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CM
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Library in Metropolitan Washington, D.C
Spring 2014
4/9/2014

Library in Metropolitan Washington D.C

Final Report

Picture Provided by Multivista from Onsite Webcam

Library In Metropolitan Washington, D.C.

Project Data

Occupant- County Library & Non-profit Art Group
Gross Square Foot- 90,000
Number of Stories- Five w/ One Story of Basement
Construction Cost- $35,000,000
Actual Project Cost- $69,530,000
Dates of Construction- January 2013 to October 2014
LEED Certification- Silver

Project Team

Owner- Undisclosed County Government
Architect- The Lukmire Partnership
Contractor- Costello Construction
Construction Manager- MBP
Envelope Commissioning- Gail
Third Party Testing/ Inspection Agent- Robert Balter
General Commissioning Agency

Construction

Delivery Method- Design, Bid, Build
Contract Types- Lump Sum (Contractor & Architect) and Time & Material (Construction Manager)
Cranes- Multiple, Two Largest 200 Ton and 120 Ton
Concrete Placement- Shoot, Crane & Bucket, and Pump
Structure Sequencing- West to Train Stop 1st Floor to Roof then Portion Over the Train Stop
Site Condition- Urban w/ Minimal Laydown & Site Space and a Residential Tower being Built in an Adjacent Lot

Architecture

The design incorporates a future light rail stop that cuts through the building leaving the profile of the first two floors in a wedge shape. On one side of the light rail stop is a glass semi-circular pavilion, and on the other side is the remainder of the first two floors to be fitted out. Spanning the pavilion and the first two floors is a three story library that also cantilevers 50' in the northern corner over the light rail platform.

MEP

An Integrated Packaged Equipment Center (IPEC) installed on the roof houses all the main pumps, blowers, and piping for the building. Mechanical system distribution is by forced air, radiators, and hydronic in-slab piping, all fed through a mechanical shaft. Two electric utility services feed the building; one 400A service for the coffee shop and a 3000A service for the rest of the building. Also on the roof is a cooling tower and a 2500KW natural gas fired generator.

Structural

42 concrete caissons will be installed at a variety of depths for proper bearing capacity. There will be three stair/ elevator towers that are cast-in-place concrete that act as shear walls for lateral bracing. Structural steel will make up the rest of the structure with composite concrete floor slabs. Roof trusses 15' in depth will span west to east. The two northern most trusses will have a 50' cantilever from which the northeast corner of the building will be hung.

Acknowledgments

Industy

Academic

Michelle Vigeant

Moses Ling

Dr. Robert Leicht

Kevin Parfitt

Ray Sowers

Special Thanks

Library's Owner

PACE Industry Members

Friends and Family

Table of Contents

Executive Summary

Throughout the 2013/2014 school year multiple technical assignments and analyses have been produce on this library in metropolitan Washington, D.C. Past Technical Assignments can be found on the CPEP website. With the help of the project team, industry members, and professors this year long capstone project included four analysis (found in this report), one of which acted as a research topic. These analyses were for educational purposes only and are not direct comparisons to accrual scenarios encountered.

Research Analysis Topic 1- Early Involvement in Design

This analysis looked at specifics of implementing early involvement on a project. Information from Design-Build Institute of America points out that early involvement projects have the potential to save 6% in costs from reduction of change orders and less rework. Schedule can also be reduced with this type of project delivery. However, funding of these types of projects can be challenging because they require higher upfront costs. Scope selection of early involvement should be carefully considered. Complex and high cost project specific scopes benefit the most from early involvement. On the library project, curtain wall, MEP, and structural installation would benefit from early involvement. Time frame inclusion should be based on specific project needs.

Analysis Topic 2- Structural Steel Sequencing

This analysis looked at comparing the current top-down sequence to an alternative shoring sequence to weigh complexity, costs, schedule, site, safety, and other trade impacts. This build's structure is complex and dynamic. Structural sequencing was a concern even when this project was being bid. Using a shoring system to support the structure over the future train stop until truss erection can be completed would reduce the already delayed schedule by 3 weeks. This savings would result in a general conditions cost savings of $30,000. A structural breadth was included in this analysis, in which involved calculating temporary load supporting requirements of 291 psf. A 26 feet high Mabey Mass 25 shoring tower design was chosen to support 100 kips per tower at a spacing of 20'x18' across the future train stop. An overall better work flow, safer site, schedule reduction, and cost savings would be experience in using the shoring sequence approach.

Analysis Topic 3- Mechanical Penthouse vs. IPEC

This analysis looked at the differences between an IPEC and a penthouse construction. A penthouse would give the designers more flexibility in their design. An estimated $1 million could have been saved with a penthouse. This comes with an addition of a 10 week onsite penthouse construction, which would have negatively affected site productivity. In the acoustical breadth included in this analysis, both mechanical rooms met the 55 dB property line and 35 dB conference room noise level requirements. In conclusion, a MEP design-build company could have provided a rooftop penthouse mechanical room meeting owner needs and is recommended for this project. A decision tree was also produced to aid owners and designers in considering their mechanical room options.

Analysis Topic 4- Caisson Rebar Cage Fabrication

This analysis looked at comparing rebar cage fabrication and installation methods to minimize wasted costs and schedule delays. The number of splices required and length of rebar added/ removed from cages will change significantly between fabricating methods and was the key player in this analysis. The original baseline fabrication method was the best choice in comparing costs and schedule (prefabricating 100% of the planned rebar cage lengths). The baseline method had the most potential positive impact to the schedule. For this project, it is recommended to use the baseline fabrication method and to always overestimate caisson installation schedules in accommodating for unknowns because caisson installation often times causes delays.

Background & Introductory Information

Architectural Elements

The Lukmire Partnership used a charrette design process on this project, which is a method of design where the general public was able to voice their feedback of the building's design. The result was a building that serves as a monument to the surrounding areas that can hold 1,827 occupants at full capacity. About two thirds of the 90,000 square feet building will be occupied by the library space, which will be located on the third, fourth, and fifth floors. The other one third will consist of a small coffee shop on the first floor and a space that is to be fitted out by a non-profit art organization, which will be occupying part of the first floor and the entire second floor. Much of the library space is open with plenty reading areas located along the exterior walls. On the first and second floor the fit out spaces are not currently design.

The most interesting architectural element of this building is how the architect incorporated the future light rail link stop into the building's form (As seen in picture to the right). The proposed location for the train stop calls for it to intersect the building. The architect incorporated this into the east, third floor entrance to the library by creating a glass, partially circular pavilion that is broken away from the first two floors to transport visitors directly to the library level. With a daring leap of faith the three story library then spans across this broken gap while also partially cantilevering the three floor glass north corner over the future train stop. When the basic shapes the architect used come together they create a monumental addition to this down town area.

Owner Information

The county owner's primary concern with the project is that it meet the requirements of an increasing urban, ethnically and culturally diverse residential and business community. Currently the county has a 16,000 SF library that is over extended and very busy, which the county would like to replace with this modern project. Fit out of the non-profit art gallery space will not start until after substantial completion because the owner does not want this to interfere with and delay the GC in any way. The county is requiring that the site adjacent to the construction site be vacated by the GC before March of 2014 because this is when the residential tower construction will start. While moving into the new space the old library will be shut down, which means this moving phase must go smoothly with no delays so the new library can open on time to the public.

Project Delivery System

Design-Bid-Build is the style of project delivery on this project. This is mainly because the owner and the community wanted to be heavily involved in the design, finishes selection, and train stop integration. To pick an architect, CM, and commissioning agents the owner has a group of preselected companies. To select a GC the owner preselected a group of contractors through a public Request for Expression of Interest (REOI), collected bids, and then selected the lowest reasonable price that was similar to the owners estimate.

GC Staffing Plan

Costello's owner is acting as the Project Executive for this project. The Quality Control Manager reports directly to the Project Executive, not to the Project Manager. There are a number of Superintendents and Assistant Managers that report to the Project Manager. Under the Senior Superintendent there is three trades Forman and Trade Foreman for the work performed by Costello Construction.

Existing Conditions

Before construction was started water lines, sanitary sewer lines, and storm drains were rerouted and electric, cable, and phone lines were ran underground near the building as to not take away from the architectural aspect of the building. In conjunction with this project a five story residential tower will be build adjacent to this site, but in a separate contract. During construction parking will be available across the street in a large parking garage. Soils encountered on site were topsoil, engineered fill, weathered rock, and residual soils.

Summary of Schedule

This library in metropolitan Washington D.C. has a 22 month construction time line, which begins in January of 2013 with a substantial completion data of October of 2014. The structure and foundation of the building will be completed in mid-October 2013. Building dry enclosure, permanent power, and conditioned air will all take place in March of 2014. After substantial completion, the librarians will be moving into the new library for approximately one and half months, then the new library will open to the public late 2014.

Demolition Requirements

Over a five year period the county bought up property that was occupying the corner location that will soon be the new library. These properties had existing buildings on them including: old four story apartment building, a large house that was being used as a Moose Lodge, a one story car repair garage, and a small fried chicken shop, all of which were required to be demolished. During the excavation period an old petroleum tank was uncovered and had to be removed by a certified specialty contractor. After removal of the tank was complete excavation continued and tiebacks were installed along the north side of the building near the existing road, and steel column and wood slat lagging were installed along the west side near the existing apartment complex.

Cast-in-place Concrete

Cast-in-place concrete was used for all the caissons, matt slabs, foundation walls, and elevator/ stair shafts. Caissons were placed to a variety of different depths depending on where the required bearing capacity was reached. After installation, the exact depth of each caisson was measured using an ultrasonic measuring tool. Both the foundation walls and the vertical shafts were formed using aluminum reusable panels. A composite slab system will be used for the elevated slabs in the building. Where it was feasible, concrete was/ will be placed directly from the truck using the shoot. If the shoot cannot be used, a crane and bucket system will be used to place the concrete on site, and where the crane does not reach, a concrete pump can be brought in for the pour.

Structural System

In the area this building is being built, a structural steel structure is common. Because of this, and the complexity of the structure, the superstructure is structural steel, other than the three vertical shafts that act as shear walls. The structural engineer was presented with a challenge because the third, fourth, and fifth floors are cantilevered over the future train stop on one corner and span the train stop on the other corner. To overcome this challenge the roof framing is made up of 15' tall trusses that are laid across the building from west to east. Two of the trusses cantilever 50' over the east side of the building, which the third, fourth, and fifth floors are then hung from.

Enclosure System

There three types of veneer masonry used on the project, which include: stone, terracotta, and CMU. All three types of veneer will be installed from stick built scaffolding. Other building enclosure systems include only the aluminum and glazing curtain wall that almost entirely comprises the North, East, and South third through fifth floor walls. Accessories that will also be applied to the curtain wall are sunshades and a UV protective glazing to prevent the books from getting UV damage.

Mechanical System

A unique mechanical system is design to condition the three story library space. This system's mechanical equipment and mechanical room will be an Integrated Packaged Equipment Center (IPEC), which is a pre-manufactured mechanical room that is brought on site and lifted into place. This system has the capability to do variable air volume control and heat recovery. To transport and exhaust the air for the library there was a vertical duct shaft that was designed into the west side of the building. Through these same ducts smoke will be exhausted in the event of a fire. The first two floors have their own mechanical system that is located in mechanical rooms on the first and second floors. Both the first two levels and the library space are conditioned using forced air and hot water piping both for heating units/ radiators and radiant floor systems where overhangs may cause cold bridging.

Electrical System

Feeders for the electrical system is 277/480V, and there are two utility lines that entire the building; one for the main portion of the building and one for the coffee shop located on the first floor. A 400A transocket is feeding the coffee shop while a 3000A main distribution switch gear distributes power to the rest of the building. Lighting controls in the building are handled through a system of Light Management Hubs which control dimming and occupancy requirements and that can be remotely controlled. As a backup power system there is a 250KW natural gas powered generator located on the roof.

LEED

LEED Silver was a requirement made by the county since the project has begun. On this particular project the GC has their own rock crushing machine that they use to make fill and construction roads from rocks found in the excavation. Another interesting, but challenging LEED credit that is being used is 75% to 95% of the construction material waste is recyclable, which is sorted offsite by the waste management contractor.

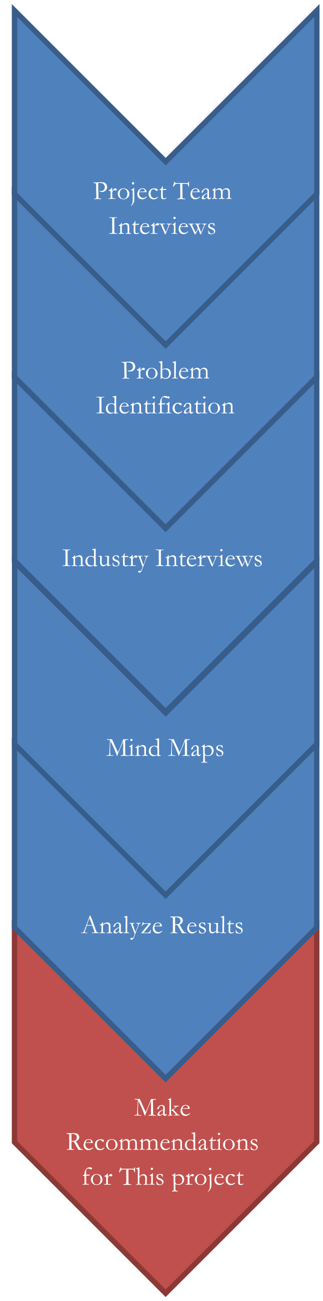
Cost Evaluation

Cost of the total project is set at $69,000,000, while the cost of construction is $35,000,000 ($389/SF). Specific system cost are as follows; General Conditions- $825,000 ($9.17/SF), Mechanical System-$3,860,000 ($42.89/SF), Sprinkler System- $352,000 ($3.91/SF), Electrical System-$4,010,000 ($44.55/SF), Structural Steel- $3,061,000 ($34.01/SF), Roofing System- $517,000 ($5.74/SF), Curtain Wall- $2,330,000 ($25.89/SF), Elevators and Escalators- $1,420,000 ($15.78/SF), IPEC- $2,650,000 ($29.44/SF), New Book Allowance is $750,000, New Radio Frequency Inventory Device (RFID) is $700,000. In the square foot estimate preformed from R.S. Means, it was estimated that the building costs $29,000,000 ($322/SF). This estimate is almost $6,000,000 lower than the actual construction cost, which could be from a number of things including the higher quality architectural finishes that are being used, the more complex structural steel frame from the cantilevered trusses, the customized IPEC system, and the new book and RFID system allowance.

Farther Information

For farthing background information about this project not included here, please refer to Technical Assignments I, II, and III. These past Technical Assignments can be found on the CPEP website or by request.

Research Analysis Topic 1- Early Involvement in Design



Goal of Research Analysis

A primary goal of this research topic is to better understand factors to be considered when choosing to use early involvement from the project team, whether it be Design-Build, design assist, or identifying other involvement resources. In this report, when the term "early involvement" is used, it is referring to either Design-Build projects, design assist projects, or some combination of these. A breakdown of the process used to perform this research analysis can be seen on the right-hand side of this page.

Project Team Interviews Conducted

In the Fall 2013 semester a series of interviews were conducted with known project team members to gain a better understanding of how this library's construction process was doing. The project was in the superstructure phase with minor rough-in work being completed when these interviews were conducted.

Key players of this project were interviewed, which included the design partnership, the owner, the construction manager, and the contractor or general contractor. These entities were all asked series of questions directly related to problematic portions of the construction phase, which was part of Technical Assignment III (Please refer to Technical Assignment III for a more detailed recollection of the problematic areas). Three common problematic areas came up in all the interviews, which included the IPEC (Integrated Packaged Equipment Center), structural steel erection delays, and the curtain wall. At the end of last semester, these issues became the focused point of the early involvement research analysis conducted this semester (Spring 2014). The specific details associated with the project problem areas will be de discussed in farther detail in the Scope Problem Identification section.

Scope Problem Identification

As part of the mechanical system design for this library, an IPEC unit was designed to house all essential equipment for building operation and conditioning, and will be located on the western side of the roof. Throughout procurement of the IPEC system, the contractor was unable to select a unit manufacture that differed from the basis of design supplier as in the specifications. This process has created headaches for the contractor. Once the contractor gave up and the basis of design supplier was chosen, coordination of exact duct, pipe, electric, finishes, and structural tie-ins needed to startup. However, this coordination has been time consuming and difficult.

Should the MEP systems in this building have been designed and procured using some type of early involvement scenario because of the uniqueness of the IPEC? If so, what are specific recommendations as to how, when, and what type of involvement should be used? Could this prefabricated mechanical penthouse have been design as a traditional mechanical room on the roof (this will tie into the third analysis topic later in this report)? These are some of the questions set out to be answered in this research analysis.

A second concern of the project team's has been the uniqueness of the superstructure resulting from the spans and cantilevers over the future light rail stop. This complex structure has experienced an approximate

6 week delay in the 19 phase structural steel erection process. The delays could have resulted from a number of different factors, which include weather, delivery of steel, site congestion, improper allocation of resources, late design changes, and coordination issues. If the steel erector and contractor were involved earlier in design, could a better understanding of how the structure goes together and a proper amount of resources have been established earlier, before construction even began? If so, what are specific recommendations as to how, when, and what type of involvement should be used, and could this structural steel erection sequence have been designed a different way (this will tie into the second analysis topic later in this report)? These are some questions that were set out to be answered in this research analysis.

As a third issue, the curtain wall has experienced difficulties in procurement and shop drawing approval. There has been little to no mock-up testing because shop drawings and sample glass panes have yet to be approved. As a side note, the curtain wall is on the critical path because approximately 53% of the building's exterior skin is comprised of curtain wall. If the curtain wall specialty contractor and the general contractor were brought on earlier, could the shop drawing and mock-ups have been approved and tested before construction even started? Would this have been beneficial? If so, in what ways and what specific recommendations as to how, when, and what type of involvement should be used? These are also some questions that were set out to be answered in this research analysis.

These three scopes (MEP, structural erection, and curtain wall) are unique and include large portions of this project and therefore play a crucial role in delivering the project on time and on budget.

Industry Member Interviews

Early in the Spring 2014 semester a second round of five interviews were conducted to obtain industry member feedback as to specific details, considerations required, and benefits achieved by early involvement type procurement methods. Interviewees consisted of Design-Build contractors (contractors dedicated to early involvement type projects), MEP specialty Design-Builders, general contractors (not heavily involved in early involvement projects), construction managers, and the County owner for this specific project. A set of standard questions were developed to assist in the interview process, which can be seen below:

- What are owner requirements in which are crucial to a successful early involvement project?
- How might you go about trying to convince an owner that early involvement is a good thing?
- What are the key benefits of delivering a project using early involvement contracts over traditional Design-Bid-Build?
- How are contracts set up in early involvement projects?
- What decisions go into picking which scopes to procure through early involvement?
- Where do you see the future of early involvement types of delivery methods going?

Other topics and conversations stemmed from the above questions, which will be discussed in more detail in the Mind Maps portion of this analysis. Similar questions were asked to each interviewee for ease of organization and analysis of their responses.

Mind Maps

After conducting the industry member interviews an easy to read and simple organization of the information gathered was needed. A mind map was elected to be the best way to present the collected data. Mind maps can easily and clearly show topics and responses from industry members while summarizing their thoughts on these topics. A mind map can also be an easy tool to compare similar topics or find patterns in data.

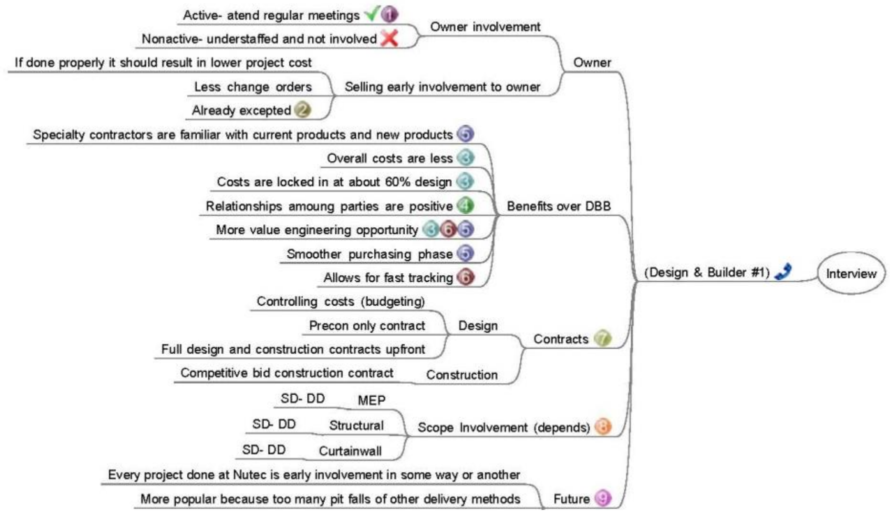


Figure 1 (Example Mind Map of Interview)

The goal of creating mind maps was to have a tool to compare and analysis results of interviews. FreeMind's mind mapping software was used to create the overall breakdown of the data collected. An example of one interview's mind map can be seen in Figure 1. The full mind map including all interviews conducted with industry members can be found in *Appendix A*.

Analyze Results

To analysis the information obtained from the interviews, the mind maps where studied. While going through each mind map, similar ideas and topics where numbered with a uniform numbering system throughout the process (as seen in the example mind map in Figure 1). These ideas and topics could be broken down into nine easily definable criteria, which can be seen in Table 1.

Table 1 – Breakdown of Similar Topics

#	Criteria	Consistency
1	Owner Buy-in	5 of 5
2	Cost Considerations	5 of 5
3	Scope Included	5 of 5
4	Relationship Outcomes	4 of 5
5	Quality & Project Flow	4 of 5
6	Schedule Considerations	4 of 5
7	Contract Considerations	3 of 5
8	Owner Involvement	3 of 5
9	Future of Early Involvement	3 of 5

Owner Considerations

Three of five of the interviewees said the level of owner involvement and buy-in could make or break an early involvement project. They pointed out that, if the owner is actively involved by attending regular meetings, then the overall process will be more beneficial because owner involvement is crucial in giving the project team direct feedback early in the design phase. An owner that can contribute the most value to early involvement projects is one who's educated in construction, can make decisions quickly and easily, is committed to the project early on, and can clearly define a program of their needs and wants. If the owner changes his or her mind multiple times throughout the project life, then the benefit of early involvement is lost. Multiple design-build companies said that most, if not all of their clients are requesting some sort of early involvement without the contractor pushing it, while the general contractor interviewed stated that they do not push for early involvement if their clients are not requiring it.

Cost Considerations

Five of five of the industry members stated that early involvement would save the owner and other project team members costs. Upfront costs may be slightly higher than with a design-bid-build project because there are more contracts and upfront costs. However the overall project cost after construction "should" be less than with design-bid-build. The estimated final project cost will be known at 60% of design in early involvement projects rather than after construction is complete with design-bid-build projects. This is because less change orders will be needed with a smoother construction progress, which, when done properly, will save a substantial amount of money. This is because change orders and construction rework is charged at a premium compared to original base work unit costs. The possibility for value engineering in design can result in a savings by the owner, contractors, and specialty contractors because design items will not be as over designed if proper construction feedback is implemented. There will be more integration through design and a negotiated upfront costs which will lock in overall costs and minimize risks in guessing actual construction costs.

Relationship Outcomes

In the past, the construction industry has not been well known for its' good relationships between entities involved on projects. Instead it seems that each party always fights for their piece of the pie' because each specialty contractor or contractor tries to minimize their own cost in any way possible, even if this means a different party's costs increase. This causes inverse relationships as a result. Four of five of the industry members interviewed claimed that early involvement projects can increase the quality of relationships maintained throughout the project and thereafter. One reason this may be is because, as mentioned before, everyone wants to win and with early involvement, everyone is more likely to win evenly in the end. Every party member's common goal is to complete the project successfully when working on early involvement projects. When contractors are brought on-board during design, they have time to get acquainted with the other project team and can get started on submittals and other contractual requirements. This will not require the contractor to turn in all submittals at one time to the architect with the expectation that they will be approved and returned quickly. In conclusion, the delicate relationship between contractor, architect, and the rest of the project team is less stressed with earlier involvement.

Quality & Project Flow

As the fifth criteria, Quality and Project Flow was chosen. This relates to the general flow of construction and minimizing problems with change orders, requests for information (RFI's), stop work orders, submittal approval, and other similar items while keeping the overall quality of the facility the same or even increasing it. Four of five industry members said construction runs smoother and of a better quality with early involvement implementation. Part of this is because specialty contractors and general contractor know and are familiar with new/current products and how they are installed. Also, with better value engineering input and a hand in design the purchasing, procurement, and submittal approval phases will operate smoother. On the other hand, with design-bid-build projects, a low bidder is often selected to perform work, but this bid could have left out important considerations and could cause the quality or even safety of their work to stay within budget and schedule.

Schedule Considerations

A typical concern for any owner is the schedule of their facility because of opening dates so they can start using it to their benefit as soon as reasonably possible. Four of five industry members said early involvement will positively influence the schedule of any project. In a nut shell, this ties back to the previous paragraph of Quality and Project Flow because less change orders, RFI's, and problems with submittal approval results in schedule savings with less time wasted because of redundant and avoidable problems. Also, early involvement may make fast tracking easier and a more valuable option to meet project demands. All in all, the value of early involvement on projects is directly relatable to construction knowledge, expertise, and planning in the design of the project to improve constructability, costs, relationships, quality, the project schedule, and to mitigate the unknowns that lay ahead in construction.

Contract Considerations

When the interviewed industry members were asked about types of contracts and roles performed in early involvement projects, their responses differed. Three of five of the industry members held that they use and have seen a variety of different contract types depending on the owner and level of involvement required. After analyzing the responses from contract considerations, the contracts can be broken down into separate design assist and construction or full design-build contracts. It's also common that a contractor will answer questions related to construction from designers without ever signing a formal contract or receiving compensation. In other cases, a contractor will hold a preconstruction contract but will still have to competitively bid for construction services, even though the same contractor typically will be chosen for construction. In this case, the owner has the option to choose to use a different contractor for construction if the owner was unhappy with the contractor's performance during design. In conclusion, contract types and levels of involvement of the entities are almost entirely flexible and are almost completely based on owner preferences or requirements.

Scope Selection

A similar response was received by almost all five industry members when asked about which scopes of a project should be procured using early involvement. The scopes selected should be project specific. In other words, which ever parts or systems of a project that are complex or are substantial to the successful completion of the project should be included in early involvement. Specialty, contractors and trades that have little or no value to design would not be included in early involvement because they could not offer design input that would justify their time and costs of involvement. Two examples of such trades would not typically be involved in design are dry-wallers and painters. On the other hand, it may be good practice to include MEP contractors in the design process on hospital projects or a casework installer in projects that are heavy in high-end case work finishes. Another statement that seemed to be consistent in all interviews was to include construction specialists as early as possible in design as to have the biggest influence before the design has gone too far. The conclusion made from this topic is that the trades procured in early involvement work should be important to the specific project and the earlier these trades can be brought on-board the better.

All design-build firms interviewed said that early involvement projects are getting more and more common. It seems that the more owners and other industry members use early involvement, the more familiar they become with it and the more they seem to be requesting and requiring it.

Recommendations and Guidelines

It is important to note that every project is different in some way shape or form and that what works for one project or organization may not work for another. It may even take years of experience working on early involvement type projects to become familiar with all typical or normal concerns and considerations. This analysis attempted to look at some norms on a very general level to gain a better understanding of early involvement projects and look at considerations for implementing such involvement on the Library project discussed in previous reports.

Upfront Decisions

Implementing early involvement type contracts onto a project should be discussed very early in the programmatic stages of a project. At this point, the project may not even have a designer, but rather the project is being considered by an owner. The decisions made at this time will affect the project through every stage here on out. An experienced owner, such as Penn State, will have the in-house capabilities of making early involvement decisions. However, inexperienced owners may be unfamiliar with early involvement and should seek assistance with these decisions from a Construction Management Agent (CMA) or a design team that will act as an owner's guide. If owners cannot put the time and dedication into a project, make quick decisions, stick with their decisions, and are not educated in construction to a basic level, which is required for early involvement, then early involvement may not be the proper delivery system for their projects.

It is important that whoever is making decisions to use construction personnel feedback in design understand the benefits and requirements of doing so. Funding for the use of early involvement is a concern or issue in some cases. It's typically very hard for state or government funded projects to use early involvement in less they have successfully implemented such delivery methods in the past. Lenders also typically stray away from high upfront cost projects because these costs are being produced with very little items put-in-place. Owners should also weigh their available resources for the project because early involvement most successfully implemented when owners are actively involvement throughout the project by attending meetings, making quick decisions, and having a high degree of commitment to their projects.

In the event the owner does get funding approved and is able to take an active position on the project, the construction costs and schedule could be drastically reduced with early involvement. Selling points of early involvement highly tied into cost savings. This is simply shown by a better and more constructible design that leads to fewer change orders and less costly rework, which has the penitential of saving the owner 6% in Unit Costs, says the Design-Build Institute of America (DBIA) in a Delivery System Study conducted in 1999 by the Construction Industry Institute and Penn State. In addition, early involvement will work well on projects needing to be fast tracked for any reason because of the contractor involvement upfront and project dedication by all project team members.

Because the county is acting as an owner for this Library they should have the experience needed to be successful in implementing early involvement. The county is also already putting a level of effort into the project that would be required by early involvement by having a full time project representative stationed onsite. Fast-tracking is not a concern for this owner, but the county would be interesting in saving construction cost, reducing change orders, and mitigating delays that have already influenced the project. Funding would be the only issue because the funding requirements are a big reason why this project was not already delivered using early involvement. See Table 2 for a comparison of the topics discussed in this section and each of the team member's' capability in each.

Table 2 - Project Rating Scale				
	Owner	CM	Contractor	Design Team
Funding	x	-	-	-
Resources Available	✓	✓	✓	✓
Experience	✓	✓	x	✓

If owners, contractors, designers, or specialty contractors wish to catch up with the current industry knowledge on early involvement, DBIA offers a variety of educational classes that range from Owner Boot Camps to BIM Execution Planning. A more detailed list of classes and seminars can be found at DBIA's website http://www.dbia.org/education/Pages/Schedule-at-a-Glance.aspx.

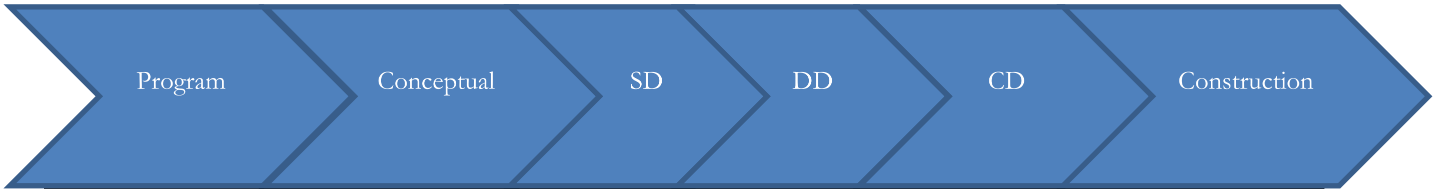
Scope Decisions

As mentioned before, every project has different requirements and scope determination and selection is no different. Which parties to include, what level of involvement, and when they will be involved is completely flexible and up to the project team during the upfront programming and meeting stages. Every project that plans to us early involvement should have a general contractor or equal party on board throughout design. However, certain projects lend their-self more easily to specific scopes being involved in design. For example, in large lab or hospital projects Design-Build MEP systems are a must because the level of complexity these systems must be design and built at. Therefore it is important to carefully pick the trades to include on an early involvement project. A good rule of thumb may be to involve trades that will likely have the most change orders on the specific project so these may be minimized through the early involvement process. As mentioned early in this analysis, the MEP systems, structural system, and curtain wall could have been potential early involvement areas specific to the Library project because these key areas have been identified as problematic by the project team.

A specific level that each trade or scope is involved in is as flexible as the scope selection itself. More complex scopes will have great amounts of involvement in design. The contractor for each project should be involved in specialty contractor selection, selecting scopes, helping identify and laying out such things as level of involvement, time frame involvement, and general design input. See Table 3 for project specific recommendations for the Library project. Note that these involvements are related to design assist and not completely Design-Build because complexities of these systems for this project do not warrant the use of Design-Build according to information obtained from research in this analysis.

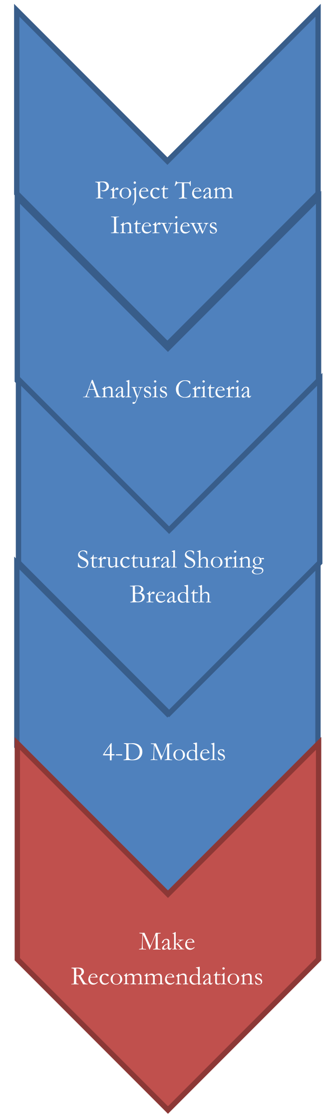
Table 3 also shows when each trade should be involved for this Library project. A contractor should be brought onboard as soon as possible to ensure smooth transition of each of the below stages. MEP and curtain wall specialty contractors are recommended to be involved before structural erectors because they can influence the design more and in different ways then steel erectors. Steel erectors should be included in the project early enough to procure long lead structural steel items. As before, time frame inclusion should be based on specific project needs.

Table 3 - Level of Involvement & Timeline



Scopes	Program	Conceptual	Schematic Design	Design Development	Construction Documents	Construction
Contractor	Start-up	Scope Selection & Sign Contract	Sub Selection & Design Input	Sub Selection & Design Input	Design Input & Long Lead Items	Management
MEP	-	Planning, Questions & Sign Contract	Consult w/ Subs	Design Input	Design Input & Long Lead Items	Procurement
Structural	-	-	-	Consult w/ Subs, Design Input & Sign Contract	Design Input & Long Lead Items	Procurement
Curtain Wall	-	-	Consult w/ Subs & Sign Contract	Design Input	Design Input & Long Lead Items	Procurement

Analysis Topic 2- Structural Steel Sequencing



Goal

The underlying goal of this analysis is to reevaluate the structural sequence used for the structural steel and structural slab erection. This process has delayed the project's critical path. An alternative solution to the current sequence will be analyzed and compared to the actual sequence to shorten the duration of erection while maintaining the budget. Currently the sequence consists of 19 phases jumping to various locations of the building. This is because part of the third, fourth, and fifth floors are hung from large trusses intersecting the fifth floor. Figure 2 shows a basic shape diagram of how the building is to be erected using the current sequence. The trusses must be placed before the lower floors can be finished and hung from the trusses. If there was a method to erect the structure with a smoother flow, then the schedule could be positively affected (shortening the overall schedule). A breakdown of processes used to perform this analysis can be seen on the right-hand side of this page.

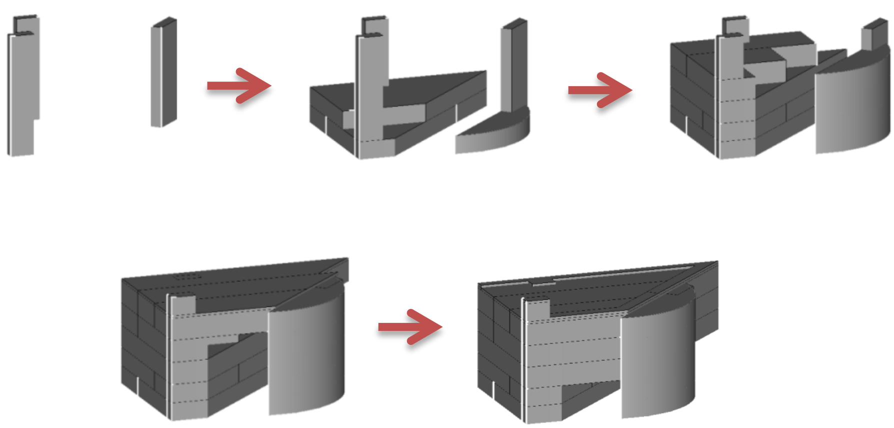


Figure 2: Current Structural Steel Erection Sequence

Project Team Interviews

As part of this analysis the contractor and designer were asked which factors influenced the original sequence. Their responses were the complexity of the structural system, schedule, cost, and the overall constructability of erection. During the bidding phase contractors were asked specifically how they would sequence erection and what means and methods they would use. Two primary methods were the top down erection (currently being used on the project) and a shoring system method to support the cantilever (alternative method not being implemented). These sequences will be analyzed in this paper.

Establishment of Judging Criteria

To pick topics to analysis from each sequence option, the responses from the project team were considered along with other important considerations derived from knowledge of the building and erection operations.

Complexity of Building

The third, fourth, and fifth floors are cantilevered over the future train stop on the north corner and span the train stop on the south side. To do this the roof framing is made of 15 feet tall trusses running from west to east. Two of these trusses cantilever 50 feet over the east side of the building, and support the third, fourth, and fifth floors using a hanging system. See Figure 3 for a basic structural model made for the purpose of this analysis and to better understand this structure.

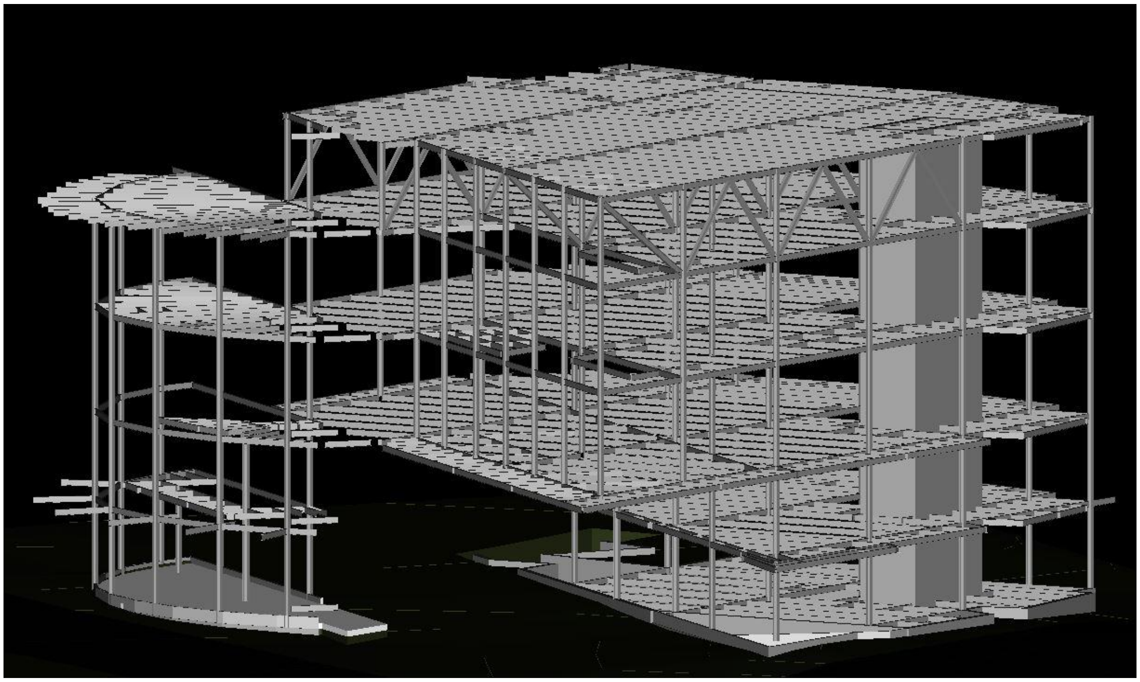


Figure 3: 3-D Structural Model (created in Revit)

A simple and easy to follow erection sequence would be highly beneficial for this project because the structure is already complex and the project team is in no need of farther complications from its erection.

Cost

Erection costs play a large role in selecting an erection method. Both costs of the top down and shoring methods will be compared in estimate form. Major cost impacts will include; general conditions, number of crews, temporary structures, number of pieces (will stay consistent between different sequences), and delivery.

Schedule and Productivity

Schedule and productivity tie back into the complexity erection. A by-product of a simplistic erection sequence will be schedule savings and production increases. Other factors play into the productivity as well, such as, crew sizes, number of crews, piece size, elevation of erection, and location of proceeding piece. Uncontrollable events like; weather and accidents can affect productivity as well. All these factors make estimating an accurate erection schedule very challenging.

Site

The site is in an urban environment, which makes logistics tight with little room to spare. Any portion of the erection using more site space will negatively affect any site activities'. Shutting down a portion of the site for a large duration could also potentially delay the critical path, and therefore introduce unnecessary delays in the schedule. Deliveries require unloading space and storage area until their installation. A shrinking site will require deliveries to arrive as that material is needed. This opens the possibility that deliveries could be delayed in traffic, which would directly stop productivity.

Safety

Safety is often times overlooked in design until immediately before installation takes place. It is easier to design sequences and systems with safety in mind from the beginning than to wait until during construction. In OSHA's 10 hour certification class they preach to engineer out unsafe conditions rather than confront them during construction. This means use best practices and construction knowledge to prevent the possibility of unsafe conditions. Heavy trusses will be installed on this project five floors above street level with three full penetration welds, which could take long durations and be very dangerous. This analysis will take into account how these welds can be performed in the safest way.

Other Trade Integration

This topic will examine how each sequence will affect other trades and their productivity. How soon will concrete slabs be able to be poured, concrete shear walls be installed, steel decking be laid, masonry walls be placed, MEP rough-ins started, and site utilities be ran? How steel erection will alter these activities will be compared as well.

Structural Breadth- Shoring System Design

In order to pick a cost effective and appropriate design for shoring to be used in a shoring sequence, a few considerations and assumptions must be made. A supper-positioning of the estimated structure weight was calculated for shoring capacities. The estimated loads were applied to the shoring system as area loads. This allowed a simplification of the structure's geometry into a manageable form. See Figure 4 for a geometric representation of the area in which the shoring must support. Once loading criteria was established a shoring system and local supplier could be selected. Rental cost will be covered in depth in the *Shoring Option* section.

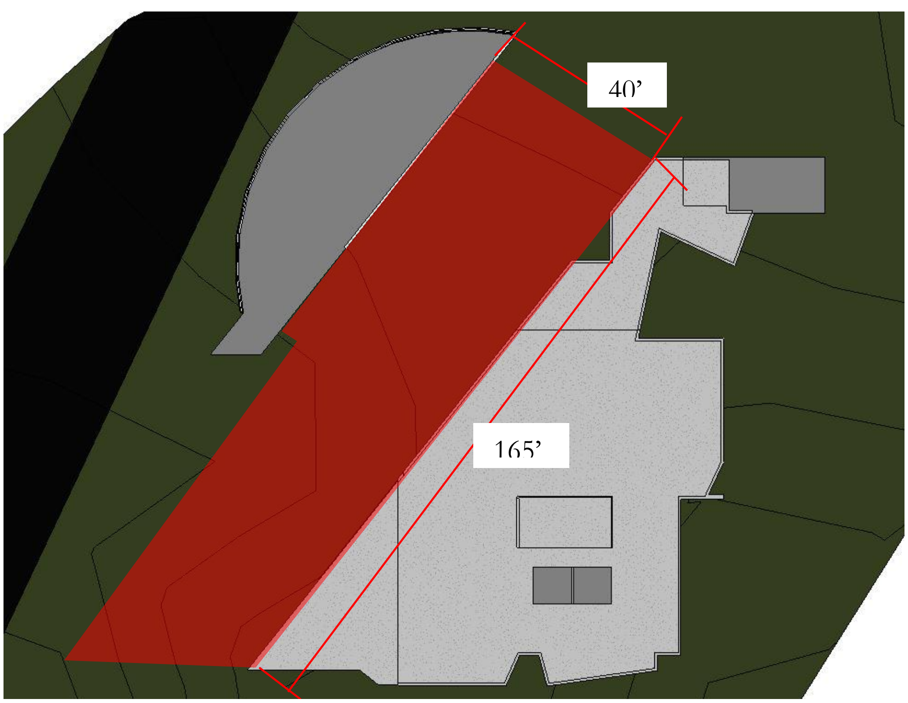


Figure 4: Shoring Support Area (shaded in red)

Loads

An understanding of how the structure is designed and how its' loads travel is needed to determine the loads placed on a shoring system. In calculating dead load from structural elements, each type of element creating load were broken up into categories such as; columns, trusses, decking, specific members by floor, and an allowance for loads not included. Using the spacing and weight of each type of member, a pound per square foot (psf) weight calculation was determined. This calculation can be found in *Appendix* B. No concrete slabs were included in this calculation because all shoring will be removed before slab pours in order to properly load the camber from all trusses. A total dead load was estimated to be 70 psf.

In calculating the live loads a 50 psf allowance was used for workers and their tools. This is small compared to a finished library live load of 80 to 150 psf because very few objects or activities will take place above the shoring before the trusses are installed to allow shoring to be removed. This 50 psf must be applied to all four floors above the shoring. That is L_0= 200 psf, when determining live loading on shores. A live load reduction is also allowed using the following formula:

$$L = L_0 |^{0.4}_{\left(0.25 + \frac{15}{\sqrt{K_{LL} A_T}}\right)}$$

L= Reduced Live Load

L_0= Unreduced Live Load

K_{LL}= Live Load Element Factor= 4

A_T= Tributary Area= 360 ft.^{2}

The detailed live load reduction calculation can be found in *Appendix* B. For a support, holding two or more floors of live load, the reduction cannot be less than $0.4L_0$. In this case we will use the $0.65L_0$ value as calculated in *Appendix* B. With this, L= 291 psf. Farther factoring the dead and live load we use;

$$P_u = 1.2D + 1.6L$$

P_u= Total Factored Load= 291 psf

D= Dead Load

P_u can then be multiplied by shoring spacing to produce an estimated load per shore.

It's important to note that this psf load will be over conservative for shoring because the methods used in this report are for permanent building structures and not temporary shoring. Also, most of the truss weight calculated on the shores will actually be supported by the trusses their self because once welded to the other truss sections, these pieces will become the cantilever supporting the permanent structure.

Picking a Shoring System

Multiple shoring suppliers were researched and contacted in the Baltimore, MD and Washington, D.C. area. Mabey Inc. was willing to offer input in picking a suitable shoring system and supplying basic rental quote. Mabey's Bridging and Structure Shoring Division offers a variety of different flexible shoring sizes that can be utilized as single shores, trusses, bridges, shoring towers, and jacking systems. Mabey offers shoring from heavy duty to light duty and all sizes in-between.

A general project overview and shoring use description was laid out for one of Mabey's structural shoring specialists. They provided technical brochures detailing each shoring system they offer. Mabey's Mass series was selected because its' capacity fell within the calculated load. Mabey offers a Mass 25, 50, 75, and 100 system, depending on the appropriate shoring spacing and layout. A tower shore configuration was selected because of their ease of installation and removal while creating a solid four leg structure with temporary pads as a base. Through additional conversations with Mabey, a cost effective option would be the Mass 25 shoring tower design (as seen in Figure 5).

Figure 5: Mass 25 Shoring Tower Example (Picture Courtesy of Maybe Inc.)

Finalizing Shoring Details

From Mabey's technical brochures, a Mass 25 shoring tower at 26 feet tall (26 feet is needed to support the third floor framing) can support about 100 kips per tower. After farther consulting with Mabey and running load and spacing numbers, it was determined that the shoring towers will be spaced 18 feet apart in the 165 feet direction and 20 feet apart in the 40 feet direction. Figure 6 shows this layout, and *Appendix* B also shows the calculations for this spacing. This spacing requires (16) 5'x5' and (2) 5'x10' shoring towers. Two 5'x10' towers are being used at the north corner because there are heavier structural pieces being supported there and this corner is odd shaped and is in need of extra support.

Mabey also offers a base for the shoring tower to mount too (as also shown in Figure 5). The soil bearing capacity is of adequate strength to support this shoring because the contractor already plans to install an engineered fill in this area for the movement and support of the 200 ton crawler crane used to erect the steel earlier in construction.

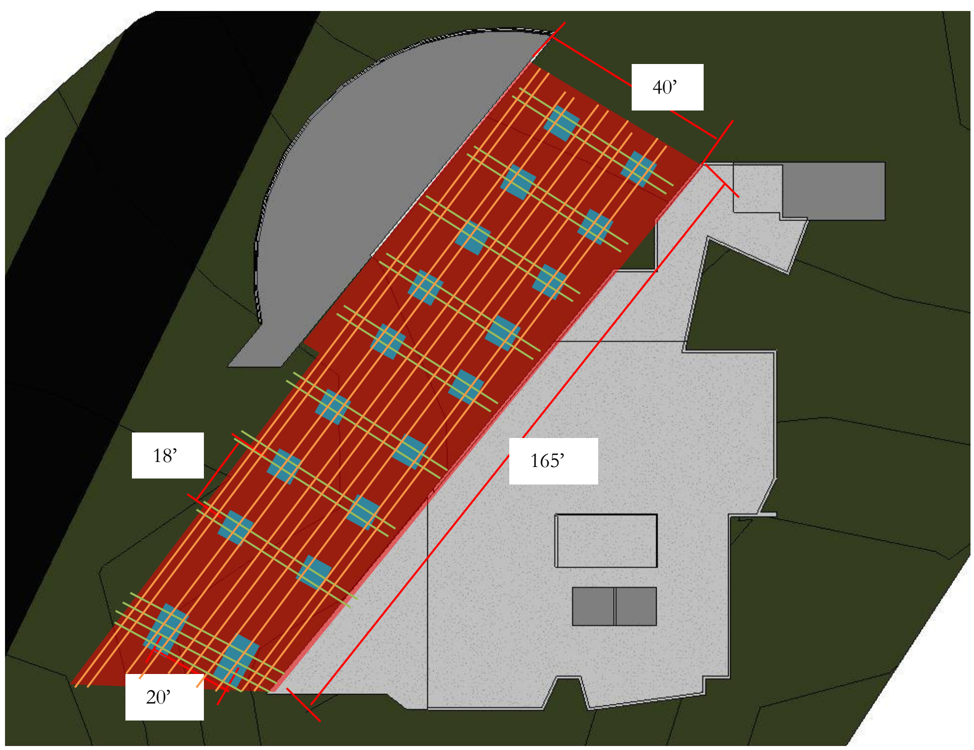


Figure 6: Shoring Tower Layout

Conclusion

Again, refer to *Appendix* B for all calculations related to this breadth topic. A total load of 291 psf will need to be supported by the chosen shoring system. Mabey assures that their Mass 25 shoring system can adequately support 100 kips when assembled into a 26 feet shoring tower. Using a spacing of 20'x18' the over conservative load estimated on each shoring tower will never exceed 105 kips. This should be more than enough support to safely construct the steel over the train stop before making final truss connections. As a side note, the west hangers may need upsized and/or redesigned in order to properly support construction loads as columns. This was not performed because this lies outside the scope of this report.

Sequencing Options & 4-D Models

A structural model was reproduced from the structural plans in Autodesk's Revit Suite. This model was then imported into Autodesk's Navisworks where the two sequences were reproduced and scheduled independently. In this section the two erection sequences will be described and shown visually.

Top-Down Sequence

The top-down method is currently being implemented on the project and will be referred to as the baseline for the sequence comparisons. To track the sequence and schedule of this erection, photos from onsite and the site webcam were used, as well as the approved contractor submittal detailing the contractor's plan to erect the steel and structural slabs.

Sequence

Refer to *Appendix C* for a five picture snapshot from Navisworks of the baseline sequence. After the foundations were finished and the concrete shear wall almost complete, steel erection begins on the first floor main building section. Steel erection continues up to the third floor then the pavilion structure also starts simultaneously with the fourth floor steel, first, and second floor slabs. Until now, there is no structure above the future train stop. Then, the trusses, fifth, and roof framing erection start from south to north. Once truss erection is complete, the rest of the third and fourth floor framing can be hung while third and fourth floor west slabs are finished. After top out, the remainder of the structural slabs are poured on floors five, the roof, four, and three, in that sequence to remove the 2" camber from the trusses without cracking slabs.

Shoring Sequence

Sequence

A shoring system was picked in the Structural Breadth (earlier in this report) and represented in the 4-D model by transparent yellow columns and framing as a place holder. Refer to *Appendix* D for picture snapshots from Navisworks of the shoring sequence and Figure 7 for a diagram showing the order of the proposed erection zones. The sequence in this option is the same until the third floor structure. Instead of starting the pavilion structure after the third floor of the main building, the main building will continue to the roof framing in the same area, with no steel over the train stop or in the pavilion. A system of shoring foundations, shoring framings, and stringers will then be constructed in the train stop area, while slabs can be poured on all floors of the main building. Once the shoring is in place, the future hangers, third, fourth, fifth, and roof will be erected in two separate zones over the train stop. No slabs in this area will be poured until the shoring is removed in order to properly remove the 2" camber by slowly loading the trusses. The camber will be removed by pouring slabs over the train stop in the same order as the baseline sequence; fifth, roof, forth and then third. The slabs in this area will be poured concurrently with the pavilion construction.

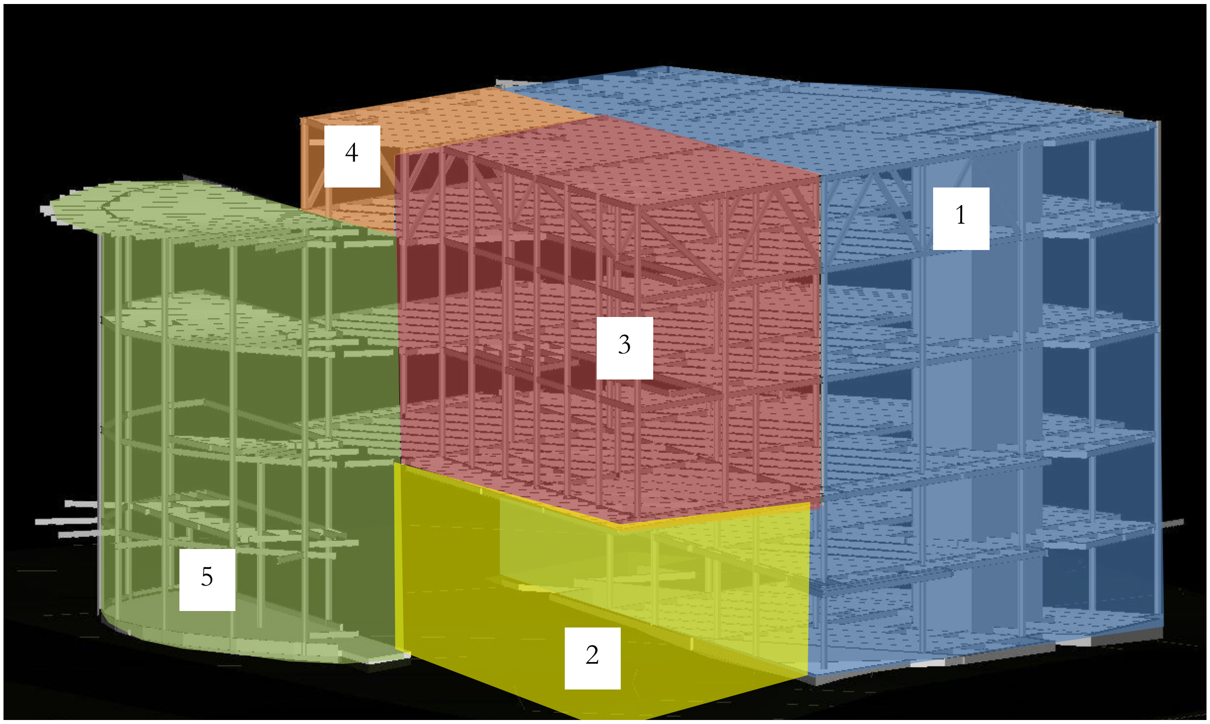


Figure 7: Shoring Option Erection Sequence

Criteria Comparisons

Complexity

The top-down sequence requires the erection team to move frequently to various locations of the building. This is believed to cause loss of productivity of the steel erector. Also, it is unsure that the steel erector fully understood the complexity of the steel structure when bidding and staffing the project.

Schedule and Productivity

The number, sizes of structural pieces, and the erection elevation will stay consistent between the different erection sequences. Because of this, these variables will have very little effect on the schedule and productivity criteria. For the purposes of this analysis the crew size and number of crews were left constant because this was how the contractor and steel erector bid the project. Increasing crew sizes and quantities would greatly complicate this comparison. Assuming uncontrollable effects of weather and accidents would also be constant the sequence would then be isolated as the only variable in which could influence the schedule. The key goal of this analysis was to see how the sequence, itself, altered the project.

Because schedule is one of the largest and more important comparison criteria, both the top-down and shoring sequences were imputed to Microsoft Project and can be found in *Appendixes* E and F. Both these schedules were then compared to the planned schedule created at the start of the project (For farther details about this schedule see Technical Assignment II). Table 4 shows the compassion of the three schedule durations.

Table 4 – Structure Duration Comparisons			
Description	**Planned**	**Top-Down Option**	**Shoring Option**
Steel Erection Start	6/25/13	7/4/13	7/4/13
Structure Complete Milestone	1/1/14	3/7/14	2/13/14
Total Duration (weeks)	28	33	30

In comparing the planned verses the accrual schedule, a five week delay was experienced in the structural erection. Figure 8 shows a small version of the actual schedule. Here it's easy to see an unusually long duration for zones 12 through 19 (shown by a red box). This may be a cause of the five week overrun. In cross comparing these zones to the 4-D model of the top-down sequence, it was discovered that the zones align with the truss installations and the third through fifth floor fill in above the train stop (as seen in Figures 9 and 10). It is believed that during this time productivity was low because the nature of this sequence. Long duration over runs were experienced due to long and tedious welding times, complexity erection of structural members after the main crane was taken down, and lack of a properly staffed crew.

In comparing the top-down sequence to the shoring sequence, a three weeks savings was estimated. This is still two weeks over the planned schedule. However, this is consistent with the duration needed to set-up and tear down the shoring system. This sequence is estimated to save three weeks over the current sequence because it follows an overall easier flow of erection, the main crane can back out of the structure allowing it to remain onsite longer, and productivity will remain constant throughout the project. Therefore, the shoring sequence will beneficial the schedule, as discussed above, and will create fewer delays to the critical path.

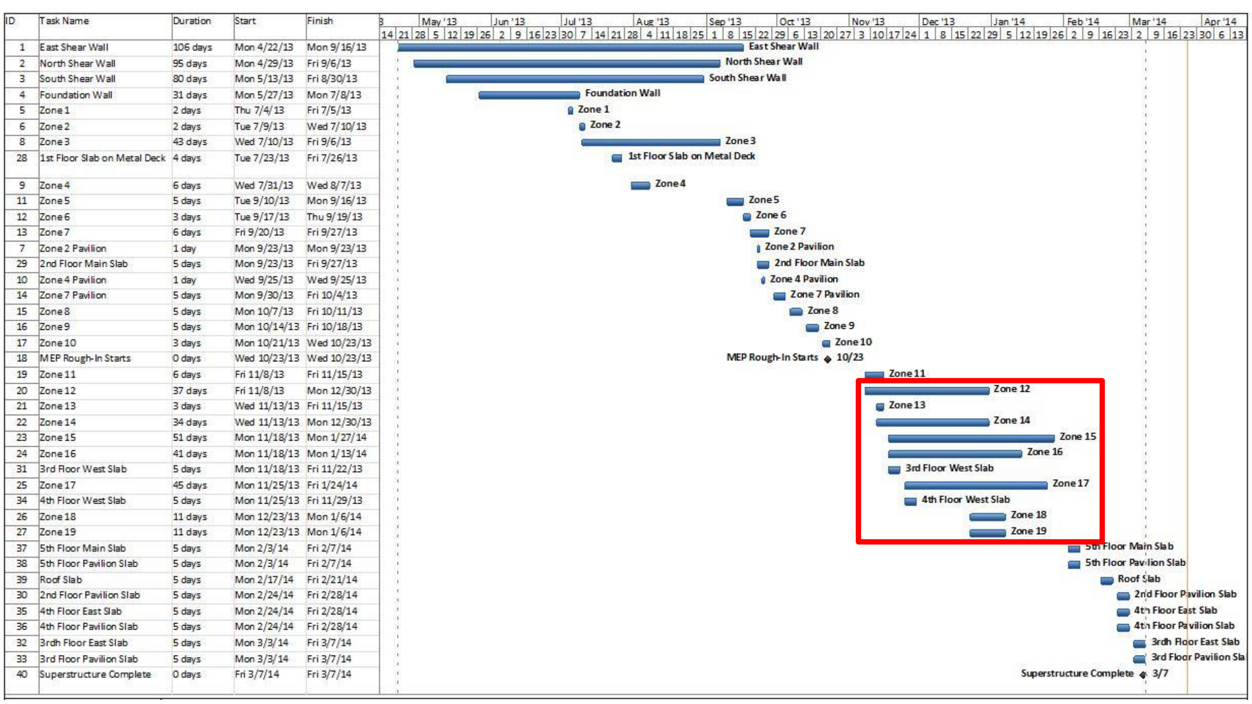


Figure 8: Actual Schedule (unusually long durations in red box)

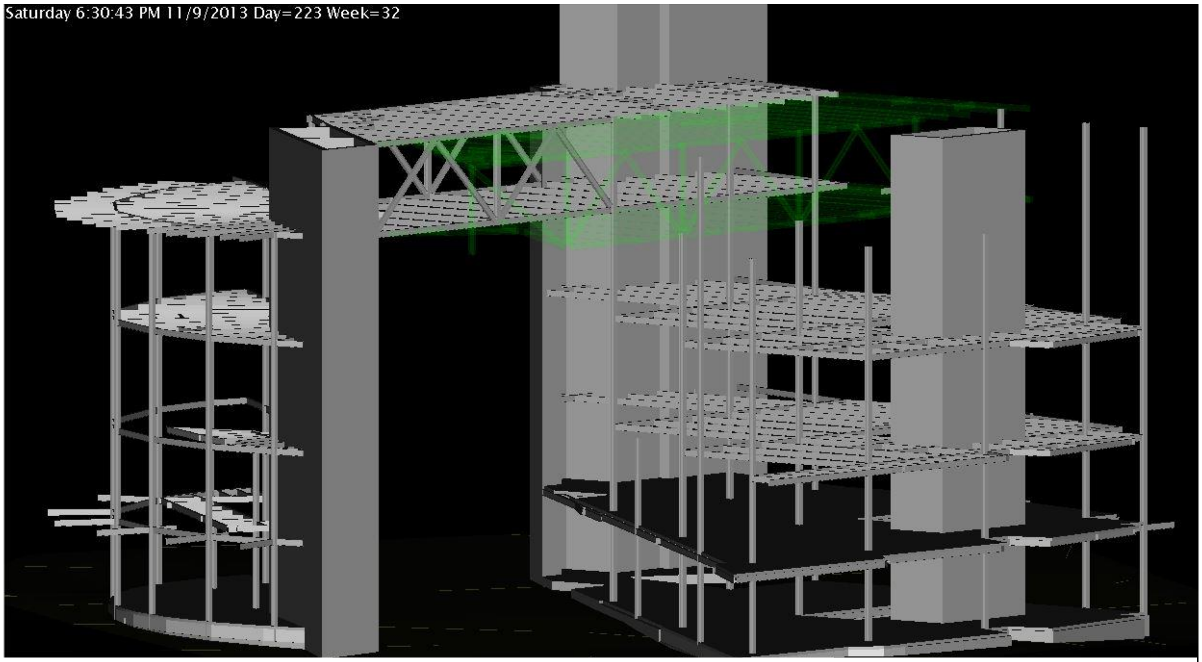


Figure 9: Truss Installations in Top-down Sequence

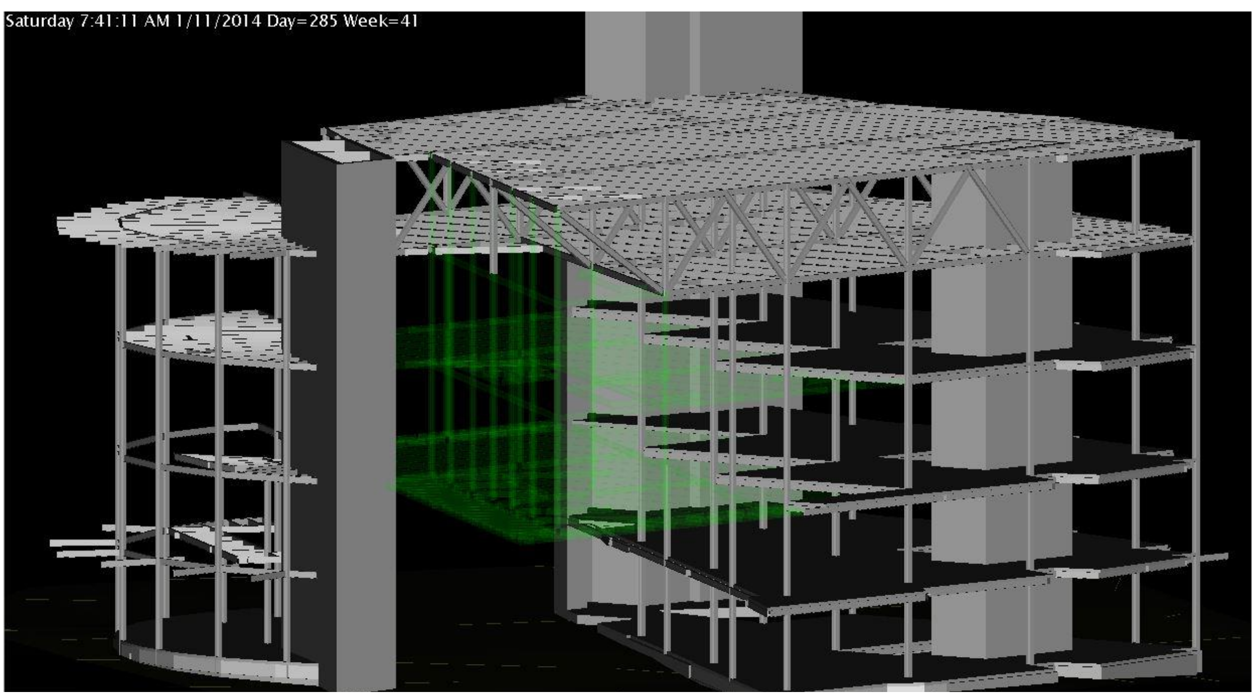


Figure 10: Third and Fourth Floor Fill-in in Top-down Sequence

Cost

In reality, the costs associated with the structural steel material will not change because the structure is not changing the two sequence options. The installation costs will change between the two sequences. More specifically, the unit costs associated with equipment, such as labor, cranes, boom lifts, welders, and other miscellaneous tools and project specific needs, will be consistent because such things are rented or charged at a monthly, weekly, or hourly rate.

Because some costs are similar between options, differences in costs will be compared. The general condition costs could be used as a ball park estimate additional costs or savings. Looking back at *Technical Assignment II*, the general conditions costs for the project were estimated at $2,140,000 or $24,300 per week (see Appendix G for a cost breakdown). Using this rate we can say, for every week spent on the structure, the general condition costs are $24,000; plus or minus a few $1,000.

With the baseline structural schedule at 49 weeks, the total general condition costs for this period would be about $1,176,000. The shoring sequence was estimated to be 46 weeks, which correlates to general condition costs of $1,104,000. This is at least a $72,000 up front savings from a schedule reduction.

Mabey was able to create a rental quote for the Mass 25 shoring system chosen in the structural breadth. This system can be rented for $1,357 per tower for the first four weeks and $207 per week per tower thereafter, and not including 6% sales tax. As stated earlier, 18 structural soring towers will be needed for a total of eight weeks. Table 5 shows these costs applied to account for all needed shoring towers, as determined in the *Structural Breadth* section.

Table 5 – Shoring Cost Break Down		
Description	**Per Tower**	**Total**
Minimum First 4 Weeks	$1357	$24,430
Every Week After for 4 Weeks	$828	$14,900
Tax (6%)	$131	$2,360
Total	$2,316	**$41,690**

Table 6 shows the difference in costs between the top-down sequence and the shoring sequence. In the end, using a shoring system to increase productivity will result in an estimated $30,000 savings. The actual cost savings may be lower than this depending on fluctuations of rental rates and freight charges. In conclusion, the shoring option has the potential of saving money due to schedule savings and accounting for shoring costs.

Table 6 –Cost Comparisons	
Description	**Per Tower**
General Condition Savings	$72,000
Shoring Costs	$41,690
Total Estimated Costs Savings	**$30,000**

Site

The site is located in an urban environment and has space limitations. A top-down sequence will benefit the site because less parts of the site will be unusable during steel erection. However, in the shoring sequence, the area shown in the Structural Breadth section (the future train stop area) will be partially blocked by the shoring towers. This is not means to announce a "No Go" conclusion for the shoring system, but it will create challenges. Referring back to Technical Assignment II, the Superstructure Site Plan was established and is included in *Appendix* H for reference. This plan shows how the steel erection crane will move during erection. In the shoring case, the crane would complete the first zone in the location showed on the site plan (The first zones refers back to the zone sequence established for the shoring sequence earlier in this report.) Once shoring begins, the crane would back out from erecting the shoring towers, while moving north to south. At this point, the shoring area will be non-assessable for storage or laydown and all deliveries will have to enter through the south gate. Delivery scheduling will get tighter, and less material will be stored on site. Many factors will change, but it is challenging to estimate exactly how much productivity will be affected by this loss of site space.

Figure 11: Full Penetration Welds Required (represented by red circles) (Picture Courtesy of Multivista.)

Safety

Site safty is of high priority to all parties involved in construction as well as the owner. Two of the four trusses designed to support the cantileaver over the train stop require three full penitration welds of W14x283 members. Full penitration welds have quite a long duration because the full steel surface area of the members being combined must be welded. To top that, the trusses needing full-penitration welds are susspended above the ground, 70 to 80 feet below. The red circles in Figure 11 show these weld locations. Heavy 3000 pound truss sections, high heights, a potential heavey wind guest, and worker error makes these long duration welds challenging and very dangours. A goal of the shoring option is to engineer out this unsafe condition by building the suspended area of structure up from the ground (using a shoring system). This would allow workers the opportunity to weld these trusses from a working surface or a small rasied height, and not in boom lifts 80 feet from the ground. In general, the shoring sequence will also alow metal decking installers to keep up with structural erection because of its' linearer organization. This is idel because OSHA regulates that steel erection can not procede upward untill steel decking is installed at most two floors below the erection level. Therefore the shoring sequence would create a safer working enviornment over the top-down sequence.

Other Trade Integration

How other trades are affected by the steel erection in concern because when trades can start and be more productive, then the whole project can run smoothly. Steel erection sequencing will have very little effect of the installation of concrete shear walls and site utilities because these activities were completed prior to the start of steel erection. Concrete slabs will be poured on floors one through five and the roof of the main building and pavilion structure in sequential order. Steel decking will be installed as soon as every second floor's erection is complete to keep the erectors and decking installers safe. Again, slabs over the shoring area will be poured after shoring is removed and in the order discussed previously to remove truss camber. The superstructure is complete after the slabs are completed. As determined in the schedule section, the shoring sequence could save up to three weeks in superstructure critical path, and therefore the shoring option would benefit these trades' productivity and schedules.

Referring back to *Appendixes* E and F, the MEP rough-in can start three weeks earlier in the top-down method (see Table 7 for specific dates). Therefore, using a shoring sequence may delay MEP rough-in by three weeks. However, because the shoring sequence is shorter in erection duration by three weeks, MEP trades could have full access to the building sooner. This could allow the MEP trades to make up the lost three weeks by applying more resources to the project sooner. As with MEP trades, masonry specialty contractors should also have full access to the building sooner and a better linear flow of work with the shoring sequence, and therefore should also experience an increase in productivity.

Table 7 –MEP Rough-in Start Dates

Description	Top-Down Option	Shoring Option
MEP Rough-in Start	10/23/13	11/14/13

Comparison

Table 8 shows a summary of how the top-down and shoring options rated in the above categories. Both have negatives and positives associated with their specific needs and requirements.

Table 8 – IPEC vs. Mechanical Penthouse		
Criteria & Categories	**Top-Down**	**Shoring**
Constructability	x	✓
Schedule	x	✓
Cost	✓	✓
Site	✓	x
Safety	x	✓
Other Trades	x	✓

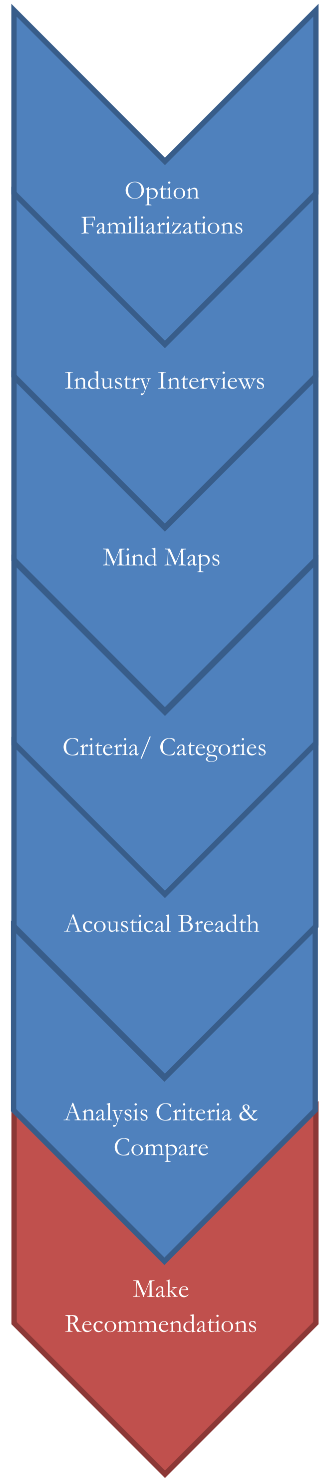
Recommendations

The top-down and the shoring sequence must be compared side by side to make a final recommendation. In complexity, the shoring option is less complex, easier to follow, and creates an overall better flow of structural erection work. In terms of schedule, the shoring option saves three weeks of critical path, and comes closer to meeting the original planned erection schedule dates. The costs of both these erection sequences differ by an estimated $30,000, with the lower being the shoring option because of its schedule savings. This cost savings is not large enough to affect the final decision to choose one option over the other because farther productivity increases or decreases in either option could lead to farther schedule savings or delays, directly saving or raising costs. A more spacious and unrestricted site will be achievable with the top-down method. On the other hand, there will be less safety risks in the shoring option because of the nature of the penetration welds needed on some trusses. Finally, MEP rough-in and masonry work can start earlier on the top-down option, but overall trade productivity is believed to be higher with the shoring option because the overall schedule is reduced. In conclusion, the benefits of using a shoring system in the structural sequence would over weigh any negatives associated with it. For this project, the shoring sequence is recommended.

Analysis Topic 3- Mechanical Penthouse vs. IPEC

Goals of Mechanical Penthouse vs. IPEC Analysis

The purpose of this analysis is to weigh pros and cons of an IPEC unit and a mechanical penthouse, gain valuable knowledge about each type of assembly, why each would be chosen, and which would be the most logical for this library project. A breakdown of the process used to perform this analysis can be seen on the right-hand side of this page.



IPEC Introduction

Currently, a 40' by 60' Integrated Packaged Equipment Center (IPEC) is designed for the project, which is to be assembled and shipped to the site in two pieces from the supplier's facility in Ohio. The IPEC houses all the building's major equipment including air handling units, pumps, fans, boilers, chillers, cooling towers, heat exchangers, heat recovery units, air separators, and more. This equipment center is constructed as two individual pieces and will be lifted to the roof separately from one another. This requires each IPEC section to be structurally designed as independent structural pieces. A double metal core frame with a dense insulation center will be used to construct the exterior of the IPEC. A membrane assembly will be used for the roof enclosure.

The IPEC sits over a MEP chase dropping three floors on the west side of the building to distribute air and piping throughout the library space. A series of 4' high CMU walls will be built as a base for the IPEC, which can be seen in figure 12. The CMU walls form a number of spaces under the IPEC, some of which will be used as outside air and exhaust plenums.

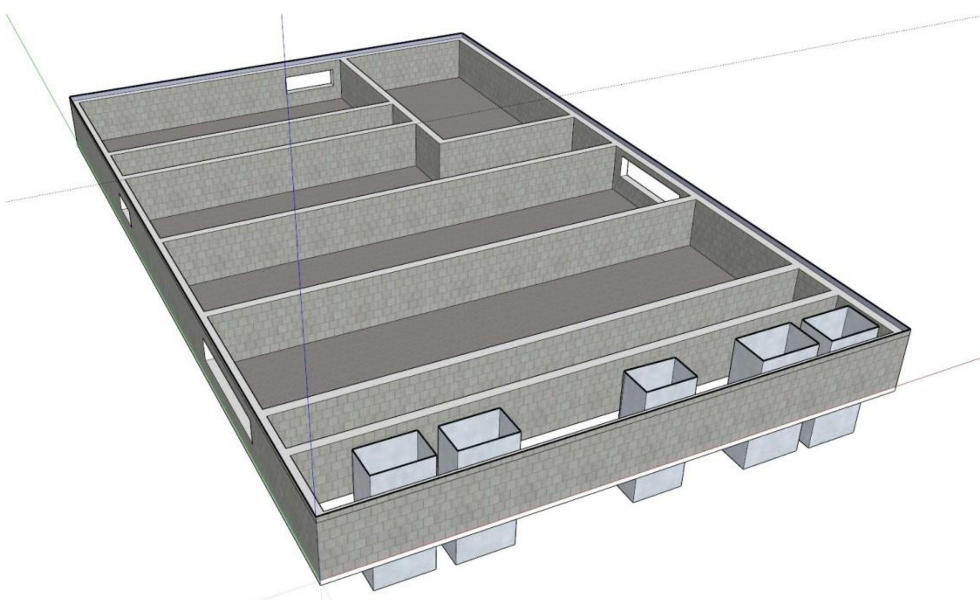


Figure 12: IPEC Base

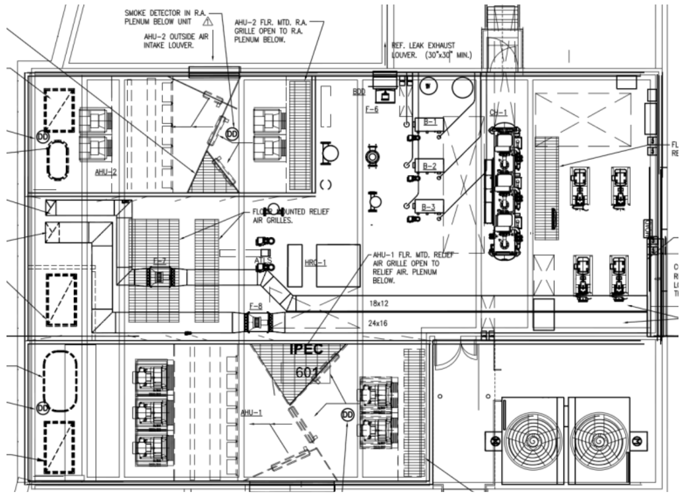


Figure 13 (IPEC Diagram) (Picture from Construction Documents Courtesy of MBP)

Mechanical Penthouse Introduction

If instead of an IPEC, a mechanical penthouse was used for the rooftop mechanical room, the penthouse would be located at approximately the same place but may cover up to 125% the of the area of the IPEC. This is because the penthouse will be built on site and bigger construction clearances will be needed to properly construct the penthouse along with the equipment it houses. The construction of the penthouse will be a steel frame, steel joists, PVC membrane roof, and steel siding wall enclosure. Much of the mechanical equipment housed in this enclosure will be the same types and same suppliers as in the IPEC because the IPEC was customized. Therefore the key difference in construction of the penthouse will be the enclosure.

Interviews

Similarly to the design-build topic earlier in this report, industry members were interviewed for their input in the differences in an IPEC and a Mechanical Penthouse. These interviews included; one mechanical professor, two MEP design-builders, one MEP designer, the library owner, the library contractor, and an IPEC supplier. Responses from these interviews were recorded and mapped using the same FreeMind software as in the design-build topic. See Figure 14 for an example of an interview mind map, and see *Appendix I* for all interviews' mind maps. Each common topic was assigned a corresponding number and farther summarized in a summary mind map also located in *Appendix I.*

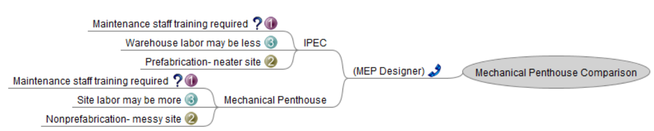


Figure 14 (Example Interview Mind Map)

Establishment of Criteria

The topics discussed in the summary mind map will be incorporated into the criteria used to judge the mechanical room decision. Also, an acoustical breath will be discussed to determine if the two options have acoustical considerations and differences. From the summary mind map, the owner's maintenance staff should be considered. The design team could be affected by design flexibility of each option. Who takes on risks and who is responsible for making sure the mechanical equipment is operating properly, should be considered as well. Site coordination, site space, site availability, site congestion, and constructability challenges will be considered. The owner is interested in cost differences between the two options. Every construction project has schedule restrictions, and therefore, schedule impacts of each option should also be taken into account.

Acoustical Breadth- Mechanical Room Noise Impacts

Acoustical impacts can be a nuisance and troublesome for building occupants and the environment. If high levels of sound pressure leave the building's property, surrounding neighbors will be affected and may cause complaints. On the other hand, if meeting rooms with-in the building have too much background noise, then these spaces become unusable for their intended purpose. The purpose of this breadth is to investigate the acoustical effects of the IPEC and mechanical penthouse on both the inside library space and the outside environment. This acoustical impact from the IPEC will act as a baseline when compared to the mechanical penthouse option. Switching the mechanical equipment enclosure to a mechanical penthouse will either positively impact the surrounding spaces or negatively impact them with higher sound pressure levels. To interpret the results of this breadth, the impact of the library space and the impact of the surrounding outside environment will be analyzed separately.

IPEC Acoustical Introduction

In order to analyze the acoustics of the IPEC on an Architectural Engineering undergraduate level, a number of rational assumptions had to be made. First, the sound level inside either mechanical room will be over conservative as an estimated average level, in which will be constant and uniform everywhere in either mechanical room. Most of the equipment being used in the mechanical space is highly customized and therefore lacks sound acoustical data. The manufacturers of equipment worked closely with the designers customize equipment that fits their needs. Acoustical data for such equipment has not been produced at this time. An estimated average sound pressure level will be used as the sound level in the mechanical space and will have octave-band values as shown below in Table 9. This estimation was taken from an average mechanical room sound level in the text *Architectural Acoustics* by M. David Egan.

Table 9 Average Sound Pressure Levels in Spaces

Octave-band Center Frequencies	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	dBA
Mechanical Rooms	87.0	86.0	85.0	84.0	83.0	82.0	80.0	78.0	88.0

Another assumption is all spaces below the IPEC, that are used as plenums, will have the same sound pressure level as the mechanical space above, because there are a number of open grates on the floor. This will cause sound in the mechanical space to travel into the plenums and then to the outside with negligible sound pressure loss. While this may be overly conservative, the actual sound losses through these spaces are complicated and are beyond the scope of this paper. With this assumption, the sound level experienced outside of the mechanical room will be similar to the sound level inside the mechanical room.

Noise Level in Library

An initial concern was sound level impacts from the IPEC on library spaces. The first item to consider was which areas in the library were placed directly below the designated mechanical space. Figure 15 shows the location of the IPEC on the roof in transparent red, while Figure 16 shows an overlay of where this IPEC is positioned in reference to the fifth floor library space, also in transparent red.

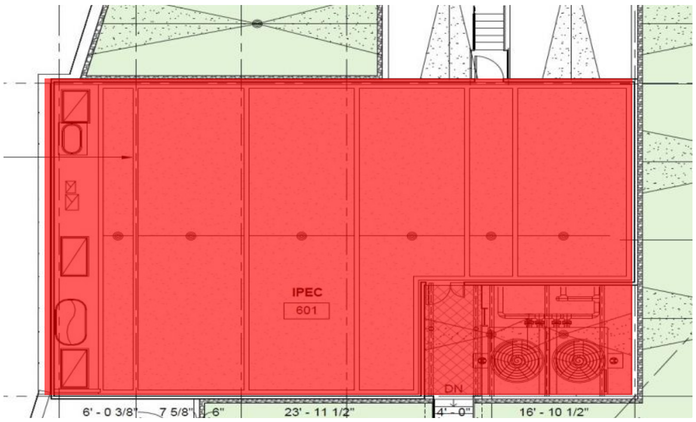


Figure 15: IPEC Roof View (Red is outline of IPEC) (Picture from Construction Documents Courtesy of MBP)

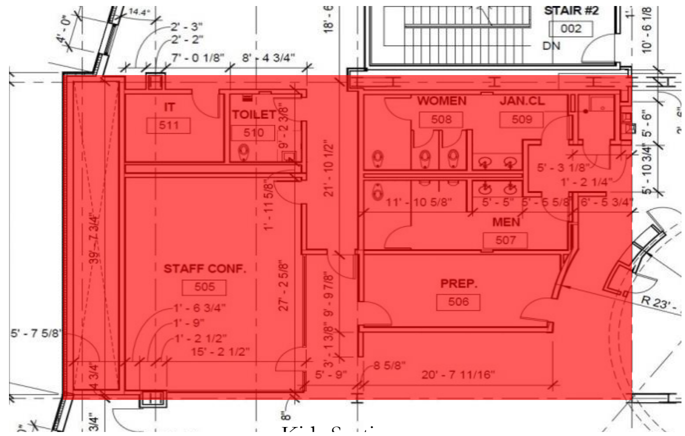


Figure 16: IPEC Impact on Fifth Floor (Red is outline of IPEC) (Picture from Construction Documents Courtesy of MBP)

Most spaces below the IPEC are non-essential such as; bathrroms, preperation spaces, hallways, and IT closets. The only important spaces located within close prosimity to the IPEC are the kid's stacks and a 27'x15' staff confernce space. Because only a small portion of the kid's stacks are near the IPEC and with proper sound isolation technics in the ceiling, the kid's stacks will not have an accoustical issue. Therefore, this space will not be considered in this analysis. However, the staff conference space is located directly under the IPEC or mechanical space, and therefore, will be acoustically analyzed in this section to ensure noise leves in this space are not disruptive to users. Besides the noise entering from the ceiling, there is also a pipe and duct chase, IT room, and bathroom adjacent to the conference room. A double lay wall with a one foot cavity seperats the conference room from the IT rooms and bathrooms. Assuming the noise level from these spaces are neglegable becuase of the double wall, this report will focus on sound penetrating the ceiling of the conference room.

Under IPEC

First, the sound pressure levels must be calculated for each plenum space under the IPEC individually. Figure 17 shows the break up of spaces under the IPEC and where the confence room is located below. In general, red zones will have higher noise levels, while green zones will have softer noise levels. Zone one is the MEP chase and will have noise levels similare to that of those inside the mechanical space. Zone two is not open to the IPEC in anyway, therefore will less direct mechanical noise. Zones three and four are acting as fresh air intake plenums and will also have similare noise leves as in the mechanical space. Zones five, six, seven, and eight are all over nonessecial spaces and will not be considered in this report.

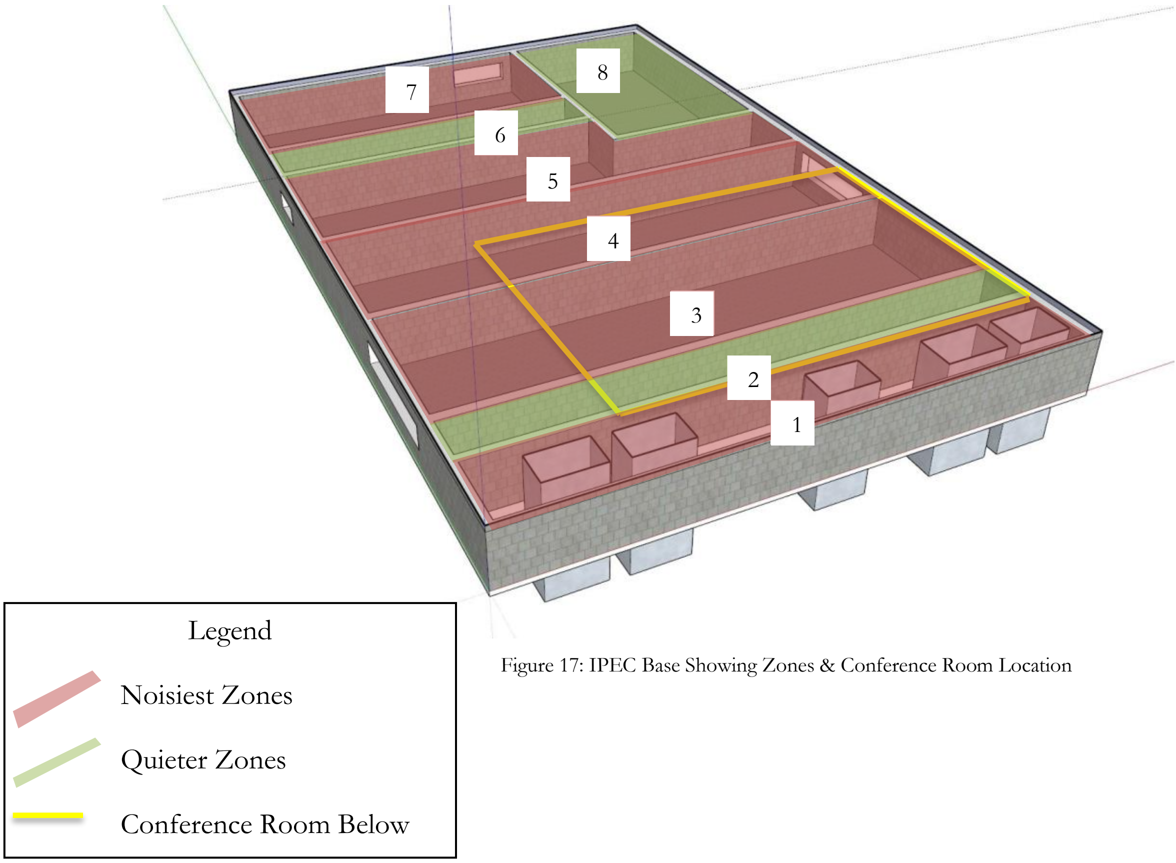


Figure 17: IPEC Base Showing Zones & Conference Room Location

Sound levels in zone two were calculated using the following equation for each octive-band center frequency 125 Hz through 4000 Hz.

$$NR = TL + 10\ log \frac{a_2}{S}$$

NR is the difference in sound levels between the two spaces (dB).

TL= sound transmission loss of barrier (dB)

a_2= absorption in receiving room (sabins)

S= surface area of common barrier (in this case 40 ft. by 4 ft. = 160 ft.^{2})

A transmission loss estimate for the IPEC floor can be seen in *Appendix J*. From here, the absorption of zone two was calculated. For a detailed calculation of this absorption see *Appendix J*. The construction documents for this project were unclear, but 3" ridged insulation was assumed to be installed on the interior of all CMU walls in the IPEC base, which was also included in the absorption calculations in *Appendix J*. All reference values in this analysis were picked from similar assemblies and materials as on this project, from the text *Architectural Acoustics* by M. David Egan. Also in *Appendix J,* the estimated noise level in zone 2 is calculated using the above equation, which yields sound pressure levels shown in Table 10.

Table 10 Estimated Noise Level in Under IPEC Zone 2						
Octave-band Center Frequencies	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Sound Pressure Level in Zone 2 From IPEC Space	49	38	27	20	14	31

Table 11 shows a breakdown of the sound pressure levels estimated in each zone in the IPEC base.

Table 11 Under IPEC Space Acoustics						
Space #	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
1	86	85	84	83	82	80
2	49	38	27	20	14	31
3	86	85	84	83	82	80
4	86	85	84	83	82	80

Conference Room From IPEC

To estimate the sound pressure level experienced in the conference room, much of the same procedure is used as in zone 2 calculation. Below, the same equation is used with different imputes.

$$NR = TL + 10\ log\frac{a_2}{S}$$

NR is the difference in sound levels of the two spaces (dB).

TL= sound transmission loss of barrier (dB).

a_2= absorption in receiving room (sabins)

S= surface area of common barrier (unique to specific zone)

This time, the sound transmission loss is across the eight inch structural concrete slab (as seen in *Appendix K*). *Appendix K* also shows the absorption calculation for the staff conference space. Each zone has its own surface area that affects the sound pressure level in the conference space. Only portions of a particular zone lying over the conference space will be included in the surface area calculation. *Appendix K* walks through the noise reduction calculation and sound pressure level estimates from each zone separately. With this, decibel addition was performed to add the noise penetrating the ceiling from each zone together using the dB addition rules in Table 12. The last chart in *Appendix K* shows the steps taken to perform the dB addition and A-weighting procedure.

Table 12 dB Addition Rules	
When Two dB Values Differ by	Add the Following dB to the Higher Value

0 to 1	3
2 to 3	2
4 to 8	1
9 or more	0

Table 13 shows the final result of the A-weighted noise levels from the IPEC to be heard in the staff conference room. A-weighting is used here because it accurately accounts for our ears' lack of sensitivity to low frequencies and sensitivity to high frequencies.

Table 13 Estimated Noise Level in Conference Room (A-Weighted)						
Octave-band Center Frequencies	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Sound Pressure Level in Zone 2 From IPEC Space	33	33	29	27	22	16

Finally, performing decibel addition one last time on the above A-weighted frequency levels, we come to a final sound level in the conference room of 37 dB. The Acoustical Society of America recommends that for a space similar to the staff conference room, the A-weighted sound level heard from mechanical equipment shall be not more than 35 dB. Because there were over conservative assumptions made in the beginning of this analysis, an estimate of 37 dB is in the high portion of the actual range and is deemed as acceptable for the purposes of this paper.

Vibrations are also important to consider in an acoustical analysis of mechanical equipment. The IPEC supplier ensured the project team that proper vibration isolation on equipment will be installed and furnished. Because the IPEC sets on a four feet high raised platform above the structural roof, structural vibration will not be a large concern. Pipes, ducts, and electrical equipment born vibrations will be more of a concern for this project. Very minimal or even no equipment isolation pads will be needed for the IPEC.

Conference Room from Mechanical Penthouse

In a mechanical penthouse construction the four feet plenum space under the IPEC will be eliminated. The louvers would be mounted on the exterior wall with exhaust and intake ducts mounted directly to the louvers (see Figure 18 for an example of this type of construction).

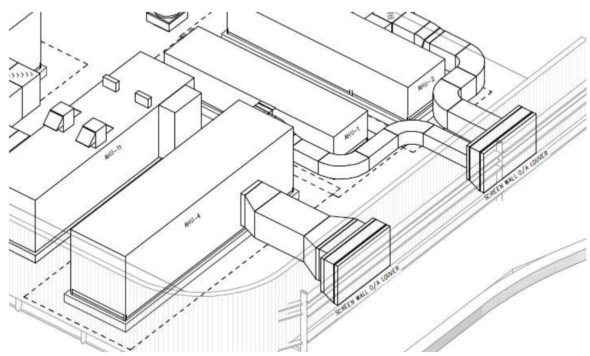


Figure 18: Example of Mechanical Penthouse Louvers

One way a mechanical penthouse differs from the IPEC is through the layout and placement of mechanical equipment. A traditional penthouse may need more roof square footage, in turn possibly affecting more of the library space below. With louvers reconfigured as well, there will be no plenums between the mechanical space and the spaces below. However, because of the conservative assumptions made previously in this analysis, the noise transmission calculation would look very similar with the exception of a slight increase in sound transmitting surface area. The noise level perceived by a mechanical penthouse in the conference room would be on the high end of the estimate made in the previous section, or more closer to the 37 dB noise level. Again, this is because the mechanical equipment would be closure to the structural roof and closer to the conference space.

Vibrations will be more concerning in the mechanical penthouse because equipment will be located directly on the 8 inch concrete roof structure. Better vibration isolators, springs, and neoprene pads will need to be used on ducts, pipes, electrical connections and hangers. Equipment isolation in the penthouse can be provided in a number of different ways such as; single concrete inertia pads, concrete inertia blocks on free standing spring isolators (see Figure 19), or a concrete floating floor system in the mechanical room. These systems will introduce more costs and schedule impacts to the penthouse construction. These costs and schedule impacts will be addressed later in this report.

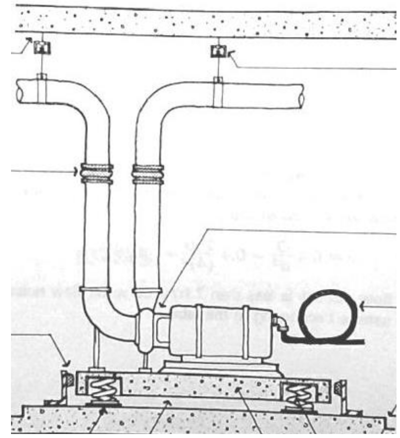


Figure 19: Free Standing Inertia Blocks

Library Impact Conclusion

Because over conservative assumtions, both the IPEC and penthouse were estimated to produce the same 37 dB noise level in the conference room. If anything, the noise heard from the IPEC would be less the 37 dB. This noise level is an estimate, but both an IPEC and a penthouse would be acceptable soultions in terms of acoustical impacts to the building occupants.

Noise Level at Property Line

An additional concern is the noise level measured from any property line around the library. Noise of disruptive levels can have a negative effect on the surrounding environment and nearby neighbors. To prevent unwanted noise disturbances, the County has public noise ordinances in which can be found on the County's website (See Table 14).

Table 14 Maximum Allowable Noise Levels in County @ Property Line

	Daytime	Nighttime
Non-Residential Areas	67 dB	62 dB
Residential Areas	65 dB	**55 dB**

It's important to note that a 10 to 12 story apartment building is adjacent to the library's site. For the sake of this breath, the residential area noise ordinance will be used as a target noise level to accommodate the apartment building's occupants. Because the mechanical room will remain fully operational at night, the nighttime noise level ordinance will be followed. Therefore, a maximum noise level at any of the library's property lines shall not be over 55dB. Sound coming from the library will be deemed as unacceptable if measured to be over 55dB. To interpret the ordinance farther, the elevation at which the sound pressure level is measured must also be considered. To simplify this analysis, the sound pressure level will be measured from the same elevation as the mechanical room to accurately account for noise produced by the mechanical room and traveling to the nearby apartment building.

From IPEC

Assemblies of the IPEC we studied to estimate the sound pressure leaving the IPEC in the surrounding environment. Although the exact wall and roof assembly information of the IPEC was not present on the construction documents, the supplier said the wall make-up is comprised of a double core metal structure with dense insulation. They also said the noise level experienced outside the IPEC would be very minimal compared to inside. However, the assumptions mentioned in this analysis conclude that the sound pressure level in some plenums under the IPEC will have the same levels as inside the IPEC. Therefore, these same sound pressure levels should pass through the louvers and propagate to the environment. Again, this assumption is overly conservative, but will be acceptable for the purposes of this paper. Noise levels from the IPEC will also propagate downward through the mechanical chase. However, the transmission loss across the chase's exterior wall will surely be adequate enough to make any mechanical noise from the chase wall unnoticeable or unrenderable. Therefore, the direct sound pressure levels originating from the louvers will create more noise and will be the limiting factor in complying with county ordinances.

In Table 9, from the previous section, the assumed average sound pressure levels in the mechanical room are presented. 88dB is the assumed noise level intensity in the mechanical space. Starting with the noise reduction formula:

$$NR = L_1 - L_2$$

L_1 is the noise intensity level at the IPEC (88 dB).

L_2 is the noise intensity level experienced at the nearest property line from the IPEC (minimum of 55dB).

NR is the difference in sound levels between the two places.

Plugging in L_1 and L_2, we get that the noise reduction (NR) has to be a minimum of 33dB to satisfy county sound ordinances. Then, the inverse-square law and noise reduction as a function of sound intensity can be combined to derive a relationship between noise reduction and the distance a listener is from a source. Below is an equation representing this and was used from the text *Architectural Acoustics* by M. David Egan.

$$NR = 20\log(\frac{d_2}{d_1})$$

d_2 is the distance from the IPEC to the nearest property line

d_1 is the distance from the IPEC to an arbitrary point chosen to be 1ft. from the IPEC.

d_2 is estimated to be approximately 60 feet. When d_2 and d_1 are plugged into this equation, a noise reduction of 35 dB occurs. This noise reduction should just barely satisfy the county ordnance. However, because the assumptions used in this calculation were over conservative, the sound pressure levels from the IPEC should fall within county ordinance.

From Mechanical Penthouse

Because the penthouse will be approximately the same distance from the property line and have similar noise levels leaving to the environment as the IPEC, the resulting noise level at the property line will have about the same 35 dB noise reduction as calculated from above. This is because the noise level leaving the exterior louvers on the penthouse were over estimated to be the same as inside (similar to the IPEC). This estimate will be more accurate for the mechanical penthouse because the sound will not be traveling through plenums (the farther sound travels the less intense it becomes). In conclusion, the sound from the mechanical penthouse will also comply with the county's noise ordinance of 55 dB measured at any property line.

Environmental Impact Conclusion

Both the IPEC and penthouse are estimated to produce a noise level of about 57 dB at the closest property line at 60 feet. The actual noise levels experienced here may be smaller, but the 57 dB was a result of over estimates. Either system should meet the 55 dB noise ordinance regulated by county officials.

Acoustical Conclusions

When checking each system (the IPEC and mechanical penthouse) for noise compliance and nuisance levels, it was concluded that both would be acoustically acceptable mechanical room solutions. More specifically, the IPEC will most likely create less noise level and vibration impacts because it is raised above the structural roof and has air plenums to act as sound buffer zones. The mechanical penthouse will generally pass more sound to the environment and into the conference room because its' closer proximity to the building. However, it is important to note that if a mechanical penthouse would be chosen, vibrations and noise penetrations through other spaces, other than the staff conference room, need to be carefully considered.

Maintenance

In total there are 15 county libraries in this county's jurisdiction. In speaking with the owner, none of these libraries have similar mechanical systems. Maintenance crews are broken up by county area and not by specific building function. Maintenance personnel assigned to this library are also assigned to other county buildings in this general area. This library is the first county building to incorporate an IPEC into its design. In this case, the IPEC is in a pilot program, meaning the designers and county are trying out an IPEC system to determine if it can be successfully implemented on other county projects. If the IPEC goes well on this project, the county and designers may use similar IPEC units in future projects.

The IPEC is new to the county's collection of buildings, and therefore is a concern to involving specific maintenance staff training. If this is the case, more time and money will be spent training the maintenance staff than originally planned. However, the contractor and owner were reassuring that both an IPEC and mechanical penthouse will require the same amount of training for the maintenance staff. This is farther reinforced by the owner and designer in selecting mechanical equipment that is typical and not overly complex.

Because the equipment selected is typical and the similarities in the estimated required training efforts, the maintenance criteria should not significantly affect the mechanical room decision. Therefore, in this consideration, either the IPEC or penthouse would both be buyable options.

Flexibility in Design

Design flexibility was a concern as well. The less flexible a design is, the harder and less cost effective it becomes in incorporating into a building. The flexibility of an IPEC is dependent on the supplier's equipment they can use. However, in most cases the IPEC can be built as a more compact system than a penthouse. But, the flexibility may be lost this very tightly built mechanical room (IPEC). For example, air handling units in IPECs may only be offered in 10,000 CFM (cubic feet per minute) intervals, while a designer designing a penthouse may have the option to specify air handling units in 5,000 CFM intervals. This could result in overdesigned capacity, therefore directly increasing costs as compared to a penthouse with more flexibility.

The designer and owner were able to select which equipment they wanted in the IPEC, which means this supplier offers flexible options. The supplier said that there IPEC systems are almost completely customizable. More specifically, the supplier has preselected equipment providers lined up and who are willing to work with design teams to allow the most flexibility. These equipment suppliers have worked with the IPEC manufacture in past projects and have equipment that easily fits an IPEC design. The IPEC supplier on this project offers more customized and flexible options than a supplier that manufactures and uses their own equipment.

In the end, a mechanical penthouse will always offer more flexibility in equipment selection and layout than an IPEC. The design professionals can hand select equipment suppliers they feel comfortable with or have good relationships with. Even though the IPEC was very customizable on this project, a mechanical penthouse can still be more flexible and dynamic. To an unexperienced MEP designer, the flexibility of an IPEC may be beneficial, but for a MEP design-build firm, a penthouse will offer more benefits and flexibility.

Responsibility

Who is responsible for the mechanical equipment design, procurement, installation, and testing? Is this party capable and trust worthy of this responsibility? These are questions that must be asked by the designer and owner when considering which mechanical equipment room type to choose. In the procurement of the IPEC, there have been coordination and submittal problems which need sorted out with the supplier. In this case, the IPEC was chosen without input from a contractor because the project is design-bid-build. Had it been an early involvement project, the contractor may have tried to convince the designer to use a penthouse because this option allows the contractor to control the construction installation of equipment instead of relying on a third part supplier. With an IPEC, the contractor must rely on the supplier for things such as coordination documents, aligning shipping dates, aligning delivery schedules, confirming pricing, and much more. If the contractor is able and accepting of this risk, using a penthouse could eliminate the third party supplier, allowing the contractor to perform these roles. However, if designers feel a contractor is incapable of managing the penthouse installation properly, an IPEC may be a better option. The IPEC supplier also offers installation assistance in knowledgeable personnel present during arrival and placement.

On this project, the contractor seems capable and willing to accept the risks of a mechanical penthouse. A penthouse would have been an acceptable option and would be preferred by the contractor on this project.

Constructability

A choice between an IPEC and a penthouse will be noticeably different during construction. The IPEC will be assembled in the supplier's warehouse facility. The environment of this facility can be controlled while wastes can be minimized. In almost cases, prefabrication can result in a cleaner working environment, resulting in less accidents and increased productivity. Trash can get in the way and cause safety concerns on an active jobsite.

On this project, a penthouse construction would require all trades to take materials and equipment to the penthouse level (sixth floor). This alone will cut production for trades for the penthouse. All trades must be properly coordinated and sequenced in penthouse construction because space is limited and production could come to a halt if the space becomes over crowded. On the other hand, the IPEC will require precise coordination of its' base and any pipe, duct, or wires connecting to it. Such coordination requires full cooperation and communication of the contractor and IPEC supplier.

Construction tolerances are also a constructability concern. This is because site built tolerances (penthouses) are greater than in a prefabrication shops (IPEC). A lower tolerance means more "stuff" can be designed into the same space without clashes during construction. In a penthouse construction, tolerances will be considerably larger than in an IPEC and therefore must be properly coordinated in design.

The library's site should be big enough to support a penthouse installation, according to the owner and contractor. Both an IPEC and penthouse have their respective constructability concerns. However, these constructability concerns should not be an issue if planned and managed properly.

Costs

Overall costs will be one of the biggest deciding factors in determining which rooftop mechanical room to use. Similar equipment will be used and therefore costs of specific mechanical equipment will remain the same between an IPEC and a penthouse. However, the cost information provided by the project team only broke IPEC costs up into two line items (total cost of IPEC and supporting systems). If the equipment cost were broken down farther, a comparison could be performed between the estimated equipment procured by a MEP design-builder and the IPEC supplier. Because this is not the case, total costs will be compared.

There are a few challenges in comparing cost of these mechanical room enclosures. One is the difference between site labor and shop labor. Shop labor's costs and productivity are unknown. However, field labor estimates will be performed in this section. The other challenge is in determining how much of a "good deal" the supplier is offering for this project. The supplier claims to get their equipment at wholesale pricing from manufacturers. It is unknown exactly how much of this savings is shared with the contractor and owner. Because IPEC systems are only offered by a handful of companies, and each supplier's IPEC is very different from one another, the supplier could be charging a premium for their product, with no way to compare these costs to other suppliers equally. If the designers specify three or more suppliers, then this should create competitive pricing. However, the designers would not approve other suppliers, other than the basis of design. This could have caused the supplier to charge more for their product.

Equipment costs for the penthouse were taken partially from Technical Assignment II and can be found in *Appendix L*. The equipment costs should be almost the same for the IPEC and penthouse. The estimated enclosure and structural costs for a penthouse construction can be seen in *Appendix M*. Table 15 shows a comparison of the estimated equipment, enclosure, and structural costs of the penthouse and of the actual IPEC costs. According to this estimate, the penthouse option may cost $1 million less than the IPEC.

Table 15 – IPEC vs. Mechanical Penthouse Costs

System	Equipment	Enclosure/ Structure	Total
IPEC	$5,800,000	$50,000	**$5,850,000**
Penthouse	$4,880,000	$100,000	**$4,880,000**

The cost differences for equipment may be the supplier's profit margin, the supplier charging a premium for their IPEC, or simply differences in the supplier's cost and the estimate values. For the enclosure and structure portion of the estimate, the difference of $50,000 is reasonable because a penthouse structure should cost more due to the nature of the onsite construction and the materials used, such as galvanized steel and PVC membrane roofing.

For this project, the penthouse would be recommended (cost considerations) because this system is less specialized and may experience cost savings by shopping around and comparing equipment to receive the best deal. A MEP design-build company could have helped with early estimates of penthouse systems to make this option more valuable. An IPEC could still have been estimated and considered in designing MEP systems. If unexpected or unforeseen costs, not included in this analysis, would have been noted by the MEP design-builder, then the IPEC option could be revisited and re-estimated during design.

Schedule

It is challenging to compare an IPEC and a penthouse construction using schedule. A penthouse will certainly take longer onsite than an IPEC because the IPEC will only take a few days onsite to install once delivered. Overall, shop productivity is more productive than onsite because needed material is fully stoked and is close by. Also, lead times for each option are drastically different. An IPEC requires a long lead time of months because the large scale and quantity of pieces to be assembled. On the other hand, a penthouse has lead time many smaller lead times of a few weeks. This is because the penthouse pieces are produced and procured individually rather than all at once from one supplier. All these individual lead times could be challenging to manage on a penthouse construction.

Estimated productivity and reasonable numbers of crews were used to calculate the estimated duration of a penthouse construction. See *Appendix N* for a detailed calculation of the equipment, structure, and enclosure durations using the same assemblies as the cost estimations. As seen in Table 16, the total duration of the penthouse construction will be 10.5 weeks. This is compared to one week duration of IPEC installation.

Table 16 –Mechanical Penthouse Schedule

Equipment	Enclosure/ Structure	Total
7.5 weeks	3 weeks	**10.5 weeks**

An addition of over 10 weeks of onsite construction would negatively affect the already delayed project schedule. However, if a penthouse was planned and incorporated into the baseline schedule, this addition would not have significantly impacted the completion date. Ideally the IPEC should positively impact the schedule, therefore reducing general condition costs and increasing site productivity.

Comparison

Table 17 shows a summary of how the IPEC and penthouse options rated in each of the above categories. Both have negatives and positives associated with their specific needs and requirements.

Table 17 – IPEC vs. Mechanical Penthouse

Criteria & Categories	IPEC	Mechanical Penthouse
Acoustical	✓	✓
Maintenance	x	✓
Flexibility in Design	x	✓
Responsibility	✓	✓

Constructability	✓	✓
Costs	x	✓
Schedule	✓	x

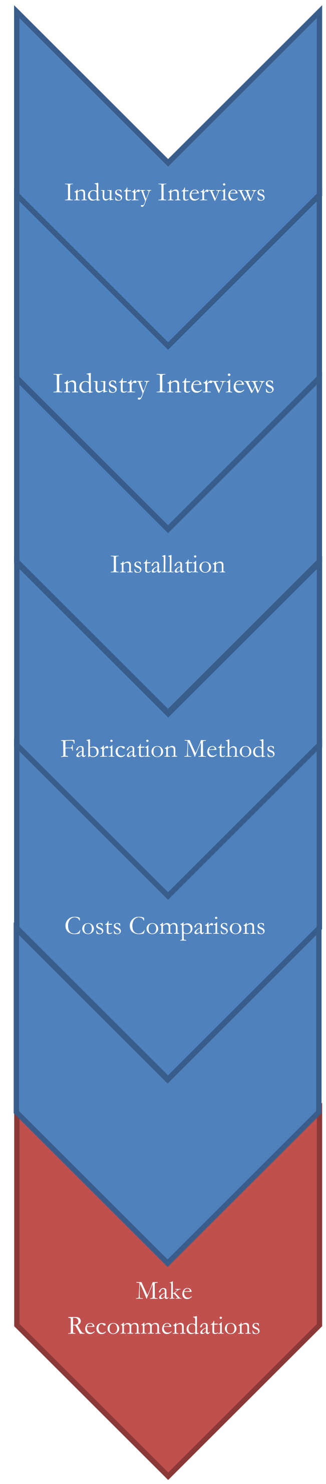
Recommendations

In analyzing the differences between an IPEC and a mechanical penthouse, each of the above categories were carefully considered. Acoustically the two options were the same, except the penthouse may be slightly noisier and affect more of the library space. An IPEC would create maintenance problems because none of the county's other buildings have a system like similar to the IPEC. A penthouse would give the designers more flexibility in their design. Both systems have constructability concerns, but the penthouse would use more space onsite. According to the assembly estimates, a penthouse would cost about $1 million less than the IPEC. Lastly, the schedule would be negatively impacting with a penthouse construction because this would require more onsite labor.

In conclusion, a MEP design-build company could have provided a penthouse mechanical room that would have met the owner's needs while saving money but negatively impacting the schedule. The owner would likely accept this trade off. Because these two systems have their pros and cons, the project team must weigh the above categories, keeping in mind team and owner values and goals. For this library project, it is recommended that a rooftop mechanical penthouse be used.

As part of this analysis, a decision tree was produced to aid owners and designers in considering their options and laying out when to use an IPEC verses a penthouse. This decision tree can be found in *Appendix O*.

Analysis Topic 4- Caisson Rebar Cage Fabrication



Goals

Primarily, the goal of this analysis is to analysis which types of fabrication methods are acceptable for rebar cages made for caissons of varying diameters and depths to minimize wasted costs and schedule delays. The library project experienced delays in the critical path because the caisson installation took longer than expected. The design of each cage, there connections, load bearing capacities, and drilling considerations will affect the method of fabrication chosen. A brief area of this analysis will also look into cage placement.

Background

Delays were caused by the caisson installation early in this library's construction. Estimated caisson depths were given to the contractor while bidding the project for budgeting purposes. When the contractor was awarded the project, the estimated caisson depths were used to prefabricate rebar cages for the caissons. As the drilling rig drilled a few caisson holes, the contractor realized the given depths were by no means an accurate estimate. Every caisson varied from their planned depth because the caissons must be drilled to a depth which results in proper bearing capacity. As a result, every prefabricated rebar cage required some amount of refabricating on site to add or delete length. The schedule was impacted by a 15 day delay with lower productivity in installing the caissons.

Interviews

Ray Sowers of OPP was interviewed to gain his input on caisson installation processes. According to Ray, delays in caisson installations are common. Caisson installation requires a large amount of front end work in planning and controlling risks. A contractor should avoid unclassified site conditions if at all possible. Unclassified sites are more risky for contractors and foundation installers than classified site conditions because an unclassified site means little or no geotechnical work has been done to verify foundation depths and subsoil conditions. Contractors will bid a project based on the given estimated caisson lengths with an allowance for uncertainty included in their price. If actual depths start to consistently run 10% over the estimated depths, then contractors would typically start to claim this as a change order to the owner and request farther compensation.

Also, a drilling company in Baltimore, MD was interviews and asked a serious of question about their experience in the metropolitan Washington, D.C. area. This company was familiar with the types of rock formations found in this area and specifics of this interview were incorporated into the *Installation Specifics* section below.

Installation Specifics

Planning and Design

The contractor bids the project with values given by the structural and geotechnical engineers. Multiple drilling companies submit bids to the general contractor based on owner conditions, or they may even work directly with the project engineers. At this stage geotechnical reports may have estimated depths or very accurate test boring records. Highly detailed test boring records are favored by the contractor to better understand subsoil conditions. Each caisson has a load in which it must sufficiently carry to support its' share of the building's load.

Drilling

Drilling is the most time consuming and costly part of the caisson installation. Typical caisson diameters range from 18" to 72". On this project caissons were 30", 48", 60", and 72". Larger holes need larger and more expensive machinery while taking longer durations to drill. Two of the biggest considerations for drillers are site accessibility and rock type (rock formations) because very specialized machinery may be required for certain types of rock. The amount and type of rock will also determine the drill speed and type of bit needed. Hard layers of rock may need percussion tools, in which are very expensive, but break up rock quickly. On this project, drilling rig access was not an issue. In the metropolitan Washington, D.C. area there are layers of weathered and decomposed rock formations that maybe very hard and durable in some areas but softer layers with low bearing capacities in other areas or layers. In this type of area, "good rock" (rock of proper bearing capacity) may be 20 feet deep in one area and 30 feet deep in just 20 feet away.

Key drilling price influencers are soil material and shaft diameter. Rock is substantially more costly and time consuming to remove. A good stable soil with clay and some decomposed rock can typically be drilled at a rate of 100 feet to 200 feet per day for a 4 feet diameter shaft. Harder soil with rock could slow productivity down to seven or even six feet per day. Contractors and drillers bid a job with estimated lengths of rock and soil to remove. Any additions or subtractions are based on a predetermined unit price per linear foot.

Accurate duration estimations for caisson installations are very difficult to account for and therefore are typically either over estimated or cause delays on the project. Experience is the key for estimating caisson durations. Project managers must look at local records from projects in close proximity for boring and drilling records. Careful review of test borings can play another key role in duration calculations. Also, it is important to read the project specifications thoroughly and accurately to properly account for rock sockets and required inspections. Delays start to accumulate if shafts are required to go deeper than expected, weather is bad, or hauling gets tied up or requires special permitting. These may be partial reasons why the caissons caused delays on this project.

Drilling should take place while highly skilled and experience personnel are on site to ensure a smooth drilling process and so that decisions can be made quickly. Typically, it is good practice to have the driller, superintendent, competent soil engineer from inspection agency, and any owner required inspectors on site while drilling operations are underway.

Rebar Cages and Concrete Placement

To ensure a caisson is of proper durability and bearing strength, rebar cages and concrete should be placed immediately after drilling to minimize soil and water seepage into shafts.

Rebar cages are, often times, partially or entirely prefabricated off-site to increase caisson installation productivity. Traditionally, it has been cheaper and easier to shorten cages with cut-off wheels than it has been to add rebar onto bottoms or tops of cages. This is because adding rebar is less productive and less cost effective than cutting off unneeded lengths. Cut-offs can also be used elsewhere in other caissons if needed. Lengths of cages can be between 30 and 60 feet because lifting and maneuvering can bend rebar if cages are too long and heavy. It is believed that rebar cage altercations caused the remaining delays on this project.

Pumps are typically used to place concrete so that the concrete gets to the bottom of the shaft with minimal segregation. Segregation of concrete aggregate can cause concrete to fail prematurely without reaching its' full bearing capacity. Also, weather can hinder concrete deliveries because concrete plants cancel scheduled deliveries in snow storms and other major weather event. This could quickly seize caisson installed production.

Fabrication Methods

To pick an appropriate fabrication method, details of the caissons were studied to find, sizes, depths and rebar cage construction specifics. In looking for similarities in caisson types, all caissons on this project could be broken up into nine different caisson construction types. Table 18 shows specific details of each caisson type. In *Appendix* P, on the Caisson Information Table, a more detailed break up of which caissons fall with-in each type of construction is shown including; each of their diameters, installation dates, planned depths, actual depths, rebar information, and whether or not the caisson has uplift.

Table 18 – Caisson Types

Type	Vertical Rebar #	Qty. of Vertical Rebar	Tie #	# of Ties per LF	Weight of Vertical Rebar (lb/LF)	Weight of Ties (lb/LF)
1a	9	8	4	1	27	6
1b	9	6	4	1	20	6
2a	11	8	4	1	43	9
2b	11	12	4	1	64	11
2c	11	16	4	1	85	13
2d	11	24	4	1	128	15
2e	11	28	5	1	149	21
2f	11	16	4	2	85	27
2g	11	28	5	2	149	41

A case study to compare to this project was not found so detailed analyzes of this building's caissons were performed. Currently, the caissons were 100% prefabricated for the planned (estimated) depth and then added or cut off of depending on specific needed depths (this will be referred to as the baseline method). It will be assumed that when the bearing capacity is met, the driller can stop, and this will be the depth of the caisson. This and other fabrication methods will be discussed in farther detail later in this report.

Figure 20: Typical Mechanical Rebar Splice

Picture from
http://news.thomasnet.com/company_detail.html?cid=31946&sa=10

Assumptions

The assumptions incorporated into this analysis will be laid out in this section. First, all caisson lengths were rounded to the nearest foot when used in calculations performed in this analysis. To determine if lap or mechanical slices were used, an industry recommended estimate was established (Lap slices can be used on bar sizes of less than #11, while any bar size #11 or over and/or any caisson having uplift will need mechanical splicing). A lap slice must be 36 bar diameters or more which was included in the cost of these slices. Lap splices where calculated using a #9 rebar overlapped 40" at an extra rebar cost of $.85 per pound, and equals a total of $9.78 per splice. Mechanical slices were assumed to be a standard transition self-aligning type with tap threads and cost $63.20 per slice (see Figure 20). Each vertical rebar in cages will be spliced at the same location. Each of these locations are called a splice set in this analysis, which occures in each area a cage is slipced (cost per slice mulipled by the number of vertical rebars is equivilent to the cost per splice set). All rebar costs in this anaylsis were priced using the rebar for columns portion of RSMeans. Prefabrication unit costs will be estimated as the same as site fabrication costs. Site fabrication costs will accually be slightly higher than prefabrication costs, but for comparison purposes, they were set equal for the purpose of this analysis. See the Unit Costs Calculation Table in Appendix P for a detailed unit cost breakdown of each caisson by type.

To setting up and define this analysis wasted costs will be compared because each caisson was a different length and therefore a different cost. Also, it will be valuable to see, on average, which fabrication method wasted the least costs (unneeded rebar and splices). Such unneeded rebar or splices would result in cutting off cages prefabricated too long or adding slices that would not have been needed if actual depths were known. An added length of rebar will not be counted towards wasted costs because this length would have been needed if the actual depths were known anyway. Additionally, if splices and rebar lengths were cut off because a cage was too long, then these would be wasted or unneeded costs. Table 19 shows this in a graphical representation. On a side note, it was assumed that no rebar cage sections could be prefabricated over lengths of 30 feet to make shipping and maneuver on site more manageable. These 30 feet sections will be lifted by a medium sized truck crane that will remain on the project for its' entire duration (provided by the contractor). This will not require additional equipment to be brought onsite specifically for caissons cage installation. Long or heavy loads would require special permitting and special lifting equipment introducing costs and unneeded constructability concerns to the caisson process. Also, the largest cage will be 6 feet in diameter which is smaller than the typical flatbed truck width of 8 feet, so the widths of these cages should not cause shipping issues.

Table 19 – Wasted Costs Classifications

Object	Required Cost	Unneeded or Wasted Cost
Length of Rebar	Addition to length of rebar cage	Cut off or length reduced
Splice	Splice between cage sections(30' sections) or at top of cages	Cut off splice or slice resulting of an addition (would not have been there otherwise)

Base line

For this project, cages were prefabricated to 100% of the planned depth and altered once the actual depths were known. Caisson shafts were stopped at appropriate bearing capacity, which in most cases was shorter than their planned depth. This means a lot of rebar was cut from the cages before installation. A total wasted rebar length and splice costs were calculated for each caisson and organized by type in the Prefabricated 100% of Planned Wasted Costs Table in *Appendix* P. A wasted cost total for this project and this fabrication method was estimated to be $22,900. Multiple places in the fabrication method analyses are orange highlighted boxes that represent rebar cage lengths that were cut off as wasted lengths and reused as added lengths to other cages. This brought the overall wasted costs down from each fabrication method. This method will be compared to other methods in Table 20 at the end of this section.

Over Estimate (+10%)

In this fabrication method, rebar cages would be prefabricated at 110% of the planned depth. Details of this method can be found in the Prefabricate Additional 10% of Planned Length Wasted Costs Table in *Appendix P* as well. A wasted cost total for this project and this fabrication method was estimated to be $32,300. If the actual depths would have been larger than planned, then the 10% over estimate would have been more appropriate. Because the actual depths were less than planned, this overestimate actually raised the wasted costs from the baseline method.

80% of Estimated

Instead of adding length to the prefabricated sections, this method cuts the prefabricated cage lengths down by 20% or 80% of the planned length. Again, details of this method can be found in the Prefabricate 80% of Planned Lengths Wasted Costs Table in *Appendix P*. The total wasted cost of this method was estimated to be $23,400; $500 less than the base line method. This method lowered costs because, the actual depth were less than planned. Wasted costs did not substantially decrease because splice costs kept overall wasted costs almost the same as the baseline.

10' Cage Sections

Instead of cutting planned lengths down, this method looks at prefabricating a serious of 10 foot cage sections of each caisson type for lighter lifting and hauling apparatuses and to increase prefabrication productivity with only one length of cage. These sections could then be combined together and excess could simply be cut off. The Prefabricated 10' Cage Length Wasted Costs Table can also be found in *Appendix* P. For this method, the wasted costs jumped to $51,500. The majority of this increase was from splices. Because every caisson will be sliced in 10 feet increments, the splice costs jumped quickly.

15' Cage Sections

As an alternative to the 10 foot cage sections, a 15 feet cage section analysis was also performed, with details in the 15' Cage Length Wasted Costs Table in *Appendix* P. The wasted costs of this method dropped back down to $21,700, as expected. This is because the splice cost fell; again playing a key role in the total wasted costs. This option seems to be more practical than the 10 feet section method discussed previously.

Cost Comparisons

A cost summery broken down by caisson type was provided at the end of *Appendix* P for comparison purposes. A quick summary of these results are included here in Table 20.

Table 20 Prefabrication Option Comparison					
Caisson Types	Base Line	Over 10% Prefab Estimation	Prefab 80% of Estimation	10' Length Sections	15' Length Sections
1a	$ 1,207.13	$ 2,018.26	$ 580.70	$ 2,545.31	$ 1, 040.01
1b	$ 1,756.59	$ 2,059.49	$ 993.63	$ 579.61	$ 285.71
2a	$ 2,313.82	$ 2,827.37	$ 1,856.53	$ 3,661.62	$ 1,512.15
2b	$ 1,845.69	$ 2,300.02	$ 937.03	$ 2,177.57	$ 260.10
2c	$ -	$ -	$ -	$ 2,022.40	$ 1,011.20
2d	$ 1,516.80	$ -	$ 1,516.80	$ 3,033.60	$ 1,516.80
2e	$ 12,484.19	$12,139.79	$ 13,377.24	$ 33,762.24	$ 15,289.27
2f	$ -	$ 243.22	$ 3,024.00	$ 3,725.88	$ -
2g	$ 1,827.72	$ 2,183.29	$ 1,116.59	$ -	$ 808.19
Grand Totals	**$ 22,951.94**	**$ 32,329.00**	**$ 23,402.52**	**$ 51,508.23**	**$ 21,723.43**

It is important to understand that the above data is a representation of results experienced in this specific project, for this geographical location, and this site. These recommendations and conclusions may not be universally used on other projects without detailed site evaluations. Also, it would be challenging to estimate the amount of reusable cutoffs generated on a project before actually drilling the caisson shafts.

Table 20 also shows which fabrication methods had the lowest wasted cost per caisson type. In smaller diameter caissons (types 1a, 1b, 2a, and 2b), it seems that 15' section lengths was more cost effective. In larger diameter caissons (types 2c through 2g), it seems that the baseline or a 10% extra prefabrication length may entail more cost savings. Overall the 15' section length method was slightly less wasteful because this method produced a large quantity of cut off cage lengths that could be reused elsewhere. However, the base line, 80% of planned length, and 15' section length methods were not different enough to cost saving to make a clear cut choice in fabrication methods.

For this analysis, it is concluded that a large decrease in prefabricated length will drastically increase the number of slice connections. Unnecessary splice connections can quickly increase wasted costs and make prefabricating small cage sections undesirable.

Schedule

Site labor verses prefabrication plant labor will have varying levels of productivity. The exact productivity of each is unknown because each prefabrication method could have different productivity and output rates. A large amount of variables affect site labor. Slow drilling can keep fabrication crews weighting, but fast drills may swamp fabrication crews while keeping the drilling rig idle. The balance of drilling and fabricating is very unique and requires careful consideration when planning and managing a project with caissons.

In general, fabrication crews can be more productive and have less duration per rebar cage if they are cutting rebar instead of adding. This is because cut offs take less time than slicing an additional length of rebar onto cages. With this in mind, the method involving the least amount of slicing would be more productive on site minimizing delays resulting from rebar cage rework.

Because most rebar cages were shorter than planned, it is believed that an unrealistic duration of drilling and caisson installation was used in the baseline schedule. Denser and more solid rock was encountered at shallower depths than originally planned, as well. This also is believed to have created the majority of the delays because rock is far more time consuming to remove than softer soils such as sand, clay and gravel.

After having consulting with industry members from this geographic location, it would be a safe assumption to estimate a drilling productivity of 80 feet of 3 feet diameter caisson per day assuming low quantities of rock were encountered.

Recommendations

Table 21 Prefabrication Option Comparison

Comparisons	Base Line	Over 10% Prefab Estimation	Prefab 80% of Estimation	10' Length Sections	15' Length Sections
Costs	✓	x	✓	x	✓
Schedule	✓	✓	x	x	x

For the purpose of this report, it was assumed that any rebar #11 and over were to be mechanical sliced, while smaller bars were to be lap sliced as described previously. A max prefabricated cage length was set at 30 feet. This was to allow ease of transportation and onsite maneuvering of the cages by the medium sized truck crane stationed onsite. Overall, the design of the rebar cages will not change between fabrication methods. The only variable that will change, and that was analyzed in this report, is the number of splices required and length of rebar added/ removed from cages.

Cost and schedule recommendations are as follows. The original baseline fabrication method was the best choice in comparing costs and schedule equally (as seen in Table 21). Wasted costs were not the lowest in this method, but only differed by $2,000 from the 15' cage sections method. However, the baseline method seemed to have the most potential positive impact on schedule. This is because a higher productivity of cutting off rebar can be achieved over adding rebar and splices to cages. Interestingly enough, the base line method points to a shorter and more productive schedule, but this project was still delayed by two to three weeks in the caisson installation. This can be explained in that larger quantities of rock was removed from shafts than originally anticipated, and caisson installation can be complex in nature, in turn typically causing delays on most projects. If a fabrication method, other than the baseline, was used, potential delays could have been larger than three weeks. In other words, overestimate caisson installation schedules to accommodate the unknown factors that may impact drilling and the overall installation process.

Final Conclusions and Recommendations

Research Analysis Topic 1- Early Involvement in Design

Every project is different and things that what work for one project may not work for another. This analysis looked at norms to gain a better understanding of early involvement projects and look at considerations for implementing such involvement on this library project.

Upfront Decisions

Implementing early involvement type contracts onto a project should be discussed very early in the programmatic stages of a project. An experienced owner may have more background in early involvement decisions. Inexperienced owners may be unfamiliar with early involvement and should seek assistance with decisions from a Construction Management Agent or a design team. Owners need to put time and dedication into a project in order to implement early involvement. Owners should also be able to make quick decisions, stick with their decisions, and be educated in construction. Construction personnel feedback should be used throughout design. Funding for early involvement project is sometimes a concern. State and government projects may have trouble using early involvement. Owners should weigh their available resources for a project because early involvement requires owners to be actively involvement throughout the project and have a high degree of commitment.

The construction costs and schedule could be drastically reduced with early involvement. Selling points of early involvement tied into substantial cost savings. This is because the design is more constructible with fewer change orders and less rework. This has the penitential of saving 6% in Unit Costs, according to the DBIA. Fast tracking a project also becomes easier to perform if the contractor is involvement upfront.

The county should have the experience needed to be successful in implementing early involvement on this project, because they already have a full time project representative stationed onsite. Fast-tracking is not a concern for this owner, but could have the benefit of saving construction cost, reducing change orders, and mitigating delays. Funding could be an issue for the county because this project is partially state funded.

DBIA offers a variety of educational classes ranging from Owner Boot Camps to BIM Execution Planning for industry members wishing to learn more about early involvement. Detailed lists of classes and seminars can be found at DBIA's website http://www.dbia.org/education/Pages/Schedule-at-a-Glance.aspx.

Scope Decisions

Every project has different requirements, which will lead to different early involvement scope selection. Things to consider are; which parties to include, what level of involvement, and when they will the involvement. Every project using early involvement should have a general contractor or such on board throughout design. It is important to carefully pick the trades to include on early involvement projects. A good rule of thumb is to involve trades that include significant costs or complexities. The MEP systems, structural system, and curtain wall could have been early involvement areas for this project because these trades have been identified as problematic. More complex scopes will have greater amounts of involvement in design. See Table 3, on page 18, for project specific recommendations for this project. A contractor should be brought onboard in the Programming phase. MEP trades are recommended to be involved in Conceptual Design. Steel erectors should be included in the project in Design Development. Curtain wall trades could be brought on board in the Schematic Design phase. Time frame inclusion should be based on specific project needs.

Analysis Topic 2- Structural Steel Sequencing

This analysis looked at comparing the current top-down sequence to an alternative shoring sequence to weigh complexity, costs, schedule, site, safety, and other trade impacts. The top-down and the shoring sequences must be compared equally to make recommendations. In complexity, the shoring option is less complex, easier to follow, and creates a better flow of work. In terms of schedule, the shoring option saves 3 weeks of critical path, and comes closer to meeting the original erection schedule dates. The shoring option is $30,000 less than the top-down sequence because of its' schedule savings. This cost savings is not large enough to affect the final decision. The top-down method will allow for a more spacious site. There will be less safety risks in the shoring option because of the nature of the penetration welds needed on a few trusses. MEP rough-in and masonry work can start earlier on the top-down option, but overall trade productivity will be higher in the shoring option because the overall schedule is reduced. In conclusion, the benefits of using a shoring system in the structural sequence would outweigh any negatives associated with it. For this project, the shoring sequence is recommended.

Structural Breadth- Shoring System Design

Refer to *Appendix* B for all calculations related to this breadth topic. This breadth focused on sizing, picking, and pricing a shoring system for the shoring option sequence. A load of 291 psf will need to be supported by the chosen shoring system. Mabey assures that their Mass 25 shoring system can adequately support 100 kips when assembled into 26 feet shoring towers. Using a spacing of 20'x18', the load estimated on each shoring tower will always be less than 105 kips. This should safely support the construct of the steel over the train stop before making truss connections.

Analysis Topic 3- Mechanical Penthouse vs. IPEC

Acoustical Breadth- Mechanical Room Noise Impacts

This breadth topic looked at acoustical impacts on the building occupants and the environment around the building of the IPEC and switching this system to a mechanical penthouse construction. County ordinances of 55 dB at any property line needed to be met by either system. In the library, a conference room was determined to be the critical space impacted by either mechanical room. Noise levels from mechanical equipment (A-Weighted) in this space should not exceed 35 dB. In performing numerous acoustical calculations, both systems produced 2 dB over the allowed property line measurement and the conference room space noise levels. This should not be an issue because calculations performed in this breadth are believed to be over conservative. Therefore, both mechanical rooms would be acoustically acceptable solutions. Specifically, the IPEC will likely create less noise levels and vibration impacts because it's raised above the structural roof and has air plenums to act as sound buffer zones. The mechanical penthouse will pass more sound to the environment and into the conference room because it is closer to the building. If a mechanical penthouse would be chosen, vibrations and noise penetrations through other spaces, other than the staff conference room, would need to be carefully considered.

Mechanical Penthouse vs. IPEC

This analysis looked at the differences between an IPEC and a penthouse construction in comparing maintenance concerns, flexibility of design, responsibility, constructability, costs, and schedule. An IPEC would create maintenance problems because none of the county's buildings have a system like this. A penthouse would give the designers more flexibility in their design. Both systems have constructability concerns, but the penthouse would use more onsite space. From the assembly estimates, a penthouse may cost about $1 million less than the IPEC. Lastly, the schedule would be negatively impacting with a penthouse construction because the requirement of a 10 week onsite construction for this system. In conclusion, a MEP design-build company could have provided a penthouse mechanical room meeting owner needs while saving money but hurting the schedule. The project team would need to weigh the above categories to properly make a decision. For this library project, it is recommended that a rooftop mechanical penthouse be used. As part of this analysis, a decision tree was produced to aid owners and designers in considering their options and can be found in *Appendix O*.

Analysis Topic 4- Caisson Rebar Cage Fabrication

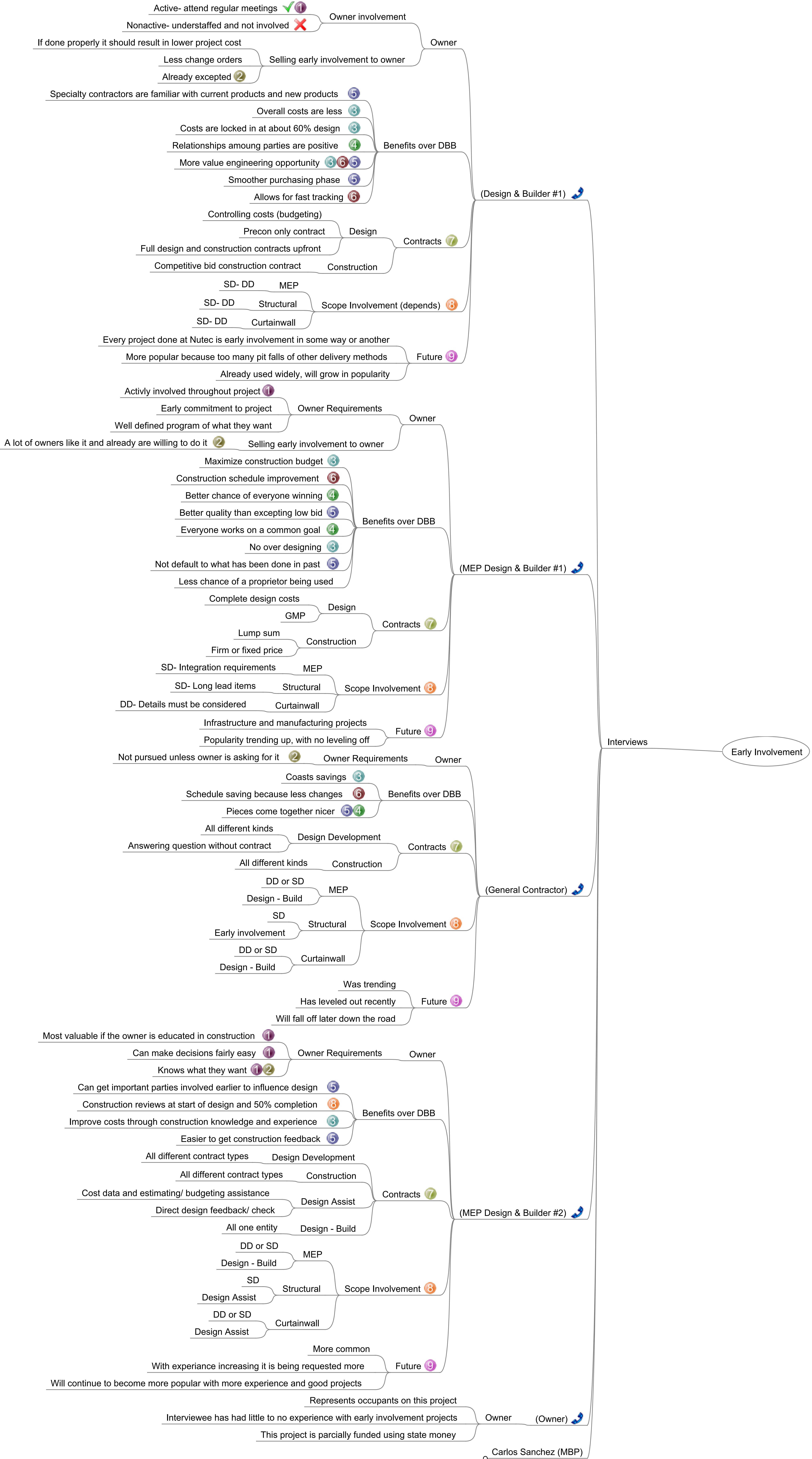
This analysis looked at comparing rebar cage fabrication and installation methods to minimize wasted costs and schedule delays. It was assumed that any rebar #11 and over will be mechanical sliced, while smaller bars were will be lap sliced. A max prefabricated cage length was set at 30 feet. This was to allow ease of transportation and onsite maneuvering of the cages. The design of the rebar cages will not change between fabrication methods. The number of splices required and length of rebar added/ removed from cages will change significantly between fabricating methods and was the key player in this analysis.

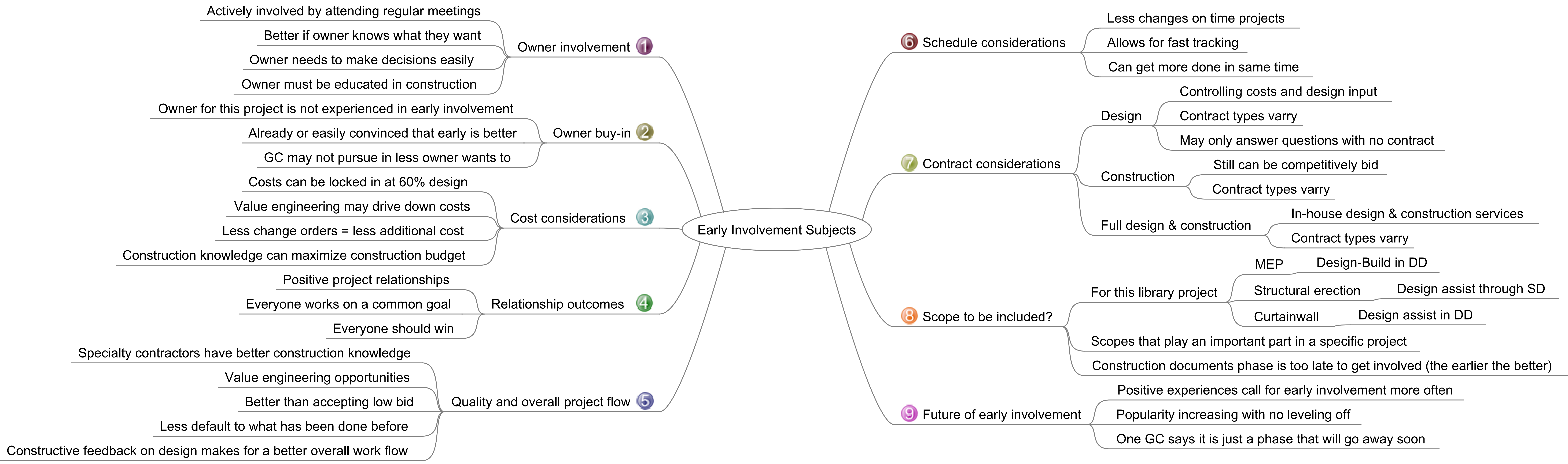
The original baseline fabrication method was the best choice in comparing costs and schedule (prefabricating 100% of the planned rebar cage lengths). Wasted costs were not the lowest in this method, but this method would be more practical than the 15' cage section method. The baseline method had the most potential positive impact to the schedule. This is because a higher productivity can be achieved by cutting off rebar than adding rebar and splices to cages. The base line method may have the shortest and most productive schedule, but this project was still delayed by three weeks in caisson installation. Larger quantities of rock were removed than originally anticipated. Typically, caisson installation causes delays on most projects. If the baseline method was not used, potential delays could have been larger than three weeks and wasted costs would have been higher. For this project, it is recommended to use the baseline fabrication method and to always overestimate caisson installation schedules in accommodating for unknowns.

Closing Remarks

As discussed above, it is recommended that the project team on this library project use early involvement, a shoring structural sequence approach, a penthouse mechanical room, and the baseline caisson fabrication method. In all, these changes could have saved the owner up to $1,030,000. The schedule would have actually grown by four weeks. However, it is unsure exactly how much costs and schedule savings would have been achieved by using early involvement (the possibilities are endless). Construction specialists could have helped the designers pick the shoring sequence, a penthouse, and even recommended the best rebar fabrication method for this project. All recommendations chosen in this paper benefit the overall project in costs, schedule, safety, constructability, and more.

Appendix A- Industry Member Interview Mind Maps


Early Involvement
Interviews
(Design & Builder #1)
Owner
Owner involvement
Active- attend regular meetings 1
Nonactive- understaffed and not involved
Selling early involvement to owner
If done properly it should result in lower project cost
Less change orders
Already excepted 2
Benefits over DBB
Specialty contractors are familiar with current products and new products 5
Overall costs are less 3
Costs are locked in at about 60% design 3
Relationships amoung parties are positive 4
More value engineering opportunity 3 6 5
Smoother purchasing phase 5
Allows for fast tracking 6
Contracts 7
Design
Controlling costs (budgeting)
Precon only contract
Full design and construction contracts upfront
Construction
Competitive bid construction contract
Scope Involvement (depends) 8
MEP
SD- DD
Structural
SD- DD
Curtainwall
SD- DD
Future 9
Every project done at Nutec is early involvement in some way or another
More popular because too many pit falls of other delivery methods
Already used widely, will grow in popularity
(MEP Design & Builder #1)
Owner
Owner Requirements
Activly involved throughout project 1
Early commitment to project
Well defined program of what they want
Selling early involvement to owner
A lot of owners like it and already are willing to do it 2
Benefits over DBB
Maximize construction budget 3
Construction schedule improvement 6
Better chance of everyone winning 4
Better quality than excepting low bid 5
Everyone works on a common goal 4
No over designing 3
Not default to what has been done in past 5
Less chance of a proprietor being used
Contracts 7
Design
Complete design costs
GMP
Construction
Lump sum
Firm or fixed price
Scope Involvement 8
MEP
SD- Integration requirements
Structural
SD- Long lead items
Curtainwall
DD- Details must be considered
Future 9
Infrastructure and manufacturing projects
Popularity trending up, with no leveling off
(General Contractor)
Owner
Owner Requirements
Not pursued unless owner is asking for it 2
Benefits over DBB
Coasts savings 3
Schedule saving because less changes 6
Pieces come together nicer 5 4
Contracts 7
Design Development
All different kinds
Answering question without contract
Construction
All different kinds
Scope Involvement 8
MEP
DD or SD
Design - Build
Structural
SD
Early involvement
Curtainwall
DD or SD
Design - Build
Future 9
Was trending
Has leveled out recently
Will fall off later down the road
(MEP Design & Builder #2)
Owner
Owner Requirements
Most valuable if the owner is educated in construction 1
Can make decisions fairly easy 1
Knows what they want 1 2
Benefits over DBB
Can get important parties involved earlier to influence design 5
Construction reviews at start of design and 50% completion 8
Improve costs through construction knowledge and experience 3
Easier to get construction feedback 5
Contracts 7
Design Development
All different contract types
Construction
All different contract types
Design Assist
Cost data and estimating/ budgeting assistance
Direct design feedback/ check
Design - Build
All one entity
Scope Involvement 8
MEP
DD or SD
Design - Build
Structural
SD
Design Assist
Curtainwall
DD or SD
Design Assist
Future 9
More common
With experiance increasing it is being requested more
Will continue to become more popular with more experience and good projects
(Owner)
Owner
Represents occupants on this project
Interviewee has had little to no experience with early involvement projects
This project is parcially funded using state money
Carlos Sanchez (MBP)



Early Involvement Subjects
1 Owner involvement
Actively involved by attending regular meetings
Better if owner knows what they want
Owner needs to make decisions easily
Owner must be educated in construction
2 Owner buy-in
Owner for this project is not experienced in early involvement
Already or easily convinced that early is better
GC may not pursue in less owner wants to
3 Cost considerations
Costs can be locked in at 60% design
Value engineering may drive down costs
Less change orders = less additional cost
Construction knowledge can maximize construction budget
4 Relationship outcomes
Positive project relationships
Everyone works on a common goal
Everyone should win
5 Quality and overall project flow
Specialty contractors have better construction knowledge
Value engineering opportunities
Better than accepting low bid
Less default to what has been done before
Constructive feedback on design makes for a better overall work flow
6 Schedule considerations
Less changes on time projects
Allows for fast tracking
Can get more done in same time
7 Contract considerations
Design
Controlling costs and design input
Contract types varry
May only answer questions with no contract
Construction
Still can be competitively bid
Contract types varry
Full design & construction
In-house design & construction services
Contract types varry
8 Scope to be included?
For this library project
MEP
Design-Build in DD
Structural erection
Design assist through SD
Curtainwall
Design assist in DD
Scopes that play an important part in a specific project
Construction documents phase is too late to get involved (the earlier the better)
9 Future of early involvement
Positive experiences call for early involvement more often
Popularity increasing with no leveling off
One GC says it is just a phase that will go away soon

Appendix B- Shoring Loading Calculations

Shoring Load Calculations (Typical Bay)

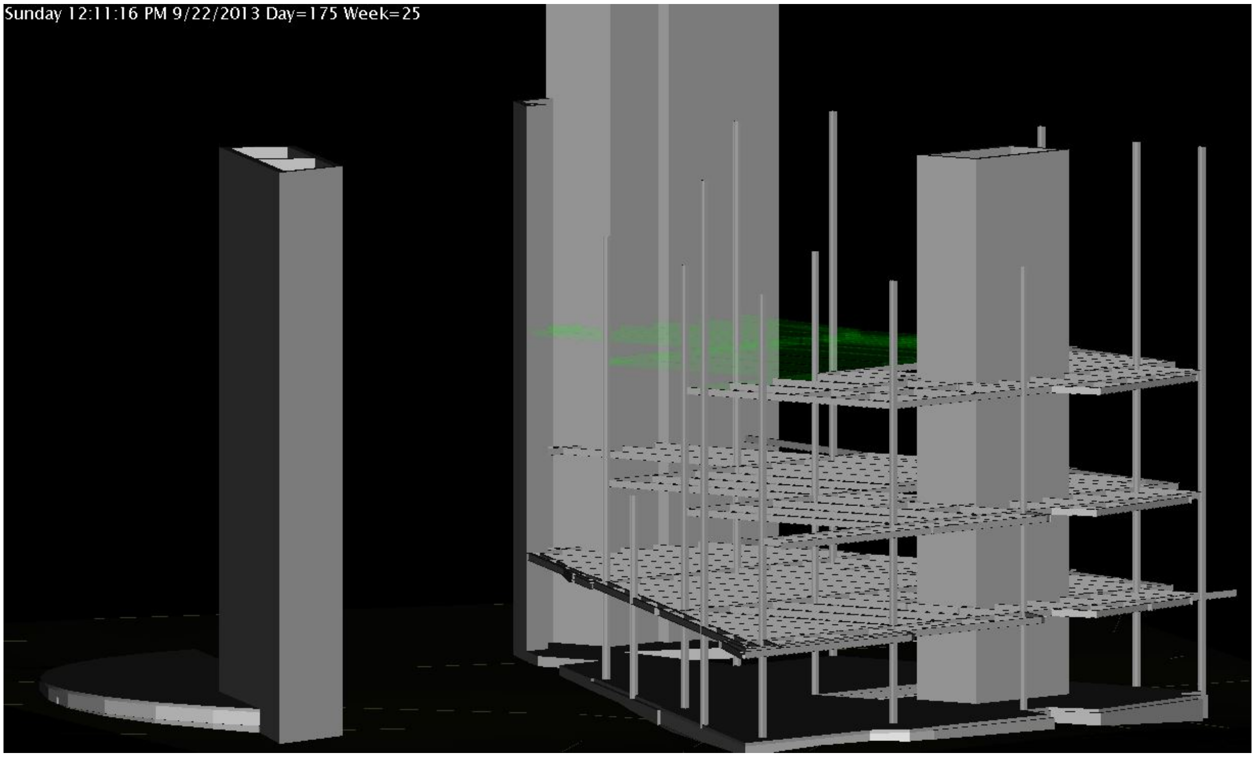
Prepared by: Lowell Stine

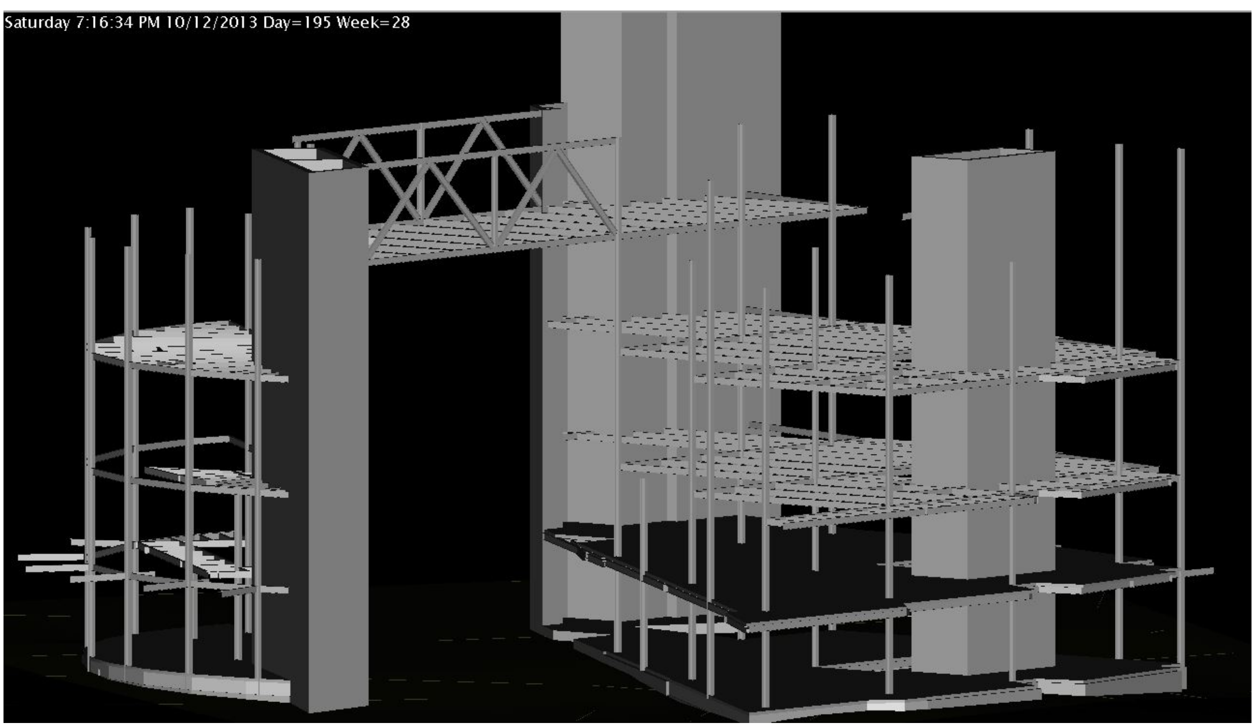
Dead Load Calculations				
Description	**Sizes**	**lb/LF**	**Spacing (ft)**	**lb/SF**
Columns	W14x82	82	40x50	2
Trusses	W14x283	283	40	7
	W14x90	90	40	2
	W14x99	99	40	2
End Truss	W14x233	233	50	5
	W14x90	90	50	2
3rd Floor Girder	W36x135	135	40	3
	W24x55	55	40	1
3rd Floor Beams	W27x84	84	10	8
4th Floor Girder	W27x84	84	40	2
4th Floor Beams	W21x50	50	10	5
5th Floor Beams	W27x84	84	10	8
Roof Floor Beams	W21x44	44	5	9
Decking				5
Allowance				8
	Total Dead Load (lb/SF)			**70**

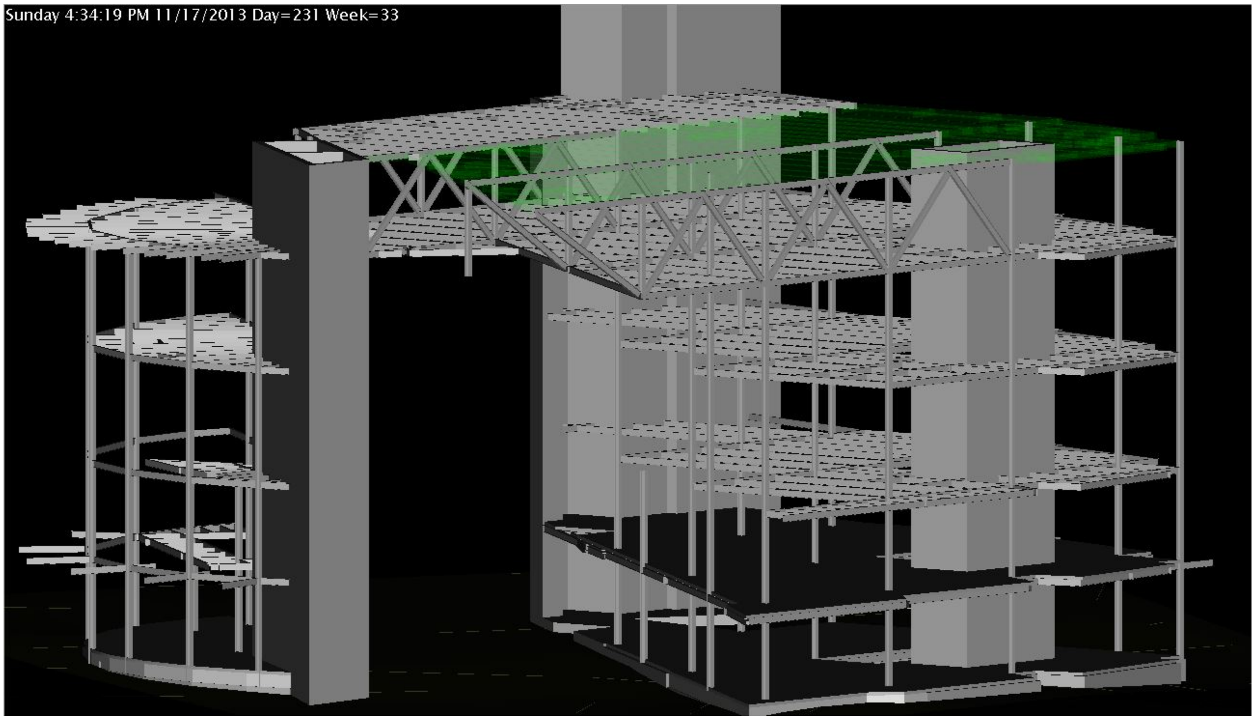
Live Load Calculations			
	Live Load of Construction Surface		50
		# of Floors	4
Live Load Allowance (lb/SF)= L_0			**200**
		K_{LL}	4
	Tributary Area= A_T	20x18	360
		SQRT (K_{LL}*A_T)	37.95
		0.25+{15/ SQRT (K_{LL}*A_T)}	0.65
		Not smaller than 0.4 so use 0.65	
Live Load Reduced (lb/SF)= L			**129**

Total Load Calculations	
Total Load= 1.2D+1.6L (lb/SF)= P_U	**291**
Shoring Tower Estimated Spacing	**20x18**
Total Estimated Load per Shoring Tower (kip)	**105**

Appendix C- Top-Down Structural Sequence



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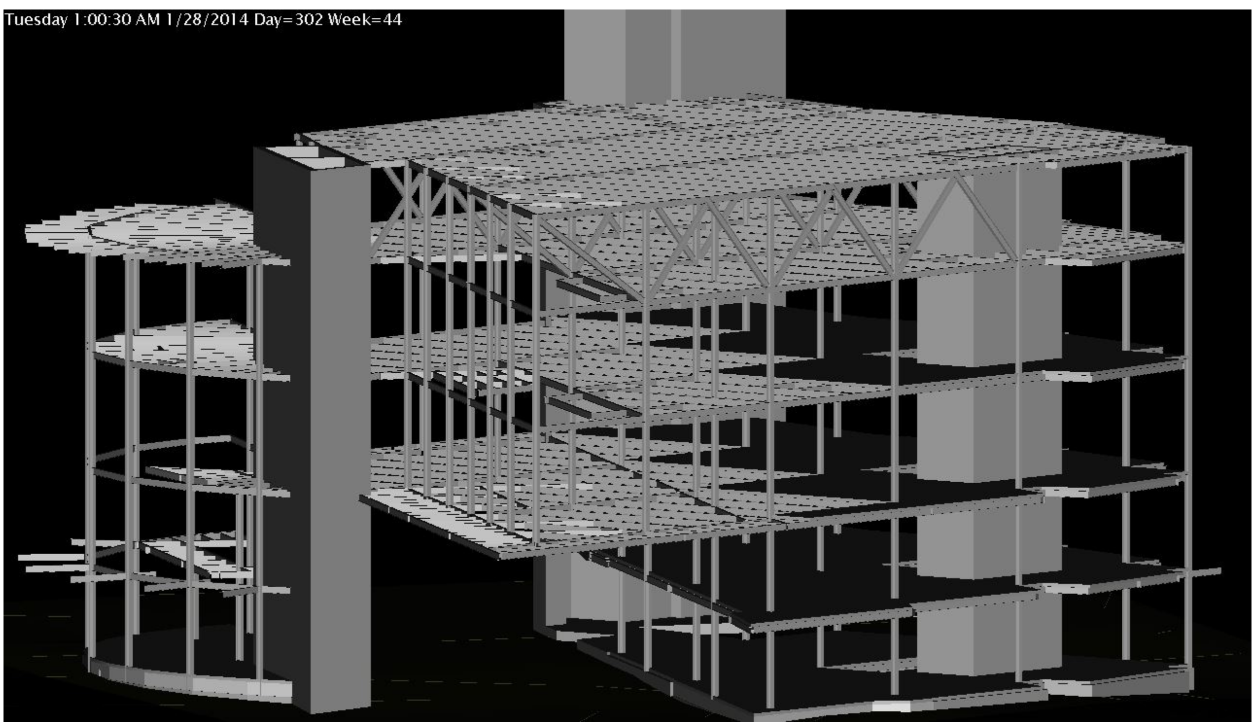
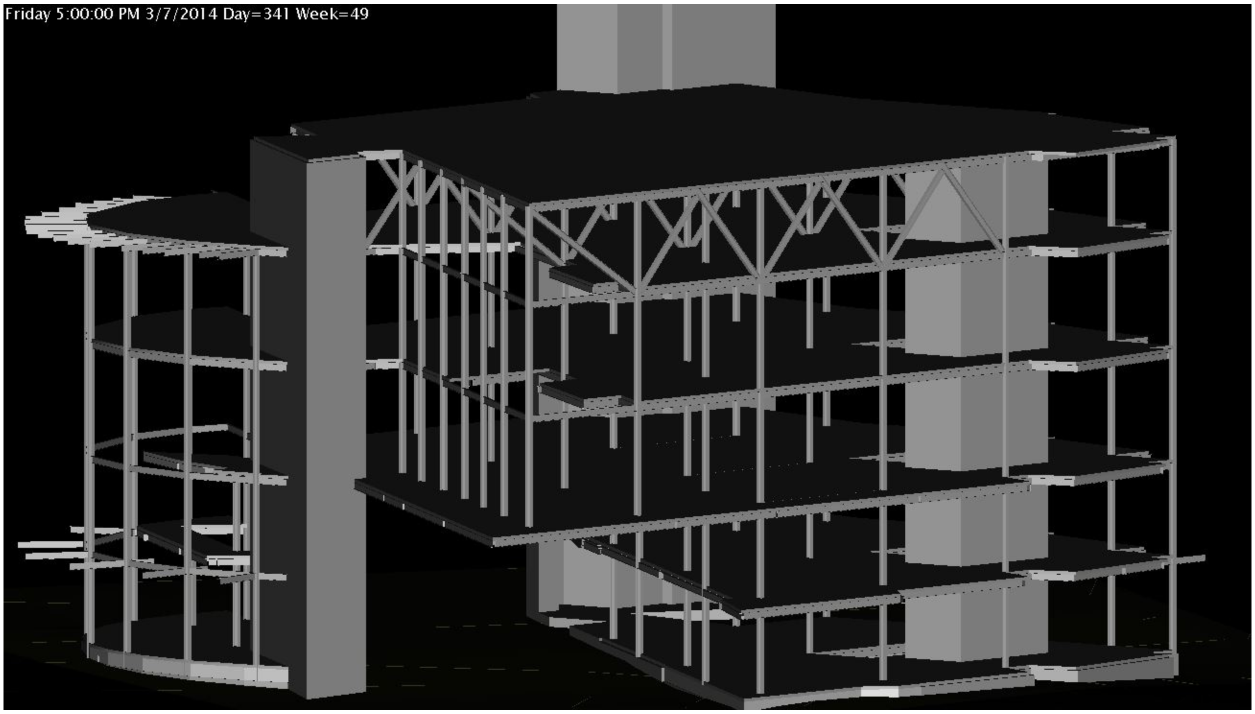
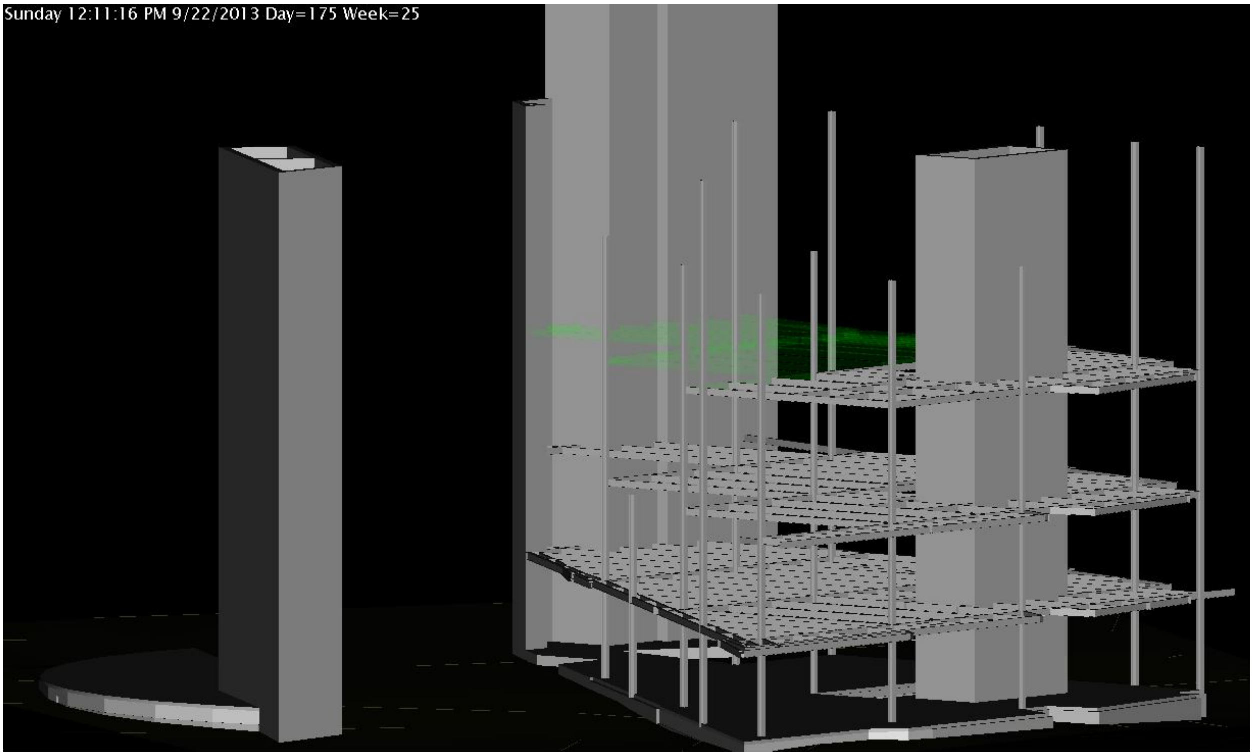
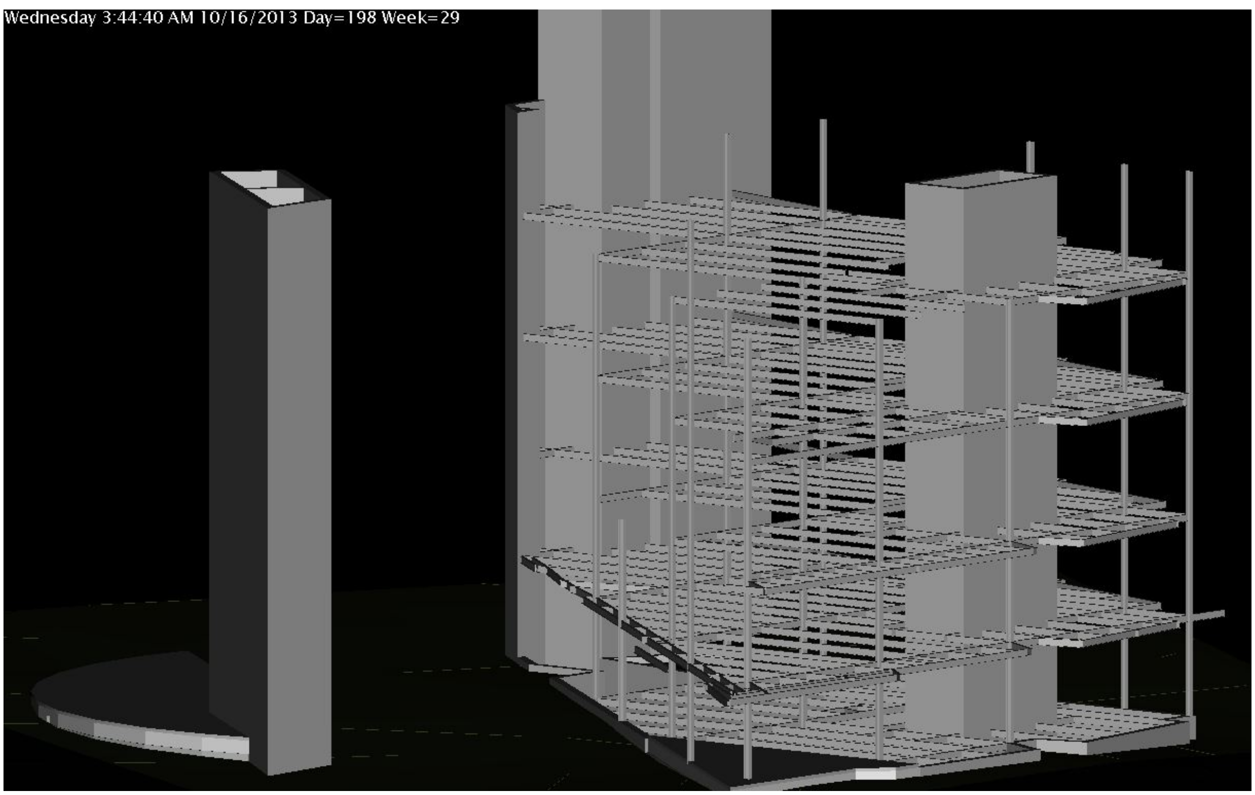
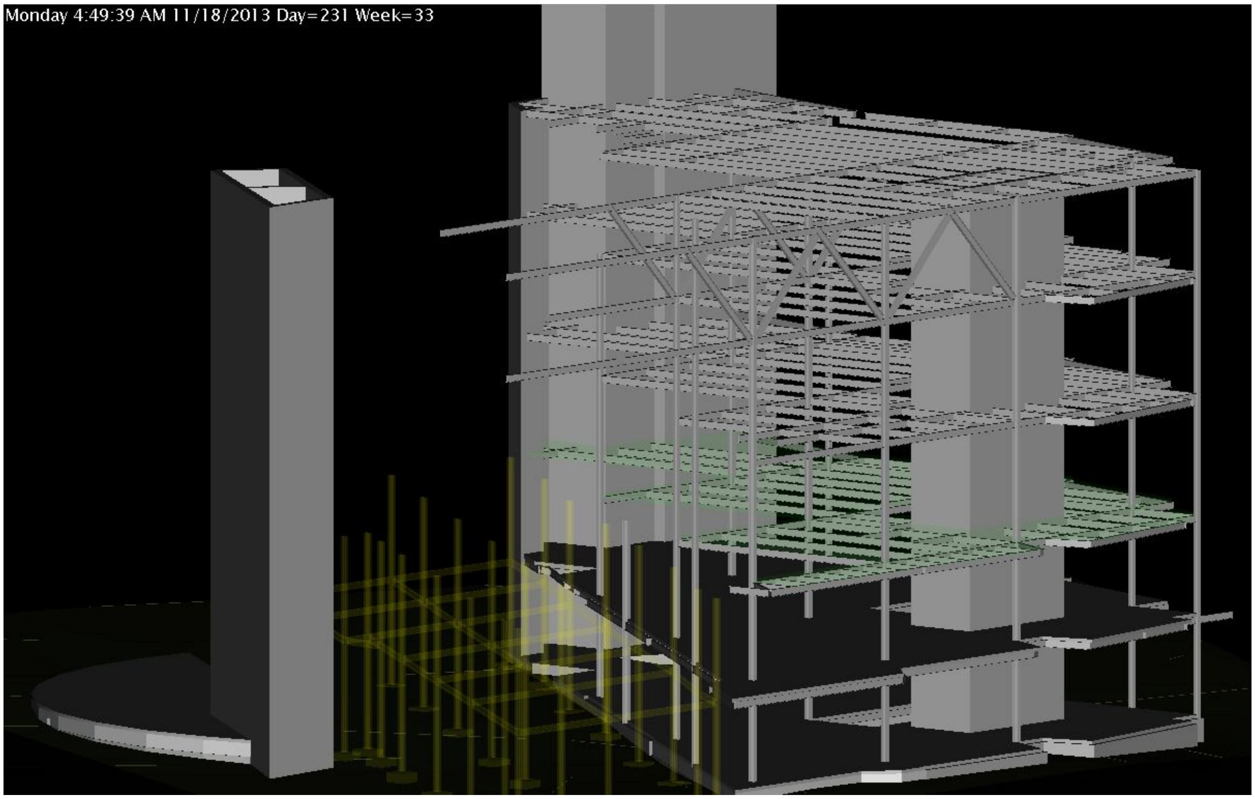

Tuesday 1:00:30 AM 1/28/2014 Day=302 Week=44

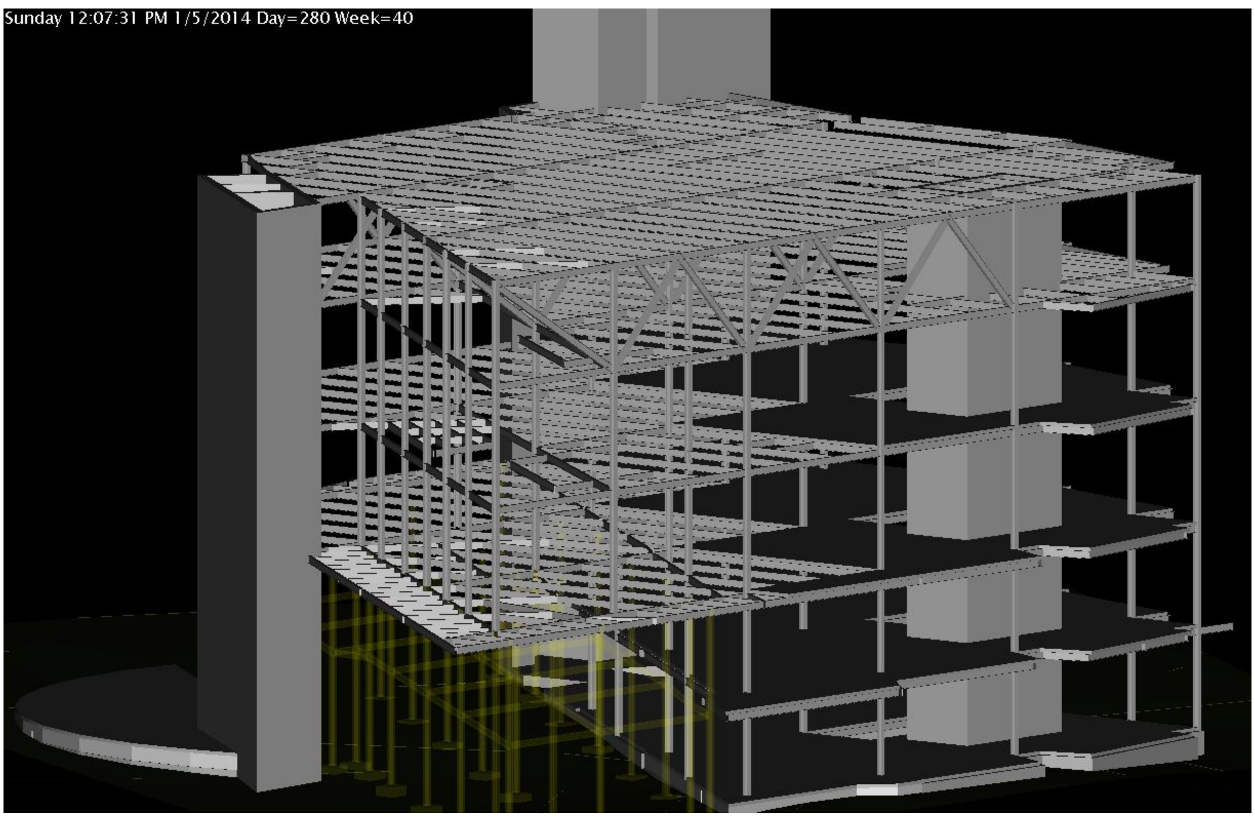

Friday 5:00:00 PM 3/7/2014 Day=341 Week=49

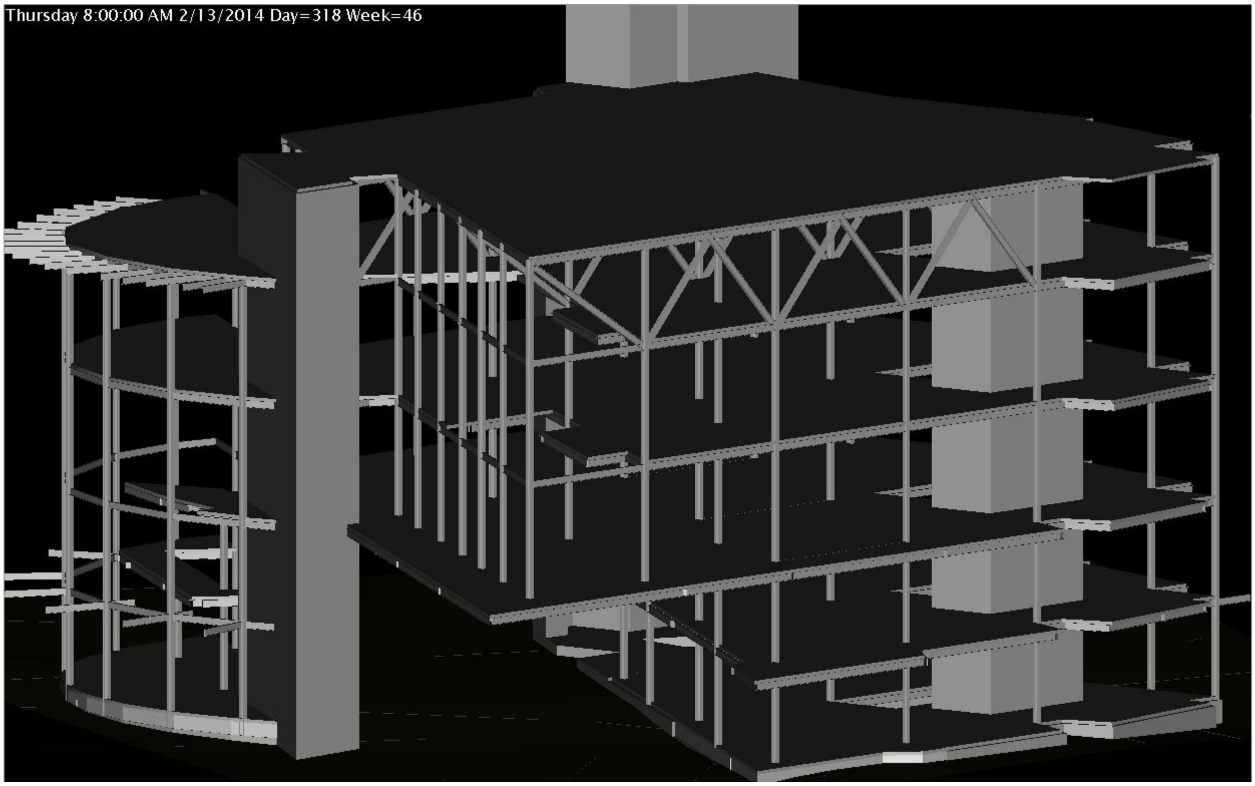
Appendix D- Shoring Structural Sequence





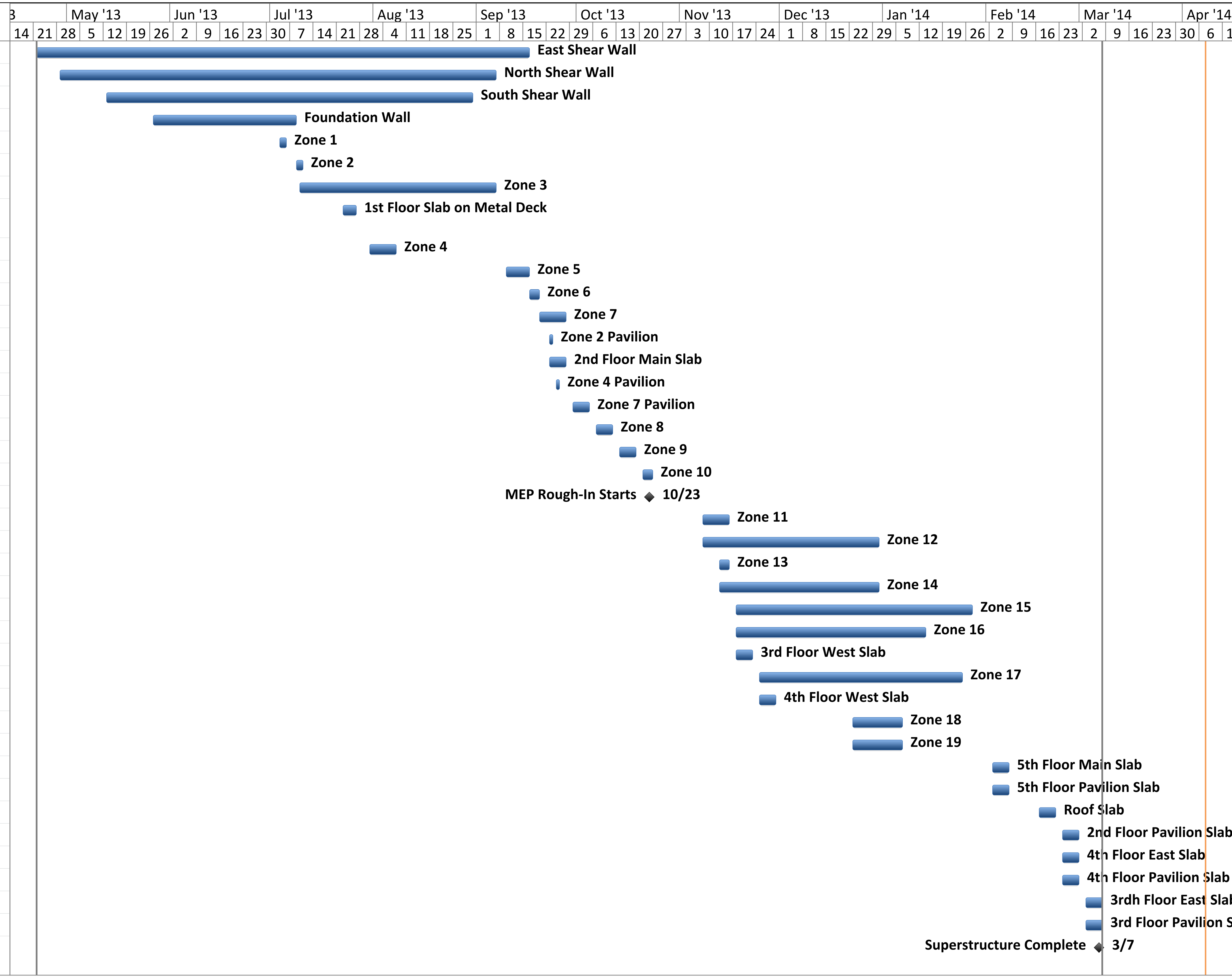

Monday 4:49:39 AM 11/18/2013 Day=231 Week=33


Sunday 12:07:31 PM 1/5/2014 Day=280 Week=40


Thursday 8:00:00 AM 2/13/2014 Day=318 Week=46

Appendix E- Top-Down Schedule

ID	Task Name	Duration	Start	Finish
1	East Shear Wall	106 days	Mon 4/22/13	Mon 9/16/13
2	North Shear Wall	95 days	Mon 4/29/13	Fri 9/6/13
3	South Shear Wall	80 days	Mon 5/13/13	Fri 8/30/13
4	Foundation Wall	31 days	Mon 5/27/13	Mon 7/8/13
5	Zone 1	2 days	Thu 7/4/13	Fri 7/5/13
6	Zone 2	2 days	Tue 7/9/13	Wed 7/10/13
8	Zone 3	43 days	Wed 7/10/13	Fri 9/6/13
28	1st Floor Slab on Metal Deck	4 days	Tue 7/23/13	Fri 7/26/13
9	Zone 4	6 days	Wed 7/31/13	Wed 8/7/13
11	Zone 5	5 days	Tue 9/10/13	Mon 9/16/13
12	Zone 6	3 days	Tue 9/17/13	Thu 9/19/13
13	Zone 7	6 days	Fri 9/20/13	Fri 9/27/13
7	Zone 2 Pavilion	1 day	Mon 9/23/13	Mon 9/23/13
29	2nd Floor Main Slab	5 days	Mon 9/23/13	Fri 9/27/13
10	Zone 4 Pavilion	1 day	Wed 9/25/13	Wed 9/25/13
14	Zone 7 Pavilion	5 days	Mon 9/30/13	Fri 10/4/13
15	Zone 8	5 days	Mon 10/7/13	Fri 10/11/13
16	Zone 9	5 days	Mon 10/14/13	Fri 10/18/13
17	Zone 10	3 days	Mon 10/21/13	Wed 10/23/13
18	MEP Rough-In Starts	0 days	Wed 10/23/13	Wed 10/23/13
19	Zone 11	6 days	Fri 11/8/13	Fri 11/15/13
20	Zone 12	37 days	Fri 11/8/13	Mon 12/30/13
21	Zone 13	3 days	Wed 11/13/13	Fri 11/15/13
22	Zone 14	34 days	Wed 11/13/13	Mon 12/30/13
23	Zone 15	51 days	Mon 11/18/13	Mon 1/27/14
24	Zone 16	41 days	Mon 11/18/13	Mon 1/13/14
31	3rd Floor West Slab	5 days	Mon 11/18/13	Fri 11/22/13
25	Zone 17	45 days	Mon 11/25/13	Fri 1/24/14
34	4th Floor West Slab	5 days	Mon 11/25/13	Fri 11/29/13
26	Zone 18	11 days	Mon 12/23/13	Mon 1/6/14
27	Zone 19	11 days	Mon 12/23/13	Mon 1/6/14
37	5th Floor Main Slab	5 days	Mon 2/3/14	Fri 2/7/14
38	5th Floor Pavilion Slab	5 days	Mon 2/3/14	Fri 2/7/14
39	Roof Slab	5 days	Mon 2/17/14	Fri 2/21/14
30	2nd Floor Pavilion Slab	5 days	Mon 2/24/14	Fri 2/28/14
35	4th Floor East Slab	5 days	Mon 2/24/14	Fri 2/28/14
36	4th Floor Pavilion Slab	5 days	Mon 2/24/14	Fri 2/28/14
32	3rdh Floor East Slab	5 days	Mon 3/3/14	Fri 3/7/14
33	3rd Floor Pavilion Slab	5 days	Mon 3/3/14	Fri 3/7/14
40	Superstructure Complete	0 days	Fri 3/7/14	Fri 3/7/14

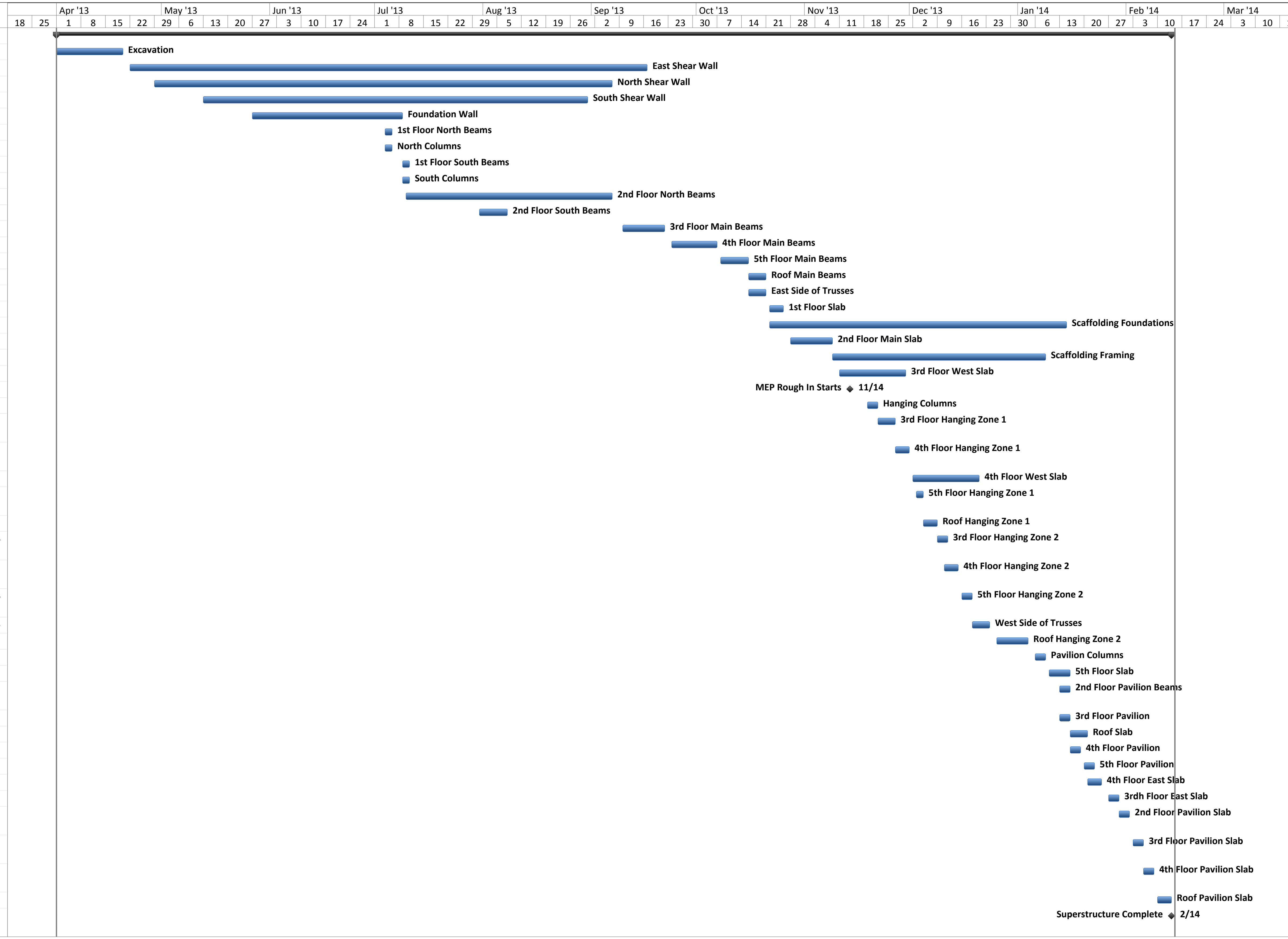


Project: Top-Down Schedule
Date: Tue 4/8/14

Task		Project Summary		Inactive Milestone		Manual Summary Rollup		Deadline	
Split		External Tasks		Inactive Summary		Manual Summary		Progress	
Milestone		External Milestone		Manual Task		Start-only			
Summary		Inactive Task		Duration-only		Finish-only			

Appendix F- Shoring Sequence Schedule

ID	Task Name	Duration	Start	Finish
1	**Shoring Sequence**	**319 days**	**Mon 4/1/13**	**Fri 2/14/14**
2	Excavation	19 days	Mon 4/1/13	Fri 4/19/13
3	East Shear Wall	148 days	Mon 4/22/13	Mon 9/16/13
4	North Shear Wall	131 days	Mon 4/29/13	Fri 9/6/13
5	South Shear Wall	110 days	Mon 5/13/13	Fri 8/30/13
6	Foundation Wall	43 days	Mon 5/27/13	Mon 7/8/13
7	1st Floor North Beams	2 days	Thu 7/4/13	Fri 7/5/13
9	North Columns	2 days	Thu 7/4/13	Fri 7/5/13
8	1st Floor South Beams	2 days	Tue 7/9/13	Wed 7/10/13
10	South Columns	2 days	Tue 7/9/13	Wed 7/10/13
11	2nd Floor North Beams	59 days	Wed 7/10/13	Fri 9/6/13
12	2nd Floor South Beams	8 days	Wed 7/31/13	Wed 8/7/13
13	3rd Floor Main Beams	12 days	Tue 9/10/13	Sat 9/21/13
14	4th Floor Main Beams	13 days	Tue 9/24/13	Sun 10/6/13
15	5th Floor Main Beams	8 days	Tue 10/8/13	Tue 10/15/13
16	Roof Main Beams	5 days	Wed 10/16/13	Sun 10/20/13
31	East Side of Trusses	5 days	Wed 10/16/13	Sun 10/20/13
17	1st Floor Slab	4 days	Tue 10/22/13	Fri 10/25/13
18	Scaffolding Foundations	85 days	Tue 10/22/13	Tue 1/14/14
20	2nd Floor Main Slab	12 days	Mon 10/28/13	Fri 11/8/13
19	Scaffolding Framing	61 days	Sat 11/9/13	Wed 1/8/14
33	3rd Floor West Slab	19 days	Mon 11/11/13	Fri 11/29/13
21	MEP Rough In Starts	0 days	Thu 11/14/13	Thu 11/14/13
22	Hanging Columns	3 days	Tue 11/19/13	Thu 11/21/13
23	3rd Floor Hanging Zone 1	5 days	Fri 11/22/13	Tue 11/26/13
24	4th Floor Hanging Zone 1	4 days	Wed 11/27/13	Sat 11/30/13
35	4th Floor West Slab	19 days	Mon 12/2/13	Fri 12/20/13
25	5th Floor Hanging Zone 1	2 days	Tue 12/3/13	Wed 12/4/13
26	Roof Hanging Zone 1	4 days	Thu 12/5/13	Sun 12/8/13
27	3rd Floor Hanging Zone 2	3 days	Mon 12/9/13	Wed 12/11/13
28	4th Floor Hanging Zone 2	4 days	Wed 12/11/13	Sat 12/14/13
29	5th Floor Hanging Zone 2	3 days	Mon 12/16/13	Wed 12/18/13
32	West Side of Trusses	5 days	Thu 12/19/13	Mon 12/23/13
30	Roof Hanging Zone 2	9 days	Thu 12/26/13	Fri 1/3/14
39	Pavilion Columns	3 days	Mon 1/6/14	Wed 1/8/14
37	5th Floor Slab	6 days	Fri 1/10/14	Wed 1/15/14
40	2nd Floor Pavilion Beams	3 days	Mon 1/13/14	Wed 1/15/14
41	3rd Floor Pavilion	3 days	Mon 1/13/14	Wed 1/15/14
38	Roof Slab	5 days	Thu 1/16/14	Mon 1/20/14
42	4th Floor Pavilion	3 days	Thu 1/16/14	Sat 1/18/14
43	5th Floor Pavilion	3 days	Mon 1/20/14	Wed 1/22/14
36	4th Floor East Slab	4 days	Tue 1/21/14	Fri 1/24/14
34	3rdh Floor East Slab	3 days	Mon 1/27/14	Wed 1/29/14
44	2nd Floor Pavilion Slab	3 days	Thu 1/30/14	Sat 2/1/14
45	3rd Floor Pavilion Slab	3 days	Mon 2/3/14	Wed 2/5/14
46	4th Floor Pavilion Slab	3 days	Thu 2/6/14	Sat 2/8/14
47	Roof Pavilion Slab	4 days	Mon 2/10/14	Thu 2/13/14
48	Superstructure Complete	0 days	Fri 2/14/14	Fri 2/14/14



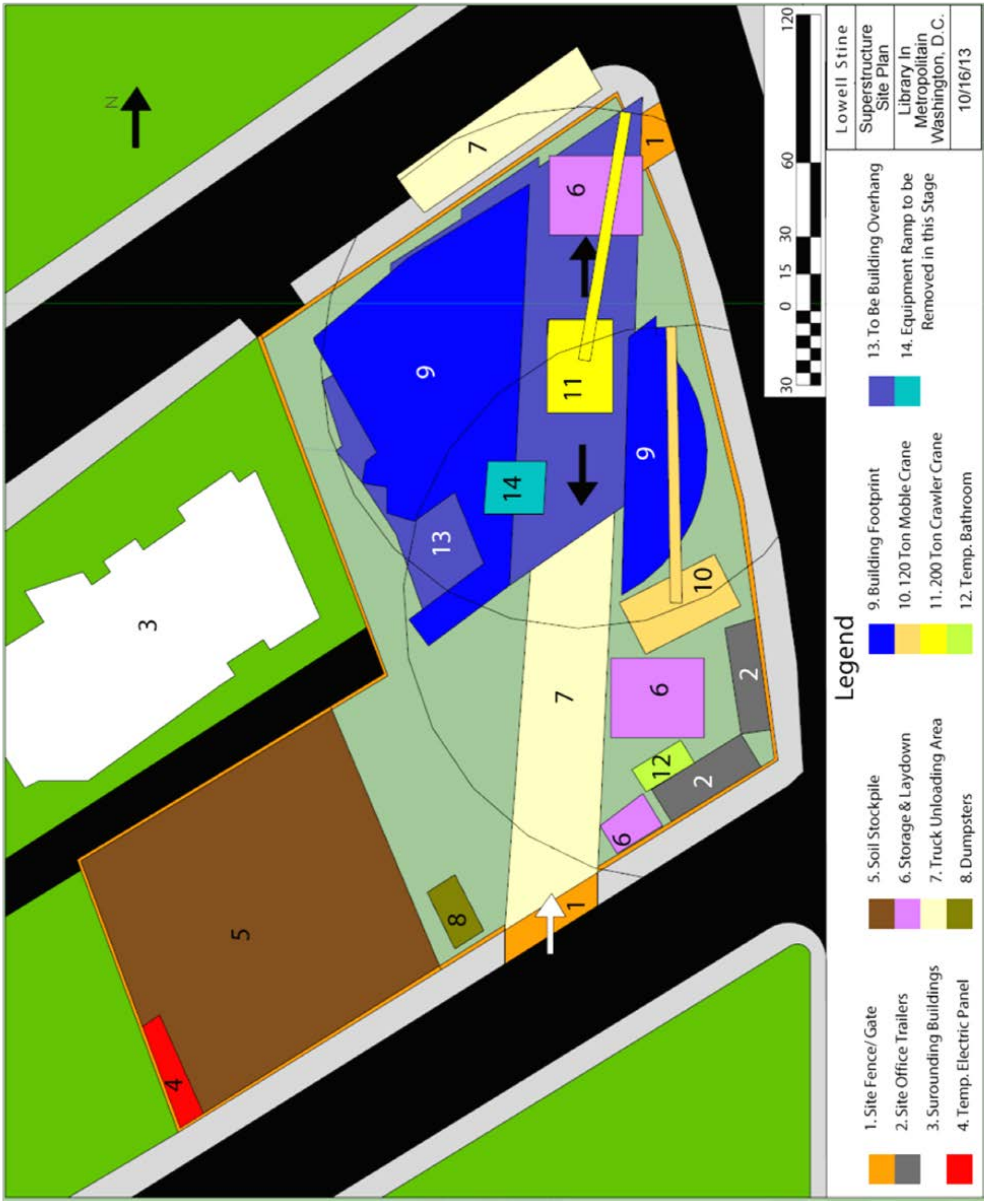
Project: Shoring Sequence Schedu
Date: Tue 4/8/14

Task	Summary	External Milestone	Inactive Summary	Manual Summary Rollup	Finish-only
Split	Project Summary	Inactive Task	Manual Task	Manual Summary	Deadline
Milestone	External Tasks	Inactive Milestone	Duration-only	Start-only	Progress

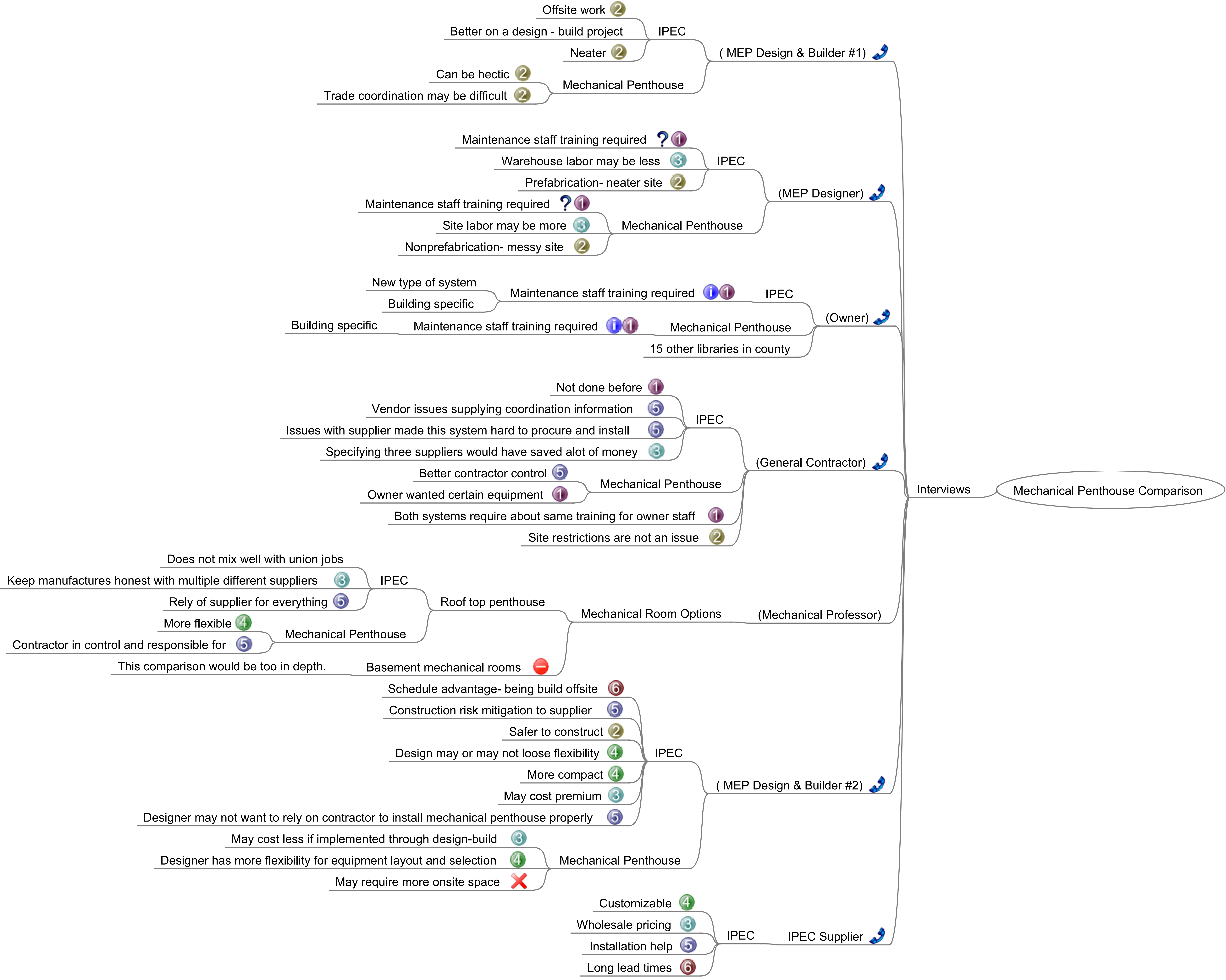
Appendix G- General Conditions Estimate

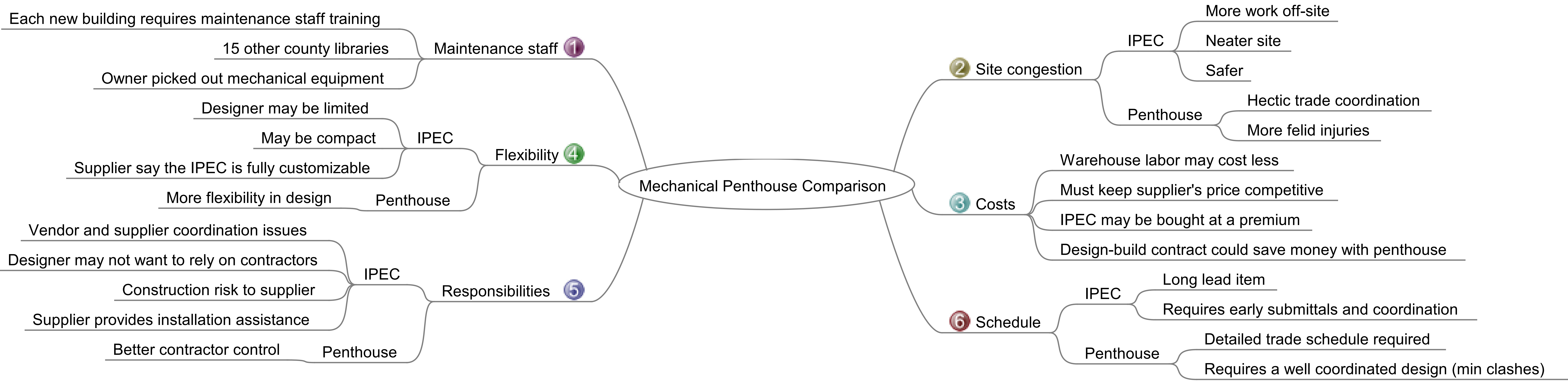
Description	Quantity	Unit	Per/Unit	Total
Site Signage (Fence Cloth)	4,588	SF	$36.04	$165,351.52
Perimater Fencing	1,185	LF	$6.32	$7,489.20
Office Trailers (2)	22	Month	$361.00	$15,884.00
Air Conditioning	22	Month	$48.76	$1,072.72
125 Ton Crane	20	Month	$16,000.00	$320,000.00
200 Ton (Crane Steel)			N/A	
1-1/2 CY Excavator	33	Month	$8,700.00	$287,100.00
Backhoe 1-1/4 CY	22	Month	$3,013.00	$66,286.00
500 BTU Heater	15	Month	$425.00	$6,375.00
Portable Toilet	22	Month	$191.78	$4,219.16
Permits	$3,589,000.00	%	0.50%	$17,945.00
Field Office Bills	22	Month	$377.00	$8,294.00
Main Office Expense	$3,589,000.00	%	3.90%	$139,971.00
Builders Risk Insurance	$3,589,000.00	%	0.42%	$15,000.00
Performance Bond	$3,589,000.00	%	2.79%	$100,000.00
Liability Insurance	$3,589,000.00	%	2.79%	$100,000.00
Multivista (Construction Documentations/ Webcam)	23	Month	$1,700.00	$39,100.00
Project Executive	22	Week	$2,475.00	$54,450.00
LEED Submittal Fees	22	Month	$727.27	$16,000.00
CM Fees	$3,589,000.00	%	3.00%	$107,670.00
Field Engineer	88	Week	$1,325.00	$116,600.00
Project Manager	88	Week	$2,150.00	$189,200.00
Superintendent	88	Week	$2,000.00	$176,000.00
General Purpose Laborer	88	Week	$1,425.00	$125,400.00
Schedule Maintainance	$3,589,000.00	%	0.03%	$1,076.70
Temp. 600 Amp Elec.	1	EA	$3,621.00	$3,621.00
Temp. 75kVA Transformer	1	EA	$3,993.00	$3,993.00
Office Trailer Hook-Up	2	EA	$374.00	$748.00
After Job Clean-up	$3,589,000.00	%	0.30%	$10,767.00
Waste Removal Dumpster	88	Week	$340.91	$30,000.00
Site Water	22	Month	$70.00	$1,540.00
Commissioning	$3,589,000.00	%	0.25%	$8,972.50
Total				**$2,140,125.80**
Project Planned Duration (Weeks)				**88**
Total General Condition Costs per Week				**$24,319.61**

Appendix H- Superstructure Site Plan



Appendix I- IPEC vs. Mechanical Penthouse Mind Maps


Mechanical Penthouse Comparison
Interviews
(MEP Design & Builder #1)
IPEC
Offsite work
Better on a design - build project
Neater
Mechanical Penthouse
Can be hectic
Trade coordination may be difficult
(MEP Designer)
IPEC
Maintenance staff training required
Warehouse labor may be less
Prefabrication- neater site
Mechanical Penthouse
Maintenance staff training required
Site labor may be more
Nonprefabrication- messy site
(Owner)
IPEC
Maintenance staff training required
New type of system
Building specific
Mechanical Penthouse
Maintenance staff training required
Building specific
15 other libraries in county
(General Contractor)
IPEC
Not done before
Vendor issues supplying coordination information
Issues with supplier made this system hard to procure and install
Specifying three suppliers would have saved alot of money
Mechanical Penthouse
Better contractor control
Owner wanted certain equipment
Both systems require about same training for owner staff
Site restrictions are not an issue
(Mechanical Professor)
Mechanical Room Options
Roof top penthouse
IPEC
Does not mix well with union jobs
Keep manufactures honest with multiple different suppliers
Rely of supplier for everything
Mechanical Penthouse
More flexible
Contractor in control and responsible for
Basement mechanical rooms
This comparison would be too in depth.
(MEP Design & Builder #2)
IPEC
Schedule advantage- being build offsite
Construction risk mitigation to supplier
Safer to construct
Design may or may not loose flexibility
More compact
May cost premium
Designer may not want to rely on contractor to install mechanical penthouse properly
Mechanical Penthouse
May cost less if implemented through design-build
Designer has more flexibility for equipment layout and selection
May require more onsite space
IPEC Supplier
IPEC
Customizable
Wholesale pricing
Installation help
Long lead times


Mechanical Penthouse Comparison
Maintenance staff
Each new building requires maintenance staff training
15 other county libraries
Owner picked out mechanical equipment
Flexibility
IPEC
Designer may be limited
May be compact
Supplier say the IPEC is fully customizable
Penthouse
More flexibility in design
Responsibilities
IPEC
Vendor and supplier coordination issues
Designer may not want to rely on contractors
Construction risk to supplier
Supplier provides installation assistance
Penthouse
Better contractor control
Site congestion
IPEC
More work off-site
Neater site
Safer
Penthouse
Hectic trade coordination
More felid injuries
Costs
Warehouse labor may cost less
Must keep supplier's price competitive
IPEC may be bought at a premium
Design-build contract could save money with penthouse
Schedule
IPEC
Long lead item
Requires early submittals and coordination
Penthouse
Detailed trade schedule required
Requires a well coordinated design (min clashes)

Appendix J- IPEC Base Zone 2 Acoustical Calculations

Transmission Losses (dB)								
Octave-band Center Frequencies		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	STC Rating
Floor of IPEC		37.0	45.0	54.0	60.0	65.0	47.0	62.0

Absorption Under IPEC Zone 2													
Surface	Area (Sq. ft.)	Absorption Coefficients											
		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Concrete	128	0	0	0	0	0	0	1	1	3	3	3	3
Ridged Insulation (3in.)	346	0	1	1	1	1	1	131	207	270	276	270	242
Metal IPEC Bottom	128	0	0	0	0	0	0	19	24	28	50	49	38
Total Absorption (sabins): a=∑ Sα →								151.81	232.96	300.29	328.96	320.77	282.88

Estimated Nosie Level in Zone 2						
Octave-band Center Frequencies	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
TL between IPEC and Under IPEC Zone 2	37	45	54	60	65	47
a_2	152	233	300	329	321	283
Surface Area Between Spaces (sq. ft.)	160					
Noise Reduction of Noise Coming from IPEC	37	47	57	63	68	49
Sound Pressure in IPEC	86	85	84	83	82	80
Sound Pressure in Zone 2 From IPEC Space	49	38	27	20	14	31

Appendix K- Staff Conference Room Calculations

Transmission Losses (dB)								
Octave-band Center Frequencies		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	STC Rating
8'' reinforced concrete slab		44.0	48.0	55.0	58.0	63.0	67.0	58.0

Absorption of Staff Conference Space													
Surface	Area (Sq. ft.)	Absorption Coefficients											
		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Carpet on Foam	409	0	0	1	1	1	1	33	98	233	282	291	299
Gypsum Board, 5/8''	506	1	0	0	0	0	0	279	71	41	20	61	56
Acoustical Ceiling, 3/4''	409	1	1	1	1	1	1	311	381	340	405	405	385
Chairs, Occupied	32	0	0	0	1	1	1	10	13	16	27	28	27
Total Absorption (sabins): a=∑ Sα →								632	562	629	735	784	766

Between Zone1 and Staff Conference Space						
Surface Area Between Spaces (sq. ft.)	325					
Noise Reduction of Noise Coming from Zone 1	42	48	56	60	65	68
Sound Pressure in Zone 1	86	85	84	83	82	80
Sound Pressure in Staff Conference Space from Zone 1	44	37	28	23	17	12

Between Zone 2 and Staff Conference Space						
Surface Area Between Spaces (sq. ft.)	120					
Noise Reduction of Noise Coming from Zone 2	47	52	60	64	69	72
Sound Pressure in Zone 2	49	38	27	20	14	31
Sound Pressure in Staff Conference Space from Zone 2	3	-14	-33	-44	-55	-42

Between Zone 3 and Staff Conference Space						
Surface Area Between Spaces (sq. ft.)	293					
Noise Reduction of Noise Coming from Zone 3	43	48	57	60	65	69
Sound Pressure in Zone 3	86	85	84	83	82	80
Sound Pressure in Staff Conference Space from Zone 3	43	37	27	23	17	11

Between Zone 4 and Staff Conference Space						
Surface Area Between Spaces (sq. ft.)	144					
Noise Reduction of Noise Coming from Zone 4	46	52	60	63	68	72
Sound Pressure in Zone 4	86	85	84	83	82	80
Sound Pressure in Staff Conference Space from Zone 4	40	33	24	20	14	8

<table>
<tr><th colspan="7">Estimated Sound Pressure Level in Staff Conference Space</th></tr>
<tr><th>Octave-band Center Frequencies</th><th>125 Hz</th><th>250 Hz</th><th>500 Hz</th><th>1000 Hz</th><th>2000 Hz</th><th>4000 Hz</th></tr>
<tr><td>From Zone 1</td><td>44</td><td>37</td><td>28</td><td>23</td><td>17</td><td>12</td></tr>
<tr><td>From Zone 2</td><td>3</td><td>-14</td><td>-33</td><td>-44</td><td>-55</td><td>-42</td></tr>
<tr><td>From Zone 3</td><td>43</td><td>37</td><td>27</td><td>23</td><td>17</td><td>11</td></tr>
<tr><td>From Zone 4</td><td>40</td><td>33</td><td>24</td><td>20</td><td>14</td><td>8</td></tr>
<tr><td>Add From Zone 1 and 2 Combined</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>From Zone 1 and 2 Combined</td><td>44</td><td>37</td><td>28</td><td>23</td><td>17</td><td>12</td></tr>
<tr><td>Add From Zones 3 and 4 Combined</td><td>2</td><td>1</td><td>2</td><td>2</td><td>2</td><td>1</td></tr>
<tr><td>From Zones 3 and 4 Combined</td><td>45</td><td>38</td><td>29</td><td>25</td><td>19</td><td>12</td></tr>
<tr><td>Add From Zone (1 and 2) and (3 and 4) Combined</td><td>3</td><td>3</td><td>3</td><td>2</td><td>2</td><td>3</td></tr>
<tr><td>Estimated Sound Level in Staff Conference Space from IPEC</td><td>48</td><td>41</td><td>32</td><td>27</td><td>21</td><td>15</td></tr>
<tr><td>A-Weighting</td><td>-15</td><td>-8</td><td>-3</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>A-Weighted Noise from IPEC</td><td>33</td><td>33</td><td>29</td><td>27</td><td>22</td><td>16</td></tr>
<tr><td>dB Addition Add</td><td colspan="2">3</td><td colspan="2">2</td><td colspan="2">1</td></tr>
<tr><td>Result</td><td colspan="2">36</td><td colspan="2">31</td><td colspan="2">23</td></tr>
<tr><td>dB Addition Add</td><td colspan="4">1</td><td colspan="2">0</td></tr>
<tr><td>Result</td><td colspan="4">37</td><td colspan="2">23</td></tr>
<tr><td>dB Addition Add</td><td colspan="6">0</td></tr>
<tr><td>Sound Level</td><td colspan="6">37 dB</td></tr>
</table>

Appendix L- Equipment Costs

Assembly Cost Estimate for Mechanical Equipment
Prepared by: Lowell Stine

Data Release :Year 2013

Quantity	Assembly Number	Description	Unit	Material O&P	Installation	Total O&P	Ext. Material O&P	Ext. Installation	Ext. Total
4	D30201061080	Boiler, gas, cast iron, hot water, 1,088 MBH	Ea.	$ 14,914.90	$ 4,706.35	$ 19,621.25	$ 59,659.60	$ 18,825.40	$ 78,485.00
90000	D30301154040	Packaged chiller, water cooled, with fan coil unit, offices, 60,000 SF, 190.00 ton	S.F.	$ 7.76	$ 5.19	$ 12.95	$ 698,400.00	$ 467,100.00	$ 1,165,500.00
40000	D30201081280	Heating systems, CI boiler, gas, terminal unit heaters, 80 MBH, 1,070 SF bldg	S.F.	$ 10.76	$ 7.56	$ 18.32	$ 430,400.00	$ 302,400.00	$ 732,800.00
90000	D30501703680	Split system, air cooled condensing unit, offices, 20,000 SF, 63.32 ton	S.F.	$ 5.46	$ 4.64	$ 10.10	$ 491,400.00	$ 417,600.00	$ 909,000.00
5	D30203301030	Pump, base mounted with motor, end-suction, 4" size, 7-1/2 HP, to 350 GPM	Ea.	$ 15,015.00	$ 4,107.50	$ 19,122.50	$ 75,075.00	$ 20,537.50	$ 95,612.50
2	D30203301020	Pump, base mounted with motor, end-suction, 3" size, 5 HP, to 225 GPM	Ea.	$ 12,812.80	$ 3,426.30	$ 16,239.10	$ 25,625.60	$ 6,852.60	$ 32,478.20
2	D30203301040	Pump, base mounted with motor, end-suction, 5" size, 15 HP, to 1000 GPM	Ea.	$ 20,720.70	$ 6,050.15	$ 26,770.85	$ 41,441.40	$ 12,100.30	$ 53,541.70
11	D30203301010	Pump, base mounted with motor, end-suction, 2-1/2" size, 3 HP, to 150 GPM	Ea.	$ 11,711.70	$ 2,994.10	$ 14,705.80	$ 128,828.70	$ 32,935.10	$ 161,763.80
90000	D30301103400	Packaged chiller, air cooled, with fan coi unit, offices, 6,000 SF, 19.00 ton	S.F.	$ 9.71	$ 5.68	$ 15.39	$ 873,900.00	$ 511,200.00	$ 1,385,100.00
1	D30406101010	Plate heat exchanger, 400 GPM	Ea.	$ 53,553.50	$11,745.60	$ 65,299.10	$ 53,553.50	$ 11,745.60	$ 65,299.10
2	D30402401040	Roof vent. system, power, centrifugal, aluminum, galvanized curb, back draft damper, 2750 CFM	Ea.	$ 3,578.58	$11,446.60	$ 15,025.18	$ 7,157.16	$ 22,893.20	$ 30,050.36
1	D30402401030	Roof vent. system, power, centrifugal, aluminum, galvanized curb, back draft damper, 1500 CFM	Ea.	$ 2,402.40	$ 5,061.10	$ 7,463.50	$ 2,402.40	$ 5,061.10	$ 7,463.50
1.33	D30401161050	AHU, rooftop, cool/heat coils, VAV, filters, 30,000 CFM	Ea.	$173,173.00	$17,149.20	$ 190,322.20	$ 230,320.09	$ 22,808.44	$ 253,128.53
1.1	D30401161030	AHU, rooftop, cool/heat coils, VAV, filters, 15,000 CFM	Ea.	$116,616.50	$12,413.80	$ 129,030.30	$ 128,278.15	$ 13,655.18	$ 141,933.33
						Subtotals	$ 3,246,441.60	$ 1,865,714.42	$ 5,112,156.02
						Location Scale		91%	$4,652,061.98
						GC OH & Profit		5%	$232,603.10
						Grand Total			$ 4,884,665.08

Appendix M- Enclosure Costs

Assembly Cost Estimate for Mechanical Equipment
Prepared by: Lowell Stine

Data Release :Year 2011

Quantity	Assembly Number	Description	Unit	Material O&P	Installation	Total O&P	Ext. Material O&P	Ext. Installation	Ext. Total
		Floor is Same Stuctural Concrete				$ -	$ -	$ -	$ -
3000	B10201206400	Steel Joist Roof	S.F.	$ 5.05	$ 2.96	$ 8.01	$ 15,150.00	$ 8,880.00	$ 24,030.00
3000	B30101206500	Single Ply 60 mils, PVC Membrane Roof Coverings Adhered	S.F.	$ 1.41	$ 0.92	$ 2.33	$ 4,230.00	$ 2,760.00	$ 6,990.00
3750	B2010146	Corrugated 22 Ga.Galvanized Steel with Structural Steel Support, Colored	S.F.	$ 4.19	$ 3.60	$ 7.79	$ 15,712.50	$ 13,500.00	$ 29,212.50
3000	D50202360960	Low Bay Lighting Fixtures, 250 watt Metal Halide	S.F.	$ 4.23	$ 5.55	$ 9.78	$ 12,690.00	$ 16,650.00	$ 29,340.00
		Allowance				$ -	$ -	$ -	$ 12,000.00
						Subtotals	$ 47,782.50	$ 41,790.00	$101,572.50
						Location Scale		91%	$92,532.55
						Inflation of 3 Years		3%	$95,308.52
						GC OH & Profit		5%	$4,765.43
						Grand Total			**$100,073.95**

Appendix N- Mechanical Schedule

Duration Estimate for Mechanical Enclosure

Prepared by: Lowell Stine

Quantity	Assembly Number	Description	Unit	Productivity (units/day)	Crews	Duration (days)
		Floor is Same Structural Concrete				
2400	B10201206400	Steel Joist Roof	L.F.	160	2	7.5
2400	B30101206500	Single Ply 60 mils, PVC Membrane Roof Coverings Adhered	S.F.	250	2	4.8
2400	B2010146	Corrugated 22 Ga.Galvanized Steel with Structural Steel Support, Colored	L.F.	800	1	3
					Total Days	15.3

Duration Estimate for Mechanical Equipment

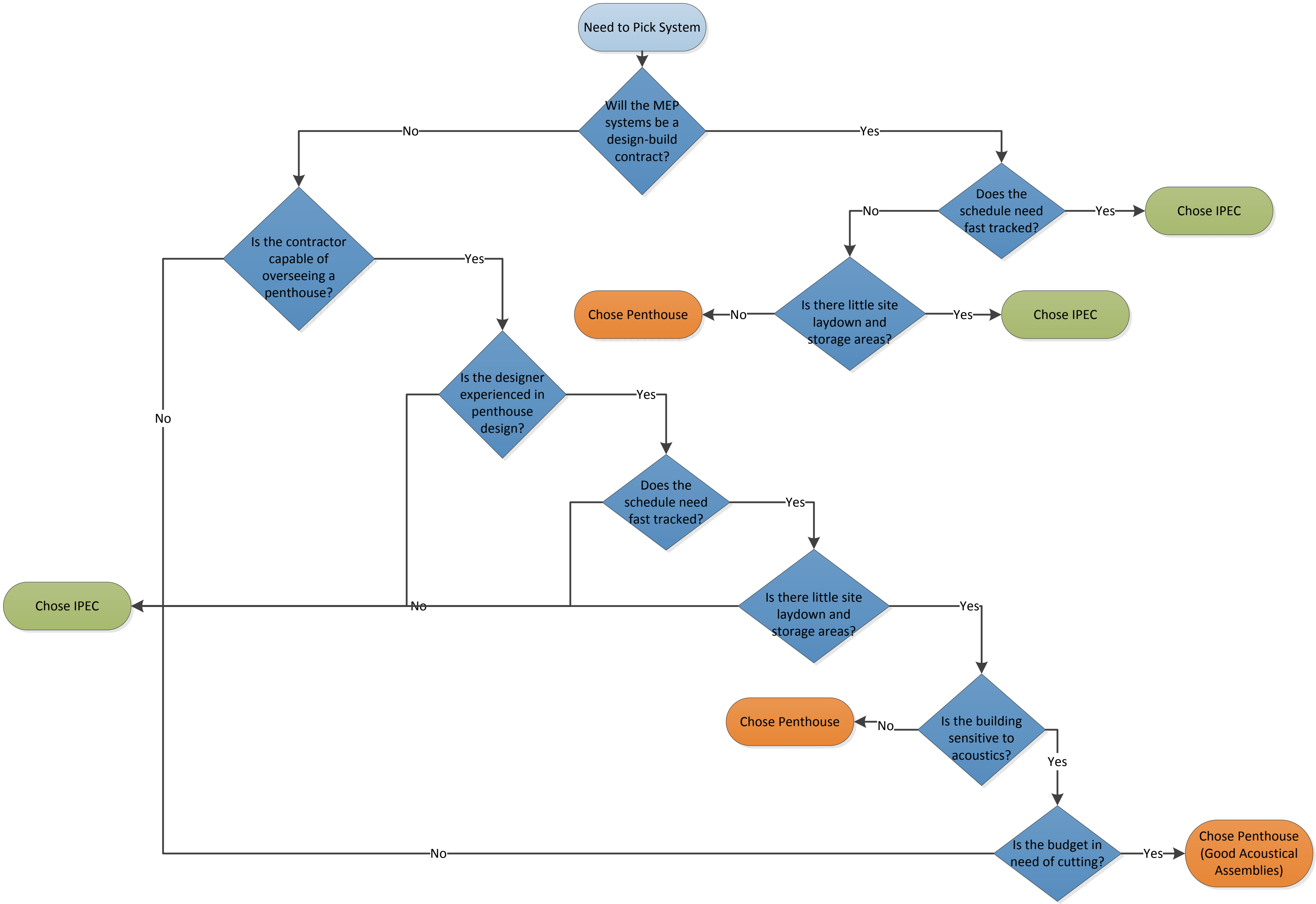
Prepared by: Lowell Stine

Data Release :Year 2013

Quantity	Assembly Number	Description	Unit	Productivity (units/day)	Crews	Duration (days)
4	D30201061080	Boiler, gas, cast iron, hot water, 1,088 MBH	Ea.	0.3	3	4.4
2	D30301154040	Packaged chiller, water cooled, with fan coil unit, offices, 60,000 SF, 190.00 ton	Ea.	0.1	3	6.7
2	D30501703680	Split system, air cooled condensing unit, offices, 20,000 SF, 63.32 ton	Ea.	0.4	1	5.0
5	D30203301030	Pump, base mounted with motor, end-suction, 4" size, 7-1/2 HP, to 350 GPM	Ea.	5	1	1.0
2	D30203301020	Pump, base mounted with motor, end-suction, 3" size, 5 HP, to 225 GPM	Ea.	7	1	0.3
2	D30203301040	Pump, base mounted with motor, end-suction, 5" size, 15 HP, to 1000 GPM	Ea.	3	1	0.7
11	D30203301010	Pump, base mounted with motor, end-suction, 2-1/2" size, 3 HP, to 150 GPM	Ea.	7	1	1.6
2	D30301103400	Packaged chiller, air cooled, with fan coil unit, offices, 6,000 SF, 19.00 ton	Ea.	0.3	1	6.7
1	D30406101010	Plate heat exchanger, 400 GPM	Ea.	0.8	1	1.3
2	D30402401040	Roof vent. system, power, centrifugal, aluminum, galvanized curb, back draft damper, 2750 CFM	Ea.	2	1	1.0
1	D30402401030	Roof vent. system, power, centrifugal, aluminum, galvanized curb, back draft damper, 1500 CFM	Ea.	2	1	0.5
1.33	D30401161050	AHU, rooftop, cool/heat coils, VAV, filters, 30,000 CFM	Ea.	0.3	1	4.4
1.1	D30401161030	AHU, rooftop, cool/heat coils, VAV, filters, 15,000 CFM	Ea.	0.3	1	3.7
					Total Days	37

Appendix O- Mechanical Room Selection Decision Tree

Decision Tree for Comparing IPEC vs. Penthouse



Created by: Lowell Stine

Appendix P- Caisson Analysis

Caisson Information and Splice Costs
Prepared by: Lowell Stine

				Planned	Actual	Difference							
Caisson Type #	Caisson Number	Diameter	Excavation Started	Planned Total LF	Actual Total LF	Total LF	Uplift?	Splice Type	Vertical Rebar #	Qty. of Vertical Rebar	Tie #	Cost per Splice	Cost per Splice Set
1a	X3-Y10	30	3/7/2013	27.03	22.86	-4.17	no	Lap	9	8	4	$ 9.78	$ 78.24
	W1-Y4	30	3/8/2013	28.28	37.68	9.40	no	Lap	9	8	4	$ 9.78	$ 78.24
	W1-Y6	30	3/8/2013	42.45	33.55	-8.90	no	Lap	9	8	4	$ 9.78	$ 78.24
	W1-Y3	30	3/11/2013	23.28	26.08	2.80	no	Lap	9	8	4	$ 9.78	$ 78.24
	W1-Y5	30	3/11/2013	33.28	29.58	-3.70	no	Lap	9	8	4	$ 9.78	$ 78.24
	W1-Y7	30	3/12/2013	42.03	32.03	-10.00	no	Lap	9	8	4	$ 9.78	$ 78.24
	X4-Y10	30	3/12/2013	28.28	25.28	-3.00	no	Lap	9	8	4	$ 9.78	$ 78.24
	X4-Y9	30	3/13/2013	37.03	35.53	-1.50	no	Lap	9	8	4	$ 9.78	$ 78.24
	X3-Y8	30	3/18/2013	42.03	28.73	-13.30	no	Lap	9	8	4	$ 9.78	$ 78.24
	1.5-X1	30	4/17/2013	31.87	28.87	-3.00	no	Lap	9	8	4	$ 9.78	$ 78.24
1b	CS8	30	3/20/2013	19.03	16.03	-3.00	no	Lap	9	6	4	$ 9.78	$ 58.68
	CS7	30	4/1/2013	11.03	7.03	-4.00	no	Lap	9	6	4	$ 9.78	$ 58.68
	CS22	30	4/1/2013	17.03	11.43	-5.60	no	Lap	9	6	4	$ 9.78	$ 58.68
	CS23	30	4/1/2013	24.03	7.33	-16.70	no	Lap	9	6	4	$ 9.78	$ 58.68
	CS4	30	4/2/2013	13.28	5.00	-8.28	no	Lap	9	6	4	$ 9.78	$ 58.68
	CS5	30	4/4/2013	15.28	5.00	-10.28	no	Lap	9	6	4	$ 9.78	$ 58.68
	CS6	30	4/16/2013	21.28	9.88	-11.40	no	Lap	9	6	4	$ 9.78	$ 58.68
	CS9	30	4/17/2013	33.37	20.16	-13.21	no	Lap	9	6	4	$ 9.78	$ 58.68
2a	4-D	48	3/9/2013	31.70	31.90	0.20	no	Mechanical	11	8	4	$ 63.20	$ 505.60
	3.5-X1	48	3/18/2013	22.78	12.98	-9.80	no	Mechanical	11	8	4	$ 63.20	$ 505.60
	2-C	48	3/19/2013	18.03	5.33	-12.70	no	Mechanical	11	8	4	$ 63.20	$ 505.60
	2.5-X1	48	3/30/2013	19.03	17.03	-2.00	no	Mechanical	11	8	4	$ 63.20	$ 505.60
	1.2-A.6	48	4/2/2013	9.28	5.00	-4.28	no	Mechanical	11	8	4	$ 63.20	$ 505.60
	2-A.3	48	4/2/2013	13.03	10.03	-3.00	no	Mechanical	11	8	4	$ 63.20	$ 505.60
	1-A.6	48	4/8/2013	8.12	5.00	-3.12	no	Mechanical	11	8	4	$ 63.20	$ 505.60
	1-D	48	4/11/2013	22.70	6.70	-16.00	no	Mechanical	11	8	4	$ 63.20	$ 505.60
2b	3-A.3	60	3/18/2013	23.03	11.13	-11.90	no	Mechanical	11	12	4	$ 63.20	$ 758.40
	3-C	60	3/20/2013	23.03	15.03	-8.00	no	Mechanical	11	12	4	$ 63.20	$ 758.40
	3-B	60	4/16/2013	23.11	14.91	-8.20	no	Mechanical	11	12	4	$ 63.20	$ 758.40
2c	1-E	72	4/18/2013	30.87	38.87	8.00	no	Mechanical	11	16	4	$ 63.20	$ 1,011.20
2d	2-D	84	4/1/2013	22.03	27.03	5.00	no	Mechanical	11	24	4	$ 63.20	$ 1,516.80
2e	CS19	72	2/20/2013	23.28	20.47	-2.81	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	CS21	72	2/21/2013	25.28	30.28	5.00	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	CS17	72	2/23/2013	23.28	20.28	-3.00	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	CS20	72	2/26/2013	24.28	30.61	6.33	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	CS18	72	3/4/2013	25.28	29.53	4.25	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	3-E	72	3/7/2013	24.28	21.53	-2.75	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	CS12	72	3/21/2013	22.45	15.40	-7.05	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	CS10	72	4/2/2013	17.45	17.40	-0.05	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	CS3	72	4/3/2013	15.28	6.00	-9.28	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	CS11	72	4/4/2013	19.45	14.28	-5.17	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	CS2	72	4/8/2013	9.28	6.00	-3.28	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	4-B	72	4/9/2013	20.45	12.08	-8.37	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	CS13	72	4/9/2013	20.45	8.98	-11.47	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	CS1	72	4/11/2013	13.28	6.00	-7.28	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
	CS14	72	4/17/2013	20.45	13.48	-6.97	no	Mechanical	11	28	5	$ 63.20	$ 1,769.60
2f	2-B	72	4/3/2013	15.36	15.25	-0.11	yes	Mechanical	11	16	4	$ 189.00	$ 3,024.00
2g	1-C	72	4/9/2013	21.03	10.22	-10.81	yes	Mechanical	11	28	5	$ 189.00	$ 5,292.00

Prefabricate 100% of Planned Wasted Costs
Prepared by: Lowell Stine

		Planned	Actual	Difference	Prefab 100% of Planned Length							
Caisson Type #	Caisson Number	Planned Total LF	Actual Total LF	Total LF	Prefab Length (LF)	# Of Splice Sets Added	# Of Splice Sets Add/ Wasted	Length Added (LF)	Length Wasted (LF)	Wasted Splice Set Costs	Wasted Length (LF)	Total Wasted Costs
1a	X3-Y10	27	23	-4	27	0	0	-	4	$ -	$ 121.80	$ 121.80
	W1-Y4	28	38	9	28	0	0	0	-	$ -	$ -	$ -
	W1-Y6	42	34	-9	42	0	0	-	0	$ -	$ -	$ -
	W1-Y3	23	26	3	23	0	0	0	-	$ -	$ -	$ -
	W1-Y5	33	30	-4	33	0	0	-	1	$ -	$ 29.21	$ 29.21
	W1-Y7	42	32	-10	42	0	1	-	10	$ 78.24	$ 292.09	$ 370.33
	X4-Y10	28	25	-3	28	0	0	-	3	$ -	$ 87.63	$ 87.63
	X4-Y9	37	36	-2	37	0	0	-	2	$ -	$ 43.81	$ 43.81
	X3-Y8	42	29	-13	42	0	1	-	13	$ 78.24	$ 388.48	$ 466.72
	1.5-X1	32	29	-3	32	0	0	-	3	$ -	$ 87.63	$ 87.63
									Totals	**$ 156.48**	**$ 1,050.65**	**$ 1,207.13**
1b	CS8	19	16	-3	19	0	0	-	3	$ -	$ 70.29	$ 70.29
	CS7	11	7	-4	11	0	0	-	4	$ -	$ 93.72	$ 93.72
	CS22	17	11	-6	17	0	0	-	6	$ -	$ 131.20	$ 131.20
	CS23	24	7	-17	24	0	0	-	17	$ -	$ 391.27	$ 391.27
	CS4	13	5	-8	13	0	0	-	8	$ -	$ 193.99	$ 193.99
	CS5	15	5	-10	15	0	0	-	10	$ -	$ 240.85	$ 240.85
	CS6	21	10	-11	21	0	0	-	11	$ -	$ 267.09	$ 267.09
	CS9	33	20	-13	33	0	1	-	13	$ 58.68	$ 309.50	$ 368.18
									Totals	**$ 58.68**	**$ 1,697.91**	**$ 1,756.59**
2a	4-D	32	32	0	32	0	0	-	-	$ -	$ -	$ -
	3.5-X1	23	13	-10	23	0	0	-	10	$ -	$ 445.49	$ 445.49
	2-C	18	5	-13	18	0	0	-	13	$ -	$ 577.32	$ 577.32
	2.5-X1	19	17	-2	19	0	0	-	2	$ -	$ 90.92	$ 90.92
	1.2-A.6	9	5	-4	9	0	0	-	4	$ -	$ 194.56	$ 194.56
	2-A.3	13	10	-3	13	0	0	-	3	$ -	$ 136.37	$ 136.37
	1-A.6	8	5	-3	8	0	0	-	3	$ -	$ 141.83	$ 141.83
	1-D	23	7	-16	23	0	0	-	16	$ -	$ 727.33	$ 727.33
									Totals	**$ -**	**$ 2,313.82**	**$ 2,313.82**
2b	3-A.3	23	11	-12	23	0	0	-	12	$ -	$ 781.63	$ 781.63
	3-C	23	15	-8	23	0	0	-	8	$ -	$ 525.46	$ 525.46
	3-B	23	15	-8	23	0	0	-	8	$ -	$ 538.60	$ 538.60
									Totals	**$ -**	**$ 1,845.69**	**$ 1,845.69**
2c	1-E	31	39	8	31	0	0	8	-	$ -	$ -	$ -
2d	2-D	22	27	5	22	1	1	5	-	$ 1,516.80	$ -	$ 1,516.80
2e	CS19	23	20	-3	23	0	0	-	3	$ -	$ 415.21	$ 415.21
	CS21	25	30	5	25	1	1	0	-	$ 1,769.60	$ -	$ 1,769.60
	CS17	23	20	-3	23	0	0	-	3	$ -	$ 443.29	$ 443.29
	CS20	24	31	6	24	1	1	0	-	$ 1,769.60	$ -	$ 1,769.60
	CS18	25	30	4	25	1	1	0	-	$ 1,769.60	$ -	$ 1,769.60
	3-E	24	22	-3	24	0	0	-	3	$ -	$ 406.35	$ 406.35
	CS12	22	15	-7	22	0	0	-	1	$ -	$ 147.76	$ 147.76
	CS10	17	17	0	17	0	0	-	-	$ -	$ -	$ -
	CS3	15	6	-9	15	0	0	-	9	$ -	$ 1,371.24	$ 1,371.24
	CS11	19	14	-5	19	0	0	-	0	$ -	$ -	$ -
	CS2	9	6	-3	9	0	0	-	-	$ -	$ -	$ -
	4-B	20	12	-8	20	0	0	-	4	$ -	$ 591.05	$ 591.05
	CS13	20	9	-11	20	0	0	-	11	$ -	$ 1,694.85	$ 1,694.85
	CS1	13	6	-7	13	0	0	-	7	$ -	$ 1,075.72	$ 1,075.72
	CS14	20	13	-7	20	0	0	-	7	$ -	$ 1,029.91	$ 1,029.91
									Totals	**$ 5,308.80**	**$ 7,175.39**	**$ 12,484.19**
2f	2-B	15	15	0	15	0	0	-	-	$ -	$ -	$ -
2g	1-C	21	10	-11	21	0	0	-	11	$ -	$ 1,827.72	$ 1,827.72
									Grand Totals	**$ 7,040.75**	**$ 15,911.19**	**$ 22,951.94**

** Orange highlighted boxes represent rebar cage lengths that were cut off as wasted lengths and reused as required lengths added to other cages.

Prefabricate Additional 10% of Planned Length Wasted Costs
Prepared by: Lowell Stine

		Planned	Actual	Difference	Prefab Additional 10% of Planned Length							
Caisson Type #	Caisson Number	Planned Total LF	Actual Total LF	Total LF	Prefab Length (LF)	# Of Splice Sets Added	# Of Splice Sets Add/ Wasted	Length Added (LF)	Length Wasted (LF)	Wasted Splice Set Costs	Wasted Length (LF)	Total Wasted Costs
1a	X3-Y10	27	23	-4	30	0	0	-	0	$ -	$ -	$ -
	W1-Y4	28	38	9	31	0	0	0	-	$ -	$ -	$ -
	W1-Y6	42	34	-9	47	0	0	-	13	$ -	$ 383.95	$ 383.95
	W1-Y3	23	26	3	26	0	0	-	-	$ -	$ -	$ -
	W1-Y5	33	30	-4	37	0	0	-	7	$ -	$ 205.28	$ 205.28
	W1-Y7	42	32	-10	46	0	0	-	14	$ -	$ 414.86	$ 414.86
	X4-Y10	28	25	-3	31	0	0	-	6	$ -	$ 170.23	$ 170.23
	X4-Y9	37	36	-2	41	0	0	-	5	$ -	$ 151.98	$ 151.98
	X3-Y8	42	29	-13	46	0	1	-	18	$ 78.24	$ 511.25	$ 589.49
	1.5-X1	32	29	-3	35	0	1	-	6	$ 78.24	$ 180.72	$ 258.96
									Totals	$ 156.48	$ 2,018.26	$ 2,174.74
1b	CS8	19	16	-3	21	0	0	-	5	$ -	$ 114.87	$ 114.87
	CS7	11	7	-4	12	0	0	-	5	$ -	$ 119.56	$ 119.56
	CS22	17	11	-6	19	0	0	-	7	$ -	$ 171.10	$ 171.10
	CS23	24	7	-17	26	0	0	-	19	$ -	$ 447.57	$ 447.57
	CS4	13	5	-8	15	0	0	-	10	$ -	$ 225.11	$ 225.11
	CS5	15	5	-10	17	0	0	-	12	$ -	$ 276.65	$ 276.65
	CS6	21	10	-11	23	0	0	-	14	$ -	$ 316.95	$ 316.95
	CS9	33	20	-13	37	0	1	-	17	$ 58.68	$ 387.68	$ 446.36
									Totals	$ 58.68	$ 2,059.49	$ 2,118.17
2a	4-D	32	32	0	35	0	1	-	3	$ 505.60	$ -	$ 505.60
	3.5-X1	23	13	-10	25	0	0	-	12	$ -	$ 549.04	$ 549.04
	2-C	18	5	-13	20	0	0	-	15	$ -	$ 659.28	$ 659.28
	2.5-X1	19	17	-2	21	0	0	-	4	$ -	$ 177.42	$ 177.42
	1.2-A.6	9	5	-4	10	0	0	-	5	$ -	$ 236.75	$ 236.75
	2-A.3	13	10	-3	14	0	0	-	4	$ -	$ 195.61	$ 195.61
	1-A.6	8	5	-3	9	0	0	-	4	$ -	$ 178.74	$ 178.74
	1-D	23	7	-16	25	0	0	-	18	$ -	$ 830.52	$ 830.52
									Totals	$ 505.60	$ 2,827.37	$ 3,332.97
2b	3-A.3	23	11	-12	25	0	0	-	14	$ -	$ 932.89	$ 932.89
	3-C	23	15	-8	25	0	0	-	10	$ -	$ 676.73	$ 676.73
	3-B	23	15	-8	25	0	0	-	11	$ -	$ 690.39	$ 690.39
									Totals	$ -	$ 2,300.02	$ 2,300.02
2c	1-E	31	39	8	34	0	1	5	-	$ 1,011.20	$ -	$ 1,011.20
2d	2-D	22	27	5	24	1	1	3	-	$ 1,516.80	$ -	$ 1,516.80
2e	CS19	23	20	-3	26	0	0	-	1	$ -	$ 147.76	$ 147.76
	CS21	25	30	5	28	1	1	0	-	$ 1,769.60	$ -	$ 1,769.60
	CS17	23	20	-3	26	0	0	-	3	$ -	$ 443.29	$ 443.29
	CS20	24	31	6	27	1	1	0	-	$ 1,769.60	$ -	$ 1,769.60
	CS18	25	30	4	28	1	1	0	-	$ 1,769.60	$ -	$ 1,769.60
	3-E	24	22	-3	27	0	0	-	5	$ -	$ 765.12	$ 765.12
	CS12	22	15	-7	25	0	0	-	9	$ -	$ 1,373.46	$ 1,373.46
	CS10	17	17	0	19	0	0	-	0	$ -	$ -	$ -
	CS3	15	6	-9	17	0	0	-	11	$ -	$ 1,597.03	$ 1,597.03
	CS11	19	14	-5	21	0	0	-	7	$ -	$ 1,051.34	$ 1,051.34
	CS2	9	6	-3	10	0	0	-	4	$ -	$ 621.79	$ 621.79
	4-B	20	12	-8	22	0	0	-	10	$ -	$ 1,538.95	$ 1,538.95
	CS13	20	9	-11	22	0	0	-	14	$ -	$ 1,997.02	$ 1,997.02
	CS1	13	6	-7	15	0	0	-	9	$ -	$ 1,271.95	$ 1,271.95
	CS14	20	13	-7	22	0	0	-	9	$ -	$ 1,332.09	$ 1,332.09
									Totals	$ 5,308.80	$ 12,139.79	$ 17,448.59
2f	2-B	15	15	0	17	0	0	-	2	$ -	$ 243.22	$ 243.22
2g	1-C	21	10	-11	23	0	0	-	13	$ -	$ 2,183.29	$ 2,183.29
									Grand Totals	$ 8,557.55	$ 23,771.44	$ 32,329.00

** Orange highlighted boxes represent rebar cage lengths that were cut off as wasted lengths and reused as required lengths added to other cages.

Prefabricate 80% of Planned Lengths Wasted Costs

Prepared by: Lowell Stine

		Planned	Actual	Prefab 80% of Planned Length & Site Build Remaining						
Caisson Type #	Caisson Number	Planned Total LF	Actual Total LF	Prefab Length (LF)	# Of Splice Sets Add/ Wasted	Length Added (LF)	Length Wasted (LF)	Wasted Splice Set Costs	Wasted Length (LF)	Total Wasted Costs
1a	X3-Y10	27	23	23	0	-	-	$ -	$ -	$ -
	W1-Y4	28	38	23	0	15	-	$ -	$ -	$ -
	W1-Y6	42	34	34	0	-	-	$ -	$ -	$ -
	W1-Y3	23	26	19	1	7	-	$ 78.24	$ -	$ 78.24
	W1-Y5	33	30	27	1	3	-	$ 78.24	$ -	$ 78.24
	W1-Y7	42	32	34	0	-	2	$ -	$ 46.56	$ 46.56
	X4-Y10	28	25	23	1	3	-	$ 78.24	$ -	$ 78.24
	X4-Y9	37	36	30	0	6	-	$ -	$ -	$ -
	X3-Y8	42	29	34	1	-	5	$ 78.24	$ 142.95	$ 221.19
	1.5-X1	32	29	25	1	3	-	$ 78.24	$ -	$ 78.24
							Totals	**$ 391.19**	**$ 189.51**	**$ 580.70**
1b	CS8	19	16	16	0	-	-	$ -	$ -	$ -
	CS7	11	7	9	0	-	2	$ -	$ 42.03	$ 42.03
	CS22	17	11	14	0	-	2	$ -	$ 51.40	$ 51.40
	CS23	24	7	19	0	-	12	$ -	$ 278.67	$ 278.67
	CS4	13	5	11	0	-	6	$ -	$ 131.77	$ 131.77
	CS5	15	5	12	0	-	7	$ -	$ 169.25	$ 169.25
	CS6	21	10	17	0	-	7	$ -	$ 167.38	$ 167.38
	CS9	33	20	27	0	-	7	$ -	$ 153.13	$ 153.13
							Totals	**$ -**	**$ 993.63**	**$ 993.63**
2a	4-D	32	32	25	0	7	-	$ -	$ -	$ -
	3.5-X1	23	13	18	0	-	5	$ -	$ 238.38	$ 238.38
	2-C	18	5	14	0	-	9	$ -	$ 413.40	$ 413.40
	2.5-X1	19	17	15	1	2	-	$ 505.60	$ -	$ 505.60
	1.2-A.6	9	5	7	0	-	2	$ -	$ 110.19	$ 110.19
	2-A.3	13	10	10	0	-	-	$ -	$ -	$ -
	1-A.6	8	5	6	0	-	1	$ -	$ 68.01	$ 68.01
	1-D	23	7	18	0	-	11	$ -	$ 520.95	$ 520.95
							Totals	**$ 505.60**	**$ 1,350.93**	**$ 1,856.53**
2b	3-A.3	23	11	18	0	-	7	$ -	$ 479.09	$ 479.09
	3-C	23	15	18	0	-	3	$ -	$ 222.93	$ 222.93
	3-B	23	15	18	0	-	4	$ -	$ 235.01	$ 235.01
							Totals	**$ -**	**$ 937.03**	**$ 937.03**
2c	1-E	31	39	25	0	14	-	**$ -**	**$ -**	**$ -**
2d	2-D	22	27	18	1	9	-	**$ 1,516.80**	**$ -**	**$ 1,516.80**
2e	CS19	23	20	20	0	-	-	$ -	$ -	$ -
	CS21	25	30	20	1	10	-	$ 1,769.60	$ -	$ 1,769.60
	CS17	23	20	20	0	-	-	$ -	$ -	$ -
	CS20	24	31	19	1	11	-	$ 1,769.60	$ -	$ 1,769.60
	CS18	25	30	20	1	9	-	$ 1,769.60	$ -	$ 1,769.60
	3-E	24	22	19	1	2	-	$ 1,769.60	$ -	$ 1,769.60
	CS12	22	15	18	0	-	3	$ -	$ 378.27	$ 378.27
	CS10	17	17	14	1	3	-	$ 1,769.60	$ -	$ 1,769.60
	CS3	15	6	12	0	-	6	$ -	$ 919.68	$ 919.68
	CS11	19	14	16	0	-	1	$ -	$ 189.14	$ 189.14
	CS2	9	6	7	0	-	1	$ -	$ 210.41	$ 210.41
	4-B	20	12	16	0	-	4	$ -	$ 632.43	$ 632.43
	CS13	20	9	16	0	-	7	$ -	$ 1,090.49	$ 1,090.49
	CS1	13	6	11	0	-	5	$ -	$ 683.26	$ 683.26
	CS14	20	13	16	0	-	3	$ -	$ 425.56	$ 425.56
							Totals	**$ 8,848.00**	**$ 4,529.24**	**$ 13,377.24**
2f	2-B	15	15	12	1	3	-	**$ 3,024.00**	**$ -**	**$ 3,024.00**
2g	1-C	21	10	17	0	-	7	**$ -**	**$ 1,116.59**	**$ 1,116.59**
							Grand Totals	**$ 14,285.59**	**$ 9,116.93**	**$ 23,402.52**

Prefabricate 10' Cage Lengths Wasted Costs
Prepared by: Lowell Stine

		Actual	Prefab 10' Cage Lengths					
Caisson Type #	Caisson Number	Actual Total LF	# of 10' Cage Lengths (LF)	# Of Splice Sets Add/ Wasted	Length Wasted (LF)	Wasted Splice Set Costs	Wasted Length (LF)	Total Wasted Costs
1a	X3-Y10	23	3	2	7	$ 156.48	$ 208.55	$ 365.03
	W1-Y4	38	4	2	2	$ 156.48	$ -	$ 156.48
	W1-Y6	34	4	2	6	$ 156.48	$ 188.40	$ 344.88
	W1-Y3	26	3	2	4	$ 156.48	$ -	$ 156.48
	W1-Y5	30	3	2	0	$ 156.48	$ 12.27	$ 168.74
	W1-Y7	32	4	2	8	$ 156.48	$ 232.80	$ 389.27
	X4-Y10	25	3	2	5	$ 156.48	$ 137.87	$ 294.34
	X4-Y9	36	4	2	4	$ 156.48	$ 130.56	$ 287.04
	X3-Y8	29	3	2	1	$ 156.48	$ 37.10	$ 193.57
	1.5-X1	29	3	2	1	$ 156.48	$ 33.01	$ 189.48
					Totals	**$ 1,564.76**	**$ 980.55**	**$ 2,545.31**
1b	CS8	16	2	1	4	$ 58.68	$ 93.01	$ 151.69
	CS7	7	1	0	3	$ -	$ 69.58	$ 69.58
	CS22	11	1	0	0	$ -	$ -	$ -
	CS23	7	1	0	3	$ -	$ 62.56	$ 62.56
	CS4	5	1	0	5	$ -	$ 117.15	$ 117.15
	CS5	5	1	0	5	$ -	$ 117.15	$ 117.15
	CS6	10	1	0	0	$ -	$ 2.81	$ 2.81
	CS9	20	2	1	0	$ 58.68	$ -	$ 58.68
					Totals	**$ 117.36**	**$ 462.26**	**$ 579.61**
2a	4-D	32	4	2	8	$ 1,011.20	$ 368.21	$ 1,379.41
	3.5-X1	13	2	1	7	$ 505.60	$ 319.12	$ 824.72
	2-C	5	1	0	5	$ -	$ 212.29	$ 212.29
	2.5-X1	17	2	1	3	$ 505.60	$ 135.01	$ 640.61
	1.2-A.6	5	1	0	5	$ -	$ 227.29	$ 227.29
	2-A.3	10	1	0	0	$ -	$ -	$ -
	1-A.6	5	1	0	5	$ -	$ 227.29	$ 227.29
	1-D	7	1	0	3	$ -	$ 150.01	$ 150.01
					Totals	**$ 2,022.40**	**$ 1,639.22**	**$ 3,661.62**
2b	3-A.3	11	1	0	0	$ -	$ -	$ -
	3-C	15	2	1	5	$ 758.40	$ 326.44	$ 1,084.84
	3-B	15	2	1	5	$ 758.40	$ 334.33	$ 1,092.73
					Totals	**$ 1,516.80**	**$ 660.77**	**$ 2,177.57**
2c	1-E	39	4	2	1	**$ 2,022.40**	**$ -**	**$ 2,022.40**
2d	2-D	27	3	2	3	**$ 3,033.60**	**$ -**	**$ 3,033.60**
2e	CS19	20	2	1	0	$ 1,769.60	$ -	$ 1,769.60
	CS21	30	3	2	0	$ 3,539.20	$ -	$ 3,539.20
	CS17	20	2	1	0	$ 1,769.60	$ -	$ 1,769.60
	CS20	31	3	2	0	$ 3,539.20	$ -	$ 3,539.20
	CS18	30	3	2	0	$ 3,539.20	$ -	$ 3,539.20
	3-E	22	3	2	8	$ 3,539.20	$ 1,251.56	$ 4,790.76
	CS12	15	2	1	5	$ 1,769.60	$ 679.71	$ 2,449.31
	CS10	17	2	1	3	$ 1,769.60	$ 384.18	$ 2,153.78
	CS3	6	1	0	4	$ -	$ 591.05	$ 591.05
	CS11	14	2	1	6	$ 1,769.60	$ 845.21	$ 2,614.81
	CS2	6	1	0	4	$ -	$ 591.05	$ 591.05
	4-B	12	2	1	8	$ 1,769.60	$ 1,170.29	$ 2,939.89
	CS13	9	1	0	1	$ -	$ 150.72	$ 150.72
	CS1	6	1	0	4	$ -	$ 591.05	$ 591.05
	CS14	13	2	1	7	$ 1,769.60	$ 963.42	$ 2,733.02
					Totals	**$ 26,544.00**	**$ 7,218.24**	**$ 33,762.24**
2f	2-B	15	2	1	5	**$ 3,024.00**	**$ 701.88**	**$ 3,725.88**
2g	1-C	10	1	0	0	**$ -**	**$ -**	**$ -**
					Grand Totals	**$ 39,845.32**	**$ 11,662.92**	**$ 51,508.23**

Prefabricate 15' Cage Lengths Wasted Costs

Prepared by: Lowell Stine

		Actual	Prefab 15' Cage Lengths					
Caisson Type #	Caisson Number	Actual Total LF	# of 15' Cage Lengths (LF)	# Of Splice Sets Add/ Wasted	Length Wasted (LF)	Wasted Splice Set Costs	Wasted Length (LF)	Total Wasted Costs
1a	X3-Y10	23	2	1	0	$ 78.24	$ -	$ 78.24
	W1-Y4	38	3	1	7	$ 78.24	$ -	$ 78.24
	W1-Y6	34	3	1	0	$ 78.24	$ -	$ 78.24
	W1-Y3	26	2	1	0	$ 78.24	$ -	$ 78.24
	W1-Y5	30	2	1	0	$ 78.24	$ 12.27	$ 90.51
	W1-Y7	32	3	1	6	$ 78.24	$ 175.25	$ 253.49
	X4-Y10	25	2	1	0	$ 78.24	$ -	$ 78.24
	X4-Y9	36	3	1	0	$ 78.24	$ -	$ 78.24
	X3-Y8	29	2	1	1	$ 78.24	$ 37.10	$ 115.33
	1.5-X1	29	2	1	1	$ 78.24	$ 33.01	$ 111.24
					Totals	**$ 782.38**	**$ 257.62**	**$ 1,040.01**
1b	CS8	16	1	0	0	$ -	$ -	$ -
	CS7	7	1	0	0	$ -	$ -	$ -
	CS22	11	1	0	4	$ -	$ 83.64	$ 83.64
	CS23	7	1	0	1	$ -	$ 23.43	$ 23.43
	CS4	5	1	0	0	$ -	$ -	$ -
	CS5	5	1	0	0	$ -	$ -	$ -
	CS6	10	1	0	5	$ -	$ 119.96	$ 119.96
	CS9	20	2	1	0	$ 58.68	$ -	$ 58.68
					Totals	**$ 58.68**	**$ 227.03**	**$ 285.71**
2a	4-D	32	3	1	0	$ 505.60	$ -	$ 505.60
	3.5-X1	13	1	0	2	$ -	$ 91.83	$ 91.83
	2-C	5	1	0	0	$ -	$ -	$ -
	2.5-X1	17	2	1	3	$ 505.60	$ 136.37	$ 641.97
	1.2-A.6	5	1	0	0	$ -	$ -	$ -
	2-A.3	10	1	0	0	$ -	$ -	$ -
	1-A.6	5	1	0	0	$ -	$ -	$ -
	1-D	7	1	0	6	$ -	$ 272.75	$ 272.75
					Totals	**$ 1,011.20**	**$ 500.95**	**$ 1,512.15**
2b	3-A.3	11	1	0	4	$ -	$ 254.19	$ 254.19
	3-C	15	1	0	0	$ -	$ -	$ -
	3-B	15	1	0	0	$ -	$ 5.91	$ 5.91
					Totals	**$ -**	**$ 260.10**	**$ 260.10**
2c	1-E	39	3	1	6	**$ 1,011.20**	**$ -**	**$ 1,011.20**
2d	2-D	27	2	1	3	**$ 1,516.80**	**$ -**	**$ 1,516.80**
2e	CS19	20	2	1	0	$ 1,769.60	$ -	$ 1,769.60
	CS21	30	2	1	0	$ 1,769.60	$ -	$ 1,769.60
	CS17	20	2	1	4	$ 1,769.60	$ 591.05	$ 2,360.65
	CS20	31	2	1	0	$ 1,769.60	$ -	$ 1,769.60
	CS18	30	2	1	0	$ 1,769.60	$ -	$ 1,769.60
	3-E	22	2	1	2	$ 1,769.60	$ 295.53	$ 2,065.13
	CS12	15	1	0	0	$ -	$ -	$ -
	CS10	17	2	1	0	$ 1,769.60	$ -	$ 1,769.60
	CS3	6	1	0	0	$ -	$ -	$ -
	CS11	14	1	0	1	$ -	$ 106.39	$ 106.39
	CS2	6	1	0	0	$ -	$ -	$ -
	4-B	12	1	0	3	$ -	$ 431.47	$ 431.47
	CS13	9	1	0	1	$ -	$ 147.76	$ 147.76
	CS1	6	1	0	9	$ -	$ 1,329.87	$ 1,329.87
	CS14	13	1	0	0	$ -	$ -	$ -
					Totals	**$ 12,387.20**	**$ 2,902.07**	**$ 15,289.27**
2f	2-B	15	1	0	0	**$ -**	**$ -**	**$ -**
2g	1-C	10	1	0	5	**$ -**	**$ 808.19**	**$ 808.19**
					Grand Totals	**$ 16,767.46**	**$ 4,955.97**	**$ 21,723.43**

** Orange highlighted boxes represent rebar cage lengths that were cut off as wasted lengths and reused as required lengths added to other cages.

Prefabricate Summary of Wasted Costs
Prepared by: Lowell Stine

	100% Method			10% Extra Method			80% Method			10' Length Method			15' Length Method		
Caisson Type #	Wasted Splice Set Costs	Wasted Length (LF)	Total Wasted Costs	Wasted Splice Set Costs	Wasted Length (LF)	Total Wasted Costs	Wasted Splice Set Costs	Wasted Length (LF)	Total Wasted Costs	Wasted Splice Set Costs	Wasted Length (LF)	Total Wasted Costs	Wasted Splice Set Costs	Wasted Length (LF)	Total Wasted Costs
1a	$ 156.48	$ 1,050.65	$ 1,207.13	$ 156.48	$ 2,018.26	$ 2,018.26	$ 391.19	$ 189.51	$ 580.70	$ 1,564.76	$ 980.55	$ 2,545.31	$ 782.38	$ 257.62	$ 1,040.01
1b	$ 58.68	$ 1,697.91	$ 1,756.59	$ 58.68	$ 2,059.49	$ 2,059.49	$ -	$ 993.63	$ 993.63	$ 117.36	$ 462.26	$ 579.61	$ 58.68	$ 227.03	$ 285.71
2a	$ -	$ 2,313.82	$ 2,313.82	$ 505.60	$ 2,827.37	$ 2,827.37	$ 505.60	$ 1,350.93	$ 1,856.53	$ 2,022.40	$ 1,639.22	$ 3,661.62	$ 1,011.20	$ 500.95	$ 1,512.15
2b	$ -	$ 1,845.69	$ 1,845.69	$ -	$ 2,300.02	$ 2,300.02	$ -	$ 937.03	$ 937.03	$ 1,516.80	$ 660.77	$ 2,177.57	$ -	$ 260.10	$ 260.10
2c	$ -	$ -	$ -	$ 1,011.20	$ -	$ -	$ -	$ -	$ -	$ 2,022.40	$ -	$ 2,022.40	$ 1,011.20	$ -	$ 1,011.20
2d	$ 1,516.80	$ -	$ 1,516.80	$ 1,516.80	$ -	$ -	$ 1,516.80	$ -	$ 1,516.80	$ 3,033.60	$ -	$ 3,033.60	$ 1,516.80	$ -	$ 1,516.80
2e	$ 5,308.80	$ 7,175.39	$ 12,484.19	$ 5,308.80	$ 12,139.79	$ 12,139.79	$ 8,848.00	$ 4,529.24	$ 13,377.24	$ 26,544.00	$ 7,218.24	$ 33,762.24	$ 12,387.20	$ 2,902.07	$ 15,289.27
2f	$ -	$ -	$ -	$ -	$ 243.22	$ 243.22	$ 3,024.00	$ -	$ 3,024.00	$ 3,024.00	$ 701.88	$ 3,725.88	$ -	$ -	$ -
2g	$ -	$ 1,827.72	$ 1,827.72	$ -	$ 2,183.29	$ 2,183.29	$ -	$ 1,116.59	$ 1,116.59	$ -	$ -	$ -	$ -	$ 808.19	$ 808.19
Grand Totals	$ 7,040.75	$ 15,911.19	$ 22,951.94	$ 8,557.55	$ 23,771.44	$ 32,329.00	$ 14,285.59	$ 9,116.93	$ 23,402.52	$ 39,845.32	$ 11,662.92	$ 51,508.23	$ 16,767.46	$ 4,955.97	$ 21,723.43