Northeastern Pennsylvania Office Building

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Construction Management

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April 4, 2012

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Project Team

Owner: Requested to Remain Anonymous

Architect: Requested to Remain Anonymous

CM/GC: LeChase Construction Services, LLC

MEP & Site Engineer: Larson Design Group, LLC

Geotechnical Engineer: CME Associates, Inc.

Building Statistics

Function: Office Building and Shop Building with 4 Work Bays and a Wash Bay

Size: 26,070 SF (Office—11,355 SF/ Shop—14,715 SF)

Number of Stories: Single Story Above Grade

Construction Schedule: June 2011—March 2012

Cost: $5.4 Million

Delivery Method: Design-Bid-Build

Lighting/Electrical

- 480/277 Volt, 800 Amp Supply from Utility Transformer to 2 Panels that Service All Lighting and Overhead Door Motors
- 2 Transformers Step Down 480/277 Volts to 208/120 Volt to Service 5 Panels that Service All Other Electrical Services in Both Buildings
- On-site Generator Provides a Fully Redundant System

Architecture and Structure

Foundation: Grade Beams, Pier Footings, Slab-on-Grade

Structural System: Pre-Engineered Metal Building (Steel Frames, Laterally Braced with Purlins)

Façade: 26-Ga. Corrugated Galvalume Panels

Roof: 26-Ga. Corrugated Galvalume Panels

Site: Includes 50 Parking Spaces, 19 Acre Gravel Laydown Area for Materials

Expansion Possibilities: Expand the Office Building into the Neighboring Gravel Laydown Area

Mechanical

- Conditioned Air System Services the Office Building
- 10 Gas Furnaces/Condensing Units Provide Conditioned Air that is Distributed Throughout the Space by a System of Metal Ductwork
- 2 Energy Recovery Ventilators Maintain a Minimum Outside Air Level Required by Code
- 12 Gas-Fired Infrared Heaters and Ceiling-Mounted Fans Service the Shop Building

Executive Summary

The Northeastern Pennsylvania Office Building is a single story project that contains an approximately 11,000 SF office building and an approximately 14,000 SF shop building. The office building will accommodate about fifty employees, while the shop building will contain four truck work bays and one wash bay. Construction is scheduled to last nine months and cost approximately $5.4 million. The owner has requested that the project name and location remain anonymous for this study.

The first analysis will determine whether an alternate structural system could replace the current pre-engineered metal building. Alternate structural systems include standard steel, cast-in-place concrete, and tilt-up concrete panels. Out of these three possible systems, the single best alternate will be further analyzed. A structural analysis will be performed to size the components of the system so that cost and duration data can be directly compared to that of the pre-engineered metal building.

Since there are two later phases of this project (Phase 2 & 3) that are nearly identical to the Northeastern Pennsylvania Office Building, the second analysis will determine whether or not these phases could be delivered as design-build projects. If it is determined that Phase 2 & 3 could be delivered in this manner, potential cost savings and schedule acceleration will be determined.

The third analysis of this report will be based on a hypothetical situation that may eventually arise for the later phases of this project. The scenario is that the owner has requested to double the size of the office building portion of the project while it is in the schematic phase of design. Expansion options that have been suggested are a vertical expansion or a horizontal expansion. This analysis will consider cost, schedule, function, and aesthetical impacts for both options. The most suitable expansion option for this project will then be recommended for further design.

The final analysis for the Northeastern Pennsylvania Office Building will be determining whether or not a geothermal system could be installed in the shop building. In order to compile cost and schedule data for the alternate system, a mechanical analysis must be performed to size the components of the system. Once the components have been sized, the initial cost and schedule data will be directly compared to that of the current natural gas heating system. Other factors, such as possible cooling effects and impacts on the environment will also be considered when comparing the two systems. The most suitable heating system for the Northeastern Pennsylvania Office Building will then be recommended to be used on this project.

Credits & Acknowledgements

I would first and foremost like to thank my family and friends who have supported and guided me during my time in the Architectural Engineering program at The Pennsylvania State University over the past five years.

I would also like to thank the following individuals for their time, patience, and consideration in assisting me as I completed my thesis over this past year:

LeChase Construction Services, LLC

John Pepper – Project Manager

Kevin Jordan – Project Superintendent

Larson Design Group, LLC

Dave Young – Site Engineer

McClure Company

Alyssa Adams – Energy Services Specialist

Poole-Anderson Construction, LLC

Rick Lawrence – Project Manager

Tom Brasher – Project Manager

Penn State Architectural Engineering Faculty

Professor Kevin Parfitt

Professor Robert Holland

Dr. Chimay Anumba

Dr. Thomas Booth

Dr. Robert Leicht

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Introduction

The Northeastern Pennsylvania Office Building is being constructed to provide additional office and shop space for a subsidiary company of the project's owner. The owner has requested to remain anonymous for undisclosed reasons. In accordance with this request, the project name, the project location, and the architect's name will also be withheld from this report.

The project is the first phase of five phase project on the outskirts of a rural community in northeastern Pennsylvania. Phase 1 of the project consists of two single-story buildings on a nineteen acre site. Security fencing will surround the site to enclose a gravel laydown yard that will allow the owner to store materials and equipment after project completion. Construction on the Northeastern Pennsylvania Office Building was scheduled to begin June 14, 2011 and be completed March 9, 2012. The project was expected to cost approximately $5.4 million to construct.

The office building is approximately 11,500 square feet and will house forty offices, a conference room, two break rooms, a reception and waiting area, and multiple restrooms and mechanical rooms. The shop building, about 14,700 square feet, will contain four work bays, a wash bay, and an equipment room.

Project Background

Project Delivery System

Due to a request from the project owner for this project to remain confidential, the owner, design architect, architect of record, mechanical contractor, and electrical contractor will remain anonymous. The only companies permitted to be addressed directly are the construction manager and general contractor, LeChase Construction Services, LLC, and the engineering team, Larson Design Group, LLC.

The construction contract between the owner and LeChase Construction on the Northeastern Pennsylvania Office Building is a standard AIA Owner/Contractor Agreement with a lump-sum agreement. The project was delivered under a design-bid-build method where LeChase was chosen based on a low-bid selection process. The design architect for the Northeastern Pennsylvania Office Building was chosen because of a long-term working relationship with the owner. Also, the architect of record was chosen for this project because they are owned by the same entity that owns the design architect. Larson Design Group, the mechanical contractor, and the electrical contractor were all chosen because they are local firms that won their respective scopes of work based on a low-bid selection process.

Since the Northeastern Pennsylvania Office building is the first phase of a multi-phase project, it should be noted that the design architect, the architect of record, and Larson Design Group have been contracted to work on the later phases of this project. The CM/GC and all other contractors for later phases will be chosen based on a low-bid selection process.

A visual representation of the project delivery system can be found as “Figure 1. Project Delivery System” in the “Referenced Material” section of this report.

Construction Management Organizational Chart

As the construction manager and general contractor for the Northeastern Pennsylvania Office Building, LeChase Construction's staffing plan for this project includes nine key players, along with several subcontractors. The team members that have the most executive control in their staffing plan are the company's president & CEO, executive vice president, and senior vice president. Since these individuals are responsible for company-based decisions, monitoring this particular project may not be atop their daily tasks. Therefore, the senior operations manager and field operations manager report the monitoring of this project to their superiors. These managers oversee all company projects and monitor the work of all project managers.

The project manager for the Northeastern Pennsylvania Office Building is responsible for properly managing, budgeting, and providing direction for the work that is to be completed. He also coordinates and communicates on a daily basis between field personnel, the architect, and the owner's representative. The project manager receives assistance with much of the project's technical and financial documentation for the project engineer. Examples of the type of documentation that the project engineer is responsible for completing include submittals, requests for information, and change order requests. The safety & quality engineer of this project was responsible for creating a site-specific safety plan, as well as ensure that all field personnel had a valid OSHA certification.

In the field, subcontractors must be monitored and directed by a representative of the CM/GC in order to ensure that the correct work is being performed. The project superintendent on this project is responsible for communicating with the subcontractors, giving directions as to what work is to be completed, monitoring the quality of the work in place, and ensuring that the project is remaining on schedule. The superintendent reports directly to the project manager with issues and updates on a daily basis.

A visual representation of the project delivery system can be found as "Figure 2. CM/GC Staffing Plan" in the "Referenced Material" section of this report.

Site Conditions and Local Conditions

The Northeastern Pennsylvania Office Building is located on an open grass lot on the outskirts of a rural community in Northeastern Pennsylvania. There are no existing buildings on or near the Phase 1 site. In fact, the only intrusion above ground is an existing electrical line that transitions from underground to overhead on the south side of the project site.

The survey of the site that was performed indicates that the existing grade generally slopes downward in the easterly direction with approximately one foot of elevation change across the shop building footprint and approximately six feet of elevation change across the office building footprint. This can be seen in “Figure 3. Site Topography and Boring Test Locations” in the “Reference Materials” section of this report.

A geotechnical report that was performed indicated that the entire site contains two to six inches of topsoil at grade. The topsoil tested was underlain by organic-rich soils. Below these layers of surfacing, the boring samples identified a “silty sand stratum”, underlain by a “silty sand and gravel stratum”. The “silty sand stratum” consists of predominately silt mixed with lesser amounts of sand, gravel, and clay. This stratum was discovered to exist from approximately two to four feet below grade and is considered medium-stiff in consistency. The “silty sand and gravel stratum” consists of silty sand and gravel with lesser amounts of clay. This stratum’s depth was determined to be about ten to twenty-five feet deep and is considered stiff. No potentially expansive soils were identified within the boring depths on the jobsite. All site soils are considered conductive to infiltration of stormwater.

The groundwater level across the site was observed by performing boring tests at thirteen different locations. The depth of the water ranged from seven feet to over thirteen feet beneath the soil surface, with an average depth of about nine and one-half feet beneath the soil surface.

One concern that the local township authorities have with the construction of the Northeastern Pennsylvania Office Building involves the permeability of the gravel laydown yard for stormwater drainage to the soils beneath the yard. The township authorities are concerned that if the contractor does not use the proper aggregate sizes and gradation on the site, water will not be able to properly permeate and will cause pooling of water.

Another concern that the local authorities have with the construction of this project is that the replacement of the open grass lot with buildings and gravel laydown yards may create an undesirable “heat island” effect due to the lack of vegetation in the area. To combat this effect, the later phases of construction that are still in the design phase will be landscaped to maximize the amount of vegetation on the total project site.

Architecture

The Northeastern Pennsylvania Office Building's aesthetical appearance is that of an industrial nature for both the shop building and office building. Galvalume metal siding will wrap both buildings on the exterior walls and will also be used as a roofing material. Although the metal siding is reflective and will inhibit the absorption of heat from sunlight, it does not give the project a visually stimulating appearance. Other than large garage-style doors on the shop building and standard windows on the office building, there are no other architectural features on either building that are significant.

Structural System

A pre-engineered metal structure is used to support both the shop building and office building of the Northeastern Pennsylvania Office Building. Pre-engineered metal buildings are typically chosen for projects such as this because they are generally cost effective and easy to erect without the use of a crane.

The main component of the pre-engineered metal structure is the metal frames. The frames consist of four pieces of rolled steel that may or may not taper from one end to the other. The four pieces of steel are bolted and/or welded together to form a three-sided frame that is composed of two vertical lengths and one horizontal section with a bolted connection in the length. On this project, there are nineteen of these frames across the two buildings. Refer to "Figure 4. Pre-Engineered Metal Building Frames and Locations" to see the shapes and location of the different types of frames used on this project.

The structural steel frames are securely bolted to concrete pier footings. These concrete piers transfer the load from the frames down to concrete spread footings. Spread footings are used to then transfer the load to the soil beneath. Both the concrete piers and concrete spread footings are reinforced with steel reinforcing.

Mechanical System

Different mechanical systems will be used to condition each building of the Northeastern Pennsylvania Office Building project. The office building will be heated with ten natural gas furnaces located in three mechanical rooms located throughout the building. Metal ducts will distribute the conditioned air throughout the building in the plenum above the ceiling system. Wall-mounted thermostats in various areas of the building will control the furnaces that supply that particular region in order to maintain comfortable air temperatures for the workers.

In the shop building, thirteen gas-fired infrared heaters are to be hung from the above structure to keep the shop warm for workers in the colder months. These heaters will be controlled by programmable wall-mounted thermostats located on either side of the building. Since the warmth produced by the heaters will travel upwards, three large ceiling fans will be used to force the warm air downwards to more evenly distribute the heat throughout the building.

Electrical System

The electrical system for the Northeastern Pennsylvania Office Building is considered a fully redundant system because there is a backup generator that will power the buildings if there is an interruption with the supply power. The supply power that will be run from the local township's utility transformer will be 800 amps at 480 volts. The power feed will then run to an automatic transfer switch before entering the building. The automatic transfer switch will switch from the utility transformer to the backup generator if the utility power is interrupted. This system ensures that the buildings will not lose power for an extended period of time.

When the power enters the building, it will enter the main distribution panel where it will be directed to two power panelboards and five lighting panelboards. The two power panelboards will supply circuits at 480 volts. Transformers will step down the power in the lines that run to the five lighting panelboards from 480 volts to 120 volts. These panelboards will then service 120 volt circuits.

Project Schedule

The detailed schedule of the Northeastern Pennsylvania Office Building can be found in “Appendix A. Detailed Project Schedule”.

Sitework

The sitework involved with the Northeastern Pennsylvania Office Building is scheduled to begin on in mid-June 2011 and be completed in mid-November 2011. Since the site is located on an open, grassy field, there isn’t an extensive amount of vegetation to be cleared. However, the entire site must be cleared and graded in preparation of the gravel laydown yard that will be constructed over the entire site. The sitework on this project includes clearing and grubbing, grading, running underground utilities, paving the asphalt parking lot, construction the gravel yard, and installing the security fence.

Foundation and Superstructure

Both the office building and the shop building of the Northeastern Pennsylvania Office Building will be utilizing a pre-engineered metal structure. Before the steel frames can be erected, the building’s pier footings, spread footings, and grade beams must be constructed. The concrete foundation work is scheduled to begin in mid-August 2011 and should be completed within a month. Once the foundation is ready to receive the load of the steel frames, base plates will be set and the frames will be erected. Structural frames for both buildings should be erected by mid-November 2011.

Building Enclosure

After a section of the structural steel frame has been erected, plumbed, and fastened, metal purlins will be attached to the frames. The metal roof and wall panels will then be fastened to the metal purlins. Windows and overhead doors can also be installed as the building structure is being constructed. The process of fully enclosing both buildings is expected to span about four weeks, from mid-November to mid-December.

Finishes

The interior finishes for both buildings will span from mid-November 2011 until early March 2012. Along with MEP rough-in and finishes, finish work will include metal stud walls, insulation, drywall, paint, carpet tiles, doors, and casework. The finishes stage also includes completing punchlist items that may arise before turnover to the owner.

Analysis 1: Replacing the Pre-Engineered Metal Building

Background Information

The structural system that has been chosen for the office building and the shop building of the Northeastern Pennsylvania Office Building is a pre-engineered metal building (PEMB). The structural subcontractor for this project was responsible for performing reactions and designing the steel frames, fabricating the pieces and delivering them to the jobsite, and erecting the structure. This choice of structural system is common for projects such as the Northeastern Pennsylvania Office Building because this type of package deal is generally the least expensive and the quickest system to erect.

Problem Statement

Although pre-engineered metal buildings are typically chosen for projects such as this because they are commonly less expensive and quicker to erect, this analysis will be comparing three other structural system to the PEMB to conceptually weigh the benefits and downfalls of each system. A standard steel frame structure, cast-in-place concrete structure, and tilt-up concrete structure will be examined. Factors that will be considered in the preliminary analysis will include constructability issues, regional constraints, and the impact of each structural system on the other building systems. The single best candidate will then be chosen to be directly compared to the PEMB. Schedule and cost impacts will be examined to determine which system is conceptually better for this project with respect to construction management practices. This analysis is only conceptual and therefore will not consider factors such as foundation changes and resizing, additional lateral bracing, or similar factors that may affect the cost and schedule of the structural systems.

Research Steps

1. List criteria to compare/contrast alternative systems
2. Rank systems based on the stated criteria
3. Choose the most suitable alternative system
4. Determine total cost of PEMB structural system
5. Determine schedule durations of PEMB structural system
6. Determine cost of alternative system
7. Determine schedule of alternative system
8. Choose and justify the most appropriate structural system for this project

Expected Outcome

With respect to the alternative structural systems, it is expected that the standard steel frames will be the most suitable candidate to be directly compared to the PEMB. Since the pre-engineered metal building system is typically used for projects such as this because it is generally the least expensive and quickest to construct, it is assumed that the PEMB will be determined to be the most appropriate system for the Northeastern Pennsylvania Office Building when directly compared to the best alternative system.

Analysis

In order to decipher which structural system would be best to directly compare to the pre-engineered metal building on the Northeastern Pennsylvania Office Building, criteria must be established in order to contrast the systems. The criteria that will be used in this study will include schedule and cost, constructability, regional constraints, impact on other building systems, and environmental impact. Each factor will be further explained under the accompanying section.

Schedule & Cost

The saying “time is money” is very apparent in the construction industry. The longer it takes for a task to be completed, the more resources, labor hours, and additional expenditures are added to the total project cost. Because of this factor, the schedule and cost impacts of the three alternative systems will be compared together in this section of the analysis.

The first system that will be considered is a standard steel framed structure. Steel structures are commonly preferred in today’s industry because they are relatively fast to erect once the components are on site. Typically, the longest duration on a project schedule with respect to the steel structure is the fabrication line item. This represents the time required for the steel members to be produced according to the project documents. Fabrication cannot get underway until the structural design is completed. However, once fabrication is completed, members can be delivered to the site, shaken out, and erected relatively quickly.

Cast-in-place structures are unique when looking at the duration for erection because the skill level of the contractor responsible for construction the structure is very important. A contractor that is highly experienced in building cast-in-place structures is much more efficient in building formwork and placing steel reinforcement than a less experienced contractor. Errors in the forming and reinforcing process can lead to extensive rework on the project. This can lead to an extended project schedule, as well as a higher project cost. Once formwork and reinforcement are in place correctly, concrete deliveries can be made to the site so that concrete can be poured. After the concrete has begun curing enough that it can support itself, the formwork and bracing can be removed from the structure. Once the formwork is cleaned, the same process can be started on the next structural frame. The construction of a cast-in-place concrete structure can occasionally begin earlier than a steel structure because there is not a fabrication time, but the actual construction of the system takes much longer to complete. This means there are embedded costs for additional labor hours for workers, as well as costs for building, placing, removing, and cleaning of formwork.

Although tilt-up structures share many similar tasks with cast-in-place concrete structures, there are distinct differences between the two systems. Individual panels for the tilt-up structure can begin being cast as soon as the designs are completed. The contractor has the ability to cast as many panels as possible before erection if space is available on the project site. However, similar to CIP concrete structures, additional costs can ensue if the contractor improperly forms or reinforces the panels. Once a number of panels have been cured and are ready for erection, the contractor can then bring a crane on site to tilt the panels into place, which is relatively quick to perform. A crane is generally needed to tilt the panels because the telehandlers used on this project would most likely not be able to lift the heavy concrete panels into place. The implementation of a crane on a project such as the Northeastern Pennsylvania Office Building creates an additional cost for the tilt-up concrete structure.

One factor to consider when comparing the costs of these three systems is fireproofing. Since tilt-up concrete and cast-in-place concrete structures are inherently fire resistant, additional fireproofing is generally not required. Steel structures, on the other hand, require additional fireproofing materials to ensure the building's structural integrity in the case of a fire. Two options for additional fireproofing for steel structures include spray-on cementious fireproofing or an intumescent paint. Both of these options increase the cost of the steel structure for this project.

Constructability

The general contractor for the Northeastern Pennsylvania Office Building has experience constructing both concrete and steel structures with previous projects. They have erected steel structures and precast tilt-up structures, as well as forming and pouring cast-in-place structures. With this respect, all three systems would be able to be constructed without the need for an additional subcontractor.

Since steel structures are fabricated off site and delivered to the site by trucks when erection is ongoing, there will not need to be a large designated area on the project site to store the steel members. Also, since the structure of the Northeastern Pennsylvania Office Building is only one story tall, there would not be any need for a crane on site. Telehandlers could be used to shakeout and erect the steel members. One disadvantage with a steel structure would be the need for field welds during erection.

Although the general contractor has experience constructing cast-in-place structures in the past, they generally try to limit their work to flatwork. If a cast-in-place concrete structure were to be implemented on this project, formwork would have to be constructed in the field. However, since concrete deliveries would be scheduled for a time slot when they were needed, there would be little to no area of the project site designated for storing materials.

Since the Northeastern Pennsylvania Office Building does not have any nearby structures, tilt-up panels could be cast on site before being erected. The general contractor would be able to cast these panels on the project site, but a large area would need to be designated to accommodate for the curing panels. Also, a crane would most likely need to be used to move and erect the large panels since the weight of the concrete panels would be much greater than the structural steel members.

Regional Constraints

The regional constraints associated with this project may include delivery issues with essential components of each system, weather constraints for this region, and typical construction practices in the area.

Delivery Issues

The location of the Northeastern Pennsylvania Office Building does not provide any major obstacles with respect to delivery methods for either steel or concrete. The closest concrete production plant is approximately a six minute drive from the project site. This means concrete deliveries would be short and consistent if cast-in-place concrete or tilt-up concrete were chosen for this project's structural system.

Assuming that the closest structural steel fabrication company was chosen to produce and deliver structural steel members, the delivery would be approximately forty-five miles. The route that the delivery truck would make is almost entirely four-lane highway and does not have any bridges with low weight restrictions or any areas with any height restrictions (i.e. overpasses, signage, etc.).

Although the delivery of the steel is about nine times longer than the concrete deliveries, it is not as essential that steel deliveries be as short as possible. This is because concrete may begin curing and harden during a long delivery. Also, a single load of steel members that is delivered to the project site provides more work for the contractors when compared to a single load of concrete. When a load of steel members arrives on site, the pieces must be removed from the truck. Workers will then use telehandlers and other equipment on site to shake-out, sort, and eventually erect the steel members. Multiple loads of concrete will have to be run simultaneously in order to keep a constant flow of work going on the project.

Weather Constraints

Since the structure of the Northeastern Pennsylvania Office Building is currently scheduled to begin in October, it is vital that impacts due to weather be considered in this section. Although it is rare to have freezing temperatures during October in northeastern Pennsylvania, this may be a factor if the structural system construction lasts more than a month or two.

All three structural systems are physically capable of being constructed in cold weather. The additional costs associated with cold weather construction, however, differ between the different systems. Erection of steel members is primarily unaffected by cold weather, aside from the possibility of workers performing the work at a slightly slower pace. If concrete is to be cast and cured on site, whether in place or in forms to later be tilted, the concrete must be attended to properly in order to ensure the curing process is efficient. Various methods of ensuring an effective curing process are used to prevent the water molecules in the uncured concrete from freezing. One method is to use heated water in the concrete mixture. This provides more time for the water in the mixture to go through the hydration process before freezing. A second method includes covering curing concrete with thermal blankets to help retain the heat and moisture during the hydration process. These two methods can also be used in combination, but both also prompt an additional cost to the project if implemented.

Typical Construction Practices

In order to determine which structural system was most commonly implement on projects in the area, local buildings that were similar in size and/or function to the Northeastern Pennsylvania Office Building were examined. The structures that were examined in the region included a cheese factory, two grocery stores, an automotive repair shop, an automotive retail store, and a strip mall.

It was found that the cheese factory and strip mall were the only concrete structures that were examined. Both of the grocery stores, as well as the auto repair garage and the auto parts shop were constructed with a steel structure. No projects that were examined had been constructed with tilt-up concrete structures.

An informal interview with a prominent concrete contractor in the area revealed that the vast majority of their business's work involved flatwork and the use of insulated concrete forms (ICFs), rather than forming, reinforcing, and pouring of structural columns and beams. It can be concluded from this conversation that concrete structures are not nearly as prevalent in the northeastern region of Pennsylvania as steel structures.

Impact on Other Building Systems

Some of the other building systems on the Northeastern Pennsylvania Office Building will not be directly affected by the implementation of any of these three alternative structural systems. For example, all of the plumbing work will either be under the concrete slab or located in the middle of the floorplan. This means the structural elements will have very little impact on the components of the plumbing system.

The electrical system and HVAC system will both see small impacts due to an alternate structure. Both systems use the plenum space between the structure and the hanging ceiling grid to run across the floorplan of the office building. In the shop building, the electrical system is attached to the underside of the PEMB structure. Much like the plumbing system, the HVAC and electrical will be virtually untouched, aside from the occasional slight relocation of some system components. However, if a concrete structure is chosen, the building supports for the other building systems will have to be altered to fasten to concrete, rather than steel.

The fire suppression system in both buildings will also not be majorly affected by a change in the structure. This is because the contractor responsible for designing and installing the sprinkler system will be doing it once the other building systems are in place. Because of this, if a structural member is in the way, the fire suppression subcontractor is responsible for redirecting the fire suppression system to avoid the member. Therefore, the fire suppression system should not be affected by the structure of the building.

The Galvalume metal siding and roofing that has been chosen for this project would be impacted if the structural system were to be replaced with a concrete system. This is because the current siding is attached to the PEMB structure by way of metal clips anchored to horizontal purlins. If a concrete structure were to be chosen, the horizontal metal purlins would have to be fastened securely to the concrete columns. Assuming the purlins are not cast within the columns, a form of steel-to-concrete fastening would have to be used to connect the purlins to the columns. On a different note, the tilt-up concrete structure would provide a different architectural finish rather than the Galvalume siding.

Environmental Impact

As our society becomes more and more educated towards our impact on the environment for future generations, there has been a movement to live our lives and produce products that are environmentally friendly. Since buildings are responsible for approximately 40% of energy consumption in the United States (Johnson 2006), it is important that projects implement construction methods and systems that have the smallest negative impact on our surroundings. There are three main factors that should be considered when comparing the impacts of different construction methods: energy consumption, resource depletion, and air emissions.

In order to adequately compare the systems, steel construction and concrete construction, we must understand what processes will be assessed for each system. For example, for steel construction, the materials that will be considered include beams, connections, and fireproofing. Concrete foundations will not be accounted for in this study. For concrete construction, the materials that will be considered include aggregates, Portland cement, plywood formwork, and reinforcing steel. The environmental impacts of each of the materials for both systems will include the following processes: raw material extraction, initial production, material manufacturing, transportation, and construction.

According to Johnson 2006, the environmental impacts of the two building systems were compared considering the structural frame of a 100,000 square foot, multi-story office building in Boston. Although the project considered in this case study was approximately five times larger than the Northeastern Pennsylvania Office Building and was located in a different location, it is assumed that the data is relatively comparable to this project.

Johnson 2006 found that the energy consumption for both the steel and concrete structures were nearly identical. Therefore, there would not be a meaningful reduction in embodied or operational energy if one system were chosen over the other. Resource depletion for a steel structure was found to be approximately 70% that of a concrete structure. This may be attributed to the larger volume of concrete in the structure that must be used when compared to a steel structure. Also, since steel can be recycled and reused, a portion of the steel structure may be recycled steel, and therefore would not have caused a full depletion of resources to fabricate the structure. The last criterion, harmful air emissions, also favors steel construction over concrete construction. Johnson 2006 found that there was about a 25% difference between the two systems. It was discovered that the largest portion of negative air emissions was produced during the production of Portland cement, which is not needed when constructing a steel structure.

Choosing an Alternative System

Based on the criteria stated in this study, a structural steel system has been chosen as the most appropriate structural system to be directly compared to the current pre-engineered metal building.

It was found that steel structures are preferred in the region of the Northeastern Pennsylvania Office Building because the projects are relatively close to a steel fabrication plant, and the structures can be erected year-round. Concrete structures that are erected in the colder months of the year require additional costs to ensure the concrete cures properly.

Although none of the three alternative systems would have a major impact on the other building systems, it was found that the steel structure would have the least impact on the other systems because the fastening of supports would most likely not have to be altered to connect to the structure. Also, the architectural exterior finish would not be altered with a steel structure as it would with a tilt-up concrete structure.

Finally, it was concluded that a structural steel frame has a smaller impact on the environment when compared to a concrete structure. This is because the process of manufacturing a steel structure emits less harmful air emissions and depletes fewer natural resources than does a concrete structure.

The following table shows a direct comparison of the three alternative systems with respect to the criteria listed above.

	Structural Steel	Cast-In-Place Concrete	Tilt-Up Precast Concrete
Schedule & Cost	X	X	X
Constructability	X	X	X
Regional Constraints	X		
Impact on Other Building Systems	X	X	X
Environmental Impact	X		

Direct Comparison of PEMB and Standard Steel Structure

Upon a request submitted to the general contractor for The Northeastern Pennsylvania Office Building, it was found that the contract for the pre-engineered metal building was valued at approximately 12.25% of the total project cost. This percentage of the project cost is about $661,500, which will be the estimated cost of the PEMB for this analysis. This estimate is assumed to include steel members, base plates, bolts and welds, horizontal purlins, and exterior metal siding/roofing. Costs for each of these categories are assumed to include material, labor, and equipment costs, including overhead and profit for the PEMB subcontractor. It is assumed that the contract value for the PEMB subcontractor included design, fabrication, and documentation fees as well.

A review of The Northeastern Pennsylvania Office Building's project schedule produced a total duration for the design, fabrication, and erection of both the office and shop buildings to be roughly 112 working days. According to the project schedule, each building will take about twenty days to erect. The erection of the buildings, however, is shown to be nearly concurrent. This shows a total duration for both buildings to be erected in about twenty-five days.

Based on the results found in "Breadth 1: Structural Analysis" of this report, the estimated cost of the standard steel structure for the shop building is about $388,800, while the office building is about $293,700. This means the estimated cost for a standard steel structure on the Northeastern Pennsylvania Office Building would be approximately $682,500. This cost estimate includes all of the assumed costs included in the cost of the PEMB, with the exception of any design, fabrication, or documentation fees.

The durations for the erection of the shop and office buildings were found to be about eleven days and thirteen days, respectively. When these durations were substituted into the project schedule for the PEMB durations for the erection of the shop and office buildings, it was found that the entire project was accelerated by about eight working days. A direct comparison of the scheduled durations for the PEMB and the standard steel structure can be seen in "Appendix B. PEMB Schedule vs. Standard Steel Schedule".

A direct comparison of the cost and schedule data found in this analysis can be seen in the table below. Please consider that the cost of the structural steel system does not include design, fabrication, or documentation fees.

	PEMB	Structural Steel
Schedule	6/14/11 – 11/16/11	6/14/11 – 11/4/11
Cost	$661,500	$682,500

Conclusion

Based on the preliminary criteria stated in this analysis, it was found that a standard structural steel system would be most appropriate to replace the pre-engineered metal building when compared to a cast-in-place concrete structure and a tilt-up concrete structure. A number of factors led to this conclusion, such as regional constraints, impact on other building systems, and environmental impact.

It was found that steel structures outnumber concrete structures in the area of the Northeastern Pennsylvania Office Building. This is in part because additional costs are encountered to heat newly poured concrete in the colder months to prevent the water molecules from freezing. Steel structures cost about the same amount to erect no matter what time of the year it may be. It was also found that steel structures typically deplete lesser amounts of natural resources and produce fewer harmful emissions when directly compared to a concrete structure of the same size. Because of these and other factors, it was decided that a standard steel structure would be used to be directly compared to the PEMB.

A structural analysis was used to size the members and eventually derive the cost and duration estimates for a standard steel structure that would effectively replace the pre-engineered metal building on the Northeastern Pennsylvania Office Building. It was found that the project schedule would be accelerated by about eight days if the PEMB were to be replaced. However, the cost of the standard steel structure was found to be about $21,000 more expensive than the PEMB. In addition to this cost, there were no design, fabrication, or documentation fees considered when calculating the cost of the steel structure. It is not expected that an acceleration in the project schedule by eight days would be enough of a reason for the owner to take on the additional cost of the alternative system. Because of this, it is suggested that the pre-engineered metal building not be replaced with a standard steel structure.

Analysis 2: Design-Build Phase 2 & 3

Background Information

The Northeastern Pennsylvania Office Building is currently being delivered as a traditional deign-bid-build project. It is the first phase of a multiphase project that the owner is intending to build. The second and third phases of this project are nearly identical to Phase 1, and will be constructed in a sequential order. This analysis will examine whether Phase 2 and 3 could be delivered as design-build projects. Cost savings, shorter schedules, and less change orders may be achieved if it is determined that these two phases could be delivered as design-build projects.

Problem Statement

Successful design-build projects generally deliver a successful building in a shorter timeframe than a traditional design-bid-build project. This is because the construction of the project is underway while the design is still being produced. Since the later phases of this project are very similar to Phase 1, the contractor may be able to assist in the design stage of the later phases because they will have experience constructing a nearly identical project. This can potentially save the owner costs and also deliver a successful project to the owner at a sooner date. Advantages and disadvantages of each delivery method must be examined with regards to this project in order to determine whether design-build is possible. If the alternative method is suitable, potential savings in the project schedules will be found to determine the overall advantage of using a design-build method.

Research Steps

1. Analyze advantages/disadvantages of D-B-B method
2. Analyze advantages/disadvantages of D-B method
3. Determine whether D-B method is acceptable
4. Determine durations of D-B-B schedule
5. Determine durations of D-B schedule
6. Compare/contrast differing methods

Expected Outcome

The expected outcome of this analysis is that Phase 2 and Phase 3 of this project will be suitable to be delivered as design-build projects. Since this method typically reduces project costs, change orders, and the project duration, the owner may be inclined to allow the contractor on Phase 1 to be responsible for constructing the later phases.

Analysis

Design-Bid-Build

Traditional design-bid-build projects have been used for an extended period of time because the process has been proven to deliver successful construction projects. D-B-B projects ensure that the owner is ultimately responsible for the design, construction, and quality of the project. After conceptual planning of the project has begun, the owner is responsible for hiring an architect that they believe will deliver a project that is professional and that suits the owner's needs effectively.

Once the architect is chosen and the preliminary design of the project is completed, the architect and design professionals complete the project documents so that they may be used by the owner to find a suitable contractor. Competitive bids can be received by the owner because contractors are given documentation that clearly states the type, quality, and amount of work that they are bidding on. Upon the selection of a contractor, which is typically based on low-bid selection, construction can begin.

Although the traditional method of project delivery is commonly implemented in the industry, there are disadvantages to the approach that must be considered. First of all, this method makes the owner at-risk for detecting errors or flaws in the design and construction of the project. For owners that are not experienced with this responsibility, it can be overwhelming or nearly impossible to monitor. Second, the amount of contracts and responsibilities across the project can cause difficulties in communication and pinpointing faults between parties involved with the project.

Since the project timeline for D-B-B project includes steps that are in sequential order, there is little to no room for delays in any stage of the project design and construction. For example, a delay in the design stage delays the subsequent stages and inevitably delays the project completion. In addition to schedule increases, cost increases are also typical on D-B-B projects. This is due to change orders that arise after the project design has been completed. Since the contractor is not involved in the design of the project, constructability issues commonly arise during construction and increase the total cost and schedule of the project.

Design-Build

The construction industry continuously drives projects to be delivered at a higher quality, lower cost, and in a shorter amount of time. In order to abide by these driving forces, there has been an increase in demand for projects to be delivered as design-build projects. This alternative delivery method has both advantages and disadvantages that must be considered when determining whether a project is suitable to be design-build.

Since some owners are not experienced with monitoring the design and construction phases of a project, it is often beneficial for them to use a D-B delivery method because the primary contractor that is chosen is responsible for a successful project delivery. The amount of responsibility that the owner instills on the contractor, however, requires an extensive amount of trust between the two parties. This is because the contractor is essentially responsible for controlling the design, construction, quality, cost, and schedule of the project. Since the owner requires a high level of trust with the contractor, the competitive bid process is generally handicapped. Contractors are selected based on their relationship with the owner, their expertise with design-build projects, and other qualifications, rather than solely the amount of the bid. Also, local subcontractors are more prone to be hired by the primary contractor to assist in the design and construction of the different building systems.

One of the best qualities of D-B projects is the savings in cost and schedule. Since the design of building systems is easily changed on design-build projects, there are typically few or no change orders. This means the original project cost remains unaffected throughout the duration of the project. Also, since the design and construction phases of the project are partially concurrent, the total project schedule is generally shorter than that of a traditional D-B-B project. This comparison can be seen in "Figure 5. D-B-B and D-B Timelines and Durations." An earlier turnover date to the owner may result in more revenue obtained by the owner, depending on the project.

Design-Build for Phases 2 & 3

The later phases of the Northeastern Pennsylvania Office Building project are unique because if they were to be delivered as design-build projects, the primary contractor would have prior experience constructing a nearly identical project, the Northeastern Pennsylvania Office Building. The trust that the owner has with the contractor, which may be the most influential factor for determining whether they could be D-B projects, would be largely dependent on the contractor's performance on the Northeastern Pennsylvania Office Building. If the contractor delivers a successful project that is under budget and turned over on time, the owner may be more inclined to select them as the primary contractor for Phases 2 and 3.

Assuming that the contractor is successful with the construction of the Northeastern Pennsylvania Office Building, other factors must be considered before determining whether the later phases could use the alternative delivery method.

Although the owner is experienced with constructing projects for their subsidiary companies to occupy, they are a large entity that is based in the southern half of the United States and may find it difficult to closely monitor the design, construction, and quality of the later phases. Because of this, it may be beneficial for them to place this responsibility on the primary contractor through the use of a design-build delivery method. If this method were to be chosen, the contractor would be in charge of monitoring the design, construction, and quality of the work for both phases.

Even though competitive bids would not be utilized to find the primary contractor on Phases 2 and 3 if they were D-B projects, the use of local subcontractors would be valuable for the owner. This is because the owner is attempting to build positive relationships with local citizens and businesses to increase their public relations. The primary contractor on D-B projects is more inclined to hire local subcontractors to assist in the design and construction of the project, which would benefit the owner.

The final factors that determine whether the alternative delivery method would be suitable for the later phases are costs saving and schedule reduction. Reductions in the project schedule would allow the subsidiary companies to occupy the spaces sooner, which would in turn produce more revenue for the owner. This additional revenue, as well as the cost savings from reducing change orders, would be incentive for the owner to deliver Phases 2 and 3 as design-build projects.

Design-Bid-Build Durations

The following durations are relevant to Phase 1, the Northeastern Pennsylvania Office Building, and are not the actual durations for Phases 2 or 3. These durations, however, should be relatively consistent with the corresponding phases because they are nearly identical projects. Therefore, the design, bid, and construction durations are assumed to be nearly identical as well.

The design phase of the Northeastern Pennsylvania Office Building began in early December 2010 and lasted approximately four months. With the design phase ending in late March 2011, bidding was opened in early April and lasted approximately one month. Construction began in mid-June 2011 and is scheduled to be completed in mid-March 2012. This means the construction phase is about nine months long.

Design-Build Durations

The first phase of the design-build method would be the bidding stage for the primary contractor. Since the primary contractor for Phases 2 and 3 would be the same contractor used on the Northeastern Pennsylvania Office Building, there would most likely not be a formal bidding process for these phases. However, one month has been delineated as the bidding phase in the project duration. This phase would be used by the owner to ensure that the contractor is suitable to take on the responsibilities of delivering the additional phases, and verify that the quality of work produced on Phase 1 is acceptable and expected on the later phases.

The second phase, the design phase, will remain similar in length to the design phase of the D-B-B method. The construction phase, however, will be beginning at an earlier date due to the fact that it will be partially concurrent with the design phase. Also, based on design-build project research performed by Konchar and Sanvido (1998), the construction speed is generally increased by about 12%. Therefore, rather than lasting nine months as in the D-B-B method, the construction phase in the D-B method can be assumed to last approximately eight months. This reduction in construction duration, as well as the overlapping of the design and construction phases, has created a four month acceleration in the project schedule when compared to the design-bid-build method. Konchar and Sanvido (1998) also concluded that most D-B projects increased their delivery speed by about 33%. In this case, Phases 2 and 3 would increase their delivery speed by about 28%. This schedule acceleration can be seen in "Figure 5. D-B-B and D-B Timelines and Durations."

Conclusion

Based on the results found in this analysis, it is recommended that Phases 2 and 3 of this project be considered for a design-build delivery method. The estimated schedule acceleration was determined to be about four months for each phase. An acceleration of this magnitude would allow the owner's subsidiary companies to occupy the space and generate revenue. This, along with the cost savings from the potential reduction in change orders, would most likely be incentive enough to convince the owner that a D-B delivery method would be beneficial. The owner's decision, however, would be greatly influenced based on the contractor's performance and quality of work on the Northeastern Pennsylvania Office building because it is nearly identical to the later phases.

Analysis 3: Horizontal Expansion vs. Vertical Expansion

Background Information

The office building of the Northeastern Pennsylvania Office Building is currently designed to provide office space and parking for about fifty employees. Now that the project is past the conceptual phase and the design is underway, the owner has increased the project size. The office building will now need to provide office space and parking for approximately one hundred employees, virtually doubling the amount of space needed. A vertical expansion (adding a second floor to the office building) or a horizontal expansion (building a nearly identical office building to the east of the original office building) are the two possibilities that the architect proposes to the owner to accommodate for the increase in personnel.

Problem Statement

With the two options for expansion in mind, the owner must decide which method the project designers will begin working on. Since the owner does not have experience of weighing the benefits and downfalls for each option, external expertise is needed for the most appropriate decision to be made. This analysis will outline the positive and negative impacts of both a horizontal and vertical expansion on for the Northeastern Pennsylvania Office Building. Impacts that may be considered include impacts on the project cost and schedule, the functionality of each option, and the aesthetics of each design.

Research Steps

1. Interview owner's representative to rank priorities
2. Compare/Contrast each priority with respect to both expansion options
3. Create graphical representations of each option
4. Suggest the more appropriate expansion option for this project

Expected Outcome

It is expected that the vertical option will be the most appropriate method for expansion of the Northeastern Pennsylvania Office Building. It is assumed that the horizontal option with cost more and will also create a longer schedule. Therefore, the owner will probably prefer that the project be redesigned as a two-story office building.

Analysis

Owner Priorities

In order to determine what factors of the Northeastern Pennsylvania Office Building are most important for the owner, a list of preferences was made and given to the owner. The owner was then asked to prioritize which factors were most vital to this expansion project. The preferences were ranked in the following order:

1. Schedule Impacts
2. Project Cost Impacts
3. Limiting Change Orders
4. Functionality
5. Aesthetics

From these results, we can conclude that the most important factor to the owner of the Northeastern Pennsylvania Office Building is choosing an expansion option that has the smaller impact on the original project schedule. It was made apparent that either option will inherently increase the project schedule, but the owner is considering which option's schedule would have a potentially earlier turnover date so the employees can occupy the space and produce revenue.

The second most important factor is to consider the total project cost. Again, the owner is aware that the cost will inherently increase due to the increase in the project size, but they are interested in which option will cost less overall.

Limiting the number and severity of change orders was of moderate concern for the owner of the Northeastern Pennsylvania Office Building. Since change orders can potentially increase both the project cost and schedule, choosing an expansion option that limits the amount of change orders will directly affect either option's schedule and project cost impacts.

Functionality and aesthetics were listed at the final two priorities because they have the least amount of bearing on the owner's decision to expand either vertically or horizontally. Aesthetics on this project was in reference to how the finished project would appear to a bystander. This does not include finishes or material types, but rather the appearance of the site upon turnover. Functionality on this project was in reference to the layout of the building for employees and visitors that would have to navigate it on a daily basis.

Schedule Impacts

According to the owner per a telephone interview, the most important factor for the Northeastern Pennsylvania Office Building to be considered a successful project is being completed per the project schedule. The owner’s heaviest concern with this project is completing it on time. This is because the office and shop buildings will be occupied by a subsidiary company of the owner once the project is completed. If the project takes longer to construct, then the subsidiary company cannot use the space to generate income for the owner. Because of this, the owner rated the impact on the project schedule as the top criteria for concern with respect to the two expansion options.

Since the owner knew that an increase in project size would inherently lengthen the project schedule, it was determined that the expansion option that had the smallest impact on the schedule would be preferred over the opposing option. An expansion, whether it is horizontal or vertical, has the potential to impact many, if not all, of the building systems. The schedule impacts that are being considered for this study include the pre-engineered metal building, the concrete foundations, and the excavation for each building footprint.

The first factor to be considered is the additional amount of excavation work that would be required to accommodate the concrete footings. Since the footings for the vertical expansion would most likely increase in size by a reasonably small factor, the additional excavation needed for this option is considered insignificant. The amount of excavation for the horizontal expansion, however, would virtually double to accommodate the nearly doubled size of the building footprint.

Typically, a project schedule would be negatively impacted by increased work on the building foundation. This additional work for the horizontal expansion option would include forming, reinforcing, and placing nearly twice as many concrete footing pads. However, the Northeastern Pennsylvania Office Building’s project schedule is not negatively affected by this increase in work because the foundation work is not on the critical path. Foundation work is currently scheduled to occur while fabrication of the steel members is occurring. Since work can only continue once fabrication is completed, the concrete foundation work can take additional time to complete, as long as it is finished before fabrication is done. The horizontal expansion option, which virtually doubles the length of time for the office building foundations to be completed, still allows for this work to be completed well before fabrication is finished. The foundation duration for the vertical expansion option remained the same because, even though the sizes and shapes of the footings may be altered, the amount of footings should remain the same. A change in size such as this would not add any significant time to the completion of the foundation work.

Schedule impacts due to a change in the size and shape of the pre-engineered metal building must finally be considered. A horizontal expansion would result in a virtual doubling of the erection duration for the office building because there would be twice as many structural frames that must be set across the building footprint, as can be seen in “Appendix C. Horizontal vs. Vertical Expansion Schedules”. For a vertical expansion, the erection of the office building would be increased by about 50%, based on a phone interview of a PEMB subcontractor that wishes to remain anonymous for this report. This is because there are two rows of horizontal beams across each structural frame. A lower beam will eventually support a concrete deck (which is not considered in this analysis), while the upper beam will support the roofing for the building.

As can be seen in “Appendix C. Horizontal vs. Vertical Expansion Schedules”, the horizontal expansion results in an increase in the project schedule by ten days when directly compared to the vertical option. This means the owner would most likely prefer the vertical expansion option because the tenants will be able to use the space at an earlier date when compared to the horizontal option. This would, in turn, lead to increased income for the owner.

Project Cost Impacts

Even if the project was to be completed sooner and the tenant was able to begin producing income sooner for the owner, the additional funds may not be significant enough to cover the cost of one expansion over the other. Because of this, the impacts on the total project cost for each expansion option must be considered. This is why the owner’s second-most important decision factor is the additional cost implications for each option.

If a vertical expansion is chosen, the footings would have to be redesigned and resized. This would assumingly increase the amount of concrete and reinforcement in each pad in order to support the larger vertical loads. An increase in material such as this would result in a minor increase of the project cost. Also, the additional excavation required for the larger foundations would not be significant.

If a horizontal expansion were to be chosen, the costs associated with footings and excavation for the footings would be significantly larger when compared to the vertical expansion option. Although the size of the footings would most likely not be affected, there would be virtually twice as many footings placed throughout the building footprint. This would require a significant amount of additional concrete, reinforcing, formwork, excavation, and labor costs incurred by the total project cost.

As far as the pre-engineered metal building is concerned, the costs associated with each expansion option are relatively close. Based on the phone interview with the previously stated PEMB subcontractor, a two-story PEMB can generally be assumed to cost about $21/SF. A single story PEMB, on the other hand, can usually be assumed to cost about $8/SF. Both of these costs are only for material, and they do not include labor or equipment costs. As can be seen in the table below, the structural material cost for the horizontal expansion of the office building is approximately 76% of the vertical expansion option. When it is considered that the foundation work for the horizontal is approximately doubled when compared to the vertical expansion, it is expected that the total material cost for both expansion options is relatively similar.

	Total SF	$/SF	Total $
Horizontal	22,000	$8.00	$176,000
Vertical	11,000	$21.00	$231,000

Limiting Change Orders

With respect to change orders on this project, it is believed that the horizontal expansion will have fewer during the construction phase. This is because the additional office building will be nearly identical to the original office building. Therefore, if an issue arises during the construction of the original building, it will be anticipated to occur on the additional building as well. Since it will be expected ahead of time, possible solutions or methods of avoiding the problem may be addressed before the problem occurs.

If a vertical expansion is chosen, change orders may be more frequent when compared to the horizontal expansion option because the two-story construction is not as repetitive as its counterpart. In other words, a problem that occurs during the construction of the first floor may not also be experienced on the second floor.

Functionality

This criterion is based on the general flow of the building for the employees that will be occupying the space after project turnover. If the workers are forced to navigate a complicated or strenuous building layout on a daily basis, they may become unhappy with the owner. Although functionality was rated as a fairly low importance factor for the owner, it is still imperative to consider when comparing the two design options.

The vertical expansion will provide a stacked design layout, which will need to include stairs and possibly elevators to allow the employees to navigate from one floor to another. On the other hand, the horizontal expansion will not need to incorporate stairs or an elevator into the design. However, the layout of the horizontal building expansion may be strenuous for employees to get from one end of the building to the other. With two buildings constructed as a single, long entity, a worker may have to walk up to 350 feet from one end of the project to another. This may be cumbersome for some employees that work in the building.

Aesthetics

The aesthetics criterion was based on how the project would look to a bystander upon completion. In order to compare the appearances of the two expansion options, graphical representations have been provided in "Figure 6. Horizontal and Vertical Expansion Models".

As the models show, a horizontal expansion results in a single-story office building that is elongated. This expansion option allows for the shop building to still be clearly visible for a passerby. The name and logo of the subsidiary company that will be occupying the building was intended to be mounted on the southern face of the shop building so that it could be seen by bystanders. A horizontal expansion still allows for this signage to be visible, as can be seen in "Figure 6. Horizontal and Vertical Expansion Models". In order to accommodate for the additional workers, the parking lot was extended in order to provide more parking spaces. The additional area of the building footprint and parking lot reduced the size of the gravel laydown yard by 5.4%, as can be seen in the table below.

A vertical expansion provides different aesthetical effects for the site. First and foremost, the additional height of the two-story office building hides the shop building from the line of sight for a passerby. This means that the name and logo of the subsidiary company must be displayed in another location if the owner still wants this to be visible upon project completion. As can be seen in "Figure 6. Horizontal and Vertical Expansion Models", the additional parking space required for this expansion option is the only factor that reduces the amount of area available for the gravel laydown yard. It produced a 3.5% reduction in total acreage, as can be seen in the table below.

	Acres	% Reduced
Original	18.82	--
Horizontal	17.80	5.4%
Vertical	18.17	3.5%

Conclusion

Based on the results of this analysis, it is suggested that a vertical expansion be used for the Northeastern Pennsylvania Office Building. A vertical expansion of the office building portion of this project would provide the lesser negative impact on the project schedule and would also produce the best results with respect to the functionality and aesthetics of the building.

Although both expansion options would lengthen the total project schedule, it was found that the structure for a vertical expansion would take less time to erect when compared to a horizontal expansion. Also, since the additional project costs for both options were similar, the accelerated schedule for the vertical expansion was determined to be significant in the decision of the more suitable expansion for this project.

Based on the functionality and aesthetics of the project, the vertical expansion option was also deemed to be more appropriate. With respect to functionality, the vertical option provided a stacked floorplan that would reduce the amount of travelling for employees across the building. If a horizontal expansion were to be chosen, workers would have to navigate across a 350 foot long floorplan. With respect to aesthetics, the vertical expansion trumped the horizontal counterpart because it provided a more traditional look for an office building. The elongated design of the horizontal option would have given onlookers a building that was awkwardly long and short. The two-story option is more natural to see in our culture today.

	Horizontal	Vertical
Schedule		X
Cost	X	X
Change Orders	X	
Functionality		X
Aesthetics		X

Analysis 4: Geothermal System

Background Information

The Northeastern Pennsylvania Office Building employs two separate systems to heat each building. The office building is currently designed to be heated using a forced hot air ductwork system with nine furnaces located throughout the space. A combination of twelve gas-fired heaters and three large ceiling fans are used to heat the shop building. If an alternate heating system were to be installed in the shop building, there may be a possibility in the reduction of natural gas used to heat this space. With a large, flat project site, a geothermal system may be used for this project to heat the shop building.

Problem Statement

A geothermal heat pump system may not only increase efficiency and lower the operating costs for heating the shop building, but it also would be more environmentally conscious. This is because geothermal heat pumps consume lesser amounts of fossil fuels during operation when compared to a natural gas system. This analysis will be comparing the installation costs and schedule lengths for both the existing heating system and an alternative geothermal heating system to determine whether it would be appropriate for this project.

Research Steps

1. Calculate installation cost and schedule data for natural gas system
2. Calculate installation cost and schedule data for geothermal system
3. Compare cost and schedule data for both systems
4. State additional factors to be considered with both systems

Expected Outcome

It is expected that this analysis will show that a geothermal system will be more appropriate for this project. This is because the price of natural gas may increase over the next few decades and raise the long-term costs for the natural gas system. Also, a geothermal system will not be burning fuels in the workspace, which is exposing the workers to potentially harmful fumes.

Analysis

Natural Gas System – Cost & Schedule

The natural gas system that is currently designed for the shop building portion of the Northeastern Pennsylvania Office Building is composed of two basic components within the actual structure. These two components are the black steel piping and the gas-fired heaters hung in the space. Additional components that will not be considered in this study include hangers, fasteners, valves, and connections. Based on the project documents, there will be about 450 feet of piping that will feed twelve heaters. The piping and heaters will all be hung from the above structure throughout the shop building.

Based on the quantities found in the project documents for both of these components, estimated cost and duration data could be determined for the existing heating system. The estimated cost for this system was approximately $22,000 and it was estimated to be about two weeks of installation time. Since the actual contracted cost of the heating system for only the shop building is unknown, it is not possible to compare to this estimate for verification of accuracy. However, the current project documents provide approximately eight weeks for mechanical system rough-in and finishing in the shop building. This duration is assumed to be significantly higher than the estimated duration because the mechanical work in the shop building also includes plumbing work and the installation of the three large ceiling fans. It is assumed that the duration of installing the twelve heaters and black steel piping would take closer to two weeks to install when compared to the eight weeks allotted in the current schedule.

Geothermal System – Cost & Schedule

This portion of the study is based on the size of the geothermal system determined in “Breadth 2: Geothermal System Design” of this report. The system included the following components: one 20 ton heat pump, 4,450 feet of PEX-AL-PEX tubing, two 1/5 horsepower circulation pumps, and approximately 300 feet of chilled beams. Excavation work to bury 4,000 feet of the tubing has also been considered. Factors that were not considered in this study include hangers, fasteners, valves, and connections. The piping and chilled beams will be hung from the above structure throughout the shop building.

Based on the quantities for each component found in “Breadth 2: Geothermal System Design” of this report, as well as cost and schedule data derived from both “RS Means Building Construction Cost Data 2012” and from direct quotes from suppliers and manufacturers, a geothermal system of this size is estimated to cost about $41,000 and take about five weeks to install. These values can be seen in the table below.

	Cost	Schedule
Natural Gas	$22,000	2 Weeks
Geothermal	$41,000	5 Weeks

When compared to the estimated cost of the natural gas system ($22,000), the cost of the geothermal seems very steep at first glance. The estimated cost of $41,000 is nearly twice as much as the original system. This hefty price tag is greater by an order of this magnitude because the geothermal system includes excavation work, a greatly increased amount of piping, and the cost of a heat exchanger. However, a geothermal system may be more economical in the long run.

If the owner of the Northeastern Pennsylvania Office Building invests its money up front for the increased installation costs of a geothermal system, a significant amount of money may be saved over the next few years. This is because a geothermal system such as this would only require electrical energy to run the two circulation pumps, the heat exchanger, and the large ceiling fans. With a natural gas system, the owner is not only paying to electrically power the ceiling fans, but they are also paying for the natural gas that is being consumed by the heating units.

In terms of durations for installation, the geothermal system will take much longer to install in the shop building of the Northeastern Pennsylvania Office Building. This is because a geothermal system requires more components to be installed when compared to the natural gas system. First of all, the underground piping system requires trenching and placement of the pipes before backfilling and compaction can occur. Next, components such as the heat exchanger and circulation pumps must be installed. Once the interior structure is ready for the mechanical equipment to be hung, a large amount of chilled beams must be suspended. Finally, piping can be run from the heat pump to the beams hung in the space. These activities all contribute to a long duration for the installation of the geothermal system.

Additional Factors

When comparing a natural gas heating system to a geothermal system, other factors must be taken into consideration rather than just the upfront cost and schedule data. For example, the geothermal system may cost more money at the onset of the project, but it is expected that it would regain those monies by having a lower operating cost over the ensuing years. Also, geothermal systems typically require less maintenance than many other heating systems. Natural gas systems such as the one designed for the Northeastern Pennsylvania Office Building, however, are also fairly low with respect to maintenance by the building occupants.

One of the largest reasons owners request for geothermal systems to be installed on their projects is because these systems are easier on the environment. There are far less natural resources depleted to install and run a geothermal system when compared to almost every other heating system. A natural gas system, for example, requires natural gas to be extracted from the earth before it can be used in the system. This includes processing and transportation of the gas as well. A geothermal system, however, only uses the electrical energy required to run the heat exchanger and circulation pumps. On this same note, geothermal systems have much fewer emissions when compared to a heating system such as natural gas burners because there are no flames combusting fuels.

The biggest advantage for the Northeastern Pennsylvania Office Building to implement a geothermal system for the shop building would be to provide cooling to the space. At this point, the shop building does not have any form of cooling in the building other than circulating the air with the large ceiling fans. A geothermal heat pump run in the opposite direction in the warmer months of the year would create an actual “chilled” beam effect in the space. However, since there are multiple overhead doors on each side of the shop building, a case can be made that the space will be sufficiently cooled by opening these doors and allowing air to circulate through the space.

Conclusion

Although a geothermal system is widely considered less harsh on the environment, it is not suggested to be installed in the Northeastern Pennsylvania Office Building for various reasons. First of all, since the owner is associated with the natural gas industry, it is not expected that they would choose to implement a system that reduces the demand of the fuel. Along with this, it is assumed that the cost for natural gas to heat the building will be available to the owner below market price. Because of this, the payback period for the geothermal system would be increased vastly. The owner, therefore, does not have any true incentive to pay the higher initial installation costs for a geothermal system.

Even though one of the largest benefits of this geothermal system is the cooling effect possible during the warmer months of the year, it is not expected to be as effective on this project when compared to others. This is because the shop building contains multiple overhead doors that can be opened during the warmer months that a different project may not have. Because of these factors, it is not recommended that a geothermal system be designed and installed in place of the current natural gas heating system for the shop building portion of the Northeastern Pennsylvania Office Building.

Breadth 1: Structural Analysis (Replacing the PEMB)

Background Information

Based on the preliminary information found in "Analysis 1: Replacing the Pre-Engineered Metal Building" of this report, standard structural steel was found to be the most appropriate structural system to replace the pre-engineered metal building. In order to further compare these two structural systems against each other to determine the most appropriate system for this project, estimates for the cost and duration of the structural steel system must be found. Each member must be properly sized in order to derive more accurate cost and duration estimates.

Research Steps

1. Find building loads
2. Find frame member reactions
3. Determine maximum shear and moment on frame members
4. Determine adequate size and shape of steel members
5. Estimate cost of steel structure
6. Estimate duration of steel structure erection

Analysis

Since the shop building and the office building of the Northeastern Pennsylvania Office Building are both supported by different shaped and different sized frames, a structural analysis of each frame was conducted for this structural breadth. Both frames consist of two steel columns, one shorter than the other, and two nearly horizontal beams. The two horizontal beams are bolted together to span across the structural frame. The joining of the horizontal beams and the vertical columns are welded connections. Finally, the columns are bolted to the concrete pier foundations at the base of the frame.

The first step of this structural breadth analysis was to determine the loads on each of the two buildings that the structures will need to support. The superimposed and collateral dead loads used in this analysis were found on the existing project documents. These account for loads due to ceiling-mounted building systems (fire suppression, HVAC, electrical), as well as loads such as the weight of the exterior façade. An assumed load of eight pound per square foot was implemented to account for the weight of the structural members. A value of thirty pounds per square foot was also implemented because this project is located in northeastern Pennsylvania. See “Appendix D. Building Load Calculations” for these calculations.

The ultimate load for each frame was found by multiplying the dead loads (superimposed, collateral, self-weight) by 1.2 and multiplying the snow load by 1.6. The sum of these two values gave the ultimate loads that should be experienced by each of the structural frames at any one time. By multiplying the ultimate loads by the tributary area supported by each frame, the ultimate distributed loads were determined. Refer to “Appendix D. Building Load Calculations” for these calculations.

With the distributed loads on each frame defined, the reactions experienced between the columns and the concrete pier foundations could be determined by creating free-body diagrams and summing forces and moments. See “Appendix E. Member Reactions Calculations” for these calculations. Once these reactions were discovered, free-body diagrams of each member could be created. These free-body diagrams allowed for the maximum shear forces and moments experienced by each structural member to be found. Refer to “Appendix F. Maximum Shear and Moment Calculations” for these calculations.

Now that the maximum shear forces and moments for each piece have been found, the pieces can be sized accordingly. By using the values in “Steel Construction Manual” (2006) for wide-flanged beam design, the size and shape of each member was determined. In order to be adequate for the design loads, each member must be able to withstand both the maximum shear forces and moments experienced at any time. See “Appendix G. Sizing Steel Members” for these calculations.

Cost and duration data for the standard steel structure that was found in this analysis was derived by using “RS Means Building Construction Cost Data 2012”. The cost and duration data for the pre-engineered metal building was provided by the general contractor for the Northeastern Pennsylvania Office Building upon request. The cost data for the PEMB is assumed to include design, fabrication, transportation, and erection of members, as well as material, labor, and equipment expenses that were needed to construct the structure. It is assumed that the cost data for the PEMB includes costs for steel members, base plates, bolts and welds, horizontal purlins, and exterior metal siding. The cost data derived for the standard steel structure includes the material, labor, and equipment costs for the same structural components. Refer to “Appendix H. Structural Steel Cost & Duration Estimate” for cost and duration estimate calculations.

The total estimated cost of a standard steel structure was approximately $682,500, including both the shop building and the office building of the Northeastern Pennsylvania Office Building. It was determined that erection of the shop building would last about eleven days, while the erection of the office building would be about thirteen days.

Conclusion

The analysis of a structural frame from the office building and the shop building of the Northeastern Pennsylvania Office Building yielded cost and duration data that was very similar to the pre-engineered metal building cost and duration data provided by the general contractor. It was determined that the structural frames for both buildings could be constructed with just four different sized and shaped wide-flanged steel members. These four shapes (W24x68, W24x76, W21x55, and W21x62) are sufficient to support the maximum dead and snow loads that would be experienced by each frame, respectively. This allowed for general cost and duration estimates to be derived through the use of "RS Means Building Construction Cost Data 2012".

Breadth 2: Geothermal System Design (Geothermal System)

Background Information

The Northeastern Pennsylvania Office Building is located on a rural and relatively unobstructed site that should allow for a geothermal heating system to be installed. The system will contain a piping network that will be using the ground as either a heat source or heat sink. Along with the piping network, there will also be a heat exchanger located within the shop building. The heat exchanger will be responsible for transferring the heat energy from the ground loop to the building loop. A building loop will either be run through the concrete slab or it will be run to terminal units within the shop building in order to dispense the heat. In order to properly gather cost and schedule information for a potential geothermal system, the system components must be adequately sized. Proper sizing of the system's components requires that each component be chosen for accurate reasons, and be reasonably justified as well.

Research Steps

1. Choose a loop system
2. Determine loop size
3. Determine a minimum heat exchanger and pump sizes
4. Choose adequate terminal units

Analysis

Loop Systems

To begin this analysis, a loop system must be chosen that will be the most cost-effective and easiest to install for the Northeastern Pennsylvania Office Building. Options for the underground loop system include open loops, horizontal loops, vertical loops, and surface water loops. Each of these loop systems has both advantages and disadvantages depending on the project variables. These loop systems can be seen in "Figure 7. Loop Systems."

Open Loops

Open loop systems use a piping and filtering system that can intake groundwater on the site that will be run to the heat exchanger. Once the heat energy has been removed from the groundwater, it is pumped through a different piping system that deposits the water back underground. This type of system is most commonly found on a project site that has sufficient groundwater available to be taken and then replaced into the earth. Some areas may have groundwater that contains minerals and other small particles that can damage the geothermal system. Open loop systems can also use filtered lake water rather than groundwater.

Horizontal Loops

A horizontal loop system uses a closed loop piping network that can transport either water or an alternate fluid. If the piping system for any type of closed loop system is ruptured, extensive rework and potential contamination of the project site may be possible. Horizontal loops are generally the least expensive of the closed loop systems to install because the loops are typically buried only a few feet under the ground. However, since the loops are not very deep, they require a vastly greater area to run the loops when compared to a vertical loop system. The Northeastern Pennsylvania Office Building's project site, which is about eighteen acres, should be sufficiently large enough to house a horizontal loop field.

Vertical Loops

Vertical loop systems are piping networks that are placed in a bored hole in the ground. The bored hole is commonly a few hundred feet deep in most cases. These types of loop systems are typically used on projects that have site restrictions such as area limitations or a highly sloped site. The drilling of the holes can be much more costly to the owner because underground rock and other unforeseen conditions may arise. Also, once the loop is placed in the bored hole, the rest of the hole must be filled with a thermally conductive grout.

Surface Water Loops

If a project is near a large pond or lake, a surface water loop system may be implemented. These systems use a closed loop network that is placed near the bottom of a water sources such as this to transfer heat. Since the Northeastern Pennsylvania Office Building is not near a pond or lake, this loop system will not be adequate.

Based on the size of the site of the Northeastern Pennsylvania Office Building and the lack of other obstructions on or around the site, a horizontal closed loop system is assumed to be the most adequate system for this project. This means a piping network will be buried approximately five feet underground. A five foot deep trench for the network will be sufficiently below the frost line (approx. 3 ½ feet) and will not require bracing to prevent the trench from collapsing.

Loop Design

The material used for the loop that will be buried underground will determine the rate at which heat energy can transfer from the earth to the liquid within the tubing. Two typical loop materials for geothermal systems are PEX tubing and PEX-AL-PEX tubing.

PEX (cross-linked polyethylene) tubing is a plastic product that is flexible and easy to install, but it is also more susceptible to being pinched or crushed when compared to PEX-AL-PEX tubing. PEX-AL-PEX tubing is composed of a thin layer of aluminum tubing that is encompassed on both the inside and outside by PEX tubing. The additional layer of aluminum provides additional stability to prevent crushing, and it also provides a higher thermal conductivity for the loop. PEX tubing with a diameter of ½ inch has a thermal conductivity of 2.6 BTU/h-ft F, while PEX-AL-PEX tubing with the same diameter has a thermal conductivity of 3.1 BTU/h-ft F. This means PEX-AL-PEX tubing absorbs a greater amount of heat energy in a shorter amount of time when compared to its counterpart. Because of this, PEX-AL-PEX will be used for the underground loop system on this project.

Other factors that needed to be determined in order to design the loop included the outdoor temperature, the indoor design temperature, the heat pump capacity, the coefficient of performance of the heat exchanger, the pipe resistance, the soil resistance, and the mean Earth temperature. The values for these factors are listed in the tables below.

Heating Cycle	
Total Building Load (MBH)	206.5
Outdoor Design Temp. (ºF)	0
Indoor Design Temp. (ºF)	50
Balance Temp. (ºF)	65
Heat Pump Capacity (MBH)	206.5
$COP_{HEATING}$	3.0
Pipe Resistance	0.323
Soil Resistance	0.5
Mean Earth Temp. (ºF)	55

Cooling Cycle	
Total Building Load (Ton)	19
Outdoor Design Temp. (ºF)	95
Indoor Design Temp. (ºF)	75
Balance Temp. (ºF)	65
Heat Pump Capacity (Ton)	19
$COP_{COOLING}$	4.5
Pipe Resistance	0.323
Soil Resistance	0.5
Mean Earth Temp. (ºF)	55

The total building load, the heat pump capacity, and the COP were all determined based on the size of the heat exchanger chosen for this project. Outdoor temperatures were determined based on the typical high and low temperatures that northeastern Pennsylvania experiences throughout the year. The soil resistance and mean earth temperature were both standard for the northeastern Pennsylvania region. The indoor design temperature for the heating cycle was found within the project documents for the current heating system. Pipe resistance is the given resistance for PEX-AL-PEX pipe.

With the assistance of a design professional from a mechanical contracting company, the above values were inserted into a computer program that designs ground source heat pump loop sizes. The resulting length of underground piping was about 3,800 feet of PEX-AL-PEX tubing. Since the efficiency of the system increases with an increase in loop length, it is assumed that a length of 4,000 feet will be sufficient for the Northeastern Pennsylvania Office Building. Eight trenches will house eight loops of piping that are each 500 feet in length to achieve this total length. Each trench will be approximately five feet deep and between three to four feet wide. The 500 foot long runs will be placed in a "slinky" pattern that can be seen in "Figure 7. Loop Systems".

Heat Exchanger Size

Based on a preliminary interview with a design professional from a local mechanical contractor, it was found that a project of this size would typically need a heat pump that can adequately provide ten and forty tons of cooling. Based on this initial recommendation, the heat pump chosen for this analysis can handle approximately twenty tons of cooling and 200 MBH of heating. These figures were used in the calculation of the loop length, as well as the unit's coefficient of performance for both cycles.

Pumps

In order for the water to circulate through the piping networks underground and inside the building, pumps must be added to the hydronic system. The industry professional that was interviewed for this study had recommended sizing recirculation pumps to be about one horsepower per one hundred tons of cooling produced by the heat pump. This is because the fluid does not have any specific flow requirements as long as the system is sufficiently recirculated. Any additional horsepower over this recommendation means the system is over powered. This means that since the heat pump chosen for this study is approximately twenty tons, the recirculation pumps should be about 1/5 HP to circulate fluids through the exterior and interior loops of the system.

Terminal Units

Once heat energy has been transferred from the exterior loop to the interior loop within the heat exchanger, the heated fluid in the interior loop must transfer its energy to the space to warm the building. There are multiple ways in which to achieve this transfer of heat, including heating concrete slabs, using a forced hot air system, or using terminal units to dissipate the heat. Since the shop building of the Northeastern Pennsylvania Office Building is an open ceiling design and is not currently using any ductwork systems, a forced hot air system will not be considered for this study. However, a heated concrete slab and the use of terminal units will both be addressed.

Heated Concrete Slab

A simple method of transferring the heat energy to the shop building would be to run a PEX tubing system through the concrete floor. The concrete floor of this building is a slab-on-grade, and would therefore not lose a significant amount of heat energy in a downwards direction. The heat energy would be transferred through conduction to the concrete slab. From the slab, heat energy would be transferred into the shop building space by radiation in an upwards direction. This would be a good system to dissipate the heat energy because there would be little to no maintenance required for the interior portion of the geothermal system

One problem that arises with using a warmed slab for the Northeastern Pennsylvania Office Building's shop building is the lack of cooling that it would provide in the warmer months of the year. Although chilled water could be run through the PEX piping, the slab will not absorb a large amount of heat from the space. In this respect, the warmed slab method would only be effective for heating and will be virtually useless for cooling.

Terminal Units

A second option that can be used to dissipate the heat energy from the geothermal system would be terminal units. Although there are many different types, shapes, and sizes of terminal units available for applications such as this, this study will focus on the use of chilled beams as terminal units. This is because chilled beams can be used for both heating and cooling without redundant piping systems.

Chilled beams are most commonly associated with use for cooling applications because when they are mounted above a space, the cooler air around the beam naturally sinks into the space and creates a natural flow of recirculating air. However, since there are three large fans mounted above the shop building space, heat energy that is generated by the beam will be forced downwards when the fan is running. Because chilled beams will be suitable for both heating and cooling applications, these units will be chosen for this project.

Conclusion

The first step to sizing the geothermal system proposed for the Northeastern Pennsylvania Office Building is to choose the size of the heat exchanger. For a project of this size, it was suggested that a unit that can adequately handle a heating load of about 200 MBH and 20 tons of cooling be selected. Based on the product data for this unit, along with regional and project specification data, a program was able to determine that approximately 4,000 feet of underground loop must be installed for an effective system. Next, a horizontal underground loop system was determined to be the most suitable loop system based on the site conditions. The final components that had to be determined were the circulation pumps and the system used to transfer energy within the building. The pump size was based on the total size of the system, while chilled beams were chosen to dissipate and absorb heat energy while the geothermal system was being used.

Conclusions

Replacing the Pre-Engineered Metal Building

The preliminary portion of this analysis found that a standard steel structural system was the most appropriate system to be compared to the PEMB. It is suggested that the PEMB remain as the structural system for the Northeastern Pennsylvania Office Building. It was determined that the standard steel structure would accelerate the schedule by about eight days, but it was also found that it would be more expensive than the PEMB to construct. An acceleration of this size does not seem sufficient enough to justify the additional costs incurred.

Design-Bid Phase 2 & 3

It was determined that Phases 2 & 3 of the project would benefit if they were delivered as design-build projects with the same project team had constructed the nearly identical Northeastern Pennsylvania Office Building. Four month schedule accelerations were estimated for both of the later phases if they implemented a design-build method rather than the intended design-bid-build method.

Horizontal Expansion vs. Vertical Expansion

The results for this analysis suggested that a vertical expansion option be chosen for the Northeastern Pennsylvania Office Building. It was found that this option had a lesser negative impact on the original project schedule, and would therefore be completed sooner than its horizontal counterpart. Since the cost data was similar for both options, the lesser important factors (functionality and aesthetics) played a larger role than originally anticipated in deciding a more suitable expansion option. The vertical expansion was determined to be more appropriate with respect to both of these factors.

Geothermal System

It was found that even though a geothermal system would cost more to install when compared to the current system and would more environmentally-friendly, it is not suggested that one should be implemented on this project. Since the owner of the Northeastern Pennsylvania Office Building is associated with the natural gas industry, it is difficult to justify reasoning for the owner to switch from a natural gas system to a geothermal system.

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Figure 1. Project Delivery System

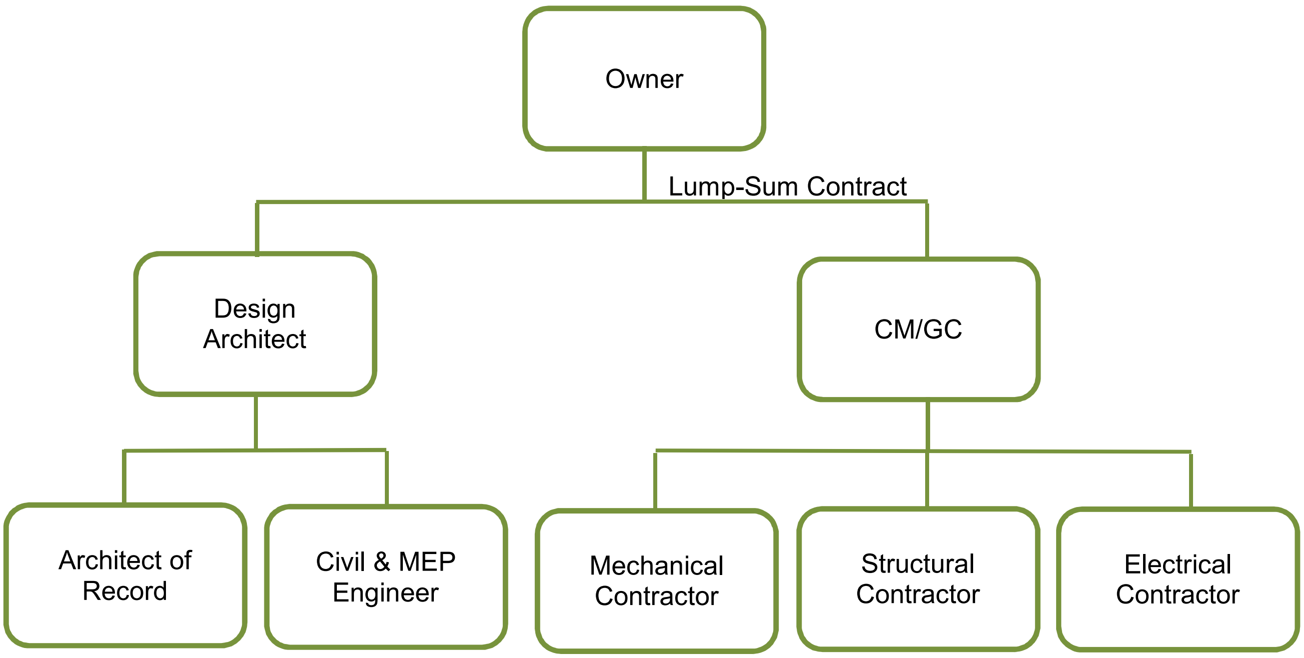


Figure 2. CM/GC Staffing Plan

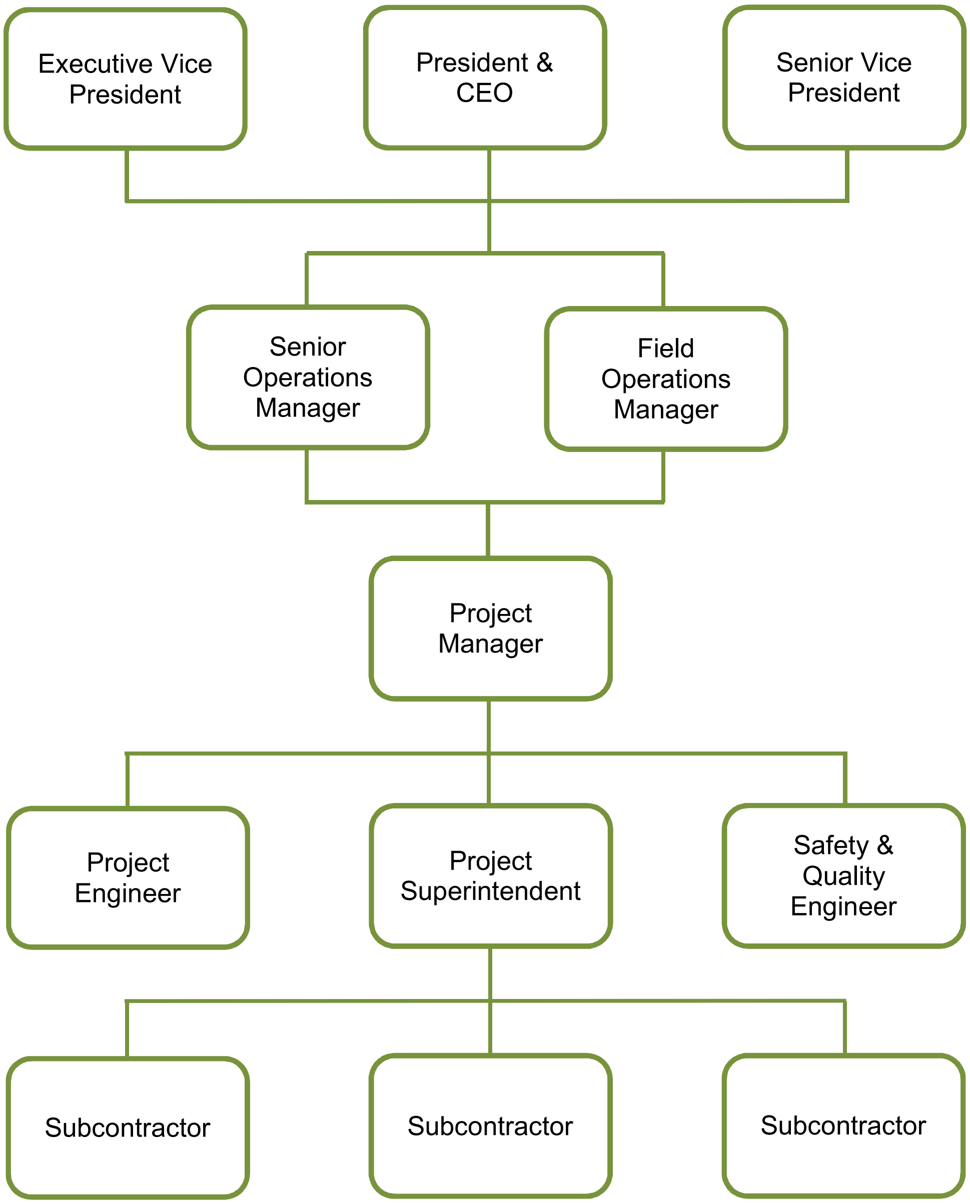
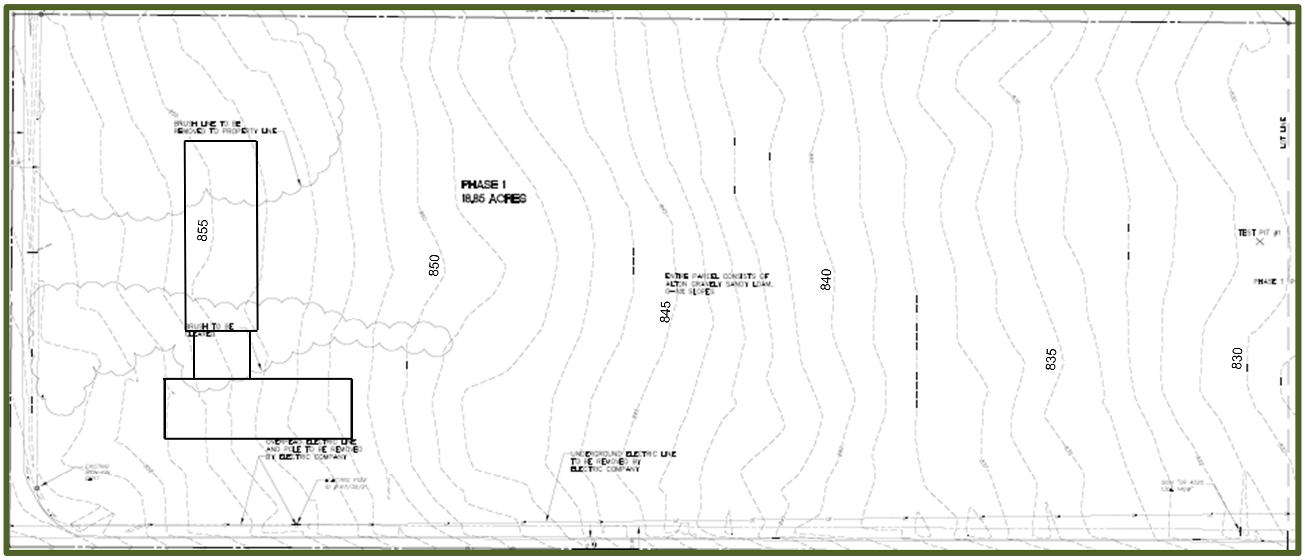
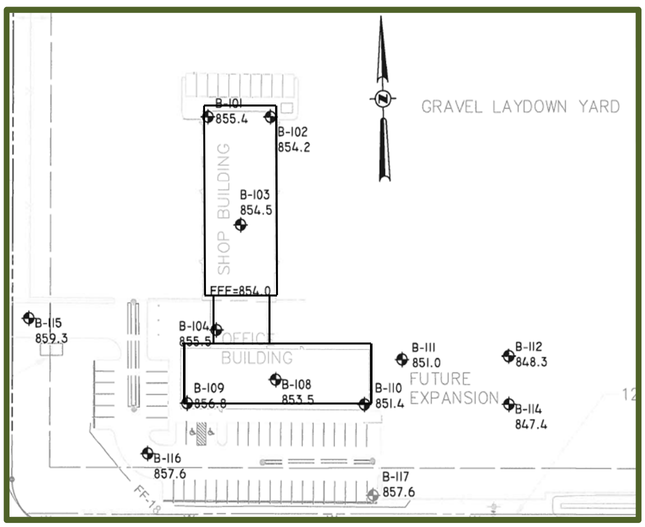


Figure 3. Site Topography and Boring Test Locations





Boring I.D.	Elevation at Grade (ft.)	Depth of Groundwater (ft.)
B-101	855.4	9.0
B-102	854.2	8.0
B-103	854.5	13.5
B-104	855.5	13.5
B-108	853.5	8.0
B-109	856.8	7.0
B-110	851.4	7.0

Boring I.D.	Elevation at Grade (ft.)	Depth of Groundwater (ft.)
B-111	851.0	8.0
B-112	848.3	13.5
B-114	847.4	8.3
B-115	859.3	9.5
B-116	857.6	9.5
B-117	857.6	8.5

Figure 4. Pre-Engineered Metal Building Frames and Locations

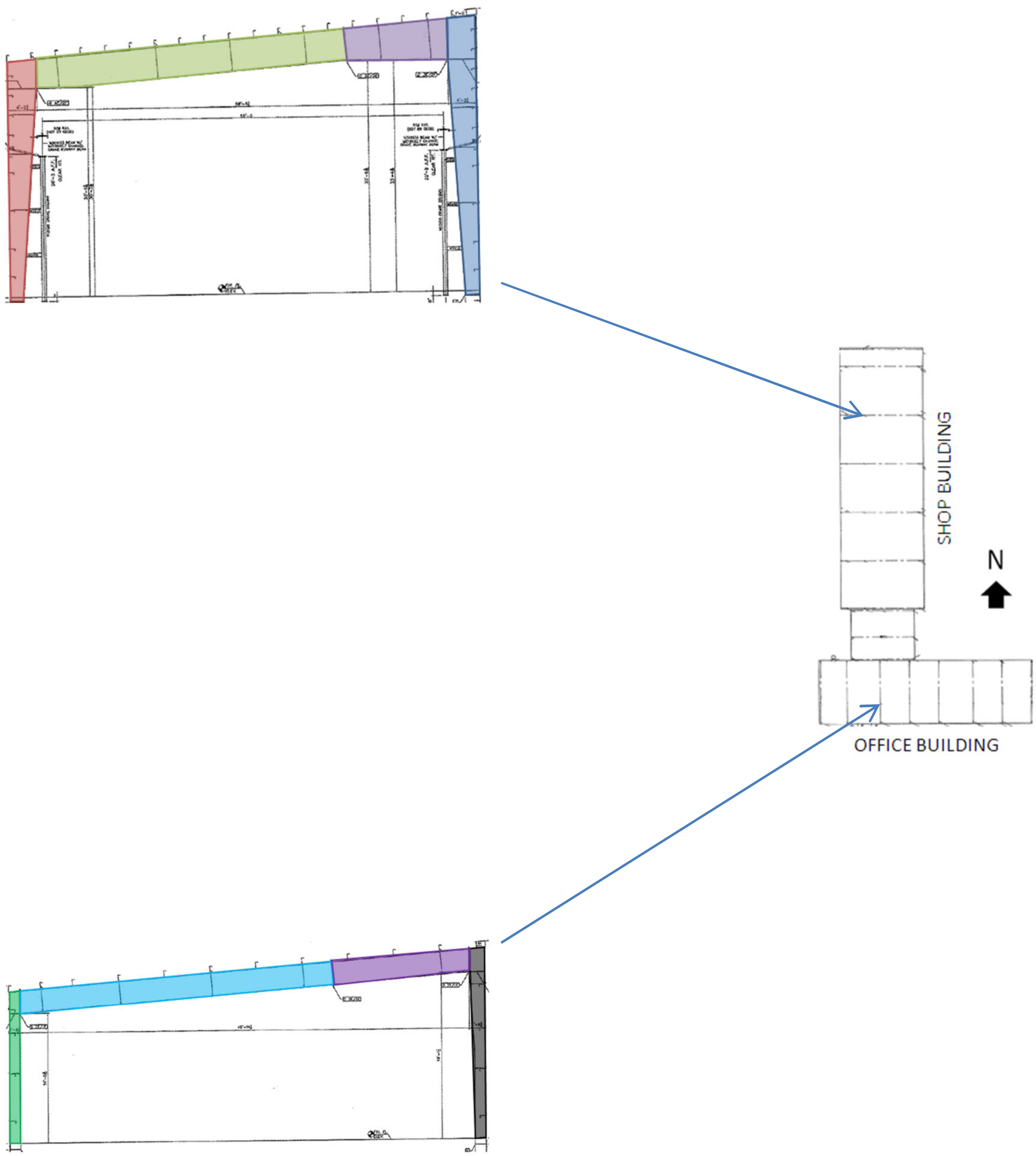
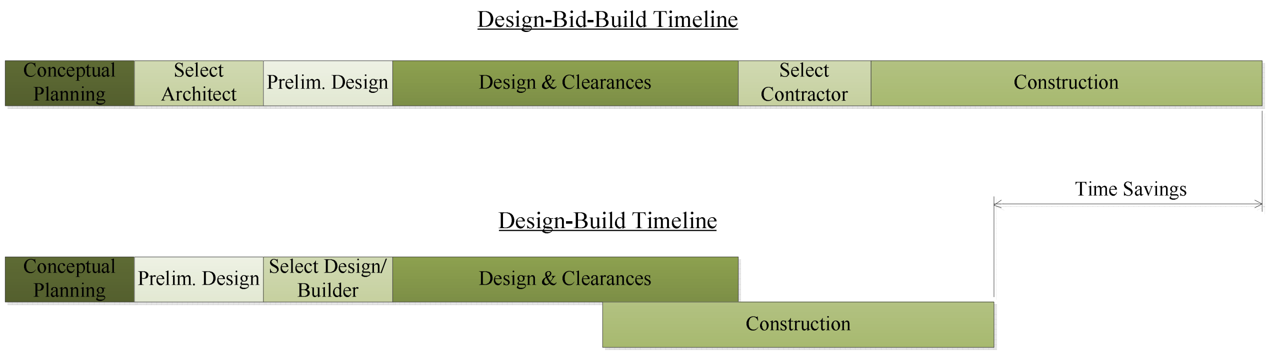


Figure 5. D-B-B vs. D-B Timelines and Durations



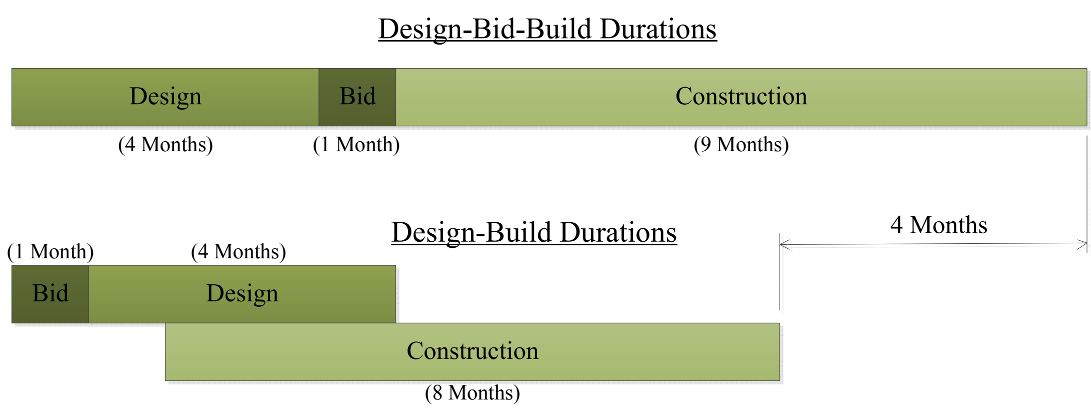
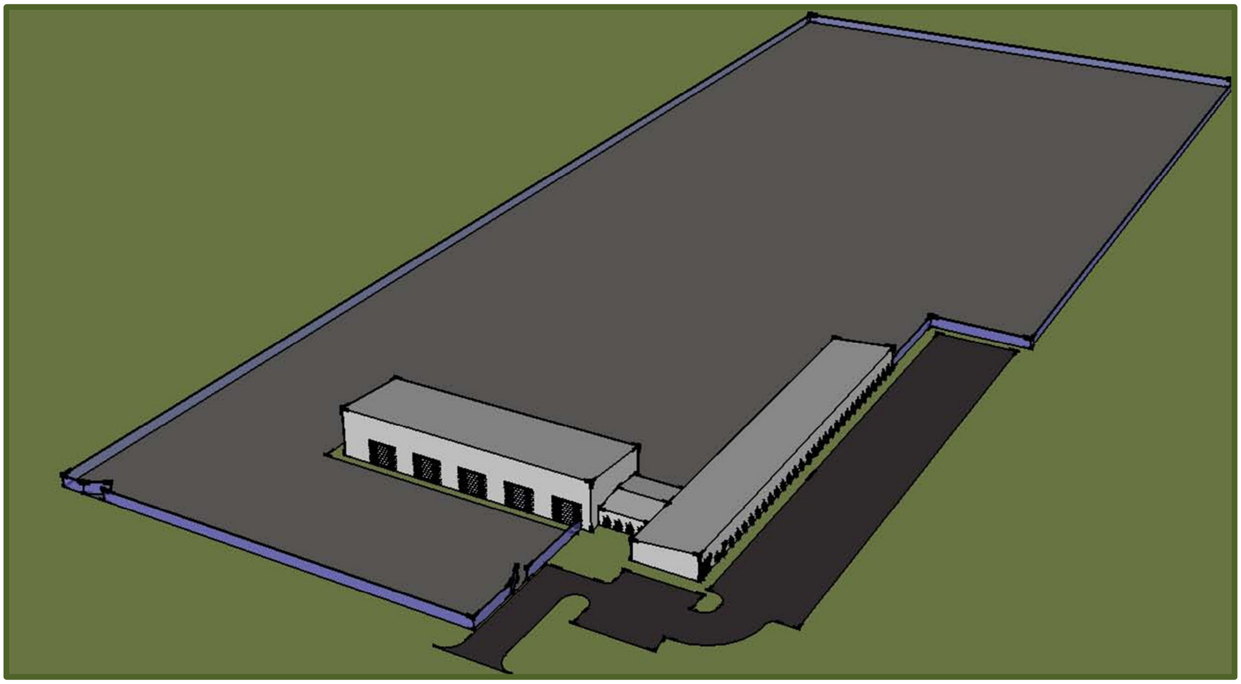
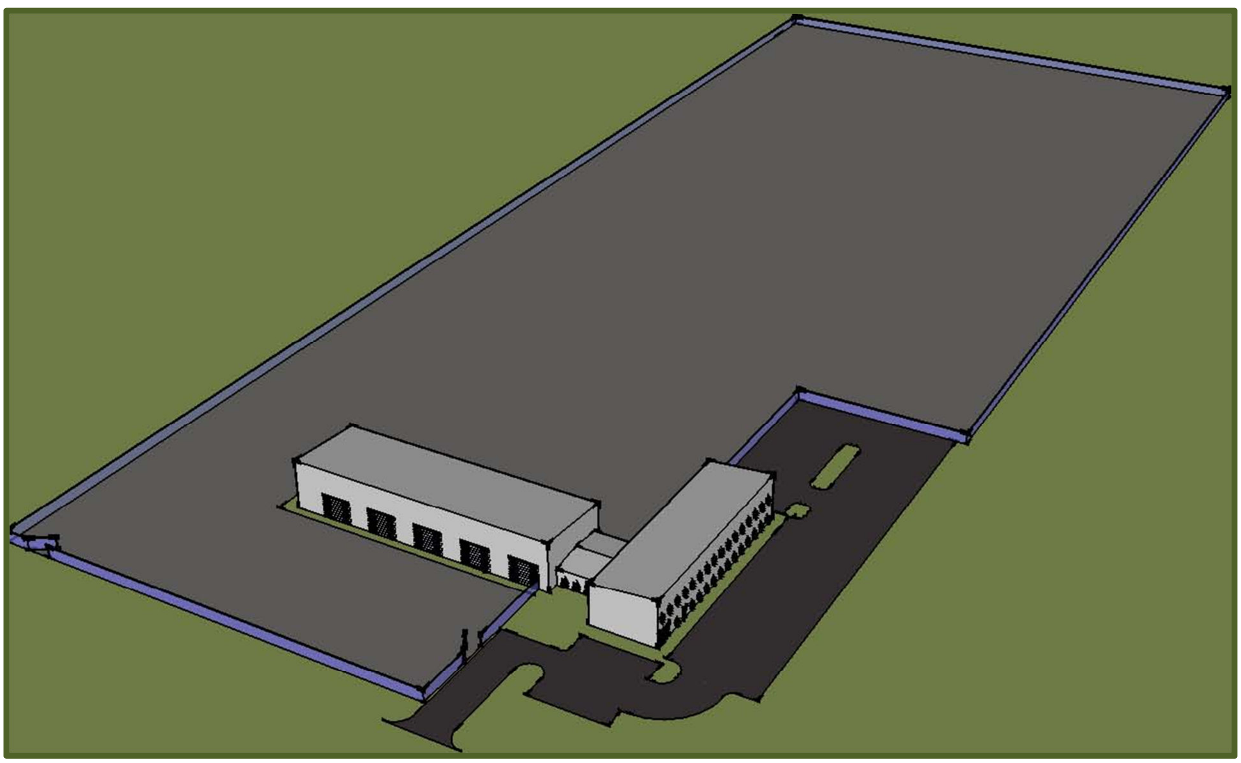


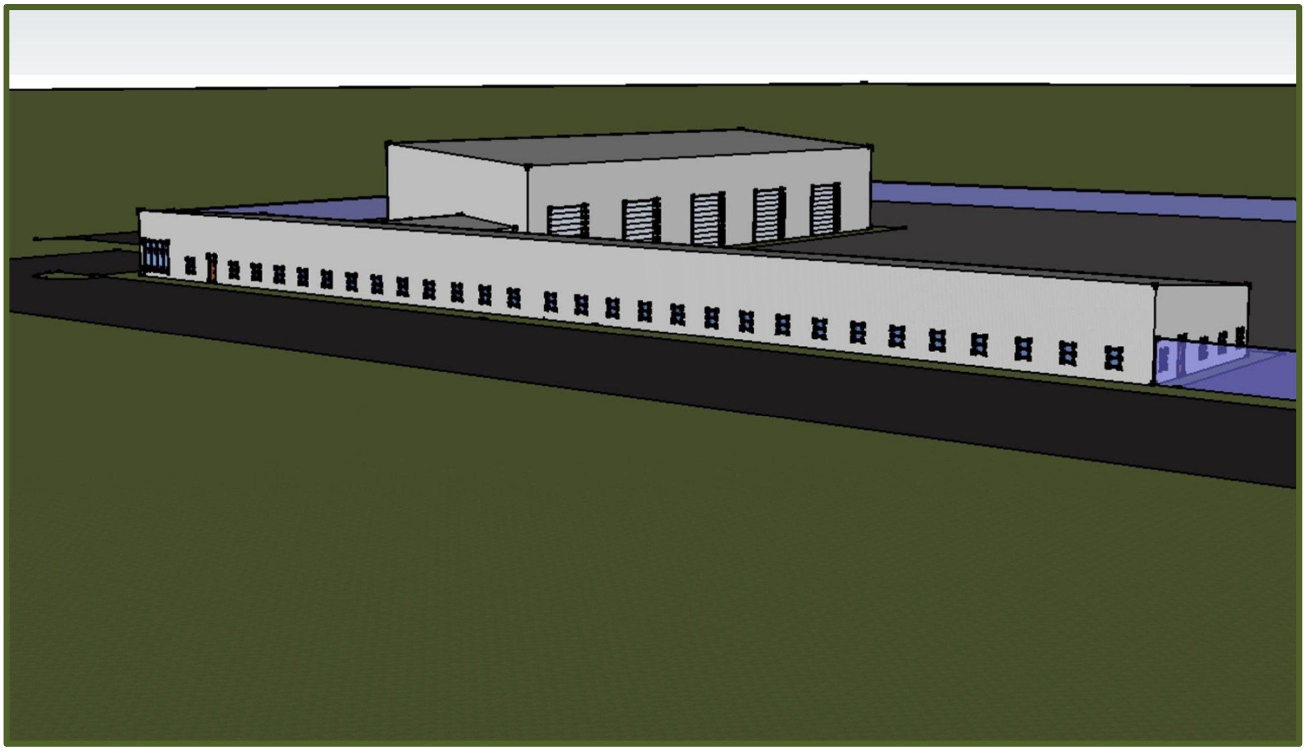
Figure 6. Horizontal and Vertical Expansion Models



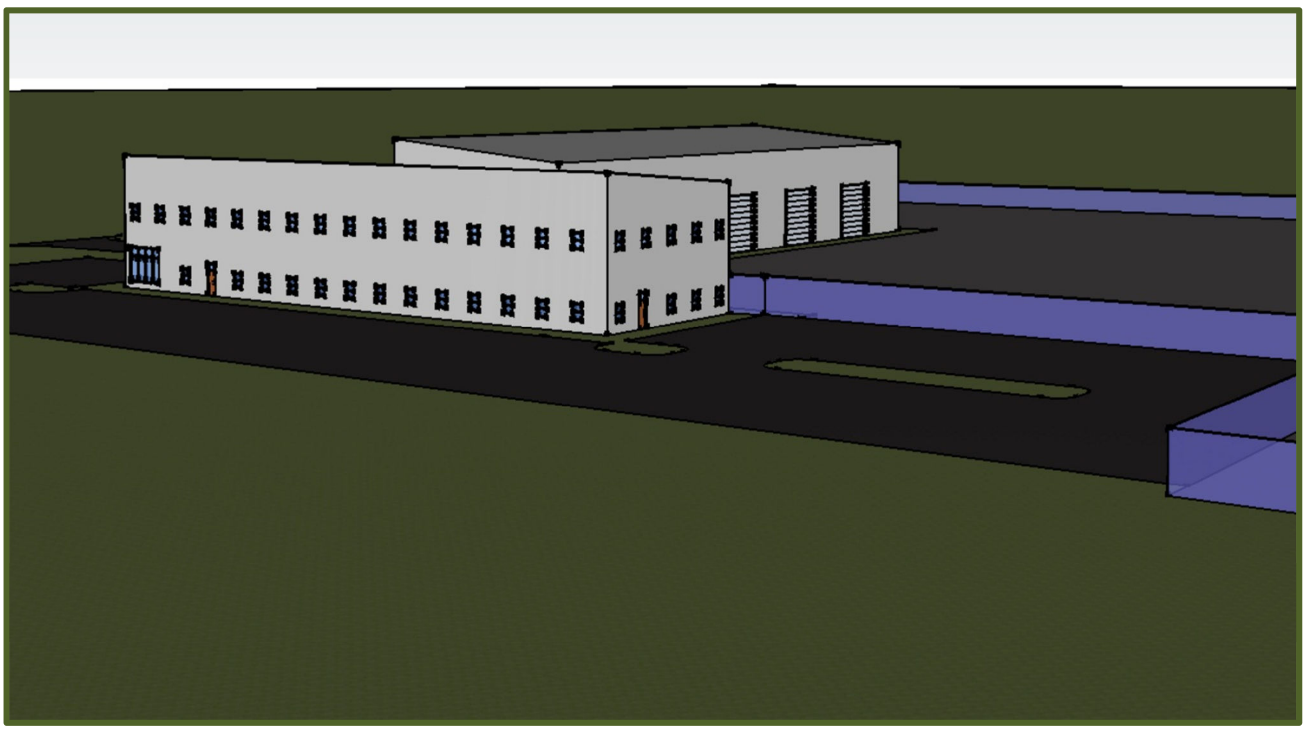
Horizontal Expansion – Southwest Perspective View



Vertical Expansion – Southwest Perspective View



Horizontal Expansion – Southeast Perspective View

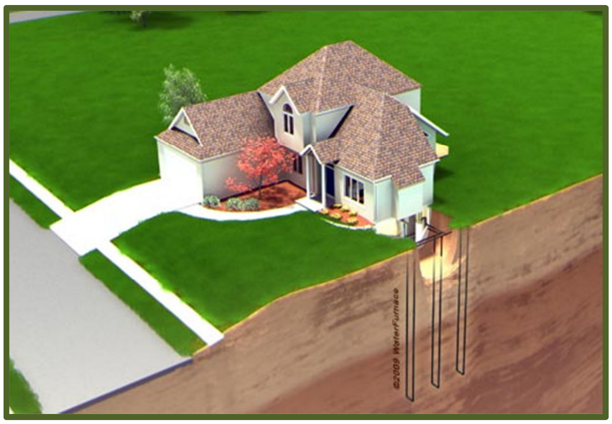


Vertical Expansion – Southeast Perspective View

Figure 7. Loop Systems

Open Loop System

Horizontal Loop System



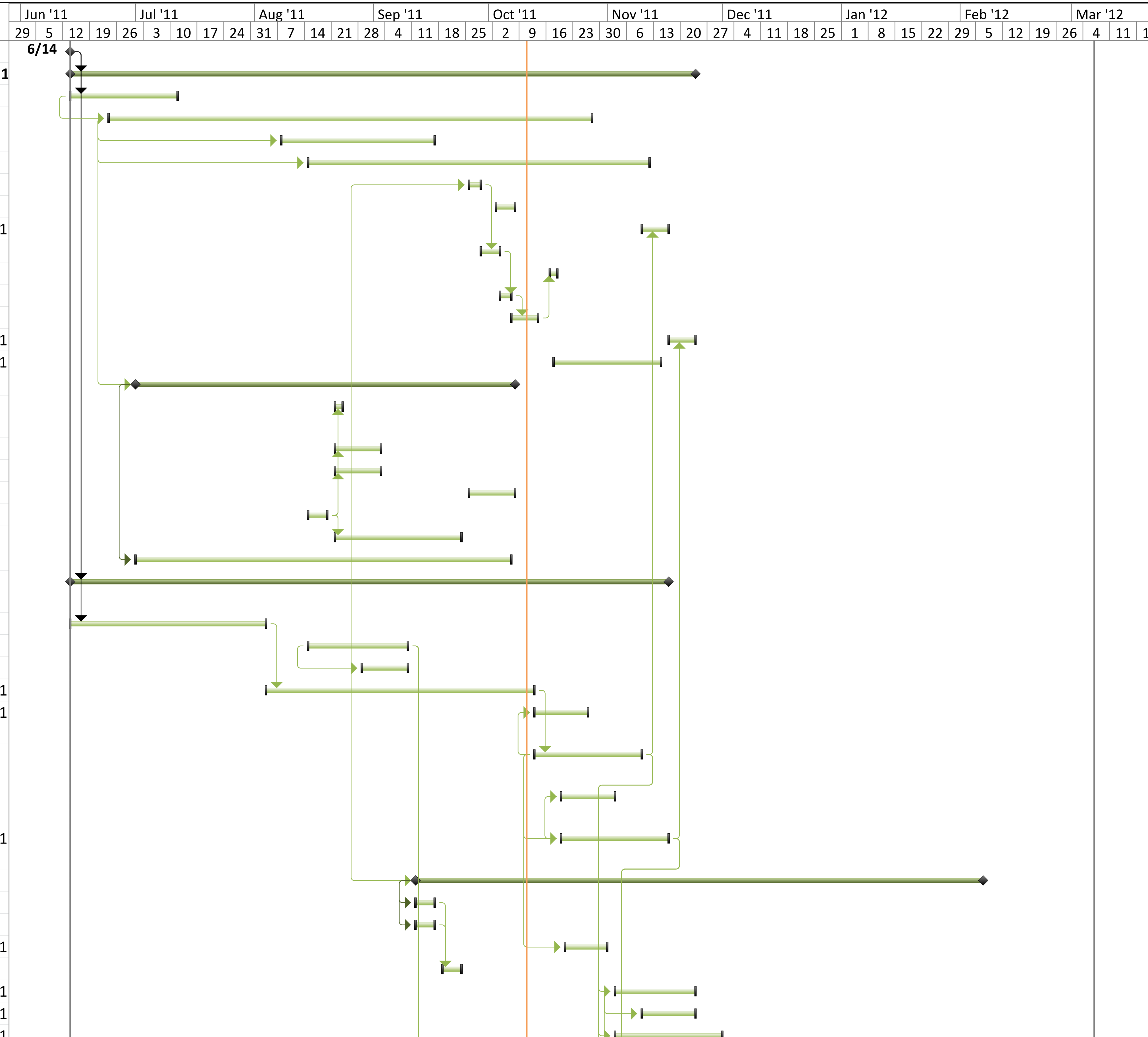
Vertical Loop System

Surface Water Loop System

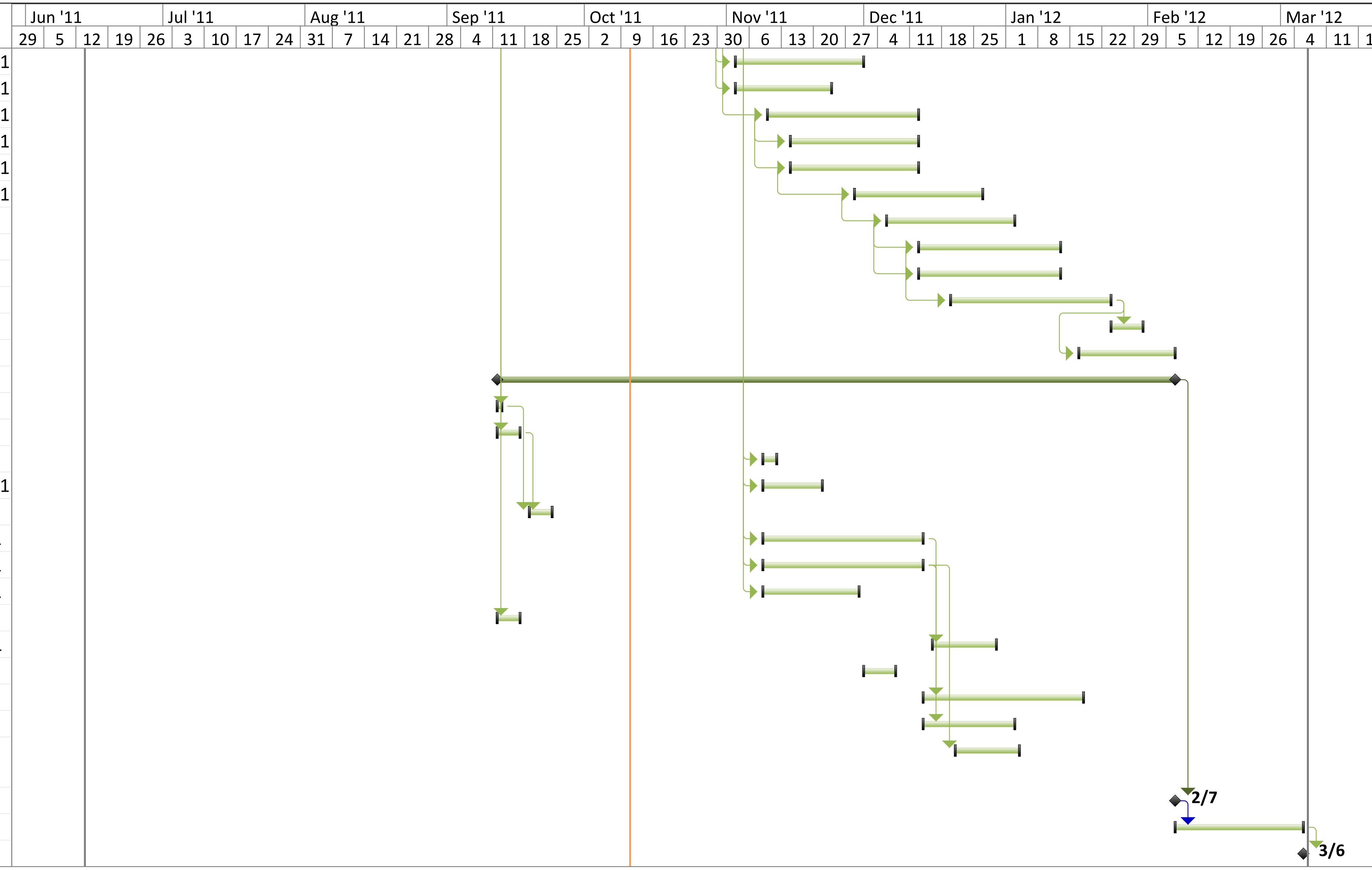
Horizontal "Slinky" Pattern

Appendix A. Detailed Project Schedule

ID	Task Mode	Task Name	Duration	Start	Finish
1		**Notice to Proceed**	**0 days**	**Tue 6/14/11**	**Tue 6/14/11**
2		**Sitework**	**117 days**	**Tue 6/14/11**	**Wed 11/23/11**
3		Clear and Grub	20 days	Tue 6/14/11	Mon 7/11/11
4		Grading	90 days	Fri 6/24/11	Thu 10/27/11
5		Site Electric	30 days	Mon 8/8/11	Fri 9/16/11
6		Stone Pipe Yard	65 days	Mon 8/15/11	Fri 11/11/11
7		Curbing	3 days	Mon 9/26/11	Wed 9/28/11
8		Dumpster/Flag Concrete	5 days	Mon 10/3/11	Fri 10/7/11
9		Dumpster Enclosure	5 days	Thu 11/10/11	Wed 11/16/11
10		Asphalt Paving Base	3 days	Thu 9/29/11	Mon 10/3/11
11		Asphalt Paving Top	2 days	Mon 10/17/11	Tue 10/18/11
12		Traffic & Panel Signage	3 days	Tue 10/4/11	Thu 10/6/11
13		Landscape	5 days	Fri 10/7/11	Thu 10/13/11
14		Dimensional Letters	5 days	Thu 11/17/11	Wed 11/23/11
15		Fence	20 days	Tue 10/18/11	Mon 11/14/11
16		**Site Utilities**	**71 days**	**Fri 7/1/11**	**Fri 10/7/11**
17		Electric Substation Underground	2 days	Mon 8/22/11	Tue 8/23/11
18		Electric	10 days	Mon 8/22/11	Fri 9/2/11
19		Telephone	10 days	Mon 8/22/11	Fri 9/2/11
20		Gas	10 days	Mon 9/26/11	Fri 10/7/11
21		Sanitary	5 days	Mon 8/15/11	Fri 8/19/11
22		Water	25 days	Mon 8/22/11	Fri 9/23/11
23		Stormwater	70 days	Fri 7/1/11	Thu 10/6/11
24		**Pre-Engineered Metal Building**	**112 days**	**Tue 6/14/11**	**Wed 11/16/11**
25		Reactions	37 days	Tue 6/14/11	Wed 8/3/11
26		Shop Foundations	20 days	Mon 8/15/11	Fri 9/9/11
27		Office Foundations	10 days	Mon 8/29/11	Fri 9/9/11
28		Fabrication	50 days	Thu 8/4/11	Wed 10/12/11
29		Set Office Building Base Plates	10 days	Thu 10/13/11	Wed 10/26/11
30		Erection of Office Building	20 days	Thu 10/13/11	Wed 11/9/11
31		Set Shop Building Base Plates	10 days	Thu 10/20/11	Wed 11/2/11
32		Erection of Shop Building	20 days	Thu 10/20/11	Wed 11/16/11
33		**Office Building**	**106 days**	**Mon 9/12/11**	**Mon 2/6/12**
34		Underground Piping	5 days	Mon 9/12/11	Fri 9/16/11
35		Underground Electric	5 days	Mon 9/12/11	Fri 9/16/11
36		Concrete Aprons	7 days	Fri 10/21/11	Mon 10/31/11
37		SOG	5 days	Mon 9/19/11	Fri 9/23/11
38		Metal Studs	15 days	Thu 11/3/11	Wed 11/23/11
39		Windows	10 days	Thu 11/10/11	Wed 11/23/11
40		Electric Rough-In	20 days	Thu 11/3/11	Wed 11/30/11

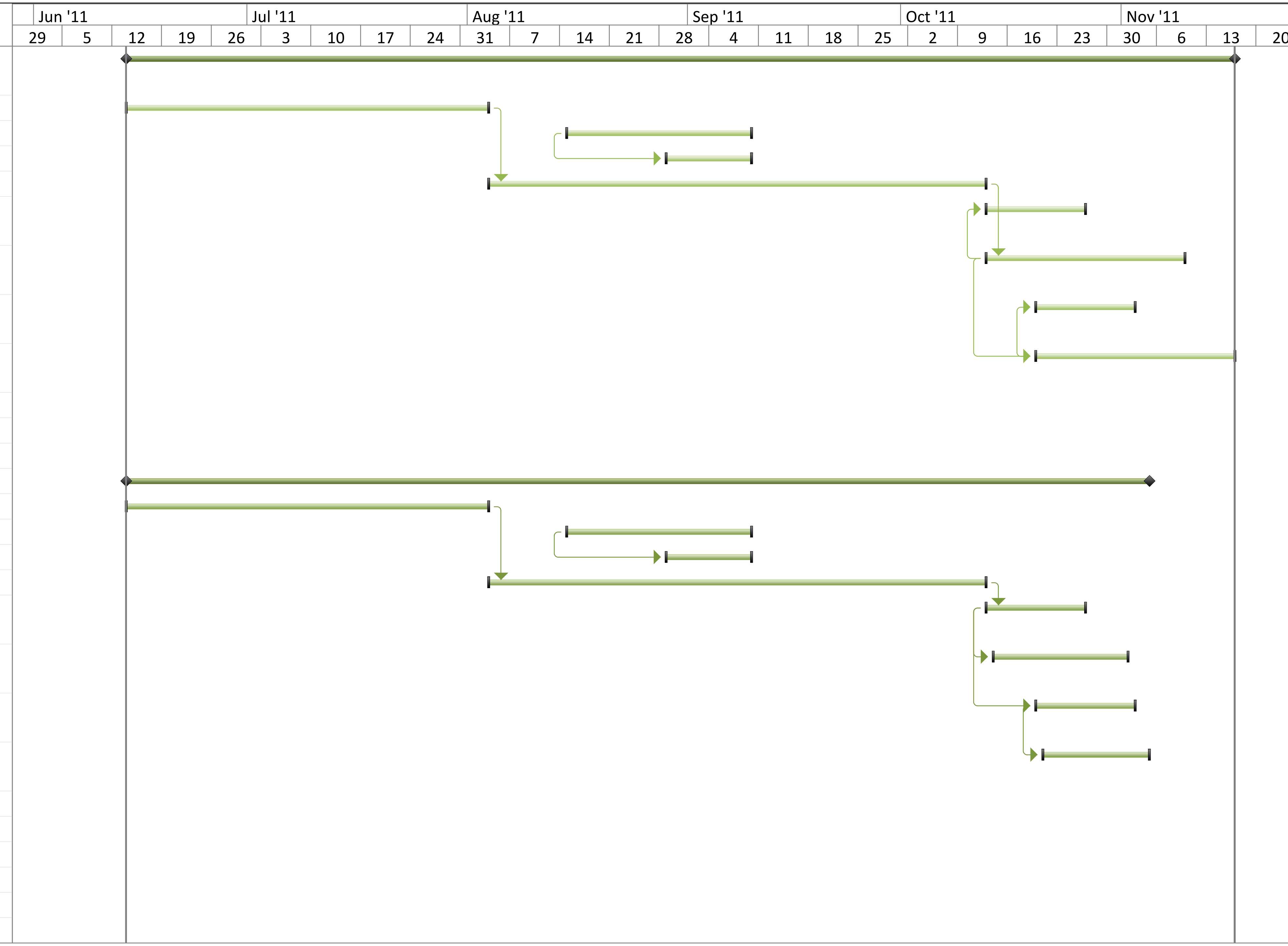


ID	Task Mode	Task Name	Duration	Start	Finish
41		Mech. Rough-in	20 days	Thu 11/3/11	Wed 11/30/11
42		Fire Sprinklers	15 days	Thu 11/3/11	Wed 11/23/11
43		Hang Drywall	23 days	Thu 11/10/11	Mon 12/12/11
44		Magnetic Wall Panels	20 days	Tue 11/15/11	Mon 12/12/11
45		Finish Drywall	20 days	Tue 11/15/11	Mon 12/12/11
46		Paint	20 days	Tue 11/29/11	Mon 12/26/11
47		Ceilings	20 days	Tue 12/6/11	Mon 1/2/12
48		Electric Finish	23 days	Tue 12/13/11	Thu 1/12/12
49		Mech. Finish	23 days	Tue 12/13/11	Thu 1/12/12
50		Ceramic Floor Tile	25 days	Tue 12/20/11	Mon 1/23/12
51		Install Doors	5 days	Tue 1/24/12	Mon 1/30/12
52		Install Casework	15 days	Tue 1/17/12	Mon 2/6/12
53		**Shop Building**	**106 days**	**Mon 9/12/11**	**Mon 2/6/12**
54		Underground Plumbing	1 day	Mon 9/12/11	Mon 9/12/11
55		Underground Electric	5 days	Mon 9/12/11	Fri 9/16/11
56		Concrete Aprons	3 days	Wed 11/9/11	Fri 11/11/11
57		Overhead Doors	9 days	Wed 11/9/11	Mon 11/21/11
58		SOG	5 days	Mon 9/19/11	Fri 9/23/11
59		Electric Rough-In	25 days	Wed 11/9/11	Tue 12/13/11
60		Mech. Rough-In	25 days	Wed 11/9/11	Tue 12/13/11
61		Fire Sprinklers	15 days	Wed 11/9/11	Tue 11/29/11
62		CMU	5 days	Mon 9/12/11	Fri 9/16/11
63		Paint	10 days	Fri 12/16/11	Thu 12/29/11
64		Install Cranes	5 days	Thu 12/1/11	Wed 12/7/11
65		Elec. Finish	25 days	Wed 12/14/11	Tue 1/17/12
66		Mech. Finish	14 days	Wed 12/14/11	Mon 1/2/12
67		Allowance Wash and Lube	10 days	Wed 12/21/11	Tue 1/3/12
68		**Substantial Completion**	**0 days**	**Tue 2/7/12**	**Tue 2/7/12**
69		Punchlist	20 days	Tue 2/7/12	Mon 3/5/12
70		**Turnover**	**0 days**	**Tue 3/6/12**	**Tue 3/6/12**



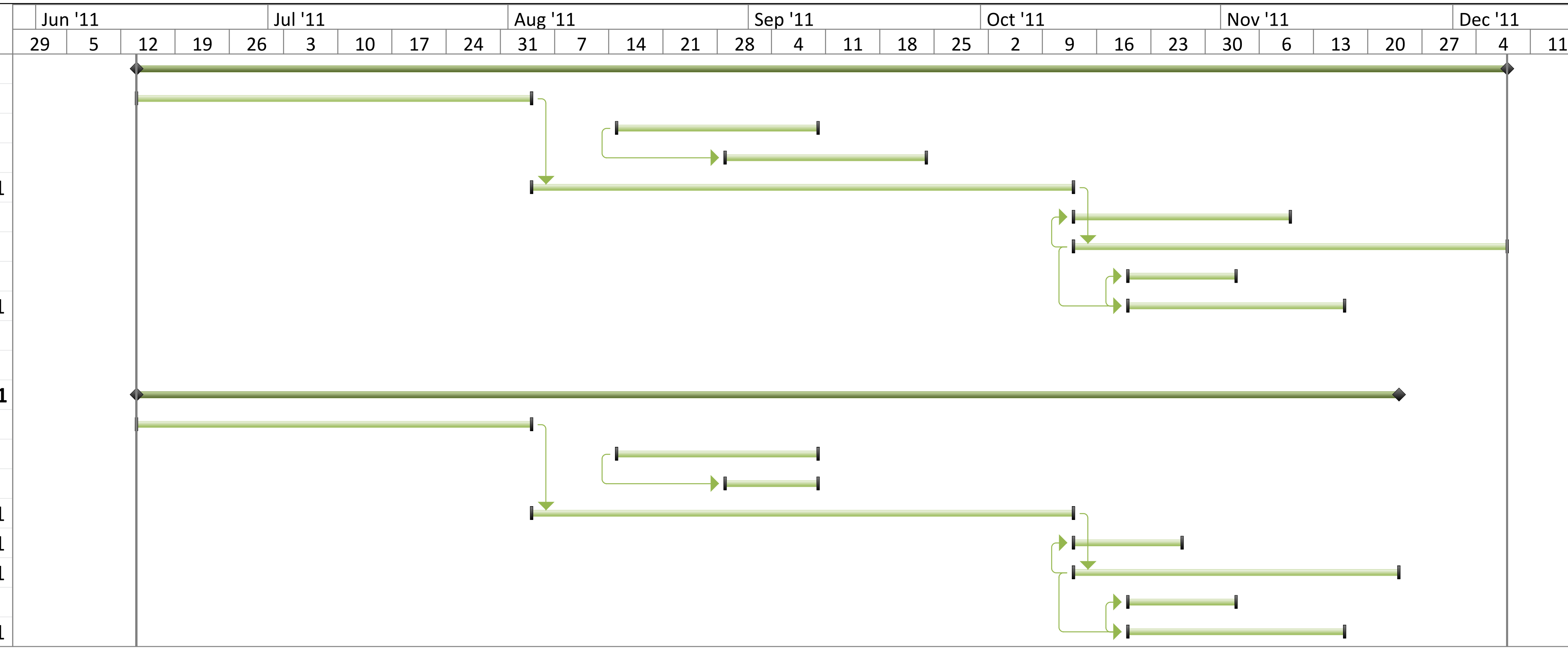
Appendix B. PEMB Schedule vs. Standard Steel Schedule

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Pre-Engineered Metal Building**	**112 days**	**Tue 6/14/11**	**Wed 11/16/11**	
2	Reactions	37 days	Tue 6/14/11	Wed 8/3/11	
3	Shop Foundations	20 days	Mon 8/15/11	Fri 9/9/11	
4	Office Foundations	10 days	Mon 8/29/11	Fri 9/9/11	3SS+10 days
5	Fabrication	50 days	Thu 8/4/11	Wed 10/12/11	2
6	Set Office Building Base Plates	10 days	Thu 10/13/11	Wed 10/26/11	7SS
7	Erection of Office Building	20 days	Thu 10/13/11	Wed 11/9/11	5
8	Set Shop Building Base Plates	10 days	Thu 10/20/11	Wed 11/2/11	9SS
9	Erection of Shop Building	20 days	Thu 10/20/11	Wed 11/16/11	7SS+5 days
10					
11					
12					
13	**Structural Steel**	**104 days**	**Tue 6/14/11**	**Fri 11/4/11**	
14	Reactions	37 days	Tue 6/14/11	Wed 8/3/11	
15	Shop Foundations	20 days	Mon 8/15/11	Fri 9/9/11	
16	Office Foundations	10 days	Mon 8/29/11	Fri 9/9/11	15SS+10 days
17	Fabrication	50 days	Thu 8/4/11	Wed 10/12/11	14
18	Set Office Building Base Plates	10 days	Thu 10/13/11	Wed 10/26/11	17
19	Erection of Office Building	13 days	Fri 10/14/11	Tue 11/1/11	18SS+1 day
20	Set Shop Building Base Plates	10 days	Thu 10/20/11	Wed 11/2/11	18SS+5 days
21	Erection of Shop Building	11 days	Fri 10/21/11	Fri 11/4/11	20SS+1 day
22					
23					
24					
25					
26					
27					

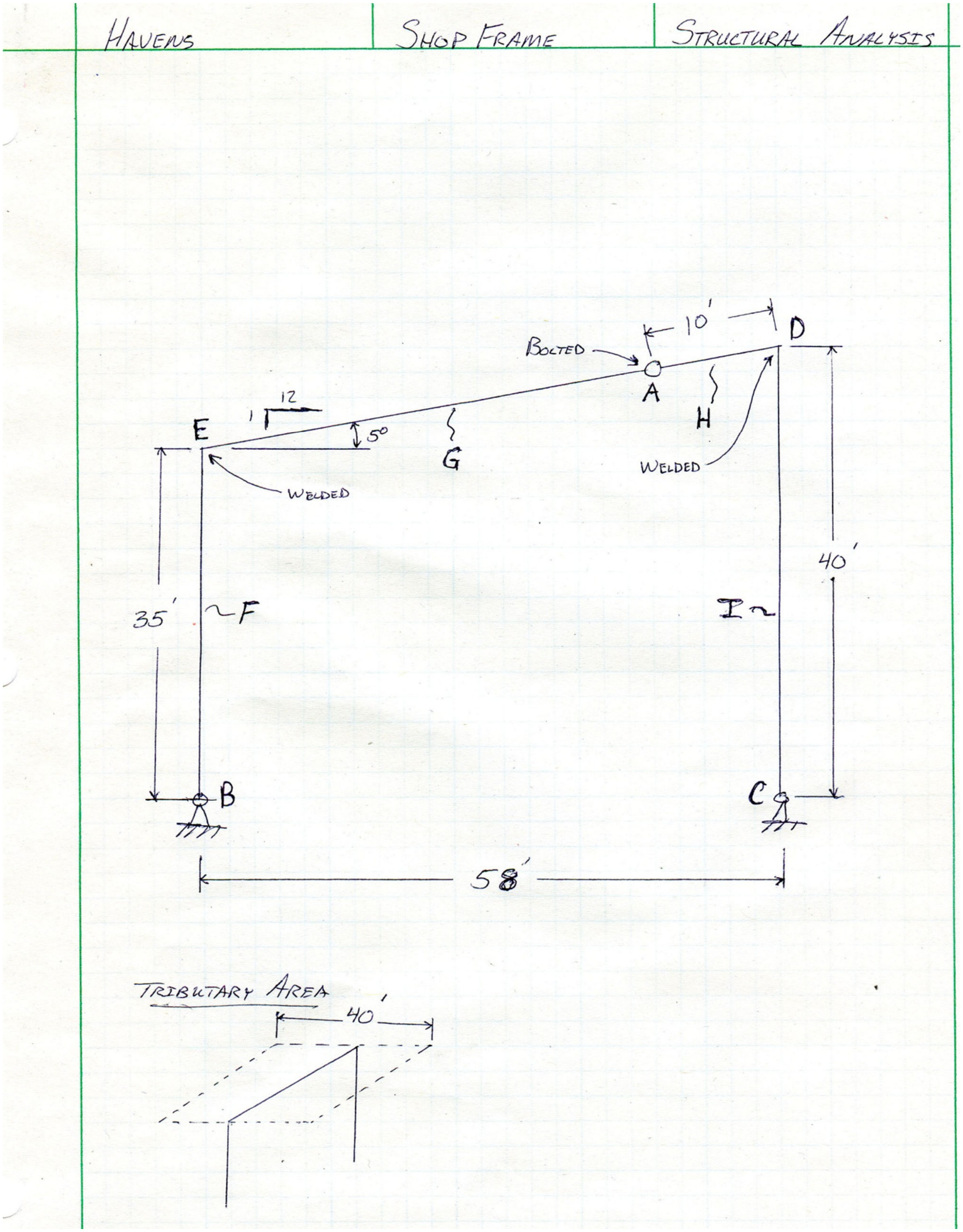


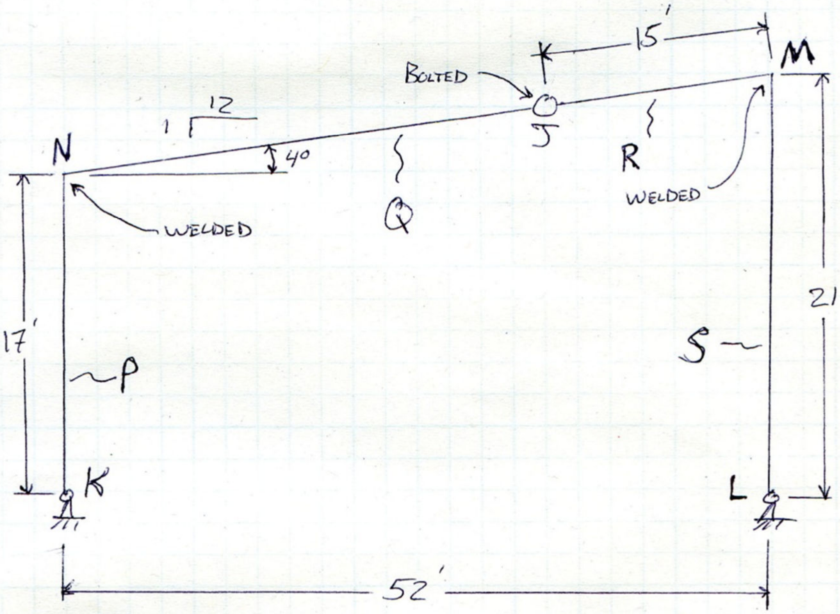
Appendix C. Horizontal vs. Vertical Expansion Schedules

ID	Task Name	Duration	Start	Finish
1	**Horizontal Office Expansion**	**127 days**	**Tue 6/14/11**	**Wed 12/7/11**
2	Reactions	37 days	Tue 6/14/11	Wed 8/3/11
3	Shop Foundations	20 days	Mon 8/15/11	Fri 9/9/11
4	Office Foundations	20 days	Mon 8/29/11	Fri 9/23/11
5	Fabrication	50 days	Thu 8/4/11	Wed 10/12/11
6	Set Office Building Base Plates	20 days	Thu 10/13/11	Wed 11/9/11
7	Erection of Office Building	40 days	Thu 10/13/11	Wed 12/7/11
8	Set Shop Building Base Plates	10 days	Thu 10/20/11	Wed 11/2/11
9	Erection of Shop Building	20 days	Thu 10/20/11	Wed 11/16/11
10				
11				
12	**Vertical Office Expansion**	**117 days**	**Tue 6/14/11**	**Wed 11/23/11**
13	Reactions	37 days	Tue 6/14/11	Wed 8/3/11
14	Shop Foundations	20 days	Mon 8/15/11	Fri 9/9/11
15	Office Foundations	10 days	Mon 8/29/11	Fri 9/9/11
16	Fabrication	50 days	Thu 8/4/11	Wed 10/12/11
17	Set Office Building Base Plates	10 days	Thu 10/13/11	Wed 10/26/11
18	Erection of Office Building	30 days	Thu 10/13/11	Wed 11/23/11
19	Set Shop Building Base Plates	10 days	Thu 10/20/11	Wed 11/2/11
20	Erection of Shop Building	20 days	Thu 10/20/11	Wed 11/16/11

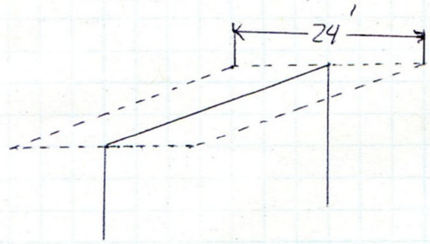


Appendix D. Building Load Calculations





TRIBUTARY AREA



SHOP BUILDING

SUPERIMPOSED - 3.52 PSF
COLLATERAL - 10.0 PSF
SNOW - 30.0 PSF

ASSUME SELF-WEIGHT - 8.0 PSF

$$W_u = 1.2(3.52 + 10 + 8) + 1.6(30) = 74 \text{ PSF}$$

$$w_u = 74 \text{ PSF}(40') = 2{,}960 \text{ PLF} = \underline{2.96 \text{ KLF}}$$

OFFICE BUILDING

SUPERIMPOSED - 2.69 PSF
COLLATERAL - 10.0 PSF
SNOW - 30.0 PSF

ASSUME SELF-WEIGHT - 8.0 PSF

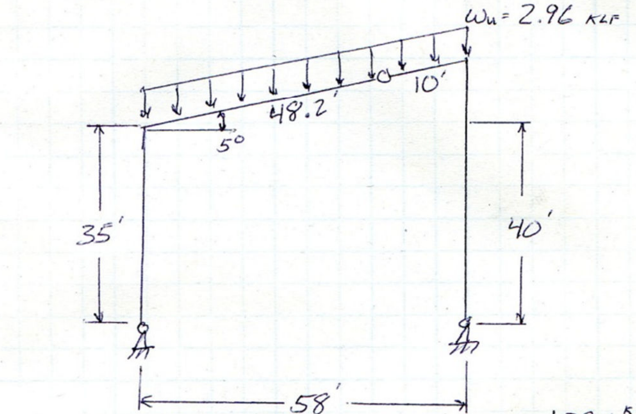
$$W_u = 1.2(2.69 + 10 + 8) + 1.6(30) = 73 \text{ PSF}$$

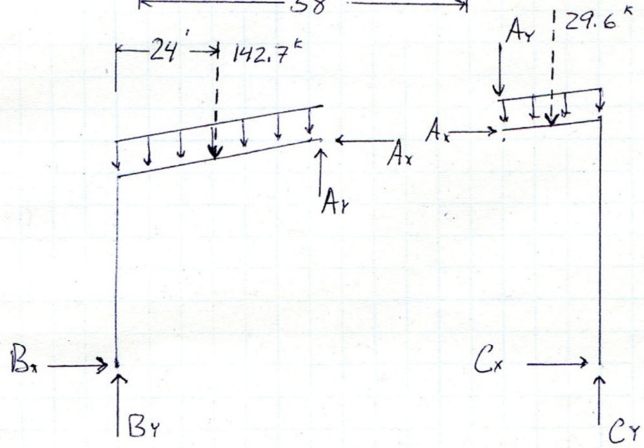
$$w_u = 73 \text{ PSF}(24') = 1{,}752 \text{ PLF} = \underline{1.75 \text{ KLF}}$$

TOPS 35502

Appendix E. Member Reactions Calculations

HAVENS | SHOP REACTIONS | STRUCTURAL ANALYSIS





$$\Sigma M_B:\ 24(142.7) = 39.14A_x + 48A_Y$$

$$39.14A_x + 48A_Y = 3424.8$$

$$\Sigma M_C:\ 4.95(29.6) + 9.9A_Y = 39.14A_x$$

$$39.14A_x - 9.9A_Y = 146.5$$

$$A_x = 3.74 + 0.253A_Y$$

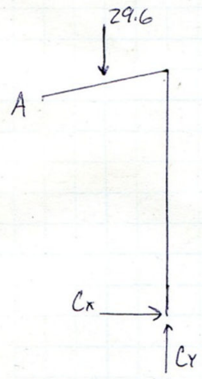
$$39.14(3.74 + 0.253A_Y) + 48A_Y = 3424.8$$

$$\underline{A_Y = 56.6^k}$$

$$\underline{A_x = 18^k}$$

ΣF_x: $B_x + C_x = 0$ $\quad B_x = -C_x$

ΣF_Y: $B_Y + C_Y = 171.7$



ΣM_A: $4.95(29.6) = 9.9(C_Y) + 39.14(C_x)$

$$9.9\,C_Y + 39.14\,C_x = 146.5$$

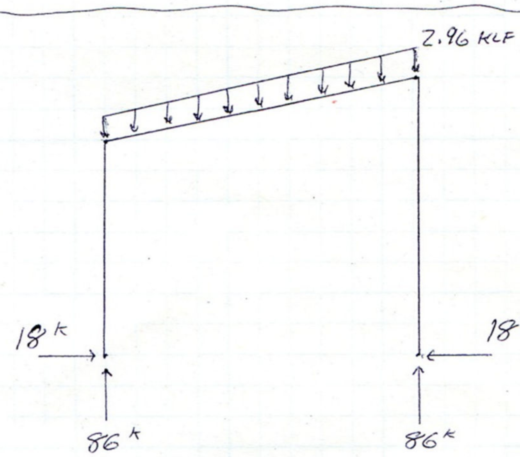
ΣM_B: $58\,C_Y = 142.7(24) + 29.6(52.95)$

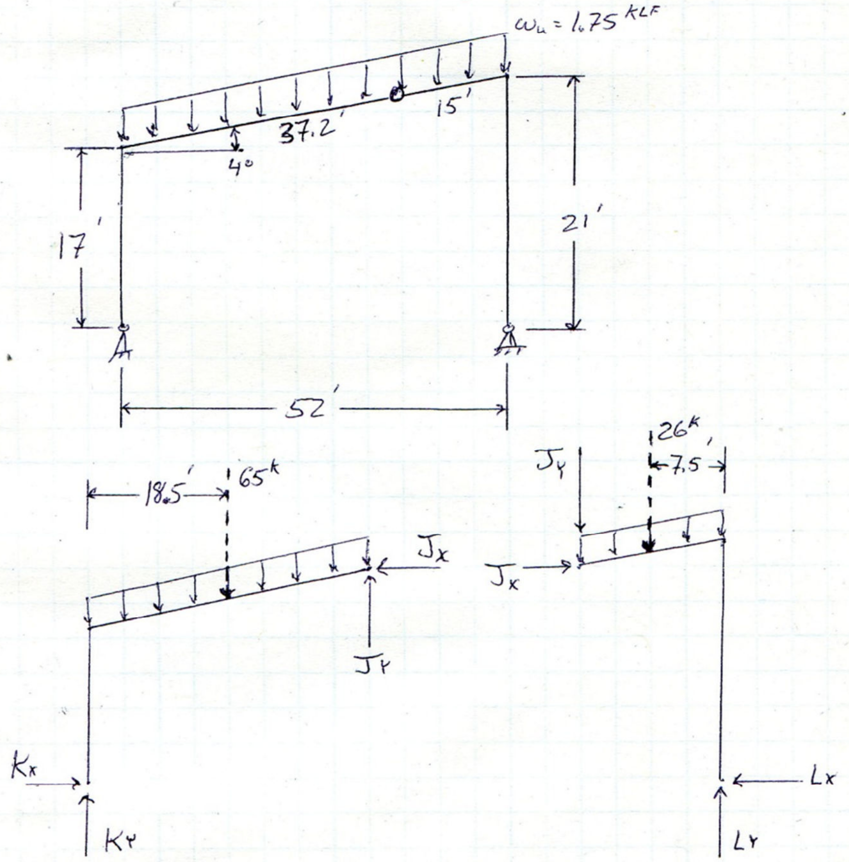
$\underline{C_Y = 86^k}$

$\underline{C_x = -18^k}$

$\underline{B_x = 18^k}$

$\underline{B_Y = 86^k}$





ΣM_K: $37.1 J_Y + 19.6 J_x = 65(18.5)$

ΣM_L: $26(7.5) + 14.9 J_Y = 19.6 J_x$

$37.1 J_Y = 1202.5 - 19.6 J_x$

$J_Y = 32.4 - 0.53 J_x$

$14.9(32.4 - 0.53 J_x) + 195 = 19.6 J_x$

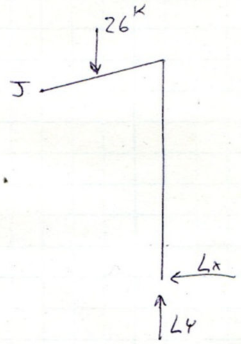
$482.76 - 7.9 J_x + 195 = 19.6 J_x$

$\underline{J_x = 24.6^k}$

$\underline{J_Y = 19.4^k}$

$\Sigma F_x: \quad K_x = L_x$

$\Sigma F_y: \quad K_y + L_y = 65 + 26$



$\Sigma M_J: \; 26(7.5) + 19.6(L_x) = 14.9(L_y)$

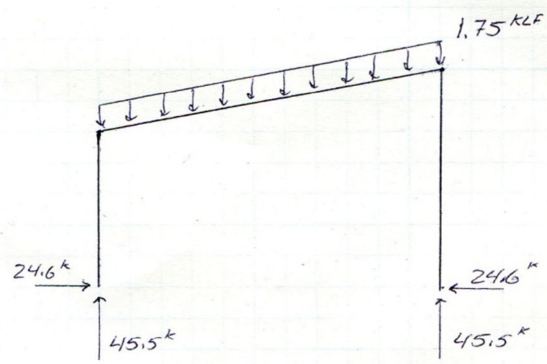
$\Sigma M_K: \; 29(91) = 58\, L_y$

$\underline{L_y = 45.5^k}$

$\underline{L_x = 24.6^k}$

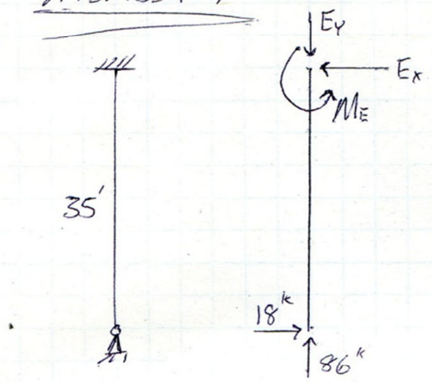
$\underline{K_x = 24.6^k}$

$\underline{K_y = 45.5^k}$



Appendix F. Maximum Shear and Moment Calculations

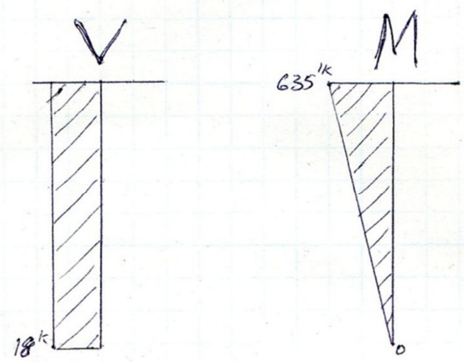
MEMBER F



$\Sigma F_x: \quad E_x = 18$

$\Sigma F_Y: \quad E_Y = 86$

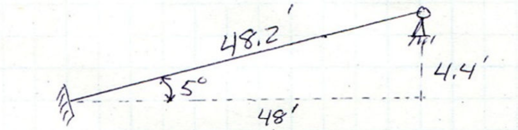
$\Sigma M_E: \quad M_E + 18(35) = 0 \qquad M_E = -635'^k$

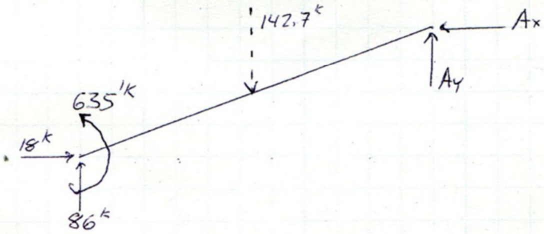


$V_{MAX} = 18^k$

$M_{MAX} = 635'^k$

MEMBER G



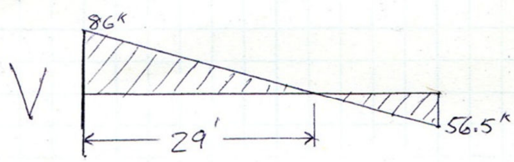


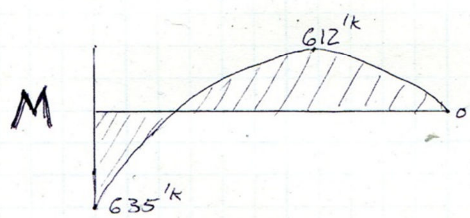
ΣF_x: $A_x = 18$

ΣF_Y: $A_Y + 86 = 142.7 \qquad A_Y = 56.5$

ΣM_A: $635 + 18(4.4) + 142.7(24) = 86(48)$

$4139 \approx 4128 \quad \underline{OK}$

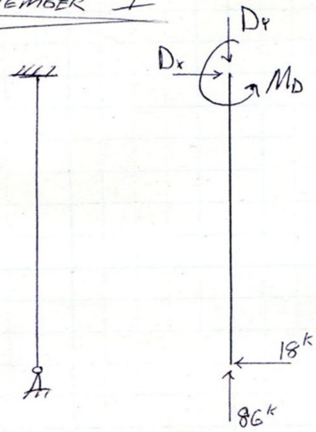




$\underline{V_{MAX} = 86^k}$

$\underline{M_{MAX} = 635'^k}$

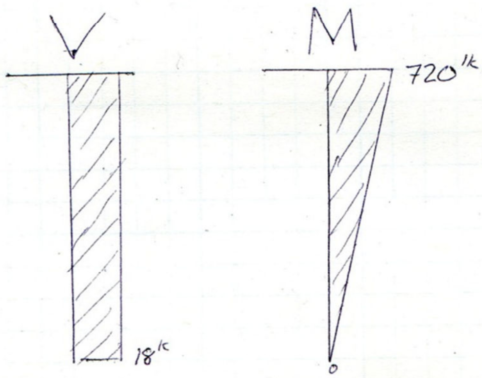
MEMBER I



ΣF_X: $D_X = 18^k$

ΣF_Y: $D_Y = 86^k$

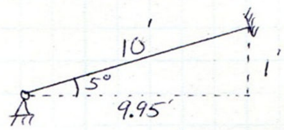
ΣM_D: $M_D = 18(40)$ $\quad M_D = 720'^k$



$V_{MAX} = 18^k$

$M_{MAX} = 720'^k$

MEMBER H

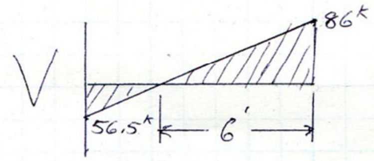


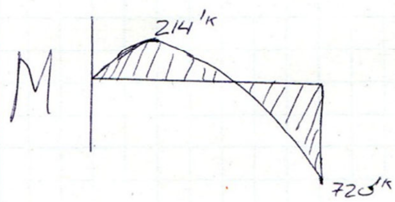
ΣF_x: $A_x = 18^k$

ΣF_Y: $A_Y = 56.5^k$

ΣM_A: $720 + 29.6(4.975) = 86(9.95) + 18(1)$

$867.3 \approx 873$ OK

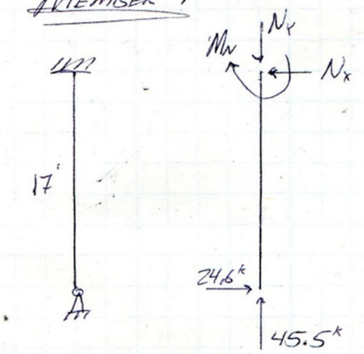




$V_{MAX} = 86^k$

$M_{MAX} = 720'^k$

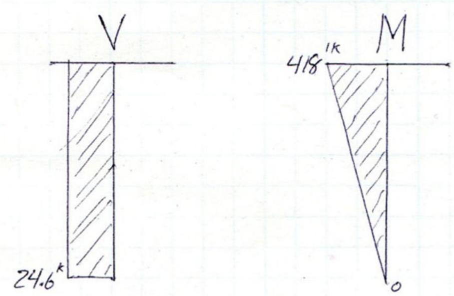
MEMBER P



ΣF_x: $N_x = 24.6^k$

ΣF_Y: $N_Y = 45.5^k$

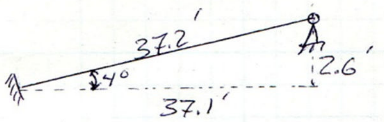
ΣM_N: $M_N = 24.6(17) = 418'^k$

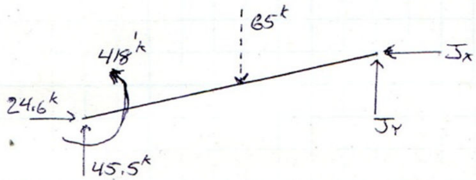


$V_{MAX} = 24.6^k$

$M_{MAX} = 418'^k$

MEMBER Q



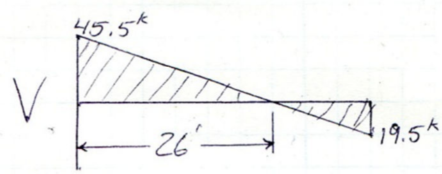


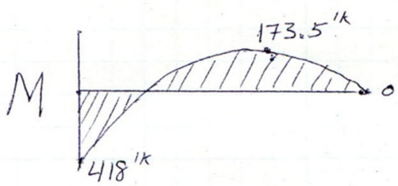
ΣF_x: $J_X = 24.6^k$

ΣF_Y: $J_Y + 45.5 = 65$ $\quad J_Y = 19.5^k$

ΣM_J: $418 + 65\left(\frac{37.1}{2}\right) + 24.6(2.6) = 45.5(37.1)$

$1687 \approx 1688$ <u>OK</u>

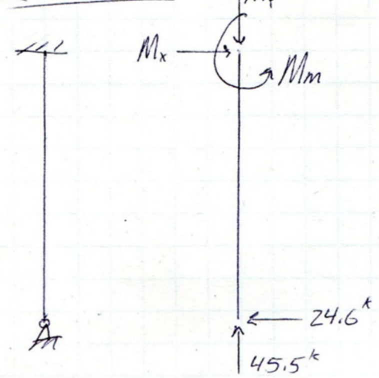




$\underline{V_{MAX} = 45.5^k}$

$\underline{M_{MAX} = 418'^k}$

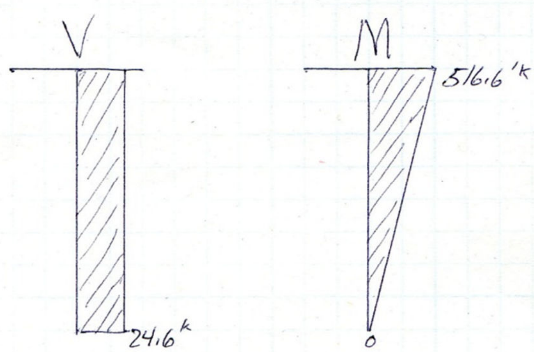
MEMBER S



ΣF_x: $M_x = 24.6^k$

ΣF_Y: $M_Y = 45.5^k$

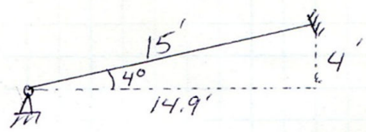
ΣM_m: $M_m = 24.6\,(21) = 516.6^{'k}$

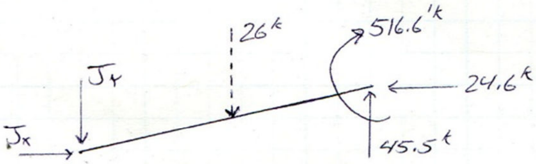


$V_{MAX} = 24.6^k$

$M_{MAX} = 516.6^{'k}$

MEMBER R



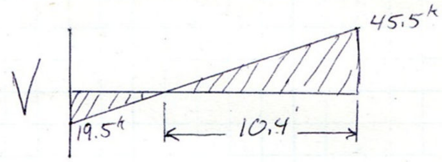


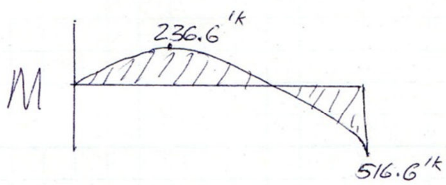
ΣF_x: $J_x = 24.6^k$

ΣF_Y: $J_Y + 26 = 45.5$ $\quad J_Y = 19.5^k$

ΣM_J: $516.6 + 26\left(\frac{14.9}{2}\right) = 24.6(4) + 45.5(14.9)$

$710.3 \approx 724.4$ ok





$V_{MAX} = 45.5^k$

$M_{MAX} = 516.6^{'k}$

Appendix G. Sizing Steel Members

MEMBER F

$M_u < \phi_b M_{px}$

$635'^k < 664'^k$ (W24 × 68)

$V_u < \phi_b V_{nx}$

$18^k < 295^k$

MEMBER G

$M_u < \phi_b M_{px}$

$635'^k < 664'^k$ (W24 × 68)

$V_u < \phi_b V_{nx}$

$86^k < 295^k$

MEMBER I

$M_u < \phi_b M_{px}$

$720'^k < 750'^k$ (W24 × 76)

$V_u < \phi_b V_{nx}$

$18^k < 316^k$

MEMBER H

$M_u < \phi_b M_{px}$

$720'^k < 750'^k$ (W24 × 76)

$V_u < \phi_b V_{nx}$

$86^k < 316^k$

MEMBER P

$M_u < \phi_b M_{px}$

$418^{'k} < 473^{'k}$ (W21×55)

$V_u < \phi_b V_{nx}$

$24.6^{k} < 234^{k}$

MEMBER Q

$M_u < \phi_b M_{px}$

$418^{'k} < 473^{'k}$ (W21×55)

$V_u < \phi_b V_{nx}$

$45.5^{k} < 234^{k}$

MEMBER S

$M_u < \phi_b M_{px}$

$516.5^{'k} < 540^{'k}$ (W21×62)

$V_u < \phi_b V_{nx}$

$24.6^{k} < 252^{k}$

MEMBER R

$M_u < \phi_b M_{px}$

$516.5^{'k} < 540^{'k}$ (W21×62)

$V_u < \phi_b V_{nx}$

$45.5^{k} < 252^{k}$

TOPS 35502

Appendix H. Structural Steel Cost & Duration Estimate

Structural Steel

Member	Type	Length	Unit	Mat. Cost	Lab. Cost	Equip. Cost
F	W24x68	35	LF	$93.50	$3.52	$1.46
G	W24x68	48.2	LF	$93.50	$3.52	$1.46
I	W24x76	40	LF	$105.00	$3.52	$1.46
H	W24x76	10	LF	$105.00	$3.52	$1.46
P	W21x55	17	LF	$69.00	$3.67	$1.52
Q	W21x55	37.2	LF	$69.00	$3.67	$1.52
S	W21x62	21	LF	$85.50	$3.77	$1.56
R	W21x62	15	LF	$85.50	$3.77	$1.56

Member	Cost/LF	Cost/LF (w/O&P)	Lab. Hr./LF	Est. Cost	Est. Duration (Hr.)
F	$98.48	$111.00	0.075	$3,446.80	2.63
G	$98.48	$111.00	0.075	$4,746.74	3.62
I	$109.98	$123.00	0.075	$4,399.20	3.00
H	$109.98	$123.00	0.075	$1,099.80	0.75
P	$74.19	$83.50	0.075	$1,260.23	1.28
Q	$74.19	$83.50	0.075	$2,759.87	2.79
S	$90.83	$90.83	0.077	$1,907.43	1.62
R	$90.83	$90.83	0.077	$1,362.45	1.16

Bolts

Connections	Bolts/Conn.	Bolts	Unit	Mat. Cost	Lab. Cost	Equip. Cost
3	8	24	EA	$2.67	$3.29	--

Cost/Bolt	Cost/Bolt (w/O&P)	Lab. Hr./Bolt	Est. Cost	Est. Duration (Hr.)
$5.96	$8.85	0.067	$143.04	1.61

Base Plates

Plates	SF/Plate	SF	Unit	Mat. Cost	Lab. Cost	Equip. Cost
2	2	4	SF	$38.50	--	--

Cost/SF	Cost/SF (w/O&P)	Lab. Hr./SF	Est. Cost	Est. Duration (Hr.)
$38.50	$42.00	--	$154.00	--

Purlins

Building	SF	Unit	Mat. Cost	Lab. Cost	Equip. Cost
Shop	5,328	SF	$2.00	$0.38	$0.04
Office	2,165	SF	$2.00	$0.38	$0.04

Cost/SF	Cost/SF (w/O&P)	Lab. Hr./SF	Est. Cost	Est. Duration (Hr.)
$2.42	$2.88	--	$15,344.64	--
$2.42	$2.88	--	$6,234.62	--

Metal Siding

Building	SF	Unit	Mat. Cost	Lab. Cost	Equip. Cost
Shop	5,328	SF	$2.02	$1.77	--
Office	2,165	SF	$2.02	$1.77	--

Cost/SF	Cost/SF (w/O&P)	Lab. Hr./SF	Est. Cost	Est. Duration (Hr.)
$3.79	$4.92	--	$26,213.76	--
$3.79	$4.92	--	$10,650.82	--

Shop Building

Single Frame	
Cost	$55,547.98
Duration	11.60 Hr.
Seven Frames	
Cost	**$388,835.83**
Duration	81.20 Hr. → **10.2 Days**

Office Building

Single Frame	
Cost	$24,473.46
Duration	8.45 Hr.
Twelve Frames	
Cost	**$293,681.50**
Duration	101.34 Hr. → **12.7 Days**