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Unum Building Green Roof Study

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A Major Qualifying Project Proposal

Submitted to the Faculty of

Worcester Polytechnic Institute

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

in Civil Engineering

by

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Abstract

This project explores the impact of installing a vegetated green roof on the first office building of the new City Square Development in Worcester, Massachusetts. Potential LEED credits were considered in the design of the green roof, a structural analysis of the roof under the additional load was performed, and a cost benefit analysis was conducted. Building information modeling software was used to aid in the design process including the Revit Design Suite, and ROBOT Structural Analysis.

Capstone Design Statement

The capstone design requirement was met for this project by exploring the impact of installing a vegetated green roof on the first office building of the new City Square Development in Worcester, Massachusetts. Potential LEED credits were considered in the design of the green roof, a structural analysis of the roof under the additional load was performed, and a cost benefit analysis was conducted. Building information modeling software was used to aid in the design process including the Revit Design Suite and ROBOT Structural Analysis.

The alternative design of the roof included a structural analysis to determine if the existing structure could support the additional weight and a cost estimate was provided. In order to comply with the requirements of the ASCE the following realistic constraints were addressed during the completion of this project: economic, manufacturability, environmental, sustainability, health and safety, and ethical.

The first constraint addressed was that of the economic impact of the alternative roof design. A structural analysis was performed to determine if the existing structure could support the additional weight. If a member was found to be inadequate, an adequate member was selected and noted. A cost analysis was then provided for the alternative structure. This was then compared to the life cycle cost of the original design to analyze overall cost of each. The structural analysis proved that only minor modifications needed to be made to the current structure to support the additional weight making our alternative design a viable option.

Manufacturability was the second realistic constraint explored. There are multiple green roof designs and each with its own recommended installation process depending on the manufacturer. Therefore, multiple designs were examined and the optimal choice proved to be a green roof design that would not produce a large effect on the current dead load and was cost effective in obtaining the additional LEED credits to obtain the LEED Gold certification. Our alternative design provides an option for easy installation and maintenance. In addition to our alternative design, we tracked the progression of the structural steel of the project on a weekly basis. This provided us with insight as to how the building was erected step by step and provided valuable information as to whether or not this task was completed ahead, on, or behind schedule.

The environmental constraint was met through the proposed alternative roof design. Introducing a green roof is a positive impact on the environment, improving a buildings stormwater runoff, reduces the urban heat island effect, and reduces the building's energy consumption. Improving stormwater runoff helps reduce the flooding that occurs in the combined sewer systems in Worcester, MA and reduces the amount of pollutants that enter this water. Reducing the heat given off by the building can lower inner city temperatures if used on a city wide scale, but more importantly on this project, it can lower the overall energy cost of Building H.

The next constraint examined was sustainability of the alternative design. The current plans have Building H set to receive a LEED Silver certification, but the alternative design aimed to have Building H receive a LEED Gold certification. Not only was the certification taken into account, but so was the added cost and maintenance. In order to provide a sustainable design, the green roof selected had little economic impact on the overall total cost and the maintenance required would be minimal. This option also extends overall roof life, reducing future costs of replacing the roofing system.

Ethics was the final constraint addressed and during the entirety of the project. Each step from conceptualization to design and analysis involves ethics. Our alternative design provides a roof system that is beneficial to all aspects from owner to inhabitant. We also used the current design methods created by ASCE to ensure our calculations were correct to maintain structural integrity.

Acknowledgements

Our Major Qualifying Project group would like to thank all of the people who assisted in the completion of our project. First, we would like to thank our two advisors: Professor Guillermo Salazar and Professor Edward Swierz who worked alongside us throughout the entire project. Second, we would like to thank Professor Suzanne LePage (WPI) and Judith Nitsch (Nitsch Engineering) for their assistance with information about the East Hall green roof. Lastly, we would like to thank Paul Galligan (Consigli) for providing access to the job-site and for providing us with project documents and information.

Authorship

All team members contributed equally to each aspect for the completion of this project.

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1.0 Introduction

The building sector accounts for nearly 40% of the United States carbon footprint, and serves as a low-cost, high-return investment strategy to reduce energy consumption and associated emissions. McKinsey and Company estimates that the largely untapped potential of increased efficiency could save the country's economy $130 billion per year and reduce emissions by 1.1 gig tons a year (U.S. Green Building Council, 2011). As a result the building sector has seen increasing interest in green building.

For conformity and regulation of green building practices the United States Green Building Council (USGBC) developed Leadership in Energy and Environmental Design (LEED). The LEED certification system is voluntary, consensus-based, market-driven and recognized internationally. It provides a framework for evaluating environmental performance from a whole-building perspective over a building's life cycle.

In Worcester, Massachusetts the old Galleria Mall located in the downtown area is now the site of a new mixed use redevelopment project known as City Square. The first building of the redevelopment, referred to as Building H, is an office building that will be occupied by the Unum Group, which has signed a 17 year lease with CitySquare II Development Co. LLC. This building is currently projected to earn 56 credits and achieve a LEED Silver certification upon completion. With an additional four credits the building could achieve the LEED Gold certification.

Building H qualifies for the sustainable site credit related to development density and community connectivity. A project that earns this credit may use a green roof to meet other sustainable site credit requirements for open space and habitat restoration. Other benefits of green roofs that can earn LEED credits include improved stormwater management, reduced energy costs, and reduced urban heat island effect.

The construction documents for Building H include elements common to commercial buildings such as a thermoplastic roof membrane (TPO). Installation of a green roof rather than the specified TPO roof could improve the design of Building H with respect to the LEED standards. A green roof has a larger gravity load than a TPO roof which may result in additional cost on the structural system of the building. The green roof must also be designed specifically to comply with LEED standards in order to guarantee that it will help to achieve a higher level of LEED certification.

The purpose of this project is to develop an alternative design for the roof of Building H, implementing a green roof. LEED standards are considered in the alternative design of the roof in an attempt to increase the LEED credits earned, and potentially achieve a LEED Gold certification. The increased load on the structural systems of Building H have been analyzed according to the Load and Resistance Factor Design (LRFD) method used for designing steel structures, permitted by the American Institute of Steel Construction (AISC). The LRFD method of analysis was used to remain consistent with the contract documents.

Structural members were reviewed for performance in strength and serviceability, and when a member was found to be inadequate, a suitable replacement was determined. For the beams and girders a set of hand calculations for each of the different load cases was developed using the previously determined design loads. After the hand calculations were verified, they were used as a model to develop and an analysis spreadsheet. RISA-2D Educational, a computer software program, was utilized to help determine design moments when the load cases and placements were not uniform. With the analysis spreadsheet and RISA-2D all the beams and girders were checked for adequacy.

Columns that spanned from the sixth floor to the roof were also evaluated for strength and serviceability under the additional dead load of the green roof. Hand calculations were provided for different load cases and were also verified. Then, like the beams and girders, an analysis spreadsheet was developed and used to check each column for adequacy.

As a part of the structural analysis, Building Information Modeling (BIM) software from Autodesk including Revit to Robot Structural Analysis was used to aid in the development of the alternative design. BIM technology is a recent development in the design and construction industry which can improve the ability of a project team to share information and achieve project goals. First, an accurate 3D model of the building was created using Revit Structure and was used to export information to the Robot Structural Analysis program. Once in Robot, the roof was designed for the increased loads that would be experienced through the installation of the green roof system. Similar to the hand calculations, this method also provided a list of members that would be inadequate, if any were found.

After the completion of the structural analysis, a cost analysis was performed. This was used to determine the installation cost of the green roof, the maintenance cost of the green roof, and the increase or decrease in costs due to different members chosen via the structural analysis. All this together provided the life cycle cost analysis of the green roof. However, the energy savings were not taken into account due to the insulation provided by the green roof, therefore there would be room for greater savings.

Upon completion of our calculations, it was determined that in the alternative roof design a new decking system was required for proper installation of the green roof. This required minor alteration to the proposed existing structure two columns were redesigned for proper strength and serviceability requirements. In addition to the structural analysis, it was determined that the actual construction progress vs. the proposed construction schedule was behind schedule. However, this was determined to have been caused due to high wind speeds that delayed project progress. Finally, upon the completion of our cost analysis, the alternative design that was provided would be a better long term economic option.

2.0 Background

Mixed-use development projects are large, complicated and involve multiple structures with various uses. It is important for project engineers to become familiar with all aspects of the project in order to design and deliver a successful project. This chapter contains the research conducted to define the scope of this project, including information on the City Square project.

2.1 City Square

On July 29th, 1971 the Worcester Center Galleria, located in downtown Worcester, Massachusetts, opened for business. The mall included 1,000,000 square feet of floor space with a 4,300-car parking structure, the largest parking structure in the world at that time (Caldor, 2006). Figure 1 shows the layout of the mall, parking garage and two adjacent office buildings.

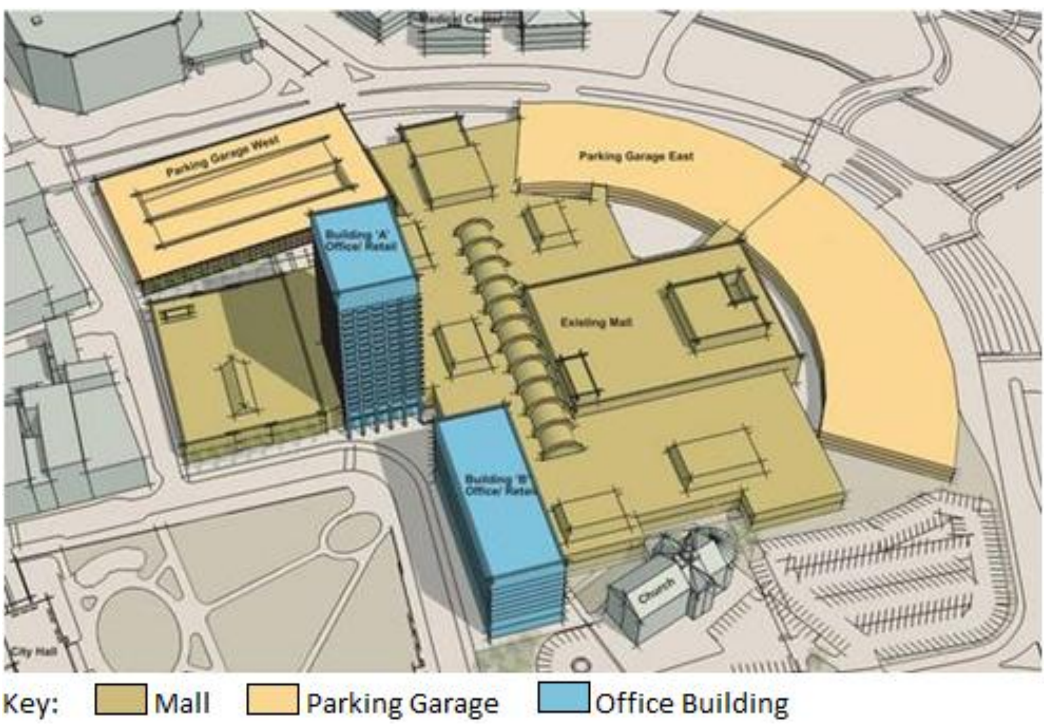

Figure 1 - Mall Site Plan (Caldor, 2006)

Since opening for business increasing local competition caused the Worcester Center Galleria to struggle. The dying mall was remarketed in the mid-1990s as the Worcester Common Fashion Outlets. In 1994 Judith Light became Worcester Common Fashion Outlet's spokeswoman, and in 1996 the name was shortened to Worcester Common Outlets (Caldor, 2006). In 1997 Wrentham Village Premium Outlets opened nearby and Worcester Common Outlets continued to lose its customer base. Finally in 2004 Berkeley Investments of Boston announced that it would purchase Worcester Common Outlets to redevelop the land, and by 2006 the mall was closed (Caldor, 2006).

Berkeley Investments' redevelopment plan for the 20.2 acre property consisted of a pedestrian friendly, mixed use development called City Square. The vision of City Square was to restore and reconnect the portion of Worcester's downtown that was occupied by the failed mall. Figure 2 illustrates the design of City Square including three new roads to connect City Square with downtown. "With an estimated project cost of $563 million, City Square is the largest public/private development project in Massachusetts history outside of the City of Boston." (City of Worcester, 2011)

Figure 2 - City Square Site Plan (Caldor, 2006)

The $94 million in public funds are provided by various State Grants and District Improvement Financing (DIF) bonds. These funds are for the demolition of the existing mall, and the construction of the proposed roads (O'Brien, 2011). In accordance with the General Development Agreement (GDA) between Berkeley and the City of Worcester, Berkeley was required to secure a tenant for at least one of the buildings designated as a trigger building before the public funds would be made accessible. Even with Unum Group, a disability and life insurance company looking for a new location in Worcester, signing a letter of intent in 2009 to occupy one of the trigger buildings little work was performed by Berkeley, due in part to a poor economic climate (Kotsopoulos, 2010).

In March of 2010 CitySquare II Development Co. LLC, a subsidiary of Opus Investments of the Hanover Insurance Group, signed a purchase and sale agreement to acquire the developable parcels of City Square from Berkeley Investments (Kotsopoulos, 2010). Hanover is an insurance company that is based in Worcester. Figure 3 illustrates an approximate property line with the areas to be demolished highlighted in blue. While Hanover acquired the property below the line, Berkeley retained ownership of Mechanics Tower, the Flagship Bank building, a portion of the parking garage and a small portion of the developable land above the line.

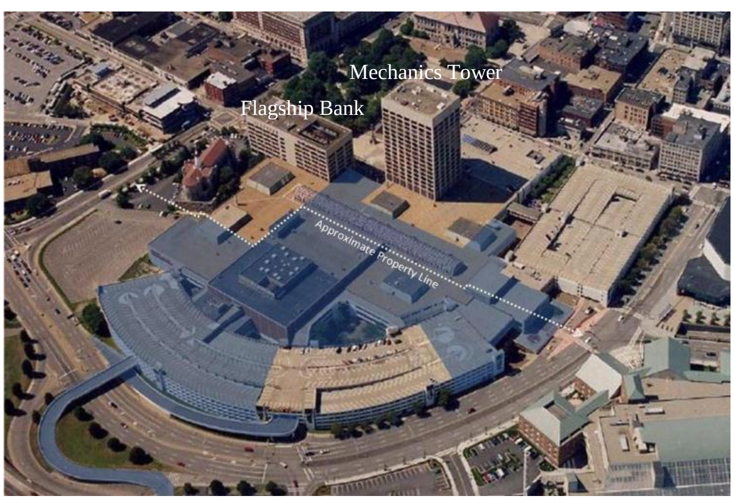

Figure 3 - Approximate Property Line (City Square Phase 1 Plans, 2010)

2.2 Building H

On May 27th, 2010 Unum Group signed a 17 year lease with CitySquare II Development Co. LLC to occupy one of the trigger buildings designated Building H (Eckelbecker, 2010). According to the GDA the lease of a major tenant made approximately $35 million in public funds available for phase one of City Square. The public funding in phase one was designated for use in demolishing the old mall and constructing Mercantile Street. Figure 4 is the site plan for the first phase of City Square, and shows the locations of Building H and Mercantile Street, along with areas of the mall to be demolished.

The lot for Building H is listed with Worcester's Assessing Division as One Mercantile Place, and having a total area of 40,573 square feet. The building permit for Building H on file with Worcester's Department of Inspectional Services is for a structure with a building footprint of 28,000 square feet, and a total developable floor area of 215,000 square feet. The Building H plans consist of a ground floor with retail space, six floors of office space, and a penthouse on the roof level for mechanical equipment.

Figure 4 - Phase One Site Plan (City Square Phase 1 Plans, 2010)

2.2.1 Organizational Breakdown Structure (OBS)

The Hanover Insurance Group, Inc. is the principal investor for the private portion of City Square including Building H. Hanover created the business entity CitySquare II Development Co. LLC to act as the owner of the private portion of City Square, and they are involved with leasing space to tenants such as Unum Group. Leggat McCall Properties LLC (LMP) is the manager of the development of City Square, and has contracted a designer and a construction manager for the Building H project. The Organizational Breakdown Structure (OBS) of the Building H project is illustrated in Figure 5.

Building H is being delivered under a traditional Design-Bid-Build (D/B/B) contract involving LMP as owner, Arrowstreet as designer, and Consigli as construction manager (CM). In a D/B/B contract the designer produces a complete set of construction documents before the CM is allowed to bid on the project. This type of contract is used to minimize cost at the expense of increasing project duration. Consigli's contract with LMP is CM at risk which is characterized by the CM agreeing to deliver the project under a cost reimbursable contract with a guaranteed maximum price (GMP). In a private project such as Building H the owner is not required to publish financial data, and no specific information on the contract amount for the construction of Building H has been made available.

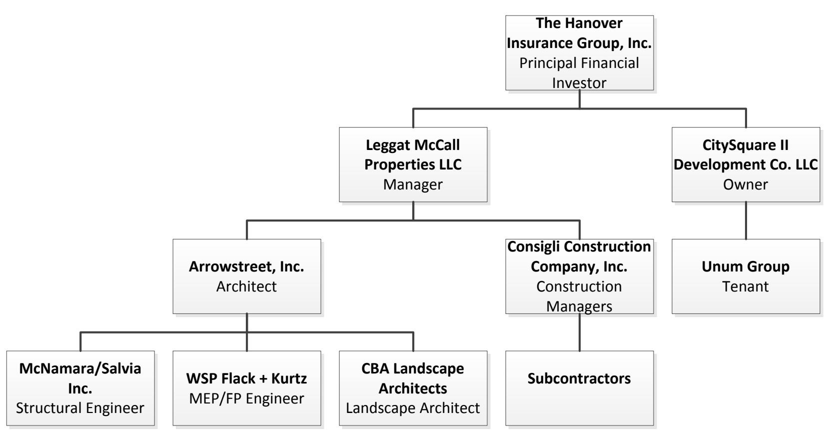

Figure 5 - OBS of Building H

2.2.2 Local Zoning Ordinance

The design of Building H must conform to the Zoning Ordinance of the City of Worcester. Building H is located in a Business District designated BG-6.0. This zone limits the floor to area ratio (FAR) to six. The FAR is defined as the ratio of total gross floor area (GFA) of buildings on a lot to the total area of the lot. An additional floor space premium is awarded in BG-6.0 for off street parking that is provided on site, or within 1000 feet of the facility to be served, at a rate of 600 square feet per parking space provided. With a FAR of 5.3 the plans for Building H comply with the BG-6.0 FAR restriction without considering its applicable parking bonus to floor area. The other dimensional control of the BG-6.0 zone is that buildings are required to have a minimum rear yard setback of ten feet.

Building H is also located within a Mixed Use Overlay District, which provides supplementary regulations in addition to the BG-6.0 regulations. This includes another dimensional control that space devoted to recreation and open space shall be equal to or greater than five percent of the GFA devoted to other uses, with at least half of the space is to be built as part of the proposed structures. The open space may be built or natural, but must be free and accessible to the public. The required open space for Building H is 10,750 square feet, with at least 5,375 square feet to be included as part of the Building H lot.

2.2.3 Design Concept

The design for Building H is a seven story structure with an additional penthouse level. Below grade is a reinforced concrete foundation consisting of continuous footings supporting the perimeter of the building and spread footings and grade beams supporting the core of the building. Above grade is a steel frame with composite metal floor decking. The building envelope consists of a curtain wall of glazed windows, stainless steel and architectural precast concrete. Figure 6 is an architectural rendering of Building H with Mercantile Street to the right as they are to be built.

Figure 6 – Rendering of Building H (Eckelbecker, 2010)

The roof of Building H is composed of metal decking, fire rated gypsum board, rigid extruded polystyrene insulation and TPO waterproofing membrane. Some of the mechanical equipment which is commonly mounted on the roof of an office building is contained within the penthouse level. The heights of the columns in the penthouse framing have been varied to achieve proper drainage while the rest of the roof has the rigid insulation tapered to drain. Figure 7 is an architectural roof plan of Building H from the contract documents. With large flat portions of roof it is possible that Building H could accommodate the installation of a green roof, which would complement the goal of Building H being a certified LEED Silver structure.

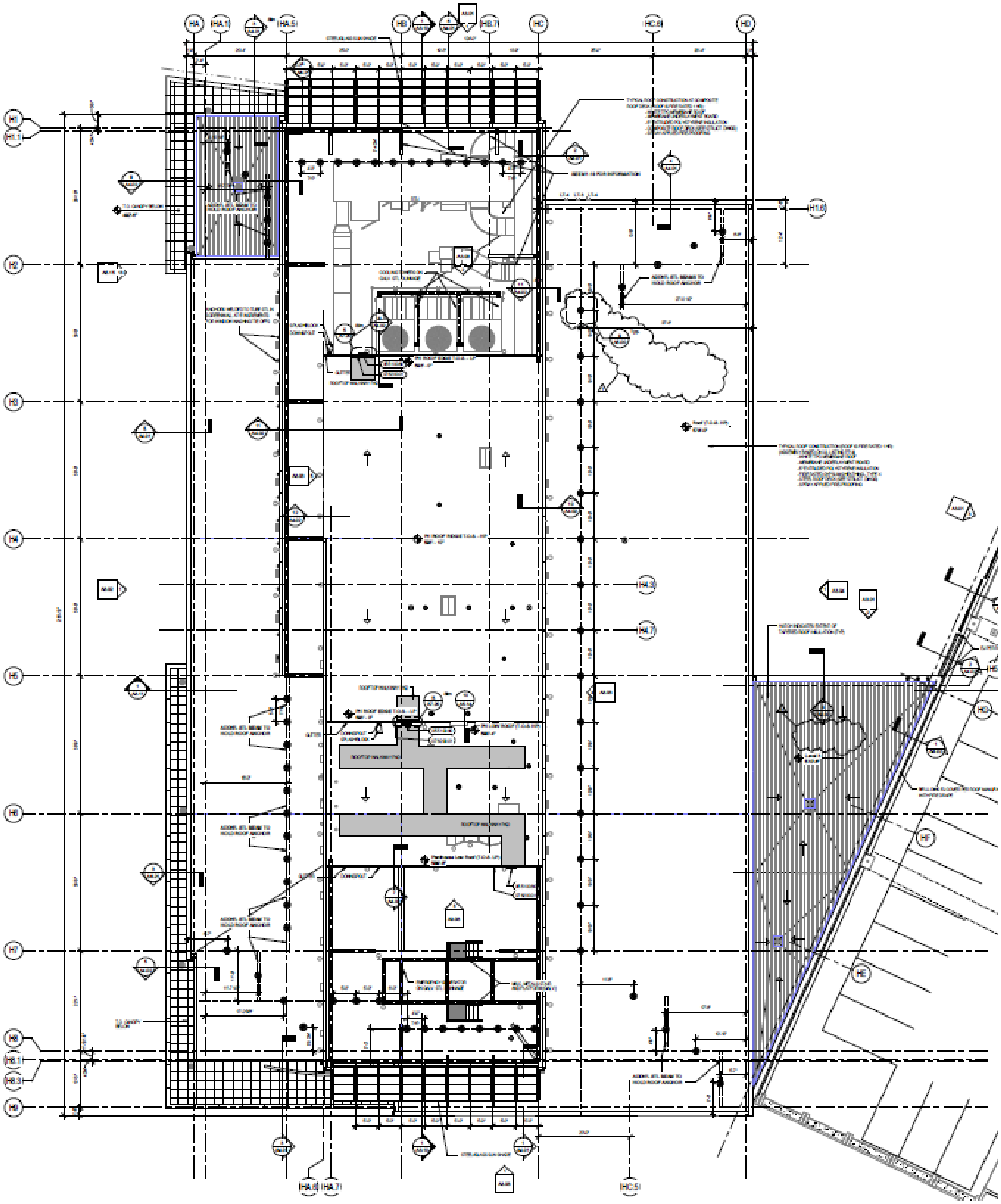

Figure 7 - Roof Plan of Building H

2.3 Green Roofs

Green roofs are systems in which the roof of a structure is fitted with a waterproof membrane, a growing medium and vegetation. In the past few years green roofs have adopted ecological and social significance that has been incorporated within the construction industry. Green roofs serve as a purpose to reduce pollution and urban heat island effects, mitigation of stormwater runoff, and maximize utilization of urban land (Weiler and Scholz-Barth, 2009). The roof can be completely or partially covered in vegetation, and can be "extensive" or "intensive".

2.3.1 Extensive Green Roof

An extensive green roof is characterized by a shallow depth of three to six inches and does not have irrigation (Apex Green Roofs, 2011). A typical extensive green roof is detailed in Figure 8, and when fully saturated an extensive green roof can weigh anywhere from 14 to 42 pounds per square foot (Weiler and Scholz-Barth, 2009). In addition to a lightweight and low maintenance advantage, the cost of an extensive green roof can be $10 per square foot (Snodgrass, 2009). An extensive green roof can be employed in lieu of a ballast roof with minimal structural impact to the roof deck or framing (Weiler and Scholz-Barth, 2009).

Figure 8 - Extensive Roof Section (Miller, 2011)

2.3.2 Intensive Green Roof

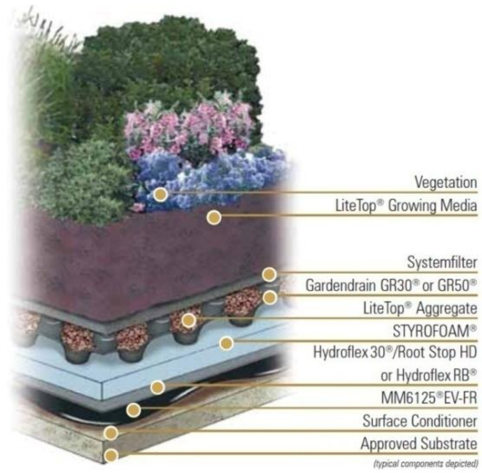

Figure 9 - Intensive Roof Section (Gray, 2010)

A typical intensive green roof system shown in Figure 9 is similar to the extensive green roof show in Figure 8. The difference is that an intensive green roof is over twelve inches in depth, providing the most design options for plant palette and biodiversity (Apex Green Roofs, 2011). As a result the maintenance costs and design loads for intensive green roof systems will be greater. For example the dead load of a grass landscape with six inches of a stone and one foot of soil is approximately 180psf. An additional foot of soil to support shrub planting increases the design load to approximately 300psf (Weiler and Scholz-Barth, 2009). The additional dead load can have a significant impact on the roof deck and framing.

2.3.3 Reduce Urban Heat Island Effect

The Urban Heat Island (UHI) effect is the rise in temperature of any man-made area, compared to the lower temperature of nearby natural landscape. In a dense urban center, such as Worcester, MA, green space has been replaced with buildings and roads. The construction materials used in these urban centers absorb the sun’s energy, and radiate heat energy into the surrounding area (Monument Info Search Ltd, 2008). Figure 10 displays the heat differential between an urban center and the surrounding rural areas.

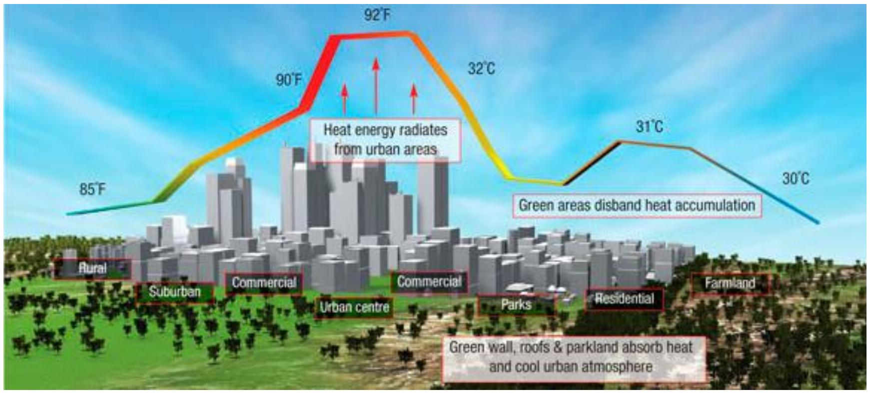

Figure 10 - Urban Heat Island Effect (Monument Info Search Ltd, 2008)

This increase in temperature leads to an increase in energy consumption for cooling, a decrease in air quality, and an increase in heat related illness and fatalities. Although the UHI can reduce energy consumption for heating in the winter, researchers consent that this benefit is outweighed by the detrimental effects that occur in summertime (Monument Info Search Ltd, 2008). Summertime data from research conducted at the University of Central Florida in Cocoa, FL shown in Figure 11 indicates that the maximum average temperature reached by a conventional roof membrane was 130 F, while the maximum average temperature reached by a green roof was 91 F (Sonne, 2006). This is a 30% reduction in the average temperature.

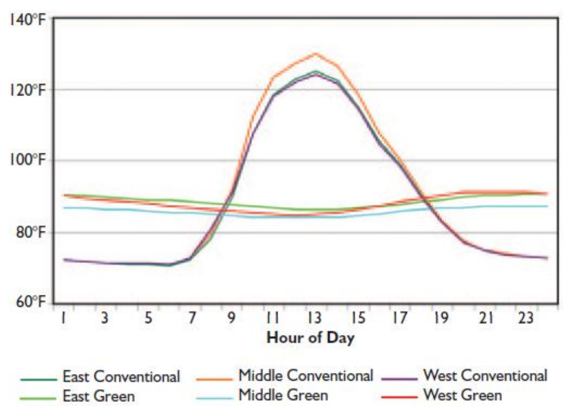

Figure 11 - Comparison of Average Roof Surface Temperatures (Sonne, 2006)

2.3.4 Stormwater Runoff Management

Green roofs are being used in urban environments to improve stormwater management by reducing total quantities of rooftop runoff and peak flow rates during intense storms (Johnson, 2008). A typical roofing system will retain about 10% of storm water runoff, while a green roof can reduce the runoff volume by 50%-90% and peak storm water runoff by 75%-90% (Apex Green Roofs, 2011). This reduction in runoff results in an average of about 50% - 75% total water retention from rainfall over a typical year (Johnson, 2008). A study performed in Portland, OR monitored two buildings with green roofs, each with different soil, to determine the stormwater management effectiveness (Bureau of Environmental Services, 2006). The results of this study are summarized in Table 1.

Table 1- Stormwater Runoff Reduction (Bureau of Environmental Services, 2006)

Facility	Monitoring Period	Size (sq ft)	Peak Flow Reduction	Volume Retention			
				Annual	Summer	Winter	CSO[1]
Hamilton Apts, West Side (Hamilton West)	4 years Jan 2002 – Dec 2005	3,655	97%	56%	86%	47%	61%
Hamilton Apts, East Side (Hamilton East)		3,811	95%	27%	67%	14%	N/A[2]
Multnomah County Green Roof	1½ years Jul 2004 – Dec 2005	7,000	86%	3%	-18%[3]	19%	11%

[1] For storms most similar to the Combined Sewer Overflow (CSO) Design Storms.
[2] Event data from the east side of Hamilton showed an exceptional amount of scatter. Some events were retained well (up to 66%) while others showed negative retention (down to –10%). This is likely the result of drainage issues that result in unintended runon from the conventional penthouse roof.
[3] Negative value is the result of daily irrigation runoff from July through September.

During rainfalls, excess water runs into the city's sewer system because of the impervious surfaces of construction. The runoff entering the sewer contains contaminants and can lead to flooding. Worcester uses a combined sewer system like the one shown in Figure 12, and during an overflow event will discharge a combination of stormwater runoff and waste water.

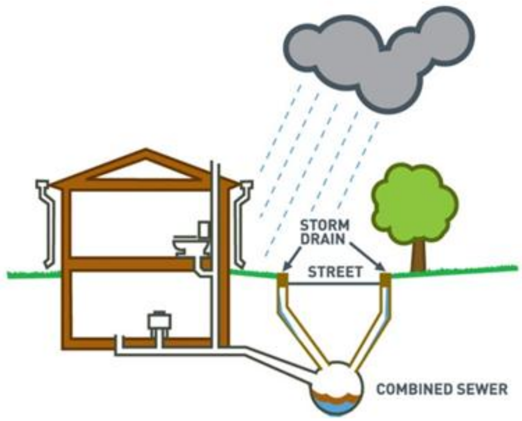

Figure 12 - Combined Sewer System (Keating, 2011)d

The installation of a green roof can mitigate these problems by absorbing a large amount of the water within the roots of the plants and releasing the rest back into the atmosphere via evapotranspiration (Apex Green Roofs, 2011). In effect, over half the annual rainfall on a typical green roof stays on the roof until it is evaporated back into the air (Johnson, 2008). Thus, this amount of water will never reach the combined sewer system. The reduction in flow rates from storms that green roofs provide can delay runoff that helps moderate combined sewer overflow events (Bureau of Environmental Services, 2005).

2.3.5 Reduced Energy Costs

The installation of a green roof provides an added layer of insulation to the roof of the structure. According to a study in Toronto, a green roof application can reduce the heat flow by 70%-90% during the summertime when compared to a conventional roof on the same building (Sonne, 2006). Also the efficiency of rooftop air conditioning units increases as ambient temperatures decrease due to the reduction in the UHI previously discussed.

For example, there are two identical buildings, one with a green roof and one with a conventional roofing membrane. Both are equipped with air conditioning units with efficiency ratings of 10 Btu/h per Watt and the total area of each roof is 3,300 square feet. During the summertime, the building with the conventional roofing membrane will reach much higher average temperatures, as discussed previously. Now, we will assume that all heat gain through the roof must be removed by the respective AC (air conditioning) systems. When both roofs are compared, the average energy use to remove the additional heat gain from the conventional roof is approximately 700 Watt-hours per day (Sonne, 2006).

2.3.6 Extended Roof Life

Another positive benefit of a green roof is that it can extend the service life by up to 2-3 times that of a typical roof system (Apex Green Roofs, 2011). In effect, the roofscaping covers and protects the waterproofing and structural components of a roof and typically, green roofs last twice as long as conventional roofs (Bureau of Environmental Services, 2005). In general, conventional roofs are exposed to ultraviolet (UV) radiation and human traffic/debris which will damage the existing waterproofing membrane. Eventually, the membrane will need to be replaced or repaired to prevent structural damage and defects. A green roof can extend the life of this membrane, so that in the long-term, higher construction costs are offset by lower repair and replacement costs (Bureau of Environmental Services, 2005).

2.4 LEED

The LEED Green Building Rating Systems are voluntary, consensus-based, and market-driven method for evaluating environmental performance from a whole-building perspective over a building's life cycle (U.S. Green Building Council., 2009). This is achieved using a weighted credit system with 100 base points with the possibility of 10 bonus points. Projects that earn 40-49 points are LEED Certified, 50-59 points LEED Silver, 60-79 points LEED Gold, and 80 points or above LEED Platinum.

LEED for Core & Shell is the appropriate rating system to evaluate the construction of Building H. Core & Shell was created for the speculative development market, in which the developer controls the design and construction of the core and shell base building, but has no control over the design and construction of the tenant fit-out (U.S. Green Building Council., 2009). The preliminary checklist is included in Appendix A, and Table 2 summarizes the results.

Table 2 - Summary of Preliminary LEED Checklist

Category	Possible Points	Expected Points		
		Yes	Maybe	No
Sustainable Sites	28	24	2	2
Water Efficiency	10	7	2	1
Energy & Atmosphere	37	2	35	
Materials & Resources	13	6	1	6
Indoor Environmental Quality	12	8	3	1
Subtotal	100	47	43	10
Bonus Categories				
Innovation & Design	6	6		
Regional Priority Credits	4	3	1	
Total	110	56	44	10

Table 3 is a summary of all of the credits that may be affected by including a green roof as part of the design of Building H. The most potential for gaining points is to evaluate the optimize energy performance credit. A green roof can contribute to energy performance by increasing the insulation of the roof, and reducing the load on air conditioning equipment by mitigating the UHI effect. The inclusion of a green roof should not sacrifice any credits that are already anticipated. Care must be taken to maintain water efficient landscaping and the use of regional and recycled materials.

Table 3 - LEED Credits Related to Green Roofs

Credit	Description	Yes	Maybe	No
	Sustainable Sites			
Credit 5.1	**Site Development,** Protect or Restore Habitat			1
Credit 5.2	**Site Development,** Maximize Open Space		1	
Credit 6.1	**Stormwater Design,** Quantity Control	1		
Credit 6.2	**Stormwater Design,** Quality Control			1
Credit 7.2	**Heat Island Effect,** Roof	1		
	Water Efficiency			
Credit 1.1	**Water Efficient Landscaping,** Reduce by 50%	2		
Credit 1.2	**Water Efficient Landscaping,** No Potable Use or No Irrigation	2		
	Energy & Atmosphere			
Credit 1	**Optimize Energy Performance**		21	
	Materials & Resources			
Credit 4.1	**Recycled Content,** 10% (post-consumer + 1/2 pre-consumer)	1		
Credit 4.2	**Recycled Content,** 20% (post-consumer + 1/2 pre-consumer)	1		
Credit 5.1	**Regional Materials,** 10% Extracted, Processed & Manufactured Regionally	1		
Credit 5.2	**Regional Materials,** 20% Extracted, Processed & Manufactured Regionally		1	
	Totals	9	23	2

2.5 Building Information Modeling (BIM)

BIM is a method of digital modeling that is based on the use parametric objects instead of the traditional line based drafting software. For example, instead of using a group of lines to represent a W22x44 beam the drafter would place an object that has all of the physical properties of a W22x44 beam in the model. As a result a properly constructed BIM model contains more information, and can serve as a reliable basis for decision-making without needing to search for the required information. From a model the user can quickly develop sheets with plan, section or elevation views, schedules, quantity takeoffs, structural analysis, energy analysis, and much more information.

The model can be shared with others involved in the design and construction process as a way to share information, and different software packages have been developed for different disciplines. The ability of software to import, modify, and analyze a model built in another software, or interoperability, is varied. This is an important issue to consider when working with multiple programs. The programs used in this report are all developed by Autodesk in an effort to minimize interoperability issues.

2.5.1 Autodesk Revit

The Autodesk Revit design suite consists of three different programs developed for three of the major disciplines in the design industry; Revit Architecture, Revit Structure and Revit MEP (Mechanical, Electrical and Plumbing). Revit Architecture can be used by the Architect to generate a 3D object-oriented parametric model of the building. This model can then be shared with structural and MEP design consultants, allowing them to add information related to the structural and MEP systems in the building. From this 3D model a set of consistent and fully coordinated 2D plans can be quickly developed.

A complete model can also be used to coordinate a collaborative design and construction effort. Once shared with a project manager or contractor information such as quantities can be extracted from the model to aid in the development of a project schedule and cost estimate. Schedule and cost information can then be added to the objects within the model to produce a 5D model. A 5D model can be used to demonstrate the construction schedule to the owner at the beginning of a project, or used to track construction progress during a project. Additional information on managing a Revit model across multiple programs to coordinate collaborative design and construction management efforts is provided in Appendix C.

2.5.2 Robot Structural Analysis

Robot Structural Analysis is a structural analysis program that was acquired by Autodesk and shaped to complement Revit Structure for a smoother workflow. The Revit Structure Extension is required to save a Revit model in a file format that Robot can read. Without this extension the designer would have to define an analytical model in Robot, making the extension critical to the interoperability between Revit and Robot. Using the extension to export Revit models to Robot results in reduced time to create multiple models for analysis, and removes the need to manually coordinate between the analysis and design models. When one model is created, the corresponding model is also created for coordination purposes but can be independently manipulated and edited (Johnson, 2010).

The models can also retain their correspondence to one another. Having the Revit and Robot models created together allows for the analysis to take into account minor details converting between models, such as whether a representation of a beam is the centerline versus the top of the beam. This can save time for CAD technicians, or possibly involve the structural engineer directly in the development of the model.

Another advantage to using Robot in conjunction with Revit includes the ability send only portions of a Revit model to Robot and vice versa so that they can be worked separately and then recombined. Autodesk suggests using this ability to do separate analysis and design models for gravity and lateral systems, steel and concrete systems, evaluations for specific elements, and phased construction options (Johnson, 2010).

2.5.3 Ecotect

Ecotect Analysis was also acquired by Autodesk to compliment Revit Architecture, and similar to Robot it requires the Revit Architecture Extension. Ecotect is targeted at the early stages of design where simple decisions can have a lasting impact on the final performance of the structure. Using information from the Architectural model such as building geometry, room designations and material properties Ecotect can evaluate day lighting, thermal performance and utility consumption.

Figure 13 is an example of the results produced by a thermal analysis in Ecotect. The temperatures within the room are displayed graphically, with yellow areas being the hottest and purple areas being the coolest. This analysis can be performed multiple times during the design phase to track the impact of design decisions on the buildings mechanical systems. Ecotect can report this information as calculated potential carbon emissions including the on-site fuel consumption and power plant emissions (Autodesk, 2010).

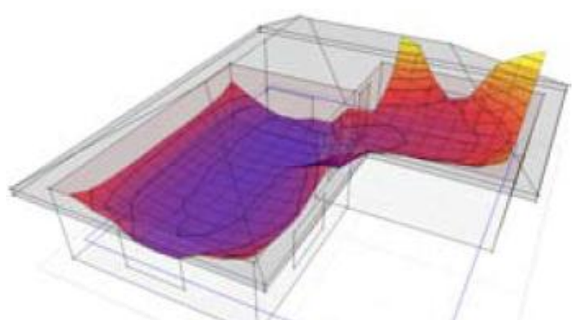

Figure 13 - Example of Thermal Analysis in Ecotect (Autodesk, 2010)

3.0 Tracking Construction

Tracking the erection of the structural steel frame of Building H was the first task. After completing the structural analysis with the additional load of a green roof members of the frame might be inadequate. By developing a full understanding of the erection process the impact of changes to the structural steel frame on the construction schedule could be easily determined.

Consigli had provided information regarding the structural steel erection task for Building H. The task began on October 17th, 2011 with a planned duration of ten weeks. The task only involved the erection of the structural steel, and did not include the complete assembly of all connections or metal decking. While these two items are an important part of the erection process and were being assembled alongside the frame, they were not to be completed until a later date that was not provided.

The first work package was to observe construction progress and site conditions. Site pictures were taken once a week. Pictures were typically taken on Sunday, with some taken on Saturday or Monday as needed. Every week a photo capturing the entire building was taken from approximately the same view, and more detailed photos as needed. Weather information was collected using weathersource.com.

The second work package was to create a structural model of the building using Revit Structure. Phases were created within the model to reflect the weekly progress observed in the site photos. The phased model was used to produce a quantity takeoff of the structural steel.

The third work package was to create a ten week schedule for the erection of structural steel. A total tonnage of steel from the Revit structure quantity takeoff was divided evenly amongst ten weeks. The actual tonnage of steel erected per week, also obtained from the Revit structure model, was compared to the average progress required to meet the 10 week schedule.

3.1 Site Observations

The weekly steel erection progress was observed from the portion of the parking garage that is owned by Berkley Investments. Figure 14 shows the construction site on October 23, 2011; one week after the erection of structural steel began. Similar pictures through the completion of the task on January 4, 2012 are included in Appendix C.1.

Figure 14 - Week 1 Progress Picture

Weather information was gathered using weathersource.com which records weather data at the Worcester Regional Airport. Extreme temperatures or precipitation can negatively impact a construction schedule, and the tower crane used in the erection process cannot operate in high winds, generally 45mph or greater.

From Figure 15 it can be determined that the temperature was reasonable if not a little warmer than average with daily highs almost reaching 60 degrees Fahrenheit as late as

December. Along with high temperatures there were few snowfalls, and they were generally insignificant. The on major snowfall event began late on Saturday October 29th and can be seen in Figure 16. In preparation for the event the contractor accelerated work by working that Saturday.

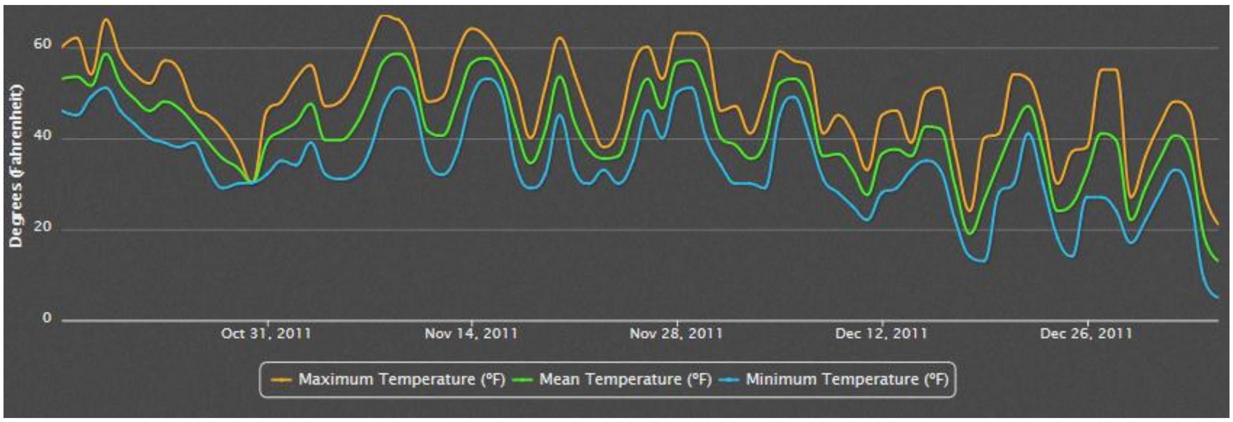

Figure 15 - Daily Temperatures

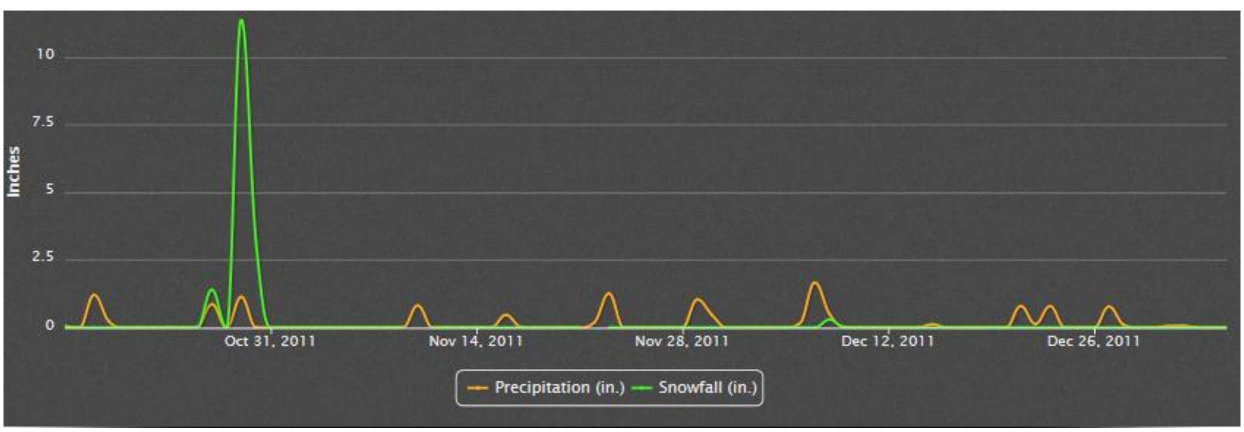

Figure 16 - Daily Precipitation and Snowfall

The only weather that may have been sever enough to seriously impact the construction schedule. Figure 17 shows that in December on multiple days the maximum wind speed for the day was greater than 40 mph. Wind speeds that high could have potentially caused the tower crane to be inoperable.

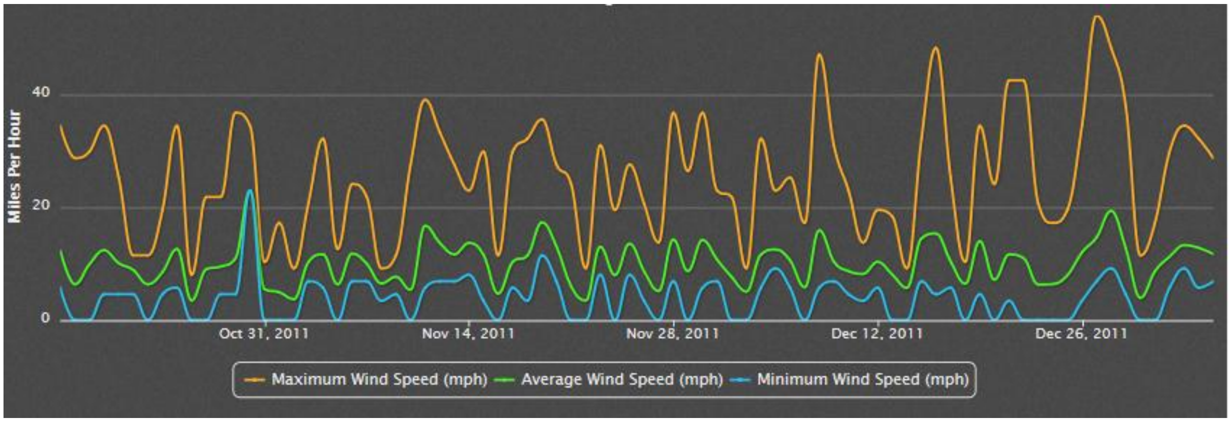

Figure 17 - Daily Wind Speeds

3.2 Revit Structure Model

The structural model of Building H was developed in the same sequence as the structural frame was constructed. First the reinforced concrete foundations were modeled, followed by slabs on grade. Then the steel frame and composite floors were modeled beginning with the first floor and continuing up to the roof. During the modeling process there were some difficulties accurately modeling the structural frame, and they are documented in this section.

The first issue encountered was the lack of some information in the Building H Contract Documents. The limit of work line for Building H is detailed in Figure 18, a portion of the City Square Phase 1 site plan provided in the Building H Contract Documents. The limit of work line traces the perimeter of the building and courtyard. As a result most of the finish grading information is included in the City Square Sitework Phase 1 Construction Documents which have not been made available. Some of the elevations of the foundation walls in the Building H Contract Documents are dependent on the finish grading, and some assumptions were made.

The foundations of Building H also marry up against existing foundations along the East Garage and the truck tunnel shown in Figure 18, and work on these existing foundations are under a separate contract. As a result some of the dimensions needed are included in the demolition and enabling drawings or the east garage drawings, both of which have not been made available. Again some dimensions were assumed, and foundation work that was under a separate contract was assigned to its own phase in the model.

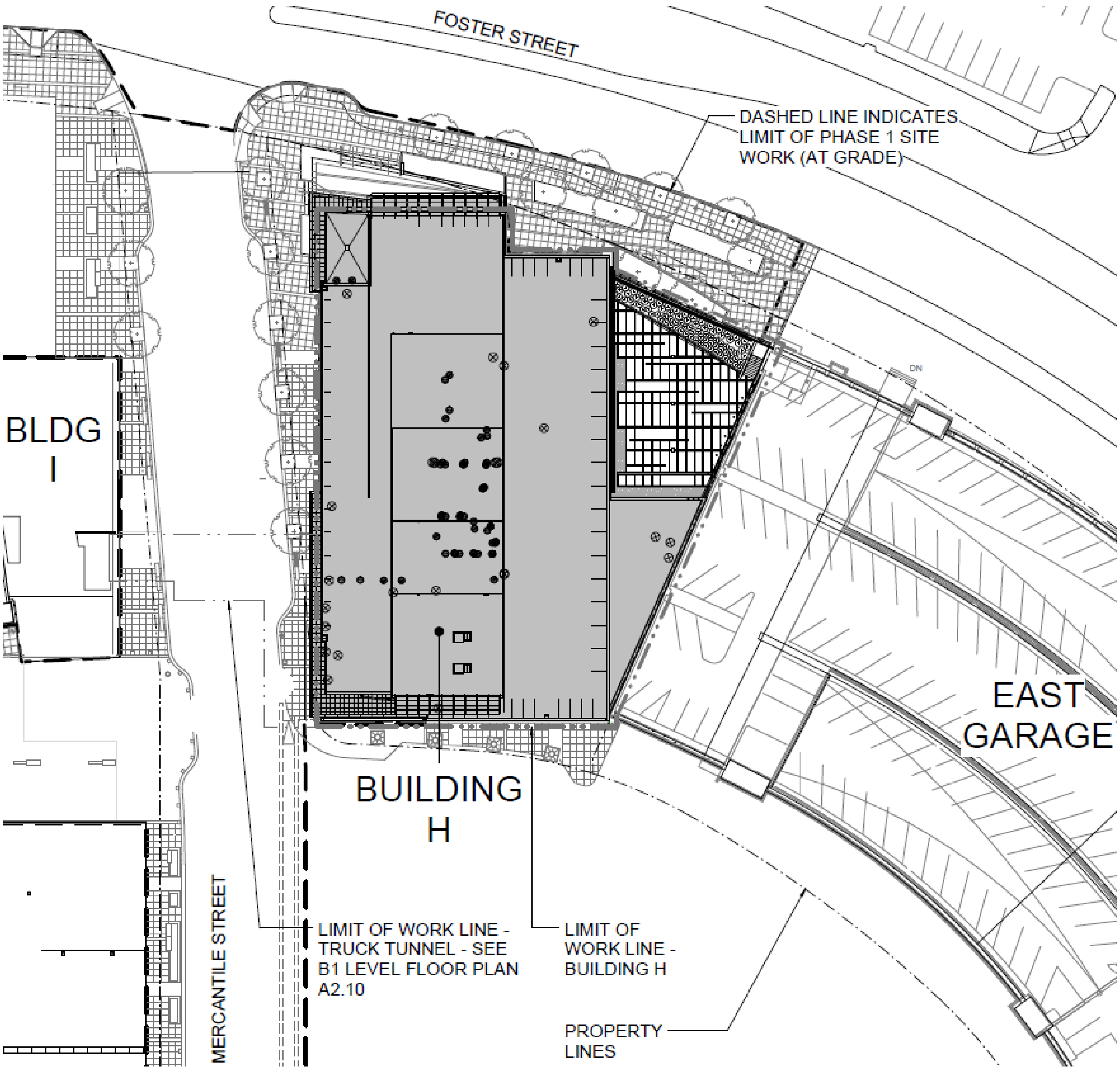

Figure 18 - Site Plan Phase 1

The grade beams shown in Figure 19 are located at the core of the building, and support the lateral frame. They slope to a lower elevation at the center to accommodate the bottom of the elevators pits. Revit Structure does not have a default family for a sloped footing, and they would have needed to be created as a custom family. A quick solution was to model the portions highlighted blue in Figure 19 as ramps with their material defined as concrete.

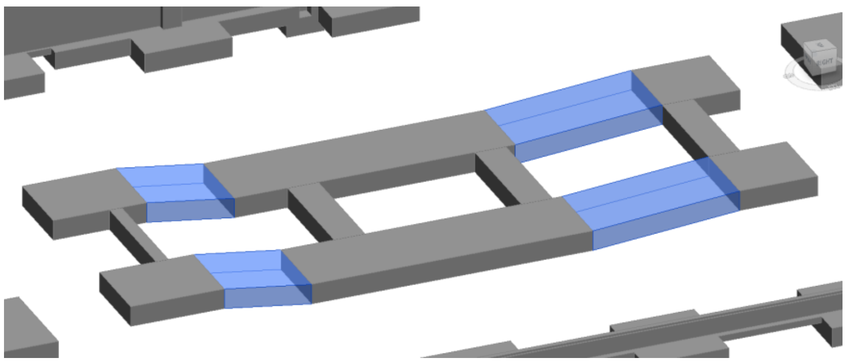

Figure 19 - Grade Beams

There were similar problems with modeling the continuous stepped wall footings shown in Figure 20 as there was no default family. To model this footing accurately would require a complex custom family. The technique that the default continuous footing family supports for creating stepped footings uses the property "default end extension length" and is demonstrated in Figure 21.

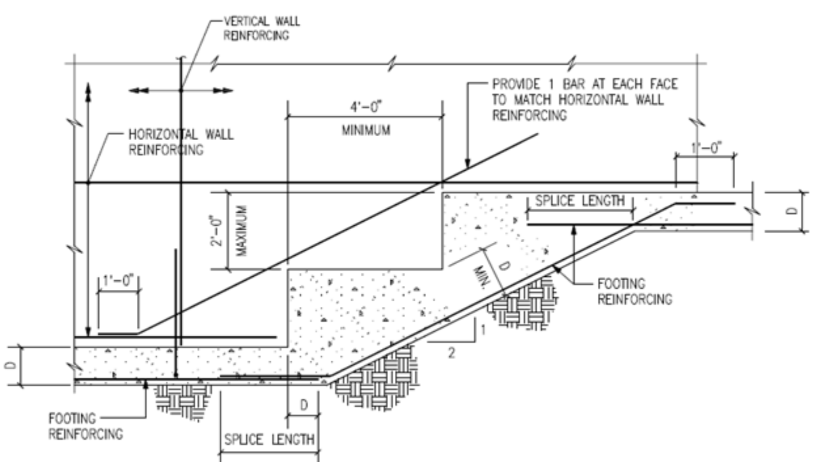

Figure 20 - Typical Detail at Continuous Stepped Wall Footing

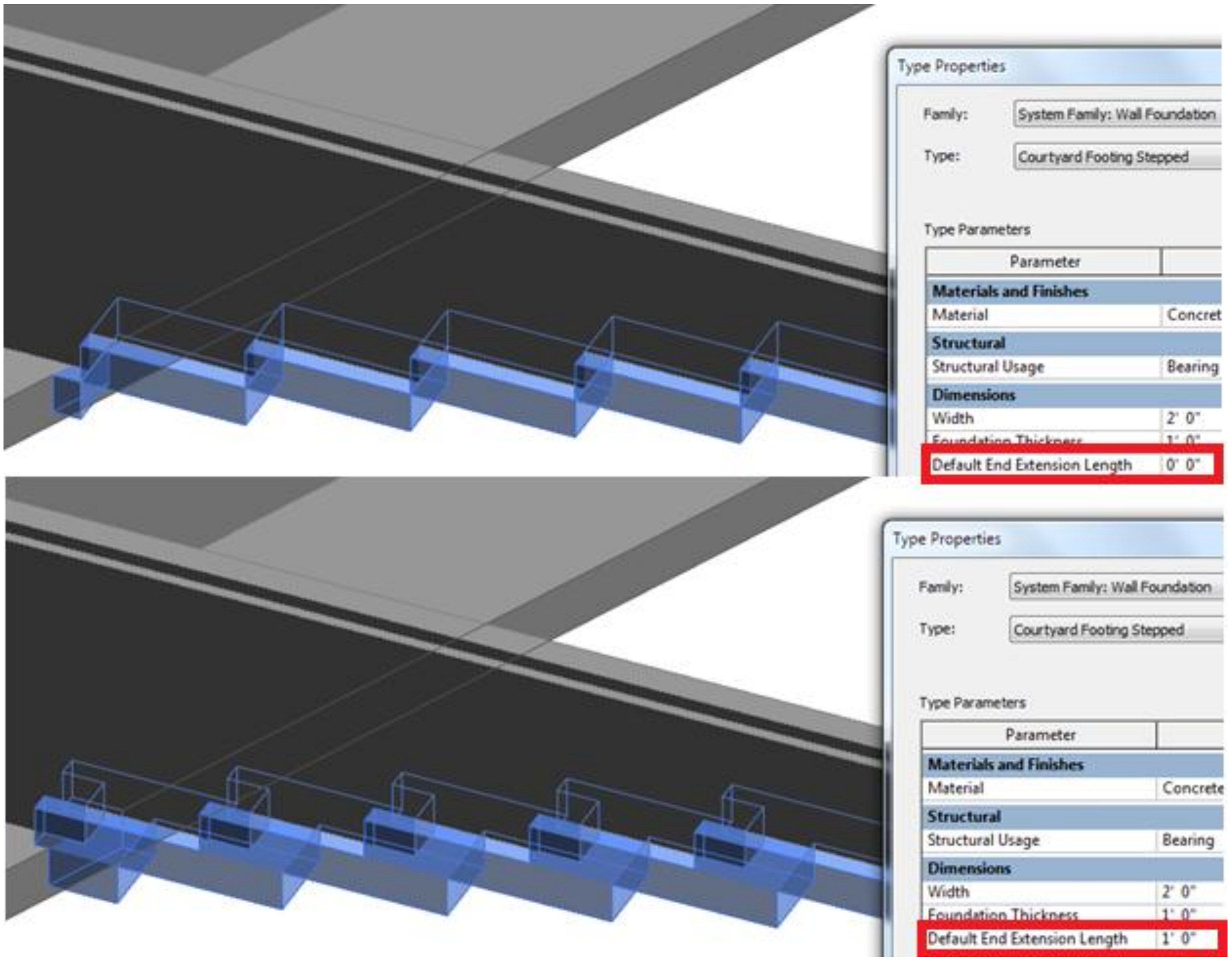

Figure 21 - Creation of Stepped Continuous Footings in Revit Structure

A second issue with the continuous footings occurred when attempting to model the eccentric continuous footings. Highlighted in red in Figure 22 are the extra extensions of the eccentric footings that occurred when Revit Structure joined the two basement wall sections at the corner. The solution was to split the walls into multiple sections, and the highlighted section of wall in Figure 22 was not assigned a footing. This was only viable considering the spread footing also located at this corner occupies the same space as the continuous footing, eliminating the need to model both.

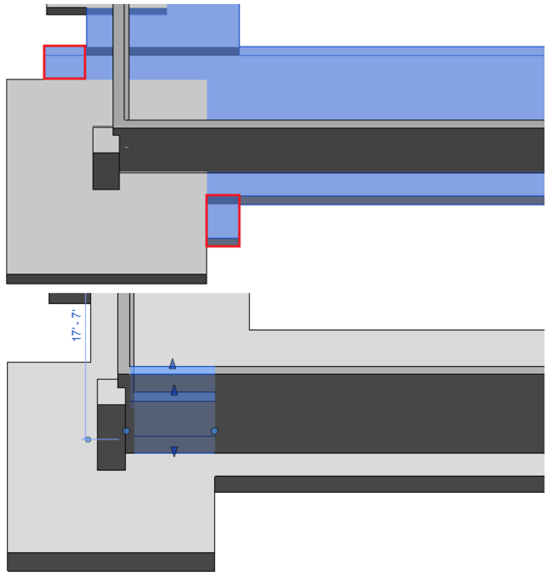

Figure 22 - Eccentric Continuous Footings

The last issue with modeling the foundation occurred where walls did not intersect at right angles. The top left of Figure 23 shows the intersection of the walls highlighted in red, and the top right shows the assumed intersection in Revit Structures also highlighted in red. The problem is compounded by the fact that the shelves for the architectural finish are at different heights, and results in a gap in the wall show in the bottom of Figure 23.

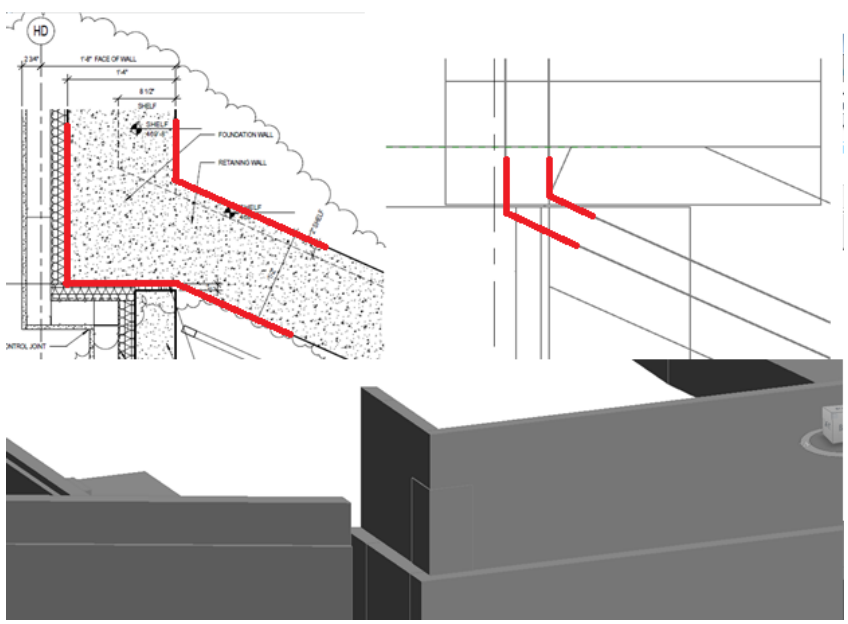

Figure 23 - Foundation Wall Intersection

After modeling the foundation there was a problem with modeling the interface between the structural steel and the sloped portion of the grade beams around the elevator pits. Figure 24 shows a wide flange column that should sit on the sloped grade beam. It instead is cut off at the elevation of the highest point of the sloped footing which is the reference plane for the footing. The fact that one column would be less than two feet short was considered to have a negligible impact on the quantity takeoff.

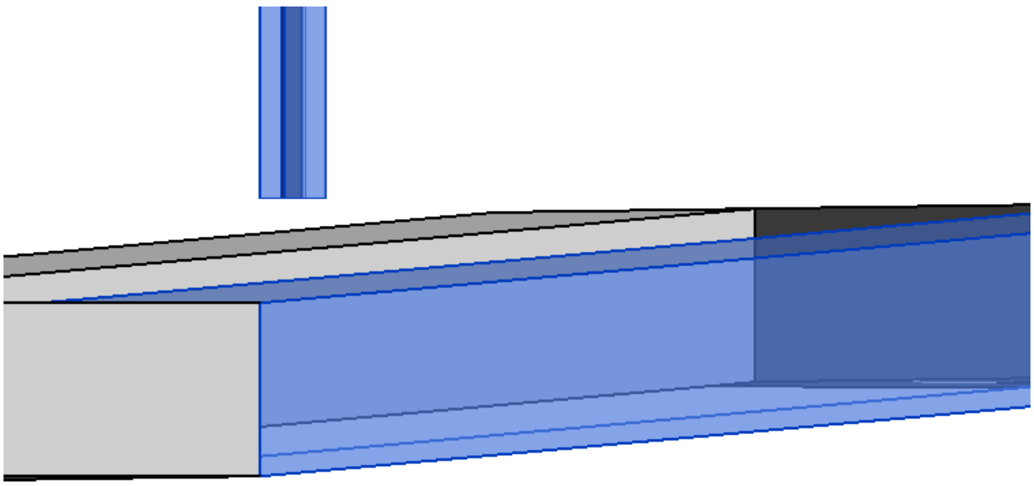

Figure 24 - Structural Steel Interface with Grade Beam

The completed model was phased to represent the progress of the steel erection observed. Images of the model representing each week are included in Appendix C.1 along with the site picture. To accurately represent the installation of the metal deck and then the slab the floors had to be modeled twice because the composite floor cannot be separated into components for phasing. A metal deck was defined as built on the date it was observed as installed and demolished on the date the concrete slab was poured. With the metal deck demolished in the model it was then replaced with a composite floor.

3.3 Scheduling

A quantity takeoff of structural steel was performed using the phased structural model. A schedule for new structural columns and new structural framing was created for each week and exported into Microsoft Excel. The schedules are included in Appendix C.2 and summarized in Table 4. With a total of 1,127.48 tons of structural steel an average of 112.75 tons would have to be completed each week to meet the ten week deadline. Using a schedule performance index (SPI) it is clear that the task was generally on schedule and only behind by 15.75 tons of steel at the scheduled completion date. With an average of 115.06 tons a week for the first nine weeks progress began slowing in week ten (December 19th to the 23rd).

Table 4 - Summary of Quantity Takeoff

Week	Work Completed (tons)	Total Work Completed (tons)	Work Budgeted (tons)	SPI
1	126.28	126.28	112.75	1.12
2	108.78	235.06	225.50	1.04
3	124.30	359.36	338.25	1.06
4	87.31	446.67	450.99	0.99
5	100.98	547.65	563.74	0.97
6	116.98	664.63	676.49	0.98
7	135.37	800.01	789.24	1.01
8	120.99	921.00	901.99	1.02
9	114.53	1035.53	1014.74	1.02
10	76.20	1111.73	1127.48	0.99
11	12.52	1124.25		
12	3.23	1127.48		

4.0 Design

The first work package of this task was to design the green roof system for Building H. With no American design standards for green roofs available, information on the recently completed WPI East Hall dormitory building green roof was used as a guide in developing the system for Building H. During the design process possible LEED credits were evaluated, and the impact on cost and construct schedule was considered. After selecting a system, the design dead load for the green roof was determined.

The second work package of the task was to evaluate the structural frame of the building under the new roof dead load; other design loads identified in the contract documents. Two methods used for designing steel structures are permitted by the American Institute of Steel Construction (AISC), the Load and Resistance Factor Design (LRFD) and Allowable Stress Design (ASD). The LRFD method of analysis was used to remain consistent with the contract documents. Structural members were reviewed for performance in strength and serviceability, and when a member was found to be inadequate, a suitable replacement was determined.

4.1 Green Roof

The Weston Solution GreenGrid system was selected for the design process. It is a modular system that consists of two foot by two foot plastic units that are delivered with plants already established at an offsite nursery. The 4.25 inch extensive option in Figure 25 offers many of the benefits of a green roof at a low cost and weight.

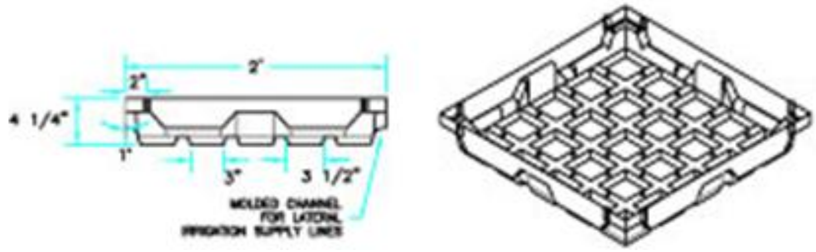

Figure 25 - Extensive GreenGrid Module

The roof will not help achieve the site development credits that are still available for Building H. An extensive roof is too thin to support the vegetation necessary to provide a habitat. In addition the roof does not meet the open space requirements as it is not accessible to the public.

According to performance information provided by Weston Solutions the roof should achieve the credit for stormwater quality control. Additionally the roof should retain 40 to 60 percent of stormwater runoff annually, reducing the load on the stormwater management system. In addition the retained water combined with a sedum planting eliminates the need for irrigation, allowing the project to maintain its credits for water efficient landscaping.

Due to the seasonal nature of the vegetation the insulation value of the roof ranges from an effective R-value of 100 in the summer and 4 in the winter. GreenGrid systems have been shown to reduce the heating and cooling costs by 25 and 50 percent respectively for the floor directly below the roof. This could contribute to an increase in credits earned for optimizing energy performance.

The LEED Materials Reporting Form for GreenGrid was provided by Weston Solutions, and has been included in Appendix D.1. Only the plastic portion of the module consists of recycled materials, but the Building H project has already earned the maximum amount of credits for recycled materials. With an additional point available for using regional material it is a benefit that 93.9 percent by weight of the module is produced regionally.

4.2 Design of Beams and Girders

The second work package of the task was to evaluate the structural frame of the building under the new roof dead load and other design loads identified in the contract documents. Two methods used for designing steel structures are permitted by the American Institute of Steel Construction (AISC), the Load and Resistance Factor Design (LRFD) and Allowable Stress Design (ASD). The LRFD method of analysis was used to remain consistent with the contract documents. Structural members were reviewed for performance in strength and serviceability, and when a member was found to be inadequate, a suitable replacement was determined.

For beams and girders a set of hand calculations for each unique load case was developed using the previously determined design loads. A set of hand calculations can be found in section D.2 of our appendix, which verifies our data. Using appropriate load factors for the LRFD method a design moment, effective flange width, and plastic neutral axis (PNA) were determined. Using the proper strength capacity and moment of inertia provided by the AISC manual the strength and deflection limits of the beam were checked for adequacy. Finally, assuming one ¾" weak stud per rib, the number of shear connectors needed was determined.

Using the hand calculations as a model, an analysis spreadsheet was developed. RISA-2D Educational was utilized to determine design moments when the load cases and placements were not uniform. The values for a moment found in RISA were within +/- 0.2 kip*feet of the calculated moments. With RISA-2D and the analysis spreadsheet all the beams and girders were checked for adequacy and number of shear connectors required.

The subsequent material presents our results from the structural analysis from the beam and girders and if any changes needed to be made to the existing structure. Table 5 displays the different loadings that could be experienced by each beam or girder.

Table 5 - Loads

Load Case 1	psf	Load Case 2	psf
6.25 in concrete cover	43.86	7.5 in concrete cover	72.86
Green Roof	30	-	-
Slip Sheet	2	-	-
TPO Membrane	2	-	-
Insulation	2	-	-
Drop Ceiling	3	-	-
MEP	5	-	-
Metal Decking	2.14	Metal Decking	2.14
Live Load (case 1)	20	Live Load	150
Snow Load	55	Snow Load	55

This Table represents the loads before the tributary area and beam self-weight were applied to the various load combinations. In order to continue with the structural analysis, the tributary area and load case needed to be determined for each beam or girder.

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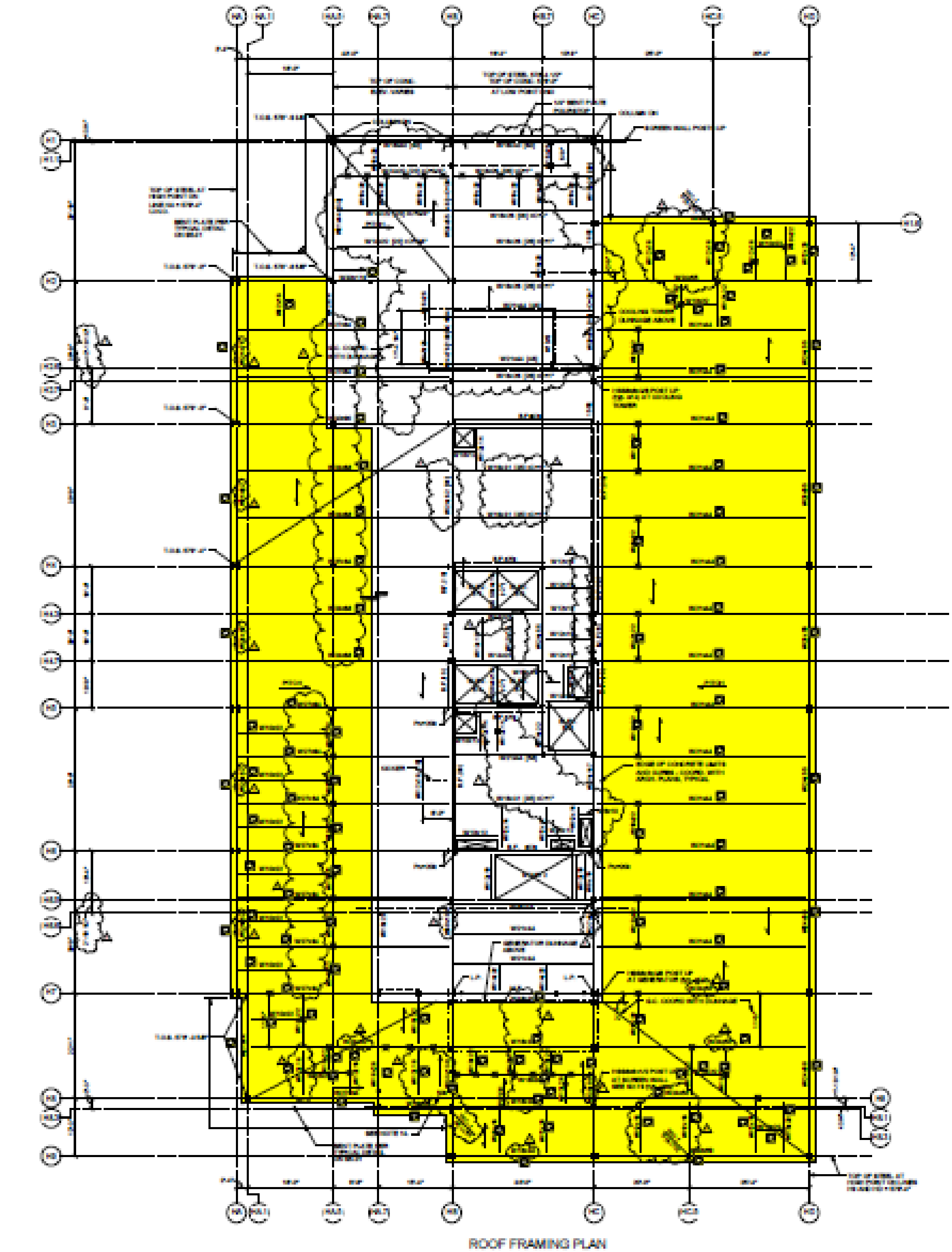

Figure 26 - Load Case Layout

Figure 26 shows the configuration of the beams and girders for the roof level. Each beam and girder that is within the shaded area would experience an increased load, and needed to be examined. Load cases were assigned based on the location within the frame. The beams and girders that are within the shaded area pertain to case 1 and the beams and girders that span from the shaded section to the non-shaded section will carry both loads from case 1 and case 2 respectively. For the penthouse roof, load case 1 is used in the calculations.

This information was the basis for determining how much weight each beam or girder must support, and was used in the Excel spreadsheet to determine the strength and serviceability of each beam and girder under inspection. The calculation spreadsheet, found in Appendix D.2, provides the Excel spreadsheet that was used to calculate the final values for required moment vs. available moment, limit of deflection vs. actual deflection, required shear vs. available shear, and required number of shear studs.

Table 6 summarizes the results from the spreadsheet calculations. Using Figure 37 and Figure 38 in Appendix D.2 each beam and girder within the structural framing plans was assigned a coordination number to organize the results. Included in the results are the strength capacity, deflection limit, and number of shear connectors required for a full composite decking/slab system. The information provided by this table includes all the beam and girders that needed to be inspected, and all of the members were found to be able to support the additional load of the green roof.

Table 6 - Beam and Girder Results

Beam Section	Number Coordination	Mu (k*ft)	ϕMN (k*ft)	Deflection Live Load (< 1in)	Deflection w/o factors (< 1in.)	Vn (k)	ϕVn (k)	# Studs
W27x84	1	678.8	1678.4	0.301	0.193	68.23	369	72
W24x68	2	673.9	1271.6	0.443	0.294	70.6	295	60
W30x90	3	831.3	1606	0.380	0.182	79.2	375	76
W27x84	4	680.8	1678.4	0.301	0.196	71.2	369	72
W21x44	5	556.1	748.5	0.267	0.526	49.1	217	60
W24x55	6	613.9	1041	0.176	0.365	54.2	251	48
W24x55	7	615.9	1041	0.176	0.370	54.3	251	48
W24x55	8	616.6	1041	0.176	0.372	54.5	251	48
W24x55	9	556.2	1015.66	0.035	0.063	73.3	251	48
W24x68	10	827.4	1262	0.059	0.152	89.6	295	60
W24x62	11	562.6	1135.6	0.031	0.059	74.5	306	56
W27x84	12	831	1748	0.485	0.231	79.2	369	72
W30x116	13	746.7	2648	0.287	0.128	70.8	509	100
W24x76	14	568.2	1373.6	0.025	0.045	75.1	316	72
W12x16	15	27.1	195.8	0.004	0	10.8	79.1	16
W10x22	16	110.5	256.28	0.055	0.029	21.7	73.2	24
W10x22	17	60.8	236.84	0.004	0.001	24.2	73.2	24
W10x22	18	79.9	241.88	0.006	0.002	27.7	73.2	24
W12x16	19	50.5	199.58	0.009	0.002	16.4	79.1	16
W30x99	20	367.7	2128	0.069	0.086	32.5	463	84
W12x26	21	91.6	310.9	0.005	0.002	29.7	84.3	24
W18x40	22	153.1	627.76	0.07	0.04	20.4	169	36
W18x35	23	278.1	550.58	0.081	0.082	37.1	159	32
W16x26	24	44.2	319.56	0.004	0.001	15.4	84.3	24
W21x44	25	285.9	800.6	0.016	0.016	51.4	217	36
W33x130	26	1347.3	2905.2	0.019	0.072	146.6	576	110
W27x84	27	563.5	1687.2	0.076	0.135	52.4	369	72
W30x99	28	1372.6	2037	0.021	0.055	150.1	463	84
Penthouse Roof								
W18x35	29	282.4	539.56	0.413	0.458	24.9	159	32
W24x76	30	188.9	1223.6	0.002	0.001	49.3	316	74
W10x12	31	62.5	140.52	0.002	0.012	16.3	56.3	12
W12x19	32	42.6	230.46	0.004	0.001	16.5	85.7	16
W16x26	33	186.8	373.6	0.126	0.095	24.9	106	24
W16x31	34	244.9	460	0.105	0.102	32.6	131	28
W14x22	35	82.9	299.8	0.036	0.013	16.5	94.8	20
W12x16	36	40	195.8	0.004	0.001	16	79.1	16
W27x102	37	374.9	1956	0.015	0.002	49.8	419	88
W8x31	38	13.7	256.09	0.0049	0	5.5	68.4	18
W12x14	39	63.1	180.12	0.024	0.007	16	64.3	12
W8x10	40	26.6	126.14	0.0059	0.002	10.6	40.2	36
W21x50	41	556.7	852.8	0.046	0.089	74	237	44
W21x44	42	556.1	773.4	0.265	0.525	49.1	217	60
W12x72	43	247.4	1013.12	0.046	0.066	33	158	62
W30x124	44	257	2969.64	0.0093	0.008	34.2	529	80
W21x44	45	550.3	755.5	0.052	0.1	73.2	217	60
W24x68	46	370.4	1238.8	0.028	0.032	49.2	295	60
W24x76	47	555.4	1373.6	0.025	0.041	73.8	316	68

4.3 Design of Columns

The third work package for this section was the analysis of the columns. The analyzed frame spanned from the 6th floor to the roof. The exterior columns only support loads from the 7th floor and the low roof, while the interior columns support loads from the 7th floor, the penthouse floor, and the pent house roof. In order to analyze each column the distributed loads for each floor needed to be calculated.

The 7th floor is at an elevation of 564'-6" and has a distributed load of 198psf was found by adding the dead loads: concrete with steel deck, drop ceiling, MEP, and Insulation. The live load for office space within the building was specified as 80psf and there was no snow load because this is not a roof level. This distributed load only covers the exterior bays of the structure, however, because the interior bays must take into account the loads from elevators and mechanical equipment. By including these separate factors the overall distributed load increased to 342psf. This completed the analysis for the 7th floor and now the roof level must be analyzed.

Figure 27 is a schematic of the floor plan for the roof of the structure and is at an elevation of 579'. The yellow shaded area represents the area in which we include our Green Roof and has an overall factored distributed load of 211psf. This was obtained by adding the dead loads: concrete with steel deck, green roof, slip sheet, TPO membrane, insulation, drop ceiling, and MEP. The live load for the roof was specified as 20psf and the snow load was deemed to be 55psf. The white area represents where there are extra live loads for the elevators and the mechanical equipment for the building and this area already contains a composite concrete/steel deck. The new live load for the mechanical equipment and the elevators was 150psf. However, the white area that is outlined in blue is exterior, so the snow load had to be included in these calculations, while the remaining white area is considered the pent house and excludes the snow load. The factored distributed load for the blue outlined area is 369.7psf and the pent house area has a 342.2psf factored distributed load. Now the penthouse roof loads must be determined.

Figure 27 - Roof Floor Plan

The penthouse roof has two elevations of 593’ for the upper portion and 590’-4” for the lower portion. Both of these can be treated similarly to the yellow shaded area on the roof level and therefore the factored distributed load equals 211psf. With all of the distributed loads calculated the real column testing could begin.

In order to find the ultimate loads on the columns two calculations must be made. First the tributary area must be calculated and then multiplied by the correct factored distributed load depending on which column is being tested. The second part is to determine the weight from all the beams and girders that are supported by the individual column. After both of these are determined they are added together providing the factored point load on the column. This process must be repeated for all levels that the column supports. Finally, all of the point loads must be combined to give an ultimate load on the column. The un-braced height for the column is 13'-6" and was used with the effective length factor K to determine the loading capacity of the column. The member is sufficient if the load capacity is greater than the factored design load. After completing all of these steps on paper, an excel spreadsheet was created to assist the calculations for the remaining columns. A sample of this spreadsheet is shown in Appendix D.3. This completes the design analysis for the columns.

After evaluating the columns that would support the new green roof load, it was determined that only two columns failed under the extra loads. These columns were a W14x61 located at H2-HB and a W14x82 located at H6-HB. Their tributary area is larger than most columns, and both are subjected to loading from the mechanical equipment and elevators, which is the largest loading case. A W14x82 and W12x96 were found to be sufficient for locations H2-HB and H6-HB respectively. Sufficient strength could be developed in the original members using plates to increase the radius of gyration about the y axis. Table 7 summarizes the results of the column analysis with the two columns that failed are highlighted in red.

Table 7 - Column Design Analysis

Columns						
Position	W Section	Stopping Elevation	ΦcPu (k)	Pu (k)	Assessment	Alternative
H1.6-HC	W14x61	579'	585.33	462.7	GOOD	-
H1.6-HD	W14x61	579'	585.33	63.6	GOOD	-
H2-HA	W14x61	579'	585.33	166.23	GOOD	-
H2-HB	W14x62	579'	585.33	617.73	FAIL!	Use W14x82
H2-HD	W14x61	579'	585.33	204.83	GOOD	-
H3-HA	W14x61	579'	585.33	321.23	GOOD	-
H3-HB	W14x82	593'-10"	789.6	678.45	GOOD	-
H3-HC	W14x82	593'-10"	789.6	471.07	GOOD	-
H3-HD	W14x61	579'	585.33	289.39	GOOD	-
H4-HA	W14x61	579'	585.33	268.28	GOOD	-
H4-HB	W14x82	593'-10"	789.6	638.71	GOOD	-
H4-HB.7	W14x82	593'-10"	789.6	143.13	GOOD	-
H4-HC	W14x82	593'-10"	789.6	263.31	GOOD	-
H4-HD	W14x61	579'	585.33	289.39	GOOD	-
H4.3-HB	W12x96	579'	1040.58	183.51	GOOD	-
H4.3-HC	W12x96	579'	1040.58	88.62	GOOD	-
H4.7-HB	W12x96	579'	1040.58	183.51	GOOD	-
H4.7-HC	W12x96	579'	1040.58	88.62	GOOD	-
H5-HA	W14x61	579'	585.33	268.28	GOOD	-
H5-HB	W14x82	593'-10"	789.6	638.71	GOOD	-
H5-HB.7	W14x82	593'-10"	789.6	142.13	GOOD	-
H5-HC	W14x82	593'-10"	789.6	263.31	GOOD	-
H5-HD	W14x61	579'	585.33	289.39	GOOD	-
H6-HA	W14x61	579'	585.33	268.28	GOOD	-
H6-HB	W14x82	590'-4"	789.6	827.29	FAIL!	Use W12X96
H6-HC	W14x82	590'-4"	789.6	323.66	GOOD	-
H6-HD	W14x61	579'	585.33	289.39	GOOD	-
H7-HA	W14x61	579'	585.33	228.76	GOOD	-
H7-HB	W14x132	579'	1524.84	578.67	GOOD	-
H7-HC	W14x132	579'	1524.84	516.03	GOOD	-
H7-HD	W14x61	579'	585.33	290.74	GOOD	-
H8-HA.1	W14x61	579'	585.33	106.01	GOOD	-
H9-HB	W14x61	579'	585.33	254.32	GOOD	-
H9-HC	W14x61	579'	585.33	282.94	GOOD	-
H9-HD	W14x61	579'	585.33	150.59	GOOD	-

4.4 Robot

As part of the structural analysis, a separate analysis of the building's roof and the columns above the sixth floor splice was performed using Robot Structural Analysis. For an analytical model, the model created in Revit Structure and used to perform the quantity takeoff was exported to Robot Structural Analysis. Exporting the model from Revit Structure to Robot was done through use of the Revit Extensions Manager add-on for Revit Structure. With the roof structure as designed and the roof deck changed to a composite deck for additional strength, the added load of the green roof was analyzed for suitability. For any members found to be insufficiently strong for the load of the green roof, they were changed to a size that was capable of carrying the load and the model re-analyzed to verify the suitability of the new members.

For Robot to perform the analysis, modification of the structural model was necessary. The roof was originally sloped for drainage but this was leveled to easily create a reinforced concrete slab that Robot would analyze correctly. Another change made to make analysis easier was that the penthouse roof was brought to one elevation instead of two. Only the top two floors of the Revit Structure model were exported to be used for analysis. The reasoning behind this was that the columns of interest spanned from below the 7th floor up to the roof or penthouse roof. To represent the supporting structure below, fixed supports were defined at the base of each column.

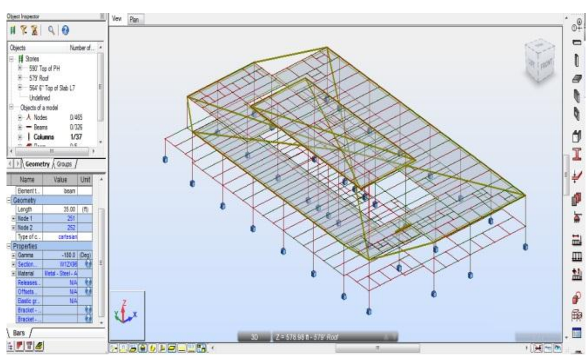

Figure 28: Analytical Model used in Robot

Getting to the point where Robot would provide reliable results presented many challenges. Although it is advertised as capable of high interoperability with Revit Structure, this assumes that the Revit model was built accurately and with interoperability in mind. First, since Robot is relatively new software for Autodesk, their forums lacked many of the answers that users were posing and support was difficult to come by when faced with issues. One specific issue was how Robot would classify the roof slab as an analytical object which affected its behavior under loading. The program defined the different options for the slab in an unfamiliar manner. The solution to this issue was to simply run separate analyses for each option until the closest match to what its actual behavior should be was found.

The first step of the actual analysis was creating the loads and load combination in Robot. For the loading applied to the roof of the model, the self-weight of the roof deck and the steel frame are automatically calculated by Robot using the object properties established in Revit and given their own designation of "Dead Load 1." A dead load of 44 pounds per square foot was created to account for the green roof, TPO membrane, insulation, and the MEP and drop ceiling of the 7^{th} floor. This second dead load was designated "Dead Load 2" and added to the first. The roof's live load of 20 psf and snow load of 55 psf were also added.

In the design it was assumed that the structure would be able to adequately resist lateral forces from wind and seismic loading as the conditions had not changed appreciably from the original design scenario. The green roof design did not alter the exposure of the building to wind. Also ground accelerations for Worcester are small, and the weight added by the green roof is small in comparison to the weight of the structure. Robot allows the user to choose which load combinations to use so the loading case chosen was the same that the hand calculations determined would be the most conservative ($1.2D_1 + 1.2D_2 + 0.5L + 1.6S$) for uniformity's sake.

When the analysis was run, Robot checked the beams and girders against ANSI/AISC 360 – 05 which is the *2010 Specification for Structural Steel Buildings* to verify that their deflections were within the allowable limits. Every beam and girder passed this test and did not need to be replaced but when the same was done for the columns there were two that did fail. These were located at H2-HB and H6-HB. When the size of the columns was changed to what the hand calculations determined to be adequate replacements, the columns passed.

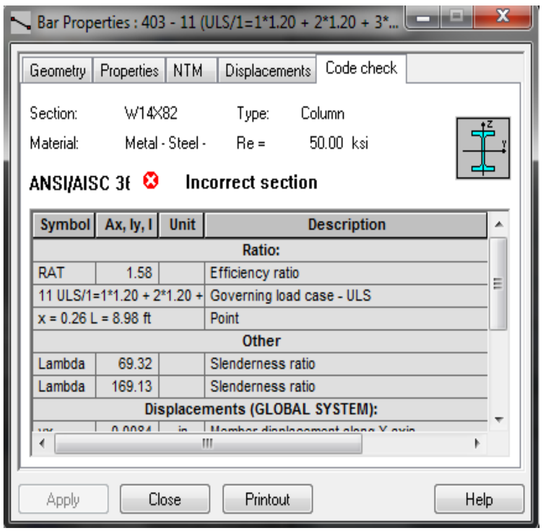

Figure 29: Robot Showing Failure of Original Column Located at H6-HB (Bar #403)

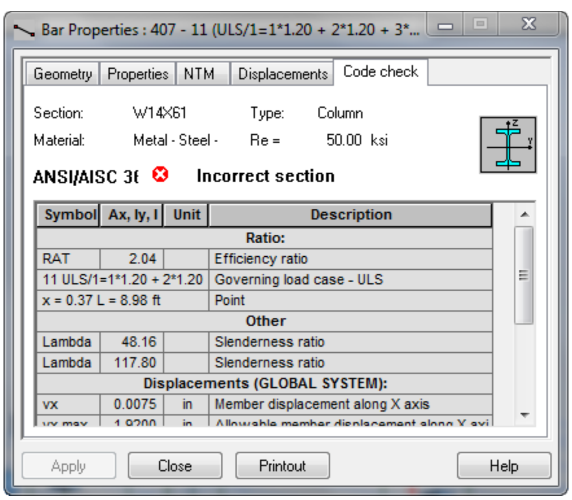

Figure 30: Robot Showing Failure of Original Column Located at H2-HB (Bar #407)

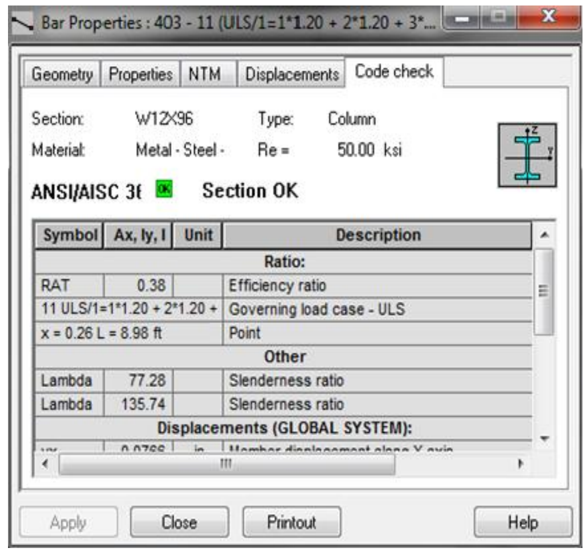

Figure 31: Robot Verifying the Replacement Column at H6-HB is Adequate

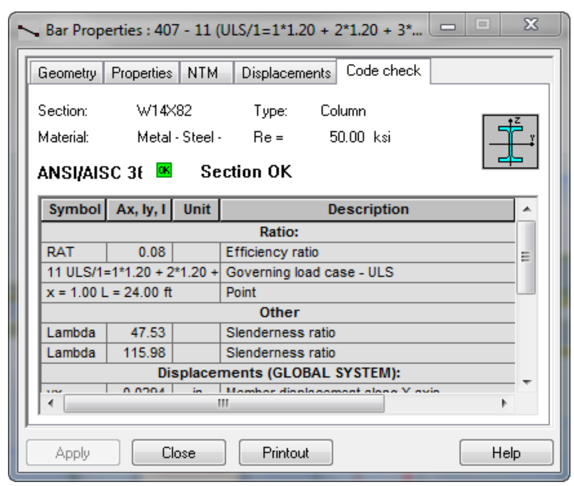

Figure 32: Robot Verifying the Replacement Column at H2-HB is Adequate

The Robot analysis returned results that fully supported the findings of the hand calculations. The code check that Robot does to verify the adequacy of members in the structure only indicated two insufficient members in the original design of the steel frame. Robot then verified that the two replacement members were of adequate strength for the additional loading of the green roof.

As far as the accuracy of the hand calculations versus Robot's calculations, the deflections computed by hand were higher than those computed by Robot about two-thirds of the time. The differences, however, are only a minor discrepancy calculated out to an average of 19.7%. This is most likely due to the fact that Robot uses finite element analysis to compute the deflections and our hand calculations were performed using the LRFD method of analysis that relies on making conservative assumptions about loading conditions.

The comparison between Robot's results and the hand calculations for the columns is not so straightforward. The hand calculations used the axial load capacity of the columns to check their suitability. Robot, however, checks lateral deflections against allowable deflections and buckling of the column due to the load. This discrepancy did not affect the results of the hand calculations because none of the columns that passed for axial loading failed Robot's additional criteria.

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Beam Coordination Number	Deflection Live Load (< 1in)	Robot Deflection	% Difference	Hand Calcs; High or Low?
1	0.301	0.2780	7.6	High
2	0.443	0.3230	27.1	High
3	0.380	0.3370	11.3	High
4	0.301	0.2181	27.5	High
5	0.267	0.3502	31.2	Low
6	0.176	0.1539	12.6	High
7	0.176	0.1150	34.7	High
8	0.176	0.2040	15.9	Low
9	0.035	0.0262	25.1	High
10	0.059	0.0636	7.8	Low
11	0.031	0.0220	29.0	High
12	0.485	0.3163	34.8	High
13	0.287	0.1677	41.6	High
14	0.025	0.0293	17.2	Low
15	0.004	0.0032	20.0	High
16	0.055	0.0481	12.5	High
17	0.004	0.0035	12.5	High
18	0.006	0.0041	31.7	High
19	0.009	0.0078	13.3	High
20	0.069	0.0819	18.7	Low
21	0.005	0.0061	22.0	Low
22	0.070	0.0627	10.4	High
23	0.081	0.1002	23.7	Low
24	0.004	0.0032	20.0	High
25	0.016	0.0114	28.8	High
26	0.019	0.0223	17.4	Low
27	0.076	0.1005	32.2	Low
28	0.021	0.0223	6.2	Low
29	0.413	0.3252	21.3	High
30	0.002	0.0023	15.0	Low
31	0.002	0.0015	25.0	High
32	0.004	0.0029	27.5	High
33	0.126	0.1130	10.3	High
34	0.105	0.1180	12.4	Low
35	0.036	0.0330	8.3	High
36	0.004	0.0045	12.5	Low
37	0.015	0.0100	33.3	High
38	0.0049	0.0049	18.3	High
39	0.024	0.0312	30.0	Low
40	0.0059	0.0059	15.7	High
41	0.046	0.0415	9.8	High
42	0.265	0.2072	21.8	High
43	0.047	0.0460	2.1	High
44	0.0093	0.0093	22.5	Low
45	0.052	0.0435	16.3	High
46	0.028	0.0205	26.8	High
47	0.025	0.0261	4.4	Low
Average % Difference			**19.71**	31
				16

5.0 Cost Analysis

The first work package of this task was to determine the cost of the green roof. This includes the cost of material, shipping, installation, and maintenance. In order to obtain this information, Weston Solutions Inc. was contacted, a trusted integrator for sustainable solutions. The green roof system we selected was through Weston Solutions, so the information provided from them was accurate in determining the cost differential.

The second work package of this task was to determine the approximate cost of additions to the structure, including the cost of structural members that needed to be changed, additional shear studs, and added cost of the concrete for a composite system that is needed for proper installation of the green roof. The website for Management Engineering & Production Services (MEPS) International LTD. was utilized in determining the cost of additional steel. MEPS (International) LTD. is a leading independent supplier of steel market information. Lemoi Erectors Inc. was contacted to discuss the costs of the additional shear studs and Aggregate Industries was contacted for a price quote on 4000psi lightweight concrete, which would be used in our alternative design.

The third work package of this task is to evaluate the energy savings due to the additional insulation provided by the green roof. This was achieved through the use of Autodesk Ecotect Analysis. When combined with the installation and maintenance costs a life cycle analysis of the green roof will be complete.

The estimate from Weston Solutions, Inc. was obtained for the cost and delivery of 14,000 square feet of the extensive GreenGrid modules. The cost of the modules was priced at

$165,340 with a delivery cost of $6,020 from Glastonbury, CT to Worcester, MA. Weston Solutions does not provide installation services but does provide a recommendation for the installation crew and process. They specify 6-10 laborers on the roof for installing the modules, about 2 riggers to coordinate the loading and hoisting of the modules, and 1 supervisor or foreman to direct the layout of the modules and coordinate all other activities related to the green roof. The cost breakdown of the roof, delivery, and installation are show in Table 8. The hourly rates for the laborers, riggers, and supervisor were obtained from labor market information provided by the Massachusetts Executive Office of Labor and Workforce Development.

Table 8 - GreenGrid Cost Including Installation and Delivery

Cost of Roof (14000sf)		$ 165,340.00
Installation Cost	Laborers	$ 18.00 /hr
	Riggers	$ 20.00 /hr
	Supervisor	$ 33.00 /hr
	Time	2 days
	Total Install Cost	$ 1,136.00
Delivery Cost (100 Front St)		$ 6,020.00
Total		$ 172,496.00

A maintenance plan is also outlined by Weston Solutions for the owners to perform. It involves seasonal inspection of the modules for weed development and removal and application of different fertilizers each season to promote the health of the plants. There is also irrigation guidelines for the spring and summer months. These guidelines specify how often to water the plants should significant rainfall not occur frequently enough which Weston states is 12-14 days. Trimming of the plants is required but only every 2 to 3 years in the spring to promote additional leaf development at the plant crown. This maintenance plan is not incredibly labor intensive and is capable of being performed by an average grounds crew along with their regular responsibilities. According to Weston Solutions, the polyurethane modules are warranted for 20 years and the growing medium for 15 years. Weston also states that a roof membrane covered by their modules has at least double the service life of an exposed roof membrane because it will not be subject to extreme changes in temperature, expansion and contraction, and UV rays.

From inspection of the structural analysis it was determined that two structural columns needed to be resized for adequacy. A W14x62 failed and so did a W14x82, and it was determined that a W14x82 and a W12x96 would be required instead. This is a total increase of 34 pounds per linear foot of steel and covers a total length of 28 feet. From the information provided by MEPS, steel is currently $1000 per ton and these two members cause an increase of 952 pounds. This increase in weight would cost approximately $476 extra. From conversations with Lemoi Erectors, it would cost approximately $3 for installation per shear stud and we have a need for an increase of 2308 additional shear studs, thus costing about $6924 extra. Finally, lightweight concrete was utilized in our alternative design and this design would require a volume of 298 cubic yards. The price quoted from Aggregate Industries was $128 per cubic yard of concrete therefore the total cost would be approximately $38,144. Table 9 provides a condensed format of this information.

Table 9 - Structural Costs

	Additional Amount Required	Cost per Additional Unit	Overall Added Cost
Structural Steel	952 pounds	$1000 per ton	$476
Shear Studs	2308 studs	$3 per stud	$6924
Lightweight Concrete	298 cubic yards	$128 per cubic yard	$38,144
Total:	-	-	$45,484

6.0 Conclusions

This report examined some aspects of the construction process in regards to the Unum Building City Square construction project in Worcester, MA. Site visits and the application of Building Information Modeling (BIM) were used to rate the performance of the actual construction progress. An alternative roof design was developed that was used to be compared to the proposed existing roof design. Finally, a cost analysis was provided to determine the overall feasibility of the alternative design.

6.1 Project Tracking

While developing the structural model of Building H the limitations of Revit Structure became apparent. When objects are eccentric, join at odd angles, or are sloped the program has difficulties, and it is often impossible to accurately model the objects with the default families provided with the software. In addition to learning the software, a firm adopting Revit Structure would need to produce a library of custom family models to fulfill their needs. It is also important to determine what level of detail should be produced in a model. When attempting to increase the level of detail in a model it can be easy to spend more time on it than the benefits are worth.

The structural steel task was proceeding on schedule for the first nine weeks of the ten week duration. In the tenth week progress slowed and it took a week and a half of slow work to finish the task. During this time of slowed progress the maximum wind speed was repeatedly over 40 mph. This led to restrictions on the operation of the tower crane used for the steel erection and caused the delays.

6.2 Design

The alternative design called for the implementation of a green roof and composite metal decking system, whereas the proposed design has no green roof and only metal decking with no concrete. This alternative design utilized a modular green grid extensive system from Weston Solutions. The modular system is 2'x2' and 4.25" inches deep. The green roof would need to cover 14,000 square feet of usable open roof space. From this, a structural analysis determined that only two structural columns would need to be replaced in order to maintain structural adequacy. A W14x82 and a W12x96 were substituted for a W14x62 and W14x82, respectively.

6.3 Cost Analysis

It was determined that the structural upgrades to the alternative design would cost approximately $45,484. The cost of the green roof system to cover 14,000 square feet would be approximately $172,496. This is a total additional cost of $218,344 and would extend the roof life expectancy by a factor of 2, or double the roof membrane life span. The cost of replacing the proposed roof is about $121,896. Therefore, the cost of the alternative design of $218,344 is less expensive than the cost $243,792, when comparing life cycle costs. Thus, the green roof system alternative design is feasible.

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Appendix A: Preliminary LEED Checklist

LEED-CS

LEED-CS 2009 Preliminary Checklist

Project Name: City Square Building H

Project Location: 1 Mercantile St Worcester, MA

19-Aug-09

Yes	?	No		Minimum Program Requirements	0 Points	Helps LEED CI	Notes
Y			Pif1	**Sharing whole-building energy and water usage data**	Required		The Tenant will share with Berkeley, USGBC and the GBCI all available actual whole-project energy and water usage data for their Tenant space for a period of at least 5 years. It is understood that this period starts on the date Tenant occupancy. Sharing this data includes supplying information on a regular basis in a free, accessible, and secure online tool or, if necessary, taking any action to authorize the collection of information directly from service or utility providers.

Yes	?	No		Sustainable Sites	28 Points	Helps LEED CI	Notes
24	2	2					
Y			Prereq 1	**Construction Activity Pollution Prevention**	Required		
1			Credit 1	**Site Selection**	1		
5			Credit 2	**Development Density & Community Connectivity**	5	*	
	1		Credit 3	**Brownfield Redevelopment**	1	*	
6			Credit 4.1	**Alternative Transportation**, Public Transportation Access	6	*	
2			Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	2	*	The Tenant will provide showers and changing facilities inside their Tenant space for 0.5% of full-time equivalent (FTE) occupants. These occupants are defined as Unum employees and other office building tenants, but not the retail tenant on the first floor.
3			Credit 4.3	**Alternative Transportation**, Low-Emitting and Fuel-Efficient Vehicles	3		
2			Credit 4.4	**Alternative Transportation**, Parking Capacity	2	*	
		1	Credit 5.1	**Site Development**, Protect of Restore Habitat	1		
	1		Credit 5.2	**Site Development**, Maximize Open Space	1		
1			Credit 6.1	**Stormwater Design**, Quantity Control	1		
		1	Credit 6.2	**Stormwater Design**, Quality Control	1		
1			Credit 7.1	**Heat Island Effect**, Non-Roof	1	*	
1			Credit 7.2	**Heat Island Effect**, Roof	1		
1			Credit 8	**Light Pollution Reduction**	1		
1			Credit 9	**Tenant Design and Construction Guidelines**	1		

Yes	?	No		Water Efficiency	10 Points		NOTES
7	2	1					
Y			Prereq 1	**Water Use Reduction, 20% Reduction**	Required	*	
2			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	2	*	
2			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	2	*	
	2		Credit 2	**Innovative Wastewater Technologies**	2	*	
3		1	Credit 3	**Water Use Reduction**	2 to 4	*	
				30% Reduction	2		
				35% Reduction	3		
				40% Reduction	4		

Yes	?	No		Energy & Atmosphere	37 Points	NOTES
2	35					
Y			Prereq 1	**Fundamental Commissioning of the Building Energy Systems**	Required	
Y			Prereq 2	**Minimum Energy Performance:** 10% New Buildings	Required	*(ALL BLANKS ARE EXPECTED TO BE FILLED IN PRIOR TO THE LEASE SIGNING)* The Tenant will provide the following energy savings within the Commercial Interior work: 1) Reduce the lighting power density to 20% below ASHRAE 90.1 - 2007. The Lighting Power Density in the office areas shall not exceed: __ W/ft^2 . 2) Provide occupancy sensors and daylight dimming controls in all Tenant spaces. 3) Reduce the design airflow rate of the floor-by-floor AHUs to ___ cfm/ft^2. 4) provide demand controlled ventilation controls in the floor-by-floor AHU's and CO_2 sensors in the main occupied areas of the Tenant space. 5) Plug loads for the Tenant office spaces shall not exceed __W/ft^2.
Y			Prereq 3	**Fundamental Refrigerant Management**	Required	All Tenant installed mechanical cooling equipment will comply with the requirements of EAp3. There will be zero use of CFC-based refrigerants in all tenant-installed new mechanical cooling equipment.
	21		Credit 1	**Optimize Energy Performance**	3 to 21	
	4		Credit 2	**On-Site Renewable Energy**	4 *	
2			Credit 3	**Enhanced Commissioning**	2	
	2		Credit 4	**Enhanced Refrigerant Management**	2	
	3		Credit 5.1	**Measurement & Verification - Base Building**	3	
	3		Credit 5.2	**Measurement & Verification - Tenant Sub Metering**	3 *	
	2		Credit 6	**Green Power**	2	

Yes	?	No		Materials & Resources	13 Points	NOTES
6	1	6				
Y			Prereq 1	**Storage & Collection of Recyclables**	Required	
		5	Credit 1.1	**Building Reuse**, Maintain % of Existing Walls, Floors & Roof	1 to 5 *	
				Maintain 25% of Existing Walls, Floors & Roof	1	
				Maintain 33% of Existing Walls, Floors & Roof	2	
				Maintain 42% of Existing Walls, Floors & Roof	3	
				Maintain 50% of Existing Walls, Floors & Roof	4	
				Maintain 75% of Existing Walls, Floors & Roof	5	
1			Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1	
1			Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1	
		1	Credit 3	**Materials Reuse**, 5%	1	
1			Credit 4.1	**Recycled Content**, 10% (post-consumer + ½ pre-consumer)	1	
1			Credit 4.2	**Recycled Content**, 20% (post-consumer + ½ pre-consumer)	1	
1			Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured Regionally	1	
	1		Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Regionally	1	
1			Credit 6	**Certified Wood**	1	

Yes	?	No		Indoor Environmental Quality	12 Points	NOTES
8	3	1				
Y			Prereq 1	**Minimum IAQ Performance**	Required *	
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required *	
1			Credit 1	**Outdoor Air Delivery Monitoring**	1 *	The Tenant will install CO2 sensors in all densely occupied spaces, such as Auditoriums, Conference Rooms, Meeting Rooms, Classrooms and Cafeterias. The CO2 sensors will be installed between 3' and 6' above the floor and programmed to generate an alarm when the conditions vary by 10% or more from the setpoint.
	1		Credit 2	**Increased Ventilation**	1 *	
1			Credit 3	**Construction IAQ Management Plan**, During Construction	1	
1			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1	
1			Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1	
1			Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1	
1			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1	
1			Credit 5	**Indoor Chemical & Pollutant Source Control**	1	The Tenant will install either a permanent entryway system (grilles, grates, mats) or roll-out mat that captures dirt and prevents particulates from entering the building at the East Garage entrance. The system shall be at least 10 feet long (as measured along the primary direction of travel) and placed immediately inside the required entry ways. The Tenant spaces will not contain any areas where hazardous gases or chemicals may be present or used (e.g. housekeeping and laundry areas, copying and printing rooms)
		1	Credit 6	**Controllability of Systems**, Thermal Comfort	1 *	
1			Credit 7	**Thermal Comfort**, Design	1 *	
	1		Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1 *	
	1		Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1 *	

Yes	?	No		Innovation & Design Process	6 Points	NOTES
6						
1			Credit 1.1	**Innovation in Design (EP)**: Commissioning required for all tenant spaces	1	The Tenant will provide fundamental and enhanced commissioning for their Tenant space to comply with EA credit 3.
1			Credit 1.2	**Innovation in Design (EP)**: IAQ management plan for 100% tenants	1	The Tenant will develop and implement an IAQ management plan for the construction and preoccupancy phases of the building, to comply with IEQ credit 3.
1			Credit 1.3	**Innovation in Design (EP)**: Double Transit Ridership	1	
1			Credit 1.4	**Innovation in Design**: Education	1	
1			Credit 1.5	**Innovation in Design**: Green Housekeeping	1	The Tenant will maintain a Green Cleaning Program as defined in the Performance Specification under the section *Tenant Requirements, Cleaning.*
1			Credit 2	**LEED® Accredited Professional**	1	

Yes	?	No		Regional Priority Credits	4 Points	Project Zipcode 01608 Other credits available: SSc3, EAc2 (1%)
3	1					
1			Credit 1.1	**Regional Priority Credit**: SSc7.1	1	
1			Credit 1.2	**Regional Priority Credit**: SSc7.2	1	
1			Credit 1.3	**Regional Priority Credit**: SSc6.1	1	
	1		Credit 1.4	**Regional Priority Credit**: MRc1.1 (75%)	1	

Yes	?	No	Project Totals (pre-certification estimates)	110 Points
56	44	10		

Certified 40-49 points **Silver** 50-59 points **Gold** 60-79 points **Platinum** 80+ points

Appendix B: Additional Information on BIM

B.1 Linking

Linking structural and architectural models is a great tool to utilize during the design process of a project. There are many advantages to this method, including the great increase in the coordination between the architect and engineer, and how changes can be effortlessly tracked between the two programs. In most cases the structural engineer starts with the architectural model and designs the supporting members based on what the architect proposes. Sometimes engineers must change the design because the building could not possibly be designed around the current layout. Communication is critical here as the architect needs to alter the plans to reflect exactly what the engineer is calling for. The linking of the two Revit drawings makes this collaboration painless and as efficient as possible.

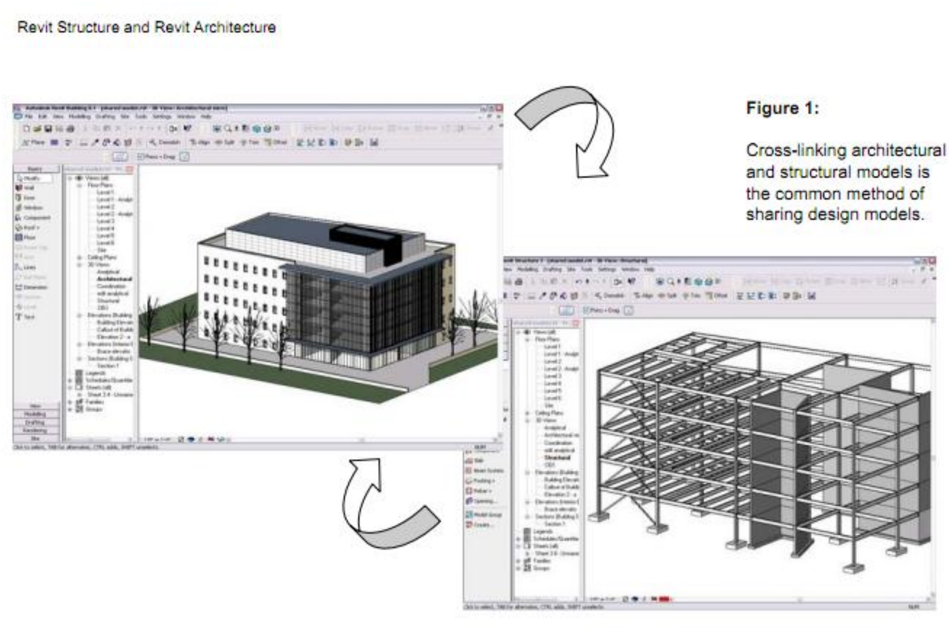


Figure 33 - Linking Architectural and Structural Drawings in Revit

The first step in creating linkable drawings is to form a standard template form that will be used for both drawings. The template should be saved in within the program and when a new project is opened be sure to select this specific template. This ensures that all aspects will be imported effectively and accurately including various views and components. If a standard format is not used between the project files then components may be brought in with different specifications and properties.

The next step is to form the building in Revit Architecture. All details and mechanisms should be drawn in the project file including floors and architectural columns where necessary. Revit Structures should now be opened using the template made earlier and the Architectural file has to be imported using the Import/Link>>RVT… command. Now the architectural drawings can be used within Revit Structures to create the structural aspects of the building.

The Engineer's main interests are the levels of the edifice, grid lines to layout structural elements, and the position of architectural columns to form structural columns. Engineers can copy these components from the architectural model to the structural one using the Copy/Monitor command which allows the engineer to create offsets of adjustments before the transition is made if necessary. A small detail to keep in mind during the transitioning process is that Revit Structures depicts elements as they go down while Revit Arch illustrates them as they move up. This means there may be some discrepancies between levels and the engineer and architect should pay special attention to this. Figure 34 shows a visual representation of this inconsistency.

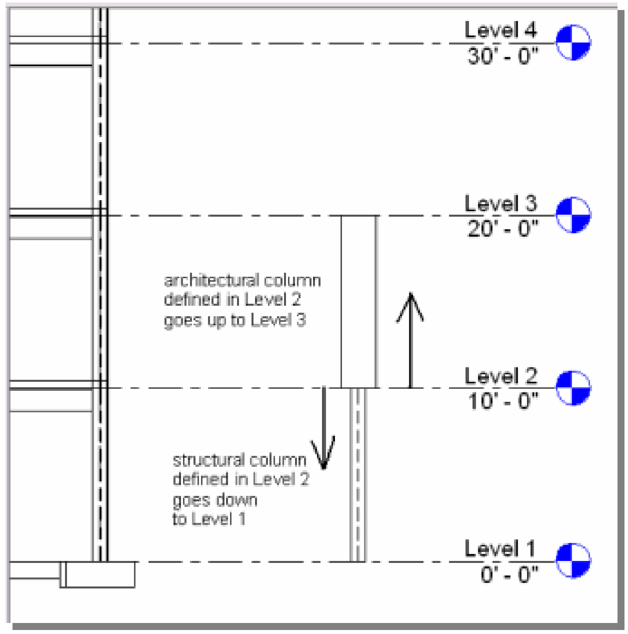


Figure 34 - Discrepancy Between Levels

After all the desired elements are copied a new floor plan must be formulated using the command View>>New>>Floor plan and chooses all levels of the structure. Now the engineer can turn off the visibility for any architectural aspects that they deem necessary. For example floors and specified walls could be turned off in order to place/view a structural component. From here the engineer must design all of the structural members based on what components are required for the given load demands of the building. As the structural engineer finishes his design the structural model can be linked into Revit Architecture where the architect can then review the design and determine if it matches what his/her original design called for.

B.2 Revit Worksharing

Sharing is when there is only one file that is mutually utilized between the engineer and the architect. This is a good approach if the architect and the engineer are working at the same firm and have access to the same network. This system works by using worksets which are reasonable sets of components that only one designer can work on at a time. The various worksets that the team wants to use are selected in the Workset window, shown below, and owners/borrowers can be assigned to each element to eliminate confusion between the disciplines. Only having one file greatly increases efficiency and allows engineers and architects to effortlessly see the deviations made by the other.

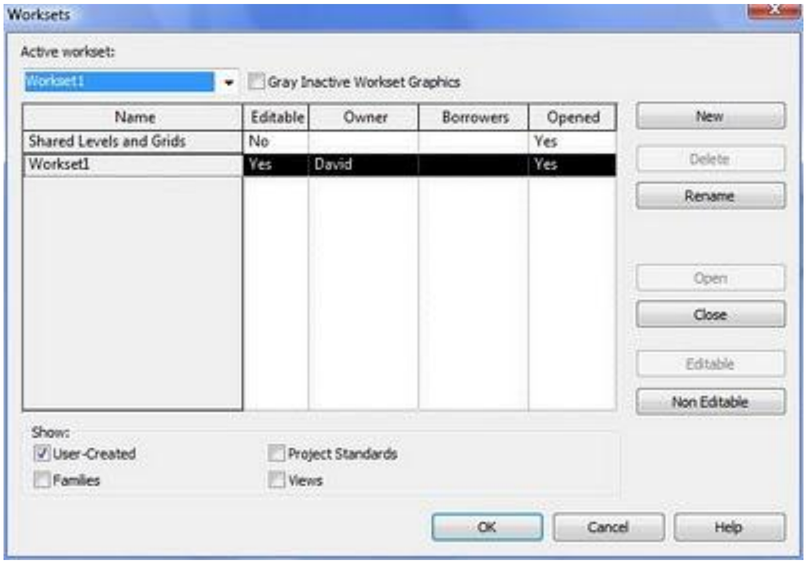


Figure 35 - Worksets Window

In order to help track the changes made between the two programs the Coordination Monitor can be exploited which shows all changes made by the engineer/architect to be viewed by the other in a comprehensive format. They can then reject, approve, or postpone these changes. This is completed when a user selects the Tools>>Copy/Monitor>>Select Link command and copies the desired grids and architectural columns that he would like to track. An Eye symbol will then appear in the architectural model on the components the engineer is monitoring. Every time the engineer logs into the model he/she can select Tools>>Coordination Review>>Select Link and then clicks the linked file and views the Coordination Review Table which shows all of the recent changes made by the architect. This allows the engineer to now change his/her structural design around the new architectural design.

B.3 Interference Checking

The Interference tool allows engineers to select various components of a project and determine if there are any discrepancies that need to be resolved before the final plans go out. This is done using the Tool>>Interference Check>>Run Command. In the Interference Check window, shown below, the desired elements are designated and the check is run. All the problem areas will be listed after the test is completed making is easy for the engineer to alter the design until there are no interferences.

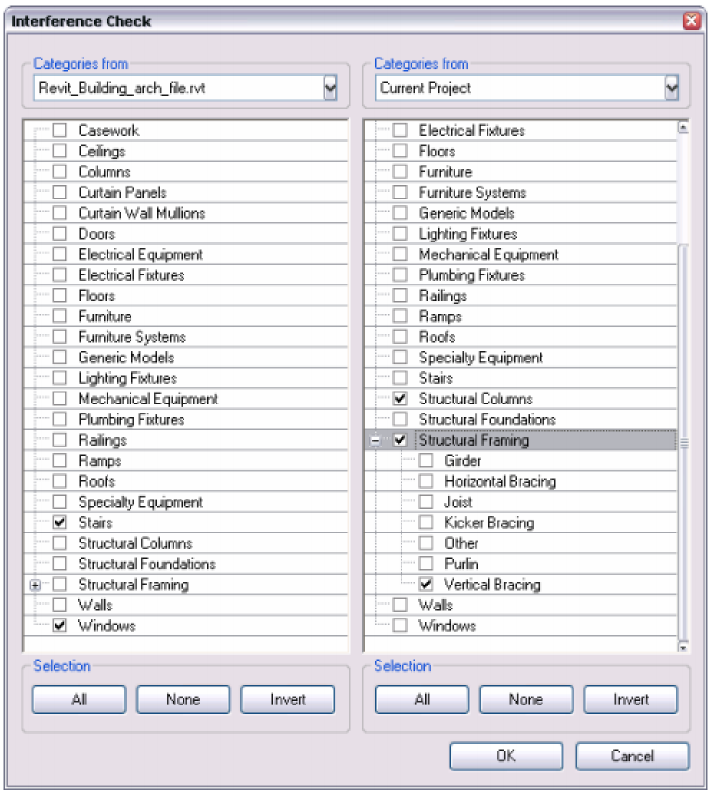
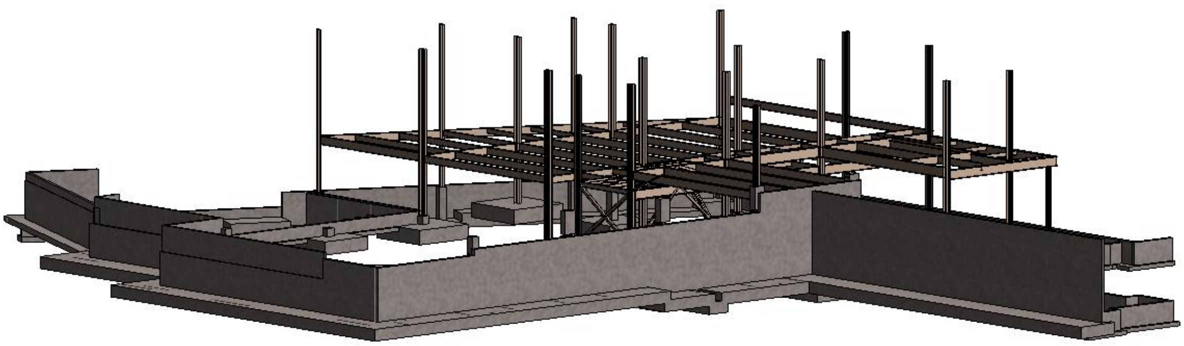


Figure 36 - Interference Check Window

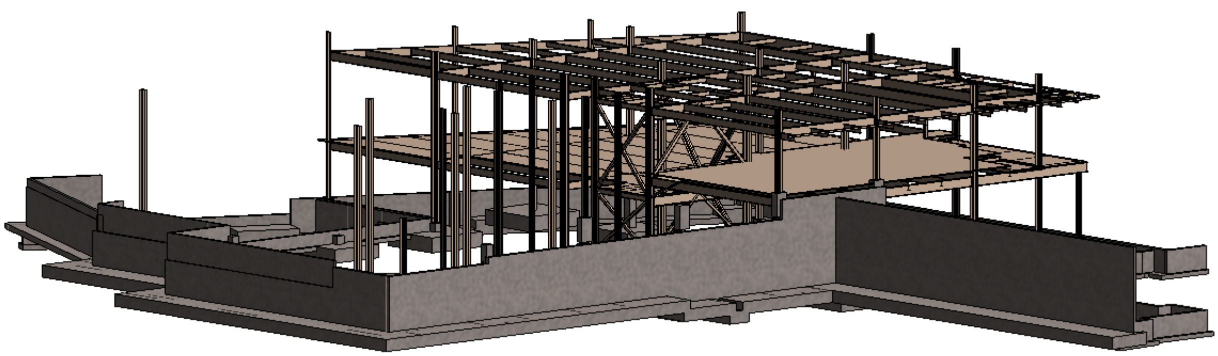
Appendix C: Project Tracking

C.1 Comparison of Weekly Site Pictures and Phased Structural Model

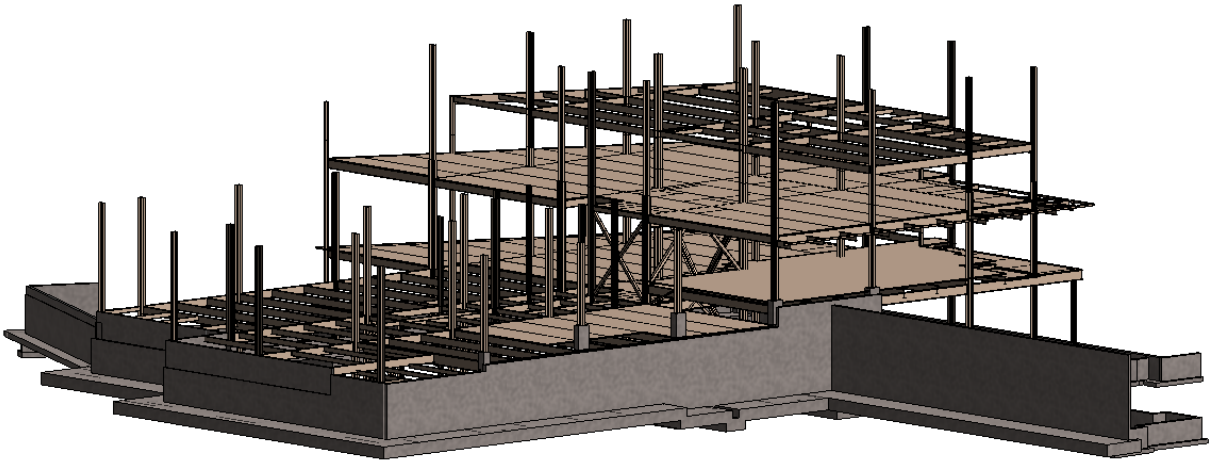
Week 1



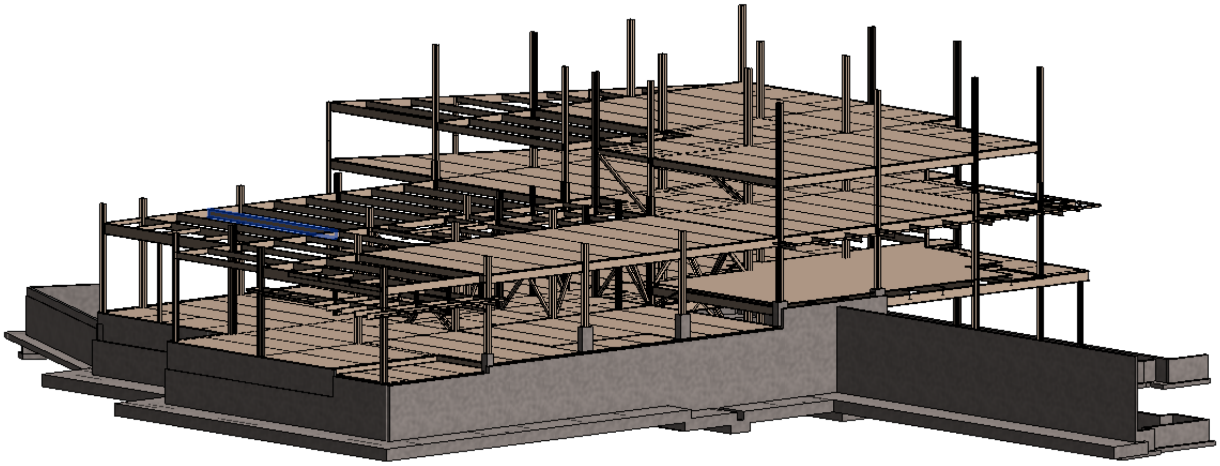
Week 2



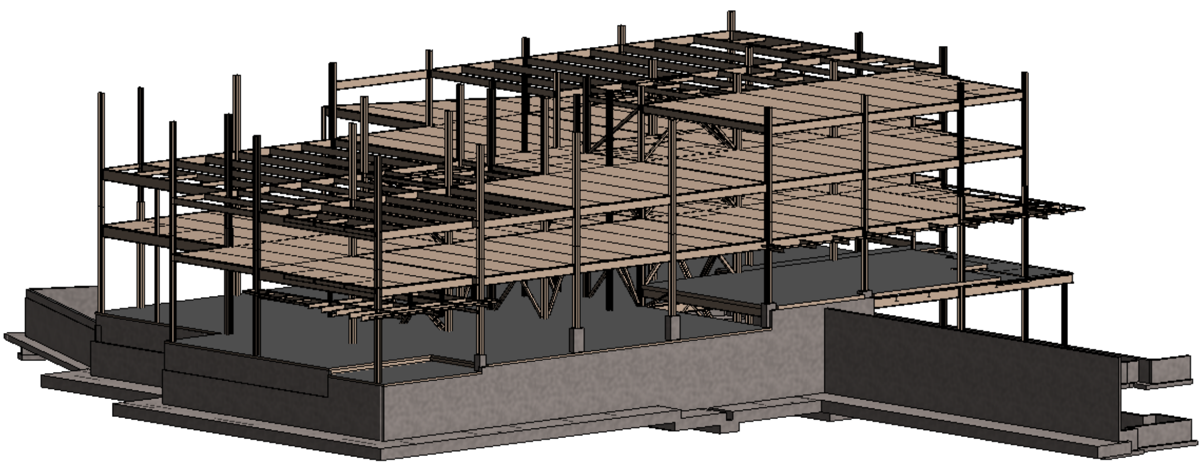
Week 3



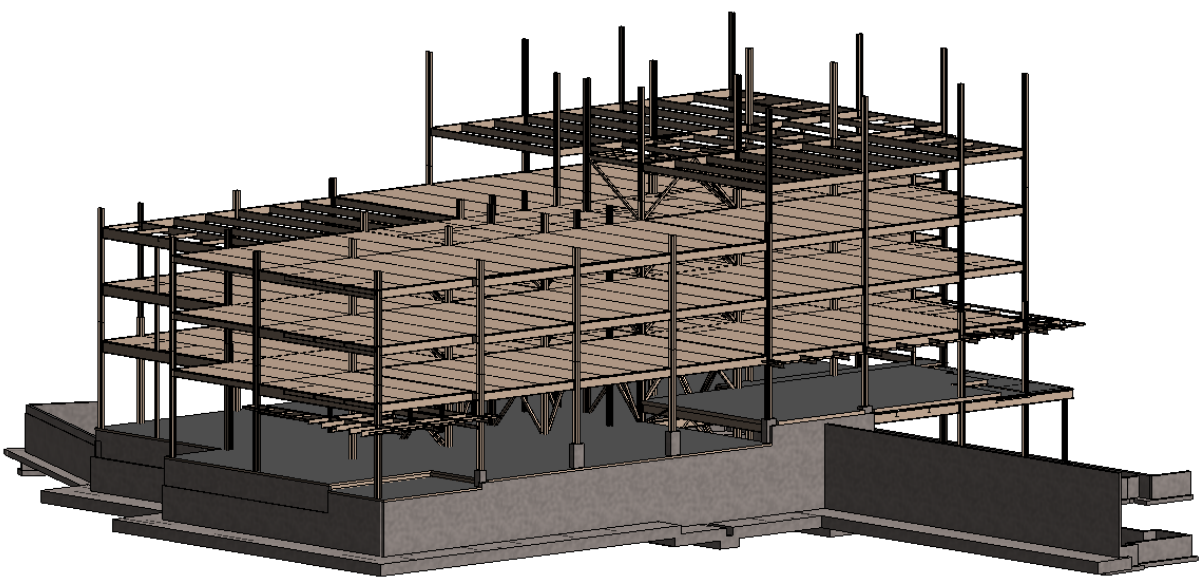
Week 4



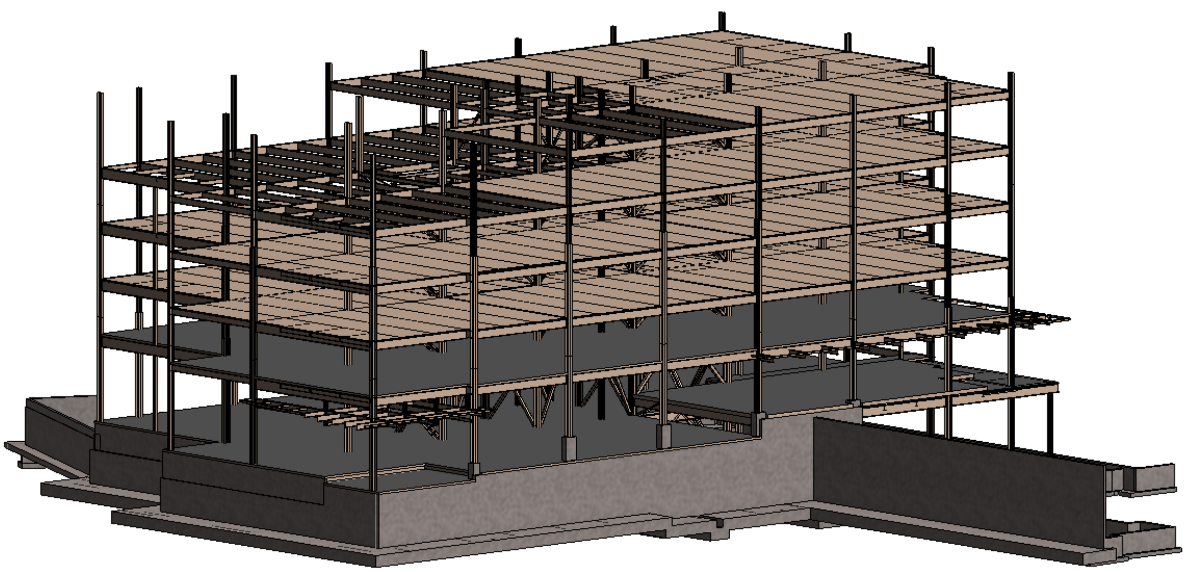
Week 5



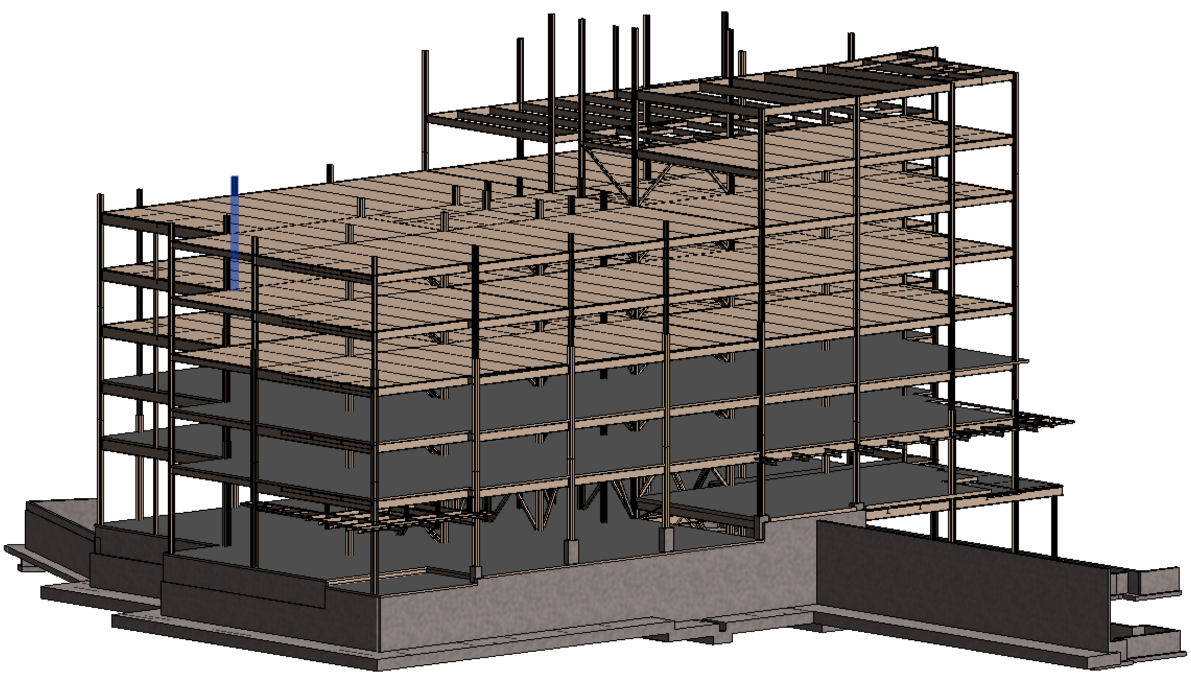
Week 6



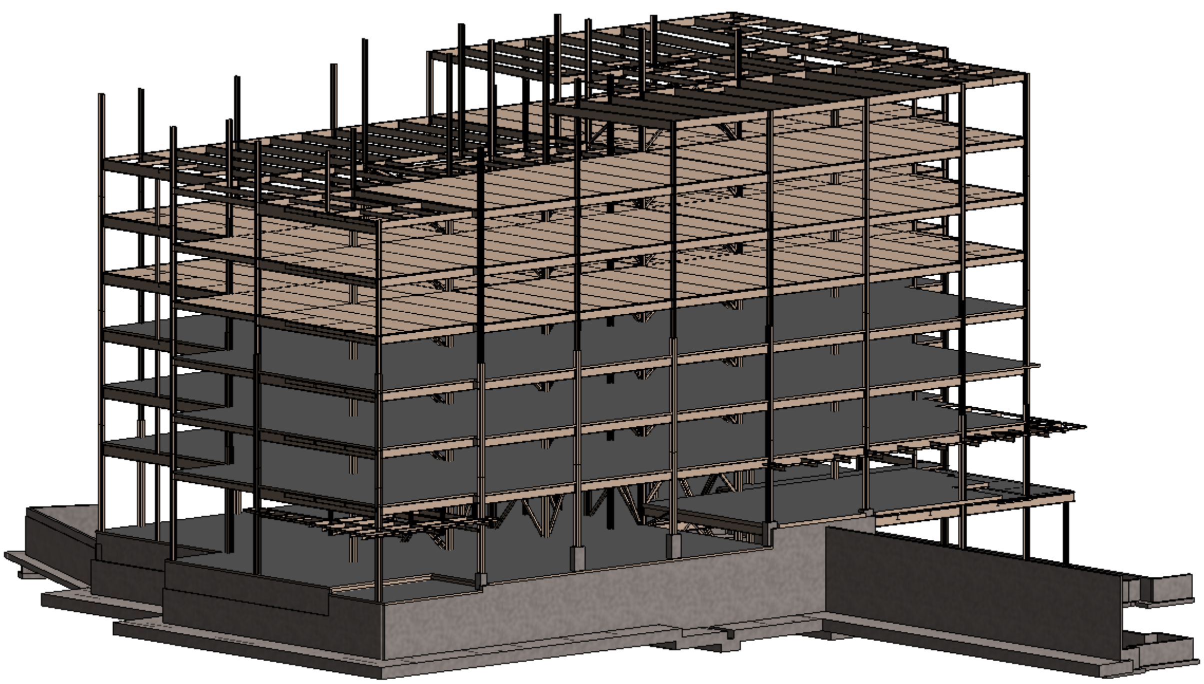
Week 7



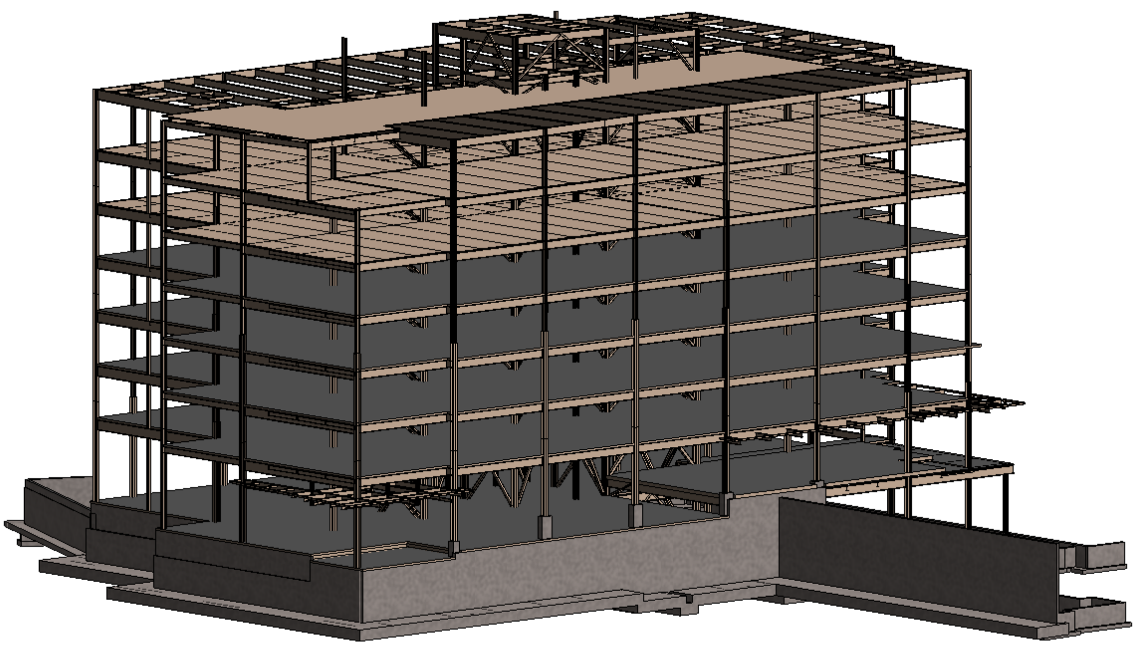
Week 8



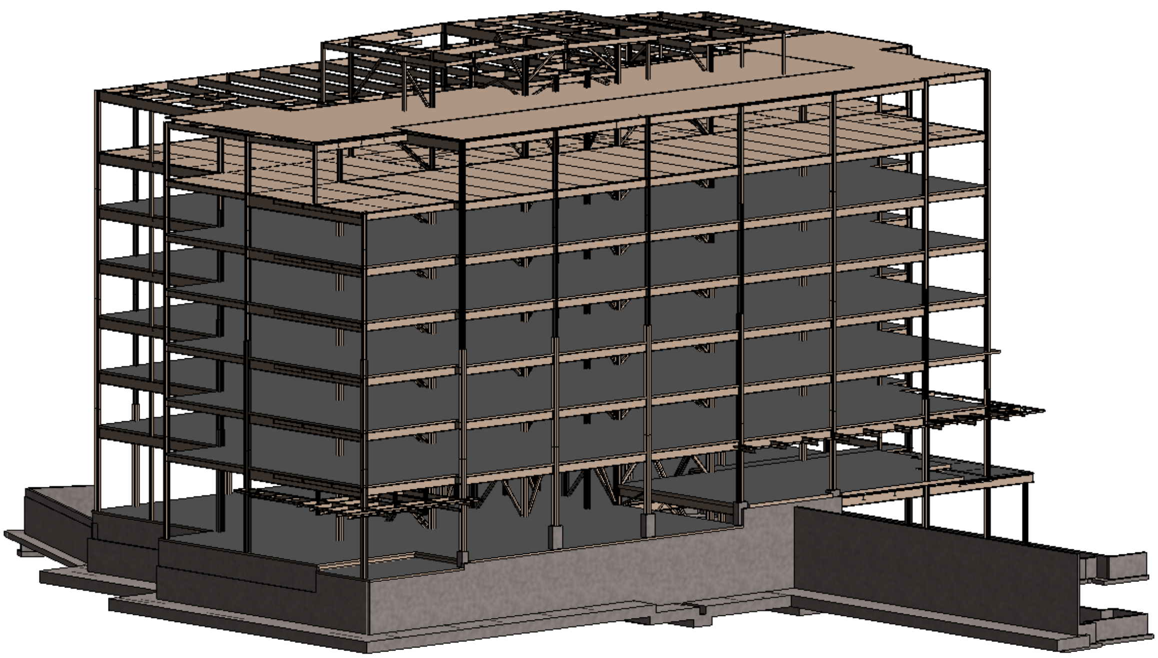
Week 9



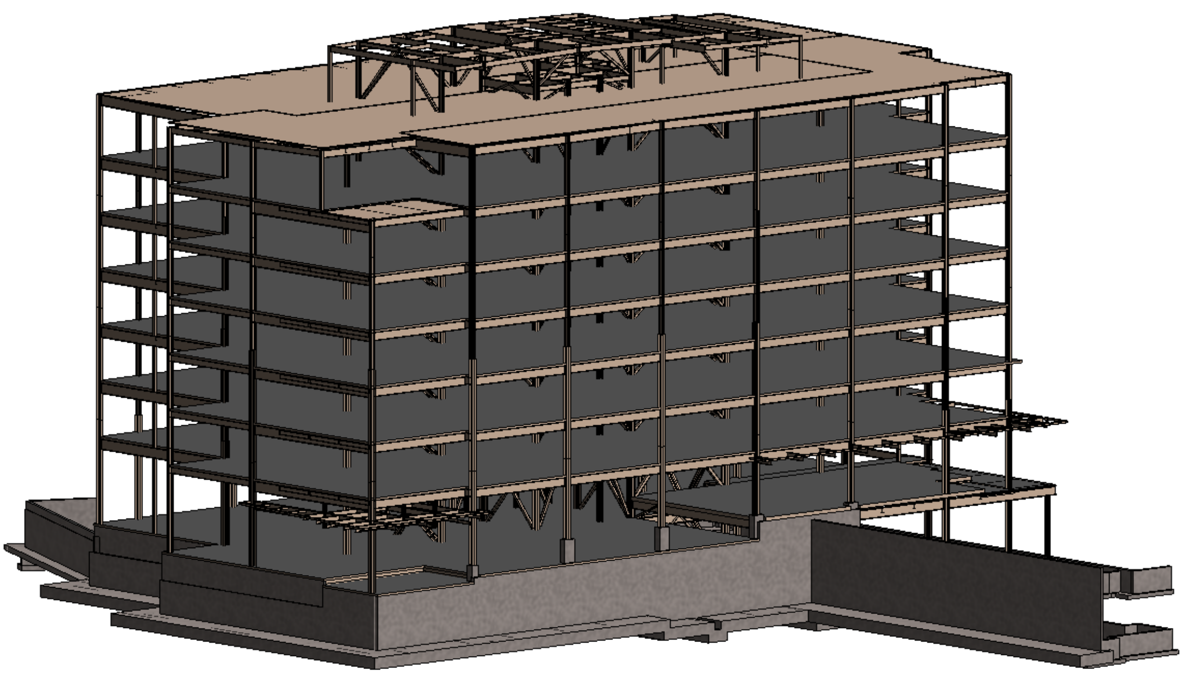
Week 10



Week 11



Week 12



C.2 Scheduling

Week 1 Column Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W14X145	44.00	145.00	6380.00
W14X145	44.00	145.00	6380.00
W14X145	44.00	145.00	6380.00
W14X61	16.11	61.00	982.71
W14X90	40.00	90.00	3600.00
W14X109	40.00	109.00	4360.00
W14X120	19.38	120.00	2325.60
W14X132	40.00	132.00	5280.00
W14X109	40.00	109.00	4360.00
W14X109	39.00	109.00	4251.00
W14X132	40.00	132.00	5280.00
W14X193	40.00	193.00	7720.00
W14X193	40.00	193.00	7720.00
W14X159	40.00	159.00	6360.00
W14X283	42.00	283.00	11886.00
W14X283	42.00	283.00	11886.00
W14X176	40.00	176.00	7040.00
W14X61	39.00	61.00	2379.00
W14X61	39.00	61.00	2379.00
W14X61	39.00	61.00	2379.00
HSS6X6X1/4	4.60	19.00	87.40
HSS6X6X1/4	4.60	19.00	87.40
HSS6X6X1/4	4.60	19.00	87.40
Sub Total (lbs)			109590.51

Week 1 Framing Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W24X55	34.11	55.00	1876.05
W24X68	32.73	68.00	2225.64
W24X68	30.80	68.00	2094.40
W24X55	34.33	55.00	1888.15
W24X55	30.00	55.00	1650.00
W24X68	30.00	68.00	2040.00
W27X84	45.33	84.00	3807.72
W21X44	30.00	44.00	1320.00
W27X84	34.33	84.00	2883.72
W24X68	30.00	68.00	2040.00
W21X83	30.00	83.00	2490.00
W21X50	45.33	50.00	2266.50
W21X50	45.33	50.00	2266.50
W21X50	45.33	50.00	2266.50
W12X16	4.05	16.00	64.80
W12X16	8.98	16.00	143.68
W12X19	13.92	19.00	264.48
W16X26 2	26.69	26.00	693.94
W14X22	18.39	22.00	404.58
W14X22	22.85	22.00	502.70
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X55	45.33	55.00	2493.15
W21X55	45.33	55.00	2493.15
W24X55	39.83	55.00	2190.65
W18X35	36.26	35.00	1269.10

Week 1 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W18X35	31.79	35.00	1112.65
W24X76	30.00	76.00	2280.00
W14X34	19.25	34.00	654.50
W16X57	30.00	57.00	1710.00
W16X26 2	30.00	26.00	780.00
W16X26 2	30.00	26.00	780.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W8X10 2	3.08	10.00	30.80
W8X10 2	3.08	10.00	30.80
W10X12	6.00	12.00	72.00
W12X16	10.00	16.00	160.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W10X12	7.00	12.00	84.00
W8X10 2	3.50	10.00	35.00
W18X35	30.00	35.00	1050.00
W16X26 2	30.00	26.00	780.00
W16X26 2	30.00	26.00	780.00
W16X26 2	30.00	26.00	780.00
W14X22	10.00	22.00	220.00
W14X22	10.00	22.00	220.00
W12X19	11.00	19.00	209.00
W12X19	11.00	19.00	209.00
W8X10 2	11.00	10.00	110.00
W27X84	34.33	84.00	2883.72
W24X68	30.00	68.00	2040.00
W30X132	34.33	132.00	4531.56
W30X99	30.00	99.00	2970.00
W24X55	45.33	55.00	2493.15
W27X94	34.33	94.00	3227.02
W30X90	45.33	90.00	4079.70
W24X68	45.33	68.00	3082.44
W24X68	46.42	68.00	3156.56
W24X68	46.42	68.00	3156.56
W27X258	30.00	258.00	7740.00
W27X129	30.00	129.00	3870.00
W33X118	43.00	118.00	5074.00
W24X62	22.08	62.00	1368.96
W24X55	29.33	55.00	1613.15
W21X44	16.00	44.00	704.00
W27X146	45.33	146.00	6618.18
W12X19	12.25	19.00	232.75
W12X19	12.25	19.00	232.75
W12X19	12.25	19.00	232.75
W12X19	12.25	19.00	232.75
W12X26	10.75	26.00	279.50
WT8X28.5	29.33	28.50	835.91
W21X68	30.00	68.00	2040.00
W21X68	45.33	68.00	3082.44
W18X35	35.33	35.00	1236.55
W12X19	8.50	19.00	161.50

Week 1 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X19	9.58	19.00	182.02
W12X19	8.50	19.00	161.50
W12X19	19.50	19.00	370.50
W12X19	7.02	19.00	133.38
W12X19	7.02	19.00	133.38
W12X19	7.02	19.00	133.38
W12X19	7.02	19.00	133.38
W12X19	7.05	19.00	133.95
MC10X25	19.25	25.00	481.25
MC10X25	19.25	25.00	481.25
HSS8X8X1/2	23.50	48.70	1144.45
HSS8X8X1/2	10.63	48.70	517.68
HSS8X8X1/2	11.99	48.70	583.91
HSS4X4X1/4	11.01	12.20	134.32
W12X106	22.28	106.00	2361.68
W12X106	22.28	106.00	2361.68
HSS5X5X5/16	15.67	19.00	297.73
HSS7X7X1/2	20.17	41.90	845.12
HSS7X7X1/2	20.17	41.90	845.12
HSS8X8X1/2	15.69	48.70	764.10
HSS8X8X1/2	15.69	48.70	764.10
Sub Total (lbs)			142961.03

Week 1 Total (tons)	126.28

Week 2 Column Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W14X145	44.00	145.00	6380.00
W14X145	44.00	145.00	6380.00
W12X96	44.00	96.00	4224.00
W12X96	44.00	96.00	4224.00
W12X96	44.00	96.00	4224.00
W12X96	44.00	96.00	4224.00
W14X74	37.48	74.00	2773.52
W14X145	44.00	145.00	6380.00
W14X120	19.38	120.00	2325.60
W14X159	40.00	159.00	6360.00
W14X283	42.00	283.00	11886.00
W14X283	42.00	283.00	11886.00
W14X74	15.33	74.00	1134.42
W14X90	40.00	90.00	3600.00
HSS8X8X5/16	14.17	31.80	450.61
HSS8X8X5/16	18.53	31.80	589.25
Sub Total (lbs)			77041.40

Week 2 Framing Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W27X94	30.00	94.00	2820.00
W24X68	45.33	68.00	3082.44
W24X68	45.33	68.00	3082.44
W12X16	10.00	16.00	160.00
W12X16	4.50	16.00	72.00
W24X55	34.33	55.00	1888.15

Week 2 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W24X55	30.00	55.00	1650.00
W24X55	34.22	55.00	1882.10
W24X55	39.83	55.00	2190.65
W24X76	30.00	76.00	2280.00
W24X68	30.67	68.00	2085.56
W24X68	32.86	68.00	2234.48
W12X16	4.08	16.00	65.28
W12X16	13.92	16.00	222.72
W12X16	9.00	16.00	144.00
W14X22	18.39	22.00	404.58
W14X22	22.85	22.00	502.70
W16X26	26.69	26.00	693.94
W18X35	31.79	35.00	1112.65
W18X35	36.26	35.00	1269.10
W30X99	45.33	99.00	4487.67
W21X62	45.33	62.00	2810.46
W21X50	45.33	50.00	2266.50
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X55	45.33	55.00	2493.15
W21X55	45.33	55.00	2493.15
W24X68	34.33	68.00	2334.44
W21X50	30.00	50.00	1500.00
W21X83	30.00	83.00	2490.00
W18X35	30.00	35.00	1050.00
W27X84	34.33	84.00	2883.72
W27X84	43.00	84.00	3612.00
W27X84	22.08	84.00	1854.72
W27X84	43.00	84.00	3612.00
W27X84	45.33	84.00	3807.72
W18X35	30.00	35.00	1050.00
W16X26	30.00	26.00	780.00
W21X50	30.00	50.00	1500.00
W27X84	30.00	84.00	2520.00
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W27X84	30.00	84.00	2520.00
W33X118	30.00	118.00	3540.00
W16X26	30.00	26.00	780.00
W18X35	30.00	35.00	1050.00
W16X57	30.00	57.00	1710.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W36X256	30.00	256.00	7680.00
W14X34	19.25	34.00	654.50
W14X22	10.00	22.00	220.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00

Week 2 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W10X12	6.00	12.00	72.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W8X10	3.50	10.00	35.00
W10X12	6.50	12.00	78.00
W10X12	10.00	12.00	120.00
W12X19	11.00	19.00	209.00
W12X19	11.00	19.00	209.00
W8X10	11.00	10.00	110.00
W14X22	10.00	22.00	220.00
W14X22	10.00	22.00	220.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
HSS8X8X1/2	28.49	48.70	1387.46
HSS8X8X1/2	13.91	48.70	677.42
HSS8X8X1/2	14.58	48.70	710.05
W12X120	25.81	120.00	3097.20
W12X120	25.81	120.00	3097.20
HSS10X10X5/8	22.28	76.10	1695.51
HSS10X10X5/8	22.22	76.10	1690.94
W21X62	11.32	62.00	701.84
W18X40	11.32	40.00	452.80
W18X40	11.32	40.00	452.80
W18X40	11.32	40.00	452.80
W12X30	11.00	30.00	330.00
W12X30	11.00	30.00	330.00
W12X30	11.00	30.00	330.00
W10X22	10.75	22.00	236.50
W10X22	10.75	22.00	236.50
W10X22	10.75	22.00	236.50
W12X30	10.75	30.00	322.50
W12X30	8.02	30.00	240.60
W18X50	8.02	50.00	401.00
W18X50	8.02	50.00	401.00
W18X40	5.69	40.00	227.60
W18X40	5.69	40.00	227.60
W18X40	5.69	40.00	227.60
W18X40	5.69	40.00	227.60
W18X40	5.69	40.00	227.60
W18X40	5.69	40.00	227.60
HSS5X5X5/16	10.75	19.00	204.25
HSS5X5X5/16	10.75	19.00	204.25
HSS5X5X5/16	10.75	19.00	204.25
HSS5X5X5/16	10.75	19.00	204.25
HSS5X5X5/16	8.02	19.00	152.38
HSS5X5X5/16	5.82	19.00	110.58
HSS5X5X5/16	5.50	19.00	104.50
HSS5X5X5/16	11.04	19.00	209.76
HSS5X5X5/16	11.04	19.00	209.76
HSS5X5X5/16	10.00	19.00	190.00

Week 2 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
HSS5X5X5/16	10.00	19.00	190.00
HSS5X5X5/16	10.00	19.00	190.00
HSS5X5X5/16	10.00	19.00	190.00
HSS5X5X5/16	10.00	19.00	190.00
HSS5X5X5/16	12.00	19.00	228.00
W18X40	5.69	40.00	227.60
W10X22	8.02	22.00	176.44
W10X22	8.02	22.00	176.44
W10X22	8.02	22.00	176.44
L4X4X5/16	9.46	8.20	77.57
L4X4X5/16	9.74	8.20	79.87
L4X4X5/16	9.46	8.20	77.57
L4X4X5/16	9.74	8.20	79.87
L4X4X5/16	9.70	8.20	79.54
L4X4X5/16	9.89	8.20	81.10
L4X4X5/16	12.05	8.20	98.81
L4X4X5/16	12.23	8.20	100.29
L4X4X5/16	12.08	8.20	99.06
L4X4X5/16	12.23	8.20	100.29
L4X4X5/16	12.08	8.20	99.06
W14X22	2.25	22.00	49.50
W14X22	11.04	22.00	242.88
W14X22	6.35	22.00	139.70
W14X22	10.68	22.00	234.96
W14X22	10.00	22.00	220.00
Sub Total (lbs)			140520.71
Week 2 Total (tons)			108.78

Week 3 Column Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W14X120	19.38	120.00	2325.60
W14X120	19.38	120.00	2325.60
W14X132	22.71	132.00	2997.72
W14X90	28.00	90.00	2520.00
W14X120	28.00	120.00	3360.00
W14x68	28.00	68.00	1904.00
W14X176	28.00	176.00	4928.00
W14X82	28.00	82.00	2296.00
W14X120	40.00	120.00	4800.00
W14X120	40.00	120.00	4800.00
W14X90	27.00	90.00	2430.00
W14X90	27.00	90.00	2430.00
W14X82	27.00	82.00	2214.00
W14X120	27.00	120.00	3240.00
W14X120	27.00	120.00	3240.00
W14X61	8.98	61.00	547.78
W14X61	8.98	61.00	547.78
W14X61	8.98	61.00	547.78
W14X61	27.00	61.00	1647.00
W14X176	27.00	176.00	4752.00
W14X90	27.00	90.00	2430.00
W14X90	27.00	90.00	2430.00
W14X90	27.00	90.00	2430.00
W14X90	27.00	90.00	2430.00

Week 3 Column Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W14X159	27.00	159.00	4293.00
W14X159	27.00	159.00	4293.00
W14X120	27.00	120.00	3240.00
W14X120	27.00	120.00	3240.00
W14X120	27.00	120.00	3240.00
W14X176	27.00	176.00	4752.00
HSS8X8X5/16	11.03	31.80	350.75
HSS8X8X5/16	11.72	31.80	372.70
Sub Total (lbs)			87354.71

Week 3 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W12X26 2	12.33	26.00	320.58
W30X116	42.33	116.00	4910.28
W14X48	30.00	48.00	1440.00
W14X34	19.25	34.00	654.50
W12X19	10.75	19.00	204.25
W21X62	30.00	62.00	1860.00
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W18X50	22.67	50.00	1133.50
W18X50	7.33	50.00	366.50
W14X34	10.00	34.00	340.00
W18X40	10.00	40.00	400.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W18X40	10.00	40.00	400.00
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X50	45.33	50.00	2266.50
W12X16	13.33	16.00	213.28
W12X16	13.33	16.00	213.28
W12X16	13.33	16.00	213.28
W24X62	30.00	62.00	1860.00
W24X76	30.00	76.00	2280.00
W24X55	29.83	55.00	1640.65
W16X26 2	30.00	26.00	780.00
W16X26 2	30.00	26.00	780.00
W16X26 2	30.00	26.00	780.00
W16X26 2	30.00	26.00	780.00
W16X26 2	31.50	26.00	819.00
W12X16	10.00	16.00	160.00
W21X62	30.00	62.00	1860.00
W12X19	10.75	19.00	204.25

Week 3 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X19	10.75	19.00	204.25
W12X19	19.25	19.00	365.75
W14X22	22.67	22.00	498.74
W12X16	15.25	16.00	244.00
W12X16	15.25	16.00	244.00
W8X10 2	5.00	10.00	50.00
W12X19	10.00	19.00	190.00
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	46.42	44.00	2042.48
W21X44	46.42	44.00	2042.48
W21X44	46.42	44.00	2042.48
W21X44	46.42	44.00	2042.48
W21X44	46.42	44.00	2042.48
W21X44	46.42	44.00	2042.48
W12X16	10.00	16.00	160.00
W12X16	7.33	16.00	117.28
HSS8X4X1/4	10.00	19.00	190.00
HSS8X4X1/4	10.00	19.00	190.00
W30X108	46.42	108.00	5013.36
W24X68	33.08	68.00	2249.44
W14X22	26.00	22.00	572.00
W14X22	26.00	22.00	572.00
W14X22	26.00	22.00	572.00
W12X19	20.42	19.00	387.98
W12X19	20.42	19.00	387.98
W12X19	20.42	19.00	387.98
W21X44	45.33	44.00	1994.52
W14X22	19.25	22.00	423.50
W14X22	19.25	22.00	423.50
W12X40	8.00	40.00	320.00
W12X40	8.42	40.00	336.80
W12X40	8.50	40.00	340.00
W12X40	10.00	40.00	400.00
W12X40	8.50	40.00	340.00
W12X40	10.00	40.00	400.00
W12X40	8.50	40.00	340.00
W12X40	10.00	40.00	400.00
W12X40	8.50	40.00	340.00
W8X10	7.46	10.00	74.60
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	3.70	16.00	59.20
W10X12	10.00	12.00	120.00
W21X55	30.00	55.00	1650.00
W21X62	34.33	62.00	2128.46
W24X55	32.84	55.00	1806.20
W24X55	34.23	55.00	1882.65
W30X99	45.33	99.00	4487.67
W18X35	30.00	35.00	1050.00
W21X83	34.33	83.00	2849.39
W27X84	43.00	84.00	3612.00
W21X44	45.33	44.00	1994.52

Week 3 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W21X44	22.08	44.00	971.52
W24X55	30.00	55.00	1650.00
W21X50	30.00	50.00	1500.00
W21X50	30.00	50.00	1500.00
W21X62	34.33	62.00	2128.46
W21X50	45.33	50.00	2266.50
W21X50	45.33	50.00	2266.50
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W12X16	4.08	16.00	65.28
W12X16	9.00	16.00	144.00
W12X19	13.92	19.00	264.48
W14X22	18.37	22.00	404.14
W14X22	22.82	22.00	502.04
W16X26	27.32	26.00	710.32
W21X44	43.00	44.00	1892.00
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W30X116	30.00	116.00	3480.00
W18X35	30.00	35.00	1050.00
W16X57	30.00	57.00	1710.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X19	11.00	19.00	209.00
W12X19	11.00	19.00	209.00
W8X10	11.00	10.00	110.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	11.04	16.00	176.64
W12X16	11.04	16.00	176.64
W12X16	11.04	16.00	176.64
W12X16	11.04	16.00	176.64
W14X22	15.35	22.00	337.70
W14X22	2.25	22.00	49.50
W12X106	19.37	106.00	2053.22
W12X96	9.22	96.00	885.12
W12X96	11.07	96.00	1062.72
MC10X25	19.25	25.00	481.25
MC10X25	19.25	25.00	481.25
HSS8X8X1/2	22.62	48.70	1101.59
HSS8X8X1/2	11.06	48.70	538.62
HSS8X8X1/2	12.44	48.70	605.83
HSS7X7X1/2	16.78	41.90	703.08
HSS7X7X1/2	16.78	41.90	703.08
HSS7X7X1/2	16.78	41.90	703.08
HSS7X7X1/2	16.78	41.90	703.08

Week 3 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X96	26.37	96.00	2531.52
Sub Total (lbs)			161254.54

Week 3 Total (tons)	124.30

Week 4 Column Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
HSS8X8X5/16	18.53	31.80	589.25
W10X30	4.15	30.00	124.50
W10X30	6.49	30.00	194.70
W10X30	4.39	30.00	131.70
W10X30	6.00	30.00	180.00
W10X30	6.75	30.00	202.50
HSS8X8X1/2	6.72	48.70	327.26
Sub Total (lbs)			1749.92

Week 4 Framing Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X50	45.33	50.00	2266.50
W30X99	45.33	99.00	4487.67
W12X26	12.33	26.00	320.58
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W21X111	42.33	111.00	4698.63
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W14X34	10.00	34.00	340.00
W18X40	10.00	40.00	400.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W18X40	10.00	40.00	400.00
W18X50	30.00	50.00	1500.00
W21X50	30.00	50.00	1500.00
W14X22	19.25	22.00	423.50

Week 4 Framing Schedule Cont.			
Type	Length	Weight	Weight
	(ft)	(lbs/ft)	(lbs)
W14X22	19.25	22.00	423.50
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X16	6.00	16.00	96.00
W12X16	10.00	16.00	160.00
W24X55	30.00	55.00	1650.00
W21X62	30.00	62.00	1860.00
W12X19	19.25	19.00	365.75
W14X22	23.50	22.00	517.00
W12X16	15.25	16.00	244.00
W12X16	15.25	16.00	244.00
W8X10	6.00	10.00	60.00
W14X34	19.25	34.00	654.50
W12X96	30.00	96.00	2880.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	17.50	26.00	455.00
W18X35	30.00	35.00	1050.00
W21X50	29.83	50.00	1491.50
W21X55	30.00	55.00	1650.00
W21X68	45.33	68.00	3082.44
W24X76	29.83	76.00	2267.08
W21X44	43.00	44.00	1892.00
W21X44	43.00	44.00	1892.00
W30X99	43.00	99.00	4257.00
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
W12X16	9.83	16.00	157.28
W12X16	9.83	16.00	157.28
W12X16	9.83	16.00	157.28
HSS8X4X1/4	10.00	19.00	190.00
HSS8X4X1/4	10.00	19.00	190.00
W12X19	10.00	19.00	190.00
W12X106	17.19	106.00	1822.14
W12X152	36.81	152.00	5595.12
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	10.75	16.00	172.00
W12X16	10.75	16.00	172.00
W12X16	10.75	16.00	172.00
W21X93	30.00	93.00	2790.00
W24X55	39.79	55.00	2188.45
W24X55	30.65	55.00	1685.75
W24X55	30.00	55.00	1650.00
W27X258	30.00	258.00	7740.00
W21X83	30.00	83.00	2490.00

Week 4 Framing Schedule Cont.			
Type	Length	Weight	Weight
	(ft)	(lbs/ft)	(lbs)
W21X44	45.33	44.00	1994.52
W21X55	45.33	55.00	2493.15
W21X55	45.33	55.00	2493.15
W18X35	31.77	35.00	1111.95
W18X35	36.23	35.00	1268.05
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W14X34	19.25	34.00	654.50
W12X14	10.00	14.00	140.00
W12X14	9.50	14.00	133.00
W10X12	10.00	12.00	120.00
W10X12	6.50	12.00	78.00
W12X14	10.00	14.00	140.00
W8X10	3.50	10.00	35.00
W12X16	10.00	16.00	160.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W10X12	6.00	12.00	72.00
W12X106	10.80	106.00	1144.80
HSS8X8X1/2	28.49	48.70	1387.46
HSS8X8X1/2	12.77	48.70	621.90
HSS8X8X1/2	14.60	48.70	711.02
HSS8X8X1/2	23.51	48.70	1144.94
W12X120	32.90	120.00	3948.00
HSS8X8X1/2	23.26	48.70	1132.76
HSS8X8X1/2	23.26	48.70	1132.76
HSS8X8X1/2	23.26	48.70	1132.76
HSS8X8X1/2	23.26	48.70	1132.76
W12X96	30.90	96.00	2966.40
HSS8X8X1/2	22.24	48.70	1083.09
HSS5X5X5/16	5.69	19.00	108.11
W16X36	8.17	36.00	294.12
W16X36	8.17	36.00	294.12
W16X36	8.17	36.00	294.12
W16X36	9.61	36.00	345.96
W16X36	9.04	36.00	325.44
W16X36	10.00	36.00	360.00
W16X36	9.83	36.00	353.88
W16X36	8.40	36.00	302.40
W16X36	7.69	36.00	276.84
W16X36	10.00	36.00	360.00
W16X36	19.83	36.00	713.88
W16X36	17.00	36.00	612.00
W16X36	17.00	36.00	612.00
W16X36	10.00	36.00	360.00
W16X36	10.00	36.00	360.00
W16X36	10.00	36.00	360.00
W12X30	10.00	30.00	300.00
W12X30	9.83	30.00	294.90
W16X36	17.00	36.00	612.00

Week 4 Framing Schedule Cont.			
Type	Length	Weight	Weight
	(ft)	(lbs/ft)	(lbs)
HSS5X5X5/16	5.83	19.00	110.77
HSS5X5X5/16	11.50	19.00	218.50
HSS5X5X5/16	9.83	19.00	186.77
HSS5X5X5/16	10.00	19.00	190.00
HSS5X5X5/16	10.00	19.00	190.00
W16X36	8.17	36.00	294.12
W12X30	7.50	30.00	225.00
W12X30	4.00	30.00	120.00
W12X30	7.05	30.00	211.50
W16X36	17.00	36.00	612.00
W24X68	26.00	68.00	1768.00
HSS6X6X1/2	6.29	35.10	220.78
HSS6X6X1/2	5.52	35.10	193.75
HSS6X6X1/2	4.76	35.10	167.08
HSS6X6X1/2	4.00	35.10	140.40
HSS6X6X1/2	6.54	35.10	229.55
HSS6X6X1/2	6.54	35.10	229.55
HSS6X6X1/2	6.54	35.10	229.55
HSS6X6X1/2	6.54	35.10	229.55
HSS8X8X1/2	19.83	48.70	965.72
HSS8X8X1/2	10.00	48.70	487.00
HSS8X8X1/2	19.33	48.70	941.37
HSS8X8X1/2	17.00	48.70	827.90
Sub Total (lbs)			172865.79
Week 4 Total (tons)			87.31

Week 5 Column Schedule			
Type	Length	Weight	Weight
	(ft)	(lbs/ft)	(lbs)
W14X90	27.00	90.00	117.00
W14X90	27.00	90.00	117.00
W14X90	27.00	90.00	117.00
W14X90	27.00	90.00	117.00
W14X61	27.00	61.00	88.00
W14X61	27.00	61.00	88.00
W14X120	27.00	120.00	147.00
W14x68	27.00	68.00	95.00
W14X109	27.00	109.00	136.00
W14X90	27.00	90.00	117.00
W14X90	27.00	90.00	117.00
W14X90	27.00	90.00	117.00
W14X159	27.00	159.00	186.00
W14X159	27.00	159.00	186.00
W14X120	27.00	120.00	147.00
W14X120	27.00	120.00	147.00
W14X120	27.00	120.00	147.00
W12X96	27.00	96.00	123.00
W12X96	27.00	96.00	123.00
W12X96	27.00	96.00	123.00
W12X96	27.00	96.00	123.00
HSS8X8X5/16	11.03	31.80	42.83
HSS8X8X5/16	11.72	31.80	43.52
HSS8X8X5/16	11.03	31.80	42.83
Sub Total (lbs)			2807.18

Week 5 Framing Schedule			
Type	Length	Weight	Weight
	(ft)	(lbs/ft)	(lbs)
W12X26	12.33	26.00	320.58
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	29.83	55.00	1640.65
W21X44	45.33	44.00	1994.52
W27X84	43.00	84.00	3612.00
W18X35	30.00	35.00	1050.00
W16X26	17.50	26.00	455.00
W30X99	45.33	99.00	4487.67
W16X77	30.00	77.00	2310.00
W21X55	30.00	55.00	1650.00
W21X50	29.83	50.00	1491.50
W21X111	42.33	111.00	4698.63
W18X50	30.00	50.00	1500.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W18X40	10.00	40.00	400.00
W18X40	10.00	40.00	400.00
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X50	45.33	50.00	2266.50
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	43.00	44.00	1892.00
W21X44	43.00	44.00	1892.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W21X50	30.00	50.00	1500.00
W14X22	19.25	22.00	423.50
W14X22	19.25	22.00	423.50
HSS8X4X1/4	10.00	19.00	190.00
HSS8X4X1/4	10.00	19.00	190.00
W12X19	10.00	19.00	190.00
W12X19	10.75	19.00	204.25

Week 5 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	19.25	19.00	365.75
W12X19	10.75	19.00	204.25
W21X62	30.00	62.00	1860.00
W12X16	16.25	16.00	260.00
W8X10	6.00	10.00	60.00
W14X22	22.67	22.00	498.74
W12X16	16.25	16.00	260.00
W14X34	19.25	34.00	654.50
W12X96	30.00	96.00	2880.00
W12X16	9.83	16.00	157.28
W12X16	9.83	16.00	157.28
W12X16	9.83	16.00	157.28
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X62	30.00	62.00	1860.00
W24X68	34.33	68.00	2334.44
W30X99	45.33	99.00	4487.67
W18X35	30.00	35.00	1050.00
W21X83	34.33	83.00	2849.39
W27X84	43.00	84.00	3612.00
W21X44	45.33	44.00	1994.52
W21X44	22.08	44.00	971.52
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W21X50	30.00	50.00	1500.00
W21X50	30.00	50.00	1500.00
W21X62	34.33	62.00	2128.46
W21X83	30.00	83.00	2490.00
W27X258	30.00	258.00	7740.00
W21X55	45.33	55.00	2493.15
W21X55	45.33	55.00	2493.15
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X50	45.33	50.00	2266.50
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X50	45.33	50.00	2266.50
W21X44	43.00	44.00	1892.00
W14X34	19.25	34.00	654.50
W30X116	30.00	116.00	3480.00
W16X57	30.00	57.00	1710.00
W16X26	30.00	26.00	780.00
Week 5 Total (tons)			100.98

Week 5 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W18X35	30.00	35.00	1050.00
W14X22	10.00	22.00	220.00
W14X22	10.00	22.00	220.00
W12X19	10.00	19.00	190.00
W12X19	10.00	19.00	190.00
W8X10	10.00	10.00	100.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W10X12	10.00	12.00	120.00
W10X12	6.50	12.00	78.00
W8X10	3.50	10.00	35.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W14X22	10.00	22.00	220.00
W10X12	6.00	12.00	72.00
W8X10	2.75	10.00	27.50
W8X10	2.75	10.00	27.50
W12X16	12.08	16.00	193.28
W12X16	12.08	16.00	193.28
W12X16	12.08	16.00	193.28
W12X16	12.08	16.00	193.28
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
HSS8X8X1/2	23.47	48.70	1142.99
W12X120	33.04	120.00	3964.80
W14X22	15.33	22.00	337.26
W14X22	2.25	22.00	49.50
HSS8X8X1/2	23.51	48.70	1144.94
W12X106	32.90	106.00	3487.40
HSS7X7X1/2	19.09	41.90	799.87
HSS7X7X1/2	21.32	41.90	893.31
HSS7X7X1/2	19.09	41.90	799.87
HSS7X7X1/2	21.32	41.90	893.31
HSS5X5X3/8	16.80	22.30	374.64
HSS5X5X3/8	16.80	22.30	374.64
HSS5X5X3/8	16.78	22.30	374.19
HSS5X5X3/8	16.78	22.30	374.19
W10X88	32.90	88.00	2895.20
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	10.75	16.00	172.00
W12X16	10.75	16.00	172.00
W12X16	10.75	16.00	172.00
Sub Total (lbs)			199161.29

Week 6 Column Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W14x68	27.00	68.00	1836.00
W14x68	27.00	68.00	1836.00
W14x68	27.00	68.00	1836.00
W14x68	27.00	68.00	1836.00
W14X74	27.00	74.00	1998.00
W14X61	27.00	61.00	1647.00
W14X61	27.00	61.00	1647.00
W14X61	27.00	61.00	1647.00
W14X82	27.00	82.00	2214.00
W14X82	27.00	82.00	2214.00
W14X109	27.00	109.00	2943.00
W14X109	27.00	109.00	2943.00
W14X90	27.00	90.00	2430.00
W14X90	27.00	90.00	2430.00
W14X90	27.00	90.00	2430.00
W14X145	27.00	145.00	3915.00
W14X145	27.00	145.00	3915.00
HSS8X8X5/16	11.03	31.80	350.75
HSS8X8X5/16	11.03	31.80	350.75
HSS8X8X5/16	11.72	31.80	372.70
Sub Total (lbs)			40791.20

Week 6 Framing Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X26	12.33	26.00	320.58
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	29.83	55.00	1640.65
W27X84	43.00	84.00	3612.00
W18X35	30.00	35.00	1050.00
W16X26	17.50	26.00	455.00
W30X99	45.33	99.00	4487.67
W21X50	29.83	50.00	1491.50
W21X111	42.33	111.00	4698.63
W21X55	30.00	55.00	1650.00
W16X77	30.00	77.00	2310.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W18X40	10.00	40.00	400.00
W18X40	10.00	40.00	400.00
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52

Week 6 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	43.00	44.00	1892.00
W21X44	43.00	44.00	1892.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W18X50	30.00	50.00	1500.00
W21X50	45.33	50.00	2266.50
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W12X96	30.00	96.00	2880.00
W14X34	19.25	34.00	654.50
HSS8X4X1/4	10.00	19.00	190.00
HSS8X4X1/4	10.00	19.00	190.00
W12X19	10.00	19.00	190.00
W21X50	30.00	50.00	1500.00
W14X22	19.25	22.00	423.50
W14X22	19.25	22.00	423.50
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	19.25	19.00	365.75
W12X19	10.75	19.00	204.25
W21X62	30.00	62.00	1860.00
W14X22	22.67	22.00	498.74
W12X16	15.75	16.00	252.00
W12X16	15.75	16.00	252.00
W8X10	5.00	10.00	50.00
W12X16	9.83	16.00	157.28
W12X16	9.83	16.00	157.28
W12X16	9.83	16.00	157.28
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
HSS8X8X1/2	23.39	48.70	1139.09
W12X106	32.88	106.00	3485.28
W21X83	34.33	83.00	2849.39
W21X44	45.33	44.00	1994.52
W21X44	22.08	44.00	971.52
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W21X50	30.00	50.00	1500.00
W21X62	34.33	62.00	2128.46
W21X83	30.00	83.00	2490.00
W27X258	30.00	258.00	7740.00
W21X55	45.33	55.00	2493.15

Week 6 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X50	45.33	50.00	2266.50
W21X50	45.33	50.00	2266.50
W21X44	43.00	44.00	1892.00
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W14X34	19.25	34.00	654.50
W30X116	30.00	116.00	3480.00
W16X57	30.00	57.00	1710.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W18X35	30.00	35.00	1050.00
W14X22	10.00	22.00	220.00
W14X22	10.00	22.00	220.00
W12X19	10.00	19.00	190.00
W12X19	10.00	19.00	190.00
W8X10	10.00	10.00	100.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W10X12	10.00	12.00	120.00
W10X12	6.50	12.00	78.00
W8X10	3.50	10.00	35.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W14X22	10.00	22.00	220.00
W10X12	6.00	12.00	72.00
W8X10	2.75	10.00	27.50
W8X10	2.75	10.00	27.50
W24X55	30.00	55.00	1650.00
W24X62	30.00	62.00	1860.00
W24X68	34.33	68.00	2334.44
W30X99	45.33	99.00	4487.67
W18X35	30.00	35.00	1050.00
W21X50	30.00	50.00	1500.00
W21X55	45.33	55.00	2493.15
W12X16	12.08	16.00	193.28
W12X16	12.08	16.00	193.28
W12X16	12.08	16.00	193.28
W12X16	12.08	16.00	193.28
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00

Week 6 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W27X84	43.00	84.00	3612.00
W14X22	15.33	22.00	337.26
W14X22	2.25	22.00	49.50
HSS7X7X1/2	23.51	41.90	985.07
W12X96	32.90	96.00	3158.40
HSS7X7X1/2	19.09	41.90	799.87
HSS7X7X1/2	21.32	41.90	893.31
HSS5X5X3/8	16.80	22.30	374.64
HSS5X5X3/8	16.80	22.30	374.64
HSS5X5X3/8	16.78	22.30	374.19
HSS5X5X3/8	16.78	22.30	374.19
W10X88	32.90	88.00	2895.20
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	10.75	16.00	172.00
W12X16	10.75	16.00	172.00
W12X16	10.75	16.00	172.00
Sub Total (lbs)			193169.83
Week 6 Total (tons)			116.98

Week 7 Column Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W14x68	27.00	68.00	1836.00
W14x68	27.00	68.00	1836.00
W14x68	27.00	68.00	1836.00
W14x68	27.00	68.00	1836.00
W14x68	27.00	68.00	1836.00
W14X74	27.00	74.00	1998.00
W14X74	27.00	74.00	1998.00
W14X61	27.00	61.00	1647.00
W14X61	27.00	61.00	1647.00
W14X61	27.00	61.00	1647.00
W14X90	27.00	90.00	2430.00
W14X90	27.00	90.00	2430.00
W14X109	27.00	109.00	2943.00
W14X109	27.00	109.00	2943.00
W14X90	27.00	90.00	2430.00
W14X90	27.00	90.00	2430.00
W14X90	27.00	90.00	2430.00
W12X96	27.00	96.00	2592.00
W12X96	27.00	96.00	2592.00
W12X96	27.00	96.00	2592.00
W12X96	27.00	96.00	2592.00
HSS8X8X5/16	11.03	31.80	350.75
HSS8X8X5/16	11.72	31.80	372.70
HSS8X8X5/16	11.03	31.80	350.75
Sub Total (lbs)			47595.20

Week 7 Framing Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	29.83	55.00	1640.65
W27X84	43.00	84.00	3612.00
W18X35	30.00	35.00	1050.00
W16X26	17.50	26.00	455.00
W30X99	45.33	99.00	4487.67
W21X50	29.83	50.00	1491.50
W21X111	42.33	111.00	4698.63
W21X55	30.00	55.00	1650.00
W16X77	30.00	77.00	2310.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W18X40	10.00	40.00	400.00
W18X40	10.00	40.00	400.00
W18X50	30.00	50.00	1500.00
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	43.00	44.00	1892.00
W21X44	43.00	44.00	1892.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W12X96	30.00	96.00	2880.00
W14X34	19.25	34.00	654.50
HSS8X4X1/4	10.00	19.00	190.00
HSS8X4X1/4	10.00	19.00	190.00
W12X26	12.33	26.00	320.58
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W21X44	45.33	44.00	1994.52
W12X19	10.00	19.00	190.00
W21X50	30.00	50.00	1500.00
W14X22	19.25	22.00	423.50
W14X22	19.25	22.00	423.50
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25

Week 7 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X19	10.75	19.00	204.25
W12X19	19.25	19.00	365.75
W12X19	10.75	19.00	204.25
W21X62	30.00	62.00	1860.00
W14X22	22.67	22.00	498.74
W12X16	15.75	16.00	252.00
W12X16	15.75	16.00	252.00
W8X10	5.00	10.00	50.00
W12X16	9.83	16.00	157.28
W12X16	9.83	16.00	157.28
W12X16	9.83	16.00	157.28
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X50	45.33	50.00	2266.50
W14X34	10.00	34.00	340.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X62	30.00	62.00	1860.00
W24X68	34.33	68.00	2334.44
W30X99	45.33	99.00	4487.67
W18X35	30.00	35.00	1050.00
W21X83	34.33	83.00	2849.39
W21X44	45.33	44.00	1994.52
W21X44	22.08	44.00	971.52
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W21X50	30.00	50.00	1500.00
W21X50	30.00	50.00	1500.00
W21X62	34.33	62.00	2128.46
W16X77	30.00	77.00	2310.00
W21X83	30.00	83.00	2490.00
W27X258	30.00	258.00	7740.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W18X40	10.00	40.00	400.00
W18X40	10.00	40.00	400.00
W21X55	45.33	55.00	2493.15
W21X55	45.33	55.00	2493.15
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X50	45.33	50.00	2266.50
W21X50	45.33	50.00	2266.50
W21X44	43.00	44.00	1892.00
W21X44	45.33	44.00	1994.52

Week 7 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W14X34	19.25	34.00	654.50
W14X34	19.25	34.00	654.50
W30X116	30.00	116.00	3480.00
W16X57	30.00	57.00	1710.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W18X35	30.00	35.00	1050.00
W14X22	10.00	22.00	220.00
W14X22	10.00	22.00	220.00
W12X19	10.00	19.00	190.00
W12X19	10.00	19.00	190.00
W8X10	10.00	10.00	100.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W10X12	10.00	12.00	120.00
W10X12	6.50	12.00	78.00
W8X10	3.50	10.00	35.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W14X22	10.00	22.00	220.00
W10X12	6.00	12.00	72.00
W8X10	2.75	10.00	27.50
W8X10	2.75	10.00	27.50
HSS8X4X1/4	10.00	19.00	190.00
HSS8X4X1/4	10.00	19.00	190.00
W12X19	10.00	19.00	190.00
W21X50	30.00	50.00	1500.00
W14X22	19.25	22.00	423.50
W14X22	19.25	22.00	423.50
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X16	12.08	16.00	193.28
W12X16	12.08	16.00	193.28
W12X16	12.08	16.00	193.28
W12X16	12.08	16.00	193.28
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W27X84	43.00	84.00	3612.00

Week 7 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
HSS7X7X1/2	23.47	41.90	983.39
W12X96	32.76	96.00	3144.96
W14X22	15.33	22.00	337.26
W14X22	2.25	22.00	49.50
HSS7X7X1/2	23.51	41.90	985.07
W12X96	32.90	96.00	3158.40
HSS7X7X1/2	19.09	41.90	799.87
HSS7X7X1/2	21.32	41.90	893.31
HSS5X5X5/16	16.80	19.00	319.20
HSS5X5X5/16	16.80	19.00	319.20
HSS5X5X5/16	16.80	19.00	319.20
HSS5X5X5/16	16.80	19.00	319.20
HSS5X5X5/16	16.78	19.00	318.82
HSS5X5X5/16	16.78	19.00	318.82
HSS5X5X5/16	16.78	19.00	318.82
HSS5X5X5/16	16.80	19.00	319.20
W10X88	32.90	88.00	2895.20
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	10.75	16.00	172.00
W12X16	10.75	16.00	172.00
W12X16	10.75	16.00	172.00
Sub Total (lbs)			223148.741
Week 7 Total (tons)			135.37

Week 8 Column Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W14X61	24.00	61.00	1464.00
W14X61	24.00	61.00	1464.00
W14X61	24.30	61.00	1482.30
W14X61	24.33	61.00	1484.13
W14X61	24.33	61.00	1484.13
W14X61	24.33	61.00	1484.13
W14X61	24.33	61.00	1484.13
W14X61	24.30	61.00	1482.30
W14X61	24.33	61.00	1484.13
W14X61	24.33	61.00	1484.13
W14X82	38.21	82.00	3133.22
W14X82	38.21	82.00	3133.22
W14X82	38.21	82.00	3133.22
W14X82	34.92	82.00	2863.44
W14X82	34.92	82.00	2863.44
W14X132	23.38	132.00	3086.16
W14X132	23.38	132.00	3086.16
HSS8X8X5/16	11.03	31.80	350.75
HSS8X8X5/16	11.03	31.80	350.75
HSS8X8X5/16	11.72	31.80	372.70
HSS8X8X5/16	12.32	31.80	391.78
Sub Total (lbs)			37562.22

Week 8 Framing Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X26	12.33	26.00	320.58
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	29.83	55.00	1640.65
W27X84	43.00	84.00	3612.00
W18X35	30.00	35.00	1050.00
W16X26	17.50	26.00	455.00
W30X99	45.33	99.00	4487.67
W21X50	29.83	50.00	1491.50
W21X111	42.33	111.00	4698.63
W21X55	30.00	55.00	1650.00
W18X50	30.00	50.00	1500.00
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	43.00	44.00	1892.00
W21X44	43.00	44.00	1892.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W12X96	30.00	96.00	2880.00
W12X19	10.75	19.00	204.25
W12X19	19.25	19.00	365.75
W12X19	10.75	19.00	204.25
W21X62	30.00	62.00	1860.00
W14X22	22.67	22.00	498.74
W12X16	15.75	16.00	252.00
W12X16	15.75	16.00	252.00
W12X16	9.83	16.00	157.28
W12X16	9.83	16.00	157.28
W12X16	9.83	16.00	157.28
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
W21X50	45.33	50.00	2266.50
W24X55	30.00	55.00	1650.00
W24X55	34.33	55.00	1888.15
W24X62	30.00	62.00	1860.00
W30X99	45.33	99.00	4487.67
W18X35	30.00	35.00	1050.00
W21X83	34.33	83.00	2849.39
W27X84	43.00	84.00	3612.00
W21X44	45.33	44.00	1994.52
W21X44	43.00	44.00	1892.00
W21X44	22.08	44.00	971.52
W24X55	30.00	55.00	1650.00

Week 8 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W24X55	30.00	55.00	1650.00
W21X50	30.00	50.00	1500.00
W21X50	30.00	50.00	1500.00
W21X62	34.33	62.00	2128.46
W21X83	30.00	83.00	2490.00
W14X34	19.25	34.00	654.50
W16X57	30.00	57.00	1710.00
W27X129	30.00	129.00	3870.00
W30X90	30.00	90.00	2700.00
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X50	45.33	50.00	2266.50
W21X50	45.33	50.00	2266.50
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W21X55	45.33	55.00	2493.15
W21X55	45.33	55.00	2493.15
W14X22	10.00	22.00	220.00
W14X22	10.00	22.00	220.00
W16X26	30.00	26.00	780.00
W18X35	30.00	35.00	1050.00
W12X19	10.00	19.00	190.00
W12X19	10.00	19.00	190.00
W8X10	10.00	10.00	100.00
W16X26	30.00	26.00	780.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W10X12	10.00	12.00	120.00
W10X12	6.50	12.00	78.00
W8X10	3.50	10.00	35.00
W16X26	30.00	26.00	780.00
W14X22	10.00	22.00	220.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W10X12	6.00	12.00	72.00
W8X10	2.75	10.00	27.50
W8X10	2.75	10.00	27.50
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.08	16.00	193.28
W12X16	12.08	16.00	193.28

Week 8 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X16	12.08	16.00	193.28
W12X16	12.08	16.00	193.28
HSS7X7X1/2	23.40	41.90	980.46
W12X96	32.88	96.00	3156.48
W30X108	30.00	108.00	3240.00
W27X129	30.00	129.00	3870.00
W27X84	43.00	84.00	3612.00
W33X130	34.35	130.00	4465.50
W21X44	22.08	44.00	971.52
W27X84	45.34	84.00	3808.56
W24X62	30.00	62.00	1860.00
W24X62	30.00	62.00	1860.00
W27X84	45.34	84.00	3808.56
W27X84	45.34	84.00	3808.56
W27X84	45.34	84.00	3808.56
W27X84	45.34	84.00	3808.56
W27X84	45.34	84.00	3808.56
W24X62	43.00	62.00	2666.00
W10X22	11.43	22.00	251.46
W10X22	11.50	22.00	253.00
W12X16	10.66	16.00	170.56
W12X16	10.66	16.00	170.56
W12X16	10.66	16.00	170.56
W16X26	10.67	26.00	277.42
W10X22	8.67	22.00	190.74
W10X22	5.31	22.00	116.82
W10X22	11.46	22.00	252.12
W14X22	15.33	22.00	337.26
W14X22	2.25	22.00	49.50
W16X26	15.33	26.00	398.58
W16X26	2.25	26.00	58.50
HSS6X6X1/2	23.51	35.10	825.20
HSS7X7X1/2	19.09	41.90	799.87
HSS7X7X1/2	21.32	41.90	893.31
W10X77	32.90	77.00	2533.30
HSS5X5X5/16	3.36	19.00	63.84
HSS5X5X5/16	4.87	19.00	92.53
HSS5X5X5/16	5.54	19.00	105.26
HSS5X5X5/16	6.04	19.00	114.76
HSS5X5X5/16	5.54	19.00	105.26
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	10.75	16.00	172.00
W12X16	10.75	16.00	172.00
W12X16	10.75	16.00	172.00
Sub Total (lbs)			204426.48

Week 8 Total (tons)	120.99

Week 9 Column Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W14X61	9.50	61.00	579.50
W14X61	24.00	61.00	1464.00
W14X61	24.00	61.00	1464.00
W14X61	24.33	61.00	1484.13
W14X61	23.38	61.00	1426.18
W14X61	23.38	61.00	1426.18
W14X61	23.38	61.00	1426.18
W14X61	24.33	61.00	1484.13
W14X61	24.33	61.00	1484.13
W14X61	24.33	61.00	1484.13
W14X61	24.33	61.00	1484.13
W14X82	38.21	82.00	3133.22
W14X82	38.21	82.00	3133.22
W14X82	38.83	82.00	3184.06
W14X82	36.32	82.00	2978.24
W14X82	38.83	82.00	3184.06
W14X61	23.38	61.00	1426.18
W12X96	28.33	96.00	2719.68
W12X96	28.33	96.00	2719.68
W12X96	23.38	96.00	2244.48
W12X96	23.38	96.00	2244.48
HSS8X8X3/8	14.31	37.60	538.06
HSS8X8X5/16	11.03	31.80	350.75
HSS8X8X5/16	13.38	31.80	425.48
Sub Total (lbs)			43488.28

Week 9 Framing Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X26	12.33	26.00	320.58
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W21X44	29.83	44.00	1312.52
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W36X160	43.00	160.00	6880.00
W18X35	30.00	35.00	1050.00
W16X26	17.50	26.00	455.00
W30X99	45.33	99.00	4487.67
W21X44	29.83	44.00	1312.52
W16X77	30.00	77.00	2310.00
W21X111	42.33	111.00	4698.63
W12X96	30.00	96.00	2880.00
W14X34	19.25	34.00	654.50
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W18X40	10.00	40.00	400.00
W18X40	10.00	40.00	400.00
W18X50	30.00	50.00	1500.00
W16X77	30.00	77.00	2310.00
W21X44	45.33	44.00	1994.52

Week 9 Framing Schedule Cont.			
Type	Length	Weight	Weight
	(ft)	(lbs/ft)	(lbs)
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X44	45.33	44.00	1994.52
W21X50	45.33	50.00	2266.50
W21X50	30.00	50.00	1500.00
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W14X22	19.25	22.00	423.50
W14X22	19.25	22.00	423.50
HSS8X4X1/4	10.00	19.00	190.00
HSS8X4X1/4	10.00	19.00	190.00
W12X19	10.00	19.00	190.00
W21X62	30.00	62.00	1860.00
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	19.25	19.00	365.75
W14X22	22.67	22.00	498.74
W12X16	15.75	16.00	252.00
W12X16	15.75	16.00	252.00
W8X10	6.00	10.00	60.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W21X101	45.33	101.00	4578.33
W21X44	29.83	44.00	1312.52
W12X19	25.00	19.00	475.00
W12X19	25.00	19.00	475.00
W12X19	18.00	19.00	342.00
W12X19	18.00	19.00	342.00
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
HSS6X6X1/2	23.68	35.10	831.17
W10X88	32.90	88.00	2895.20
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X68	45.33	68.00	3082.44
W24X55	45.35	55.00	2494.25
W21X44	45.34	44.00	1994.96
W21X44	45.34	44.00	1994.96

Week 9 Framing Schedule Cont.			
Type	Length	Weight	Weight
	(ft)	(lbs/ft)	(lbs)
W21X44	45.35	44.00	1995.40
W21X44	45.34	44.00	1994.96
W21X44	45.34	44.00	1994.96
W21X44	45.35	44.00	1995.40
W24X68	34.33	68.00	2334.44
W27X84	30.00	84.00	2520.00
W21X147	30.00	147.00	4410.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W18X40	10.00	40.00	400.00
W30X90	30.00	90.00	2700.00
W16X67	30.00	67.00	2010.00
W14X48	19.25	48.00	924.00
W10X22	10.00	22.00	220.00
W10X22	10.00	22.00	220.00
W10X22	10.00	22.00	220.00
W21X44	30.00	44.00	1320.00
W21X44	30.00	44.00	1320.00
W21X44	30.00	44.00	1320.00
W14X22	6.33	22.00	139.26
W14X22	6.33	22.00	139.26
W12X19	11.00	19.00	209.00
W12X19	11.00	19.00	209.00
W8X10	11.00	10.00	110.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W16X31	30.00	31.00	930.00
W12X14	10.00	14.00	140.00
W10X12	6.75	12.00	81.00
W8X10	3.25	10.00	32.50
W21X44	30.00	44.00	1320.00
W14X22	10.00	22.00	220.00
W12X14	10.00	14.00	140.00
W12X14	10.00	14.00	140.00
W10X12	6.00	12.00	72.00
W18X40	30.00	40.00	1200.00
W24X62	30.00	62.00	1860.00
W27X84	45.34	84.00	3808.56
W27X84	45.34	84.00	3808.56
W24X68	45.34	68.00	3083.12
W24X68	45.34	68.00	3083.12
W30X99	34.35	99.00	3400.65
W24X55	45.34	55.00	2493.70
W24X55	45.33	55.00	2493.15
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W12X16	12.25	16.00	196.00
W10X22	12.25	22.00	269.50
W10X22	6.00	22.00	132.00
W10X22	10.67	22.00	234.74
W10X22	10.67	22.00	234.74
W10X22	7.83	22.00	172.26
W10X22	11.42	22.00	251.24
W18X35	30.00	35.00	1050.00
W18X35	30.00	35.00	1050.00
W18X35	30.00	35.00	1050.00

Week 9 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X16	10.00	16.00	160.00
W12X16	10.00	16.00	160.00
W12X26	6.46	26.00	167.96
W10X22	6.44	22.00	141.68
W10X22	6.43	22.00	141.46
W10X22	6.44	22.00	141.68
W16X26 2	10.00	26.00	260.00
HSS6X6X1/2	24.04	35.10	843.80
W10X68	33.28	68.00	2263.04
HSS7X7X1/2	19.74	41.90	827.11
HSS7X7X1/2	21.90	41.90	917.61
HSS5X5X5/16	16.80	19.00	319.20
HSS5X5X5/16	16.51	19.00	313.69
HSS5X5X5/16	16.78	19.00	318.82
HSS5X5X5/16	16.80	19.00	319.20
W10X68	32.90	68.00	2237.20
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	1.00	16.00	16.00
W12X16	10.75	16.00	172.00
W12X16	10.75	16.00	172.00
W12X16	10.75	16.00	172.00
Sub Total (lbs)			185567.87
Week 9 Total (tons)			114.53

Week 10 Column Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
HSS8X8X1/4	14.63	25.80	377.45
HSS8X8X1/4	14.63	25.80	377.45
HSS6X6X3/8	4.21	27.40	115.35
HSS6X6X3/8	4.21	27.40	115.35
HSS8X8X5/16	12.49	31.80	397.18
Sub Total (lbs)			1382.80

Week 10 Framing Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W8X10	5.00	10.00	50.00
W30X90	30.00	90.00	2700.00
W27X84	19.25	84.00	1617.00
W27X84	19.25	84.00	1617.00
W12X19	10.00	19.00	190.00
W12X19	10.00	19.00	190.00
W12X19	10.00	19.00	190.00
W12X30	10.00	30.00	300.00
W12X30	10.00	30.00	300.00
W12X19	4.67	19.00	88.73
W12X19	9.63	19.00	182.97
W16X31	9.75	31.00	302.25
W24X62	10.75	62.00	666.50
W16X31	11.81	31.00	366.11
W24X62	10.75	62.00	666.50

Week 10 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W24X68	19.25	68.00	1309.00
W24X68	19.25	68.00	1309.00
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W18X40	10.00	40.00	400.00
W14X34	11.81	34.00	401.54
W24X76	30.00	76.00	2280.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W24X55	30.00	55.00	1650.00
W21X44	45.34	44.00	1994.96
W21X44	45.34	44.00	1994.96
W21X44	45.35	44.00	1995.40
W21X44	45.34	44.00	1994.96
W21X44	45.34	44.00	1994.96
W21X44	45.35	44.00	1995.40
W21X44	45.34	44.00	1994.96
W21X44	45.34	44.00	1994.96
W24X55	45.35	55.00	2494.25
W30X99	45.35	99.00	4489.65
W12X26	12.33	26.00	320.58
W24X62	30.00	62.00	1860.00
W24X76	30.00	76.00	2280.00
W30X90	42.33	90.00	3809.70
W24X55	29.83	55.00	1640.65
W14X34	10.00	34.00	340.00
W14X34	10.00	34.00	340.00
W18X40	10.00	40.00	400.00
W18X50	30.00	50.00	1500.00
W12X106	30.00	106.00	3180.00
W14X48	19.25	48.00	924.00
W10X22	10.00	22.00	220.00
W10X22	10.00	22.00	220.00
W10X22	10.00	22.00	220.00
W10X22	10.00	22.00	220.00
HSS8X4X1/4	10.00	19.00	190.00
W14X22	19.25	22.00	423.50
W24X55	30.00	55.00	1650.00
W12X19	10.00	19.00	190.00
W12X19	10.00	19.00	190.00
W14X22	19.25	22.00	423.50
HSS8X4X1/4	10.00	19.00	190.00
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	10.75	19.00	204.25
W12X19	8.50	19.00	161.50
W12X19	4.50	19.00	85.50
W16X31	30.00	31.00	930.00
W16X31	30.00	31.00	930.00
W12X14	10.00	14.00	140.00
W10X12	5.50	12.00	66.00
W16X26	30.00	26.00	780.00

Week 10 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W21X44	30.00	44.00	1320.00
W21X44	30.00	44.00	1320.00
W16X26	30.00	26.00	780.00
W12X16	11.35	16.00	181.60
W18X35	17.50	35.00	612.50
W18X40	30.00	40.00	1200.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	30.00	26.00	780.00
W16X26	7.46	26.00	193.96
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
W12X16	12.33	16.00	197.28
W10X22	12.33	22.00	271.26
W10X22	6.84	22.00	150.48
W10X22	10.00	22.00	220.00
W10X22	10.00	22.00	220.00
W10X22	7.50	22.00	165.00
W18X40	25.00	40.00	1000.00
W21X44	29.83	44.00	1312.52
W24X62	30.00	62.00	1860.00
W30X116	45.34	116.00	5259.44
W27X84	45.34	84.00	3808.56
W27X84	45.34	84.00	3808.56
W30X90	45.35	90.00	4081.50
W24X68	45.34	68.00	3083.12
W24X68	45.34	68.00	3083.12
W14X22	25.01	22.00	550.22
W14X22	25.01	22.00	550.22
W14X22	25.01	22.00	550.22
W10X22	7.46	22.00	164.12
W10X22	7.46	22.00	164.12
W10X22	7.46	22.00	164.12
W10X22	7.46	22.00	164.12
W10X22	7.46	22.00	164.12
W16X26	7.46	26.00	193.96
W10X22	7.46	22.00	164.12
W16X26	7.46	26.00	193.96
W16X26	7.46	26.00	193.96
W16X26	10.00	26.00	260.00
W16X26	10.00	26.00	260.00
W21X44	30.00	44.00	1320.00
W12X72	30.00	72.00	2160.00
W21X50	30.00	50.00	1500.00
W16X31	30.00	31.00	930.00
W21X50	30.00	50.00	1500.00
W30X124	30.00	124.00	3720.00
W16X31	30.00	31.00	930.00
W16X31	30.00	31.00	930.00
W24X76	30.01	76.00	2280.76
W24X68	30.01	68.00	2040.68
W8X31	10.00	31.00	310.00
W8X31	10.00	31.00	310.00
W12X16	10.00	16.00	160.00
W12X14	10.00	14.00	140.00

Week 10 Framing Schedule Cont.			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W12X16	10.00	16.00	160.00
W8X31	10.00	31.00	310.00
W8X31	10.00	31.00	310.00
W8X31	10.00	31.00	310.00
W12X14	10.01	14.00	140.14
W12X16	10.00	16.00	160.00
W30X124	30.00	124.00	3720.00
W10X68	33.28	68.00	2263.04
HSS6X6X1/2	24.04	35.10	843.80
HSS6X6X3/8	10.50	27.40	287.70
HSS6X6X3/8	10.50	27.40	287.70
HSS6X6X3/8	14.81	27.40	405.79
HSS6X6X3/8	14.81	27.40	405.79
HSS6X6X3/8	10.50	27.40	287.70
HSS6X6X3/8	10.50	27.40	287.70
HSS6X6X3/8	14.34	27.40	392.92
HSS6X6X3/8	14.34	27.40	392.92
W10X88	32.90	88.00	2895.20
HSS7X7X1/2	18.93	41.90	793.17
HSS7X7X1/2	18.93	41.90	793.17
HSS5X5X5/16	17.53	19.00	333.07
HSS5X5X5/16	17.53	19.00	333.07
HSS5X5X5/16	10.85	19.00	206.15
HSS5X5X5/16	10.85	19.00	206.15
HSS7X7X1/2	18.56	41.90	777.66
HSS7X7X1/2	18.21	41.90	763.00
HSS5X5X5/16	17.53	19.00	333.07
HSS5X5X5/16	17.53	19.00	333.07
HSS10X10X5/8	10.69	76.10	813.51
HSS10X10X5/8	21.47	76.10	1633.87
W10X68	33.28	68.00	2263.04
Sub Total (lbs)			151026.05

Week 10 Total (tons)	76.20

Week 11 Column Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
HSS8X8X1/4	11.29	25.80	291.28
HSS8X8X1/4	11.29	25.80	291.28
HSS8X8X1/4	11.29	25.80	291.28
HSS8X8X1/4	14.63	25.80	377.45
HSS8X8X1/4	14.63	25.80	377.45
Sub Total (lbs)			1628.75

Week 11 Framing Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W18X35	45.33	35.00	1586.55
W18X35	45.33	35.00	1586.55
W18X35	30.00	35.00	1050.00
W18X35	15.33	35.00	536.55
W24X76	15.33	76.00	1165.08
W12X19	10.34	19.00	196.46
W12X19	10.34	19.00	196.46
W8X10	10.34	10.00	103.40
W12X14	15.33	14.00	214.62
W21X44	15.33	44.00	674.52
W14X22	20.18	22.00	443.96
W8X31	9.83	31.00	304.73
W12X16	9.83	16.00	157.28
W12X16	9.83	16.00	157.28
W12X19	9.83	19.00	186.77
W24X76	15.33	76.00	1165.08
W16X26	30.01	26.00	780.26
W24X76	15.33	76.00	1165.08
W10X12	15.33	12.00	183.96
W10X12	15.33	12.00	183.96
W12X16	15.33	16.00	245.28
W21X44	30.01	44.00	1320.44
W27X102	30.01	102.00	3061.02
W12X16	5.50	16.00	88.00
W12X16	10.00	16.00	160.00
W16X26	30.01	26.00	780.26
W10X12	15.33	12.00	183.96
W8X10	9.00	10.00	90.00
W12X19	9.00	19.00	171.00
W12X19	9.00	19.00	171.00
W12X72	30.00	72.00	2160.00
W24X76	15.33	76.00	1165.08
HSS7X7X1/2	21.10	41.90	884.09
HSS7X7X1/2	21.09	41.90	883.67
Sub Total (lbs)			23402.35
Week 11 Total (tons)			12.52

Week 12 Column Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
None			
Sub Total (lbs)			0.00

Week 12 Framing Schedule			
Type	Length (ft)	Weight (lbs/ft)	Weight (lbs)
W16X31	30.00	31.00	930.00
W16X31	30.00	31.00	930.00
W12X16	10.00	16.00	160.00
W10X12	15.33	12.00	183.96
2L4X4X3/8	10.27	19.40	199.24
HSS7X7X1/2	21.42	41.90	897.50
HSS7X7X1/2	21.32	41.90	893.31
2L4X4X3/8	10.27	19.40	199.24
HSS8X8X1/2	21.32	48.70	1038.28
HSS8X8X1/2	21.32	48.70	1038.28
Sub Total (lbs)			6469.81
Week 12 Total (tons)			3.23

Appendix D: Design

D.1 GreenGrid Information

LEED Materials Reporting Form - GreenGrid Green Roof Systems

SAMPLE

PROJECT NAME: Unum Insurance Building
VENDOR: Weston Solutions Inc.
SPEC SECTION: Specification Not Provided
CONTACT NAME: Jared Markham, LEED AP BD+C
PHONE: 860-368-3200

Contracted Material Cost (including freight) $171,360.00

Component	Vendor or Manufacturer	Total Material Cost	% of product salvaged refurbished or reused	Recycled Content		% Weight of assembled System	Location and distances from manufacturing point to project site AND raw material harvesting point to project site (Miles)	% of Product that is rapidly renewable
				% Post Consumer	% Pre-Consumer			
GreenGrid G4 Extensive Modules	Weston Solutions	$9,596.16	0%	0%	100%	5.60%	Harvest: Mixed >500Mi Manufacture: Mixed >500mi	0%
GreenGrid Extensive Media (Aggregates)	Weston Solutions	$121,494.24	0%	0%	0%	70.90%	Harvest: Saugerties, NY; 169 mi Manufacture: Saugerties, NY; 169 mi	0%
GreenGrid Extensive Media (Compost)	Weston Solutions	$21,591.36	0%	0%	0%	12.60%	Harvest: Fairfield, CT; 133mi Manufacture: Fairfield, CT; 133 mi	0%
Geosynthetic Liner	Dow	$856.80	0%	0%	0%	0.50%	Harvest: Mixed >500Mi Manufacture: Mixed >500mi	0%
GreenGrid Extensive Plants	Weston Solutions	$17,821.44	0%	0%	0%	10.40%	Harvest: Kensington, CT; 86 mi Manufacture: Kensington, CT; 86 mi	0%

Vendor Certification:

I, **Jared Markham** a duly authorized representative of **Weston Solutions Inc.** herby certify that the material information contained herin is an accurate preresentation of the material qualificationsto be provided by us, as components of the final building construction. Furthermore, I understand that any change in such qualifications during the purchasing period will require written approval from the Construction Manager and Owner.

Signature of Authorized Representative:

Date:

D.2 Design of Beams and Girders

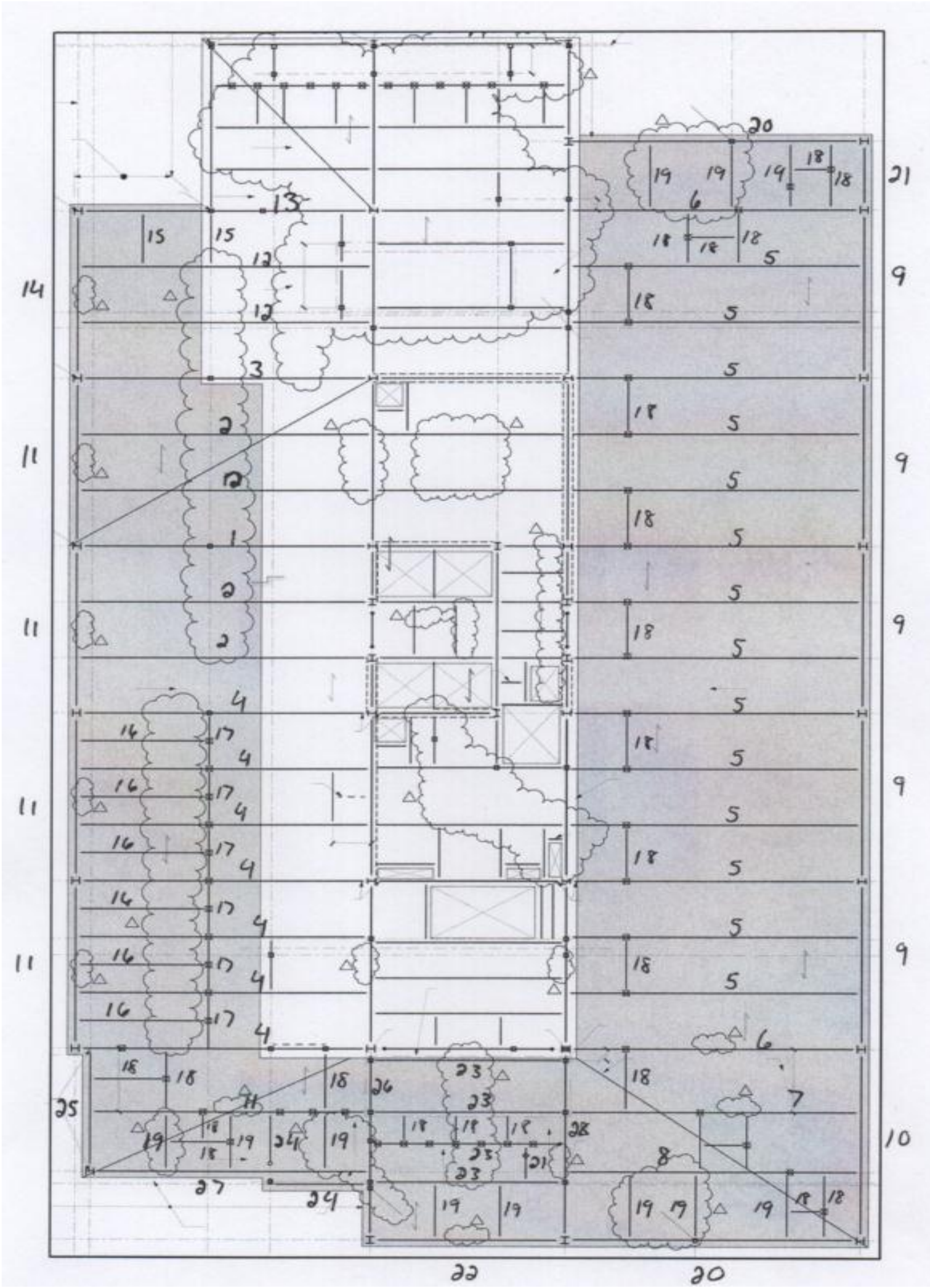


Figure 37 - Load Case Layout (Roof)

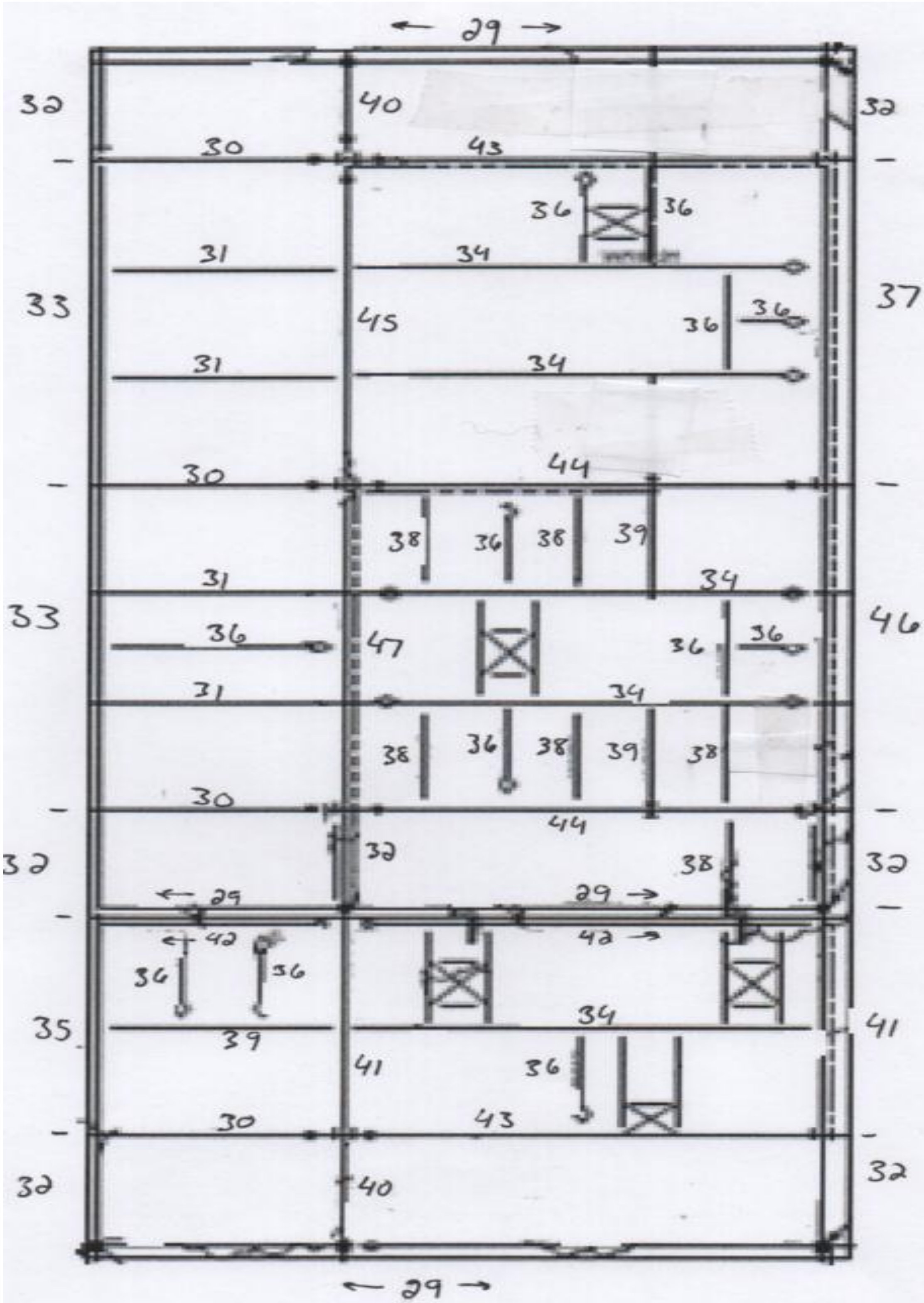


Figure 38 - Load Case Layout (Penthouse Roof)

Hand Calculations for Beams/Girders

Roof Structural Analysis (beam Uniform Load)

LW concrete $f'_c = 4000$ psi

Steel - ASTM A-572 or A992 Grade 50

Metal Roof Deck: 3 inch Type N × 20 gauge

Studs not spaced more than 12" o/c

3/4" ϕ Shear stud connectors

3 1/4" LW Concrete

Total thickness = 6 1/4" → 46psf (Vulcraft)

↳ 46 − 2.14 = 43.86 psf concrete

Loads:

Concrete w/ Ponding: $43.86 \times 1.1 \times 10' = 482.5$ lb/ft

Green Roof = 30psf (10) = 300 lb/ft
Slip Sheet = 2 psf (10) = 20 lb/ft
TPO Membrane = 2psf (10) = 20 lb/ft
Insulation = 2psf (10') = 20 lb/ft
Drop Ceiling = 3psf (10') = 30 lb/ft
MEP = 5psf (10') = 50 lb/ft

Dead Load = 922.5 lb/ft

Roof Live Load = 20psf (10') = 200 lb/ft

Roof Snow Load = 55psf (10') = 550 lb/ft

Load Factors

$1.4D = 1291.5$ lb/ft

$1.2D + 1.6L + 0.5(L_r \text{ or } S) = 1107 + 320 + 275 = 1702$ lb/ft

$1.2D + 0.5L + 1.6(L_r \text{ or } S) = 1107 + 100 + 880 = 2087$ lb/ft → governs $= w_u$

$M_u = \frac{w_u l^2}{8} = \frac{2087(45.33)^2}{8000} = 536.05$ k-ft

Effective Flange Width

$b_e = 2\left(\frac{1}{8} \times 45.33 \times 12"\right) = 136"$

$b_e = 2\left(10' \times \frac{1}{2} \times 12"\right) = 120"$ → governs

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W21 x 44 Full Composite Check

Weight = 44 lb/ft PNA Location = TFL $C_1 = 161$
Area = 13 in^2 Y_{con} = 6.25 in $Y_1 = 0$
I_x = 843 in^4 Assume a = 3 in $Y_2 = 6.25 - \frac{3}{2} = 4.75$ in

Dead Load = 922.5 lb/ft + 44 lb/ft = 966.5 lb/ft

$w_u = 1.2(1966.5) + 0.5(200) + 1.6(550) = 2139.8$ lb/ft

$M_u = \frac{2139.8(45.33)^2}{8000} = 549.61$ k·ft

$\Sigma Q_n = 13\text{ in}^2(50\text{ ksi}) = 650$ kips

Actual $a = \frac{650}{0.85(4)(120)} = 1.59"$

Actual $Y_2 = 6.25" - \frac{1.59}{2} = 5.46"$

$I_{LB} = 2370 + \frac{(2470-2370)}{.5}(5.46 - 5) = 2462$ in^4

$\phi M_n = 746 + \frac{(771-746)}{.5}(5.46-5) = 769$ k·ft > 549.61 k·ft ✓ Good

Qn from Table 3-21 AISC

Deck Perpendicular
- Assume Weak Studs 3/4"
- Assume 1 Stud per rib → $Q_n = 17.2$

Number of studs = $\frac{2(650)}{17.2}$ = 76 studs * need 152 overall

Deflection & Strength Checks

Service Deflection Check: $M_L = \frac{(200\text{ lb/ft})(45.33)^2}{8000} = 51.37$ k·ft

$\Delta_L = \frac{51.37(45.33)^2}{161(2462)} = .27$ in < 1 in ✓ Good

Strength: DL = 44 lb/ft LL = 482.5 lb/ft → concrete w/ ponding

$w_u = 1.2(44) + 1.6(482.5) = 824.8$ lb/ft

$M_u = \frac{824.8(45.33)^2}{8000} = 211.85$ k·ft < 769 k·ft ✓ Good

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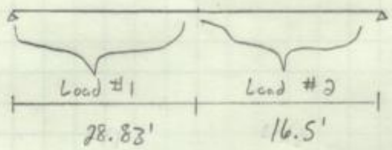
$M_u = \dfrac{526.5\,(45.33)^2}{8000} = 135.23$ k·ft

$\Delta = \dfrac{5\,(135.23)\left(\frac{1}{12000}\right)(45.33 \times 12)^4}{384 \times 29000 \times 843} = \underline{0.53 \text{ in}} < 1 \text{ in}$ ✓ Good

Page 3/

Roof Structural Analysis (Beam non-uniform Load)

W27×84 @ 45.33' long 10' o/c



Load #1:

LW concrete & metal decking 6'1/4"

Concrete w/ponding

= 43.86 × 1.1 × 10' = 482.5 lb/ft

Green Roof = 300 lb/ft
Slip Sheet = 20 lb/ft
TPO membrane = 20 lb/ft
Insulation = 20 lb/ft
Drop Ceiling = 30 lb/ft
MEP = 50 lb/ft

Dead Load = 922.5 lb/ft

Live Load = 200 lb/ft

Snow Load = 550 lb/ft

Load factors:

1.2D + 0.5 + 1.6 (Lr or S)

= 2087 lb/ft

Load #2:

NW concrete & metal decking 7'1/2"

150 psf live Load for mechanical areas

Concrete w/ponding

= 72.86 × 1.1 × 10' = 801.5 lb/ft

801.5 lb/ft

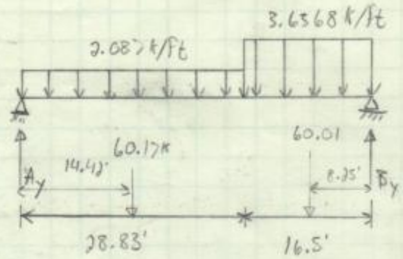
150 psf (10') = 1500 lb/ft

550 lb/ft

1.2D + 1.6 L + 0.5 (Lr or S)

= 961.8 lb/ft + 2400 lb/ft + 275 lb/ft
= 3636.8 lb/ft

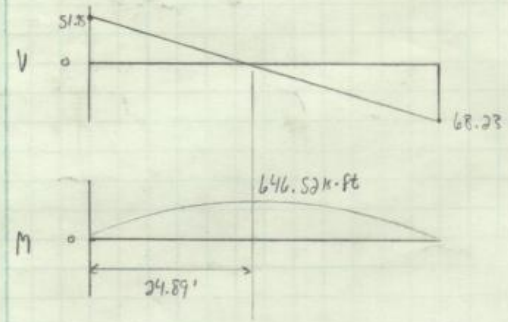
Page 1



$M_A = -60.17(14.42) - 60.01(37.08) + B_y(45.33)$

$= -867.65 - 2225.17 + 45.33 B_y$

$B_y = 68.23^k \uparrow \quad A_y = 51.95^k \uparrow$



M_u = 646.7 k-ft (RISA Value) in the 6¼" composite decking

Will interpolate to find max moment in the "1½" composite decking

$615.635 + \frac{(646.634 - 615.635)}{.5}(6.36 - 6) = 637.95$ k-ft (Used Tables from RISA)

Check Strength and Deflection for 6¼" composite decking

W27×84

weight = 84 lb/ft PNA Location = TFL $C_1 = 161$ Effective Flange Width = 120"

area = 24.8 Y_{con} = 6.25 in $Y_1 = 0$

$I_x = 2850 in^4$ Assume a = 3 in $Y_2 = 6.25 - \frac{3}{2} = 4.75$ in

Dead Load = 922.5 + 84 = 1006.5 lb/ft & 801.5 + 84 = 885.5 lb/ft

$W_u = 1.2(1006.5) + 0.5(200) + 1.6(550) = 2187.8$ lb/ft Load #1

$1.2(885.5) + 1.6(1500) + 0.5(550) = 3737.6$ lb/ft Load #2

M_u = 672.4 k-ft (RISA Value)

$\Sigma Q_n = 24.8 in^2 (50 ksi) = 1240$ kips.

Actual $a = \frac{1240}{.85(4)(120)} = 3.04$ in

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Actual $y_2 = 6.25 - \frac{3.04}{2} = 4.73 in$

$I_{LB} = 6800 + \left(\frac{7020 - 6800}{.5}\right)(4.73 - 4.5) = 6901.2 in^4$

$\phi M_n = 1660 + \left(\frac{1700 - 1660}{.5}\right)(4.73 - 4.5) = 1678.4 k \cdot ft > 672.4 k \cdot ft$ ✓ Good

Q_n from Table 3-21 AISC = 17.2

Number of studs = $\frac{2(1240)}{17.2}$ = 144 studs * 288 overall (Check w/ Spacing)

Deflection & Strength Checks

Service Deflection check: M_L = 162.5 k·ft (RISA Value)

$\Delta_L = \frac{162.5(45.33)^2}{161(6901.2)} = 0.30 in < 1 in$ ✓ Good

Strength DL = 84 lb/ft Line Load = 482.5 lb/ft & 801.5 lb/ft

Load #1 = 1.2(84) + 1.6(482.5 lb/ft) = 872.8 lb/ft

Load #2 = 1.2(84) + 1.6(801.5) = 1383.2 lb/ft

M_u = 260.3 k·ft < 1678.4 k·ft ✓ Good
↳ RISA

Load w/o factors

Load #1 = 566.5 lb/ft

Load #2 = 885.5 lb/ft

M_u = 168.1 k·ft (RISA)

$\Delta = \frac{5(168.1)\left(\frac{1}{12000}\right)(45.33 \times 12)^4}{384 \times 29000 \times 2850} = 0.19 in < 1 in$ Good ✓

Do not need to check the beam through the 7.5 in composite decking as it provides more strength and experiences a lesser moment, thus it will be able to withstand the loading.

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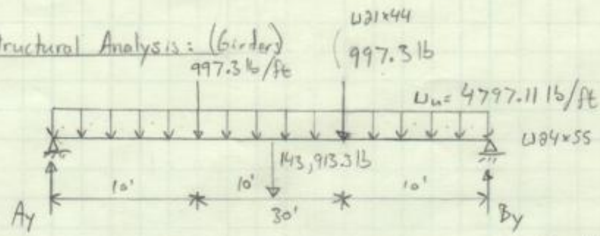
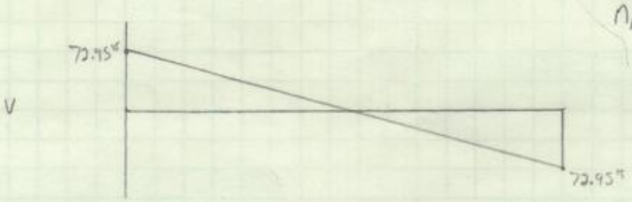
Roof Structural Analysis: (Girders)

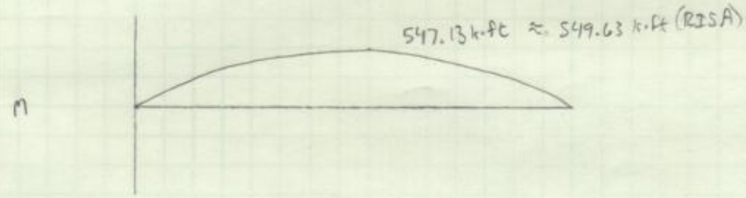


M_A = 997.3(10) + 997.3(20) − B_y(30) + 143,913.3(15)



B_y = 72,953.95 lb → 72.95k

A_y = 72.95k



Loads:

Concrete w/ Ponding: 43.86 × 1.1 × 22.67 = 1093.74 lb/ft (→ Tributary Area)

Green Roof = 30 psf
Slip Sheet = 2 psf
TPO membrane = 2 psf
Insulation = 2 psf
Drop Ceiling = 3 psf
MEP = 5 psf

} 44 psf (22.67) = 997.5 lb/ft

Beam Weight = 55 lb/ft

Dead Load = 2146.24 lb/ft

Roof Live Load = 22.67 (20) = 453.4 lb/ft

Roof Snow Load = (22.67)(55) = 1246.85 lb/ft

Load Factors:

1.4 D = 3004.74 lb/ft

1.2 D + 0.5L + 1.6 (L_r or S) = 4797.11 lb/ft ← governs

M_u = 549.63 k-ft (RISA)

Page 1/

Effective Flange width

$b_e = 2(1/8 \times 30 \times 12") = 90"$ → governs

$b_e = 2(45.33 \times 1/2 \times 12") = 543.96"$

W24x55 Full composite check

weight = 55 lb/ft PNA Location: TFL $C_1 = 161$
area = $16.2 in^2$ Y_{con} : 6.25in $Y_1 = 0$
I_x = 1350 in^4 Assume a = 3in Y_2 = 4.75in

$\Sigma Q_n = 16.2(50 ksi) = 810 k$

Actual $a = \frac{810}{.85(4)(90)} = 2.65"$

Actual $y_2 = 6.25 - \frac{2.65}{2} = 4.93"$

$I_{LB} = 3500 + \left(\frac{3630-3500}{.5}\right)(4.93-4.5) = 3611.8 in^2$

$\phi M_n = 989 + \left(\frac{1020-989}{.5}\right)(4.93-4.5) = 1015.66$ k-ft > 549.63 k-ft ✓ Good

Deflection & Strength Checks

Service Deflection Check : $M_L = \frac{453.4(30)^2}{8000} + \frac{997.3(30)}{3000} = 60.97$

$\Delta_L = \frac{60.97(30)^2}{161(3611.8)} = 0.094in < 1in$ ✓ Good

Strength : DL = 55 lb/ft LL = 1093.74 lb/ft Pt Loads = 997.3 lb

$1.2(55) + 1.6(1093.74) = 1815.98$ lb/ft

$M_u = \frac{1815.98(30)^2}{8000} + \frac{997.3(30')}{3000} = 214.27$ k-ft < 1015.66 k-ft ✓ Good

Load w/o factors

$M_u = \frac{1148.74(30)^2}{8000} + \frac{997.3(30')}{3000} = 139.21$ k-ft

$\Delta = \frac{5(139.21)\left(\frac{1}{12000}\right)(30 \times 12)^4}{384 \times 29000 \times 1350} = 0.065in < 1in$ ✓ Good

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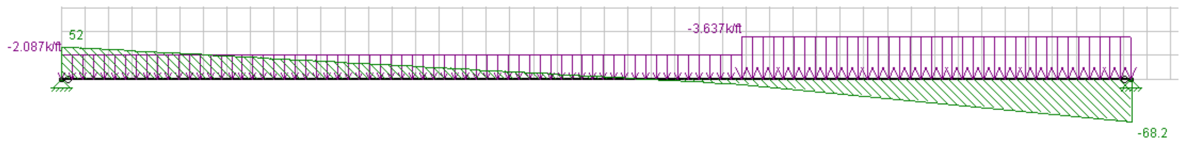
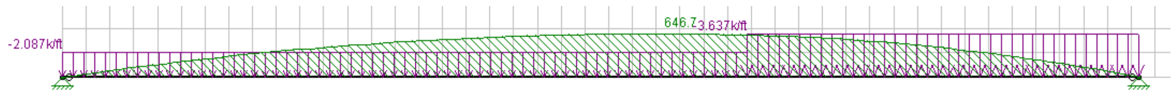
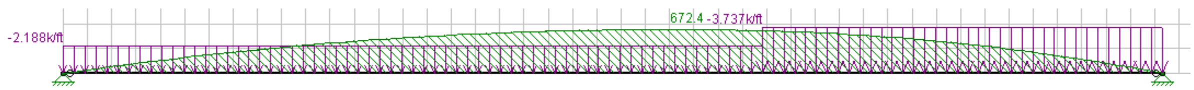
RISA Data (Corresponds to Hand Calculations)

27x84

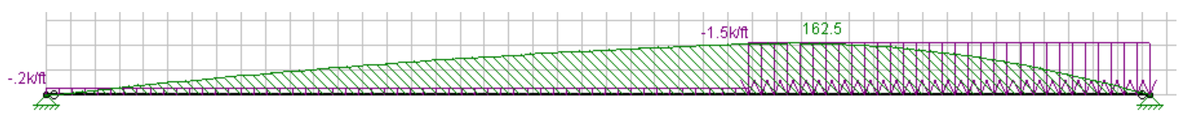




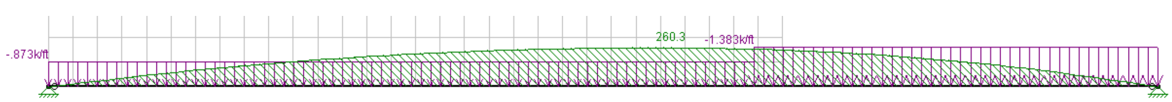
After beam weight has been added (below)



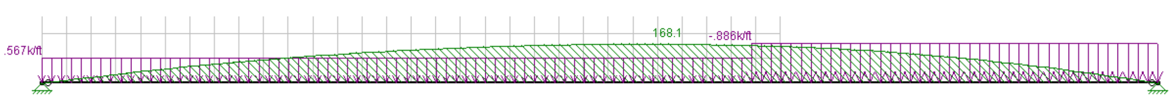
Service Live Load Moment



Strength Check



Load w/o factors



Excel Spreadsheet for Beams and Girders

Loads	(psf)	(lb/ft)
6.25 in concrete cover	43.86	
7.5 in concrete cover	72.86	
Green Roof	30	300
Slip Sheet	2	20
TPO Membrane	2	20
Insulation	2	20
Drop Ceiling	3	30
MEP	5	50
Metal Decking	2.14	21.4
Beam Weight		84
Tributary Area (ft)	10	
6.25 in concrete w/ ponding		482.46
7.5 in concrete w/ ponding		801.46

Dead Load		
case 1		1027.86
case 2		906.86
Live Load		
case 1	20	200
case 2	150	1500
Snow Load	55	550

Load Factors	Case 1	Case 2
1.4D	1439.00	1269.60
1.2D + 1.6L + 0.5S	1828.43	3763.23
1.2D + 0.5L + 1.6S	2213.43	2718.23

Mu (Obtained from RISA) k*ft	678.8

W-Section	27x84	PNA Location	TFL	c1	161
Area (in^2)	24.8	Ycon (in)	6.25	y1	0
Ix (in^4)	2850	Assume a (in)	3	y2 (in)	4.75
Beam Span (Ft)	45.33	Effective Flange Width (in)	135.99		
Beam Spacing (ft)	10	Effective Flange Width (in)	120		

∑Qn	2266.5	Smaller EFW	120

Actual a	3.04

Actual y2	4.73

I LB (in^4)	Lower	Upper	6901.2
in^4	6800	7020	
in	4.5	4.73	

ϕMn (k*ft)	Lower	Upper	1678.4
k*ft	1660	1700	
in	4.5	4.73	

∑Qn	Qn	No. of studs per side of CL
309	17.2	36

Deflection & Strength Checks		Limit	Good	Not Good
M(L) (RISA) k*ft	168.6			
ΔL	0.301	1in	X	
Strength				
Mu (RISA) k*ft	678.80	1678.4	X	
Load w/o Factors				
case 1	566.46			
case 2	885.46			
Mu (RISA) k*ft	171.9			
ΔL	0.193	1in	X	
Shear Check (k)	68.23	369	X	

D.3 Design of Columns

Hand Calculations for Columns

1/2

Load Cases

Load Case 1

Exterior Regular Roof Loading

Light Weight Concrete with ponding => 1.1×43.86 psf = 48.25 psf

Metal Decking => 2.14 psf

Green Roof => 30 psf

Slip Sheet => 2 psf

TPO Membrane => 2 psf

Insulation => 2 psf

Drop Ceiling => 3 psf

MEP => 5 psf

ΣDL => 94.4 psf

DL => 94.4 psf

LL => 20 psf

SL => 55 psf

Factored load => 1.2(94.4 psf) + 0.5(20 psf) + 1.6(55 psf)

=> 211.3 psf

Load Case 2

Exterior Roof + Mechanical Equipment Loading

Normal Weight Concrete with ponding => 1.1×72.86 psf = 80.15 psf

\+ 2 psf Insulation

3 psf Drop Ceiling

DL => 85.15 psf

LL => 150 psf (Mechanical Equipment)

SL => 55 psf

Factored Load => 1.2(85.15 psf) + 1.6(150 psf) + 0.5(55 psf)

=> 369.7 psf

Load Case 3

Interior Loading (Penthouse Floor)

DL = 85.15 psf

LL = 150 psf

SL = 0 psf

Factored Load => 1.2(85.15 psf) + 1.6(150 psf)

=> 342.2 psf

2/2

7th Floor Regular Interior

$6\frac{1}{4}$" Light weight Concrete with ponding: 1.1 × 43.86 psf = 48.25 psf
Metal Decking: 2.14 psf

Drop Ceiling => 3 psf
MEP => 5 psf
Insulation => 2 psf

Load Case 4

DL = 58.25 psf
LL = 80 psf

Factored Load => 1.2(58.25 psf) + 1.6(80 psf)
=> 198 psf

Penthouse Roof Loads

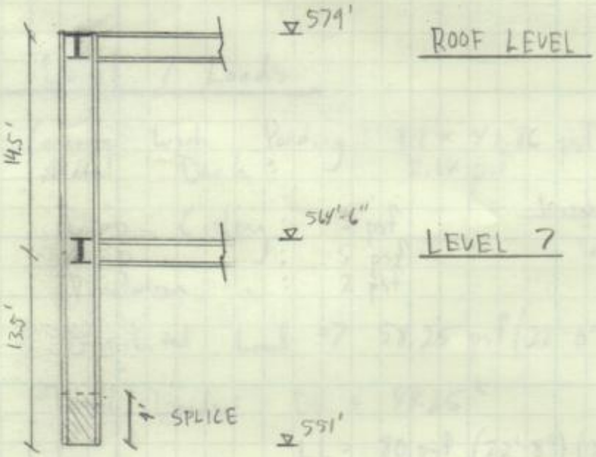
Considered Load Case 1

=> Same as exterior regular roof => 211.3 psf

Column Calculations

1/3

Column H3 - HD Roof Level W14×61



ROOF LEVEL LOADS

from Vulcraft

Concrete with Ponding: 1.1×43.86 psf $= 48.25$ psf

Metal Deck: 2.14 psf

Green Roof: 30 psf

Slip Sheet: 2 psf

TPO Membrane: 2 psf

Insulation: 2 psf

Drop Ceiling: 3 psf

MEP: 5 psf

= 94.4 psf

Weight from Beams/Girders

$(3)(44\ plf)(22'\text{-}8'') = 3.0^k$

$(2)(55\ plf)(15') = 1.65^k$

Distributed Load => $94.4\ psf\ (22'\text{-}8'')(30') = 64.2^k$

Total Loads: $DL = 68.85^k$

$LL = 20\ psf\ (22'\text{-}8'')(30') = 13.6^k$

$SL = 55\ psf\ (22'\text{-}8'')(30') = 37.4^k$

Load Factors:

$1.4D = 1.4(68.85^k) = 96.4^k$

$1.2D + 1.6L + 0.5(L_r \text{ or } S) = 1.2(68.85^k) + 1.6(13.6^k) + 0.5(37.4^k) = 123^k$

$1.2D + 0.5L + 1.6(L_r \text{ or } S) = 1.2(68.85) + 0.5(13.6) + 1.6(37.4) = 143.7^k$ governs

$P_u = 149.3^k$

Level 7 Loads

Concrete with Ponding : 1.1×43.86 psf $= 48.25$ psf
Metal Deck : 2.14 psf

Drop Ceiling : 3 psf
MEP : 5 psf
Insulation : 2 psf

Weight from Beams/Girders, Same as Roof $= 4.65^k$

Distributed Load $\Rightarrow$ $58.25 \text{ psf}(22'\text{-}8'')(30') = 39.6^k$

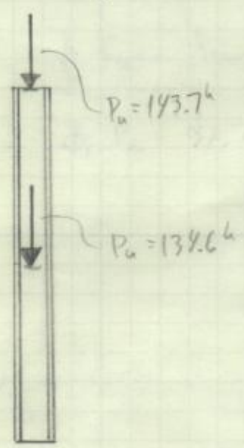
Total Loads: $DL = 44.25^k$
$LL = 80 \text{ psf}(22'\text{-}8'')(30') = 54.4^k$

Load Factors:

$1.4D = 1.4(39.6^k) = 55.44^k$

$1.2D + 1.6L = 1.2(39.6^k) + 1.6(54.4^k) = 134.6^k$ Governs

$P_u = 134.6^k$



$\Rightarrow$ This column is under two loads and is braced in the middle by the beams / girders from the 7th floor. We will analyze the top half with only the Roof loads and the bottom half with both the Roof and 7th Floor Loads.

3/3

Top Half

Unbraced length = 14.5'

$P_u = 143.7^k$

W14x61 $A = 17.9\ in^2$ $r_y = 2.45\ in$

Pin-Pin

$$\frac{kL}{r} = \frac{(1.0)(14.5' \times 12''/1')}{2.45\ in^2} = 71.0$$

$\phi_c F_{cr}$ from AISCM 4.22 = 31.1

$\phi_c P_u = 31.1 \times 17.9\ in^2 = 557^k > 143.7^k$ GOOD

Bottom Half

Unbraced length = 13.5

$P_u = 143.7^k + 134.6^k = 278.3^k$

W14x61 $A = 17.9\ in^2$ $r_y = 2.45\ in$

$$\frac{kL}{r} = \frac{(1.0)(13.5' \times 12''/1')}{2.45\ in^2} = 66.1$$

$\phi_c F_{cr}$ from AISCM 4.22 = 32.7

$\phi_c P_u = 32.7 \times 17.9\ in^2 = 585^k > 278.3^k$ GOOD

Sample Excel Spreadsheet Column Analysis

Column Position	H3-HC	Units
Column Size	W14x82	
Cross-sectional Area	24	in2
ry	2.48	in
Penthouse Roof Tributary Area	292.5	ft2
Interior Tributary Area	292.5	ft2
Regular Roof Tributary Area	542.5	ft2
Regular 7th Floor Tributary Area	542.5	ft2
Roof and Mechanical Tributary Area	0	ft2
Penthouse Roof Beams/Girders	3.4	k
Penthouse Floor Beams/Girders	6.3	k
7th Floor Loads from Beams/Girders	9.4	k
Penthouse Roof Loads		
DL	31012	lbs
LL	5850	lbs
SL	16087.5	lbs
Factored Roof Load	65879.4	lbs
Penthouse Floor Loads		
DL	82418.375	lbs
LL	54725	lbs
Factored 7th Floor Load	186462.05	lbs
7th Floor Loads		
DL	65907	lbs
LL	87275	lbs
Factored 7th Floor Load	218728.4	lbs
Bottom Half Analysis		
kl/r	65.32258065	
ΦcFcr from AISCM 4.22	32.9	
ΦcPu	789.60	k
Pu	471.07	k

Appendix E: Cost Analysis

Weston Solutions Green Grid Quote

GreenGrid® Materials Estimate

GreenGrid ROOFS

Weston Solutions, Inc.
124 Hebron Ave, Suite 3B
Glastonbury, CT 06033
Ph: (860) 368-3200
Fax: (860) 368-3201
Email: melissa.bezanson@westonsolutions.com

Estimate Date 4/6/2012 Exp Date: 5/6/2012
Project Name Unum Insurance Building (Conceptual Estimate)
Customer Name John Rodrigues - WPI Student
Customer Address Worcester Polytechnic Institute
Worcester, MA
Email or Fax jrod5280@wpi.edu
Weston Bid # 113915

Base Bid - Conceptual Pricing Only

Square Feet (sf)	Module Count (based on 2'x2' units)	Module Type	Planting Density (Plants / sf)	Unit Cost (/ sf)	Extended Cost
Extensive Modules - 4.25" G4 System @ 30lbs/sf					
14,000	3,500	2'x2'x4.25" Extensive	2.00	$11.81	$165,340.00
This estimate is based on the an email request dated 4/5/12. Please note, no project specifications were provided, so the extensive (sedum) G4 GreenGrid system assumed acceptable in its standard configuration with standard warranty and 85% min coverage on delivery. This estimate includes the furnish and delivery of the GreenGrid system only, no other drainage mat, root barrier, or other layer is necessary, as all of these components are integrated into the module. Protection fabric is the responsibility of the installer.				Base Subtotal	$165,340.00
				Base Freight	$6,020.00
				Base Total	$171,360.00
				Est Sales Tax (7%)	$11,995.20

It is the purchaser's responsibility to confirm roof dimensions, square footages, and module quantities prior to order placement, and to scale the project total up or down using the unit cost presented above (within 5% of the total area quoted). Please requote for >5% change in area.