Final Report

Senior Thesis

Main & Gervais
Columbia, South Carolina

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I. Executive Summary

This thesis focuses primarily on the curtain wall for Main & Gervais. The first analysis examines the two methods for constructing a curtain wall, stick-built (current method) and prefabricated (proposed method). The second analysis examines the design of the curtain wall by evaluating the efficiency and providing a better alternative.

Curtain Wall Prefabrication Analysis

The current method of curtain wall construction for Main & Gervais is the stick-built method. The first portion of this thesis compares stick-built construction and prefabrication of curtain wall systems to determine if prefabrication is a better alternative. There are several methods for comparing the two separate systems. First, a comparison of technical advantages and disadvantages for both systems is examined and indicates prefabrication has more advantages. Second, a schedule comparison points out that it takes a third of time to install prefabricated panels as opposed to constructing the panels on-site. Third, a cost comparison reveals that the material costs for prefabrication are higher than stick-built construction. Finally, the conclusion summarizes the basics of the analysis and states that prefabrication with schedule savings integrated into the estimate, will cost 8% more than stick-built construction.

Curtain Wall Design Analysis

The current curtain wall design for Main & Gervais is complicated in certain areas. The curtain wall on the west elevation is sloped and extends away from the building at 5.63^{o}. This analysis examines the benefits and consequences of eliminating this angle. The following are important factors for this analysis. First, considering the additional area gained is important to understanding the benefits of extending the curtain wall. The total area added to the floor plan amounts to 2756 ft^2, which allows the owner to charge an additional $57,876.00 to its tenants a year. Second, understanding the structural implications of adding area to the building footprint is important to verify if this addition is possible. The verification in this analysis proved that the new structural elements would support the additional loads and will cost $30,828.07 for the construction of these elements. Third, switching the angle of the curtain wall changes the angle in which the sun shines through the glazing. The new energy demand of the air conditioning units to manage the hotter temperature inside is $2,176.40 for the year. In conclusion, it would be beneficial for the owner to eliminate the slope in the curtain wall on the west façade as the owner will be able to earn more rent money with the extra floor plan area.

Combining Both Analyses

Suppose prefabrication is the chosen method and the curtain wall slope is eliminated. There will be an increase of upfront costs by $351,842.40 for prefabricated curtain wall panels. The extra floor space available from eliminating the slope on each floor will provide an additional $50,414.06 in revenue per year to the owner. The owner will break even after eight years if both actions are implemented on Main & Gervais. In the end, the finer quality of prefabricated curtain wall panels is worth the increased upfront cost because the owner will break even eventually.

II. Project Background

Main & Gervais is an office building located in downtown Columbia, South Carolina, right next to the State Capital Building. It sits on the corner of Main Street and Gervais Street at 16 stories high. There is a lobby on the ground floor consisting of a signature restaurant and a bank. Above the lobby are six levels are parking space available to the tenants of the building. Resting on top of the lobby and parking garage are nine floors of office space with breathtaking views all around.

The structure is primarily composed of cast-in-place concrete that will be post-tensioned. The skin of the building is a glazed aluminum curtain wall that will be tied into the structure. Starting from floor nine extending through floor 11, there is an exterior terrace that allows the tenant to escape for a moment of fresh air and get a look a closer look of the downtown landscape.

Main & Gervais started construction July 1, 2008, and will extend to the scheduled completion date of December 31, 2009. The contract value is currently at $41,151,000. The general contractor is Holder Construction Company and the delivery method is design-bid-build.

Figure 2.1: Aerial View of Main & Gervais

Client Information

The developer for Main & Gervais is Holder Properties and there are three clients to occupy the office levels when the project is complete. Holder Properties also develops corporate offices, contact centers, data centers, residential, and educational facilities. The building is in a prime location in Columbia, South Carolina, considering it is right next to the State Capitol. This would leave only the best façade and impressive interiors acceptable for the building's tenants. Each of the three tenants has their own three floors stacked on one another above the parking garage.

The three tenants that are going to occupy the building have already executed their leases to start when construction is scheduled to finish, otherwise there are penalties assigned each day the building is incomplete. Coordination is a key part of this project because there are three different tenants each with their own interior architects. There are phased occupancy requirements for the tenants because each is moving in on different dates.

Site Plan and Existing Conditions

The site is located in downtown Columbia, South Carolina. Cast-in-place concrete is the preferred method of construction in Columbia, which is what Main & Gervais chosen method happens to be. The building is identified as the black rectangle on the map below. In a situation such as this, there is generally limited to no parking for the workers on site. All employees working on site have to park in the parking lots/decks available in downtown Columbia.

From the soils report conducted, it appears that the subsurface profile consists of a few feet of surficial fill (silty and clayey sand with some debris) with coastal plain deposits underneath extending to 100 feet below grade. Coastal plain deposits consist of medium dense to dense silty and clayey sands interbedded with low plasticity sandy clays extending to 75 feet and below 75 feet there are medium dense silty sands with considerable gravel. This soil analysis indicates that shallow footings would not be appropriate for the foundation. Groundwater was reached at 45 to 50 feet below grade.

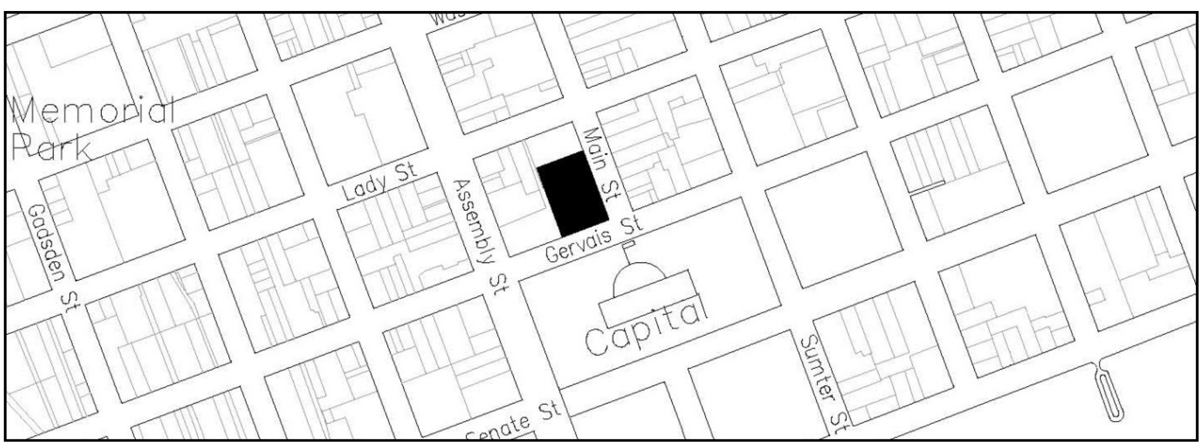

Figure 2.2: Location of Main & Gervais

The site plan with existing conditions can be seen in **Appendix A.**

Project Delivery System

The project was delivered as a design-bid-build project with a building permit set out on June 7, 2008. The 100% construction documents will be out early October of 2008. Holder Construction Company rarely uses a design-build delivery system. The developer, Holder Properties, and the general contractor, Holder Construction Company, have owners that are brothers. It is easy to see how the two came across each other. The following chart lists the contracts that are held for this project. The developer holds a contract with the architect and the general contractor. The architect then holds contracts with all the designers and consultants. The general contractor holds contracts with all the subcontractors and vendors. I posted only major cost subcontractors and vendors. There are smaller subcontractors and vendors to list, but I chose to leave them out to eliminate unnecessary repetition. Holder has chosen some of the subcontractors they have previously worked with and this helps eliminate some extra relationship building. **Figure 2.3** displays how the contracts are setup for this project.

Figure 2.3: Contract Chart

Building Systems Summary

Yes	No	Work Scope	Comments
X		Demolition	There was an existing parking lot that had to be removed. Some items including existing storm drainage, some brick, and a retaining wall remained. Parking meters and fire hydrants were removed and need to be replaced.
X		Structural Steel Frame	The crane onsite is a SK415 tower crane from Amquip. There is structural steel bracing for the screen wall on the penthouse level.
X		Cast in Place Concrete	The concrete will be pumped and bucketed into place for the most part, or placed directly from the chute where possible.
X		Precast Concrete	Electrical vault and water vault are precast by Tindall.
X		Mechanical System	Lobby: Mechanical room is centralized. There is a self contained A/C unit capable of 6,330 CFM and a split system AHU rated at 2,000 CFM Parking Garage Levels: No mechanical rooms. There are split systems AHUs capable of 800 CFM in the elevator lobby and electric wall heaters with 4.8KW capacities in the stairways. Office Space Levels: Mechanical rooms are located in the core of each floor. Each room has self-contained A/C units each rated around 20,000 CFM connected to galvanized ductwork with VAV boxes at the end. Rooftop: Many items including: Two stair pressurization intake fans rated at 16,000 CFM. Outside air flow fan rated at 22,700 CFM. Two cooling towers rated at 999.5 GPM. Two chill water pumps rated at 1,999 GPM each. Two split system AHUs with one rated at 3,000 and the other 600 CFM. Fire Suppression System: Automatic wet sprinkler system in office tower/retail areas. Class 1 standpipe system for office portion and class 1 manual dry standpipe system for parking garage. The storage tank and pump are located on the lobby floor.
X		Electrical System	There is an electrical room on the lobby floor. For every floor above the lobby, there is an electrical room in the core near the elevator. The 3-phase diesel generator is located on the lobby floor rated at 600KW. The main feed is a 3-phase single sided busway rated at 4000A, 480/277V.
X		Masonry	Some of the interior non load bearing walls consists of concrete masonry units.
X		Curtain Wall	There is a glazed aluminum curtain wall installed as unit-and-mullion assemblies to the cast-in-place concrete structural system.
X		Support Excavation	For the most part they were able to step all the excavations except for a few where they used trench boxes. They are putting in HDPE pipe for the foundation drain.

Project Schedule

Key Project Dates

Notice to Proceed	9/15/2007
Substructure Construction Begins	8/18/2008
Excavation Complete	10/10/2008
Superstructure Construction Begins	10/6/2008
Interior Construction Begins	1/5/2009
Curtain Wall Construction Begins	3/31/2009
Superstructure Construction Completion	6/4/2009
Tenant Upfit – Edens & Advant	6/1/2009
Tenant Upfit – NBSC	8/3/2009
Tenant Upfit – McNair	11/16/2009
Final Completion	12/31/2009

Structural Construction

There are three main sections to the building. These include the lobby, the parking garage, and the office portion. Each of these sections has different concrete placement sequences. The lobby requires MEP rough in and storm line installation on the south side before the slab on grade can be placed. The lobby is scheduled for 22 days. The parking garage levels are broken into four separate subsections of formwork, rebar, and concrete placement. Each parking garage level is scheduled to take on average 16 days. There is one exception with the parking garage and that is the first level in which it has three larger subsections and will take 24 days. Lastly, the office space has two separate subsections of formwork, rebar, and placement that will take on average, ten days a level.

Façade Construction

The curtain wall is scheduled to begin on March 31, 2008, and will take approximately 135 days to complete. Installing the vertical and horizontal mullions and inserting the glass will take approximately 50 days for every floor. The level next in line will be able to start as soon as the layout and clips are complete for the concurrent level. This will allow the schedule to shrink down to 135 days for the aluminum glazed curtain wall.

Interior Construction

Shell finishes will begin in January of 2009 and continue until October of the same year. Activities within this section include MEP rough in, drywall, and masonry walls. The interior finishes will begin 6 months later in June 2009 just after the shell construction finishes for level 12 of the office portion. Interior finishes have a long schedule due to the fact that there are three separate tenants moving into the building. The three tenants have their own architect designing the interior portions of the office building. Because of the complexity of all the coordination required, the schedule allows 13 months for interior finishes.

A project schedule with more detail can be found in **Appendix B**.

Project Costs

Square footage of office building: 205,000 ft^2
Square footage of parking garage: 210,000 ft^2
Total square footage: 415,000 ft^2
Total Project Cost: $41,151,000
TC/SF: $99.16/$ft^2$

The actual contract value for Main & Gervais is $41,151,000. The total square footage of the building, including the parking garage and office tower, is 415,000 ft^2. This results in a $99.16/$ft^2$ for the cost of the total building costs. The following tables breakdown the general conditions and structural costs of the building.

General Conditions Estimate Summary			
Category	Unit (Month)	Monthly Cost	Total Cost
Equipment	18	34045.83	$ 612,824.94
Material	18	15747.86	$ 283,461.48
Labor	18	35201.76	$ 633,631.68
Project	18	231029.02	$ 2,772,348.20
	Totals	316024.47	$ 4,302,266.30

Table 2.1: General Conditions Costs

The values generated in the general conditions estimate were obtained by utilizing R.S. Means Building Cost Data 2008, pages 10-22. The above table, **Table 2.1**, displays the breakdown of costs for labor, material, equipment, and project items (fee, insurance, etc.) for the project as a whole. The chosen unit is months so that the observer can get an idea of the monthly cash flow for general conditions. It can also be understood what potential costs might be added/subtracted in case the project schedule changes. The total general conditions estimate of $4,302,266.24 represents approximately 10% of the total contract value of $41,151,000.00. A more detailed breakdown of the general conditions estimate is located in **Appendix C**.

Structural Estimate Summary				
Description	Quantity	Unit	Cost/Unit	Total
03 11 13 Forms In Place	857232	SFCA	$ 4.07	$ 3,484,808.47
03 21 10 Reinforcing In Place	2032	tons	$ 1,192.75	$ 2,423,672.60
03 23 05 Prestressing Tendons	242	tons	$ 2,970.40	$ 718,836.80
03 31 05 Placing Concrete	19317	CY	$ 36.37	$ 702,560.27
03 31 05 Normal Weight Concrete	19317	CY	$ 102.24	$ 1,974,913.10
31 62 13 Concrete Piles	25650	VLF	$ 33.83	$ 867,683.07
			Total	$ 10,172,474.31

Table 2.2: Structural Estimate Summary

Table 2.2 outlines the cost for each of the categories in the detailed structural estimate, which is located in **Appendix D.** The estimate was done utilizing R.S. Means 2008. There were several assumptions made during the estimate and they can be found in the following paragraphs. The final cost for the structural portion of the building came to $10,172,474.31. Due to the restrictions preventing the release of cost information about the project, there is no comparison between the estimated and actual cost.

Foundations

For this particular foundation, there were 270 concrete piles with an 18" diameter that reached a depth of 95' into the ground. On average, the pile caps resting on these piles were 11'x11'. The size was obtained by averaging the values shown for each of the pile caps on the drawings. The pile caps were assumed to have #9 top and bottom bars placed in each direction.

Slab on Grade/Elevated Slabs

Each slab was typically 7" thick and had #4 top and bottom reinforcing bars at 12" on center. The elevated slabs were taken off as flat plate slabs in square feet.

Girders/Joists/Beams

These structural items were each common sized to 24"x24" and 30' in length due to the limitations of R.S. Means. The parking garage had a larger quantity considering it has a larger footprint than the office levels so there was a separate average taken for each portion of the building. The post-tensioning was calculated using pricing guidelines outline in the drawings. The girders, joists, and beams were assumed to have 0.30, 0.35, and 0.55 pounds per square foot of overall building area respectively.

Columns

A typical column was assumed to have dimensions of 36"x36" and 12' in height. There was assumed to be 16 #10 bars running vertical to reinforce each of the columns.

Concrete Placement

For the most part, concrete placement was assumed to be done by bucket with the tower crane. Although with slab on grade, it was assumed the concrete would be pumped into place.

III. Curtain Wall Prefabrication Analysis (Construction Depth)

Introduction

During the PACE Seminar in 2008, the topic of prefabrication was brought up for discussion. It was mentioned that because of where the construction industry was headed, prefabrication would become more prevalent. This was so for several reasons. The economy's condition was and still is resulting in diminishing job opportunities throughout many industries including construction. Therefore, fewer laborers would be available to perform certain tasks on the job site. Architects are developing more involved designs for their projects, which require higher quality control for the finished product. Finally, time is becoming ever more sensitive. Where time can be conserved, money can be saved as well. Prefabrication provides the opportunity to accomplish these requirements in a demanding industry such as construction.

Problem Statement

Main & Gervais is a sixteen-story office building located in Columbia, South Carolina. At this geographical location, unions are not that prevalent. This fact results in cheaper labor and the ability to combine tasks so the output from laborers is maximized. For Main & Gervais, it has an aluminum curtain wall system as its façade. The chosen way for construction of the curtain wall is the stick-built method. The stick-built method has a few disadvantages attached to it including a messier site, lower quality control, and a slower process. The one main advantage it does have is the potential for cheaper labor costs. The problem here is that one advantage, why is the choice stick-built instead of prefabrication just because of cheaper labor?

Research Goal

The goal of this research is to better understand advantages and disadvantages of introducing prefabrication into Main & Gervais. By including the disadvantages, it will be clearer if the advantages are actually worth the effort of prefabrication. The idea is to find a method to ensure maximum quality in the final project while reducing the schedule in the process. After establishing the implications of this research, it will be important to apply these ideas to Main & Gervais to fully understand the advantages of prefabrication.

Research Methods

The first section of this research outlines advantages and disadvantages of the current method for construction of the curtain wall on Main & Gervais, which is the stick-built method, and compares it to the prefabrication method. The second section observes the current schedule of the curtain wall and provides a new schedule if prefabrication were chosen instead. The third section breakdowns the costs of both methods and identifies the one that costs less. Lastly, the final section summarizes the main points of this analysis.

Construction Method Evaluation

Current Method

The current method of construction for the curtain wall system for Main & Gervais is stick-built. There are various advantages and disadvantages associated with this method. These are outlined in the table below and further described in the following paragraphs. By acknowledging the problem, it can be understood how we can approach a better solution.

Advantages	Disadvantages
Money: If this method is in a geographical location that is not unionized, the labor has the potential to be cheaper	**Time:** Construction of the curtain wall system can take longer if the majority of the assembly takes place on-site
Delivery: The materials that are necessary for a curtain wall can be effectively compacted on a truck and delivered to site	**Site Condition:** With all the materials being delivered to site, it creates the opportunity for clutter to develop
Flexibility: There is more flexibility for the workers when constructing the panels since they are manufactured on site	**Quality Control:** The quality diminishes when the assembly takes place in an uncontrollable environment
	Hoisting: Curtain wall provides another set of materials that could hog the hoist and limit the time for use from other trades

Table 3.1: Advantages and Disadvantages to Stick-Built Construction

As shown in the table above, the disadvantages outweigh the advantages. All the materials are delivered to site but with all the materials on site at once it can congest the site. There are other trades that need space as well, for example, the drywall contractor will need space to lay down all his drywall. Also, having all the materials separate on site requires all them to be assembled together just before installation. The environment is always variable in terms of what other trades will be around and how the weather pans out. This insecure environment could damage the materials.

Because all the construction in a stick-built situation takes place on site, it presents some more problems. On-site assembly requires more workers to be on site assembling the curtain wall. The workers must assemble the metal, stone, glazing, and insulation, and then finish up with caulking. All these steps could be done by the same workers on a non-unionized project. The testing on site is limited to none. Therefore, any leaks could potentially be missed. This could cause moisture problems in the future.

The advantages to stick-built include a better delivery system for the materials and the potential to save money on labor costs. The materials will come in on trucks packed as effectively as possible to maximize how much material is brought in one trip. This will reduce the amount of trucks coming in and out on such a small site plan. There are not many unions in Columbia, South Carolina, which is where Main & Gervais is located. This will result in cheaper labor costs.

Proposed Method

Now that the current method is analyzed, it is important to take a look at an alternative method. An alternative method for curtain wall construction is prefabrication of the panels. Like any method, there are several advantages and disadvantages associated with the activities involved. Outlined in the table below are these important points and following are paragraphs describing these points even further.

Advantages	Disadvantages
Time: The time it takes to enclose a building is significantly shorter and can allow interior trades to begin	**Delivery:** The panels large size will require more trucks and the obscure arrangement on the truck will result in "shipping air"
Quality Control: Panels are manufactured in a controlled environment, which increases the quality of the final product	**Crane:** More crane use and operator engineer employment would be necessary to lift panels into place for installation
Site Condition: There is no clutter from assembling the panels because this is done in a plant where the waste is controlled	**Cost:** The cost to have the panels manufactured at a plant off-site is set higher because of the higher quality and facility costs (labor, equip., material)
Secure Barrier: The panels are secured tightly to prevent leaks of any kind through the curtain wall, which limits any damage in the future	

Table 3.2 Advantages and Disadvantages to Prefabrication

The table above shows some distinct advantages that come with some disadvantages. The time it takes to enclose the building with prefabrication is a considerable advantage to have on a construction project. The panels are assembled off-site so all that is necessary to take place on-site is lifting the panel into place. If the building can be enclosed quicker, the interior trades can begin working on their projects sooner, which can speed up the schedule. Speeding up the schedule can also save money.

Having the panels assembled off-site has some specific advantages. The manufacturing plant ensures a secure environment to assemble the panels. This results in a better quality final product when the panel is complete. After the panel is complete, tests can be conducted to thoroughly check if the panel is secured properly, which will prevent any leaks to occur after installed in the field. Another point to consider, since the panels are assembled before they arrive on-site, there is no clutter on-site due to extra materials and laborers creating unnecessary mess.

With the advantages stated, there are some disadvantages as well. The cost increases to cover the manufacturing expenses including labor, equipment, and material in the facility. While having the panels manufactured off-site ensures a better quality panel, it has to be shipped that way. Because of the inability to compact the panels on a truck bed, there is a possibility of "shipping air." This will result in utilizing more trucks to ship all the panels to site for installation, which costs more money. When the panels arrive, they must be hoisted into place by a crane. This will require an operating engineer for a longer period of time depending on what he has to lift in a typical day. Main & Gervais is a cast-in-place structure utilizing the crane and bucket method. Extra coordination would be necessary to mix this activity with curtain wall construction.

Schedule Evaluation

Current Schedule

This section displays the schedule of the curtain wall construction for Main & Gervais. The schedules below are portions that focus on curtain wall construction. It is currently set at 50 days for two floors at a time. The activities include: material layout, vertical and horizontal mullion setup, preparation of the glass, and then glazing. After the first activity is complete, that same activity can begin for the next set of two floors. The total schedule for the Curtain wall is set for 115 days.

ID	Task Name	Duration	Start	Finish
1	**Exterior Skin**	**115 days**	**Tue 3/31/09**	**Mon 9/7/09**
2	**Parking Garage**	**70 days**	**Tue 3/31/09**	**Mon 7/6/09**
3	**Levels P1 / P2**	**50 days**	**Tue 3/31/09**	**Mon 6/8/09**
4	Layout & Clips	10 days	Tue 3/31/09	Mon 4/13/09
5	Vertical Mullions	10 days	Tue 4/14/09	Mon 4/27/09
6	Horizontal Mullions	10 days	Tue 4/28/09	Mon 5/11/09
7	Prep for Glass	10 days	Tue 5/12/09	Mon 5/25/09
8	Glaze	10 days	Tue 5/26/09	Mon 6/8/09
9	**Levels P3 / P4**	**50 days**	**Tue 4/14/09**	**Mon 6/22/09**
10	Layout & Clips	10 days	Tue 4/14/09	Mon 4/27/09
11	Vertical Mullions	10 days	Tue 4/28/09	Mon 5/11/09
12	Horizontal Mullions	10 days	Tue 5/12/09	Mon 5/25/09
13	Prep for Glass	10 days	Tue 5/26/09	Mon 6/8/09
14	Glaze	10 days	Tue 6/9/09	Mon 6/22/09
15	**Levels P5 / P6**	**50 days**	**Tue 4/28/09**	**Mon 7/6/09**
16	Layout & Clips	10 days	Tue 4/28/09	Mon 5/11/09
17	Vertical Mullions	10 days	Tue 5/12/09	Mon 5/25/09
18	Horizontal Mullions	10 days	Tue 5/26/09	Mon 6/8/09
19	Prep for Glass	10 days	Tue 6/9/09	Mon 6/22/09
20	Glaze	10 days	Tue 6/23/09	Mon 7/6/09

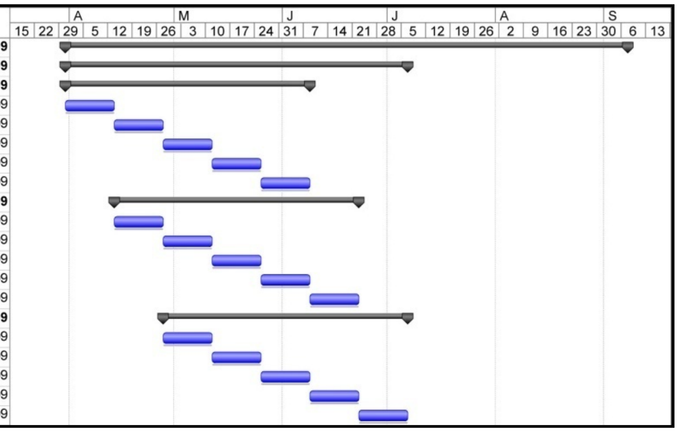

Figure 3.1: Parking Garage Stick-Built Curtain Wall Schedule

ID	Task Name	Duration	Start	Finish
1	**Exterior Skin**	**115 days**	**Tue 3/31/09**	**Mon 9/7/09**
2	**Parking Garage**	**70 days**	**Tue 3/31/09**	**Mon 7/6/09**
21	**Office Tower**	**85 days**	**Tue 5/12/09**	**Mon 9/7/09**
22	**Levels 9 / 10**	**50 days**	**Tue 5/12/09**	**Mon 7/20/09**
23	Layout & Clips	10 days	Tue 5/12/09	Mon 5/25/09
24	Vertical Mullions	10 days	Tue 5/26/09	Mon 6/8/09
25	Horizontal Mullions	10 days	Tue 6/9/09	Mon 6/22/09
26	Prep for Glass	10 days	Tue 6/23/09	Mon 7/6/09
27	Glaze	10 days	Tue 7/7/09	Mon 7/20/09
28	**Levels 11 / 12**	**50 days**	**Tue 5/26/09**	**Mon 8/3/09**
29	Layout & Clips	10 days	Tue 5/26/09	Mon 6/8/09
30	Vertical Mullions	10 days	Tue 6/9/09	Mon 6/22/09
31	Horizontal Mullions	10 days	Tue 6/23/09	Mon 7/6/09
32	Prep for Glass	10 days	Tue 7/7/09	Mon 7/20/09
33	Glaze	10 days	Tue 7/21/09	Mon 8/3/09
34	**Levesl 14 / 15**	**50 days**	**Tue 6/9/09**	**Mon 8/17/09**
35	Layout & Clips	10 days	Tue 6/9/09	Mon 6/22/09
36	Vertical Mullions	10 days	Tue 6/23/09	Mon 7/6/09
37	Horizontal Mullions	10 days	Tue 7/7/09	Mon 7/20/09
38	Prep for Glass	10 days	Tue 7/21/09	Mon 8/3/09
39	Glaze	10 days	Tue 8/4/09	Mon 8/17/09
40	**Levels 16 / 17**	**50 days**	**Tue 6/23/09**	**Mon 8/31/09**
41	Layout & Clips	10 days	Tue 6/23/09	Mon 7/6/09
42	Vertical Mullions	10 days	Tue 7/7/09	Mon 7/20/09
43	Horizontal Mullions	10 days	Tue 7/21/09	Mon 8/3/09
44	Prep for Glass	10 days	Tue 8/4/09	Mon 8/17/09
45	Glaze	10 days	Tue 8/18/09	Mon 8/31/09
46	**Level 18**	**30 days**	**Tue 7/7/09**	**Mon 8/17/09**
47	Layout & Clips	5 days	Tue 7/7/09	Mon 7/13/09
48	Vertical Mullions	5 days	Tue 7/14/09	Mon 7/20/09
49	Horizontal Mullions	5 days	Tue 7/21/09	Mon 7/27/09
50	Prep for Glass	5 days	Tue 7/28/09	Mon 8/3/09
51	Glaze	5 days	Tue 8/4/09	Mon 8/10/09
52	Coping	5 days	Tue 8/11/09	Mon 8/17/09
53	Screenwall	20 days	Tue 8/11/09	Mon 9/7/09

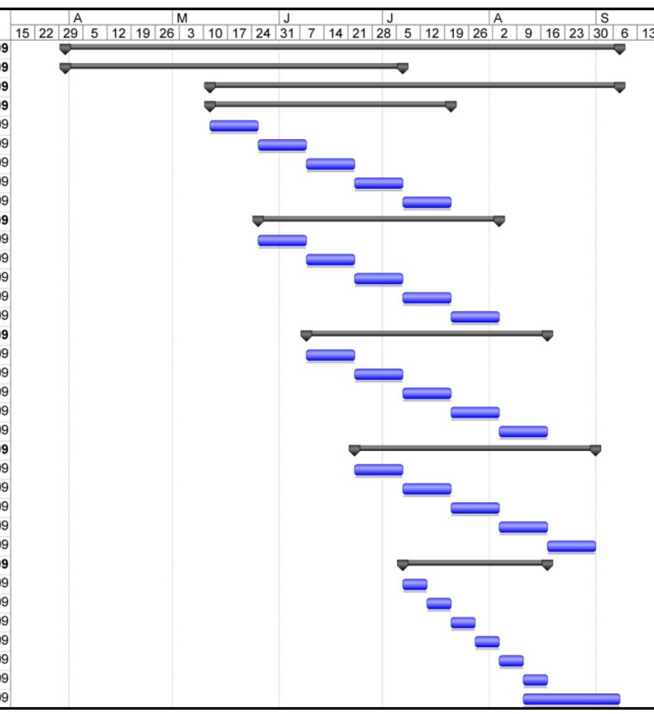

Figure 3.2: Office Level Stick-Built Curtain Wall Schedule

Proposed Schedule

After understanding the current schedule, it is appropriate to view an alternative schedule provided prefabrication of the curtain wall is selected instead. As shown in **Figure 3.3**, the exterior skin would take a total of 34 days to complete. Each line item is identified by the floor where the curtain wall panel installation is to take place. Installation is the only activity because the panels are manufactured before they arrive on-site. The few assumptions made to implement this schedule are listed below **Figure 3.3**.

ID	Task Name	Duration	Start	Finish
1	**Exterior Skin**	**34 days**	**Tue 3/31/09**	**Fri 5/15/09**
2	**Parking Garage**	**9 days**	**Tue 3/31/09**	**Fri 4/10/09**
3	Levels P1/P2	3 days	Tue 3/31/09	Thu 4/2/09
4	Levels P3/P4	3 days	Fri 4/3/09	Tue 4/7/09
5	Levels P5/P6	3 days	Wed 4/8/09	Fri 4/10/09
6	**Office Tower**	**25 days**	**Mon 4/13/09**	**Fri 5/15/09**
7	Level 9	2.5 days	Mon 4/13/09	Wed 4/15/09
8	Level 10	2.5 days	Wed 4/15/09	Fri 4/17/09
9	Level 11	2.5 days	Mon 4/20/09	Wed 4/22/09
10	Level 12	2.5 days	Wed 4/22/09	Fri 4/24/09
11	Level 14	2.5 days	Mon 4/27/09	Wed 4/29/09
12	Level 15	2.5 days	Wed 4/29/09	Fri 5/1/09
13	Level 16	2.5 days	Mon 5/4/09	Wed 5/6/09
14	Level 17	2.5 days	Wed 5/6/09	Fri 5/8/09
15	Level 18	2.5 days	Mon 5/11/09	Wed 5/13/09
16	Screenwall	2.5 days	Wed 5/13/09	Fri 5/15/09

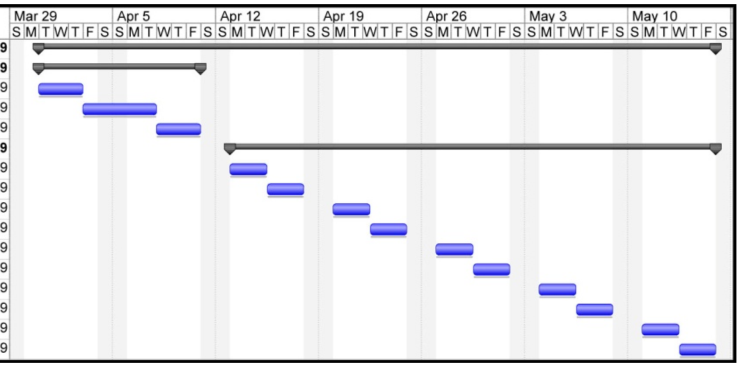

Figure 3.3: Entire Building Prefabrication Curtain Wall Schedule

Assumptions

- ~42 panels can be delivered to site each day by truck
- ~50 panels can be installed each day
- A manipulator crane is used so installation can take place all day
- ~64 panels per garage level
- ~94 panels per office floor

Lifting prefabricated panels into place takes a third of the time it takes to utilize the stick-built method. This difference amounts to a huge time savings of 81 days. This will reduce the amount of time laborers will need to be on-site to construct the curtain wall. Also, there will be fewer laborers because the manufacturing of the panels is taking place off-site. This will reduce labor costs for the curtain wall portion of the project. Another advantage to consider, the building is enclosed faster with this method. This allows the interior trades to start their work earlier. This could lead to money savings since the owner would be able to open his building at an earlier date.

Cost Evaluation

Current Estimate

This section outlines the costs for the curtain wall construction for the current method, which is stick-built. Non-union and union labor rates are compared and material costs are added in addition to form a total square foot cost.

	Hourly Rate	Workers	Total/Hr	Hours	Total/Day	Days	Total
Non-Union	$ 28.47	30	$ 854.24	8	$ 6,833.96	115	$ 785,905.00
Union	$ 70.00	30	$ 2,100.00	8	$ 16,800.00	115	$ 1,932,000.00

Table 3.3: Stick-Built Labor Costs

Item	Cost
Materials	$ 1,761,095.00
Glass/Panel	$ 1,158,452.00
Glass/Panel Glazing	$ 330,000.00
Interior Insulation & Trim	$ 179,900.00
Imbeds & Inserts	$ 78,000.00
Caulking	$ 127,244.00
Total	$ 3,634,691.00
Material $/SF	**$ 38.67**

Table 3.4: Stick-Built Material Costs

As seen in **Table 3.3**, the total cost of labor for the parking garage and office level floors is $785,905.00. Labor activities include: material layout, vertical and horizontal mullion setup, preparation of the glass, and then glazing. The 115 day schedule is obtained from **Figure 3.1** and **Figure 3.2**. The 30 workers are broken into different groups to work on several activities at once. Once one of the several activities is complete, another set of workers will work on the next activity and so on. The hourly rate for each of the non-union workers is around $28.47. If the labor is unionized, it would cost approximately $1,146,095.00 more than non-unionized labor for this project. **Table 3.4** outlines the breakdown for how much each of the materials cost and the total material square foot cost.

	Material	Labor	Total	SF	Total $/SF
Non Union	$ 3,634,691.00	$ 785,905.00	$ 4,420,596.00	94000	$ 47.03
Union	$ 3,634,691.00	$ 1,932,000.00	$ 5,566,691.00	94000	$ 59.22

Table 3.5: Total Square Foot Cost

After breaking down the costs for labor and material, the total cost per square foot is $47.03 for non-unionized labor and $59.22/ft^2 for unionized labor. This is important to understand as it will be compared to the labor and material costs for prefabricated curtain wall construction in the next section.

Proposed Estimate

This section outlines the costs for the curtain wall construction for the proposed method, which is prefabrication. The amounts are specifically just for two floors and include the material and labor costs for installing the curtain wall.

	Hourly Rate	Workers	Total/Hr	Hours	Total/Day	Days	Total
Non-Union	$ 28.47	10	$ 284.70	8	$ 2,277.60	34	$ 77,438.40
Union	$ 70.00	10	$ 700.00	8	$ 5,600.00	34	$ 190,400.00

Table 3.6: Prefabrication Labor Costs

The hourly rate listed in **Table 3.6** is based off union wages, which are higher than non-union laborers because of all the fringe benefits included in union wages. This hourly rate is included in the comparison because the assumption is that prefabrication typically takes place where unions are prevalent. Expensive labor rates is one of the reasons why stick-built is chosen over prefabrication. It is also shown that there are less workers and they work for less time than stick-built. This is because the panels are already completed before arriving to site so that all the labors have to do is lift the panels into place and install them. The amount that is not listed here is the labor cost to manufacture the panels. This amount is included in the material costs.

	Cost/SF	SF	Cost
Material	$ 60.00	94,000	$ 5,640,000.00

Table 3.7: Prefabrication Material Costs

Table 3.7 shows another reason why prefabrication is not widely chosen in the industry. The material costs are higher than stick-built material costs. The square foot cost in this table is averaged from different subcontractors. There is a higher cost associated with the material because it manufactured off site in a controlled facility. All the costs listed in **Table 3.4** and the cost of manufacturing off site is included in the $\$60.00/ft^2$. The cost of manufacturing off site includes: labor costs for workers in facility, equipment used to manufacture panels, the facility itself, etc.

	Material	Labor	Total	SF	Total $/SF
Non Union	$ 5,640,000.00	$ 77,438.00	$ 5,717,438.40	94,000	$ 60.82
Union	$ 5,640,000.00	$ 190,400.00	$ 5,830,709.00	94,000	$ 62.03

Table 3.8: Total Square Foot Cost

The material cost raises the overall cost for prefabricated curtain wall panel construction. With non-unionized labor, prefabrication is $1,296,842.40 more than stick-built construction, which is a 29% increase in cost. With unionized labor, prefabrication is $263,709.00 more than stick-built construction, which is a 5% increase in cost. In the case of Main & Gervais, it is obvious why stick-built is the chosen method for curtain wall construction because it is in a non-unionized location. If the project were located where unions were prevalent, prefabrication might be a smarter choice because a 5% increase would be worth it for a better final product and a faster schedule.

Conclusion

Prefabrication and stick-built curtain wall construction were evaluated under three different categories. These categories include advantages and disadvantages, schedule factors, and cost considerations. The following conclusions were obtained after conducting research.

Advantages and Disadvantages

The major advantages for stick-built construction are cost savings and delivery flexibility. The labor and material costs are less than prefabrication. Also, delivering curtain wall materials to site unconstructed allows for a larger quantity of material to fit on a truck bed for each trip. The major drawbacks of this method are a slower schedule, lower quality final product, and a messier site.

Prefabrication lends itself to several different advantages but has one major drawback. The advantages include a better quality final product, faster building enclosure, and a cleaner site. The cost for these advantages is primarily an expensive budget. It costs more to prefabricate the panels at a separate manufacturing facility. The owner is less likely to pick this option since it will cost more money.

Schedule Evaluation

After observing the schedules between the two methods, it was clear to see that the prefabrication method has a faster schedule. The stick-built method takes three times longer than installing prefabricated panels. This is because with the stick-built method, all the construction of the panels takes place on-site. With prefabrication, all of the manufacturing takes place at an off-site facility and all that needs to be done on-site is lifting the panels into the proper location. To enclose the building faster, prefabrication is the method of choice.

Cost Evaluation

Comparing the two methods through estimating means establishes an advantage for the stick-built method. Prefabrication costs 29% more than the stick-built method with this particular project if labor is not unionized and 5% more if labor is unionized. Therefore, the method of choice is stick-built construction because it is cheaper where there are non-union wages.

Final Comments

After summarizing the different evaluations performed in this report, a link between the evaluations is found. It is important to note that the schedule is shortened by 81 days with the prefabrication method. This could imply a quicker building turnover for the owner. Assuming the owner can begin leasing out the available space over more than two months earlier would indicate the owner could bring in rent money earlier.

Office Area	$/ft2/year	Year	81 Days	Non-U Difference	Union Difference
200,000	$ 21.00	$ 4,200,000.00	$ 945,000.00	$ (351,842.40)	$ 681,291.00

Table 3.9: Extra Rent Income

Table 3.9 indicates an extra $945,000.00 in income from an earlier turnover. This amount can contribute to the extra amount it costs for prefabrication. If non-union wages are utilized, there is still a loss of $351,842.40. Though, prefabricated curtain wall panels may be more enticing because now it is only 8% more than stick-built construction with this factor included instead of 29%. The owner of Main & Gervais may find a better quality product in prefabricated panels worth the extra 8%.

On a side note, in an area where unions are prevalent, it would be a savings of $681,291.00. So it is wiser to choose prefabrication in this situation, which seems to be the case already in locations where there are unions.

In conclusion, the choice is likely to remain stick-built construction over prefabrication for a majority of the time. Instances where prefabrication is an option are locations where unions are prevalent and sites are rather congested. For example, New York City would choose prefabrication construction because constructing stick-built panels on-site is very inefficient due to the lack of space and limited daytime construction. Also, there are more unions in this location. Prefabrication would allow a quick efficient installation while utilizing less labor. If the owner is looking to close up the building in a third of the time it would take for stick-built construction, it may be a smarter choice to go with prefabrication. For now, stick-built construction will remain a cheaper alternative until material costs for prefabrication decline. This could eventually happen if prefabrication is chosen more often, which would bring the prices down because of more competition.

IV. Curtain Wall Design Analysis

Introduction

The building's façade is primarily a glazed aluminum curtain wall with the exception of some areas around the parking garage. The curtain wall ties into the cast-in-place concrete structure through steel anchor plates. On the west elevation, the curtain wall is sloped outward at 5.63^{o} all the way from lobby floor up to the roof of the building. The slope of the curtain wall can be seen in **Figure 4.1** outlined by the arrow in the box.

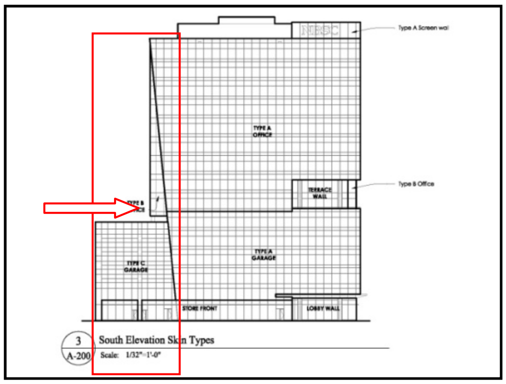

Figure 4.1: South Elevation

Problem Statement

This design adds to the complexity of constructing the curtain wall. The complexity comes from having to install different shaped pieces of glass at different angles. **Figure 4.2** shows the sloped wall joining the vertical wall where unique curtain wall panels will be necessary. The different shaped pieces of glass necessary will add to the cost since this eliminates the opportunity to order in a mass quantity. This curtain wall design also eliminates some floor area of the building on the lower levels. If the slope is eliminated and more square footage is provided, the owner could increase the cost to its tenants because he is providing more leasable area.

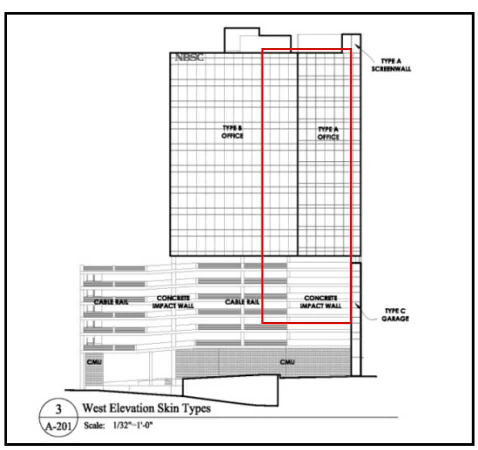

Figure 4.2: West Elevation

Analysis Goal

The goal of this analysis is to understand what the implications are of eliminating the slope in the curtain wall. Eliminating the slope will be done by extending the shorter horizontal distance to line up in the same plane as the longer horizontal distance at the top of the building. This can be seen in **Figure 4.3.** This would provide more square footage to the building's leasing area. Adding more square footage requires adding more concrete slab area to the floor plan. This will change the demands of the structure, specifically the columns located near the curtain wall. Changing the slope of the curtain wall will affect how the sun shines through the glazing. If the new sun angles on the façade changes in a way that increases solar gain through the window significantly, it could heighten the energy demands of the cooling system during the summer months.

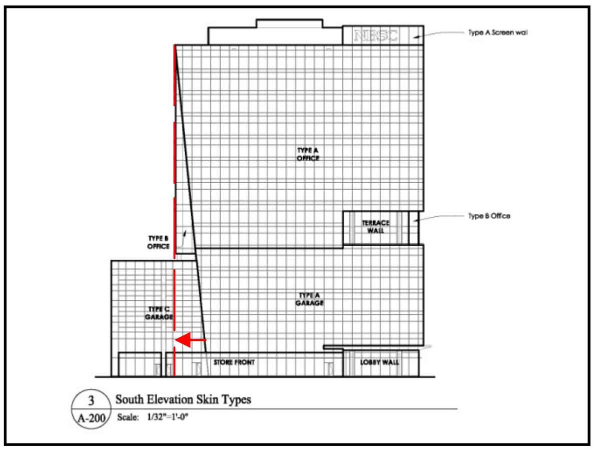

Figure 4.3: Curtain Wall Extension

Analysis Methods

The first section of this analysis will consider the area gained with an expanded floor plan. Floor plans are provided to obtain a clearer picture of the advantages with extending the floor plan. A table is included that provides the amount of extra square footage added to the floor plans. Finally, with the additional floor area, the extra money the owner can obtain from this new leasable area is suggested.

The second section analyzes the new demands of the structure to support the curtain wall vertical to the ground. It will be necessary to add any columns, beams or joists to support the additional concrete slab. After the necessary structural elements are implemented, the construction costs of these items are calculated.

The third section involves analyzing the solar gain through the curtain wall. The location of the proposed curtain wall revision is on the west elevation. The sun angles during the later portion of the day will have the most impact on the curtain wall. If the solar gain is considerable, it might change the energy demands of the cooling system during the summer months.

Additional Area Analysis

By eliminating the slope of the curtain wall and extending the wall, the floor plan increases the square footage available. Starting with the ninth floor, which is the first office level, the most area is gained and the increments of area obtained slowly declines as the wall extends to the roof level. The areas gained in the floor plans can be seen in **Figure 4.4**. A red box outlines the new areas obtained. Also indicated in **Figure 4.4** is a red circle, which shows where the floor plan cannot be utilized effectively. The tenant might find it difficult to locate an office around the column near the red circle. If the floor plan is extended, the area can be utilized more efficiently.

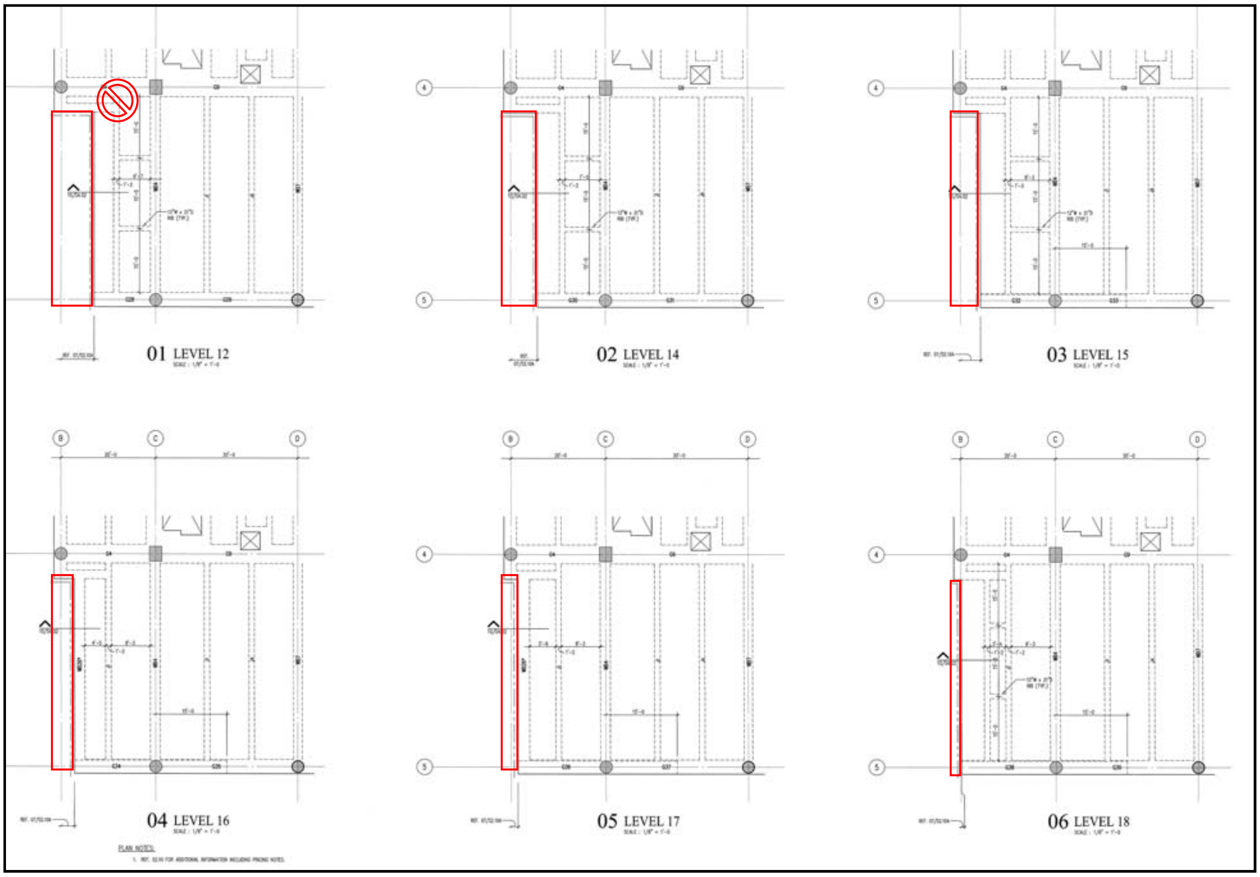

Figure 4.4 Office Floor Plans

Office Floor	Length	Width	Additional Area
9	12'-10 5/8"	41'-6"	535 ft^2
10	11'-5 ½"	41'-6"	475 ft^2
11	10'-6"	41'-6"	435 ft^2
12	8'-8 ½"	41'-6"	362 ft^2
14	7'-3 7/8"	41'-6"	304 ft^2
15	5'-11 3/8"	41'-6"	247 ft^2
16	4'-6 ¾"	41'-6"	190 ft^2
17	3'-2 ¼"	41'-6"	133 ft^2
18	1'-9 ¾"	41'-6"	75 ft^2
Total	-	-	**2756 ft^2**

Table 4.1: Additional Area Provided per Floor

Eliminating the slope in the curtain wall and extending the floor plan provides an additional 2756 ft^2 to the building. **Table 4.1** shows the additional area provided by each floor. This allows the owner to charge more to the tenants for them to lease the space. By observing rent costs that other owners are charging, it can be estimated that the rent/ft^2/year for Main & Gervais is around $21.00/$ft^2$/year. At $21.00/$ft^2$/year the owner could charge an additional $57,876.00 each year to its tenants. After ten years, that amount would reach over half a million dollars. This is a considerable amount of money to convince the owner to consider the option of eliminating the slope.

(ft^2)	(rent/ft^2/year)	(rent/year)	(ten years)
2756	$ 21.00	$ 57,876.00	$ 578,760.00

Table 4.2: Proposed Rent Costs

Structural Load Analysis (Structural Breadth)

The proposed method of adding area to the building's footprint requires a structural analysis to determine whether the addition is acceptable. Most likely, additional support is necessary to maintain structural integrity. This is done by adding an additional column and joist to each floor of the office tower. Also, the beam that is located on the perimeter between the proposed column and existing column needs to be resized. The following analysis provides the structural adjustment necessary to allow the curtain wall extension.

The first section of this analysis displays the location of the new columns in the building and the calculations to verify the application. The second section indicates which beam needs replacement to support the additional loads. The third section provides the additional costs that accompany the extra joists, columns, and slabs.

The program *pcaColumn* was utilized for the column analysis. RAM Conce*pt* was used to analyze the beam to replace the existing beam because eliminate the beam is post-tensioned. Hand calculations were performed where necessary.

Column Addition Calculation

The corner of the building where there is originally nothing will now require a column to support the additional load placed on the larger concrete slab it supports. The new column placement can be seen in **Figure 4.5**. The necessity of this column is based on the assumption of symmetry. At the top left of the floor plan, there is a column located in the corner. The span is the same as in the lower left hand corner; therefore a column is necessary to maintain the structural integrity of the building.

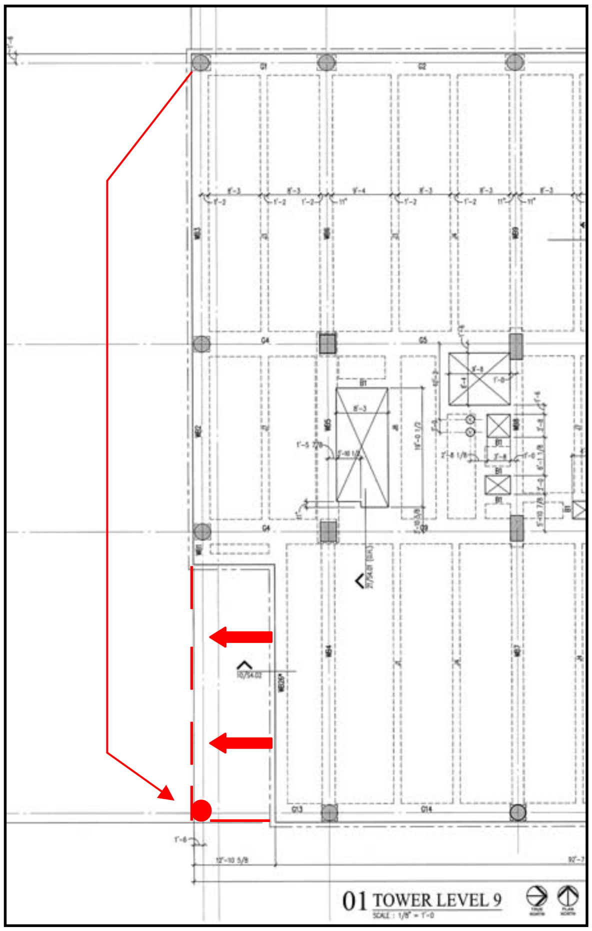

Figure 4.5: Column Placement

This placement of the column is continuous on all the office floors. There are nine office floors; therefore it is necessary to add nine columns (one for each floor). Since the column loads decrease as the levels get higher, implementing a smaller second column is possible. A second column with different properties is placed on floors fifteen through eighteen in the northwest corner. This same design is applied to the southwest corner. The first column (column **A**) proposed is a circular column. Its diameter is 30" and stands 13' tall. There are (16) #9 vertical bars with #4 bars @ 13" for ties. The column is made up of concrete with a compression strength of 7000 psi. The second column (column **B**) proposed is a circular column with the same dimensions but the concrete properties are changed. The compression strength of the concrete can sustain a reduction to 5000 psi.

Several calculations are necessary to verify that the column can support its loads. It is necessary to consider the dead load and live load. The wind load is not considered in these calculations as the dead load and live load are factored to compensate. The axial load is calculated after the factored loads are determined. Entering the properties of the columns into *pcaColumn* provide the max loads the columns can withstand. If the calculated axial loads are under this max, then the column is strong enough.

Structural Loads		
Live Load (psf)	Dead Load (psf)	Column (lb/ft^3)
120	63	150

Table 4.3: Structural Loads

	Load	Factor	Factored Load	Units
Live	120	1.6	192	psf
Dead	63	1.2	75.6	psf
Column	9572	1.2	11486	pounds

Table 4.4: Factored Loads

Table 4.3 provides the structural loads and **Table 4.4** shows these loads factored to calculate the axial loading on the column. The factored loads are calculated as follows.

- Live Load Calculation:
  - $Office\ Load\ \left({}^{lbs}/_{ft^2}\right) + \ Partition\ Load\ \left({}^{lbs}/_{ft^2}\right) = Live\ Load\ \left({}^{lbs}/_{ft^2}\right)$
    - $100\ psf + 20\ psf\ = 120\ psf$

- Dead Load Calculation (floor slab):
  - $Concrete\ Weight\ \left({}^{lbs}/_{ft^3}\right) x\ Slab\ Thickness\ (ft) = Dead\ Load\ ({}^{lbs}/_{ft^2})$
    - $\left(150\ {}^{lbs}/_{ft^3}\right)\ x\ \left(\frac{5in}{\frac{12in}{ft}}\right) = 9572\ lbs$

- Column Load Calculation:
  - $Concrete\ Weight\ ({}^{lbs}/_{ft^3})\ x\ Area\ (ft^2) x\ Length(ft) = Column\ Weight\ (lbs)$
    - $\left(150\ {}^{lbs}/_{ft^3}\right)\ x\ \left(\frac{\pi(15in)^2}{\frac{144\ in^2}{ft^2}}\right)\ x\ (13ft) = 9572\ lbs$

Column	Floor	n	A_t (ft^2)	Total Load (ksf)	Column Load (kips)	Axial Load (kips)
A	9	9	225	0.268	11.5	634
B	15	4	225	0.268	11.5	275

Table 4.5: Axial Loads

Table 4.5 displays the axial loads on column **A** and column **B**. Column **A** is the stronger column because it is supporting more loads above it. Any floors above it will take fewer loads than the column below it; therefore it is redundant to calculate floors ten through fourteen. Column **B** supports less therefore it uses concrete with less compressive strength. The axial loads are calculated as follows.

- $P_n = n\ x\ A_t\ x\ Total\ Load + (n-1)(Column\ Load)$

- Column **A** (floor 9):
  - $P_9 = (9)\ x\ (225ft^2)\ x\ (0.268\ ksf) +\ (9-1)\ x\ (11.5\ kips)$
    - $P_9 = 634\ kips$

- Column **B** (floor 15):
  - $P_4 = (4)\ x\ (225ft^2)\ x\ (0.268\ ksf) +\ (4-1)\ x\ (11.5\ kips)$
    - $P_4 = 275\ kips$

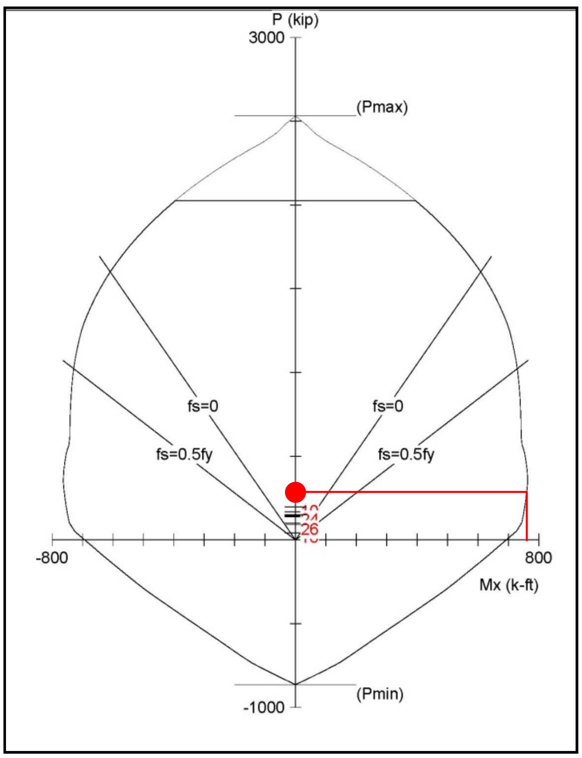

Figure 4.6: ***pcaColumn*** **Diagram (Column B)**

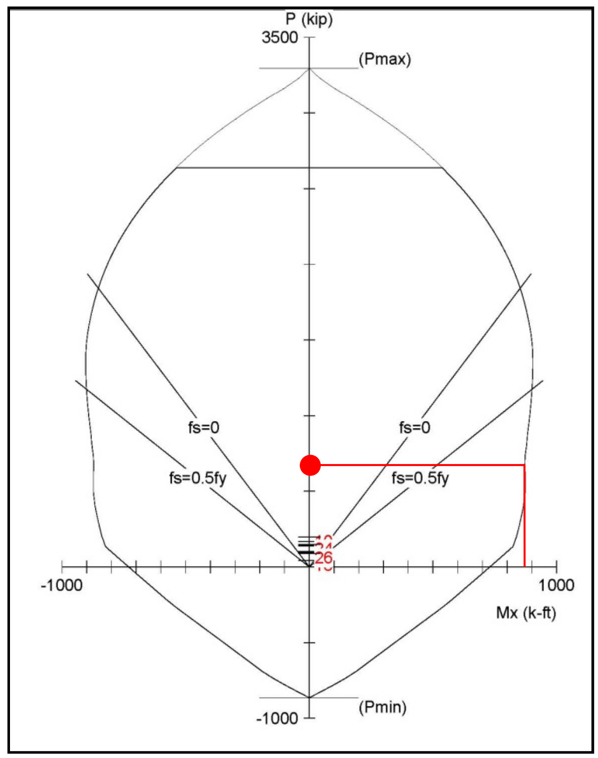

Figure 4.7: ***pcaColumn*** **Diagram (Column A)**

Figure 4.6 and **4.7** are diagrams that display the graphs obtained from *pcaColumn*. These are just the graphs; the whole sheets are located in **Appendix E**. As seen in the figures indicated by the red circle, the calculated axial loads fall well within the allowable load. The line is extended to the right to determine the max moment the columns can withstand. This shows that the column is strong enough to resist the lateral loads (wind loads). These columns are sufficient enough to support the structural loads.

Beam Replacement Calculation

Extending the floor plan will increase the span distance between the columns. This result requires resizing the beam to support the new load applied to the slab. This assumption is based on symmetry. The other side of the building, or the other side of the red dashed line in **Figure 4.8**, shows that a larger beam is necessary to support the load given the larger area. **Figure 4.8** also displays where the existing beam is and the new beam's location for level nine.

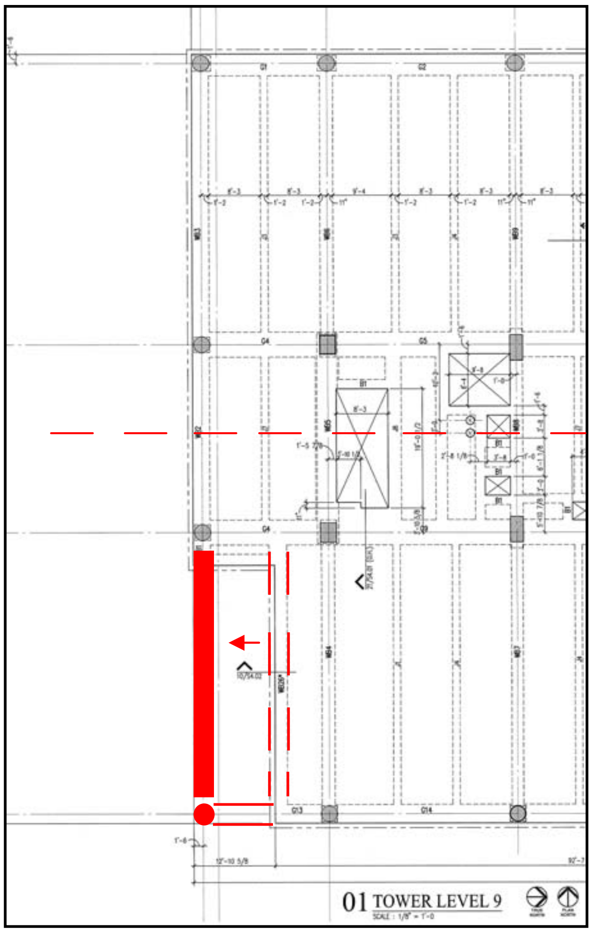

Figure 4.8: Beam Replacement

The existing beam is 23 ¾ inches in width and 21 inches deep and is outlined above in red dash marks. The replacement beam is 36 inches wide and 21 inches in depth. The reinforcement for each of the beams changes as well. These changes are displayed in **Table 4.6**. The existing beam is identified by WB26, the second row. And the proposed beam is identified by WB3, located in the first row.

WIND BEAM SCHEDULE MARK "WB"																
WIND BEAM				WIND BEAM REINFORCING						POST-TENSIONING						
MARK	FLOOR	WIDTH (IN.)	DEPTH (IN.)	BOTTOM N-S-T	TOP N-S-T	MIDBAR N-S-T (EA. FACE)	STIRRUPS S-T	STIRRUPS SPA. EA. END	NOTES	TYPE	PEFF (KIPS)	A (IN.)	B (IN.)	C (IN.)	X (FT-IN)	NOTES
WB3	9-18	36*	21	6-6-W	5-7-P	4-6-P	#4-02	1@2, 16@6, R@12		1	188	18 1/2	2 1/2	12	22'-6	
WB26*	9,16,17	23 3/4	21	4-8-A	4-8-A	4-6-A	#4-02	1@2, 16@6, R@12		1	322	12 3/4	2 1/2	12 3/4	22'-6	

Table 4.6: Reinforcement Properties

All this information presented in the figures and tables is necessary to utilize RAM Conce*pt*. The strip wizard in RAM Conce*pt* is simple enough for this application. The model drawn in RAM is shown in **Figure 4.9**. The beam in the left portion of the figure is the beam of interest. Main & Gervais is a post-tensioned cast-in-concrete structure, meaning that the structural integrity of one beam is dependent on the surrounding structural elements. Because of this, the beams along the same column line were considered too.

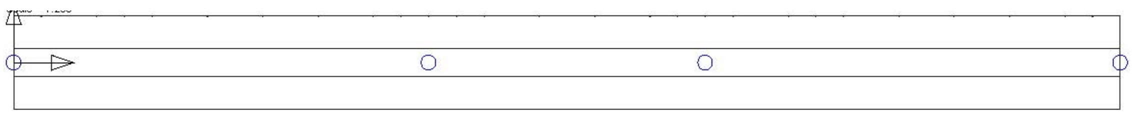

Figure 4.9: Model Plan from RAM Conce*pt*

To establish this model, the following properties were inputted into the program. The loads applied to the structure are the same as presented in **Table 4.3**. Concrete properties are 5000 psi for the slabs and beams and 6000 psi for the columns. Rebar and post-tensioning properties are taken from **Table 4.6**. All other inputs are located in **Appendix F**.

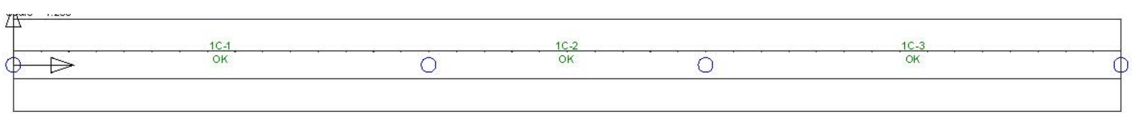

Figure 4.10: Status Plan from RAM Concept

As shown in **Figure 4.10**, the beam is structurally strong enough to support the loads applied to it. This is just for tower floor level nine. There are eight more floors of office above this floor that require resizing of the same beams. It is assumed that the proposed beam will suffice in the rest of the floors. This is because the scenario is similar for each of the floors.

Joist Addition Assumption

It is assumed that additional joists are necessary for the proposed floor plan. By observing **Figure 4.11,** it is shown by symmetry that the joist in the top left portion of the floor plan is necessary in the lower left hand corner if the floor plan is extended. Additional calculations are not necessary as it will be redundant considering the previous section, *Beam Replacement Calculation*. This section considered the load implications for the floor area above the replacement beam, which are similar to that which the loads the joists are supporting. Based on the symmetry of the design and the verification from the calculations in the previous section, the 14" wide and 21" deep joist in the upper left area is sufficient to support the additional floor area. This assumption is applied to all the office levels. This requires an additional nine joists to bridge the gap between the beams, one for each floor.

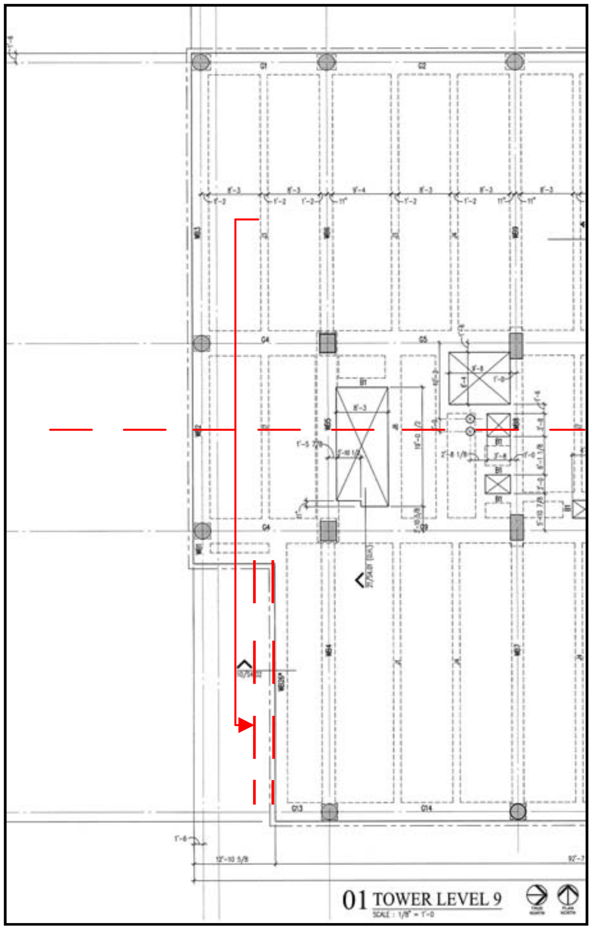

Figure 4.11: Joist Placement

Construction Costs

The additional columns, joists, and slabs will require additional material. The main materials required are concrete and reinforcement bars since each of the additional items are cast-in-place concrete. The cast-in-place concrete is designed for post-tensioning except for the columns. It is assumed that there is no additional formwork costs because each of the items exists on the drawings. In this case, the formwork is already purchased. The difference for construction costs in the replacement beams and the existing is minimal and not considered in **Table 4.7**.

Item	Description	Count	Unit	Material	Labor	Equip.	Cost/Unit	Total
Concrete	5000 psi (elevated slabs)	40	CY	$ 109.00			$ 109.00	$ 4,360.00
	6000 psi (joists)	40	CY	$ 124.00			$ 124.00	$ 4,960.00
	8000 psi (columns)	36	CY	$ 203.00			$ 203.00	$ 7,308.00
Rebar	Joists, #8 to #18	1.89	tons	$ 980.00	$ 520.00		$ 1,500.00	$ 2,835.00

	Columns, #8 to #18	0.76	tons	$ 980.00	$ 600.00		$ 1,580.00	$ 1,200.80
	Elevated Slabs, #4 to #7	0.86	tons	$ 1,020.00	$ 480.00		$ 1,500.00	$ 1,290.00
Placement	Joists, crane & bucket	40	CY		$ 52.50	$ 26.50	$ 79.00	$ 3,160.00
	Columns, "	36	CY		$ 23.50	$ 11.90	$ 35.40	$ 1,274.40
	Elevated Slabs, "	40	CY		$ 21.50	$ 10.80	$ 32.30	$ 1,292.00
Prestressing	PT, 50' span, 300 kip	0.84	tons	1820	$ 1,860.00	$ 80.00	$ 3,760.00	$ 3,147.87
Total								**$ 30,828.07**

Table 4.7: Construction Costs

As shown in **Table 4.7**, the total additional cost of extending the curtain wall amounts to $30,828.07.

Solar Heat Gain Analysis (Mechanical Breadth)

The original design for the curtain wall is sloped on the west façade. The way the sun shines in on sloped glazing differs from the way it shines in on vertical glazing. The angle of incidence of the sun changes for the tilt in the glazing. Therefore, the reflectivity of the glass is going to change at a different angle. The following analysis observes the current design of the curtain wall and compares it to the proposed method.

The first two sections provide calculations and their respective results for the total solar radiation on the glazing. The third section provides a means of measuring window heat gain for Main & Gervais. The last section compares the current state of Main & Gervais and the proposed design for the curtain wall on the west elevation in terms of energy expenses.

Calculation methods and solar data were obtained from *Heating, Ventilating, and Air Conditioning, 6th Edition* by McQuiston, Parker, and Spitler. Sun angles were obtained by *Sustainable by Design* at www.susdesign.com/sunposition. Information was obtained from the *ASHRAE Handbook, 2005* as well.

Sloped Façade Solar Radiation Calculation

To obtain the solar radiation for the west façade, it is necessary to calculate the direct radiation, diffuse radiation, and reflected radiation. The summation of these values will provide the total radiation on a sloped surface, specifically the west façade of Main & Gervais. This section provides the means of obtaining these values. The first subsection includes the calculations necessary and then the following subsection applies these calculations to Main & Gervais.

Calculation Steps

The following steps include the calculations necessary to obtain the amount of total solar radiation on the sloped curtain wall façade.

Step 1

- Calculate normal direct irradiation, $\mathbf{G_{ND}}$ (btu/hr-ft^2)

- $G_{ND} = \frac{A}{e^{\frac{B}{\sin\beta}}} \times C_N$
  - A = apparent solar irradiation at air mass equal to zero (btu/hr-ft^2)
  - B = atmospheric extinction coefficient
  - β = solar altitude angle
  - C_N = clearness number

Step 2

- Calculate direct radiation, $\mathbf{G_D}$ (btu/hr-ft^2)
- $G_D = G_{ND}\cos\theta$
  - G_{ND} = normal direction irradiation
  - θ = angle of incidence
    - $\cos\theta = \cos\beta\cos\gamma\sin\alpha + \sin\beta\cos\alpha$
      - β = solar altitude angle
      - γ = surface solar azimuth
      - α = angle of tilt for an arbitrary surface (Σ in **Figure 4.12**)
      - **Figure 4.12** displays these angles

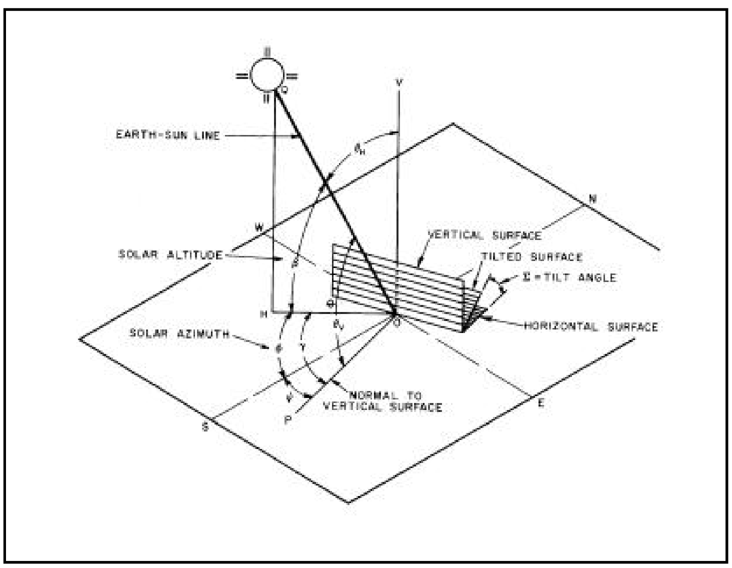

Figure 4.12: Solar Angles for Vertical and Horizontal Surfaces

Step 3

- Calculate diffuse irradiation, $G_{d\theta}$ (btu/hr-ft^2)
- $G_{d\theta} = C G_{ND} F_{ws}$
  - C = dimensionless factor
  - G_{ND} = normal direction irradiation
  - F_{ws} = fraction of the energy that leaves the surface and "strikes" the sky directly

- $F_{ws} = \frac{1+\cos\alpha}{2}$

Step 4

- Calculate reflected irradiation, G_R (btu/hr-ft^2)
- $G_R = G_{tH}\rho_g F_{wg}$
  - G_{tH} = rate at which the total radiation (direct plus diffuse) strikes the horizontal surface or ground in front of the wall (btu/hr-ft^2)
  - ρ_g = reflectance of ground or horizontal surface
  - F_{wg} = configuration or angle factor from wall to ground, defined as the fraction of the radiation leaving the wall of interest that strikes the horizontal surface or ground directly
    - $F_{wg} = \frac{1-\cos\alpha}{2}$
      - α = angle of tilt for an arbitrary surface

Step 5

- Calculate **G_t,** total solar radiation, by summing **G_D (Step 2)**, **$G_{d\theta}$ (Step 3)**, **G_R (Step 4)**
- $G_t = G_D + G_{d\theta} + G_R = [\cos\theta + CF_{ws} + \rho_g F_{wg}\sin\beta + C\,]G_{ND}$

Application to Main & Gervais

Now that the steps to calculate the total solar radiation on a sloped surface have been outlined, it is necessary to apply them to Main & Gervais in its current state. The application below is set for 3:00 pm on May 21, 2009, at 34° latitude, which is where Columbia, South Carolina, is located. **Table 4.8** provides the information necessary to complete the steps listed in the previous section. This section will provide a simple version of the calculation. The written calculations can be found in **Appendix G.**

Solar Data	Solar Angles	Surface Properties
A = 350.6 btu/hr-ft^2	β = 64.12°	ρ_g = 0.32 (concrete)
B = 0.177	Ψ = 255°	
C = 0.130	ϕ_z = -64.51°	
C_N = 0.94	γ = 40.5°	
	α = 95.63°	

Table 4.8: Information for May 21, 2009 in Columbia, South Carolina

- $G_{ND} = \frac{350.6\ {btu}/{hr-ft^2}}{e^{\frac{0.177}{\sin 64.12°}}} \times 0.94$
  - $G_{ND} = 270.71\ {btu}/{hr-ft^2}$

- $\cos\theta = \cos 64.12° \cos 40.5° \sin 95.63° + \sin 64.12° \cos 95.63°$

- $\cos\theta = 0.242$

- $F_{ws} = \frac{1+\cos 95.63°}{2}$
  - $F_{ws} = 0.451$

- $F_{wg} = \frac{1-\cos 95.63°}{2}$
  - $F_{wg} = 0.549$

- $G_t = [0.242 + (0.13)(0.451) + (0.32)(0.549)\sin(64.12° + 0.13)](270\ {}^{btu}/_{hr-ft^2})$
  - $G_t = 124.22\ {}^{btu}/_{hr-ft^2}$

The total solar radiation on Main & Gervais' sloped curtain wall on the west elevation at 3:00 pm May 21, 2009, is 124.22 btu/hr-ft^2. **Appendix H** provides a comprehensive list of values for the 21st of May, June, July, and August. The values listed in the table are only for the times in which the sun is shining down on the west façade. All other points of the day are irrelevant for this analysis.

Vertical Façade Solar Radiation Calculation

Calculation Steps

The following steps include the calculations necessary to obtain the amount total solar radiation on the proposed vertical curtain wall façade.

Step 1

- Calculate normal direct irradiation, $\mathbf{G_{ND}}$ (btu/hr-ft^2)
- $G_{ND} = \frac{A}{e^{\frac{B}{\sin\beta}}} \times C_N$
  - A = apparent solar irradiation at air mass equal to zero (btu/hr-ft^2)
  - B = atmospheric extinction coefficient
  - β = solar altitude angle
  - C_N = clearness number

Step 2

- Calculate direct radiation, $\mathbf{G_D}$ (btu/hr-ft^2)
- $G_D = G_{ND}\cos\theta$
  - G_{ND} = normal direction irradiation
  - θ = angle of incidence
    - $\cos\theta = \cos\beta\cos\gamma$
      - β = solar altitude angle
      - γ = surface solar azimuth

Step 3

- Calculate diffuse irradiation, $\mathbf{G_{d\theta}}$ (btu/hr-ft^2)
- $G_{d\theta} = \frac{G_{dV}}{G_{dH}} C G_{ND}$
  - $G_{dV}/G_{dH} = 0.55 + 0.437 \cos\theta + 0.313 \cos^2\theta$
  - C = dimensionless factor
  - G_{ND} = normal direction irradiation

Step 4

- Calculate reflected irradiation, G_R (btu/hr-ft^2)
- $G_R = G_{tH} \rho_g F_{wg}$
  - G_{tH} = rate at which the total radiation (direct plus diffuse) strikes the horizontal surface or ground in front of the wall (btu/hr-ft^2)
  - ρ_g = reflectance of ground or horizontal surface
  - F_{wg} = configuration or angle factor from wall to ground, defined as the fraction of the radiation leaving the wall of interest that strikes the horizontal surface or ground directly
    - $F_{wg} = \frac{1 - \cos\alpha}{2}$
      - α = angle of tilt for an arbitrary surface

Step 5

- Calculate $\mathbf{G_t}$**,** total solar radiation, by summing $\mathbf{G_D}$ **(Step 2)**, $\mathbf{G_{d\theta}}$ **(Step 3)**, $\mathbf{G_R}$ **(Step 4)**
- $G_t = G_D + G_{d\theta} + G_R = \left[\cos\theta + \frac{G_{dV}}{G_{d\theta}} C + \rho_g F_{wg} \sin\beta + C \right] G_{ND}$

Application to Main & Gervais

Now that the steps to calculate the total solar radiation on a vertical surface have been outlined, it is necessary to apply them to the proposed curtain wall design for Main & Gervais. The application below is set for 3:00 pm on May 21, 2009, at 34° latitude. **Table 4.8** provides the information necessary to compute the calculations. This section will provide a simple version of the calculation. The written calculations can be found in **Appendix G.**

- $G_{ND} = \frac{350.6\ btu/hr-ft^2}{e^{\frac{0.177}{\sin 64.12°}}} \times 0.94$
  - $G_{ND} = 270.71\ btu/hr-ft^2$

- $\cos\theta = \cos 64.12° \cos 40.5°$
  - $\cos\theta = 0.242$

- $G_{dV}/G_{dH} = 0.55 + 0.437(0.242) + 0.313(0.242)^2$
  - $G_{dV}/G_{dH} = 0.73$

- $F_{wg} = \frac{1-\cos 90°}{2}$
  - $F_{wg} = 0.5$

- $G_t = [0.242 + (0.242)(0.73) + (0.32)(0.5)\sin(64.12° + 0.13)\,](270\ {btu}/_{hr-ft^2})$
  - $G_t = 154.58\ {btu}/_{hr-ft^2}$

The total solar radiation on Main & Gervais' vertical curtain wall on the west elevation at 3:00 pm May 21, 2009, is 154.58 btu/hr-ft^2. **Appendix I** provides a list of values for the 21st of May, June, July, and August. The values listed in the table are only for the times in which the sun is shining down on the west façade. All other points of the day are irrelevant for this analysis.

Window Heat Gain Calculation

The two previous sections provided the total solar radiation on the building at a specific time. Now it is important to note how that solar radiation will impact the curtain wall. This analysis focuses strictly on the office portion of the building. The typical glazing for the office tower is Solarscreen Radiant Low-E (VRE) Insulating Glass VRE 1-46 manufactured by Viracon.

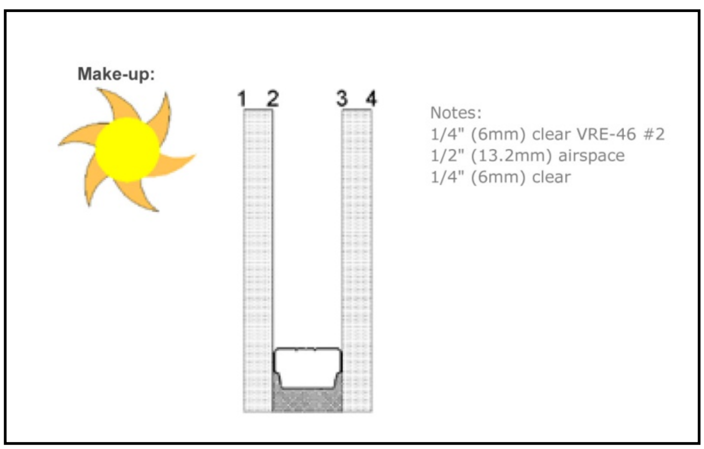

Figure 4.12: Curtain Wall Glazing Properties

The solar factor (SHGC) for this product is 0.278. This value multiplied by the total solar radiation, which is highlighted in each of the two previous sections, will obtain the window heat gain at 3:00 pm on May 21, 2009. **Appendix I** provides a list of values for window heat gain for the 21st of May, June, July, and August.

- $q_i = (G_i)(SHGC)$
- $q_i = (124.22)(0.278)$
- $q_i = 34.53\ {}^{btu}/_{hr-ft^2}$

- $q_i = (G_i)(SHGC)$
- $q_i = (154.58)(0.278)$
- $q_i = 43.06\ {}^{btu}/_{hr-ft^2}$

The left column displays the calculations for the sloped curtain wall and the right column displays the calculations for the vertical curtain wall. There is a 25% increase in heat gain for this particular hour.

Energy Load Comparison

The previous sections analyzed one particular hour for one day for the purpose of understanding the calculations. The following table, **Table 4.9**, provides the increase in window heat gain over the course of four months: May, June, July, and August. This provides a legitimate means of comparing the energy costs between the two different designs.

	Day (btu/ft^2/day)				Month (btu/ft^2/month)			
Month	Sloped	Vertical	q_i Inc.	% Inc.	Sloped	Vertical	q_i Inc.	% Inc.
May	279	333	54.29	19%	8364	9993	1628	19%
June	281	337	55.92	20%	8437	10115	1677	20%
July	273	327	54.53	20%	8189	9825	1636	20%
August	244	292	48.90	20%	7322	8789	1466	20%

Table 4.9: Energy Comparison

As shown in **Table 4.9**, the energy demand increases by 20%. This will increase the energy bill each month for the owner of the building. The average utility rate during November 2008 for commercial buildings in South Carolina is 8.76 cents/kwh. This value was obtained from the Energy Information Administration. **Table 4.10** provides the converted numbers to be capable of calculating the energy costs. **Table 4.11** provides the energy costs for the select months and the increase in cost for the change in design.

	(btu/ft^2/hr)		(btu/hr)		(kwh)	
Month	Sloped	Vertical	Sloped	Vertical	Sloped	Vertical
May	39.83	47.58	52692	62953	15.44	18.45
June	40.18	48.17	53156	63725	15.57	18.67
July	39.00	46.79	51593	61899	15.12	18.14
August	34.87	41.85	46130	55371	13.52	16.22

Table 4.10: Energy Unit Conversion

	($/day)		($/month)		$ Inc.	% Inc.
Month	Sloped	Vertical	Sloped	Vertical	Sloped	Vertical
May	$ 324.58	$ 387.79	$ 9,737.39	$ 11,633.73	$ 1,896.34	19%
June	$ 327.44	$ 392.54	$ 9,823.14	$ 11,776.29	$ 1,953.15	20%
July	$ 317.81	$ 381.30	$ 9,534.31	$ 11,438.95	$ 1,904.64	20%
August	$ 284.16	$ 341.09	$ 8,524.81	$ 10,232.61	$ 1,707.80	20%

Table 4.11: Energy Costs

The energy consumption in btu/hr is calculated in **Table 4.10** given that the area of curtain wall under consideration is 4,536 ft^2. As seen in **Table 4.11**, the price for energy costs increases by 20%. The amount expressed under ($/day) is based on seven hours of the day that the energy is transmitting through the window. These months under consideration are assumed to be when the air conditioning system will be running. The total increase in price during this time period is $7,461.94. This amount is minimal considering this portion is a fraction of the total footprint of the building.

Conclusion

The implementation of the new curtain wall design requires several considerations. These considerations include examining the benefits of the new curtain wall design, inputting new structural elements and verifying the integrity, and calculating the increases in energy demand due to window heat gain. The following conclusions can be obtained from this analysis.

Additional Area

Extending the curtain wall provides additional area to the floor plan for each level of office space. This extra area amounts to 2756 ft^2. The owner can charge $21.00/$ft^2$/year for this space, which will amount to an additional $57,876.00.

Structural Load Analysis

Adding extra floor area will require additional columns, joists, and beams to support the extended slab. The construction costs for adding these elements will cost $30,828.07.

Solar Heat Gain Analysis

Changing the slope of the curtain wall will change the amount of solar energy that transmits through. The amount of window heat gain increases by 20% with the proposed design. This will result in an additional $7,461.94 for the energy bill each year.

Final Comments

Implementing the new design will put more money in the owner's pocket over time. There is an upfront cost of $30,828.07 for construction of the new structural elements. Also, each year the owner will expect an increase in the energy budget of $7,461.94 to run the air conditioning units to compensate for the window heat gain. The first year, the owner can expect an additional $19,585.99 in revenue. Years following, the owner can expect to bring an additional $50,414.06. This can be seen in **Table 4.12**.

	Construction Cost	Energy Cost	Rent Income	Difference
Year 1	$ 30,828.07	$ 7,461.94	$ 57,876.00	$ 19,585.99
Year 2	$ -	$ 7,461.94	$ 57,876.00	$ 50,414.06
Year 3	$ -	$ 7,461.94	$ 57,876.00	$ 50,414.06

Table 4.12: Profit

V. Thesis Conclusion & Recommendations

After conducting these analyses, it is important to indicate the next course of action. The first analysis provides a better alternative of construction methods for the curtain wall. The second analysis establishes a more efficient design for the curtain wall, which will put more money in the owner's pockets. Both of these analyses provide better methods than what is currently being implemented.

Curtain Wall Prefabrication Analysis

The current method of curtain wall construction for Main & Gervais is the stick-built method. It is clear that the advantages of prefabrication outweigh the disadvantages for prefabrication. After identifying these specific advantages and disadvantages, it is important to consider two issues that are very important in construction. These two issues are time and money. The schedule for prefabrication is a third of the time it takes for the stick-built method. This extra time allows the interior trades to begin their work since the building is enclosed faster. The cost evaluation shows that the material costs for prefabrication construction are higher than the stick-built method. This fact would lead to an increase in overall cost by 29% for non-union labor. It is important to mention the cost savings from turning over the building to the owner quicker. Finishing the building possibly 81 days earlier will allow the owner to bring in $945,000.00 for leasing the space. This brings down the overall cost of prefabrication to only be 8% more than stick-built. This provides a stronger case to the owner to choose prefabrication.

Curtain Wall Design Analysis

Eliminating the slope of the curtain wall provides additional area to each floor of the office tower. This extra area amounts to an additional 2756 ft^2 in area. The owner can charge an additional $57,876.00 a year for this space. Adding this area does come at a cost to the owner. This cost is in the form of structural support, construction costs, and energy bills. It is concluded that extra columns and joists, and a resizing of the beams are necessary to support the additional slab area. Also, changing the slope of the curtain wall alters the amount of window heat gain the façade allows. The structural addition amounts to an upfront cost of around $30,828.07. And the new energy load increases the energy bill by approximately $7,461.94 for the year. After the first year, the owner annually brings in an extra $50,414.06 in rent money. In conclusion, putting this change into action is a profitable business plan.

Combining Both Analyses

After completing both analyses, there is an important conclusion that is revealed. The surplus revenue from extending the floor plan can compensate for the additional cost to choose prefabrication over stick-built construction. The additional floor plan will provide the owner an additional $372,484.41 after eight years. This surplus can contribute to the additional cost of prefabrication, which is $351,842.40. The owner will break even if prefabricated curtain wall panels were chosen and curtain wall slope was eliminated on the west elevation of the façade. Therefore, it is suggested that the curtain wall panels be prefabricated and the slope of the curtain wall on the west elevation be eliminated.

VI. Acknowledgements

This thesis would not be possible without the following people. Thank you for all your efforts.

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    - Holder Construction Company
        - Adam Barnes – Project Engineer
        - Bryan Taylor – Project Manager
        - Chad Martin – Regional Director
- Sub Contractor
    - Johnson Architectural Metal Co., Inc.
        - Van Nguyen – Project Manager
    - Wausau Window and Wall Systems
        - Ken Carpenter
    - AGC Flat Glass North America
        - Steve Brisdon
    - Architectural Glazing Technologies
        - John Blanchard
    - W.C. Johnston Architectural Sales, LLC
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        - Dr. Riley
        - Moses Ling
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        - Erik Carlson – CM
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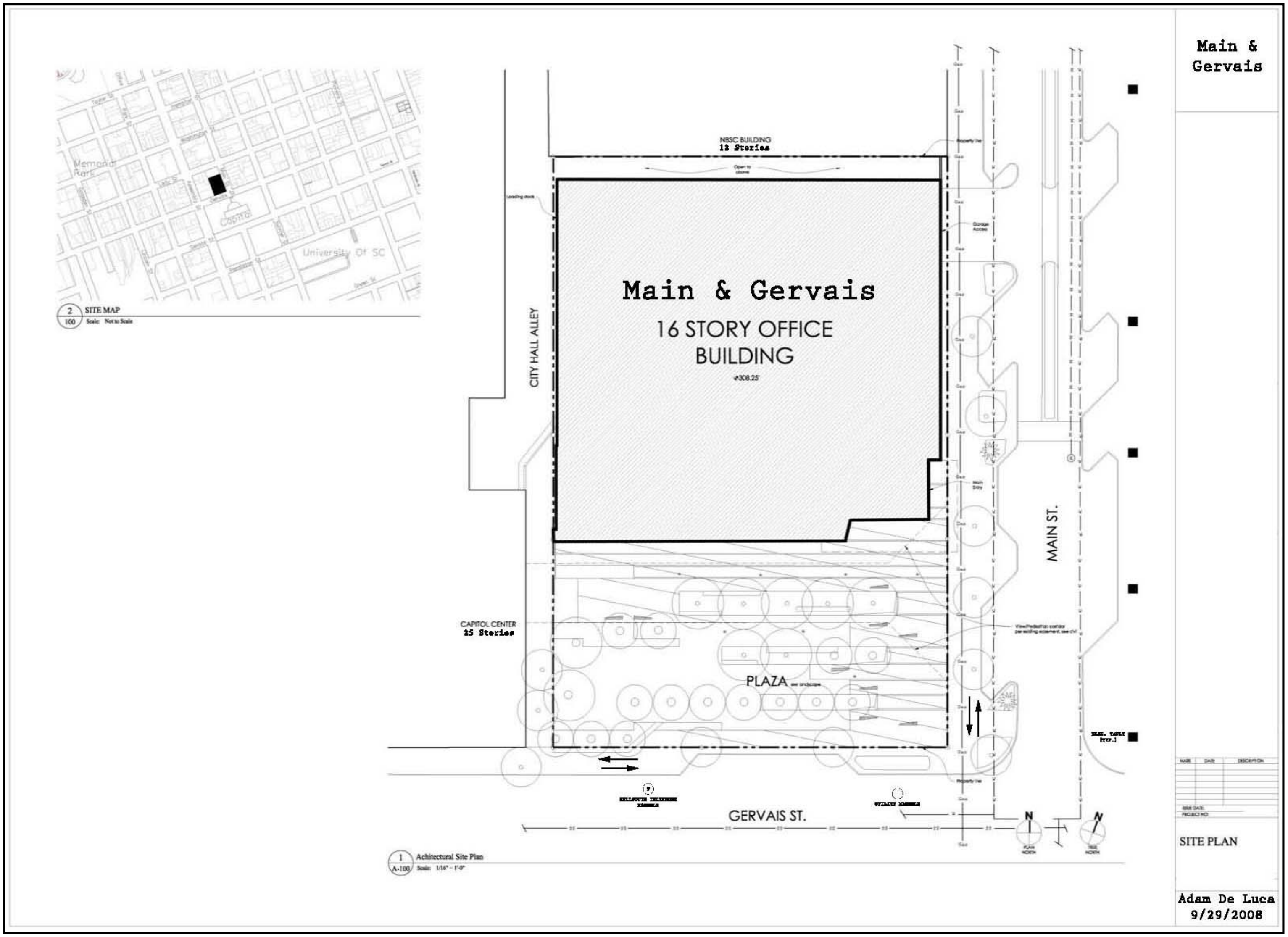
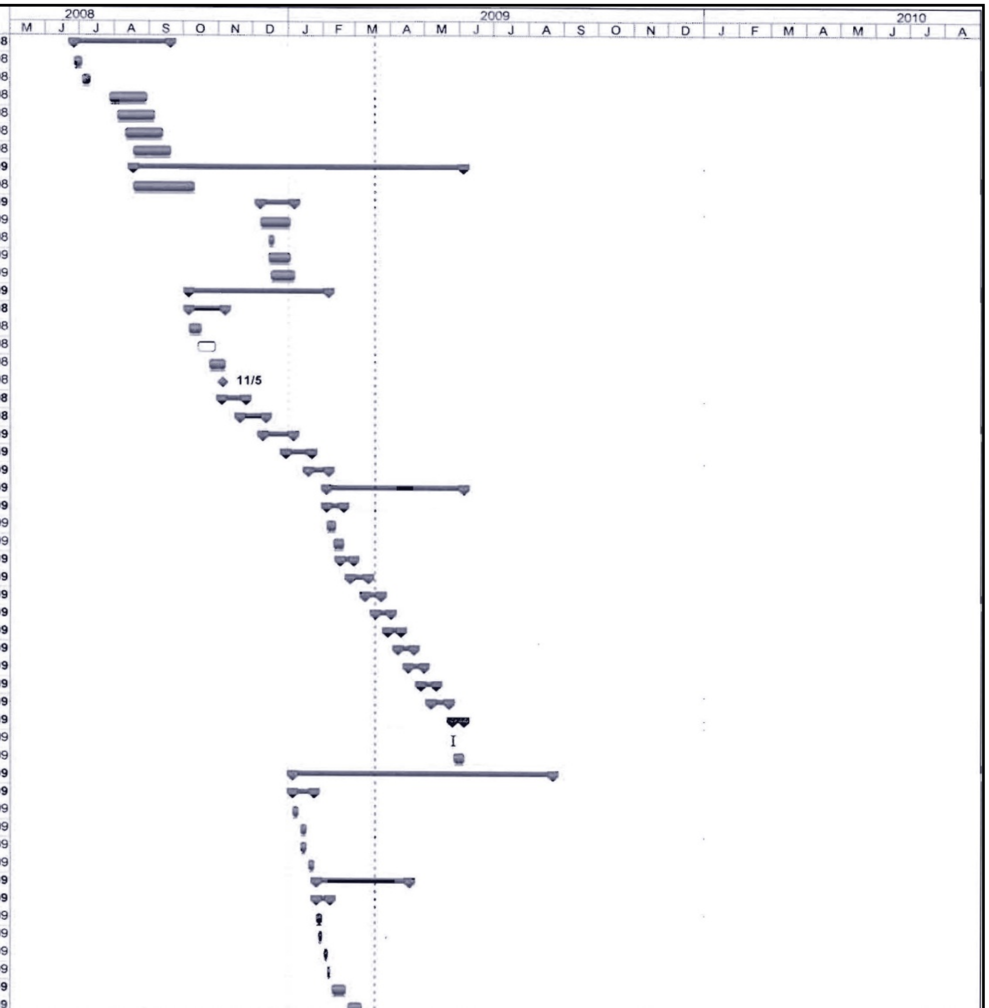
        - Matt Haapala – Structural
        - Rachael Chicchi – Structural
        - Scott Rabold – Structural
        - Dan Hanley – Mechanical
        - Jonathan Walker – Lighting/Electrical

Appendix A: Site Plan



Appendix B: Project Schedule

ID	Task Name	Duration	Start	Finish
1	**Site Work**	**61 days**	**Fri 6/27/08**	**Fri 9/19/08**
2	Mobilize	5 days	Fri 6/27/08	Thu 7/3/08
3	Demolition	5 days	Fri 7/4/08	Thu 7/10/08
4	Deep Foundations	25 days	Mon 7/28/08	Fri 8/29/08
5	Earthwork/Site Utilities	25 days	Mon 8/4/08	Fri 9/5/08
6	MEP Underground	25 days	Mon 8/11/08	Fri 9/12/08
7	Foundations	25 days	Mon 8/18/08	Fri 9/19/08
8	**Structure**	**209 days**	**Mon 8/18/08**	**Thu 6/4/09**
9	Foundation Walls & Columns	40 days	Mon 8/18/08	Fri 10/10/08
10	**Lobby Slab on Grade**	**22 days**	**Mon 12/8/08**	**Tue 1/6/09**
11	MEP Slab on Grade Rough-In	20 days	Mon 12/8/08	Fri 1/2/09
12	Storm Line Installation - S. Side	5 days	Mon 12/15/08	Fri 12/19/08
13	Prep Slab on Grade	15 days	Mon 12/15/08	Fri 1/2/09
14	Pour Lobby Slab on Grade	15 days	Wed 12/17/08	Tue 1/6/09
15	**Parking Garage**	**89 days**	**Mon 10/6/08**	**Thu 2/5/09**
16	**Level P1**	**24 days**	**Mon 10/6/08**	**Thu 11/6/08**
17	F/R/P A	9 days	Mon 10/6/08	Thu 10/16/08
18	F/R/P B	11 days	Tue 10/14/08	Tue 10/28/08
19	F/R/P C	10 days	Fri 10/24/08	Thu 11/6/08
20	Table Makeup	0 days	Wed 11/5/08	Wed 11/5/08
21	**Level P2**	**15 days**	**Tue 11/4/08**	**Mon 11/24/08**
27	**Level P3**	**17 days**	**Thu 11/20/08**	**Fri 12/12/08**
32	**Level P4**	**19 days**	**Wed 12/10/08**	**Mon 1/5/09**
37	**Level P5**	**17 days**	**Tue 12/30/08**	**Wed 1/21/09**
42	**Level P6**	**14 days**	**Mon 1/19/09**	**Thu 2/5/09**
48	**Office Tower**	**87 days**	**Wed 2/4/09**	**Thu 6/4/09**
49	**Level 9**	**11 days**	**Wed 2/4/09**	**Wed 2/18/09**
50	F/R/P A	6 days	Wed 2/4/09	Wed 2/11/09
51	F/R/P B	7 days	Tue 2/10/09	Wed 2/18/09
52	**Level 10**	**10 days**	**Mon 2/16/09**	**Fri 2/27/09**
55	**Level 11**	**12 days**	**Wed 2/25/09**	**Thu 3/12/09**
58	**Level 12**	**10 days**	**Tue 3/10/09**	**Mon 3/23/09**
61	**Level 14**	**10 days**	**Thu 3/19/09**	**Wed 4/1/09**
64	**Level 15**	**10 days**	**Mon 3/30/09**	**Fri 4/10/09**
67	**Level 16**	**10 days**	**Wed 4/8/09**	**Tue 4/21/09**
70	**Level 17**	**10 days**	**Fri 4/17/09**	**Thu 4/30/09**
73	**Level 18**	**10 days**	**Tue 4/28/09**	**Mon 5/11/09**
76	**Level 19**	**12 days**	**Thu 5/7/09**	**Fri 5/22/09**
79	**Machine Room**	**8 days**	**Tue 5/26/09**	**Thu 6/4/09**
80	Columns to machine room	1 day	Tue 5/26/09	Tue 5/26/09
81	F/R/P	7 days	Wed 5/27/09	Thu 6/4/09
82	**Shell Finishes**	**165 days**	**Mon 1/5/09**	**Fri 8/21/09**
83	**Lobby**	**15 days**	**Mon 1/5/09**	**Fri 1/23/09**
84	MEP Overhead Rough In	5 days	Mon 1/5/09	Fri 1/9/09
85	Masonry Walls	5 days	Mon 1/12/09	Fri 1/16/09
86	Frame Drywall Walls	5 days	Mon 1/12/09	Fri 1/16/09
87	MEP in Wall Rough In	5 days	Mon 1/19/09	Fri 1/23/09
88	**Parking Garge**	**60 days**	**Mon 1/26/09**	**Fri 4/17/09**
89	**Level P1**	**10 days**	**Mon 1/26/09**	**Fri 2/6/09**
90	MEP Overhead Rough In	5 days	Mon 1/26/09	Fri 1/30/09
91	Masonry Walls	3 days	Wed 1/28/09	Fri 1/30/09
92	Frame Drywall Walls	3 days	Mon 2/2/09	Wed 2/4/09
93	MEP in Wall Rough In	2 days	Thu 2/5/09	Fri 2/6/09
94	**Level P2**	**10 days**	**Mon 2/9/09**	**Fri 2/20/09**
95	**Level P3**	**10 days**	**Mon 2/23/09**	**Fri 3/6/09**



Project: Schedule
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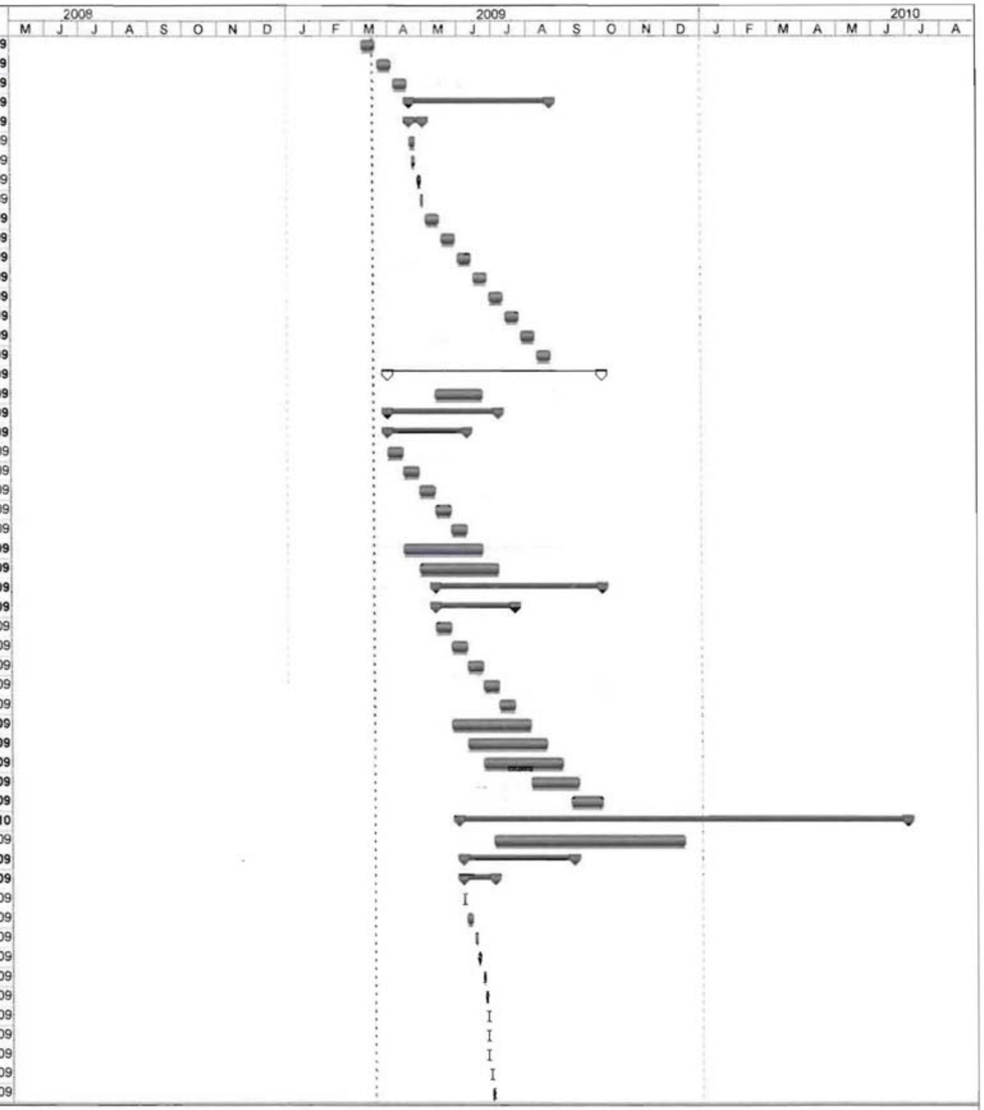
ID	Task Name	Duration	Start	Finish
96	**Level P4**	**10 days**	**Mon 3/9/09**	**Fri 3/20/09**
97	**Level P5**	**10 days**	**Mon 3/23/09**	**Fri 4/3/09**
98	**Level P6**	**10 days**	**Mon 4/6/09**	**Fri 4/17/09**
99	**Office Tower**	**90 days**	**Mon 4/20/09**	**Fri 8/21/09**
100	**Level 9**	**10 days**	**Mon 4/20/09**	**Fri 5/1/09**
101	MEP Overhead Rough In	5 days	Mon 4/20/09	Fri 4/24/09
102	Masonry Walls	3 days	Wed 4/22/09	Fri 4/24/09
103	Frame Drywall Walls	3 days	Mon 4/27/09	Wed 4/29/09
104	MEP in Wall Rough In	2 days	Thu 4/30/09	Fri 5/1/09
105	**Level 10**	**10 days**	**Mon 5/4/09**	**Fri 5/15/09**
106	**Level 11**	**10 days**	**Mon 5/18/09**	**Fri 5/29/09**
107	**Level 12**	**10 days**	**Mon 6/1/09**	**Fri 6/12/09**
108	**Level 14**	**10 days**	**Mon 6/15/09**	**Fri 6/26/09**
109	**Level 15**	**10 days**	**Mon 6/29/09**	**Fri 7/10/09**
110	**Level 16**	**10 days**	**Mon 7/13/09**	**Fri 7/24/09**
111	**Level 17**	**10 days**	**Mon 7/27/09**	**Fri 8/7/09**
112	**Level 18**	**10 days**	**Mon 8/10/09**	**Fri 8/21/09**
113	**Exterior Skin**	**135 days**	**Tue 3/31/09**	**Mon 10/5/09**
114	**Lobby**	**30 days**	**Tue 5/12/09**	**Mon 6/22/09**
115	**Parking Garage**	**70 days**	**Tue 3/31/09**	**Mon 7/6/09**
116	**Levels P1/P2**	**50 days**	**Tue 3/31/09**	**Mon 6/8/09**
117	Layout & Clips	10 days	Tue 3/31/09	Mon 4/13/09
118	Vertical Mullions	10 days	Tue 4/14/09	Mon 4/27/09
119	Horizontal Mullions	10 days	Tue 4/28/09	Mon 5/11/09
120	Prep for Glass	10 days	Tue 5/12/09	Mon 5/25/09
121	Glaze	10 days	Tue 5/26/09	Mon 6/8/09
122	**Levels P3/P4**	**50 days**	**Tue 4/14/09**	**Mon 6/22/09**
123	**Levels P5/P6**	**50 days**	**Tue 4/28/09**	**Mon 7/6/09**
124	**Office Tower**	**105 days**	**Tue 5/12/09**	**Mon 10/5/09**
125	**Levels 9/10**	**50 days**	**Tue 5/12/09**	**Mon 7/20/09**
126	Layout & Clips	10 days	Tue 5/12/09	Mon 5/25/09
127	Verical Mullions	10 days	Tue 5/26/09	Mon 6/8/09
128	Horizontal Mullions	10 days	Tue 6/9/09	Mon 6/22/09
129	Prep for Glass	10 days	Tue 6/23/09	Mon 7/6/09
130	Glaze	10 days	Tue 7/7/09	Mon 7/20/09
131	**Levels 11/12**	**50 days**	**Tue 5/26/09**	**Mon 8/3/09**
132	**Levels 14/15**	**50 days**	**Tue 6/9/09**	**Mon 8/17/09**
133	**Levels 16/17**	**50 days**	**Tue 6/23/09**	**Mon 8/31/09**
134	**Level 18**	**30 days**	**Tue 8/4/09**	**Mon 9/14/09**
135	**Screenwall**	**20 days**	**Tue 9/8/09**	**Mon 10/5/09**
136	**Interior Finishes**	**284 days**	**Mon 6/1/09**	**Thu 7/1/10**
137	Lobby	120 days	Thu 7/2/09	Wed 12/16/09
138	**Parking Garage**	**70 days**	**Fri 6/5/09**	**Thu 9/10/09**
139	**Level P1**	**20 days**	**Fri 6/5/09**	**Thu 7/2/09**
140	Hang Walls	1 day	Fri 6/5/09	Fri 6/5/09
141	Install Storefront	5 days	Mon 6/8/09	Fri 6/12/09
142	Finish Walls	2 days	Mon 6/15/09	Tue 6/16/09
143	Prime Paint	3 days	Wed 6/17/09	Fri 6/19/09
144	Touch up Walls	2 days	Mon 6/22/09	Tue 6/23/09
145	Final Paint	2 days	Wed 6/24/09	Thu 6/25/09
146	Install Ceiling Grid	1 day	Fri 6/26/09	Fri 6/26/09
147	Center Heads/Drop Lights	1 day	Fri 6/26/09	Fri 6/26/09
148	Install Ceiling Tile	1 day	Fri 6/26/09	Fri 6/26/09
149	Install Flooring	1 day	Mon 6/29/09	Mon 6/29/09
150	Install Doors/Hardware	2 days	Tue 6/30/09	Wed 7/1/09



Project: Schedule
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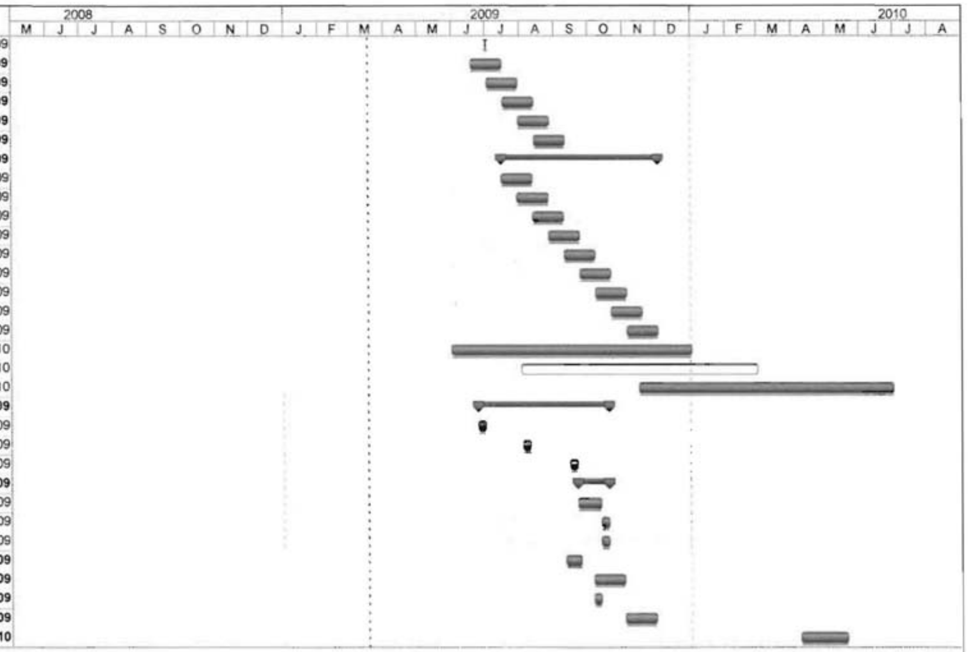
ID	Task Name	Duration	Start	Finish
151	Final Clean	1 day	Thu 7/2/09	Thu 7/2/09
152	**Level P2**	**20 days**	**Fri 6/19/09**	**Thu 7/16/09**
153	**Level P3**	**20 days**	**Fri 7/3/09**	**Thu 7/30/09**
154	**Level P4**	**20 days**	**Fri 7/17/09**	**Thu 8/13/09**
155	**Level P5**	**20 days**	**Fri 7/31/09**	**Thu 8/27/09**
156	**Level P6**	**20 days**	**Fri 8/14/09**	**Thu 9/10/09**
157	**Office Tower**	**100 days**	**Thu 7/16/09**	**Wed 12/2/09**
158	Level 9	20 days	Thu 7/16/09	Wed 8/12/09
159	Level 10	20 days	Thu 7/30/09	Wed 8/26/09
160	Level 11	20 days	Thu 8/13/09	Wed 9/9/09
161	Level 12	20 days	Thu 8/27/09	Wed 9/23/09
162	Level 14	20 days	Thu 9/10/09	Wed 10/7/09
163	Level 15	20 days	Thu 9/24/09	Wed 10/21/09
164	Level 16	20 days	Thu 10/8/09	Wed 11/4/09
165	Level 17	20 days	Thu 10/22/09	Wed 11/18/09
166	Level 18	20 days	Thu 11/5/09	Wed 12/2/09
167	Upfit - Edens & Advant	155 days	Mon 6/1/09	Fri 1/1/10
168	Upfit - NBSC	151 days	Mon 8/3/09	Mon 3/1/10
169	Upfit - McNair	164 days	Mon 11/16/09	Thu 7/1/10
170	**Roofing**	**83 days**	**Thu 6/25/09**	**Mon 10/19/09**
171	Temporary Roofing - Lobby Roof	5 days	Thu 6/25/09	Wed 7/1/09
172	Temporary Roofing - Level 11	5 days	Tue 8/4/09	Mon 8/10/09
173	Temporary Dry In - High Roof	5 days	Tue 9/15/09	Mon 9/21/09
174	**Permanent Roofing**	**20 days**	**Tue 9/22/09**	**Mon 10/19/09**
175	Roof Membrane	15 days	Tue 9/22/09	Mon 10/12/09
176	Sheet Metal/Coping	5 days	Tue 10/13/09	Mon 10/19/09
177	Zinc Panels at Penthouse	5 days	Tue 10/13/09	Mon 10/19/09
178	**Parking Control Equipment**	**10 days**	**Fri 9/11/09**	**Thu 9/24/09**
179	**Asphalt Paving/Curb & Gutter**	**20 days**	**Tue 10/6/09**	**Mon 11/2/09**
180	**Loading Dock Equipment**	**5 days**	**Tue 10/6/09**	**Mon 10/12/09**
181	**Landscaping/Irrigation/Hardscape**	**20 days**	**Tue 11/3/09**	**Mon 11/30/09**
182	**Commissioning**	**30 days**	**Fri 4/9/10**	**Thu 5/20/10**



Project: Schedule
Date: Wed 3/18/09

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Appendix C: General Conditions Estimate

Staffing			
Position	Unit (week)	Labor Cost	Total Cost
Project Manager	78	$ 2,100.00	$ 163,800.00
Project Engineer (2)	156	$ 1,005.00	$ 52,260.00
Superintendent	78	$ 1,950.00	$ 101,400.00
Field Engineer (2)	156	$ 1,300.00	$ 67,600.00
Layout Crew	8	$ 4,788.00	$ 38,304.00
Clerk	78	$ 365.00	$ 18,980.00
Total			$ 442,344.00

Office Support			
Materials	Unit (month)	Material Cost	Total Cost
Rented Office Space	18	$ 1,565.00	$ 28,170.00
Office Supplies	18	$ 95.00	$ 1,710.00
Telephone	18	$ 210.00	$ 3,780.00
Storage	18	$ 147.00	$ 2,646.00
Office Equipment	18	$ 150.00	$ 2,700.00
Total			$ 39,006.00

Material Hoists			
Equipment	Unit (month)	Labor/Equip. Cost	Total Cost
Tower Crane	13	$ 28,800.00	$ 374,400.00
Mobile Crane (100 ton)	3	$ 3,985.00	$ 358,650.00
All-Terrain Forklift	13	$ 3,675.00	$ 47,775.00
Total			**$ 780,825.00**

Temporary Utilities			
Utility	Time	Unit Cost/CSF	Total Cost
Heat (winter months)	5 Months	$ 13.50	$ 54,391.50
Lighting (interior const.)	7 Months	$ 13.33	$ 53,706.57
Power	7 Months	$ 47.00	$ 189,363.00
Total			**$ 297,461.07**

Miscellaneous Items			
Equipment	Unit	Unit Cost	Total Cost
Temporary Fencing	932 LF	$ 3.00	$ 2,796.00
Quality Control Testing	Project	$ 48,182.00	$ 48,182.00
Permits	Project	2.00%	$ 823,020.00
Total			**$ 873,998.00**

Insurance and Fees			
Item	Unit	Unit Cost	Total Cost
Contractors Fee	Project	4.00%	$ 1,646,040.00
All-Risk Insurance	Project	0.62%	$ 255,136.20
Total			**$ 1,901,176.20**

General Conditions Total	**$ 4,302,266.24**

Appendix D: Structural Estimate

03 11 13 Forms In Place							
Description	Quantity	Unit	Material	Labor	Equipment	Cost/Unit	Total
Pile Caps	7722	SFCA	$ 0.86	$ 3.02		$ 3.88	$ 23,669.47
Joists	124320	SFCA	$ 0.89	$ 4.51		$ 5.40	$ 530,349.12
Beams	137760	SFCA	$ 0.89	$ 4.51		$ 5.40	$ 587,684.16
Girders	114240	SFCA	$ 0.88	$ 5.50		$ 6.38	$ 575,792.45
Columns	69120	SFCA	$ 0.78	$ 4.72		$ 5.50	$ 300,326.40
Slab on Grade	756	LF	$ 0.32	$ 1.93		$ 2.25	$ 1,343.79
Elevated Slabs	403314	SF	$ 1.42	$ 3.18		$ 4.60	$ 1,465,643.08
Total							**$ 3,484,808.47**

03 21 10 Reinforcing In Place							
Description	**Quantity**	**Unit**	**Material**	**Labor**	**Equipment**	**Cost/Unit**	**Total**
Beams & Girders, #8 to #18	1410	tons	$ 980.00	$ 520.00		$ 1,500.00	$ 1,670,850.00
Columns, #8 to #18	198	tons	$ 980.00	$ 600.00		$ 1,580.00	$ 247,143.60
Slab on Grade, #3 to #7	41	tons	$ 940.00	$ 660.00		$ 1,600.00	$ 51,824.00
Elevated Slabs, #4 to #7	383	tons	$ 1,020.00	$ 480.00		$ 1,500.00	$ 453,855.00
Total							**$ 2,423,672.60**

03 23 05 Prestressing Tendons							
Description	Quantity	Unit	Material	Labor	Equipment	Cost/Unit	Total
Post-tensioned, 50' span, 300 kip	242	tons	$ 1,820.00	$ 1,860.00	$ 80.00	$ 3,760.00	$ 718,836.80
Total							**$ 718,836.80**

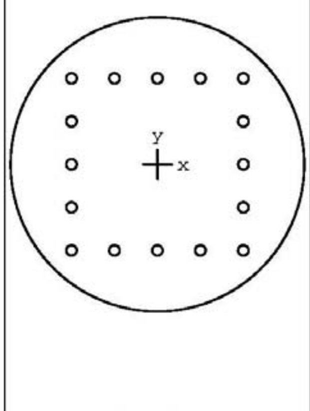
03 31 05 Placing Concrete							
Description	Quantity	Unit	Material	Labor	Equipment	Cost/Unit	Total
Pile Caps, pumped	787	CY		$ 12.80	$ 6.40	$ 19.20	$ 11,937.22
Joists, crane & bucket	2302	CY		$ 52.50	$ 26.50	$ 79.00	$ 143,667.82
Beams, "	2551	CY		$ 52.50	$ 26.50	$ 79.00	$ 159,207.91
Girders, "	2116	CY		$ 36.50	$ 18.30	$ 54.80	$ 91,605.87
Columns, "	2296	CY		$ 23.50	$ 11.90	$ 35.40	$ 64,209.94
Slab on Grade, pumped	551	CY		$ 16.00	$ 6.00	$ 22.00	$ 9,576.38
Elevated Slab, crane & bucket	8714	CY		$ 21.50	$ 10.80	$ 32.30	$ 222,355.14
Total							**$ 702,560.27**

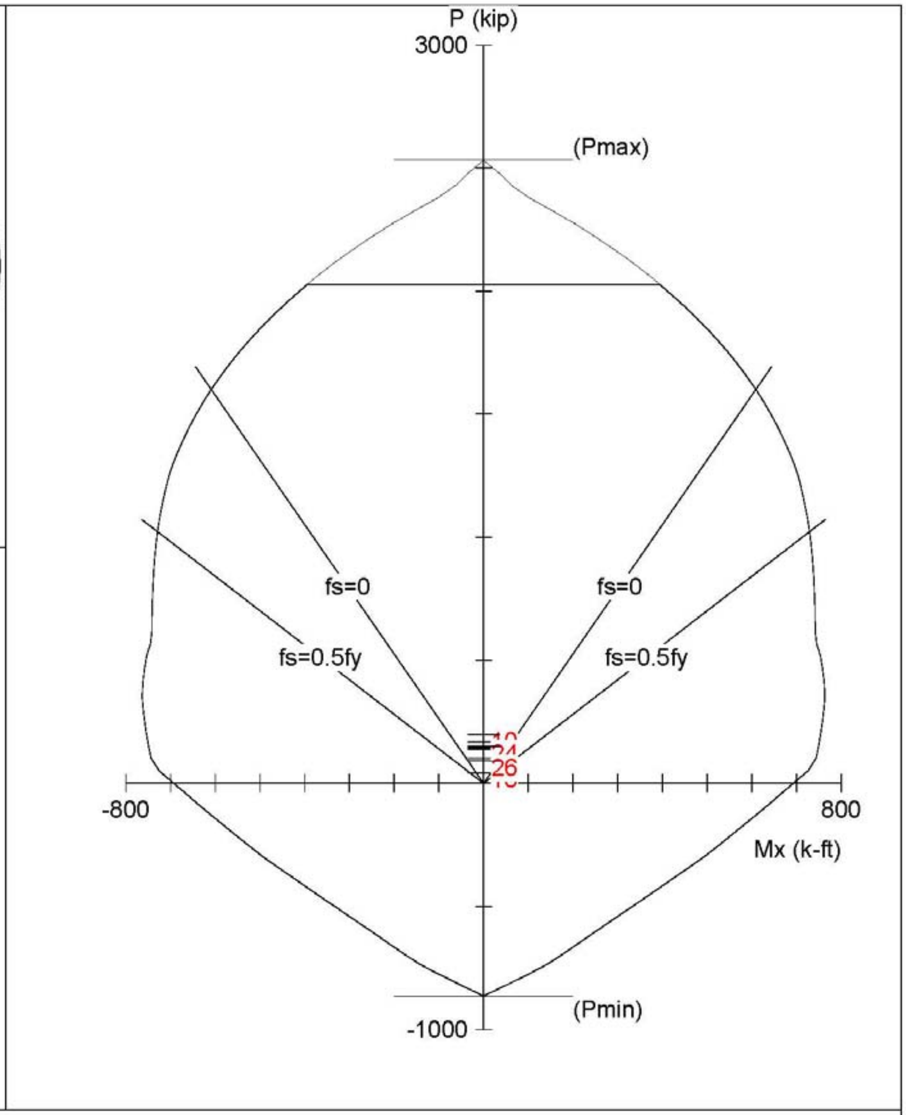
03 31 05 Normal Weight Concrete							
Description	Quantity	Unit	Material	Labor	Equipment	Cost/Unit	Total
5000 psi	9265	CY	$ 109.00			$ 109.00	$ 797,809.15
6000 psi	6969	CY	$ 124.00			$ 124.00	$ 682,683.24
8000 psi	3083	CY	$ 203.00			$ 203.00	$ 494,420.71
Total							**$ 1,974,913.10**

31 62 13 Concrete Piles							
Description	Quantity	Unit	Material	Labor	Equipment	Cost/Unit	Total
Prestressed Concrete Piles, d=18"	25650	V.L.F.	$ 35.00	$ 4.06	$ 3.76	$ 42.82	$ 867,683.07
Total							**$867,683.07**

Grand Total	**$ 10,172,474.31**

Appendix E: Column Loading Results (pcaColumn)





Code: ACI 318-02

Units: English

Run axis: About X-axis

Run option: Investigation

Slenderness: Considered

Column type: Structural

Bars: ASTM A615

Date: 03/04/09

Time: 20:22:06

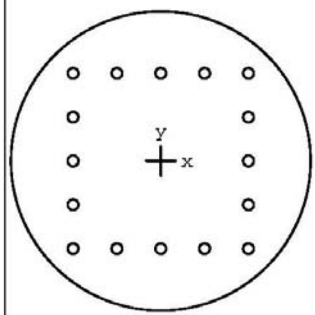
pcaColumn v3.64. Licensed to: Penn State University. License ID: 52411-1010265-4-22545-28F4D

File: P:\Thesis\Curtain Wall Analysis\Column Load Analysis\5000.col

Project: Main & Gervais

Column: A5		Engineer: Adam	
f'c = 5 ksi	fy = 60 ksi	Ag = 706.858 in^2	16 #9 bars
Ec = 4031 ksi	Es = 29000 ksi	As = 16.00 in^2	Rho = 2.26%
fc = 4.25 ksi	fc = 4.25 ksi	Xo = 0.00 in	Ix = 39760.8 in^4
e_u = 0.003 in/in		Yo = 0.00 in	Iy = 39760.8 in^4
Beta1 = 0.8		Clear spacing = 3.31 in	Clear cover = 1.88 in
Confinement: Tied	phi(a) = 0.8, phi(b) = 0.9, phi(c) = 0.65		

kx(braced) = 1, kx(sway) = N/A



30 in diam.

Code: ACI 318-02

Units: English

Run axis: About X-axis

Run option: Investigation

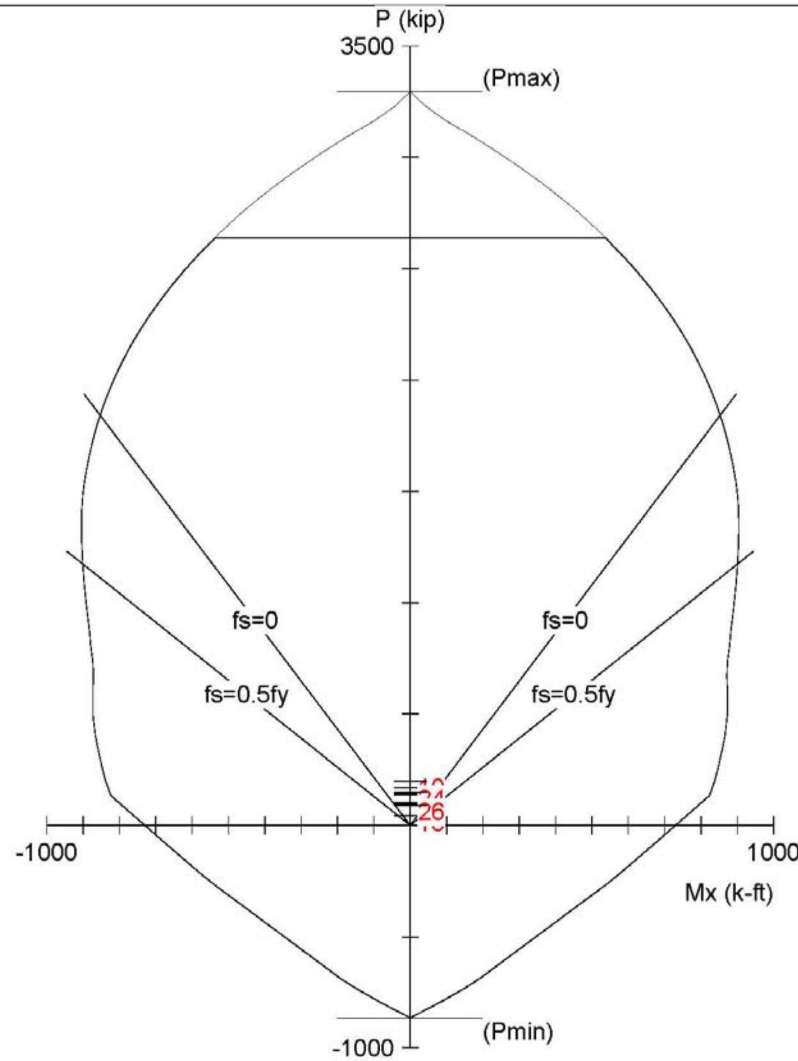
Slenderness: Considered

Column type: Structural

Bars: ASTM A615

Date: 03/04/09

Time: 17:38:45



pcaColumn v3.64. Licensed to: Penn State University. License ID: 52411-1010265-4-22545-28F4D

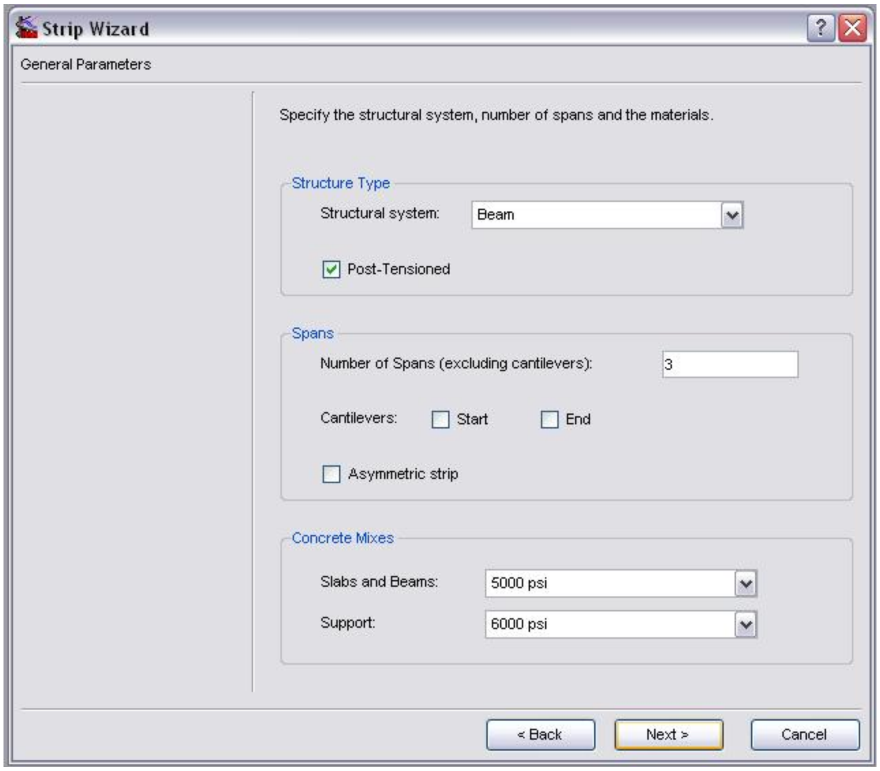
File: P:\Thesis\Curtain Wall Analysis\Column Load Analysis\7000.col

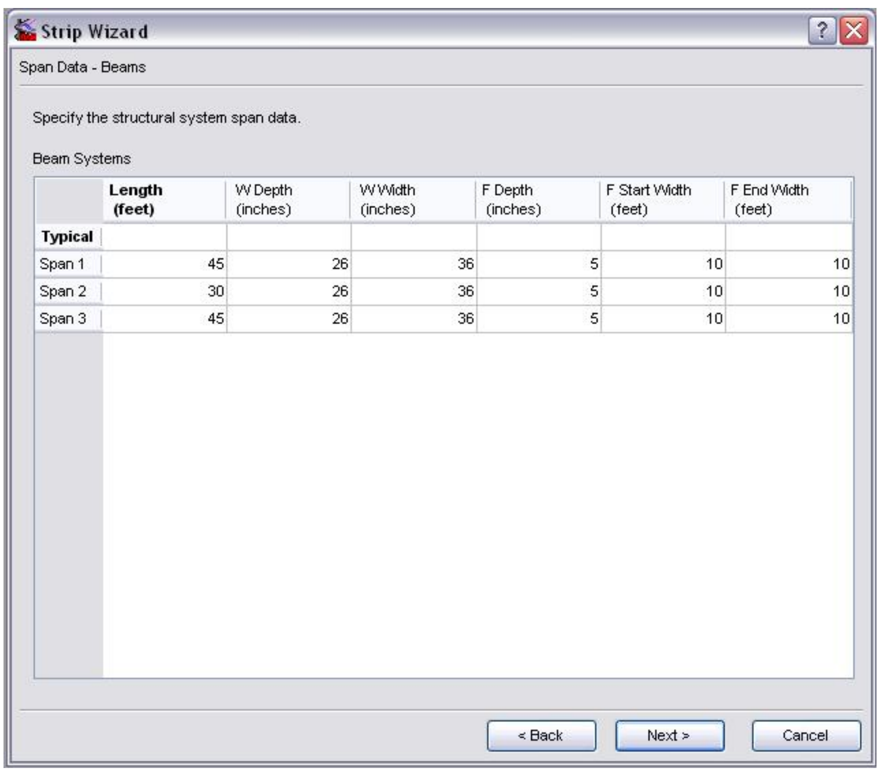
Project: Main & Gervais

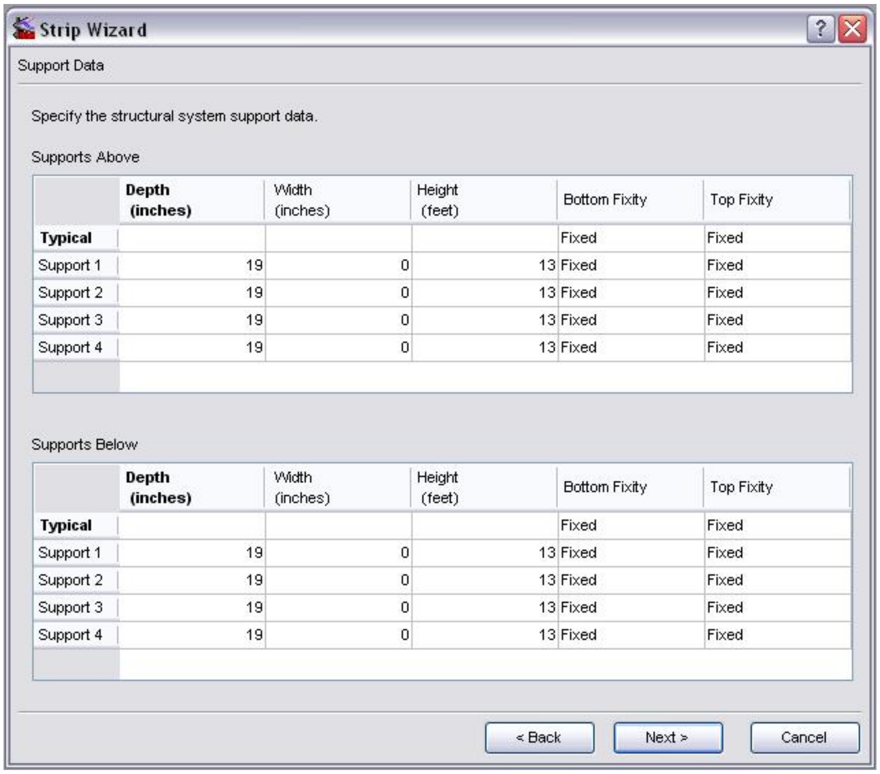
Column: A5		Engineer: Adam	
f'c = 7 ksi	fy = 60 ksi	Ag = 706.858 in^2	16 #9 bars
Ec = 4769 ksi	Es = 29000 ksi	As = 16.00 in^2	Rho = 2.26%
fc = 5.95 ksi	fc = 5.95 ksi	Xo = 0.00 in	Ix = 39760.8 in^4
e_u = 0.003 in/in		Yo = 0.00 in	Iy = 39760.8 in^4
Beta1 = 0.7		Clear spacing = 3.31 in	Clear cover = 1.88 in
Confinement: Tied	phi(a) = 0.8, phi(b) = 0.9, phi(c) = 0.65		

kx(braced) = 1, kx(sway) = N/A

Appendix F: Strip Wizard Input (RAM Con*cept*)







Strip Wizard

Support Data

Specify the structural system support data.

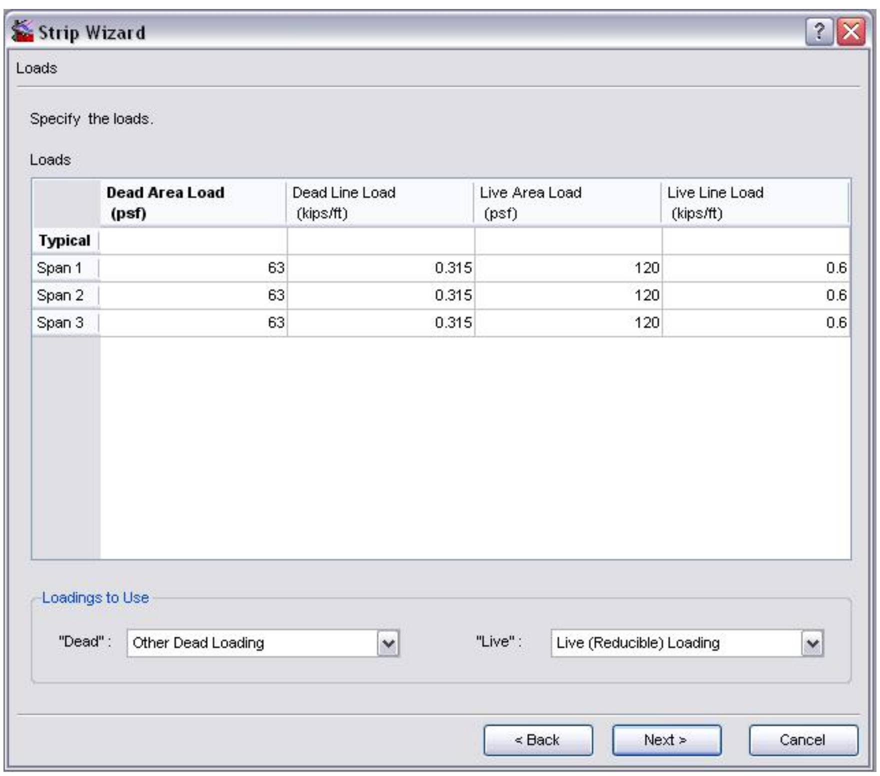
Supports Above

	Depth (inches)	Width (inches)	Height (feet)	Bottom Fixity	Top Fixity
Typical				Fixed	Fixed
Support 1	19	0	13	Fixed	Fixed
Support 2	19	0	13	Fixed	Fixed
Support 3	19	0	13	Fixed	Fixed
Support 4	19	0	13	Fixed	Fixed

Supports Below

	Depth (inches)	Width (inches)	Height (feet)	Bottom Fixity	Top Fixity
Typical				Fixed	Fixed
Support 1	19	0	13	Fixed	Fixed
Support 2	19	0	13	Fixed	Fixed
Support 3	19	0	13	Fixed	Fixed
Support 4	19	0	13	Fixed	Fixed

< Back   Next >   Cancel



Strip Wizard

Loads

Specify the loads.

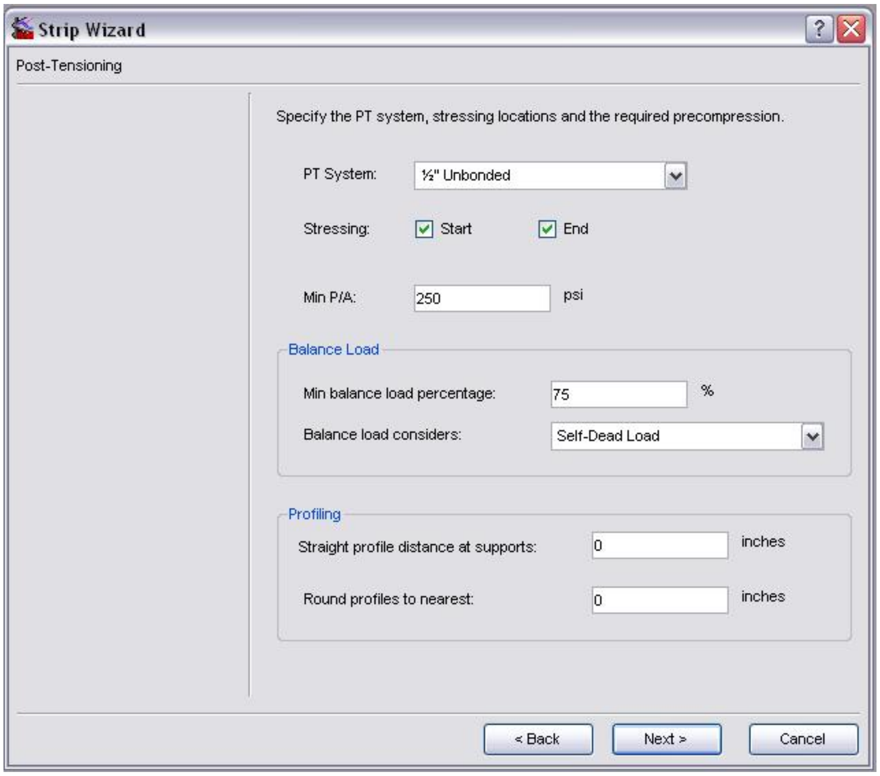
Loads

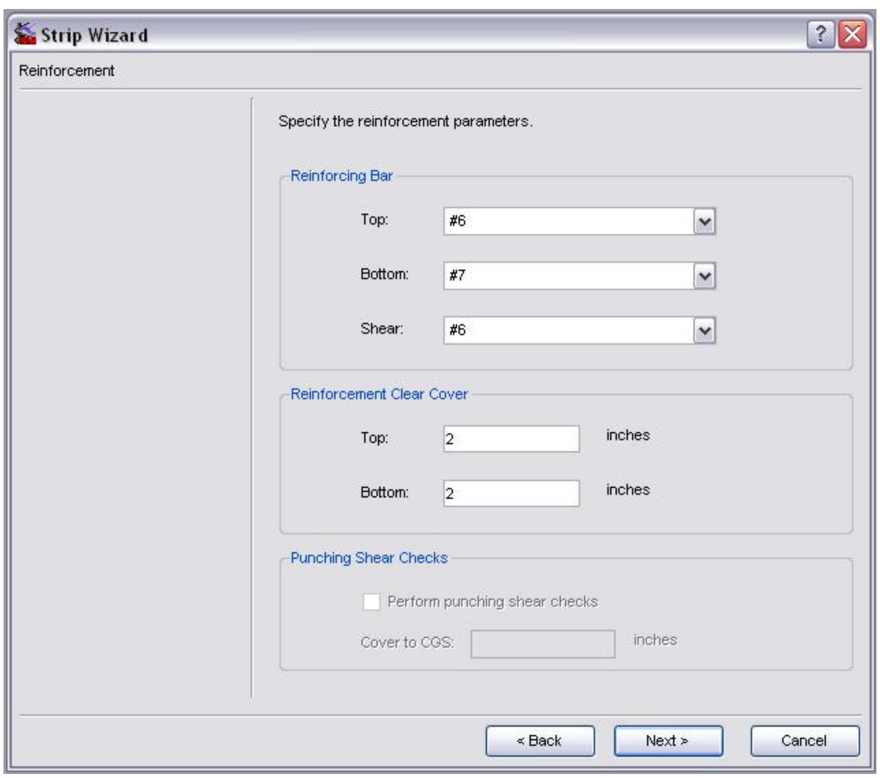
	Dead Area Load (psf)	Dead Line Load (kips/ft)	Live Area Load (psf)	Live Line Load (kips/ft)
Typical				
Span 1	63	0.315	120	0.6
Span 2	63	0.315	120	0.6
Span 3	63	0.315	120	0.6

Loadings to Use

"Dead" : Other Dead Loading   "Live" : Live (Reducible) Loading

< Back   Next >   Cancel


Strip Wizard
Post-Tensioning
Specify the PT system, stressing locations and the required precompression.
PT System:
½" Unbonded
Stressing:
Start
End
Min P/A:
250
psi
Balance Load
Min balance load percentage:
75
%
Balance load considers:
Self-Dead Load
Profiling
Straight profile distance at supports:
0
inches
Round profiles to nearest:
0
inches
< Back
Next >
Cancel


Strip Wizard
Reinforcement
Specify the reinforcement parameters.
Reinforcing Bar
Top:
#6
Bottom:
#7
Shear:
#6
Reinforcement Clear Cover
Top:
2
inches
Bottom:
2
inches
Punching Shear Checks
Perform punching shear checks
Cover to CGS:
inches
< Back
Next >
Cancel

Appendix G: Solar Radiation Hand Calculations

WINDOW HEAT GAIN ANALYSIS

May 21 - 3pm 2009

$C_N = 0.94$ $\rho_g = 0.32$

$A = 350.6\ Btu/hr\text{-}ft^2$

$B = 0.177$ $\gamma = |\phi - \psi|$

$C = 0.130$ $\gamma = |295.5 - 255|$

$\beta = 64.12°$ $\gamma = 40.5°$

$\phi_z = -64.51°$ $\alpha = 95.63°$

SLOPED

$$G_{ND} = \frac{A}{\exp(B/\sin\beta)} C_N$$

$$G_{ND} = \frac{350.6}{\exp(0.177/\sin 64.12)}(0.94)$$

$$G_{ND} = 270.71$$

$$G_D = G_{ND}\cos\theta$$

$$G_D = (270.71)(0.487)$$

$$G_D = 131.84$$

$$\cos\theta = \cos\beta\cos\gamma\sin\alpha + \sin\beta\cos\alpha$$

$$\cos\theta = \cos(64.12)\cos(40.5)\sin(95.63) + \sin(64.12)\cos(95.63)$$

$$\cos\theta = 0.242$$

$$F_{ws} = \frac{1+\cos\alpha}{2} = \frac{1+\cos(95.63)}{2}$$

$$= 0.451$$

$$F_{wg} = \frac{1-\cos\alpha}{2} = \frac{1-\cos(95.63)°}{2}$$

$$= 0.549$$

$$G_t = [\cos\theta + CF_{ws} + \rho_g F_{wg}(\sin\beta + C)]G_{ND}$$

$$= [0.242 + (0.13)(0.451) + (0.32)(0.549)(\sin(64.12 + 0.13)](270.71)$$

$$= 0.459\ (270.71)$$

$$= 124.22\ Btu/hr\text{-}ft^2$$

$$q = SHGC(G_t) = 0.278(124.22) = 34.53\ Btu/hr\text{-}ft^2$$

VERTICAL

$$G_{dv}/G_{dh} = 0.55 + 0.437\cos\theta + 0.313\cos^2\theta$$

$$= 0.73$$

$$\cos\theta = \cos\beta\cos\gamma$$

$$\cos\theta = \cos(64.12)\cos(40.5)$$

$$\cos\theta = 0.332$$

$$G_t = \left[\cos\theta + \frac{G_{dv}}{G_{dh}}C + \rho_g F_{wg}(\sin\beta + C)\right]G_{ND}$$

$$= [0.332 + (0.730)(0.13) + (0.32)(0.5)(\sin(64.12 + 0.13))](270.71)$$

$$= 0.571\ (270.71)$$

$$= 154.58\ Btu/hr\text{-}ft^2$$

$$q = SHGC(G_t) = 0.278(154.88) = 43.057\ Btu/hr\text{-}ft^2$$

$$\%\ Diff = \frac{43 - 34.5}{34.5} \times 100 = 25\%$$ increase for this hour

Appendix H: Sloped Façade Solar Radiation Calculation Tables

May 21 - Solar Data			
A	B	C	C_N
350.6	0.177	0.13	0.94

SLOPED WALL															
Date	Time	β (Altitude)	φ_z (Azimuth)	G_{nd}	φ	Ψ	γ	α	cos θ	F_{ws}	F_{wg}	N/A	G_t (btu/hr-ft^2)	SHGC	Window Heat Gain (btu/hr-ft^2)
21-May	12:00	76.1	0	274.63	360.00	255.00	105.00	95.63	-0.16	0.45	0.55		19.82	0.278	5.51
21-May	13:00	70.78	-47.57	273.23	312.43	255.00	57.43	95.63	0.08	0.45	0.55		84.26	0.278	23.42
21-May	14:00	60.05	-70.14	268.67	289.86	255.00	34.86	95.63	0.32	0.45	0.55		143.40	0.278	39.86
21-May	15:00	47.97	-82.62	259.69	277.38	255.00	22.38	95.63	0.54	0.45	0.55		190.26	0.278	52.89
21-May	16:00	35.57	-91.61	243.10	268.39	255.00	13.39	95.63	0.73	0.45	0.55		216.74	0.278	60.25
21-May	17:00	23.21	-99.37	210.32	260.63	255.00	5.63	95.63	0.87	0.45	0.55		210.28	0.278	58.46
21-May	18:00	11.11	-106.92	131.53	253.08	255.00	1.92	95.63	0.96	0.45	0.55		138.10	0.278	38.39
													Total btu/ft^2/day		**278.792**

June 21 - Solar Data			
A	B	C	C_N
346.1	0.185	0.137	0.94

SLOPED WALL															
Date	Time	β (Altitude)	φ_z (Azimuth)	G_{nd}	φ	Ψ	γ	α	cos θ	F_{ws}	F_{wg}	N/A	G_t (btu/hr-ft^2)	SHGC	Window Heat Gain (btu/hr-ft^2)
21-Jun	12:00	79.43	0	269.52	360.00	255.00	105.00	95.63	-0.14	0.45	0.55		24.50	0.278	6.81
21-Jun	13:00	73.16	-55.06	268.15	304.94	255.00	49.94	95.63	0.09	0.45	0.55		86.27	0.278	23.98
21-Jun	14:00	61.78	-75.97	263.72	284.03	255.00	29.03	95.63	0.33	0.45	0.55		142.89	0.278	39.72
21-Jun	15:00	49.49	-87.08	255.07	272.92	255.00	17.92	95.63	0.54	0.45	0.55		187.76	0.278	52.20
21-Jun	16:00	37.06	-95.26	239.34	264.74	255.00	9.74	95.63	0.72	0.45	0.55		213.39	0.278	59.32
21-Jun	17:00	24.79	-102.53	209.27	257.47	255.00	2.47	95.63	0.86	0.45	0.55		208.71	0.278	58.02
21-Jun	18:00	12.85	-109.76	141.60	250.24	255.00	4.76	95.63	0.95	0.45	0.55		148.16	0.278	41.19
													Total btu/ft^2/day		**281.25**

July 21 - Solar Data			
A	B	C	C_N
346.4	0.186	0.138	0.94

SLOPED WALL

Date	Time	β (Altitude)	φ_z (Azimuth)	G_{nd}	φ	Ψ	γ	α	cos θ	F_{ws}	F_{wg}	N/A	G_t (btu/hr-ft²)	SHGC	Window Heat Gain (btu/hr-ft²)
21-Jul	12:00	76.55	0	268.94	360.00	255.00	105.00	95.63	-0.16	0.45	0.55		20.95	0.278	5.82
21-Jul	13:00	71.1	-48.43	267.50	311.57	255.00	56.57	95.63	0.08	0.45	0.55		83.83	0.278	23.30
21-Jul	14:00	60.28	-70.83	262.84	289.17	255.00	34.17	95.63	0.32	0.45	0.55		141.42	0.278	39.31
21-Jul	15:00	48.16	-83.14	253.68	276.86	255.00	21.86	95.63	0.54	0.45	0.55		186.81	0.278	51.93
21-Jul	16:00	35.75	-92.03	236.83	267.97	255.00	12.97	95.63	0.73	0.45	0.55		211.96	0.278	58.92
21-Jul	17:00	23.38	-99.71	203.77	260.29	255.00	5.29	95.63	0.87	0.45	0.55		204.38	0.278	56.82
21-Jul	18:00	11.29	-107.22	125.92	252.78	255.00	2.22	95.63	0.96	0.45	0.55		132.60	0.278	36.86
													Total btu/ft²/day		**272.98**

Aug 21 - Solar Data			
A	B	C	C_N
350.9	0.182	0.134	0.94

SLOPED WALL

Date	Time	β (Altitude)	φ_z (Azimuth)	G_{nd}	φ	Ψ	γ	α	cos θ	F_{ws}	F_{wg}	N/A	G_t (btu/hr-ft²)	SHGC	Window Heat Gain (btu/hr-ft²)
21-Aug	12:00	68.25	0	271.15	360.00	255.00	105.00	95.63	-0.19	0.45	0.55		10.09	0.278	2.80
21-Aug	13:00	64.3	-35.69	269.52	324.31	255.00	69.31	95.63	0.06	0.45	0.55		76.27	0.278	21.20
21-Aug	14:00	55.09	-58.64	264.20	301.36	255.00	46.36	95.63	0.31	0.45	0.55		136.68	0.278	38.00
21-Aug	15:00	43.72	-73.01	253.48	286.99	255.00	31.99	95.63	0.54	0.45	0.55		183.61	0.278	51.04
21-Aug	16:00	31.55	-83.38	232.94	276.62	255.00	21.62	95.63	0.74	0.45	0.55		207.27	0.278	57.62
21-Aug	17:00	19.13	-92.03	189.29	267.97	255.00	12.97	95.63	0.88	0.45	0.55		189.76	0.278	52.75
21-Aug	18:00	6.77	-100.13	70.44	259.87	255.00	4.87	95.63	0.97	0.45	0.55		74.29	0.278	20.65
													Total btu/ft²/day		**244.07**

Appendix I: Vertical Façade Solar Radiation Calculation Tables

May 21 - Solar Data			
A	B	C	C_N
350.6	0.177	0.13	0.94

VERTICAL WALL															
Date	Time	β (Altitude)	φ_z (Azimuth)	G_{nd}	φ	Ψ	γ	α	cos θ	N/A	F_{wg}	G_{dv}/G_{dh}	G_t (btu/hr-ft²)	SHGC	Window Heat Gain (btu/hr-ft²)
21-May	12:00	76.1	0	274.63	360.00	255.00	105.00	90.00	-0.06		0.50	0.52	44.31	0.278	12.32
21-May	13:00	70.78	-47.57	273.23	312.43	255.00	57.43	90.00	0.18		0.50	0.64	112.37	0.278	31.24
21-May	14:00	60.05	-70.14	268.67	289.86	255.00	34.86	90.00	0.41		0.50	0.78	174.66	0.278	48.55
21-May	15:00	47.97	-82.62	259.69	277.38	255.00	22.38	90.00	0.62		0.50	0.94	223.45	0.278	62.12
21-May	16:00	35.57	-91.61	243.10	268.39	255.00	13.39	90.00	0.79		0.50	1.09	249.57	0.278	69.38
21-May	17:00	23.21	-99.37	210.32	260.63	255.00	5.63	90.00	0.91		0.50	1.21	238.83	0.278	66.39
21-May	18:00	11.11	-106.92	131.53	253.08	255.00	1.92	90.00	0.98		0.50	1.28	154.97	0.278	43.08
													Total btu/ft²/day		**333.09**

June 21 - Solar Data			
A	B	C	C_N
346.1	0.185	0.137	0.94

VERTICAL WALL															
Date	Time	β (Altitude)	φ_z (Azimuth)	G_{nd}	φ	Ψ	γ	α	cos θ	N/A	F_{wg}	G_{dv}/G_{dh}	G_t (btu/hr-ft²)	SHGC	Window Heat Gain (btu/hr-ft²)
21-Jun	12:00	79.43	0	269.52	360.00	255.00	105.00	90.00	-0.05		0.50	0.53	49.18	0.278	13.67
21-Jun	13:00	73.16	-55.06	268.15	304.94	255.00	49.94	90.00	0.19		0.50	0.64	114.69	0.278	31.88
21-Jun	14:00	61.78	-75.97	263.72	284.03	255.00	29.03	90.00	0.41		0.50	0.78	174.60	0.278	48.54
21-Jun	15:00	49.49	-87.08	255.07	272.92	255.00	17.92	90.00	0.62		0.50	0.94	221.58	0.278	61.60
21-Jun	16:00	37.06	-95.26	239.34	264.74	255.00	9.74	90.00	0.79		0.50	1.09	247.04	0.278	68.68
21-Jun	17:00	24.79	-102.53	209.27	257.47	255.00	2.47	90.00	0.91		0.50	1.20	238.44	0.278	66.29
21-Jun	18:00	12.85	-109.76	141.60	250.24	255.00	4.76	90.00	0.97		0.50	1.27	167.31	0.278	46.51
													Total btu/ft²/day		**337.17**

July 21 - Solar Data			
A	B	C	C_N
346.4	0.186	0.138	0.94

VERTICAL WALL

Date	Time	β (Altitude)	φ_z (Azimuth)	G_{nd}	φ	Ψ	γ	α	cos θ	N/A	F_{wg}	G_{dv}/G_{dh}	G_t (btu/hr-ft^2)	SHGC	Window Heat Gain (btu/hr-ft^2)
21-Jul	12:00	76.55	0	268.94	360.00	255.00	105.00	90.00	-0.06		0.50	0.52	45.16	0.278	12.55
21-Jul	13:00	71.1	-48.43	267.50	311.57	255.00	56.57	90.00	0.18		0.50	0.64	111.81	0.278	31.08
21-Jul	14:00	60.28	-70.83	262.84	289.17	255.00	34.17	90.00	0.41		0.50	0.78	172.75	0.278	48.02
21-Jul	15:00	48.16	-83.14	253.68	276.86	255.00	21.86	90.00	0.62		0.50	0.94	220.28	0.278	61.24
21-Jul	16:00	35.75	-92.03	236.83	267.97	255.00	12.97	90.00	0.79		0.50	1.09	245.19	0.278	68.16
21-Jul	17:00	23.38	-99.71	203.77	260.29	255.00	5.29	90.00	0.91		0.50	1.21	233.30	0.278	64.86
21-Jul	18:00	11.29	-107.22	125.92	252.78	255.00	2.22	90.00	0.98		0.50	1.28	149.60	0.278	41.59
													Total btu/ft^2/day		**327.51**

Aug 21 - Solar Data			
A	B	C	C_N
350.9	0.182	0.134	0.94

VERTICAL WALL

Date	Time	β (Altitude)	φ_z (Azimuth)	G_{nd}	φ	Ψ	γ	α	cos θ	F_{ws}	F_{wg}	G_{dv}/G_{dh}	G_t (btu/hr-ft^2)	SHGC	Window Heat Gain (btu/hr-ft^2)
21-Aug	12:00	68.25	0	271.15	360.00	255.00	105.00	90.00	-0.10	0.50	0.50	0.51	32.89	0.278	9.14
21-Aug	13:00	64.3	-35.69	269.52	324.31	255.00	69.31	90.00	0.15	0.50	0.50	0.62	102.74	0.278	28.56
21-Aug	14:00	55.09	-58.64	264.20	301.36	255.00	46.36	90.00	0.39	0.50	0.50	0.77	166.38	0.278	46.25
21-Aug	15:00	43.72	-73.01	253.48	286.99	255.00	31.99	90.00	0.61	0.50	0.50	0.94	215.25	0.278	59.84
21-Aug	16:00	31.55	-83.38	232.94	276.62	255.00	21.62	90.00	0.79	0.50	0.50	1.09	238.23	0.278	66.23
21-Aug	17:00	19.13	-92.03	189.29	267.97	255.00	12.97	90.00	0.92	0.50	0.50	1.22	215.15	0.278	59.81
21-Aug	18:00	6.77	-100.13	70.44	259.87	255.00	4.87	90.00	0.99	0.50	0.50	1.29	83.21	0.278	23.13
													Total btu/ft^2/day		**292.97**