10870	Form S2	15-Apr-15	17-Apr-15	3
A10880	Rebar S2	16-Apr-15	20-Apr-15	3
A10890	Pour S2	21-Apr-15	21-Apr-15	1
A10900	Form S3	20-Apr-15	21-Apr-15	2
A10910	Rebar S3	21-Apr-15	22-Apr-15	2
A10920	Pour S3	23-Apr-15	23-Apr-15	1
A10930	F/R/P Col/Walls to Roof - S1	17-Apr-15	21-Apr-15	3
A10940	F/R/P Col/Walls to Roof - S2	22-Apr-15	24-Apr-15	3
A10950	F/R/P Col/Walls to Roof - S3	27-Apr-15	29-Apr-15	3
16091 15-10-22...9 Roof		**22-Apr-15 A**	**30-Apr-15 A**	**14**
3R710	Form Slab on Deck - Roof Nort	22-Apr-15 A	25-Apr-15 A	3
3R720	Rebar Slab on Deck - Roof Nor	23-Apr-15 A	25-Apr-15 A	3
3R740	Form Slab on Deck - Roof Sout	27-Apr-15 A	29-Apr-15 A	3
3R750	Rebar Slab on Deck - Roof Sou	28-Apr-15 A	29-Apr-15 A	2
3R760	Pour Slab on Deck - Roof Sout	30-Apr-15 A	30-Apr-15 A	1
3R770	Slab on Deck Pours Complete -		30-Apr-15 A	0

Production Rates - Alternative Formwork

Sequence	*System*		*Qty*	*Unit*	*Production Rate (LH/SF)*	*Required LH*	*Required Days*	*Total Days with overlapping crew work*
1	Multiflex	Forms	1533	SF	0.055	84.315	1.1	2
		Plywood	1533	SF	0.011	16.863	0.85	
	Sky Deck	Forms	2912	SF	0.04	116.48	1.46	
2	Multiflex	Forms	1258	SF	0.055	69.19	1.15	3
		Plywood	1258	SF	0.011	13.838	0.7	
	Sky Deck	Forms	5538	SF	0.04	221.52	2.72	
3	Multiflex	Forms	1950	SF	0.055	107.25	1.35	2
		Plywood	1950	SF	0.011	21.45	1.07	
	Sky Deck	Forms	3435	SF	0.04	137.4	1.7	
Totals								**7**

Labor Hours Associated With Peri Systems (per floor)

Sequence	*System*	*Labor Type*	*Qty*	*Labor Hours*
1	Multiflex	Sys. Carp.	8	84
		Ply Carp.	2	17
	Sky Deck	Carpenter	8	117
2	Multiflex	Sys. Carp.	8	70
		Ply Carp.	2	14
	Sky Deck	Carpenter	8	222
3	Multiflex	Sys. Carp.	8	108
		Ply Carp.	2	22
	Sky Deck	Carpenter	8	138
Total	-	-	-	792

Appendix D:

Formwork System Cost Estimates

Cost Estimates of Formwork Systems

Formwork System		*Qty*	*Unit*	*2016 Bare Costs*			*Totals*			
				Material	*Labor*	*Total Including O&F*	*Total Material*	*Total Labor*	*Total Including O&F*	*System Total*
Original	Forms in Place, Elevated Slabs, Flat Slab, Drop Panels, job-built plywood, 4 use	150,125	SF	-	$ 4.15	$ 5.19	-	$623,018.75	$ 778,773.44	**$792,442.04**
	Plywood	14,388	SF	$ 0.76	-	$ 0.95	$ 10,934.88	-	$ 13,668.60	
Alternative	Peri Skydeck	23770	SF	$ 5.55	-	$ 6.94	$ 131,923.50	-	$ 164,904.38	**$414,631.83**
		106965	SF	-	$ 1.04	$ 1.30	-	$110,976.19	$ 138,720.23	
	Peri Multiflex	43160	SF	-	$ 1.04	$ 1.30	-	$ 44,778.50	$ 55,973.13	
		9592	SF	$ 3.45	-	$ 4.31	$ 33,092.40	-	$ 41,365.50	
	Plywood	14388	SF	$ 0.76	-	$ 0.95	$ 10,934.88	-	$ 13,668.60	

Note: All cost information was attained from RS Means 2016 or from manufacturer cost data

Appendix E:

Facade Crane Selection Calculations & Information

GENERAL NOTES:

- SITE IS ONLY Approx 80' wide ∴ absolute max CRANE RADIUS IS 80'.
- Max lift height = 113'

LARGEST PANEL:

Colored GREEN IN REPORT → FIGURE 14

Total SF → 125 SF

Total load = 125 SF × 12 lb/SF = 1500 lbs

Safety Factor → Assume 10% total load

1500 lbs × 1.10 = 1650 lbs

CRANE MUST LIFT 1650 lbs to max height of 113' at max Radius of 80'

REFER TO CRANE LOAD CHARTS FOR FINAL SELECTION

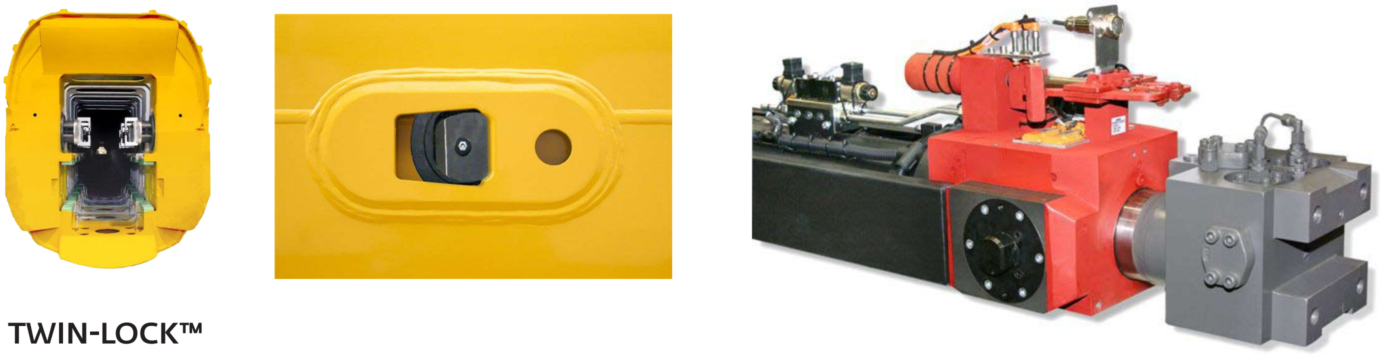
Grove GMK3055

Product Guide

Features

- 9,7 m – 43 m (32 ft – 141 ft) 6-section full power boom
- Patented TWIN-LOCK™ boom pinning system
- 8,7 m –15 m (28.5 ft – 49.2 ft) bi-fold lattice swingaway, hydraulic luffing or manual offset
- 11 600 kg (25,500 lb) counterweight with hydraulic removal system
- 260 kW (349 hp) Mercedes OM501LA 6 cylinder turbo-charged diesel engine. ZF, AS Tronic transmission
- MEGATRAK™ independent hydro-pneumatic suspension

Features

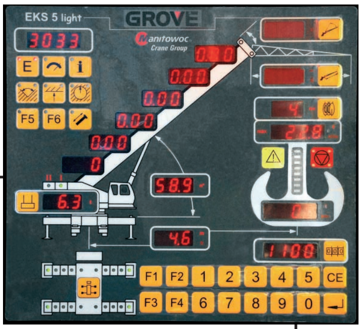


TWIN-LOCK™

Boom pinning mechanism automatically pins the sections in position using two horizontal pins.

ECOS

Electronic Crane Operating System - ECOS enables control of the entire crane's principle operations. Simple programming eases lift planning and a supply of essential information allows full concentration on the lift itself.



EKS 5 Light

Monitoring the lifting condition of the crane at all times EKS works together with, but independently of the ECOS as a complete command and control system or separately as a load moment indicator.

MEGATRAK™

The MEGATRAK™ suspension system is the best off road driveline available on the market today. The system's versatility and performance allows the GMK3055 to operate as a true all-terrain crane. The MEGATRAK™ independent suspension and all-wheel steer system allows wheels to remain on the ground at all times so stresses and weight are not continually transferred between axles. MEGATRAK™ provides true ground clearance where others just raise the chassis.

Other benefits of the MEGATRAK™ system are:
- A reliable suspension system
- Excellent job site maneuverability with all-wheel steering
- Commonality among almost all models
- A driveline that remains aligned at all times
- A steering linkage system that is protected against damage
- Constant tire contact for equal tire wear
- Reduced maintenance

Contents

Specifications

Superstructure

Boom

9,7 m – 43 m (32 ft – 141 ft) six section, full power boom with patented TWIN-LOCK™ boom pinning system. Maximum tip height: 45,8 m (150 ft).

Boom nose

Five nylatron sheaves, mounted on heavy duty tapered roller bearings with removable pin-type rope guards. Quick reeve boom nose. Removable auxiliary boom nose with removable pin type rope guard.

Boom elevation

Single lift cylinder with safety valve provides boom angle from -2.7° to +82.8°.

Hydraulically offsettable lattice extension

8,7 m – 15 m (28.5 ft – 49.2 ft) bi-fold lattice swingaway extension hydraulically offsettable and luffing under load: 0° – 40°. Controlled from the crane cab.

Maximum tip height: 60,7 m (199 ft)

*Offsettable lattice extension

8,7 m – 15 m (28.5 ft – 49.2 ft) bi-fold lattice swingaway extension manually offset: 0°, 20° or 40°.

Maximum tip height: 60,7 m (199 ft)

Load moment and anti-two block system

Load moment and anti-two block system with audio/visual warning and control lever lockout provides electronic display of boom angle, length, radius, tip height, relative load moment, maximum permissible load, load indication and warning of impending two-block condition.

Cab

All aluminum construction cab with acoustical lining, tinted safety glass, adjustable operator's seat, sliding windows in side and cab rear, hinged front window with wiper, sunvisor and window shade. Other features include diesel heater/defroster, armrest integrated crane controls, and ergonomically arranged instrumentation.

Crane control system

Full electronic control of all crane movements using electrical control levers with automatic reset to zero. Controls are integrated with the LMI and engine management system by CAN-BUS. ECOS system with graphic display.

Swing

Axial piston fixed displacement motor and planetary gear box. Infinitely variable to 2.5 rpm. Holding and service brake.

Counterweight

11 600 kg (25,500 lb) consisting of 6600 kg (14,500 lb) bolted to the turntable, 1 X 2000 kg (4409 lb) and 3 X 1000 kg (2204 lb) sections with hydraulic installation/removal system. Controlled from the superstructure cab.

Hydraulic system

2 separate circuits, 1 axial piston variable displacement pump (load sensing) with electronic power limiting control and 1 gear pump for swing.

Dual thermostatically controlled oil coolers keep oil at optimum operating temperature.

Tank capacity: 600 L (159 gal)

Hoist

Main and auxiliary hoist are powered by axial piston motor with planetary gear and brake. "Thumb-thumper" hoist drum rotation indicator alerts operator of hoist movement.

	Main	**Auxiliary**
Line length:	170 m (558 ft)	170 m (558 ft)
Rope diameter:	16 mm	16 mm
Line speed:	120 m/min (394 fpm)	120 m/min (394 fpm)
Line pull:	50 kN (11,240 lb)	50 kN (11,240 lb)

*Denotes optional equipment

Specifications

Superstructure – continued

*Optional equipment

- Windspeed indicator
- Worklights mounted on base section
- Aircraft warning lights
- Hook blocks/headache ball
- Retractable cab foot walk
- Additional spotlight on superstructure cab
- Radio/CD player for superstructure cab
- Air conditioning – combined system for both cabs
- EKS 5 with graphic display in lieu of standard EKS 5 light
- Additional strobe light for superstructure
- Working range limiter
- Wireless remote control for all crane functions (Hetronic)
- Automatic centralized lubrication for superstructure
- 360˚ positive swing lock (NYC requirement)

Carrier

Chassis

Box type, torsion resistant frame is fabricated from high strength steel.

Outrigger system

Four hydraulic single stage outrigger beams with vertical cylinders and outrigger pads, 500 mm (19.7 in) square. Outriggers can be set in 3 positions:

Full	6,2 m (20.3 ft)
Partial	4,4 m (14.4 ft)
Retracted	2,3 m (7.6 ft)

Independent horizontal and vertical movement controlled from each side of carrier and the superstructure cab. Electronic crane level indicators.

Engine

Mercedes-Benz OM 501 LA six cylinder, water cooled, turbo-charged, with 260 kW (349 bhp) @ 1800 rpm. Max. torque 1730 Nm (1276 ft/lb) @ 1080 rpm. Compression and exhaust brakes.

Engine emissions: EUROMOT/EPA/CARB (off road)

Fuel tank capacity

300 L (79 gallons).

Transmission

ZF, AS Tronic, 12 speeds forward, 2 reverse.

Drive/steer

6x4x6

Axles

1st axle line – steer (optional drive)

2nd axle line – drive/steer

3rd axle line – drive/steer (connects for all wheel steer)

Drive axles with planetary hub reduction and center mounted gearing. Inter-axle and cross axle differential locks.

Suspension

Grove's exclusive MEGATRAK™ suspension. Independent hydro-pneumatic system acting on all wheels with hydraulic lockout. Suspension can be raised 170 mm (6.7 in) or lowered 130 mm (5.1 in) both longitudinally and transversely. Features an automatic leveling system for highway travel.

Tires

6 tires, 16.00R25

Steering

Dual circuit, hydraulic power assisted steering system. Transfer case mounted, ground driven emergency steering pump. Axles 1 and 2 steer on highway. Separate steering of the 3rd axle for all wheel and crab steering, controlled by an electric rocker switch.

Brakes

Service brakes: pneumatic dual circuit acting on all wheels.

Parking brake: pneumatically operated spring loaded brake acting on axle lines 1 and 3.

Air dryer.

**Denotes optional equipment*

Specifications

Carrier – continued

Cab

Two-man, aluminum construction with the following features: safety glass, driver and passenger seats with pneumatic suspension, engine-dependent hot water heater, complete instrumentation and driving controls. Cab tilts forward for easy engine access.

Electrical system

24V system with three phase alternator, 28V/100A
2 batteries, 12V/170 Ah

Maximum speed

80 km/h (50 mph) 14.00 tires
85 km/h (53 mph) 16.00/20.5 tires

Gradeability (theoretical)

82% - 14.00 tires
72% - 16.00/20.5 tires

Miscellaneous standard equipment

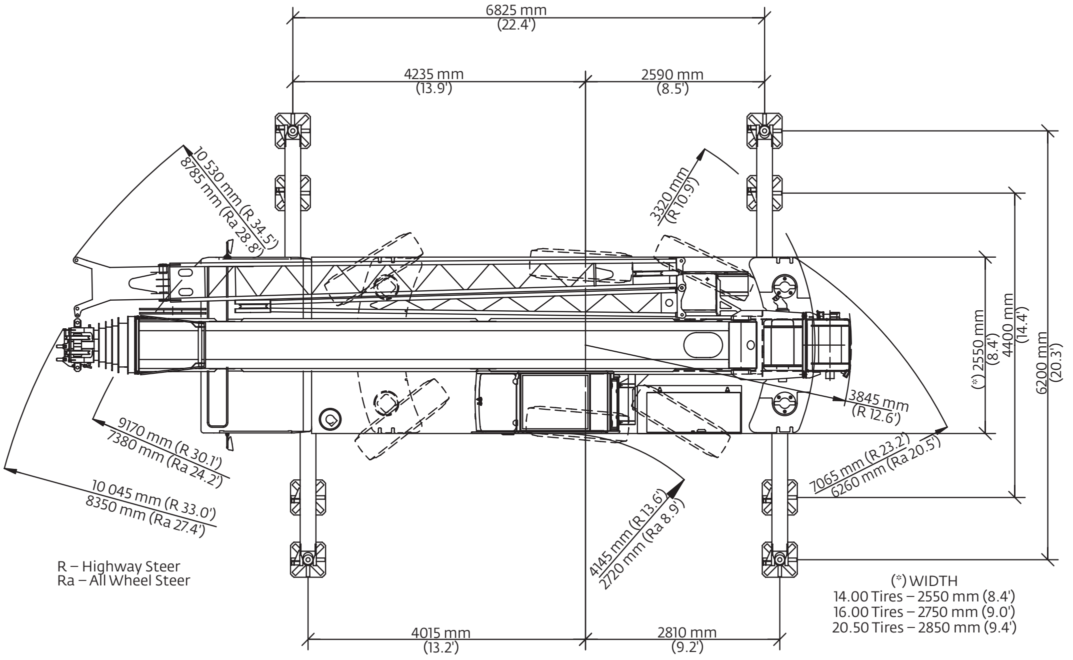
Work light; tool kit; fire extinguisher; auxiliary boom nose; radio/CD player in carrier cab, heated rear view mirrors, and cruise control.

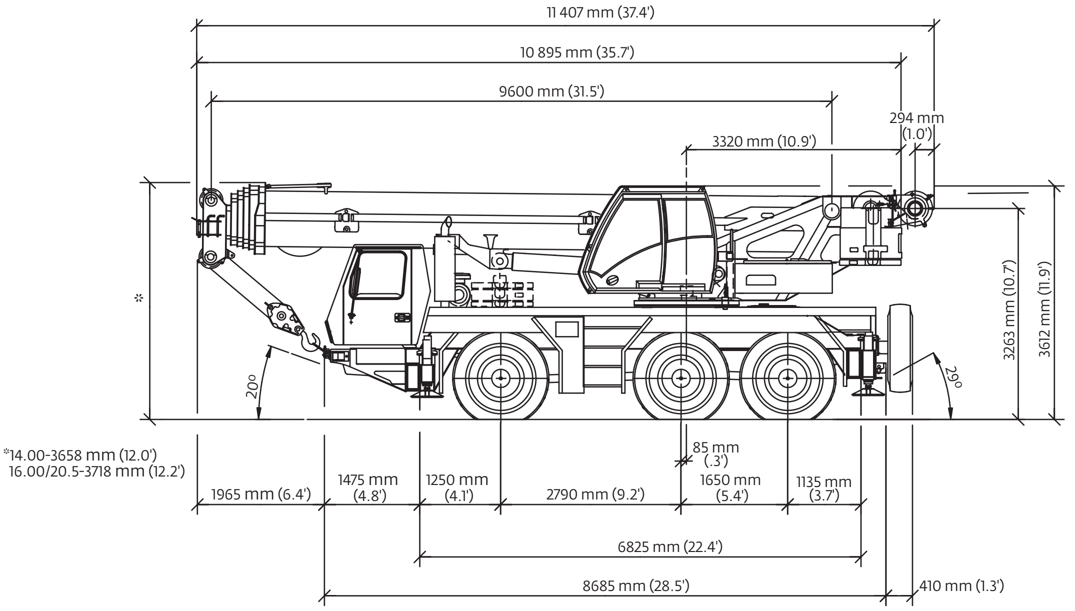
*Optional equipment

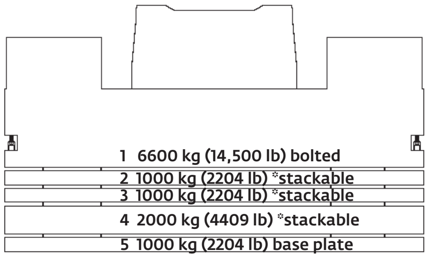
- Stainless steel exhaust system with spark arrestor
- Air conditioning – combined system for both cabs
- 14.00R25 tires (vehicle width 2,55 m (8.4 ft)
- 20.5R25 tires (vehicle width 2,85 m (9.4 ft)
- 6x6x6 drive/steer
- Electric driveline retarder
- Engine independent diesel cab heater, with engine pre-heater
- Strobe light
- Worklights for outriggers
- Data logger
- Spare tire and wheel with carry bracket
- Engine shut down valve
- Outrigger pad load indicator
- Trailer hitch

**Denotes optional equipment*

Dimensions







Counterweight configuration	1	2	3	4	5
6600 kg (14,500 lb)	●				
7600 kg (16,700 lb)	●				●
8600 kg (18,900 lb)	●	●			●
9600 kg (21,100 lb)	●	●	●		●
10 600 kg (23,300 lb)	●	●		●	●
11 600 kg (25,500 lb)	●	●	●	●	●

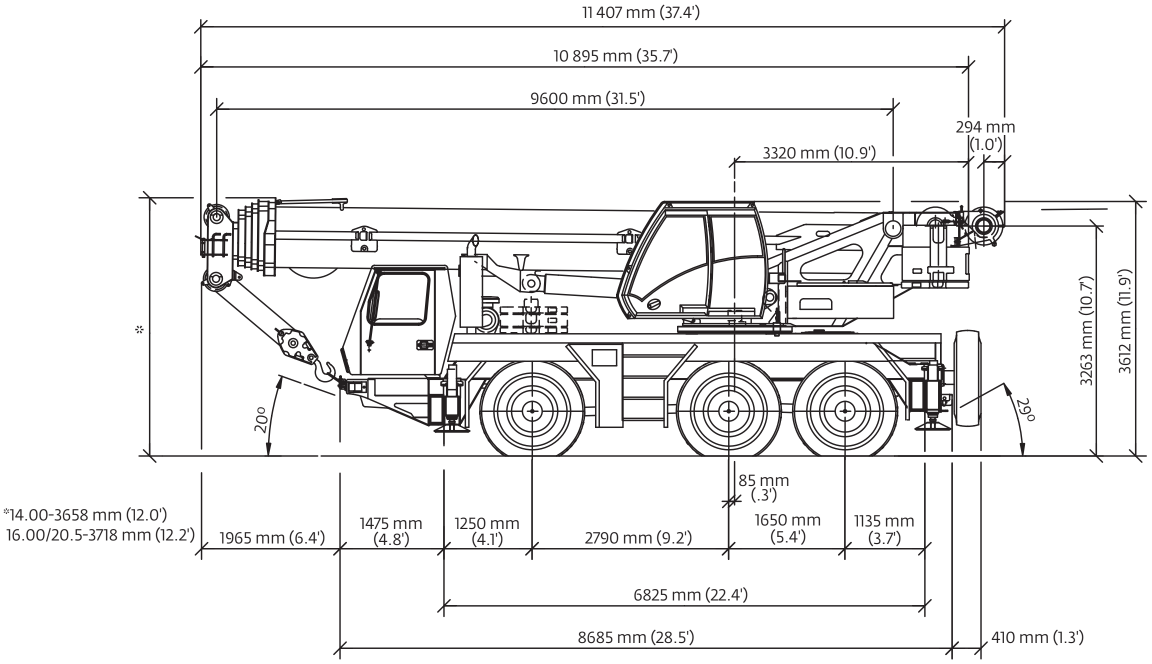
Load chart configuration – 360°

Counterweight	25,500 lb	23,300 lb	21,100 lb	18,900 lb	16,700 lb	14,500 lb
Main boom	✖ ■	✖ ■	✖ ■	✖ ■ ●	✖ ■ ● □ ○	✖ ■ ● □ ○
28.5' swingaway	✖ ■	✖ ■	✖ ■	✖ ■	✖ ■	✖ ■
49.2' swingaway	✖ ■	✖ ■	✖ ■	✖ ■	✖ ■	✖ ■

Outrigger span 20.3' = ✖ 14.4' = ■ 7.6' = ●
Rubber P&C = □ 360° = ○

Weight proposals

Boom over front



Boom over front

Basic weights - kg (lb)	Axle 1		Axles 2 and 3		Total	
Mercedes power, 28.5' – 49.2' hydraulic offset swingaway including brackets and hose reel, 16.00R25 tires, 6x4x6 drive/steer, 2nd oil cooler, outrigger pads, auxiliary hoist, 6600 kg (14,550 lb) counterweight fixed to superstructure, driver and tanks filled.	11 517	(25,391)	23 957	(52,815)	35 474	(78,206)
Additions:						
6x6x6 drive/steer	339	(748)	21	(46)	360	(794)
Electric driveline retarder	-17	(-37)	187	(412)	170	(375)
Spare wheel 14.00 R25 XGC steel rim with stowage	-179	(-394)	444	(979)	265	(584)
Spare wheel 16.00 R25 XGC steel rim with stowage	-218	(-482)	539	(1189)	321	(708)
Spare wheel 20.5 R25 XGC steel rim with stowage	-252	(-557)	620	(1368)	368	(811)
1000 kg (2200 lb) counterweight slab clamped to superstructure	-616	(-1359)	1656	(3651)	1040	(2293)
2000 kg (4400 lb) counterweight slab clamped to superstructure	-1227	(-2704)	3297	(7268)	2070	(4564)
1000 kg (2200 lb) counterweight slab on carrier deck (base plate)	1042	(2297)	-2	(-4)	1040	(2293)
2000 kg (4400 lb) counterweight slab on carrier deck	2074	(4572)	-4	(-9)	2070	(4564)
Substitutions:						
14.00R25 tires	133	(292)	265	(585)	-398	(877)
20.5R25 tires	94	(207)	188	(414)	282	(622)
Removals:						
Brackets for hydraulic swingaway	-71	(-157)	11	(24)	-60	(-132)
Hose reel for hydraulic swingaway	-120	(-265)	55	(122)	-65	(-143)
10 m – 17 m (33 ft – 56 ft) hydraulic swingaway	-1019	(-2247)	134	(296)	-885	(-1951)
Auxiliary boom nose	-128	(-283)	68	(151)	-60	(-132)
Outrigger floats front	-97	(-214)	25	(55)	-72	(-159)
Outrigger floats rear	38	(84)	-108	(-238)	-70	(-154)

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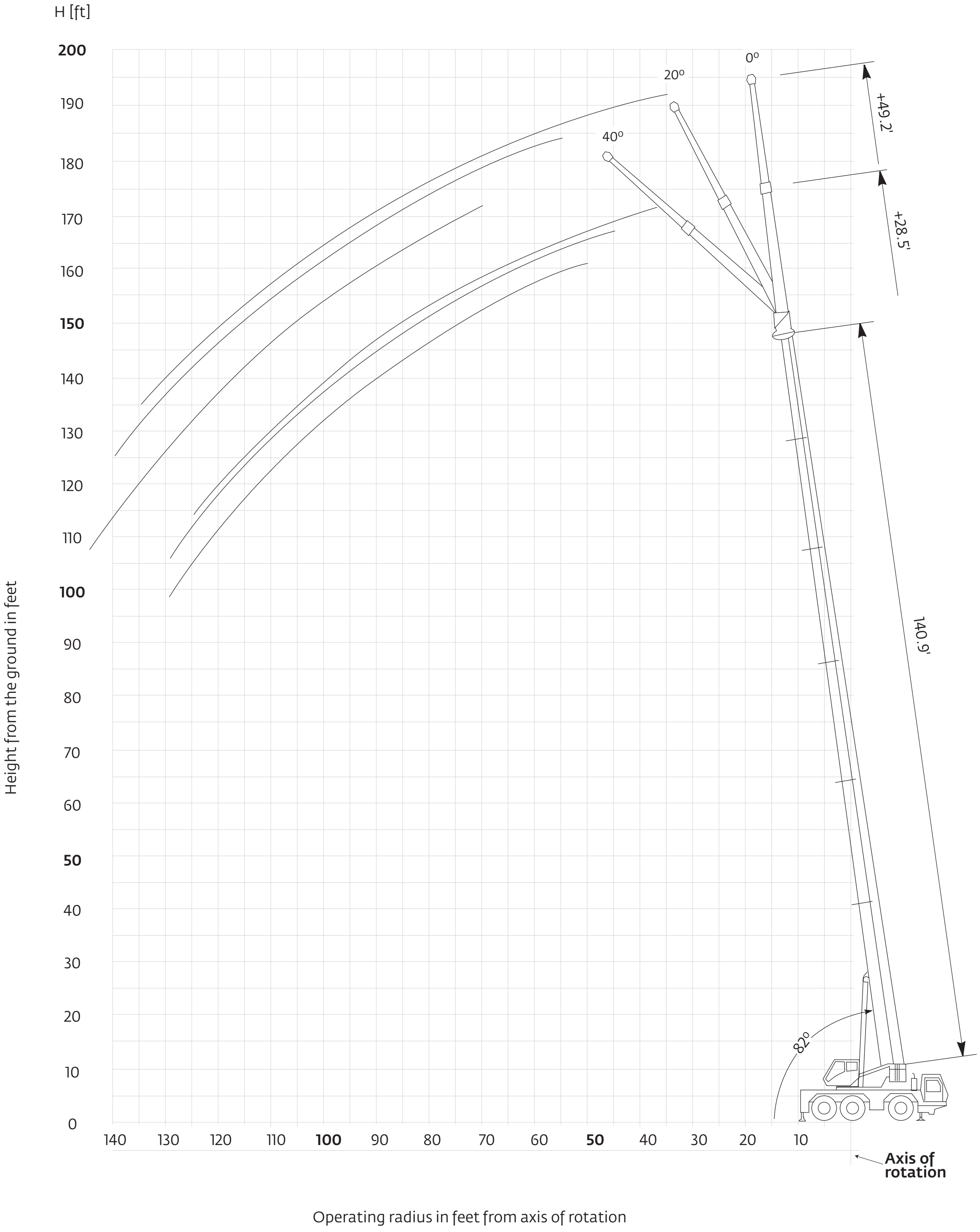
Use of jib is required to lift panels to upper levels

Working range

32 ft – 141 ft main boom with 28.5 ft and 49.2 ft swingaway



Tip heights shown in the working range diagram do not consider loaded boom deflection.

Load charts

Manual offsettable swingaway

43 m
(141 ft)

8,7 m
(28.5 ft)
Manual offset

11 600 kg
(25,500 lb)

22.4 ft x 20.3 ft
100%

360˚

Feet	**Pounds x 1000**									
	28.5 ft length									
	0º Offset					**40º Offset**				
	87.4	**99.6**	**117.4**	**128.5**	**140.9**	**87.4**	**99.6**	**117.4**	**128.5**	**140.9**
20.0	17.4	17.0	–	–	–	–	–	–	–	–
25.0	16.0	16.0	12.4	–	–	–	–	–	–	–
30.0	14.6	15.0	12.4	9.2		–	–	–	–	–
35.0	13.6	14.0	12.0	9.2	9.4	8.0	–	–	–	–
40.0	12.6	13.2	11.0	9.2	9.4	7.8	7.8	–	–	–
45.0	11.4	12.4	10.0	9.2	9.4	7.6	7.6	7.6	–	–
50.0	10.4	11.6	9.0	9.2	9.4	7.4	7.6	7.4	7.4	7.4
55.0	10.0	10.8	8.4	8.6	8.8	7.2	7.4	7.4	7.4	7.4
60.0	9.4	10.2	7.8	8.0	8.2	7.2	7.2	7.2	7.2	7.2
65.0	8.8	9.4	7.2	7.6	7.8	7.0	7.2	6.8	7.0	7.2
70.0	8.4	8.6	6.8	7.0	7.4	7.0	7.0	6.4	6.6	6.8
75.0	8.0	7.6	6.4	6.6	7.0	7.0	7.0	6.2	6.4	6.6
80.0	7.6	6.8	6.0	6.4	6.2	7.0	7.0	5.8	6.0	6.2
85.0	6.8	6.0	5.6	6.0	5.6	7.0	6.6	5.6	5.8	6.0
90.0	6.0	5.2	5.2	5.6	4.8	6.2	5.6	5.2	5.6	5.6
95.0	5.2	4.4	4.8	5.0	4.2	5.4	4.8	5.0	5.2	4.8
100.0	4.6	3.8	4.4	4.4	3.8	–	4.2	4.6	5.0	4.2
105.0	–	3.2	4.2	4.0	3.2	–	3.4	4.4	4.4	3.8
110.0	–	2.8	3.8	3.4	2.8	–	2.8	4.0	3.8	3.2
115.0	–	[illegible]	3.4	3.0	2.4	–	–	3.6	3.4	2.8
120.0	–	–	3.0	2.6	2.0	–	–	3.0	2.8	2.4
125.0	–	–	2.6	2.2	1.6	–	–	–	2.4	2.0
130.0	–	–	2.2	1.8	–	–	–	–	2.0	1.4
135.0	–	–	–	1.6	–	–	–	–	1.6	–

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Load charts

Manual offsettable swingaway

43 m
(141 ft)

15 m
(49.2 ft)
Manual offset

11 600 kg
(25,500 lb)

22.4 ft x 20.3 ft
100%

360˚

Feet	**Pounds x 1000**									
	49.2 ft length									
	0º Offset					**40º Offset**				
	87.4	**99.6**	**117.4**	**128.5**	**140.9**	**87.4**	**99.6**	**117.4**	**128.5**	**140.9**
20.0	9.2	–	–	–	–	–	–	–	–	–
25.0	8.8	8.4	–	–	–	–	–	–	–	–
30.0	8.4	8.2	6.6	5.8	–	–	–	–	–	–
35.0	7.8	7.8	6.6	5.8	5.6	–	–	–	–	–
40.0	7.2	7.4	6.4	5.8	5.6	–	–	–	–	–
45.0	6.8	7.0	6.4	5.8	5.6	–	–	–	–	–
50.0	6.2	6.4	6.2	5.8	5.6	4.0	–	–	–	–
55.0	6.0	6.2	6.0	5.8	5.6	4.0	4.0	–	–	–
60.0	5.6	5.8	5.8	5.8	5.4	3.8	3.8	3.8	–	–
65.0	5.2	5.6	5.4	5.6	5.4	3.8	3.8	3.8	–	–
70.0	5.0	5.2	5.2	5.4	5.4	3.6	3.8	3.8	3.8	3.8
75.0	4.8	5.0	5.0	5.2	5.2	3.6	3.6	3.6	3.6	3.6
80.0	4.6	4.8	4.8	5.0	5.0	3.6	3.6	3.6	3.6	3.6
85.0	4.4	4.6	4.6	4.8	4.8	3.4	3.6	3.6	3.6	3.6
90.0	4.2	4.4	4.4	4.6	4.6	3.4	3.4	3.4	3.4	3.6
95.0	4.0	4.2	4.2	4.4	4.6	3.4	3.4	3.4	3.4	3.4
100.0	3.8	4.0	4.0	4.2	4.0	3.4	3.4	3.4	3.4	3.4
105.0	3.8	4.0	3.8	4.0	3.6	3.4	3.4	3.4	3.4	3.4
110.0	3.6	3.4	3.6	3.8	3.2	3.4	3.4	3.4	3.4	3.4
115.0	3.6	3.0	3.4	3.4	2.8	3.4	3.4	3.4	3.4	3.4
120.0	3.4	2.6	3.2	3.0	2.4	–	3.0	3.2	3.4	3.2
125.0	–	2.2	3.0	2.6	2.0	–	2.6	3.2	3.2	2.8
130.0	–	1.8	2.6	2.2	1.6	–	2.0	3.0	2.8	2.4
135.0	–	–	–	2.0	1.4	–	–	–	2.4	2.0
140.0	–	–	–	1.6	–	–	–	–	2.0	1.6
145.0	–	–	–	1.4	–	–	–	–	1.6	1.4
150.0	–	–	–	–	–	–	–	–	1.4	–

Crane at this configuration has the capacity to lift the largest panel at the highest point

Load charts

Manual offsettable swingaway

43 m
(141 ft)

8,7 m
(28.5 ft)
Manual offset

7600 kg
(16,700 lb)

22.4 ft x 20.3 ft
100%

360˚

Feet	Pounds x 1000									
	28.5 ft length									
	0º Offset					40º Offset				
	87.4	99.6	117.4	128.5	140.9	87.4	99.6	117.4	128.5	140.9
20.0	17.4	17.0	–	–	–	–	–	–	–	–
25.0	16.0	16.0	12.4	–	–	–	–	–	–	–
30.0	14.6	15.0	12.4	9.2	–	–	–	–	–	–
35.0	13.6	14.0	12.0	9.2	9.4	8.0	–	–	–	–
40.0	12.6	13.2	11.0	9.2	9.4	7.8	7.8	–	–	–
45.0	11.4	12.4	10.0	9.2	9.4	7.6	7.6	7.6	–	–
50.0	10.4	11.6	9.0	9.2	9.4	7.4	7.6	7.4	7.4	7.4
55.0	10.0	9.8	8.4	8.6	8.8	7.2	7.4	7.4	7.4	7.4
60.0	9.4	8.4	7.8	8.0	7.8	7.2	7.2	7.2	7.2	7.2
65.0	8.4	7.2	7.2	7.6	6.6	7.0	7.2	6.8	7.0	7.2
70.0	7.2	6.2	6.8	6.6	5.8	7.0	7.0	6.4	6.6	6.8
75.0	6.4	5.4	6.2	5.6	5.0	7.0	6.2	6.2	6.4	5.8
80.0	5.6	4.6	5.4	5.0	4.2	6.0	5.2	5.8	5.8	5.0
85.0	4.8	3.8	4.8	4.2	3.6	5.2	4.4	5.4	5.0	4.4
90.0	4.0	3.2	4.2	3.8	3.0	4.4	3.8	4.8	4.4	3.6
95.0	3.4	2.6	3.6	3.2	2.4	3.6	3.0	4.2	3.8	3.2
100.0	3.0	2.2	3.2	2.8	2.0	–	2.4	3.6	3.2	2.6
105.0	–	1.6	2.8	2.4	1.6	–	1.8	3.0	2.8	2.2
110.0	–	–	2.4	2.0	–	–	1.2	2.6	2.2	1.6
115.0	–	–	2.0	1.6	–	–	–	2.2	1.8	–
120.0	[illegible]	–	1.6	–	–	–	–	1.8	1.4	–

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Load charts

Manual offsettable swingaway

43 m
(141 ft)

15 m
(49.2 ft)
Manual offset

7600 kg
(16,700 lb)

22.4 ft x 20.3 ft
100%

360˚

Pounds x 1000

49.2 ft length

Feet	0º Offset					40º Offset				
	87.4	**99.6**	**117.4**	**128.5**	**140.9**	**87.4**	**99.6**	**117.4**	**128.5**	**140.9**
20.0	9.2	–	–	–	–	–	–	–	–	–
25.0	8.8	8.4	–	–	–	–	–	–	–	–
30.0	8.4	8.2	6.6	5.8	–	–	–	–	–	–
35.0	7.8	7.8	6.6	5.8	5.6	–	–	–	–	–
40.0	7.2	7.4	6.4	5.8	5.6	–	–	–	–	–
45.0	6.8	7.0	6.4	5.8	5.6	–	–	–	–	–
50.0	6.2	6.4	6.2	5.8	5.6	4.0	–	–	–	–
55.0	6.0	6.2	6.0	5.8	5.6	4.0	4.0	–	–	–
60.0	5.6	5.8	5.8	5.8	5.4	3.8	3.8	3.8	–	–
65.0	5.2	5.6	5.4	5.6	5.4	3.8	3.8	3.8	–	–
70.0	5.0	5.2	5.2	5.4	5.4	3.6	3.8	3.8	3.8	3.8
75.0	4.8	5.0	5.0	5.2	5.2	3.6	3.6	3.6	3.6	3.6
80.0	4.6	4.8	4.8	5.0	4.6	3.6	3.6	3.6	3.6	3.6
85.0	4.4	4.4	4.6	4.6	4.0	3.4	3.6	3.6	3.6	3.6
90.0	4.2	3.8	4.4	4.0	3.4	3.4	3.4	3.4	3.4	3.6
95.0	4.0	3.4	4.0	3.6	2.8	3.4	3.4	3.4	3.4	3.4
100.0	3.6	2.8	3.6	3.0	2.4	3.4	3.4	3.4	3.4	3.4
105.0	3.2	2.4	3.2	2.6	2.0	3.4	3.2	3.4	3.4	3.0
110.0	2.8	2.0	2.8	2.2	1.6	3.2	2.8	3.4	3.2	2.6
115.0	2.4	1.6	2.4	2.0	–	2.6	2.2	3.0	2.8	2.2
120.0	2.0	–	2.0	1.6	–	–	1.6	2.6	2.4	1.8
125.0	–	–	1.8	1.4	–	–	–	2.2	2.0	1.4
130.0	–	–	1.4	–	–	–	–	1.8	1.6	–

Symbols glossary

Axles

Boom

Boom elevation

Boom extension

Boom length

Boom nose

Brakes

Cab

Counterweight

Drive

Electrical system

Engine

Extension

Frame

Fuel tank capacity

Gear

Grade

Heavy duty jib

Hoist

Hookblock

Hydraulic system

Lights

Oil

Outrigger controls

Outriggers

Radius

Rotation

Speed

Steering

Suspension

Swing

Tires

Transmission

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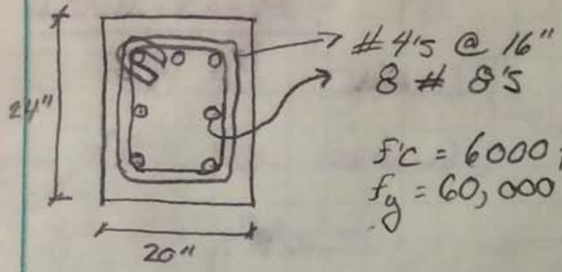
Appendix F:

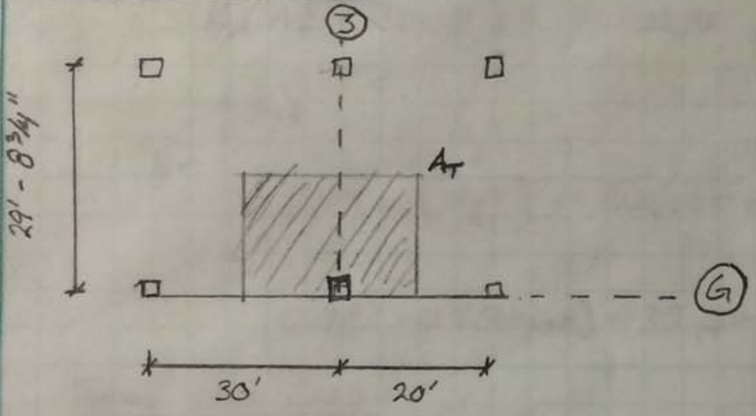
Structural Breadth Calculations

COLUMN REINFORCEMENT



$f'c = 6000$ psi
$f_y = 60{,}000$ psi

TRIBUTARY AREA



$A_T = 25'\left(\frac{29'\text{-}8\frac{3}{4}"}{2}\right)$

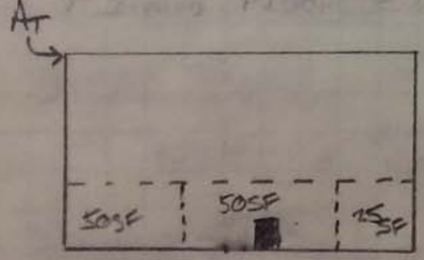
$A_T = \underline{371.62\ ft^2}$

FLOOR SLAB (Typical)

7" PT SLAB
4" Continuous Edge Drop
8" Drop Panel @ Column
→ 5000 psi NW CONCRETE

DEAD LOAD SUMMARY

CONCRETE SLAB → 150 PCF



7" SLAB → $\frac{7"}{12"}(150)(371.62) = \underline{32.5}$ KIP

4" DROP → $4/12(150)(75) = \underline{3.75}$ KIP

8" DROP → $8/12(150)(50) = \underline{5.00}$ KIP

Superimposed DL → 10 psf → 10 psf (371.62) = $\underline{3.72}$ Kip

FLOOR Finish DL → 2 psf → 2 psf (371.62) - $\underline{0.75}$ Kip

Total DEAD LOAD:

$$32.5 + 3.75 + 5.00 + 3.72 + 0.75 = \underline{45.72\ \text{Kips}}$$

LIVE LOADS -

20 psf unreduced ⎤
80 psf Reduced ⎦ → ATTAINED FROM LOADING PLANS

LL Reduction

$K_{LL} = 4$ b/c exterior column w/ cantilever

$K_{LL} A_T = 1486.48\ SF > 400\ SF$ ✓

$$L = \left| \begin{array}{l} 0.5 \\ L_0\left(.25 + \dfrac{15}{\sqrt{K_{LL} A_T}}\right) = 80\left(.25 + \dfrac{15}{\sqrt{1486.48}}\right) = 42\ \text{psf} \end{array} \right.$$

$0.4L = 0.4(80\text{psf}) = 32\ \text{psf}$ $\quad 42\text{psf} > 32\text{psf}$ ✓

TOTAL LIVE LOAD

$$(42\text{psf} + 20\text{psf}) * (371.62\ \text{SF}) = \underline{23.04\ \text{Kips}}$$

TOTAL FLOOR LOADS

$$1.2D + 1.6L = 1.2(45.72\ \text{Kip}) + 1.6(23.04\ \text{Kips})$$
$$= 54.86 + 36.86$$
$$= \underline{91.72\ \text{Kips}}\ ^{*}$$

DEAD LOAD - FACADE

PREFAB PANELS

$943\ \text{SF} * \overline{12\ \text{lb/SF}} = 11,316\ \text{lbs}$ → calculated panel weight

WINDOWS/StoreFront

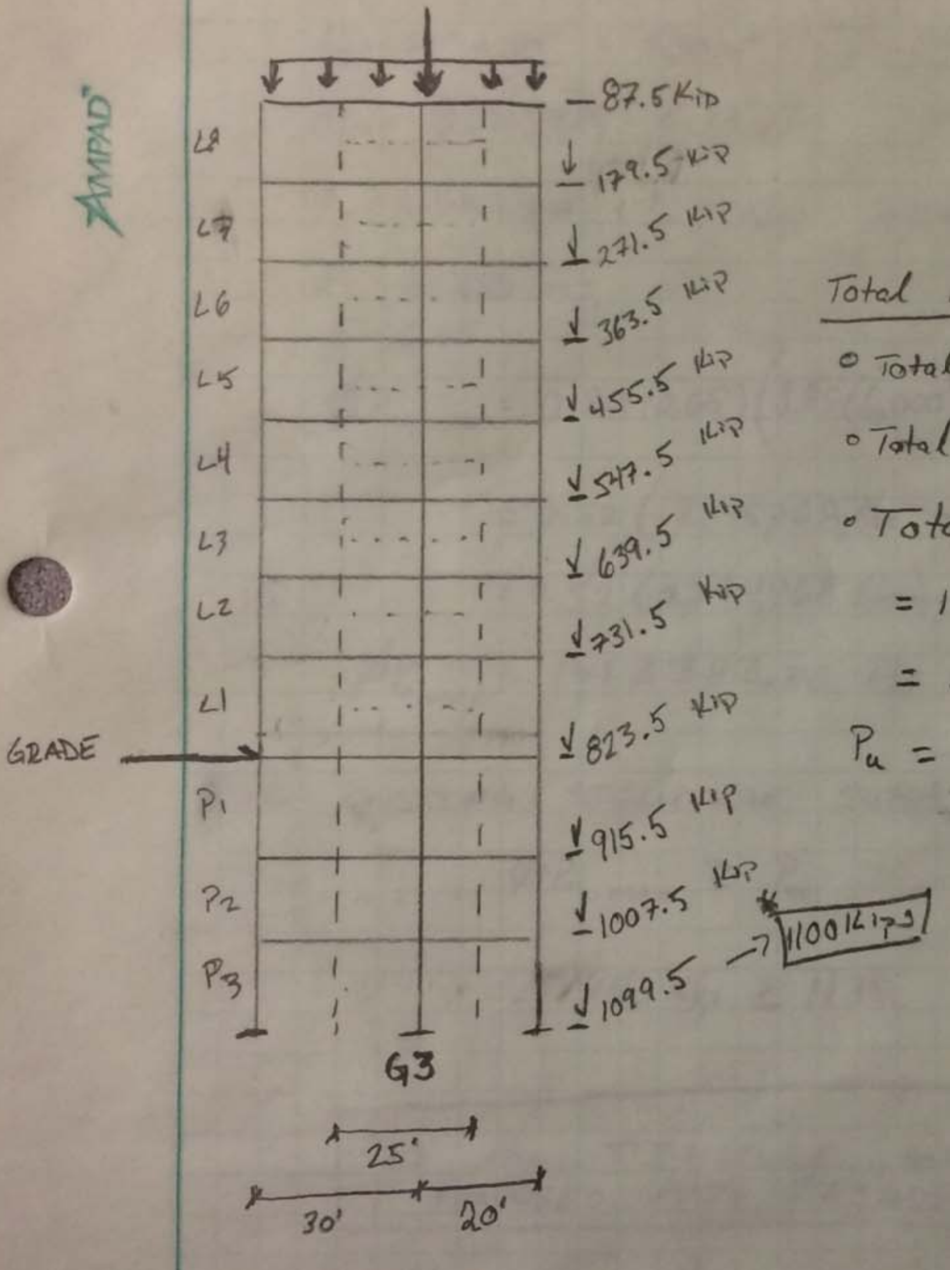
$1018\ \text{SF} * 15\ \text{psF} = 15,270\ \text{lbs}$

DEAD LOAD - FACADE CONT.

TOTAL

11,316 lbs + 15,270 lbs = 26.59 Kips

↳ TOTAL FOR ENTIRE A_T OF EAST FACADE



TOTAL FLOOR LOAD → 91.72 Kip

Use 92 Kip per FLOOR

Total LOAD ON COLUMN:

- Total FLOOR LOAD → 1100 Kips
- Total FACADE LOAD → 26.59 Kips
- Total COMBINED LOAD

= 1100 + 1.2 (26.59 Kips)

= 1100 + 31.91

P_u = 1131.91 Kips

↳ TOTAL LOAD ON COLUMN G3 = 1,132 Kips*

COLUMN STRENGTH:

ACI Chapter 10 EQ 10-2

$$\phi P_{n,max} = 0.80\,\phi\left[0.85 f'_c (A_g - A_{ST}) + f_y A_{ST}\right]$$

*REF. PG #1 for Column G-3 dimensions

$A_g = 20" * 24" = 480 in^2$

$A_{ST} = 8(0.79 in^2) = 6.32 in^2$

$f_y = 60{,}000$ psi → PROJECT DESIGN REQUIREMENT

$f'_c = 6{,}000$ psi

$\phi = 0.65$

$$\phi P_{n,max} = 0.80(0.65)\left(0.85(6{,}000)(480 - 6.32) + 60{,}000(6.32)\right)$$

$$= 0.52(2{,}415{,}768 \text{ lbs} - 379{,}200 \text{ lbs})$$

$$= 0.52(2{,}794{,}968 \text{ lbs})$$

$$\phi P_{n,max} = 1453383.36 \text{ lbs} \rightarrow \boxed{1453 \text{ KIPS}}$$

WILL EXISTING STRUCTURE SUPPORT ALT. FACADE?

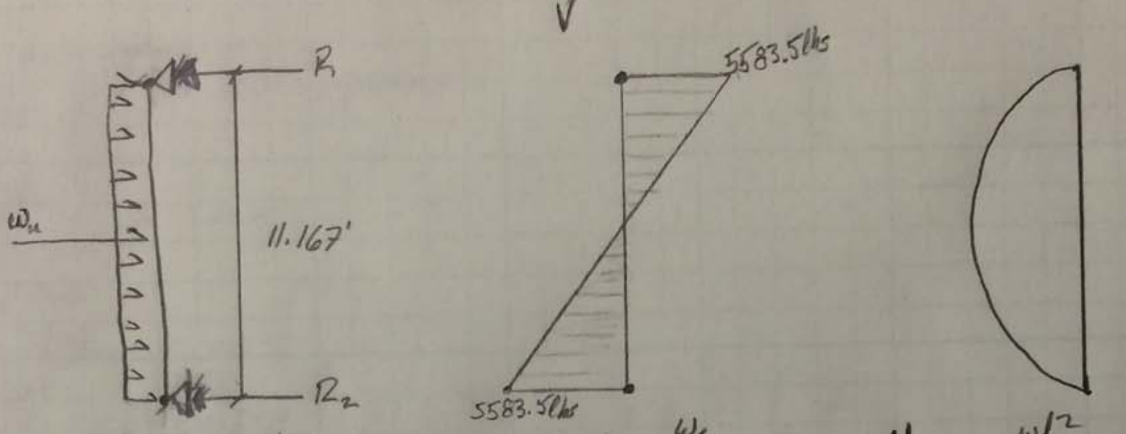
$$\phi P_{n,max} \geq P_u$$

1453 Kip ≥ 1132 Kip ∴ OKAY ✓

YES the STRUCTURE WILL SUPPORT THE PROPOSED ALT. FACADE

Moment Check @ Typical column

Min design wind speed → 90 MpH
Ultimate → 115 mph as per Code → USE 40 PSF



$w_u = 40\ psf\ (A_T)$

$= 40\ psf\ (11.167' * 25')$

$= 40\ (279.175)$

$= 11,167\ lbs$

$R_1 = R_2 = w/2$

$= 11,167/2$

$= 5583.5\ lbs$

$$M_{max} = \frac{wl^2}{8}$$

$$= \frac{1000\ plf(11.167^2)}{8}$$

$= 15,587.74$ ft-lbs

$= 187$ in-Kip

A: per CRSI TABLES: USE 22"x22" column

$\phi M_{n,max}$ @ 8 #8's = 2204 in-Kip

2204 in-Kip > 187 in-Kip ∴ OK ✓

Appendix G:

Mechanical Breadth

Precast Concrete w/Stone Veneer

Room Checksums

By ACADEMIC

Room - 001

COOLING COIL PEAK / CLG SPACE PEAK

Peaked at Time: Mo/Hr: 9 / 16 — Mo/Hr: 9 / 16
Outside Air: OADB/WB/HR: 83 / 69 / 85 — OADB: 83

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	0	0	0	0	0
Glass Solar	6,831	0	6,831	75	6,831	80
Glass/Door Cond	436	0	436	5	436	5
Wall Cond	396	259	654	7	396	5
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	0		0	0	0	0
Sub Total ==>	7,663	259	7,922	87	7,663	90
Internal Loads						
Lights	561	140	701	8	561	7
People	500	0	500	5	250	3
Misc	0	0	0	0	0	0
Sub Total ==>	1,061	140	1,201	13	811	9
Ceiling Load	66	-66	0	0	66	1
Ventilation Load	0	0	0	0	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		0	0	0		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	8,790	333	9,123	100.00	8,540	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 17

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	-3,013	-3,013	83.45
Wall Cond	-391	-650	18.01
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0.00
Infiltration	0	0	0.00
Sub Total ==>	-3,405	-3,664	101.46
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-29	0	0.00
Ventilation Load	0	0	0.00
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		0	0.00
OA Preheat Diff.		0	0.00
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
System Plenum Heat		53	-1.46
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-3,434	-3,611	100.00

TEMPERATURES

	Cooling	Heating
SADB	62.0	78.7
Ra Plenum	76.0	69.6
Return	76.0	69.6
Ret/OA	76.0	69.6
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	589	354
Terminal	589	354
Main Fan	589	177
Sec Fan	0	177
Nom Vent	0	0
AHU Vent	0	0
Infil	0	0
MinStop/Rh	177	177
Return	589	177
Exhaust	0	0
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	0.0	0.0
cfm/ft²	2.87	0.86
cfm/ton	674.16	
ft²/ton	234.91	
Btu/hr·ft²	51.08	-31.03
No. People	1	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter °F	Enter gr/lb	Leave DB/WB/HR °F	Leave °F	Leave gr/lb
Main Clg	0.9	10.5	8.9	589	76.0	62.9	64.9	62.0	57.1	61.8
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.9	10.5								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	205		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	320	160	50
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-6.4	354	65.8	78.7
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Reheat	-2.0	177	62.0	70.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-6.4			

Precast Concrete w/Stone Veneer

MONTHLY UTILITY COSTS

By ACADEMIC

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative 1													
Electric													
On-Pk Cons. ($)	62	56	61	59	62	61	64	63	60	61	60	62	729
On-Pk Demand ($)	29	27	25	26	27	28	29	29	30	27	26	25	327
Total ($):	91	83	86	85	88	88	92	92	90	88	86	87	1,056
Monthly Total ($):	91	83	86	85	88	88	92	92	90	88	86	87	1,056

Building Area = 416 ft²

Utility Cost Per Area = 2.54 $/ft²

Alternative Facade System

Room Checksums

By ACADEMIC

Room - 001

COOLING COIL PEAK / CLG SPACE PEAK / HEATING COIL PEAK

COOLING COIL PEAK — Peaked at Time: Mo/Hr: 9 / 16; Outside Air: OADB/WB/HR: 83 / 69 / 85

CLG SPACE PEAK — Mo/Hr: 9 / 16; OADB: 83

HEATING COIL PEAK — Mo/Hr: Heating Design; OADB: 17

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)		Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads							**Envelope Loads**			
Skylite Solar	0	0	0	0	0	0	Skylite Solar	0	0	0.00
Skylite Cond	0	0	0	0	0	0	Skylite Cond	0	0	0.00
Roof Cond	0	0	0	0	0	0	Roof Cond	0	0	0.00
Glass Solar	6,831	0	6,831	77	6,831	82	Glass Solar	0	0	0.00
Glass/Door Cond	436	0	436	5	436	5	Glass/Door Cond	-3,013	-3,013	89.99
Wall Cond	222	146	368	4	222	3	Wall Cond	-220	-366	10.93
Partition/Door	0		0	0	0	0	Partition/Door	0	0	0.00
Floor	0		0	0	0	0	Floor	0	0	0.00
Adjacent Floor	0	0	0	0	0	0	Adjacent Floor	0	0	0.00
Infiltration	0		0	0	0	0	Infiltration	0	0	0.00
Sub Total ==>	7,490	146	7,636	86	7,490	90	*Sub Total ==>*	-3,233	-3,379	100.92
Internal Loads							**Internal Loads**			
Lights	561	140	701	8	561	7	Lights	0	0	0.00
People	500	0	500	6	250	3	People	0	0	0.00
Misc	0	0	0	0	0	0	Misc	0	0	0.00
Sub Total ==>	1,061	140	1,201	14	811	10	*Sub Total ==>*	0	0	0.00
Ceiling Load	59	-59	0	0	59	1	**Ceiling Load**	-17	0	0.00
Ventilation Load	0	0	0	0	0	0	**Ventilation Load**	0	0	0.00
Adj Air Trans Heat	0		0	0	0	0	**Adj Air Trans Heat**	0	0	0
Dehumid. Ov Sizing			0	0			**Ov/Undr Sizing**	0	0	0.00
Ov/Undr Sizing	0		0	0	0	0	**Exhaust Heat**		0	0.00
Exhaust Heat		0	0	0			**OA Preheat Diff.**		0	0.00
Sup. Fan Heat			0	0			**RA Preheat Diff.**		0	0.00
Ret. Fan Heat		0	0	0			**Additional Reheat**		0	0.00
Duct Heat Pkup		0	0	0			**System Plenum Heat**		31	-0.92
Underflr Sup Ht Pkup			0	0			**Underflr Sup Ht Pkup**		0	0.00
Supply Air Leakage		0	0	0			**Supply Air Leakage**		0	0.00
Grand Total ==>	8,609	227	8,836	100.00	8,359	100.00	***Grand Total ==>***	-3,250	-3,348	100.00

TEMPERATURES

	Cooling	Heating
SADB	62.0	78.4
Ra Plenum	75.9	69.7
Return	75.9	69.7
Ret/OA	75.9	69.7
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	576	346
Terminal	576	346
Main Fan	576	173
Sec Fan	0	173
Nom Vent	0	0
AHU Vent	0	0
Infil	0	0
MinStop/Rh	173	173
Return	576	173
Exhaust	0	0
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	0.0	0.0
cfm/ft²	2.81	0.84
cfm/ton	680.66	
ft²/ton	242.53	
Btu/hr·ft²	49.48	-29.48
No. People	1	

COOLING COIL SELECTION

	Total Capacity ton	MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	°F	gr/lb	Leave DB/WB/HR °F	°F	gr/lb
Main Clg	0.9	10.2	8.6	576	75.9	62.9	64.9	62.0	57.1	61.9
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.9	10.2								

AREAS

	Gross Total	Glass ft²	(%)
Floor	205		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	320	160	50
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-6.1	346	65.9	78.4
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Reheat	-1.9	173	62.0	70.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-6.1			

Alternative Facade System

MONTHLY UTILITY COSTS

By ACADEMIC

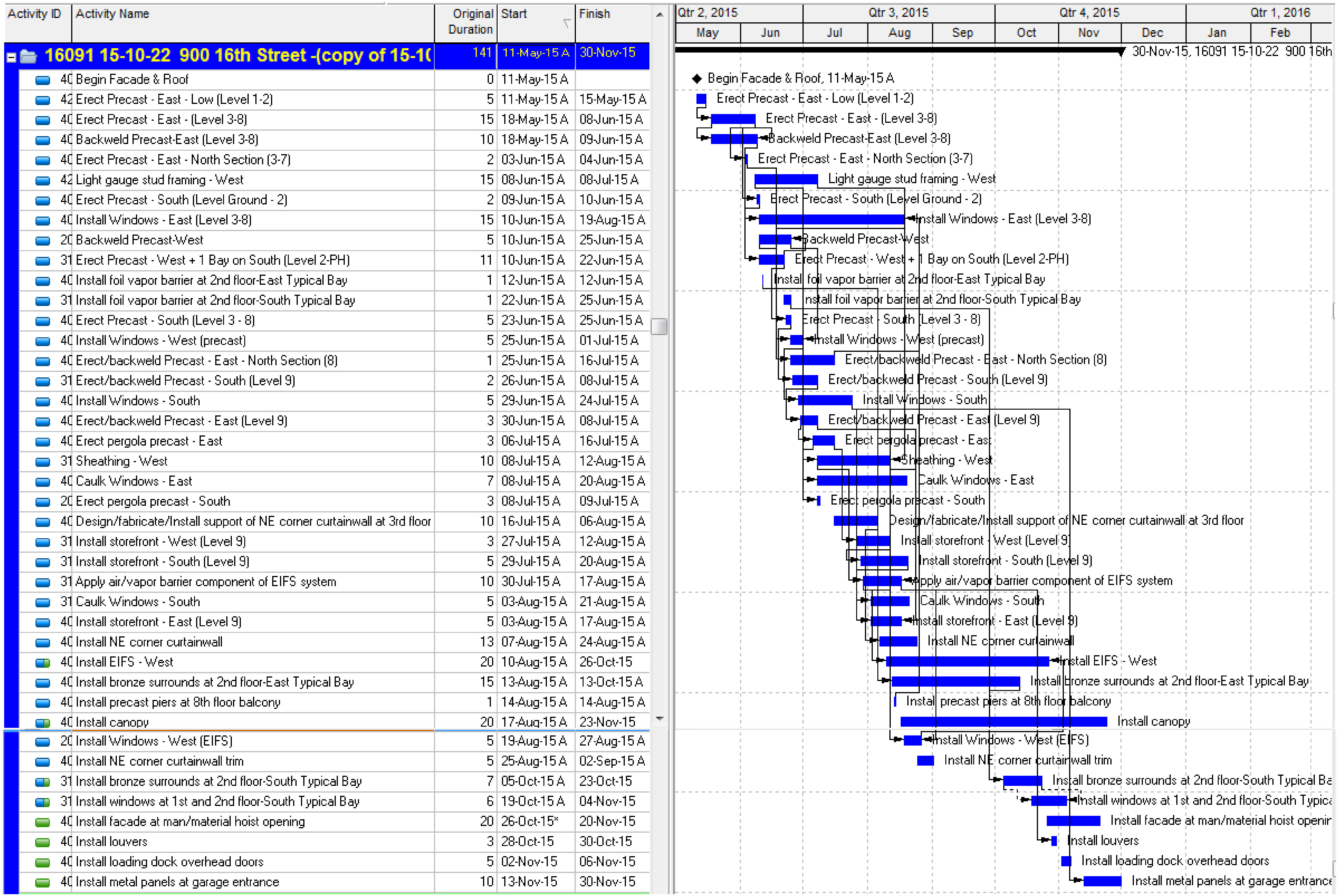
Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
					------- Monthly Utility Costs -------								
Alternative 1													
Electric													
On-Pk Cons. ($)	61	55	61	59	61	60	63	63	60	61	59	62	725
On-Pk Demand ($)	28	24	24	26	26	28	28	29	29	26	26	25	321
Total ($):	90	79	85	84	88	88	92	92	90	87	85	87	1,046
Monthly Total ($):	90	79	85	84	88	88	92	92	90	87	85	87	1,046

Building Area = 416 ft²

Utility Cost Per Area = 2.52 $/ft²

Appendix H:

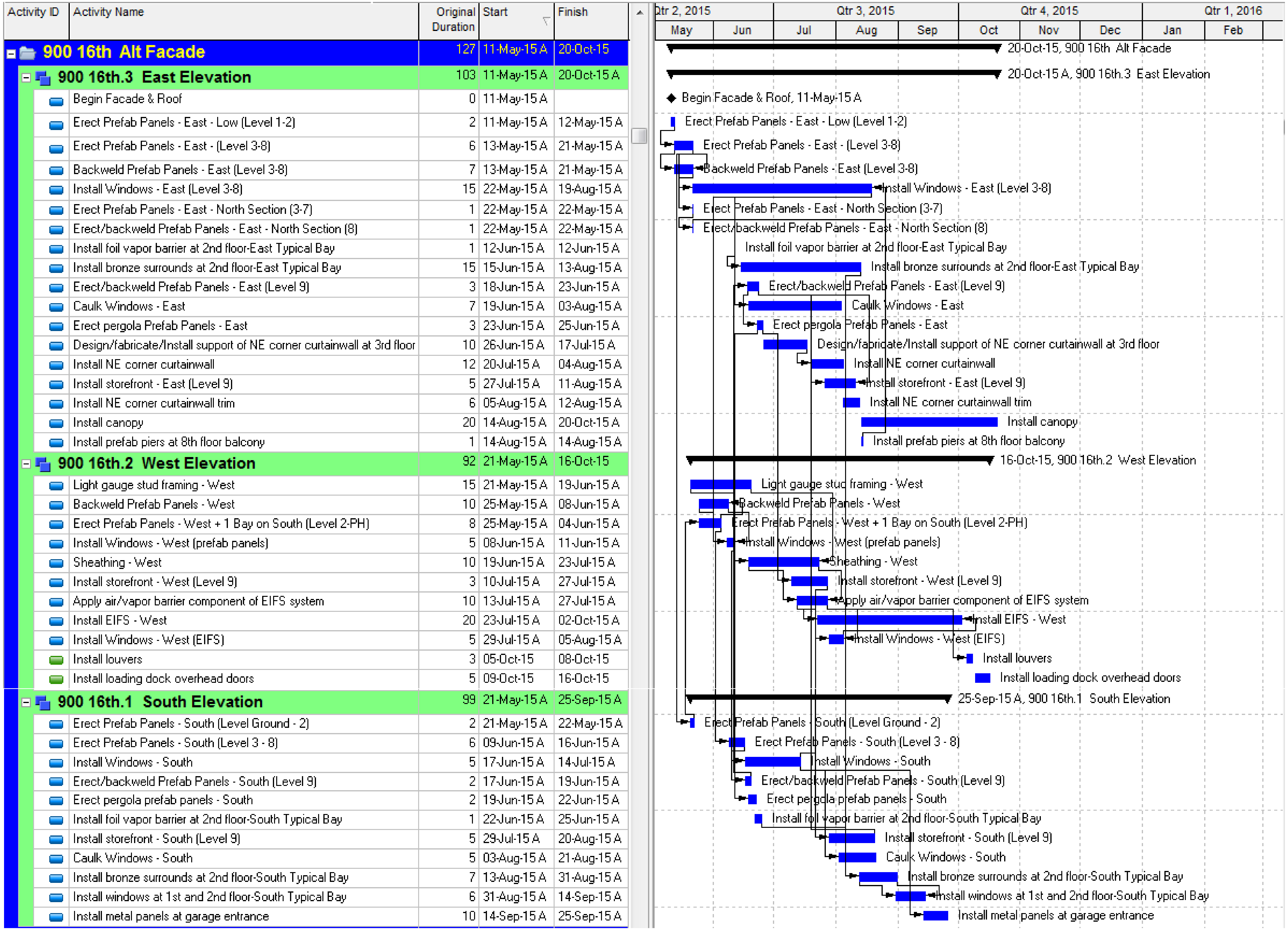
Original Façade Schedule



Activity ID	Activity Name	Original Duration	Start	Finish
	16091 15-10-22 900 16th Street -(copy of 15-1(	141	11-May-15 A	30-Nov-15
40	Begin Facade & Roof	0	11-May-15 A	
42	Erect Precast - East - Low (Level 1-2)	5	11-May-15 A	15-May-15 A
40	Erect Precast - East - (Level 3-8)	15	18-May-15 A	08-Jun-15 A
40	Backweld Precast-East (Level 3-8)	10	18-May-15 A	09-Jun-15 A
40	Erect Precast - East - North Section (3-7)	2	03-Jun-15 A	04-Jun-15 A
42	Light gauge stud framing - West	15	08-Jun-15 A	08-Jul-15 A
40	Erect Precast - South (Level Ground - 2)	2	09-Jun-15 A	10-Jun-15 A
40	Install Windows - East (Level 3-8)	15	10-Jun-15 A	19-Aug-15 A
20	Backweld Precast-West	5	10-Jun-15 A	25-Jun-15 A
31	Erect Precast - West + 1 Bay on South (Level 2-PH)	11	10-Jun-15 A	22-Jun-15 A
40	Install foil vapor barrier at 2nd floor-East Typical Bay	1	12-Jun-15 A	12-Jun-15 A
31	Install foil vapor barrier at 2nd floor-South Typical Bay	1	22-Jun-15 A	25-Jun-15 A
40	Erect Precast - South (Level 3 - 8)	5	23-Jun-15 A	25-Jun-15 A
40	Install Windows - West (precast)	5	25-Jun-15 A	01-Jul-15 A
40	Erect/backweld Precast - East - North Section (8)	1	25-Jun-15 A	16-Jul-15 A
31	Erect/backweld Precast - South (Level 9)	2	26-Jun-15 A	08-Jul-15 A
40	Install Windows - South	5	29-Jun-15 A	24-Jul-15 A
40	Erect/backweld Precast - East (Level 9)	3	30-Jun-15 A	08-Jul-15 A
40	Erect pergola precast - East	3	06-Jul-15 A	16-Jul-15 A
31	Sheathing - West	10	08-Jul-15 A	12-Aug-15 A
40	Caulk Windows - East	7	08-Jul-15 A	20-Aug-15 A
20	Erect pergola precast - South	3	08-Jul-15 A	09-Jul-15 A
40	Design/fabricate/Install support of NE corner curtainwall at 3rd floor	10	16-Jul-15 A	06-Aug-15 A
31	Install storefront - West (Level 9)	3	27-Jul-15 A	12-Aug-15 A
31	Install storefront - South (Level 9)	5	29-Jul-15 A	20-Aug-15 A
31	Apply air/vapor barrier component of EIFS system	10	30-Jul-15 A	17-Aug-15 A
31	Caulk Windows - South	5	03-Aug-15 A	21-Aug-15 A
40	Install storefront - East (Level 9)	5	03-Aug-15 A	17-Aug-15 A
40	Install NE corner curtainwall	13	07-Aug-15 A	24-Aug-15 A
40	Install EIFS - West	20	10-Aug-15 A	26-Oct-15
40	Install bronze surrounds at 2nd floor-East Typical Bay	15	13-Aug-15 A	13-Oct-15 A
40	Install precast piers at 8th floor balcony	1	14-Aug-15 A	14-Aug-15 A
40	Install canopy	20	17-Aug-15 A	23-Nov-15
20	Install Windows - West (EIFS)	5	19-Aug-15 A	27-Aug-15 A
40	Install NE corner curtainwall trim	5	25-Aug-15 A	02-Sep-15 A
31	Install bronze surrounds at 2nd floor-South Typical Bay	7	05-Oct-15 A	23-Oct-15
31	Install windows at 1st and 2nd floor-South Typical Bay	6	19-Oct-15 A	04-Nov-15
40	Install facade at man/material hoist opening	20	26-Oct-15*	20-Nov-15
40	Install louvers	3	28-Oct-15	30-Oct-15
40	Install loading dock overhead doors	5	02-Nov-15	06-Nov-15
40	Install metal panels at garage entrance	10	13-Nov-15	30-Nov-15

Appendix I:

Alternative Façade Schedule



Activity ID	Activity Name	Original Duration	Start	Finish
	900 16th Alt Facade	127	11-May-15 A	20-Oct-15
	900 16th.3 East Elevation	103	11-May-15 A	20-Oct-15 A
	Begin Facade & Roof	0	11-May-15 A	
	Erect Prefab Panels - East - Low (Level 1-2)	2	11-May-15 A	12-May-15 A
	Erect Prefab Panels - East - (Level 3-8)	6	13-May-15 A	21-May-15 A
	Backweld Prefab Panels - East (Level 3-8)	7	13-May-15 A	21-May-15 A
	Install Windows - East (Level 3-8)	15	22-May-15 A	19-Aug-15 A
	Erect Prefab Panels - East - North Section (3-7)	1	22-May-15 A	22-May-15 A
	Erect/backweld Prefab Panels - East - North Section (8)	1	22-May-15 A	22-May-15 A
	Install foil vapor barrier at 2nd floor-East Typical Bay	1	12-Jun-15 A	12-Jun-15 A
	Install bronze surrounds at 2nd floor-East Typical Bay	15	15-Jun-15 A	13-Aug-15 A
	Erect/backweld Prefab Panels - East (Level 9)	3	18-Jun-15 A	23-Jun-15 A
	Caulk Windows - East	7	19-Jun-15 A	03-Aug-15 A
	Erect pergola Prefab Panels - East	3	23-Jun-15 A	25-Jun-15 A
	Design/fabricate/Install support of NE corner curtainwall at 3rd floor	10	26-Jun-15 A	17-Jul-15 A
	Install NE corner curtainwall	12	20-Jul-15 A	04-Aug-15 A
	Install storefront - East (Level 9)	5	27-Jul-15 A	11-Aug-15 A
	Install NE corner curtainwall trim	6	05-Aug-15 A	12-Aug-15 A
	Install canopy	20	14-Aug-15 A	20-Oct-15 A
	Install prefab piers at 8th floor balcony	1	14-Aug-15 A	14-Aug-15 A
	900 16th.2 West Elevation	92	21-May-15 A	16-Oct-15
	Light gauge stud framing - West	15	21-May-15 A	19-Jun-15 A
	Backweld Prefab Panels - West	10	25-May-15 A	08-Jun-15 A
	Erect Prefab Panels - West + 1 Bay on South (Level 2-PH)	8	25-May-15 A	04-Jun-15 A
	Install Windows - West (prefab panels)	5	08-Jun-15 A	11-Jun-15 A
	Sheathing - West	10	19-Jun-15 A	23-Jul-15 A
	Install storefront - West (Level 9)	3	10-Jul-15 A	27-Jul-15 A
	Apply air/vapor barrier component of EIFS system	10	13-Jul-15 A	27-Jul-15 A
	Install EIFS - West	20	23-Jul-15 A	02-Oct-15 A
	Install Windows - West (EIFS)	5	29-Jul-15 A	05-Aug-15 A
	Install louvers	3	05-Oct-15	08-Oct-15
	Install loading dock overhead doors	5	09-Oct-15	16-Oct-15
	900 16th.1 South Elevation	99	21-May-15 A	25-Sep-15 A
	Erect Prefab Panels - South (Level Ground - 2)	2	21-May-15 A	22-May-15 A
	Erect Prefab Panels - South (Level 3 - 8)	6	09-Jun-15 A	16-Jun-15 A
	Install Windows - South	5	17-Jun-15 A	14-Jul-15 A
	Erect/backweld Prefab Panels - South (Level 9)	2	17-Jun-15 A	19-Jun-15 A
	Erect pergola prefab panels - South	2	19-Jun-15 A	22-Jun-15 A
	Install foil vapor barrier at 2nd floor-South Typical Bay	1	22-Jun-15 A	25-Jun-15 A
	Install storefront - South (Level 9)	5	29-Jul-15 A	20-Aug-15 A
	Caulk Windows - South	5	03-Aug-15 A	21-Aug-15 A
	Install bronze surrounds at 2nd floor-South Typical Bay	7	13-Aug-15 A	31-Aug-15 A
	Install windows at 1st and 2nd floor-South Typical Bay	6	31-Aug-15 A	14-Sep-15 A
	Install metal panels at garage entrance	10	14-Sep-15 A	25-Sep-15 A

Appendix J:

Alternative Façade Cost Estimate

Alternative Façade Cost Estimate

Description	Qty	Unit	2016 Bare Costs			Total Material	Total Labor	Total Equipment	Total Incl. O&F
			Material	Labor	Equipment				
6" Structural Studs, 12" OC	1355	LF	$ 48.00	$ 26.50	$ -	$ 65,040.00	$ 35,907.50	$ -	$ 126,184.38
1/2" GWB	16904.4	SF	$ 0.33	$ 0.39	$ -	$ 5,578.45	$ 6,592.72	$ -	$ 15,213.96
Fluid Applied Weather Barrier	16904.4	SF	$ 0.01	$ 0.23	$ -	$ 169.04	$ 3,888.01	$ -	$ 5,071.32
2" EPS Insulation R8	16904.4	SF	$ 0.52	$ 0.57	$ -	$ 8,790.29	$ 9,635.51	$ -	$ 23,032.25
Building Felt	16904.4	SF	$ -	$ 0.10	$ -	$ -	$ 1,690.44	$ -	$ 2,113.05
Metal Lath	16904.4	SY	$ -	$ 5.05	$ -	$ -	$ 85,367.22	$ -	$ 106,709.03
Base Coat	16904.4	SF	$ -	$ 0.26	$ -	$ -	$ 4,395.14	$ -	$ 5,493.93
3/8" Thermocromex Coating	16904.4	SF	$ 12.00	$ 0.47	$ 0.04	$ 202,852.80	$ 7,945.07	$ 676.18	$ 264,342.56
TOTAL	-	-	-	-	-	$ 282,430.58	$ 155,421.61	$ 676.18	$ 548,160.46
Panel Erection									
60 Ton Hydraulic Truck Crane	35	Day	$ -	$ 785.00	$ 1,650.00	$ -	$ 27,475.00	$ 57,750.00	$ 106,531.25
Connection Labor	35	Day		$2,629.00	$ -	$ -	$ 92,015.00	$ -	$ 92,015.00
TOTAL	-	-	-	-	-	-	-	-	$ 198,546.25
Joint Protection									
Aluminum Drip Edge Flashing	563	LF	$ 0.82	$ 0.97	$ -	$ 461.66	$ 546.11	$ -	$ 1,158.94
Backer Rod	10	CLF	$ 6.50	$ 80.50	$ -	$ 65.00	$ 805.00	$ -	$ 1,000.50
1/2" Joint Sealant	1000	LF	$ 0.38	$ 1.35	$ -	$ 380.00	$ 1,350.00	$ -	$ 1,989.50
TOTAL	-	-	-	-	-	-	-	-	$ 4,148.94
TOTAL									$ 750,855.65

Note: All cost information was attained from RS Means 2016 or from manufacturer cost data

Appendix K:

Alternative Glazing Unit Estimate

Alternative Manufacturer Glazing Unit Cost Estimate (Not Including Delivery)

Spec Code	*Description*	Unit	*2016 Bare Costs*				*Calculated Values*				
			Material	Labor	Equipment	Total	SF of Glazing	Material Costs	Labor Costs	Total Costs	Total O&F
088110	Laminated HS Clear Glass (1/4")	SF	$ 6.40	$ 6.25	-	$ 12.65	3120	$ 19,968.00	$ 19,500.00	$ 39,468.00	$ 45,388.20
088716	PVB Layer (60 mils)	SF	$ 8.16	$ 7.48	-	$ 15.64	3120	$ 25,459.20	$ 23,337.60	$ 48,796.80	$ 56,116.32
088110	Laminated HS Clear Glass (1/4")	SF	$ 6.40	$ 6.25	-	$ 12.65	3120	$ 19,968.00	$ 19,500.00	$ 39,468.00	$ 45,388.20
088713	Guardian Sunguard HP-Silver 35 Coating	SF	$ 3.21	$ 5.85	-	$ 9.06	3120	$ 10,015.20	$ 18,252.00	$ 28,267.20	$ 32,507.28
	Air gap (1/2")	-	-	-	-	-	-	-	-	-	-
088110	Laminated HS Clear Glass (1/4")	SF	$ 6.40	$ 6.25	-	$ 12.65	3120	$ 19,968.00	$ 19,500.00	$ 39,468.00	$ 45,388.20
088716	PVB Layer (60 mils)	SF	$ 8.16	$ 7.48	-	$ 15.64	3120	$ 25,459.20	$ 23,337.60	$ 48,796.80	$ 56,116.32
088110	Laminated HS Clear Glass (1/4")	SF	$ 6.40	$ 6.25	-	$ 12.65	3120	$ 19,968.00	$ 19,500.00	$ 39,468.00	$ 45,388.20
TOTALS	-	-	-	-	-	-	-	$ 140,805.60	$ 142,927.20	$ 283,732.80	**$ 326,292.72**

Note: All cost information was attained from RS Means 2016 or from manufacturer cost data

Appendix L:

Tim Jones Interview Transcript

Collocation:

1. How do you define collocation on the jobsite?

I would have to say that collocation consists of bringing key members of the project team together in close proximity. When I say close proximity I mean that they are under the same roof. We have learned that providing both individual offices and shared spaces works the best. While many members of the team choose to have their own drawing tables, there is still a drawing table with a few set of drawings in a shared space so the team can interact. I think that the use of both private and shared spaces provides the best atmosphere to promote cooperation and togetherness that all projects need.

2. What are the key parties that should partake in collocation?

It really all depends on the point in which the project is in and the scope of the project. A project such as this would look to bring together your foundations, excavations, and demo in the beginning. Once the project is well underway we will bring in masonry, steel, MEP, and others. Any company that is present on site that has a "non-working" superintendent, someone who isn't preforming work on a daily basis, we want them in the collocation trailer with us. Their job tends to revolve more around solving problems so being around the other subcontractors they will be able to do that much easier. But again it really is dependent on the exact project.

3. Do you think it is needed to have the owner and architect partake in collocation? Or do you see this more as an opportunity to bring the subcontractors together?

I definitely don't think that it hurts to have them on site. In terms of the way we operated on HHD, having the architect their three times a week significantly decreased the number of RFI's and the duration of active RFI's. It became a habit to instead of writing an RFI, put something in the back of your mind or write down to discuss with the architect when they were on site the next day.

A big issue that I've seen is that people tend to get lost in translation when answering or writing RFI's. They tend to spend more time figuring out exactly what is being said then solving the issue or answering the question at hand. Having the ability to go over a possible issue with the architect in person really cuts all that out and helps you get an immediate solution. So they don't need to be there all the time but having them present at minimum once a week would have a huge positive impact.

4. Obviously bringing parties together in a central office hub for the duration of a project is going to create some additional costs. What size job, contract value wise, do you see this practice not being worthwhile?

I honestly cannot answer that question entirely, but I do agree that there is a point that makes implementing collocation not as valuable. You would have to look at the complexity and scope of a job to determine that. A project as complicated as 900 16th Street probably could have benefited from using collocation.

Last Planner:

1. How does Massaro define the last planner system?

I wouldn't say that we use last planner in the traditional sense. We more focus on its implementation in the project execution phase rather than the development of the schedule. Schedulers make the master schedule then we have subs break out their weekly work plans and write them on a white board every Monday at our weekly meeting. We define the milestones of the week based off of a 6 week look ahead and what myself and the field supervisor see as necessary to complete to meet that six week goal.

2. What day of the week would you think weekly work plan meetings be the most beneficial?

It would definitely be on Monday's. That's not to say that planning does not occur on the Fridays before or during the week. The field supervisor tracks the progress of each subcontractor throughout the week and we usually sit down on Friday's to set the milestones for the next week. If we see that the production rate of any sub does not meet the schedule we bring them in on the meeting to try to mitigate the issue.

3. Does the Massaro team define the goals of the week for the project team or are the subcontractors responsible for providing them ahead of time?

Both. The field supervisor tracks and sets the weekly milestones for the job and the subcontractors are responsible for breaking out their daily work on the white board that is visible to all contractors.

4. Is it a key to creating accountability to have the daily/weekly goals of all subcontractors in the open for all to see? (i.e. the white board in the job trailer)

The white boards that we use to have subs create their daily plans on definitely play a huge role in creating accountability. You saw this in action on HHD where the subs would be constantly asking each other if the work they were planning would impact certain trades or when tasks would be completed so they could begin their own work. If a trade was behind schedule it would be known right away so that all the effected parties could plan their work accordingly. Subs often explain why they were delayed and they worked out a way to allow work to begin in certain areas rather than nothing at all.

5. If a certain subcontractor is not "buying in" to the system, how do you deal with them?

On HHD it was contractual. The subs signed on to be a part of the process the minute they accepted the contract to complete their scope of work. However a big part of it comes down to the way we as construction managers interact with them. If we are helpful and friendly you begin to almost break troublesome subs down to buying into the system. It's not always easy but it does take time and patience to bring certain people into the system.

6. Massaro believes in daily huddles with individuals within the company as an integral part of last planner, do you think it would be beneficial to have a job wide daily huddle run by the field supervisor? Or is that reflected in the presence of the whiteboard in the job trailer?

It is sort of represented in the whiteboard in the job trailer because all of the tasks for the day are laid out right there. That being said there can be an unexpected change to a project at any time that will cause those activities to change. A daily huddle for about 15 minutes first thing in the morning, around 7 am, where our field supervisor makes the superintendents of the main contractors on site aware of any changes would certainly be beneficial. At the beginning of the project it probably wouldn't be needed but once the project began to really ramp up "job wide" daily huddles could help.

7. Do you think the costs and time associated with making last planner work are worth the potential positive impact that they have on the project?

Absolutely. As we talked about before with collocation, there is definitely a point that it may not have a significant impact depending on the size of the job. I would highly recommend this process for any base building project or heavy remodel.

General Questions:

1. What is the most difficult part of implementing last planner and collocation properly?

It would have to be getting the right people involved in the project. When you think about it, even though there are numerous companies on a job, we are all coworkers. While I work for a different company then them these are the people I work with on a daily basis. Just like in any job setting it is key that you get along with your coworkers. This also plays into getting that collaborative atmosphere that you need for these practices to provide a maximum benefit. If you don't get along with an individual they are much more likely to not work with everyone to do what is best for the project.

2. In your opinion is last planner dependent on having a collocated project team? Or vice-versa?

I don't think that any one is particularly dependent on the other but I believe that collocation has a significant impact on how successful last planner can be on a project.