LDA 0809
GFS 0802

WORCESTER POLYTECHNIC INSTITUTE: A REDESIGN OF WPI'S NEW RESIDENCE HALL USING REINFORCED CONCRETE

A Major Qualifying Project
Submitted to the faculty of
Worcester Polytechnic Institute
In partial fulfillment of the requirements for the
Degree of Bachelor of Science

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Date: March 8, 2008

Abstract

This project assessed Gilbane Building Company, Cannon Design, and WPI's decision to build with steel instead of reinforced concrete for the new on-campus residence hall. By redesigning the residence hall using reinforced concrete, developing our own management schedule, and performing a cost analysis we were able to compare the concrete design process to the steel design process that was used. We weighed the structural changes in the building, scheduling differences, and final cost to gain an understanding of the differences.

Authorship Page

This Major Qualifying Project was developed by thee undergraduate students who each contributed to all aspects of the project. Each member of the team worked both together on each aspect of the project while spearheading their own section. The sections were divided by the design, the schedule and cost analysis, and the writing of the report, respectively as signed below.

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Acknowledgements

The group would like to thank all that helped us through this project, especially our co-advisors Professor Guillermo Salazar and Leonard Albano for their direction and help. We would also like to thank the architect and structural engineer, Cannon Design's Ed Mello and Lynne Deninger, and the project management firm, Gilbane Building Co.'s Neil Benner and Don Venerus for their guidance during this work. Allowing us to sit in on their weekly meetings with WPI and by making all necessary material and information available made this project possible. In addition, we would like the thank WPI's Janet Richardson, Jeffrey Solomon, Alfredo Dimauro, Brent Arthaud, and Philip Clay for their support and willingness to provide the necessary information for our report and include us in their design ideas for this new residence hall.

Capstone Design Statement

The capstone design requirement of this project was met by proposing an alternative design of WPI's new residence hall with reinforced concrete instead of the structural steel which was used in actual construction. WPI's faculty and students are interested in this comparison because the decision to use steel could have had important implications in the physical and performance characteristics of the building. Construction using steel can greatly alter the makeup of the building as well as the monetary price to WPI. The current floor plan and architectural layout requirements are kept for the new design as much as possible and all structural steel members and columns are replaced with the appropriate reinforced concrete to handle the required loads. For the entire project, the group did a complete take-off of the materials, a cost estimate, and schedule for the new design.

These seven realistic constraints listed in the ASCE commentary were addressed when doing the capstone design:

Economic

The cost of the project was affected by the change in design to reinforced concrete. The feasibility of this project was compared to the current construction process in a number of ways. A material take-off showed the differences in cost of materials, an estimate of construction materials and labor costs showed the cost modifications in construction practices, and then a schedule comparison gave the difference in duration of the project.

Environmental

The residence hall construction was a LEED-certified building making it environmentally friendly. By changing the material to reinforced concrete the group investigated the relevant LEED certification criteria and assessed the new processes conformity as well as the difference in cost to maintain the certification. The group analyzed if there are prominent changes needed to generate LEED points or if the project will generate more or less points with reinforced concrete.

Sustainability

The group was able to investigate the building materials sustainability by using literature reviews. LEED made this process increasingly easier. With the LEED project evaluation, a large portion of their requirements and thus point system was derived from sustainability. In the LEED section of this report, there is information about how the sustainability of the project affects the LEED status, which is an affect upon a campus, the neighborhood, and more importantly the environment for both status and performance in the years that the building will be in use. With the requirements in order to provide the required sustainability and understanding the effects, the group compared the sustainability of both structural steel and the suggested reinforced concrete to compare how the two have upheld over time.

Constructability

Reinforced concrete is a major construction material used in the United States. The group was able to utilize the skills learned in CE 3020 *Construction Project Management* to develop a schedule of construction for the proposed concrete project. This looks at the differences that go into the construction of the concrete structure as opposed to the steel structure. Constructability was looked at in areas of modularity, conceptual planning, field operations, and the level of shop fabrication. Simply said, the group used these fields to provide an idea of the ease of construction.

Health and Safety

The group also attended to the differences in Health and Safety – both during and after the construction. Using different construction materials affects many aspects of health and safety including building codes provisions, construction zones, fire proofing materials, workman's compensation, and construction safety precautions as well as many others. General work on a site is greatly altered by the type of materials being used. There are different risks when reinforced concrete and steel are used. The group analyzed the different construction methods, explored a history of accidents in the industry, and determined which method of construction was safer for those on site during and after the construction of the project.

When assessing risk, a contractor also receives different workman's compensation benefits due to the level of risk. The group analyzed the different amounts of given compensation to laborers if such an accident were to occur and how this affected the final outcome.

Safety also has an influence during and after the construction to the workers, students, and surrounding areas. It was necessary to build to all building codes and the design followed the Worcester requirements. LEED's certification takes care of this with greater requirements.

Social

The social impacts of changing the construction from steel to concrete is defined by the social and current labor market in the specified area. While the design of the building remained the same in functionality and should pose no great differences in social impact, the construction has the ability to be drastically effected. New England carries a strong steel labor force and the social impacts of this can be seen easily.

Political

Political issues can arise from a wide variety of sources. These issues can include problems with neighbors or the city about the function of a building. Economical issues can arise to make an unsettling situation or issues may arise in the way a building must be constructed. Similar to the social impact of the project, the political aspects of the project are not changed very much because the function of the building is not being altered with the design. The process of purchasing different materials from different companies may pose some different political aspects as well as zoning regulations or permit processes. The group captured this by tracking the steel construction and comparing problems that arise to what would happen in the concrete construction.

However, needs within the city may change greatly such as road closings or detailing work. The group compared what needs to be done during concrete construction with the problems and city services used during the steel construction.

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1. Introduction

Throughout the stages of a construction project, there are many decisions made that drastically affect the cost, schedule, and quality of the project. These should be done with careful analysis; however, this is not always the procedure. It is important for the owner, architect, and contractors to coordinate with each other so that everyone can have the project needs met. Since each project is unique, there is no perfect way to make these decisions so it is important to study past projects and make estimates based on current building conditions. Project management and design decisions are a very important part of the construction industry, and each small decision can determine the final outcome of the project.

While there are ways to estimate how much money it will cost to build using certain construction methods, it can vary between each project. The cost of building materials is a variable that can change the cost of construction. Steel and concrete are two specific structural building materials that are commonly used and have costs that can vary greatly depending on many different factors such as market conditions, shop fabrication, material delivery, equipment needed, and ease of installation. If a job is done over an extended period of time, it is important for estimators to account for the inflation of the material costs in their bids. Architects and owners generally consider cost and schedule as the major deciding factor between using concrete and steel – although each has their own advantages.

Worcester Polytechnic Institute (WPI) is a prestigious school located in Worcester, Massachusetts that continues to grow, with both student body and the size of its campus. With this growth, WPI is always planning ways to upgrade aspects of the campus to improve the attractiveness of the school to potential incoming students. There has also been a demand for more student housing, particularly on-campus housing. With a goal in their master plan to increase the size in the student-body, this demand will only grow. WPI decided to build a new residence hall for upperclassmen to increase on-campus housing capacity. In the early stages of the project the design team was faced with a decision between concrete and steel for the structural support. This choice shaped the entire project and had a domino effect on the other decisions that were made in the project – such as the schedule, subcontractors, delivery methods, and in the end, project cost.

As a part of their studies, WPI faculty and the student body are interested in looking at how the current choice for steel construction formed the project development and what would have happened if WPI had chosen reinforced concrete. By performing this analysis, there is now a greater library of knowledge to facilitate future decision making. The purpose of this project is to study and develop a great understanding to the implications of making an alternative choice.

In our project we designed the new residence hall using reinforced concrete instead of steel and performed a cost comparison between the two. This analysis should help WPI academia learn more about their construction decisions and project management practices. The data that was needed was obtained through literature reviews, gaining information from Neil Brenner of Gilbane, attending the owner's meetings with Gilbane, and by our design work and analyzing cost and schedule. We then used techniques adopted from our coursework at WPI to analyze these options. This project will provide helpful information in structure design an in the art and science of project management.

2. Background

In order to complete this project, our group has identified three major objectives. First, our group redesigned the WPI Residence Hall to meet the same building specifications as the current structure. Next, the group analyzed how the potential schedule and construction methods would be different by developing a schedule for the concrete structure and comparing it to the current schedule. Our third objective was to perform a cost-analysis on the new reinforced concrete residence hall. Once these objectives were completed the group was able to make recommendations based on the results. To understand where this project has come from, this chapter analyzes the complete background of the project for the new residence hall.

2.1. Residence Hall

It seems all major colleges these days have multiple construction sites on their campuses. Athletic centers, art centers, research and lab buildings, and residence halls are springing up on campuses across the United States. WPI is also upgrading their campus by constructing new facilities. In 2007, construction began on an upperclassman apartment style residence hall.

2.1.1. History

The motivation for Worcester Polytechnic Institute (WPI) to build a new residence hall on campus started in 2004. As a result of a survey conducted by the dean of students, the formation of the Residence Hall Planning Committee (RHPC) began.

The RHPC was a response to the increased size of freshman classes entering WPI and the strain that the increased class sizes were putting on the on-campus housing. One of the first steps taken, the RHPC was to survey the student body about what features they would like to see in a new residence hall. There were over 1,000 responses to the survey, and the results showed that students preferred apartment-style living with amenities such as phone, cable, network connections, and on-campus parking. In 2006 the site for the residence hall (formed from an apartment building, an office building, and the campus police house and parking lot) was determined to be next to Founders Hall on Boynton Street. The RHPC considered many variables including a property that had to be acquired, but the most important factor was that no current students would need to be displaced by using this property. The RHPC then evaluated current needs for WPI and decided the size of the building was to be between 200 and 300 beds (Worcester Polytechnic Institute 2007). In the summer of 2006, approximately 7 architectural firms were interviewed and Cannon Design of Boston was selected as the architect for the project. WPI then looked for a construction management team, and Gilbane Building Company (GBC) was chosen in October of 2006 and became immediately involved in the project (Arellano, 2007).

2.1.2. Location

WPI's new apartment style housing is located between Boynton Street and Dean Street on WPI's lower campus, shown in the superimposed 3D representation in Figure 1. This is directly adjacent to the existing upperclassmen housing at Founders Hall, which was built in 1985. The new residential hall is part of an effort to revitalize the lower campus, which already includes residential and fraternity housing. Along with the construction of the residence hall, a parking garage is being constructed to alleviate student-parking concerns on the streets. The construction is also accompanied with changes made to Founders Hall including the addition of a restaurant and convenience store. Along with revitalizing the lower campus, these changes are all aimed to help keep upperclassmen on-campus and promote a stronger community amongst WPI students and faculty (Worcester Polytechnic Institute 2007).

Figure 1: Arial View of Residence Hall Representation from Boynton Street

2.1.3. Description

The new residence hall is a 232-bed apartment style complex that is slated to open in the fall of 2008. The apartments will include amenities required for individual living such as a full kitchen, living room, compartmentalized bathrooms, and single or double bedrooms. The building is 103,610 square feet and will be a LEED certified project. In the building there will also be fitness facilities and tech-suites, which are meeting rooms on each floor designed to accommodate all the technical needs of a WPI student. The building will be fully air-conditioned and have full wireless Internet access. The structure will be accompanied by an adjacent parking garage housing spaces for 189 cars (Worcester Polytechnic Institute 2007).

2.1.4. Building Progress

From the start, the design and building construction schedule has been using the "fast track" method. This is a form of project delivery where construction of the project actually begins before all of the details of construction and design have been finalized. This is used to speed up the completion of the project as opposed to the traditional design-bid-build method where the process is done sequentially (Fast Track 2007). The fast track method can be extremely rewarding in the interest of time, but it is an incredibly risky approach and required GBC, Cannon Design, and WPI to work together from the very beginning of the project. Coordination is incredibly important during fast track process. Essentially, the construction has begun before the design is finished, there will be many changes during the construction and this is where the project becomes risky. The motivation for fast track is to be able to move in early. The rate of design time would take too long, however, the project is designed enough to start the construction of the project. WPI decided this was a must in order to have students move in for the 2008-2009 school year.

2.2. Participants

In any construction project there are three main participants: the owners, the design team, and the construction company. For this new residence hall at WPI, Cannon

Design was chosen for the design team and Gilbane Building Co. won their bid for the construction management of this large project. WPI is obviously the owner of this project and by completing this project they are expanding the campus in Worcester, Massachusetts.

2.2.1. WPI

Worcester Polytechnic Institute was established in 1865 as one of the nation's first universities of technology. It is located in Worcester, Massachusetts, the third largest city in New England, on an 80-acre hilltop campus. WPI is the owner and its students will be the end users of the 232-bed apartment style residence hall. WPI is an elite institution that is often recognized as one of the top schools in the country. Unlike many schools that use internships for experience, WPI has a unique project-based approach to learning. Its cutting edge research has produced many breakthroughs and innovations in many different scientific disciplines. The residence hall is a plan to rejuvenate the lower campus of WPI along with the new Goats Head Restaurant and adjacent convenience store that was opened in the beginning of the 2007-2008 school year. These features are planned to further boost the reputation of WPI and continue to make it more appealing to incoming students (Worcester Polytechnic Institute 2007).

2.2.2. Gilbane Building Company

Founded by Thomas and William Gilbane in 1873, Gilbane Building Company was started as a privately owned and family run company and still remains that way today. They are a construction management firm based out of Providence, Rhode Island and are the project managers on the new residence hall construction project. The company offers its services in an array of markets with over 1800 employees and annual revenues of $3 billion. They were the owner's representatives as project managers for the beautiful WPI Campus Center that was completed in 2001 and were the construction managers at risk for the Bartlett center completed in 2007. Gilbane has been involved in many Worcester projects including a parking garage at the new WPI Gateway Park and they know the area well. Neil Benner of Gilbane is the lead project manager for the residence hall and will be putting in tireless hours to manage the building of a quality product (Gilbane Building Company 2007).

2.2.3. Cannon Design

Cannon Design is an international architectural, engineering, and planning firm that was started over 60 years ago. It has a staff of more than 700 employees with 15 offices located from coast to coast. Cannon's scope of projects range into 48 states in the United States and abroad to many countries including locations in Europe, Asia, Latin America, and others, making it a well-versed company in its discipline. Cannon has designed structures for over 50 colleges and universities across the country and is the architectural firm handling the design of the new WPI residence hall. Cannon is an expert in sustainable design (green design) which is applied to the new WPI residence hall. The company grosses over $100 million each year and has received citations for numerous awards around the country in many areas including some from American School and University as well as American Society of Civil Engineers (Cannon Design 2007).

2.3. Concrete Construction

The use of concrete in modern engineering has really opened the world up to a vast new area of construction. Reinforced concrete architect Auguste Perret was the first designer to make this form of concrete construction acceptable in the early 1900s. Constructing the Notre Dame du Raincy in 1922 represented the first significant design using the newly accepted design process of reinforcing members of a structure. (History of Concrete Construction, 1992) Concrete construction can be found decorating city scopes across the world. When comparing the material to other types, there are four main categories that differentiate its construction. These key ingredients to any structural project are safety, cost, material availability, and project scheduling. This section will take a look at these four aspects of the concrete construction world.

2.3.1. Safety

Safety is always a large concern with any type of construction project. Larry Silverstein Ground Zero developers have recently made statements about safety precautions at World Trade 7 that concrete is safer, reflecting what has been said by the concrete community for quite some time. (Building Magazines, 2007) In the events of terrorist attacks, fires, or explosions, cast-in place concrete has outstanding resistance. Stairwells and power systems that are protected by 2-foot thick concrete walls in the core of the building can also help save these aspects of the building in the event of attack or catastrophe. Concrete can also withstand very high heats from fire for extended periods of time, with no extra fire proofing, while still maintaining its structural integrity. Due to the large mass and heaviness of concrete, it can withstand winds of up to 200 miles per hour making it very good at resisting man-made and natural disasters. Although seemingly very rigid, concrete structures with proper detailing of reinforcement can also stand up well to earthquakes (Buildings Magazine Online 2007). According to the Portland Cement Association, performance of a structure under earthquake loads is largely a function of its design and not its construction material. If engineered properly concrete construction can do very well with resisting earthquakes. As proof, the earthquakes that hit Kobe, Japan in January 1995 caused a lot of destruction but steel and concrete structures shared similar fates with only 4.9% of concrete structures collapsing and 5.3% of steel structures collapsing (Portland Cement Association 2007).

2.3.2. Cost

Cost is an obvious concern with any type of construction because it is a competitive industry. Cost in a project is important to the owner for obvious reasons. In general, ready-mixed concrete remains fairly stable in cost as shown in Figure 2 (PCA Newsroom 2007). It has a thirty percent rise from 2003 but this is because there is a rise of all building materials. Across the world construction materials are rising, as you can see in Figure 2, concrete is the most stable of the main three materials – this is discussed in section 2.3.3 and 2.4.3. There is a larger up-front cost for concrete construction than other comparable types of construction, such as steel. However, this cost differential can be greatly offset by the savings in insurance costs down the road. Insurance companies can charge lower premiums for concrete structures because of the mentioned safety benefits such as increased structural integrity and better-protected egress systems. According to Gerosa from Metal Buildings Guide, recognizing the long term safety benefits can help owners save almost 25 percent annually over other types of construction. (Metal Buildings Guide 2007)

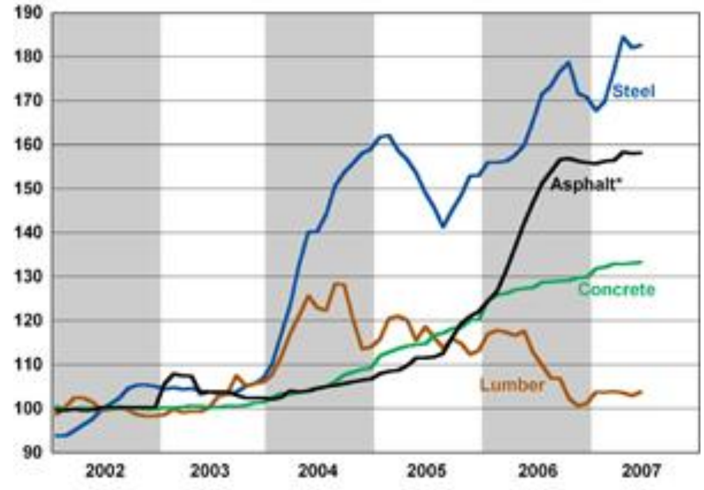

Figure 2: Producer Price Indices Competitive Building Materials

2.3.3. Material Availability

Material availability differs by region but in recent times cement has been reported to be in limited supply – which will influence cost. Cement is the main bonding agent used in making concrete. Twenty four percent of the cement used in the United States comes from China. With the economy of China growing, they have cut back on their exports of cement (Toolbase Services 2007). Shipping rates and a lack of ships for transportation also contribute to the shortages of concrete around the country (Buildings Magazine Online 2007).

2.3.4. Project Scheduling

Concrete is undoubtedly the faster form of construction when compared to steel because there is no preorder fabrication time required. It also takes longer to procure and mobilize the needed equipment for steel construction. The saying “time is money” is especially true in the construction world. A popular form of concrete construction follows the 2-day cycle – not including delays for the formwork erection and placement of rebar. (Buildings Magazine Online 2007) This means that up to 20,000 square feet of concrete can be placed every two days – depending on the specifications calling for different amounts of rebar or different types of formwork needed. The faster a building can go up, the faster capital can be recuperated and profits can be made. Time and money can also be saved with concrete construction verses steel because the use of large cranes and staging areas is cut down making the entire process a lot quicker and simpler (Buildings Magazine Online 2007). However, concrete also is affected and slowed down to a greater extent than steel construction because of weather factors. Concrete, if the weather is unruly, can have numerous setbacks in the construction process.

2.4. Steel Construction

Steel has been used in the construction industry since it started to be mass produced in the late 1800's for structural support in bridges, buildings, and skyscrapers. Steel provides a very versatile material with a variety of possibilities including I-beams, Z-Shape, and many other shapes (United Steel Building 2007). Structural steel is available in many shapes and sizes that are all fabricated to meet published standards and specifications. The specifications allow the design of steel structures to be extremely accurate because of the established load capacities for each type of beam. This section will take a look at how steel performs in the areas of safety, cost, material availability, and project scheduling.

2.4.1. Safety

Even though steel has a reputation of being susceptible to heat, this is often wrong. While steel does have the tendency to bend and melt when it is exposed to extremely high temperatures, this is a hazard that requires the necessary precautions including fireproofing. Spray-on fireproofing is widely used now as a method of insulating the steel so that it does not experience a large temperature increase. Steel has many positive safety characteristics also. Since steel is a very ductile material, it has the ability to undergo a large amount of strain without breaking, which allows it to withstand very high wind and seismic loads. Although steel can help in seismic zones, it is still very important to have a well-designed structure because ultimately it is the design that determines how well the structure will react to these problems (Buildings Magazine Online 2007). Steel is also safer during the actual construction process as well. As stated in our results, steel is a much safer product than concrete during the construction phase of a project.

2.4.2. Cost

The cost of concrete and steel for a construction project – which includes materials and labor – at the time of construction usually, determines which method will be used. These prices can fluctuate a lot and affect the entire construction industry. Since November 2003 the price of steel has increased 70 to 80 percent over mill prices (Buildings Magazine Online 2007). While some people let this dissuade them from using steel, the cost of all building materials has also increased. This makes it important to evaluate each individual project to see which method is more cost efficient. Depending on the design of the structure and construction methods used, it could end up being less expensive to use steel even if the cost of the raw material is more expensive because of efficient construction processes This makes it important to evaluate each project on a case-by-case basis. One disadvantage to using steel is that sometimes the material needs to be stored off-site and transported to the construction site only when they are ready to use it. This is especially true in the urban setting when space is limited and job sites are not large. This requires more coordination efforts, and if mistakes are made, time and money can be lost.

2.4.3. Material Availability

The availability of steel and the related shipping cost vary greatly with location. This can greatly affect the total cost of a project. Often the raw material for steel beams are purchased overseas and shipped to the United States for fabrication. Many speculated that there was a shortage of steel available recently, but the United States has the ability to produce 6 million tons of structural steel, and the industry only used 4 million tons last year (Buildings Magazine Online 2007).

2.4.4. Project Scheduling

Usually steel construction is considered a slower process than other forms of construction because it needs to be fabricated off-site and delivered; however it can still do well if planned properly – as the erecting time is typically faster. Steel does allow for fast-tracked projects in some cases and might not cost the owner any more money for extra time – meaning a lower cost project. Since most of the steel is stored offsite, it is very important for the project manager to plan in advance exactly which pieces they will need for any given day. Even with longer pre-order time for steel than for reinforced concrete, this can be sometimes be countered by shorter erection times. These factors require increased planning by the project managers and the design team.

There are many differences between using concrete and steel as the primary building material for a project. Table 1 shows a summary of some of the advantages and disadvantages of using each of these building materials with respect to safety, cost, material availability, and project scheduling. It is very important to look at all of these aspects when deciding on a construction material to find the most appropriate method. Our project focuses on looking at these aspects of the different building materials for the WPI Residence Hall.

Table 1: Concrete vs. Steel Construction

	Concrete Construction		Steel Construction	
Category	**PROS**	**CONS**	**PROS**	**CONS**
Safety	• Core protection against attack and catastrophe • Stands up well to heat from fire • Stands up well to high wind loads and natural disasters		• Ductility allows for high tolerance to wind loads and seismic load	• Bends and melts under high heat
Cost	• Ready mix concrete cost remains fairly stable • Insurance savings due to better safety	• Larger upfront cost	• Low maintenance	• Price of steel varies and has steadily increased in recent years
Material Availability		• Cement in limited supply during recent years • Shipping problems cause limited supply	• Dependent on region however US is able to produce 6M tons for an average use of only 4M	
Project Scheduling	• Quicker than other construction (20,000 ft^2 poured every 2 days) • Low pre-order time		• Can be used in fast track projects	• Storage of material off-site • Staging are required

3. An Alternative Design to WPI's New Residence Hall

One goal of this project was to redesign the new WPI Residence Hall on Boynton Street using reinforced concrete, instead of the steel structure that WPI, Gilbane, and Cannon decided to use. This Major Qualifying Project (MQP) will be useful to WPI students, faculty, and Gilbane in their estimates and decision making in future projects. This project will aid WPI students completing their MQP in the future as an educational resource. The team accomplished this goal by using background research, tracking current project progress and decisions, and using skills that we have acquired throughout our Civil Engineering coursework at WPI.

Designing a buildings structural framing is an extensive process. There are extremely strict professional engineering codes that must be followed, as well as a professional licensed engineer to sign off and stamp the design from their licensed state's accredited programs. However, our job was not to design the whole project, but to redesign the structural columns, girders, beams, rigid frame, and slabs for the new residence hall. This changed it from a steel structure to one of reinforced concrete material while still keeping the structure architecturally the same.

We were able to use the steel structural plans from Cannon Design for our basis and rework them changing the position of only a few columns. For every member in the existing building plans, a reinforced concrete beam, girder, or column had to be derived. Using ACI standards, the rebar amounts were calculated so the members would meet specifications to withstand all loads placed on the building. The next sections explain how this was done.

3.1. Design Background

In this objective the group redesigned the new Residence Hall using reinforced concrete. The group examined architectural drawings, which were provided by Cannon Design, to be sure that the design of the new structure would maintain the same specifications as the current design. This portion of the project required the knowledge from many of our Civil Engineering courses we have taken while attending WPI. We utilized the skills we learned in CE 2000, CE 2001, and CE 2002─which covers basic design knowledge. The most important course that we have needed was *CE 3008 – The Design of Reinforced Concrete Structures*.

While our coursework had provided a good foundation for the design basics of the residence hall, we were also required to perform extensive literature reviews on the design of reinforced concrete structures. This new knowledge provided us with the necessary information for the concrete design and made it possible to consider necessary changes from the steel design. Running a safe construction site was a main concern in our analysis and is very important to all parties. It lowers the possibility of claims for workers compensation for incidents. Our group looked into the affects of changing to reinforced concrete while still maintaining a high level of safety. To do this, research upon reinforced concrete construction safety hazards was carried out. We found that the accident level has a much greater risk when using concrete. In New York City alone, of the forty-one instances of injuries on concrete sites during a two-year span, twenty-five of them were during concrete pouring (Eligon 2008). Unlike concrete, steel construction erection is typically safer because the products are manufactured under factory-controlled conditions.   In these conditions, it is safer than the working conditions on the construction site because the workers are not exposed to the elements while fabricating the steel. Furthermore, steel construction products are manufactured using automated or semi-automated processes that are far safer than manual site operations for concrete erection. On the construction site, steel products are quickly and simply erected. Spending less time in an open area on the top of building limits the time during which the workers are exposed to the most common accident risks – including but not limited to falls, falling objects and vehicle accidents). Modern steel composite construction, in which the steel deck acts as permanent formwork to the concrete, is inherently safe. The steel floor decking provides a safe working platform for workers on that floor and protects workers below from falling objects. (Sustainability)

Since WPI desires this to be a LEED certified project, the group needed to incorporate this into our design. The group's use of information from LEED's literature made it possible to find out what level of LEED certification is acceptable. LEED certification information can be found on the WPI website and other information provided to us by Cannon Design allowed the group to produce a score for the redesign of the project by LEED's standards. Because the as built structure is expecting to be LEED certified, a comparison was made between the point differences with the different forms of construction. With the LEED standards in hand, the design and construction, including cost and schedule, could be altered as needed to become LEED certified. Using these methods, the group feels that it was able to provide itself with the necessary skills and information to have completed the LEED certified residence hall design using reinforced concrete.

To complete our MQP for a bachelor's degree at WPI, we must perform a capstone design relating to our project. To fulfill this for our project, the design was completed in the form of reinforced concrete – the design of the new residence hall was originally done in steel by Cannon Design. To design the reinforced concrete alternatives the loads for the current building, changed due to changes with the material, and architectural drawings were used. To be sure this was done, an architectural rendering of the building and design were used to make sure that the new reinforced concrete designs satisfied the owner's (WPI) requirements for the new suite style residence hall. Then, the design of the reinforced concrete was used to make sure that the load requirements were satisfied.

3.2. Gravity load design

At this point, the design loads for the simply supports beams had to be completed. The beams were numbered as shown below in Figure 3 for the North and South pods and in Figure 4 for the middle pod. The North pod is the left side of the building if looking at the front of the building from Boynton Street. Since the North and South pods are identical in layout they were labeled only once. Then each of the beams were analyzed and given the structure requirements, including the amount of rebar, the beam sizes, and that the required loads were satisfied by all load requirements. These loads, calculations, and beam designs are all stated in the spreadsheet in Appendix 9.2. In this appendix, there is an example spreadsheet on how all the numbers were solved. Each beam and girder must be analyzed separately due to different loads affecting them. The hand calculations for the beams can be seen in Appendix 9.7.

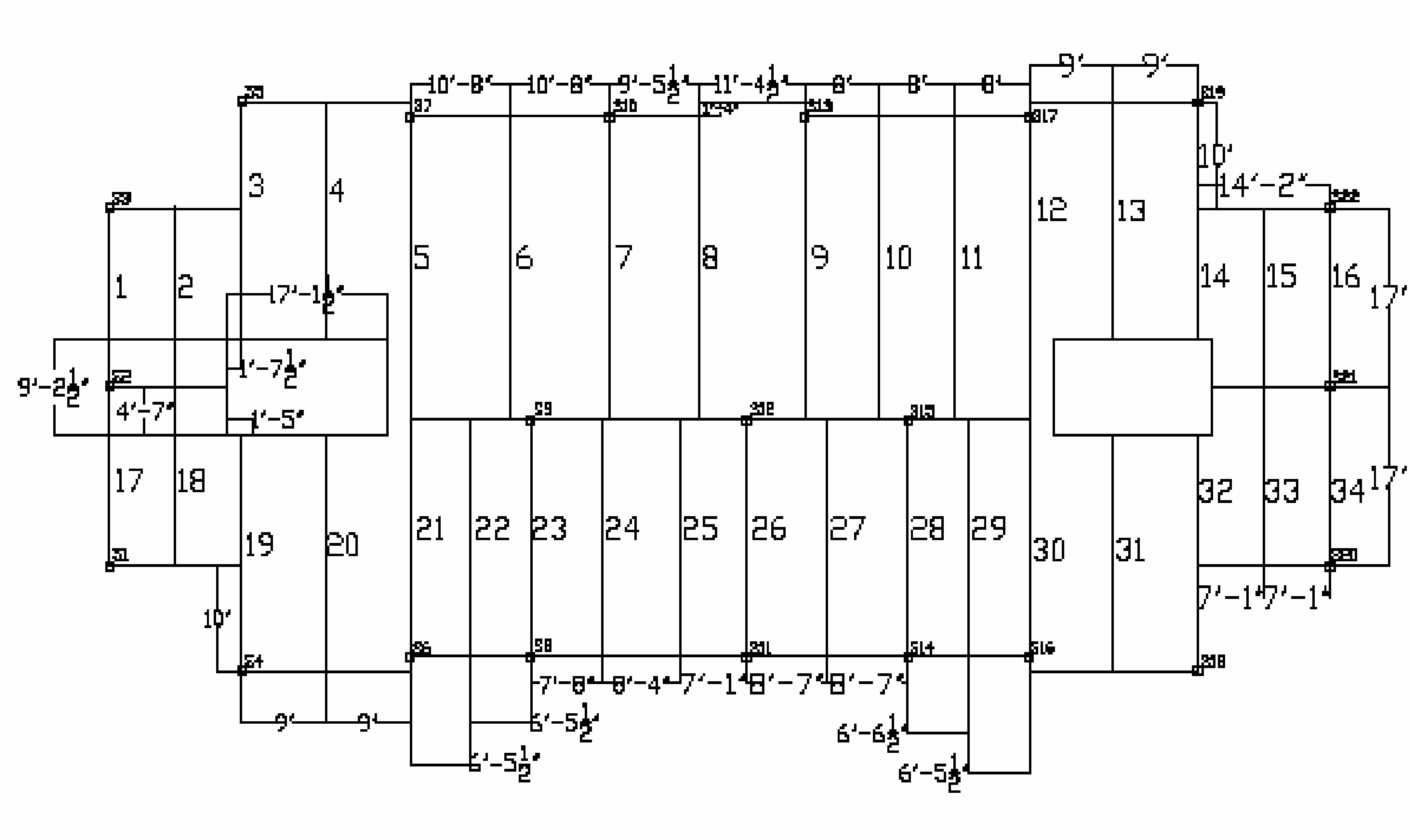

Figure 3: North and South Labeling

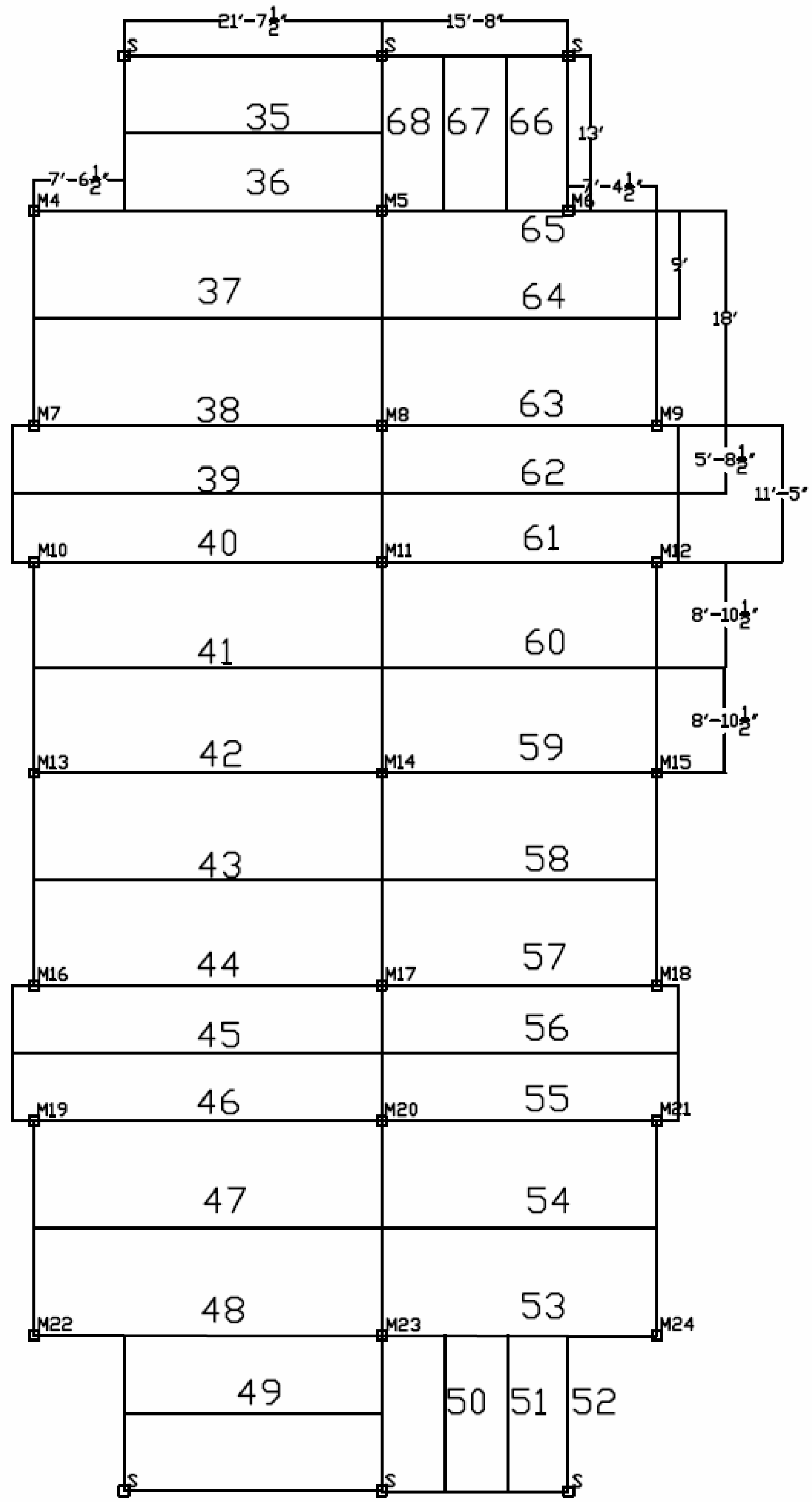

Figure 4: Middle Pod Labeling

For the beams, in order to find the sizes required, equations from ACI can be utilized to design to withstand the maximum moment and shear the gravity loads will induce on the beam. The first step was to determine the length of the beam and the tributary width of slab it would be holding up. We learned this in CE 3008 as well as many of our other civil engineering classes here at WPI. Then we were able to determine the dead load and live load that would be exerted by the slab by using the given live loads from Cannon on the front sheet of their structural plans and using the previously determined slab thickness along with the weight of reinforced concrete to be 150 lbs/cf to determine the dead load. The live load is 60 psf on the upper floors in most cases, however the hallways are 80 psf, which are accounted for in some beams labeled in the spread sheet as the load for five feet (which is the width of the hallway). These loads need to be analyzed with the different ACI factoring equations to determine the maximum factored load. The equation yielding the largest factored loads for the beams was determined to be FL = (1.2*DL) + (1.6LL). The next step was to estimate the "Weight of Beam" so it could be added to the factored load as an additional dead load. There were 2 forms of estimation used and reflected in the spreadsheets. One form estimates the beam dimensions using percentages of its length and the other is a range of beam weight between 10% and 20% of the load it carries. In order to move forward from here, you need to find the widths and the heights of the beams. Once we produced the estimated weights of the beam some judgment was used in determining a common middle ground WOB, which was used as our trial weight. At this point we had reached the point where our factored load for the beam was complete. The factored loads were then used to calculate the shear and moment diagrams. This uses the theory that the sum of the forces in the Y direction equals zero and that the moments around a single point when summed are equal zero.

$\Sigma Fy = 0$

$\Sigma Ma = 0$

This theory was often used in the spread sheet analysis and if the computations did not lend themselves to be done in a spreadsheet then they were done by hand. Now that the maximum moment was determined we calculated the beams minimum height using the equation.

$h_{min} = L/16$ where L is the length of the beam

Shown below in Figure 5 is a typical cross-section of a T-Beam that shows some of the variables used in these equations.

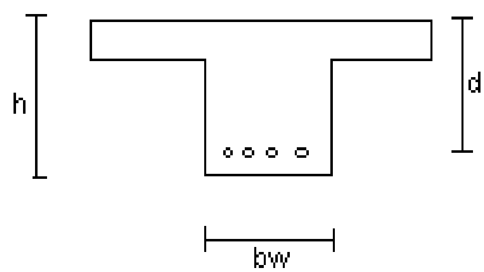

Figure 5: T-Beam Cross-Section

Using the minimum beam depth and the maximum moment the following equation allowed us to determine the beam width.

$bd^2/1200 = Mu/ \phi kn$

Where: b = beam width

d = distance from reinforcement to edge of beam (h – 2.5in)

Mu = maximum moment designed for

kn = strength of concrete(psi)*w*(1-(0.59*w)) = 456.9 with (w = .15)

ϕ = strength reduction factor = .9 for tension controlled

Now that we determined our beam dimensions using 4000 psi concrete we could go on to assess the reinforcement needed.

Reinforcement in the concrete is used because the concrete can not resist tensile stresses well and the steel used for reinforcement has a much higher tensile strength. The amount of steel was calculated by using the following formula.

As = (Mu*12000)/(ϕ*Fy*j*d)

Where: Mu = maximum design moment

Fy = strength of steel = 60,000psi

J = .95 approximation

d = distance from reinforcement to edge of beam (h – 2.5in)

ϕ = strength reduction factor = .9 for tension controlled

The estimated j value in the formula is refined later utilizing effective flange widths of the T -beams to make a more accurate As required.

The area of steel required also has specifications for a minimum through ACI, which must be calculated as well with the following 2 equations.

As_{min} = (3*(f'c^.5)*bw*d)/fy or As_{min} = (200*bw*d)/fy

Where: d = distance from reinforcement to edge of beam (h – 2.5in)

Fy = strength of steel = 60,000psi

bw = the width of the beam

From the three equations for As the largest value of steel required is always used to meet specifications for all standards. Once the As is found, the dimensions of the beam and reinforcement are complete except for the spacing of the reinforcement for crack control which are calculated simply in accordance with ACI.

The girders were done slightly differently when sizing the beams, since using the same equation as before for minimum height required the beam to be too wide. This is because the loads on the girder are much greater than the beams. Since the formula for the minimum height made an unreasonable size, the height of the beam was increased to conform to the common ratio of 1.5 for d/bw. Using this ratio and the formula from before using bd^2 the dimensions were achieved with reasonable size and ample load capacity. From there, all steps were the same for the rebar calculations of area required and spacing.

After the beams and girders were analyzed, the proper information was now available to determine the column loads. This was done by taking the load put upon each column from the reactions at the ends of each beam and girder that were supported by that column. There was no need to factor any loads or account for tributary areas because the slab was one direction and transferred its entire load to the beams which already factored the loads. The beams either transferred their loads to the girders or the columns directly as a pre-factored point load on the column. By adding all of the point loads we determined the combined load on the column, which we designed the column to withstand.

The loads for each column were done by each floor and making sure to add the loads from the floor above which would transfer the load downward. When designing with concrete, there is a limitation to the amount of reinforcing steel that can be put in the concrete. This limitation is by percentage of between one and four percent steel within the concrete. To determine our column dimension we assumed that the column with the greatest load would contain the 4% steel and then we would be able to change the steel in the rest of the columns while keeping them a constant and regular dimension. The following equation was used with the maximum load (on the first floor) and the assumed amount of steel to be 3.5% (not 4% to give safety factor).

$P_{n(max)} = 0.80[0.85*f'_c(A_g – A_{st}) + f_y(A_{st})]$

Where: $P_{n(max)}$ = maximum load on column

f'_c = compressive strength of concrete

A_g = Area of concrete ($A_g = A_{st}*(1-0.035)$)

A_{st} = Area of steel (3.5% or 0.035)

This equation determined the area of column required and we used that to determine the smallest square column that would suffice. Once we had the dimensions of the column we kept this constant throughout the building and used the above equation to determine the As or area of steel reinforcement required. As the height of the column is increased, the percent of steel changes but the columns dimensions remain the same.

To help us in the process of designing the columns, a similar notation system to the ones we used for the beams were used. As you can see in the Figure 3 and Figure 4 shown previously, each column has a marker next to it. On the side pods, they begin with an S and on the middle pod they begin with an M.

3.3. Rigid Frame Design

Once the columns were designed, work could commence on the rigid framing. This rigid framing would take into account the wind and seismic loading put onto the building. The rigid frame would have to be strong enough so that the forces pushing upon the building wouldn't overwhelm the load bearing strength given to the framing. The loads from wind and seismic activity develop moments that are placed at the end of the girders or beams and the loads try to bend the beam the opposite way of the gravity loads. This means that reinforcement needs to be put on the top layer of the beam or girder to withstand the loads. While both of these loads, wind and seismic, take into account the size of the building, it is obvious that the wind loads affect the building in a different way then the seismic loads. The area of the walls the wind blows against is in direct harm from the wind loads. These walls will push against the girders and beams of the building which will then put stress onto the columns – all of which are attached to the rigid framing of the building. For seismic loadings, the frame of the building itself is in direct contract from an event such as an earthquake. These loadings are determined from ASCI tables and codes. If this project was being done in a greater risk area to earthquakes or larger storms, the rigid frame would have to be increasingly stronger.

We first looked into using the same rigid frames that had been used in the original design. There were four in the East-West direction and three in the North-South direction. We input the size of our members into a program called *Frame*. This program allowed us to model a specific frame by placing loads on it and *Frame* calculated the moments that were produced in each member. We ran the program with the loads we found for seismic or wind in the direction in question, divided by the number of frames that would support the load. We found that the loads required excessive reinforcement because the moments created in the members were too high. To solve this problem we increased the number of rigid frames by a multiple of two and added some negative reinforcing steel to the affected members. This provided more reasonable moments that could be withstood by placing less than 4% steel in the members. The results of the frame program can be seen in Appendix 9.4.

The first step in designing the slab for each floor is determining its thickness. This was done with the following equations for minimum and maximum height.

h_{min} = LN(800+(.005*fy))/(3600+(5000*B*(1+Bs)))

hmax = LN(800+(.005*fy))/36000

Where: fy = strength of steel (60000psi)

B = length(E-W)/length(N-S)

Bs = 1

The lengths of span used was the greatest span in the building so that the slab could be used the same thickness throughout and effectively withstand the proper loads. The hand calculations for the slab design can be seen in Appendix 9.6. The steps of the design start with an estimation of the thickness of the floor, based on ACI Table 9.5(a), unless deflections are computed, this will give you the minimum thicknesses. After the estimation was made, we computed the trial unfactored loads. For this a dead load is taken from the slab and added to the other dead loads – which includes floor cover, mechanical equipment, and a ceiling. If done right, a load and strength-reduction factor is concluded from load factors and combinations from ACI 813-02 Section 9.2.1 and ACI 318-02 Section 9.3. Once the slab was determined to be 6" thick it was checked with the maximum shear and moments it would encounter to make sure it could withstand these. The thickness of the slab was determined to be sufficient and now the reinforcement needed to be designed.

To design a reinforced concrete structure's slab design, a process must be done based on the thickness of the slab. A tension-controlled test strip of slab was used to design the reinforcement. This test strip can be considered as if it was a beam and the calculations are the same as the beam calculations. From here, one can assume, through ACI 10.3.4, that the member is one that has an extreme tensile strain. Finally we checked to see if our calculated thickness and reinforcement met the required moment and shear and since they did the slabs were done.

After the design was completed, on this specific project there was a way to check the numbers for this project. Different ways of checking the loads are possible because this project was created in steel already. To do these checks, one had to look at the loads from the actual steel building; if there are loads that are significantly bigger on our design, than there is a problem. However, this is because on an actual steel site, a construction company will use as similar steel beams as possible for ease of constructability. Gilbane may use over-designed columns rather then use smaller steel columns because it makes the construction faster and easier – with less possibility for mistakes. So, checks back to the actual as built building have to be done with caution and can not be simply done member to member. The designer must look at an area of the building to compare these numbers. Also, these checks can be done by checking with the other loads of the project, checking with typical RS-Means values, and then again back to the actual as built structure to make sure the numbers seem accurate.

For the project there were two main areas to design, the middle pod and the north and south pods. However, the north and south pods are identical, which makes the design process easier. The wind loads and seismic loads are equal for the north and south pod as well as the interior live and dead loads. Because of this, a single spreadsheet can be used for each of the side pods. The middle pod, however, is different. Being the main entrance, the first floor has a wider opening in the middle for a lobby, while on the first floor of the side pods are more typical because the rooms are not designed for an entrance feel.

At this point during the project, the beams, girders, columns, slabs, and rigid frames had been designed. The next steps are the irregular parts of the building. As no building will ever be exactly alike, there are many differences that an engineer and design must account for while designing their structure. Irregularities include stairways, chillers mechanical rooms and equipment on the roof, connection areas between pods, bracing for pre-cast hanging walls, entranceways, and many more. Typically, designers take most of their time developing the needs for these areas of a building. These areas are not as easily done using a spreadsheet or program. The loads must all be individually calculated and derived separately. Usually, a problem with determinates for the irregularities have not been come across before and of harder nature to solve. An example of this was our design of the chillers. The chillers sit on the roof in a mechanical room. To find the needed load bearing structure for the chillers, the group had to perform additional calculations. The first step was to find the weight of each chiller from Cannon Design. We found that the chillers weighed 90 tons. From here, the members (beams, girders, and columns) were re-evaluated. After another process of testing the designed members for the new loads, we found that 5 beams, 3 girders, and 6 columns had to be changed. The sizes were increased and steel was added.

An example of the required area of steel values can be seen in the spreadsheet in Appendix 9.2. In some atypical beams, it was necessary to add positive and negative reinforcing steel. All of the beams had positive reinforcing steel but some of the beams also required negative reinforcing steel which was designated by a plus and minus sign in the spreadsheet. Shear and moment diagrams were used to find the maximum positive and negative moment and then the steel required was calculated.

The last check that our group made was to see if the footings used in the steel structure could also be used in the concrete structure. After looking at the plans, it was determined that the soil had a bearing stress of 4 kips per square foot that could not be exceeded. After a quick check on the weights of each column, the group determined that our design would require the footing sizes to increase by one size. The sizes of the footings can be seen in Appendix 9.10 which was taken from the steel buildings footing schedule.

4. Schedule and Construction Analysis

To meet the second objective the group analyzed the potential schedule and construction methods that are different for a concrete design. This objective also required background research and skills we learned in classes such as CE 3020 *Project Management*. We used information from past projects that were completed using reinforced concrete structures to complete an accurate schedule. This schedule was used to compare the differences in scheduling and construction methods between the two proposed concrete design and the actual steel construction.

Another very important resource for schedule and construction analysis was the Gilbane, Cannon, and WPI weekly owner's meetings. These meetings were a valuable tool for the group to learn about the types of problems the current project was experiencing. Being a fast-track project, problems were inevitable - having the construction phase begin while the design phase was still in progress meant that changes were likely to occur. Changes caused from design errors and omissions were likely to occur during construction because the design had yet to be finalized. This meant that it was even more important to stay on schedule, and the project management decisions played a vital role in seeing that it did. One way to stay on schedule is to schedule the processes by ease of constructability. What these means is simply, schedule the project with the thought of possible problems occurring and making every effort to avoid them. For example, sometimes using a drop down ceiling is easier because the crews for concrete construction and the electricians, HVAC crews, and crews for other components that go into the ceilings of a building can work faster and easier to be sure everything is done on different days. This is an alternative used instead of putting all these into the concrete ceiling, in which all these crews would have to be on site at the same time and an extremely large amount of coordination must be used. Another example is being able to use the same forms for the reinforced concrete construction. Generally, forms can be used about four times each but this can vary depending on the material and usage of the forms. Because of this, if columns or flooring is similar, the forms can be used again up to three times so that the construction crew isn't required to build this form so many times that is causes the scheduling to slow down. Using the forms multiple times also saves money on the cost of labor and materials for formwork. These examples of what the group has analyzed are examples of project management decisions that need to be made throughout construction projects.

Owners meetings also provided insight to the project management methods used by Gilbane and whether or not the subcontractors were staying on schedule. From this we were able to learn which steps in the project were typically sources of problems. Gaining this insight at the owner's meetings allowed us to think hypothetically about the implications of our project and the differences introduced by reinforced concrete construction.

4.1. Deriving the Tasks

In order to identify all the tasks to achieve the final product, the group used the schedule provided by Gilbane Construction. The beginning of this schedule can be seen in Appendix 9.8 which was the part used by the group. The durations of all processes that were common to both forms of construction, reinforced concrete and steel erection, were kept the same in both schedules. The group decided to focus only on the differences in erecting the steel structural frame compared with erecting the concrete structural frame. Focusing on these differences allowed the group to see how much time could be saved by using the concrete design. The group then decided that there were several distinct steps that were involved in constructing the concrete building. These included forming, reinforcing, and placing the concrete. *RS Means Building Construction Data 2007* provided the necessary information to calculate the daily output including all of these steps for different aspects of construction. The group then broke down the scheduling tasks into beams and girders, columns, and slabs. Table 2 shows the daily output values for the tasks that we used (RS Means Building Construction Data 2007).

Table 2: Daily Output Values (RS Means, 2007)

	Daily Output Value
Beams and Girders	60 CY Per Day
Columns	60 CY Per Day
6 Inch Slab	2585 SF Per Day

Using these values the group was able to calculate the durations of the various activities which the full calculations can be seen in Appendix 9.9. RS Means provided values for each of these scheduling tasks including daily output values of reinforcing, forming, and placing the concrete.

4.2. Deriving the Schedule

In order to schedule the construction of the concrete residence hall, the group had to make several important decisions. The first step was to decide the most logical sequence of steps for the building to be constructed. The group decided to continue to use the conventions established in the design phase of constructing the building by pod (North, South, and Middle). Since concrete also requires a curing period, the group also concluded that it would be better to complete one of the tasks for one pod and then move on to the next pod for the same task. This would provide the concrete time to cure and gain structural integrity while not impeding the progress of the building. With the basic sequencing of tasks established, the durations of each task were calculated.

After the design was completed, a quantity take-off of the concrete, reinforcing, and forming was completed based on our proposed design. The take-off results are shown below in Table 3 and scheduled tasks in Figure 6. The production rates for the beams, girders, and columns all include the formwork and reinforcing so it is not necessary to include these quantities and durations. The production rates for the slabs all depend on the square footage of a 6 inch slab so square footage was calculated as opposed to the amount of concrete.

Table 3: Take off Quantities

	Beams and Girders	**Slabs (6 inch)**	**Columns**
1st Floor Middle Pod	N/A	6261 SF	12.73 CY
1st Floor N/S Pod	N/A	6682 SF	13.05 CY
2nd-5th Floor Middle Pod each	91.5 CY	6261 SF	9.79 CY
2nd-5th Floor N/S Pod each	100.42 CY	6682 SF	10.04 CY
Roof Middle Pod	100.71 CY	6261 SF	N/A
Roof N/S Pod	89.8 CY	6682 SF	N/A

WPI Residence Hall		80	80	0%	01-Jun-07	20-Sep-07
North Pod		72	72	0%	01-Jun-07	10-Sep-07
A1000	Level 1: Slab on Grade	3	3	0%	01-Jun-07*	05-Jun-07
A1030	Level 1: Columns	1	1	0%	05-Jun-07*	05-Jun-07
A1060	Level 2: Beams, Girders, Slab	4	4	0%	29-Jun-07	04-Jul-07
A1090	Level 2: Columns	1	1	0%	04-Jul-07	04-Jul-07
A1120	Level 3: Beams, Girders, Slab	4	4	0%	17-Jul-07	20-Jul-07
A1150	Level 3: Columns	1	1	0%	20-Jul-07	20-Jul-07
A1180	Level 4: Beams, Girders, Slab	4	4	0%	02-Aug-07	07-Aug-07
A1210	Level 4: Columns	1	1	0%	07-Aug-07	07-Aug-07
A1240	Level 5: Beams, Girders, Slab	4	4	0%	20-Aug-07	23-Aug-07
A1250	Level 5: Columns	1	1	0%	23-Aug-07	23-Aug-07
A1300	Roof: Beams, Girders	4	4	0%	05-Sep-07	10-Sep-07
Middle Pod		65	65	0%	18-Jun-07	14-Sep-07
A1010	Level 1: Slab on Grade	2	2	0%	18-Jun-07*	19-Jun-07
A1040	Level 1: Columns	1	1	0%	19-Jun-07*	19-Jun-07
A1070	Level 2: Beams, Girders, Slab	4	4	0%	05-Jul-07	10-Jul-07
A1100	Level 2: Columns	1	1	0%	10-Jul-07	10-Jul-07
A1130	Level 3: Beams, Girders, Slab	4	4	0%	23-Jul-07	26-Jul-07
A1160	Level 3: Columns	1	1	0%	26-Jul-07	26-Jul-07
A1190	Level 4: Beams, Girders, Slab	4	4	0%	08-Aug-07	13-Aug-07
A1220	Level 4: Columns	1	1	0%	13-Aug-07	13-Aug-07
A1260	Level 5: Beams, Girders, Slab	4	4	0%	24-Aug-07	29-Aug-07
A1270	Level 5: Columns	1	1	0%	29-Aug-07	29-Aug-07
A1310	Roof: Beams, Girders, and Slabs	4	4	0%	11-Sep-07	14-Sep-07
South Pod		63	63	0%	26-Jun-07	20-Sep-07
A1020	Level 1: Slab on Grade	3	3	0%	26-Jun-07*	28-Jun-07
A1050	Level 1: Columns	1	1	0%	28-Jun-07	28-Jun-07
A1080	Level 2: Beams, Girders, Slab	4	4	0%	11-Jul-07	16-Jul-07
A1110	Level 2: Columns	1	1	0%	16-Jul-07	16-Jul-07
A1140	Level 3: Beams, Girders, Slab	4	4	0%	27-Jul-07	01-Aug-07
A1170	Level 3: Columns	1	1	0%	01-Aug-07	01-Aug-07
A1200	Level 4: Beams, Girders, Slab	4	4	0%	14-Aug-07	17-Aug-07
A1230	Level 4: Columns	1	1	0%	17-Aug-07	17-Aug-07
A1280	Level 5: Beams, Girders, Slab	4	4	0%	30-Aug-07	04-Sep-07
A1290	Level 5: Columns	1	1	0%	04-Sep-07	04-Sep-07
A1320	Roof: Beams, Girders, and Slab	4	4	0%	17-Sep-07	20-Sep-07

Figure 6: Task Durations

The required time for each task was calculated once the concrete design take-off was completed and the daily output values were found. Durations for each task were calculated by taking the overall quantities and dividing it by the daily output value. Some of the tasks did not take up a full day, so the group paired these tasks with other tasks that would not require a full day and would not slow down the critical path. This was especially true with the columns for each pod so they were scheduled to be completed after the beams and girders for the same pod. The columns each only required partial days so they were completed after the slabs for their floor had been poured. The columns for each floor added up to be approximately one full day which can be seen in Appendix 9.9. Shown below in Figure 7 is a schematic that displays the number of days spent on each floor doing the beams, girders, and slab and then the number of days spent on the columns to get to the next floor.

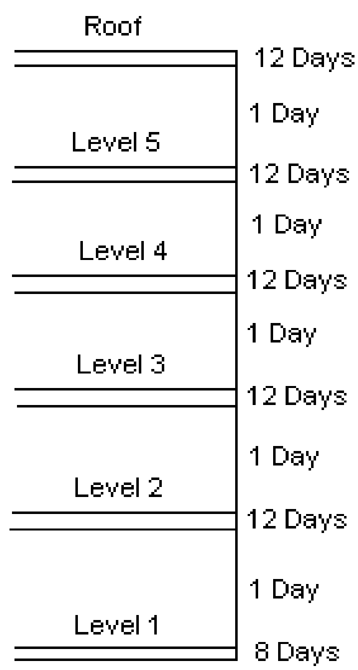

Figure 7: Durations Diagram

After the durations and the sequencing had been established, the group used *Primavera Project Management* to create the schedule. Each task was created and separated by pod in the software. They were then assigned durations and the tasks were dependent on the sequencing that was already established. The durations of each task can be seen in Figure 6 above. Then the complete schedule was able to be completed and that can be seen in Figure 8 below.

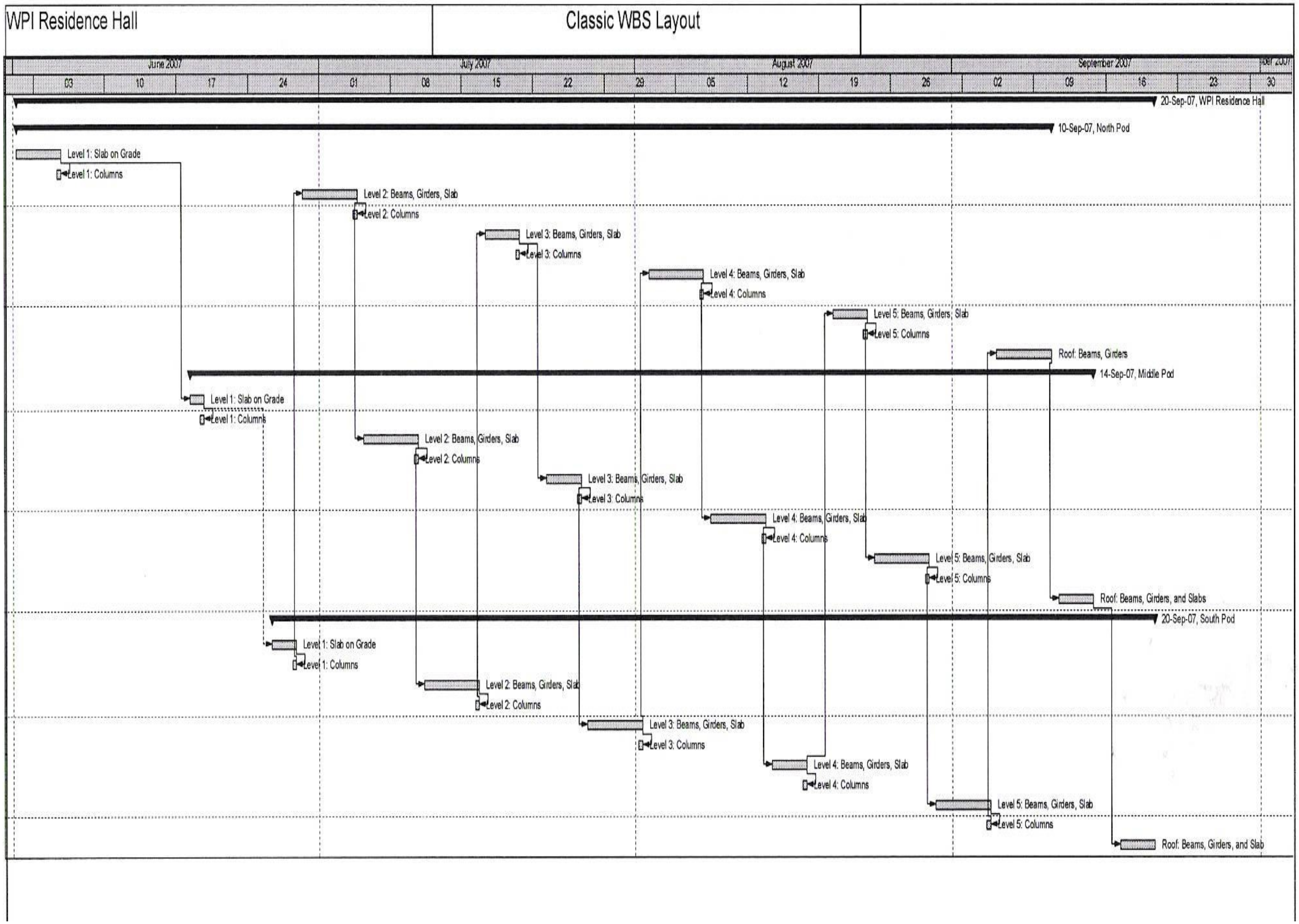

Figure 8: Complete Schedule

4.3. Significant Changes to Construction Process

When comparing the two projects, the group assumed that the steps leading up to the actual building construction would remain the same. This included obtaining the building permits, performing the utility work, and demolishing of the existing building. However, once the construction process of the building began the group found several major changes. Using steel construction requires the steel to be ordered in advance and then allowing time for it to be fabricated. Once the steel is fabricated and delivered then the construction can begin. While waiting for the steel to be fabricated, the excavation and foundation of the building can begin so they are completed when the steel arrives. In concrete construction it is much easier to start the project earlier because the concrete does not need to be ordered so far in advance. This allowed us to move our starting date up a few weeks before the date that they were originally ready for the steel. The group was not able to move up the concrete construction to the date that the steel was ordered because there were several things that were being held up including the demolition of the existing building. Normally the concrete would be able to be moved up further but in this project the schedule was not as flexible.

The group looked at a preliminary schedule of the project that was provided by Gilbane (Appendix 9.8) in order to obtain approximate times for the steel erection. The approximate finish date for the concrete slabs and steel erection was September 20th, 2007. From the results of our schedule the finish date for the concrete erection and all the slabs was also September 20th, 2007. This schedule included not working on standard holidays and weekends. The results show that according to our schedule the concrete erection would be completed approximately the same day that the steel erection was completed. These results are interesting because concrete construction is supposed to be faster than steel construction. The concrete construction could have been completed earlier by working on Saturdays or by adding extra crews. Since our calculations were done using the standard crew sizes provided in RS Means, the production could be accelerated by increasing the number of crews. Using some of these methods could increase costs initially but would save time and overhead costs in the long run.

5. Cost-Analysis of Reinforced Concrete Design

The group had to follow several distinct steps in order to perform a complete cost-analysis on our proposed concrete building design. As each aspect of the project was designed, it was then passed on to the cost-analysis phase of the project. This process was an ongoing process that accumulated throughout the term and developed into the final estimate. This required constant communication between the group members to transform the evolving design into a cost estimate.

The first step of the process was to obtain the design specifications that the group was creating in the design phase. After the specifications were obtained, the design was examined to evaluate and improve its constructability. If the design was not practical for construction purposes, then alterations were made in order to make the design possible. For example, some of the beams had a cantilever end so they needed to be designed using negative reinforcing steel. The next step was to perform a complete takeoff to determine the quantities of materials needed. *RS Means Building Construction Data 2007* was then used to determine the unit costs for each of the construction steps. This is a publication that provides information for construction companies on the costs of materials, equipment, and methods for each region across the country. Using the unit costs and the material take-off, we were able to multiply them together and get an estimate of the costs.

5.1. Deriving the Unit Costs

The numbers used by subcontracting companies are typically confidential since this could provide a competitive advantage for competitors. Because of this, the published prices for each unit of activity and material found in RS Means are used in order to find the average unit prices. There are many different prices presented in RS Means so it is important to understand what each price includes. Some prices include materials, equipment, and labor while other prices strictly referred to only one of these categories. The group needed to examine the unit costs to see if everything needed was already included or if other costs needed to be added.

The group divided the major steps of concrete construction into forming, reinforcing, and placing the concrete. The first costs determined were the prices for the girders and beams. These unit costs were generally the same but varied by the size of the beam. For example, a 12 inch wide beam cost $9.90 while a 24 inch wide beam cost $9.20 per square foot of contact area for 4 uses of formwork. The group decided it was practical to use the plywood forms 4 times each before discarding.

The choices for reinforcing costs were all the same for #3 to #7 bars, and then they were the same for #8 to #18 bars. Based on the required area of steel obtained in the design, the group decided to use mostly #7 bars for the reinforcing but there were several exceptions that were dealt with on an individual basis. Using the same type of bars for most of the reinforcing decreases the confusion and the possible installation errors that could occur placing many different sized bars.

The costs for the concrete varied based on the sizes being placed but there were not many obstacles in choosing these prices. There were also several instances where the group needed to add adjustment factors for the elevations. The costs for placing concrete slabs on the upper floors were more than it was for the lower floors. These were the general practices used by the group to determine the unit costs for each of the aspects of the concrete construction.

5.2. Deriving the Prices

After the material take-off was completed and the unit-price costs were determined, the costs for each activity were able to be computed. The quantities were multiplied by their unit costs to determine the cost for each individual beam, girder, slab, or column. Then they were summed to determine the cost of formwork, reinforcing, and placing concrete per floor. After the costs were determined for each floor, it was multiplied by the number of floors that would have the same costs.

Another important factor to consider was the location of the project. Concrete construction in New England is more expensive than the average for the rest of the United States so adjustment factors needed to be used to account for this regional bias. The region multipliers for Worcester, Massachusetts are shown in Table 4 shown below (RS Means 2007).

Table 4: Worcester Region Multipliers

Construction Activity	Worcester Adjustment Factor
Concrete Formwork	1.29
Concrete Reinforcing	1.125
Concrete Pouring	1.206

These factors were used to multiply the totals obtained for each of these activities to adjust for the increased concrete construction costs in Worcester. The concrete reinforcing was also multiplied by an additional factor of 1.10 to account for the 10 percent waste that is typical when installing reinforcement.

After all the costs of the beams, columns, girders, and slabs were determined they were added together to obtain the completed estimate. The breakdown of the costs can be seen below Table 5.

Table 5: Breakdown of Costs

Construction Element	Cost
Beams Floors	$861,794.80
Beams Roof	$167,920.24
Girders Floors	$326,794.23
Girders Roof	$87,413.25
Slabs	$719,875.74
Columns	$244,171.22
Stairs	$238,809.47
TOTAL	$2,646,779.46

This table shows the accumulated project cost of about $2.65 million for the structural concrete. The cost estimate can be seen in Appendix 9.5 which shows the detailed spreadsheet with the quantities, unit prices, and adjustment factors used to determine the total estimate. This estimate relies heavily on the accuracy of the data presented in RS Means and some general assumptions made by the group. It is important to keep in consideration that the market conditions at the time of the bidding for this project could have been slightly different than the current conditions. The market conditions can also provide the concrete industry to be more aggressive in bidding to compete with the steel industry. However, using the information available to us, this estimate reflects the group's design and cost analysis efforts.

The accumulated cost of almost $2.65 million dollars is more than the $2.2 million dollars that was awarded to the structural steel subcontractor. However, our cost estimate includes the concrete slabs while the steel subcontractor's quote does not. The concrete slabs for the current building are about 3" thick so we can assume they would be about half as much as our estimate for the concrete slabs. If we factor in an allowance for the slabs, then their estimate would go up by $255,000 which would bring their total to a little more than $2.45 million dollars. Generally in New England the steel construction market is more competitive than the concrete construction industry. There is a difference of about 8 percent between the two cost estimates. The differences in the prices are not extremely far apart on a project of this size but they are significant. It is important to consider this cost difference along with the other advantages and disadvantages of each building material.

6. Integrating the Findings

This project touched on a variety of areas that were specified in the Capstone Design Statement. This section is intended to bring everything together and tie up the loose ends. This section talks about the LEED certification, ethical issues, and attending the weekly owner's meetings related to this project.

6.1. LEED Certification

While LEED Rating Systems can be useful just as tools for building professionals, there are many reasons why LEED project certification can be an asset: (LEED, 2008)

1. Be recognized for your commitment to environmental issues in your community, your organization (including stockholders), and your industry;
2. Receive third party validation of achievement;
3. Qualify for a growing array of state and local government initiatives;
4. Receive marketing exposure through USGBC Web site, Greenbuild conference, case studies, and media announcements.

What all this means to a university is that they are taking the initiative to build a building on their campus that is healthy for the environment. By having these structures on campus, it pleases the students, faculty, and board members while at the same time giving the university an appearance that it stands for a better environment. This is taken from the LEED self promoting writing on why it is valuable to build with LEED certification: (LEED, 2007)

> "Buildings fundamentally impact people's lives and the health of the planet. In the United States, buildings use one-third of our total energy, two-thirds of our electricity, one-eighth of our water, and transform land that provides valuable ecological resources. Since the LEED Green Building Rating System for New Construction (LEED for New Construction version 2.0) was first published in 1999, it has been helping professionals across the country to improve the quality of our buildings and their impact on the environment.
>
> As the green building sector grows exponentially, more and more building professionals, owners, and operators are seeing the benefits of green building and LEED certification. Green design not only makes a positive impact on public health and the environment, it also reduces operating costs, enhances building and organizational marketability, potentially increases occupant productivity, and helps create a sustainable community. LEED fits into this market by providing rating systems that are voluntary, consensus-based, market-driven, based on accepted energy and environmental principles, and they strike a balance between established practices and emerging concepts."

To become LEED certified, a certain number of points must be given to a project for specific tasks carried out that are helpful for the environment, by LEED's standards.

6.1.1. LEED's Project Score System

While achieving the required points for LEED certification, a building is graded by the LEED scorecard. This scorecard includes ways in which to use sustainable sites, increase water efficiency, optimize energy performance, use recycled materials, create indoor environmental quality, and to develop innovation in design. With a possible thirty-seven achievable points identified for the current project, WPI's new residential hall is expected to have silver certification. As shown in Appendix 9.1.

6.1.2. Green Issues

Many of the points that WPI's new residential hall is receiving on the steel structure would also be gained for the reinforced concrete design. The design of the building is going to be the same for the points from sustainable sites category as well as for water efficiency, energy and atmosphere, indoor environmental quality, and innovation in design. With the concrete, there is a possibility that indoor environmental quality may lose one point due to the temperature differences in concrete compared with steel; however, this is not expected because concrete is a better insulator with more thermal mass. In Appendix 9.1 is the full LEED scorecard with the Total Project Score, and the breakdown of the score. This project will receive a Silver Certification whether it is built with reinforced concrete or steel.

6.1.3. Recycling

For WPI's new residential hall, an additional point or two would be available because of the reinforced concrete construction. Concrete aggregates would be formed from recycled material which would give WPI an additional point if it could reuse an additional five percent (or two points if they could reach 10). With the structural steel, WPI does not receive credit for these recycled materials. Even though structural steel is usually made of about 80 percent of recycled products, on Cannon Designs Plan, WPI does not receive any credit for this. This would add to the approximately 92-95% of already recycled materials that Gilbane is using to construct the building as built.

6.2. Risk Implications

With construction sites and projects, there are many intangibles that typically are not thought of during the estimation/pre-construction phase by the onlooker. Issues that cause the contracting companies, owners, and designers to have to plan accordingly can create a smooth project phase and create a surplus of problems that can greatly detract from the positives of a project. Choosing the right contractor, ensuring that strict health and safety risks are addressed, understanding the social impacts of the decisions, and understanding the local political issues are all parts to a project that must be taken of in the proper manor.

6.2.1. Choosing the Contractor

In choosing a contractor, many different factors can greatly affect the process of the construction on a project. For this project Gilbane Construction was hired on a Guaranteed Maximum Price (GMP) basis. This puts the construction company at risk; if the total price exceeds the GMP, Gilbane is then at risk (obeying too many contractual agreements). If this was done differently or if a different company was hired, the project could be drastically changed. Gilbane does many of its projects at risk, while other companies don't hold the size and strength to pull off such projects in such a time sensitive environment. For example, there are many construction companies or construction management companies that would not receive the bonds and insurance to acquire a project because a severity and insurance company wouldn't back their company, which is required by law. Because of this, WPI would then be held responsible for not only the construction process but also the further affects from the project if the schedule was not matched perfectly.

To assess the issue of whether it is ethically fair for WPI to favor Gilbane because of their closeness to the school, helpfulness to the academics, and familiarity to the location – WPI made no ethically problematic decisions in going with Gilbane Construction. They have done work on WPI's campus many times before, done a good job, and have been able to not compromise the everyday life of the students, faculty, and staff on campus.

However, it would be different if the risk for this project was greater then the past projects, and Gilbane could not maintain the correct protection for all contributors on the project. Then there would be a principled hindrance with hiring Gilbane. Essentially, if a company has done well in the past, but the magnitude of a project is beyond their capability, even with their rich history, an owner should be sure not to make the mistake of hiring them for the project. It would be easy for a company to be overlooked in this situation because of their history with a company. Fortunately, WPI's new residential hall project is within the scope of the Gilbane Construction Company's ability and the group has found this not to be a problem. Gilbane contained the ability because of their history, this satisfies the group's requirements.

6.2.2. Health and Safety

The Gilbane Building Company during their rich history has taken great pride in ensuring the safety and health of all personnel working on their projects. Since Gilbane project managers and their teams care about the contractors, they have developed award-winning programs that protect workers. (Gilbane, 2008) With an alliance with the Occupational Safety and Health Administration (OSHA), Gilbane Construction has been able to advance the cause of jobsite safety at a much higher rate than most construction companies proven by their number of accidents being considerably lower than the industry average. Gilbane has earned numerous industry honors as the safest contractor in America.

In a world of fast-track projects and intense schedules, Gilbane's devotion to safety has made sure that they are sending their workers home safely. As a result, the clients benefit from better project performance and a clear reduction in unanticipated costs. This great work has won Gilbane the Construction Industry Safety Excellence Award in 2006 and the Liberty Mutual Gold Award for outstanding safety performance in 2003, as well as many health and safety awards in the past.

With this rich history of strong awareness for the good of their workers, the environment, and the neighborhood of their projects, Health and Safety is not an issue of concern for a project such as WPI's new residential hall's construction – there has been no days lost on the job because of this problem. This is also beneficial to the economic portion of the project. Accidents can lead to great loss of time, which is extremely important to the construction industry.

6.2.3. Social Impacts of Decisions

In all construction projects there are benefits to the local economy. These benefits are greater if the construction materials and workers are local as well. In deciding which material to build WPI's new residence hall, the largest factor is pricing for the material and the work. For projects of this size, they are typically done by region.

With Gilbane being a nationwide country, the only thing needed to be able to achieve a well done estimate and to find companies to be able to build a reinforced concrete structure would be a phone call to another office. However, Gilbane found that building with steel was the right choice for Gilbane, Cannon Design, and WPI by a first cost basis. It keeps the construction regionally local and Gilbane is able to use familiar subcontractors and unions.

6.2.4. Political Issues

For many construction projects, it is very difficult for a contractor to be able to work at a fast speed while not disturbing any neighbors. Looking at other projects in Massachusetts, it is clear that this can be a major problem for both the abutters and the contracting company. Dust in the air, road closures, large and heavy trucks creating road deformities, truck idling, noise, and other inconveniencies can cause havoc for the project. These environmental and political issues that are created during a project are always concerns. However, WPI maintains a pleasant relationship with their neighbors and the city of Worcester and Gilbane Construction runs a first-rate site. This is assessed because while Gilbane has been on WPI's campus, WPI and the neighborhood have not been interrupted in any other way than those stated in pre-construction meetings. (WPI, 2007)

However, if WPI did not have a good relationship with the city or did not have good relations with the neighborhood, a project like this could be a disaster. Local businesses would be disrupted and losing money and neighbors would be complaining to the city and government agencies. The project would be slowed down, and Gilbane would not have been allowed to proceed with some of the steps that were needed to expedite the project. One of these steps was to close Boynton Street for the summer months. Steps such as these would be difficult to obtain if the institution was not looked upon with such high regard. Also, parking disruptions and hindrance to the Church next door would have been extremely hard to coordinate if WPI did not have its great reputation.

6.2.5. Changes in Construction

If this project were to use a reinforced concrete structural frame instead of one of steel, some of the above problems for which WPI may have needed alterations for would have been avoided. An example of one thing that could have been avoided is the closing of Boynton Street. With reinforced concrete, the delivery concrete trucks would have been located on site while the concrete was pumped into the formwork. Once the concrete was placed and cured, subsequent work would be on site and there wouldn't be the problem of the closure of such roads. However, with concrete comes the destruction of roads, the idling of trucks, noise from the idling trucks, and a greater abundance of truck delivery. These are the decisions that need to be made by weighing the advantages and disadvantages of both sides.

6.3. Observations from Owner's Meetings

Going through this project not only taught the group members about how much time and work the pre-construction aspect of a project takes but by attending the owner's meeting with Cannon Design, Gilbane Construction, and WPI's representatives, we learned a great deal about what goes on during the actual construction phases as well. During the owner's meetings we gathered indispensable information about our project the new construction as a whole. This taught us a great deal about the magnitude of processes to which a firm must pay complete attention to. From changes in the details to delivery delays, learning about problems with subs and products – the group was informed weekly about various steps of the project. The owner's meetings may not have been as significant to our project for the design and schedule aspect of the project, but it was a great learning experience for the group. This information made it possible for the group to be able to understand what the pre-construction process leads to in the real world and the changes that are made on site that will affect the project significantly.

7. Conclusion and Recommendation

In our project we designed the new residence hall using reinforced concrete instead of steel and performed a cost and schedule comparison between the two. This analysis helps WPI academia learn more about their construction decisions and project management practices. After our objectives were completed, we formulated the comparisons based on our results and analysis. Using the design, schedule, and cost analysis, the group was able to show WPI the differences in using reinforced concrete for their new residence hall construction. Our results showed a difference of about 8 percent increased costs for just the structure, and the project duration was about the same even though concrete is generally quicker. This project looked at the differences in construction process, design, duration, LEED, and cost for the new WPI Residence Hall.

After completing the design, cost-analysis, and schedule of the concrete structure, the group was able to come to several conclusions. The design of the building was completed using a one way reinforced slab. This lead to the group needing to double the number of rigid frames and to increase the footing sizes. If we would have had more time to perform this analysis and explore other design methods, then this may not have happened.

The results of the schedule comparison show that there is practically no time saved by using concrete construction. The group concluded that the reason for this was the lack of flexibility in the early stages of the project. We started our concrete schedule based on when the footings were ready for the structural steel. However, the footings were not able to be started earlier because of obtaining permits and demolition of existing buildings. If we were able to start the footings earlier, then we would've been able to start the concrete construction much earlier and would've seen some time and overhead savings. Using the concrete structure would allow the slabs for each floor to be in place earlier so it would allow some control over the scheduling of other activities. HVAC and other interior subcontractors would be able to start their work earlier so this would be one of the advantages of using concrete even though the structure would still be completed about the same time. The steel structure is still on schedule to finish before August 11th, 2008 when the owner is supposed to move in so using either building material should not be a problem.

Our cost comparison showed that the initial cost differences between the two designs were about $200,000. This is not as significant when looking at the overall cost of the entire project so the group does not feel that this should be the deciding factor. However, this comparison is a first cost analysis and does not reflect the long term cost implications that could happen by choosing concrete over steel. Concrete and steel both have their long-term advantages depending on the project.

Based on our findings for the new WPI Residence Hall, we concluded that concrete could've been used for this building. However, using concrete would not have allowed us to save as much time as other concrete projects because the early part of the schedule was not as flexible. Using concrete as the primary building material would have also come with some increased costs but would not have required a crane or off-site storage of the steel. The group decided that concrete could've been used for this project but that the factors that would've made concrete the logical choice did not exist.

Overall this project touched many areas of the construction process and possibly, too many. The group recommends that in the future this project could be split into sections and made into greater in-depth projects. The LEED material is a new idea in the construction industry, and many different types of projects could be formed through this subject. Deeper studies of the design, cost-analysis, and scheduling could be conducted through three distinct projects. This would allow each project to be much more involved and give more credibility to the final results. The group recommends this as something for WPI to consider in the future furthering the effectiveness of the Major Qualifying Project.

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Figures Sourced:

Figure 1 – taken from Cannon Design

Figure 2 – taken from Metal Buildings Guide

9. Appendices

9.1. LEED Scorecard

Worcester Polytechnic Institute - New Residence Hall LEED Scorecard 1/17/07

Cost Impact - Add

Minor Cost Impact - Add

Yes	Maybe	No	Total Project Score		
			Sustainable Sites		**Keyword description**
Y			Prereq 1	**Erosion & Sedimentation Control**	**Sediment and Erosion Control Plan**
1			Credit 1	**Site Selection**	**Avoid Sensitive Sites**
1			Credit 2	**Urban Redevelopment**	**Increased Site density**
		1	Credit 3	**Brownfield Redevelopment**	**Remediate Contaminated Sites**
1			Credit 4.1	**Alternative Transportation**, Public Transportation Access	**Proximity to Public Transportation**
1			Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	**Bike Storage and Changing Rooms**
		1	Credit 4.3	**Alternative Transportation**, Alternative Fuel Refueling Stations	**Alternate Fueling / Stations**
1			Credit 4.4	**Alternative Transportation**, Parking Capacity	**Meet/Not Exceed Zoning - Van Pool Park'g.**
		1	Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	**Restored habitat for 50% of open space**
		1	Credit 5.2	**Reduced Site Disturbance**, Development Footprint	**Open space = Building Footprint**
		1	Credit 6.1	**Stormwater Management**, Rate and Quantity	**< Predevelopement or 25% decrease**
1			Credit 6.2	**Stormwater Management**, Treatment	**Eliminate Contaminants - Onsite Filtration**
		1	Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands**, Non-Roof	**High Albedo / Open Grid Parking**
1			Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands**, Roof	**Energy Star Compliant Roof**
1			Credit 8	**Light Pollution Reduction**	**IESNA Cutoffs**
			Water Efficiency		
1			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	**Portable Water reduction for Landscape**
1			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	**No Landscape Irrigation Proposed**
		1	Credit 2	**Innovative Wastewater Technologies**	**Reducing Wastewater by 50%**
1			Credit 3.1	**Water Use Reduction**, 20% Reduction	**1992 Energy Policy Act 20% < Baseline**
1			Credit 3.2	**Water Use Reduction**, 30% Reduction	**30% < Baseline**
			Energy & Atmosphere		
Y			Prereq 1	**Fundamental Building Systems Commissioning**	**Incorporate Commissioning into Design**
Y			Prereq 2	**Minimum Energy Performance**	**ASHRAE / IESNA 90.1 - 1999**
Y			Prereq 3	**CFC Reduction in HVAC&R Equipment**	**Zero CFC's**
2			Credit 1.1	**Optimize Energy Performance**, 20% New / 10% Existing	**Reduce regulated Energy Costs by 20%**
2			Credit 1.2	**Optimize Energy Performance**, 30% New / 20% Existing	**30%**
	2		Credit 1.3	**Optimize Energy Performance**, 40% New / 30% Existing	**40%**
	2		Credit 1.4	**Optimize Energy Performance**, 50% New / 40% Existing	**50%**
		2	Credit 1.5	**Optimize Energy Performance**, 60% New / 50% Existing	**60%**
		1	Credit 2.1	**Renewable Energy**, 5%	**Incorporate Renewable Energy Technologies**
		1	Credit 2.2	**Renewable Energy**, 10%	**Incorporate Renewable Energy Technologies**
		1	Credit 2.3	**Renewable Energy**, 20%	**Incorporate Renewable Energy Technologies**
1			Credit 3	**Additional Commissioning**	**Outside Team**
1			Credit 4	**Ozone Depletion**	**No HCFCs or Halons - Montreal Protocol**
		1	Credit 5	**Measurement & Verification**	**Continuous Equipment Monitoring / DDC**
	1		Credit 6	**Green Power**	**Contract for Green Power**
			Materials & Resources		
Y			Prereq 1	**Storage & Collection of Recyclables**	**Stations Required**
		1	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	**Building Reuse**
		1	Credit 1.2	**Building Reuse**, Maintain 100% of Existing Shell	**Building Reuse**
		1	Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	**Building Reuse**
1			Credit 2.1	**Construction Waste Management**, Divert 50%	**Weight or Volume**
1			Credit 2.2	**Construction Waste Management**, Divert 75%	**Weight or Volume**
		1	Credit 3.1	**Resource Reuse**, Specify 5%	**Salvaged or Reused Materials**
		1	Credit 3.2	**Resource Reuse**, Specify 10%	**Salvaged or Reused Materials**
1			Credit 4.1	**Recycled Content**, Specify 5%	**Post Consumer + 1/2 Post Industrial**
1			Credit 4.2	**Recycled Content**, Specify 10%	**Post Consumer + 1/2 Post Industrial**
1			Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	**Manufactured Locally**
1			Credit 5.2	**Local/Regional Materials**, of 20% Above, 50% Harvested Locally	**Extracted or Harvested Locally**
		1	Credit 6	**Rapidly Renewable Materials**	**5% Threshold**
1			Credit 7	**Certified Wood**	**50% Threshold - Forest Stewardship Council**

			Indoor Environmental Quality		
Y			Prereq 1	**Minimum IAQ Performance**	ASHRAE 62-1999
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	No Smoking Required
1			Credit 1	**Carbon Dioxide** (CO_2) **Monitoring**	Permanent Monitoring ASHRAE 62-2001
		1	Credit 2	**Increased Ventilation**	ASHRAE 129-1997 (E)>=.9
1			Credit 3.1	**Construction IAQ Management Plan**, During Construction	SMACNA Guidelines for Protection/Air FIltering
1			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	After Construction / Before Occupancy
1			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	Product Compliance SCAQMD
1			Credit 4.2	**Low-Emitting Materials**, Paints	Product Compliance Green Seal GS-11
1			Credit 4.3	**Low-Emitting Materials**, Carpet	Product Compliance Carpet Rug Institute
1			Credit 4.4	**Low-Emitting Materials**, Composite Wood	Product Compliance - No Formaldehyde
1			Credit 5	**Indoor Chemical & Pollutant Source Control**	Design Featues (Mats, drains, partitions, others)
	1		Credit 6.1	**Controllability of Systems**, Perimeter	Operable Windows / Lighting Zones
1			Credit 6.2	**Controllability of Systems**, Non-Perimeter	Airflow/Temp/ Lighting 50% non-perimeter
		1	Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	Temp / Humidity Control
		1	Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	DDC Control of Thermal / Humidity
1			Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	Daylighting to Occupied Areas
1			Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	Views to Occupied Areas
			Innovation & Design Process	Possible Points	0
		1	Credit 1.1	**Innovation in Design**:	Double -up Green Power
1			Credit 1.2	**Innovation in Design**:	Academic / Educational Program
		1	Credit 1.3	**Innovation in Design**:	Double-up recycled content or regional mat's.
		1	Credit 1.4	**Innovation in Design**:	Open
1			Credit 2	**LEED™ Accredited Professional**	Design Team Professional
38	6	25		**Project Totals**	
				33-38 point required for Silver Certification	

9.2. Beam Design Spreadsheet

beam #	length	Trib width	DL	LL(5ft)	LL	FL (5ft)	FL (rest)	WOB 10%	WOB 20%	h 8%	h 10%	bw 8%
35	21.63	6.5	715	520	390	1690	1482	169	338	21	26	11
+36	29.17	4.5	495	360	270	1170	1026	117	234	28	35	14
-36	29.17	4.5	495	360	270	1170	1026	117	234	28	35	14
37	29.17	9	990	720	540	2340	2052	234	468	28	35	14
+38	30.96	7.38	811.8	590.4	442.8	1918.8	1682.64	191.88	383.76	30	37	15
-38	30.96	2.88	316.8	230.4	172.8	748.8	656.64	74.88	149.76	30	37	15
39	30.96	5.75	632.5	460	345	1495	1311	149.5	299	30	37	15
+40	30.96	7.38	811.8	590.4	442.8	1918.8	1682.64	191.88	383.76	30	37	15
-40	30.96	2.88	316.8	230.4	172.8	748.8	656.64	74.88	149.76	30	37	15
41	29.17	8.88	976.8	710.4	532.8	2308.8	2024.64	230.88	461.76	28	35	14
42	29.17	9.5	1045	760	570	2470	2166	247	494	28	35	14
43	29.17	8.88	976.8	710.4	532.8	2308.8	2024.64	230.88	461.76	28	35	14
+44	30.96	7.38	811.8	590.4	442.8	1918.8	1682.64	191.88	383.76	30	37	15
-44	30.96	2.88	316.8	230.4	172.8	748.8	656.64	74.88	149.76	30	37	15
45	30.96	5.75	632.5	460	345	1495	1311	149.5	299	30	37	15
+46	30.96	7.38	811.8	590.4	442.8	1918.8	1682.64	191.88	383.76	30	37	15
-46	30.96	2.88	316.8	230.4	172.8	748.8	656.64	74.88	149.76	30	37	15
47	29.17	9	990	720	540	2340	2052	234	468	28	35	14
+48	29.17	4.5	495	360	270	1170	1026	117	234	28	35	14
-48	29.17	4.5	495	360	270	1170	1026	117	234	28	35	14
49	21.63	6.5	715	520	390	1690	1482	169	338	21	26	11
6	29.66	10.66	1172.6	852.8	639.6	2771.6	2430.48	277.16	554.32	28	36	14
7	29.66	10.02	1102.2	801.6	601.2	2605.2	2284.56	260.52	521.04	28	36	14
8	29.66	10.38	1141.8	830.4	622.8	2698.8	2366.64	269.88	539.76	28	36	14
9	29.66	9.69	1065.9	775.2	581.4	2519.4	2209.32	251.94	503.88	28	36	14
10	29.66	8	880	640	480	2080	1824	208	416	28	36	14
11	29.66	8	880	640	480	2080	1824	208	416	28	36	14
22	22.5	6.46	710.6	0	387.6	0	1472.88	147.288	294.576	22	27	11
+23	22.5	7.07	777.7	0	424.2	0	1611.96	161.196	322.392	22	27	11
-23	22.5	7.07	777.7	0	424.2	0	1611.96	161.196	322.392	22	27	11
24	22.5	8	880	0	480	0	1824	182.4	364.8	22	27	11
25	22.5	7.73	850.3	0	463.8	0	1762.44	176.244	352.488	22	27	11
26	22.5	7.86	864.6	0	471.6	0	1792.08	179.208	358.416	22	27	11

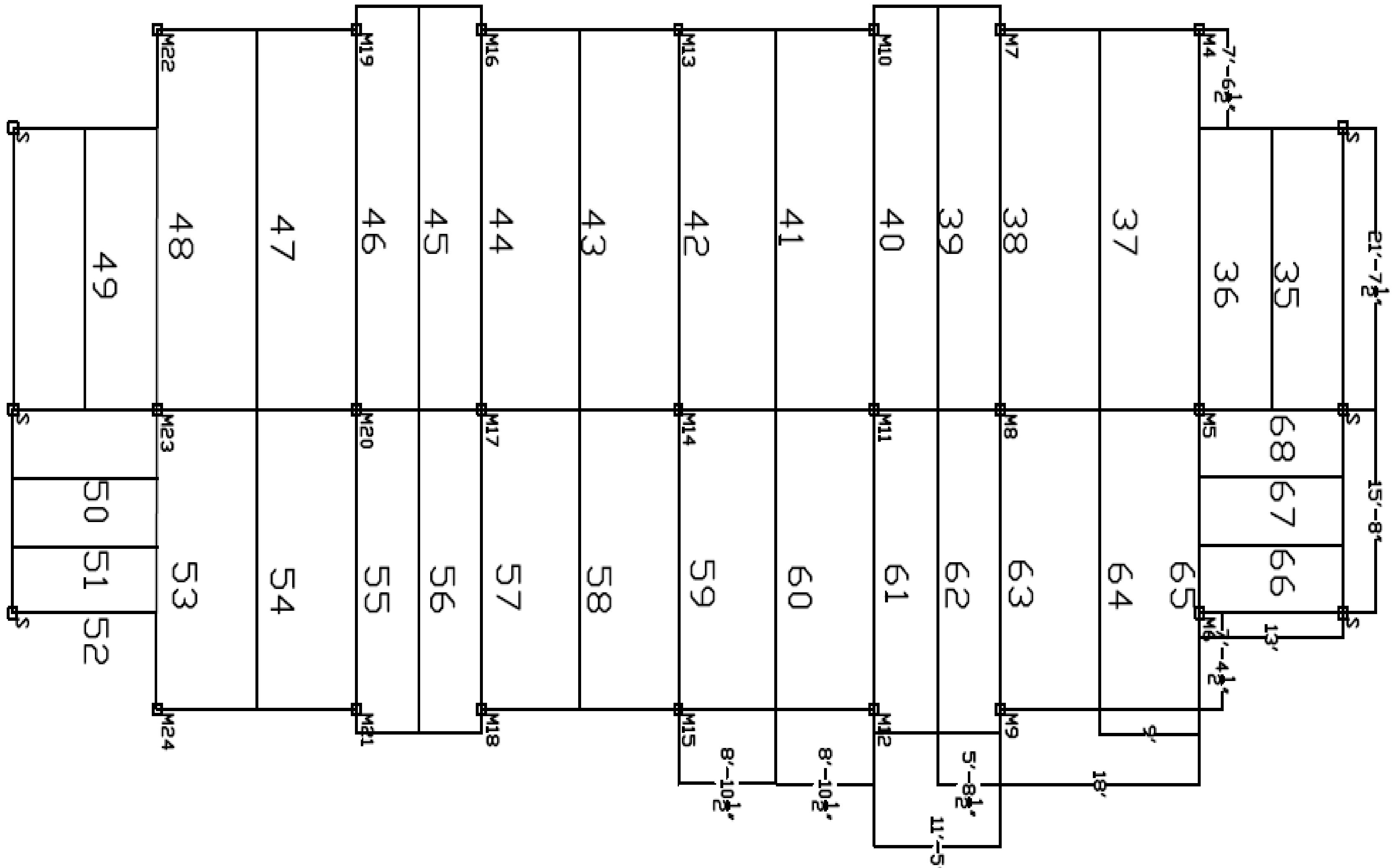
27	22.5	8.58	943.8	0	514.8	0	1956.24	195.624	391.248	22	27	11

bw 10%	**WOB #1**	**Wob #2**	**Trial WOB**	**FL(5ft)**	**FL #2**	**Ay**	**By**	**Shear(k)**
13	240.625	352.0833333	**300**	2050	1842	20.84102658	20.04143342	20.84102658
18	408.3333333	656.25	**300**	1530	1386	35.85	43.69	43.69
18	408.3333333	656.25	**300**	1530	1386	35.85	43.69	43.69
18	408.3333333	656.25	**400**	2820	2532	38.24580553	37.05263447	38.24580553
19	468.75	732.2916667	**400**	2398.8	2162.64	24.26	48.79	25.94
19	468.75	732.2916667	**400**	1228.8	1136.64	24.26	48.79	25.94
19	468.75	732.2916667	**400**	1975	1791	28.57039059	27.79896941	28.57039059
19	468.75	732.2916667	**400**	2398.8	2162.64	24.26	48.79	25.94
19	468.75	732.2916667	**400**	1228.8	1136.64	24.26	48.79	25.94
18	408.3333333	656.25	**450**	2848.8	2564.64	38.70430546	37.52704334	38.70430546
18	408.3333333	656.25	**450**	3010	2706	40.85673917	39.59728083	40.85673917
18	408.3333333	656.25	**450**	2848.8	2564.64	38.70430546	37.52704334	38.70430546
19	468.75	732.2916667	**400**	2398.8	2162.64	24.26	48.79	25.94
19	468.75	732.2916667	**400**	1228.8	1136.64	24.26	48.79	25.94
19	468.75	732.2916667	**400**	1975	1791	28.57039059	27.79896941	28.57039059
19	468.75	732.2916667	**401**	2400	2163.84	24.26	48.79	25.94
19	468.75	732.2916667	**400**	1228.8	1136.64	24.26	48.79	25.94
18	408.3333333	656.25	**400**	2820	2532	38.24580553	37.05263447	38.24580553
18	408.3333333	656.25	**300**	1530	1386	35.85	43.69	43.69
18	408.3333333	656.25	**300**	1530	1386	35.85	43.69	43.69
13	240.625	352.0833333	**300**	2050	1842	20.84102658	20.04143342	20.84102658
18	408.3333333	675	400	3251.6	2910.48	44.72425576	43.30618104	44.72425576
18	408.3333333	675	400	3085.2	2764.56	42.46649331	41.13355629	42.46649331
18	408.3333333	675	400	3178.8	2846.64	43.73648469	42.35565771	43.73648469
18	408.3333333	675	400	2999.4	2689.32	41.30233455	40.01329665	41.30233455
18	408.3333333	675	400	2560	2304	35.34043059	34.27620941	35.34043059
18	408.3333333	675	400	2560	2304	35.34043059	34.27620941	35.34043059
14	252.0833333	393.75	300	0	1832.88			20.6199
14	252.0833333	393.75	300	0	1971.96			22.18455
14	252.0833333	393.75	300	0	1971.96			22.18455
14	252.0833333	393.75	300	0	2184			24.57
14	252.0833333	393.75	300	0	2122.44			23.87745
14	252.0833333	393.75	300	0	2152.08			24.2109
14	252.0833333	393.75	300	0	2316.24			26.0577

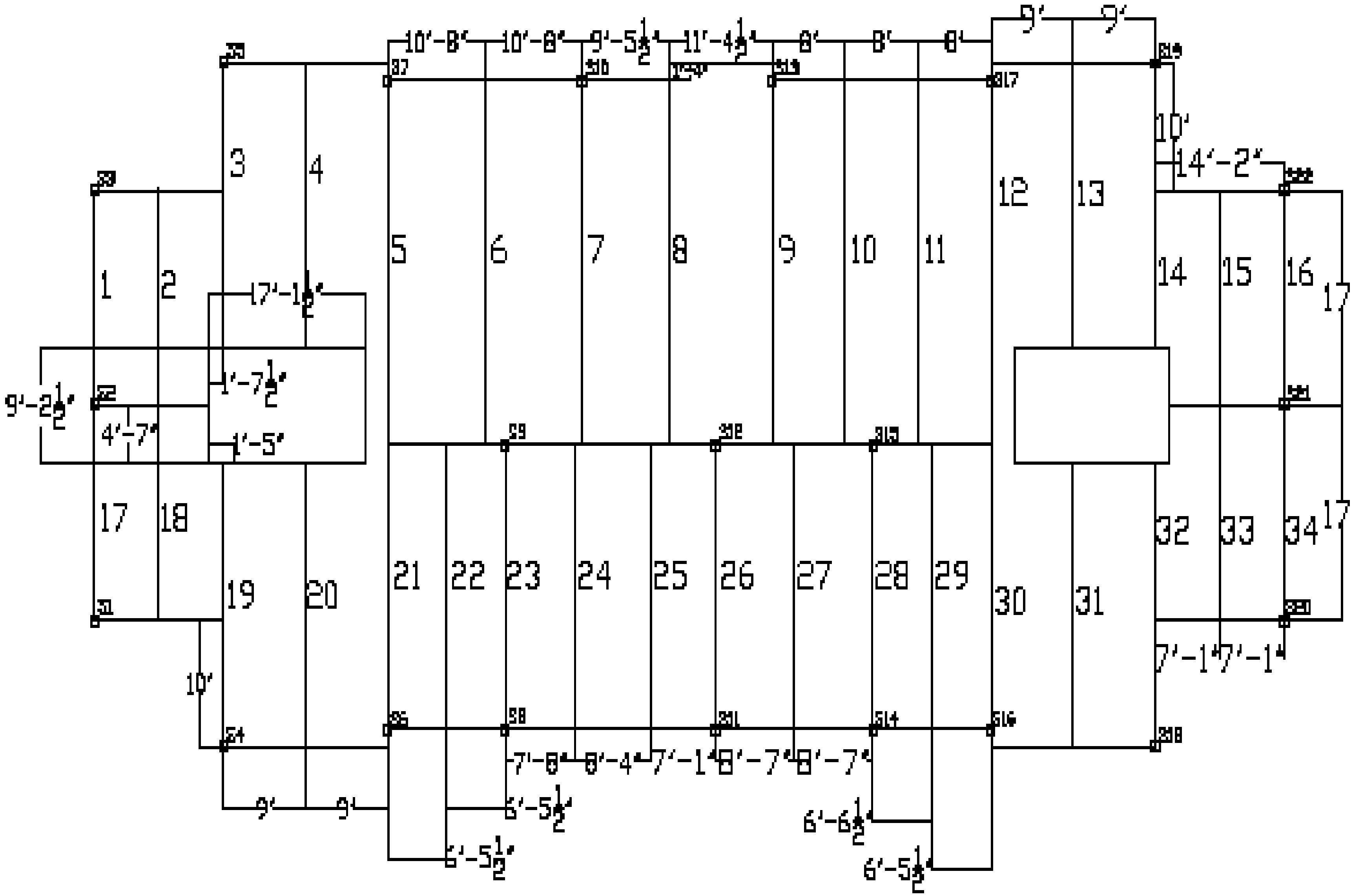
Moment(max)	h (min)	d (min)	w	kn	bd^2	bw	Vn	EFW 1	EFW 2	EFW 3	As	a	a/dt	New As
109.03	16.22	13.72	0.15	546.90	2658.08	14.12	91.88	64.89	110.12	78.00	1.86	0.51	0.04	1.80
293.02	21.88	19.38	0.15	546.90	7143.78	19.03	174.87	87.51	115.03	54.00	3.54	1.16	0.06	3.46
611.00	21.88	19.38	0.15	546.90	14896.08	39.67	364.64	87.51	135.67	54.00	7.38	2.41	0.12	7.47
271.11	21.88	19.38	0.15	546.90	6609.60	17.60	161.80	87.51	113.60	108.00	3.27	0.66	0.03	3.16
161.30	23.22	20.72	0.15	546.90	3932.47	9.16	90.03	92.88	105.16	88.56	1.82	0.36	0.02	1.75
38.90	23.22	20.72	0.15	546.90	948.38	2.21	21.71	92.88	50.21	34.56	0.44	0.22	0.01	0.42
215.74	23.22	20.72	0.15	546.90	5259.72	12.25	120.41	92.88	108.25	69.00	2.44	0.62	0.03	2.35
161.30	23.22	20.72	0.15	546.90	3932.47	9.16	90.03	92.88	105.16	88.56	1.82	0.36	0.02	1.75
38.90	23.22	20.72	0.15	546.90	948.38	2.21	21.71	92.88	50.21	34.56	0.44	0.22	0.01	0.42
274.56	21.88	19.38	0.15	546.90	6693.65	17.83	163.85	87.51	113.83	106.56	3.31	0.67	0.03	3.20
289.72	21.88	19.38	0.15	546.90	7063.24	18.81	172.90	87.51	114.81	114.00	3.50	0.71	0.04	3.38
274.56	21.88	19.38	0.15	546.90	6693.65	17.83	163.85	87.51	113.83	106.56	3.31	0.67	0.03	3.20
161.30	23.22	20.72	0.15	546.90	3932.47	9.16	90.03	92.88	105.16	88.56	1.82	0.36	0.02	1.75
38.90	23.22	20.72	0.15	546.90	948.38	2.21	21.71	92.88	50.21	34.56	0.44	0.22	0.01	0.42
215.74	23.22	20.72	0.15	546.90	5259.72	12.25	120.41	92.88	108.25	69.00	2.44	0.62	0.03	2.35
161.30	23.22	20.72	0.15	546.90	3932.47	9.16	90.03	92.88	105.16	88.56	1.82	0.36	0.02	1.75
38.90	23.22	20.72	0.15	546.90	948.38	2.21	21.71	92.88	50.21	34.56	0.44	0.22	0.01	0.42
271.11	21.88	19.38	0.15	546.90	6609.60	17.60	161.80	87.51	113.60	108.00	3.27	0.66	0.03	3.16
293.02	21.88	19.38	0.15	546.90	7143.78	19.03	174.87	87.51	115.03	54.00	3.54	1.16	0.06	3.46
611.00	21.88	19.38	0.15	546.90	14896.08	39.67	364.64	87.51	135.67	54.00	7.38	2.41	0.12	7.47
109.03	16.22	13.72	0.15	546.90	2658.08	14.12	91.88	64.89	110.12	78.00	1.86	0.51	0.04	1.80
322.18	22.25	19.75	0.15	546.90	7854.82	20.15	188.70	88.98	116.15	127.92	3.82	0.76	0.04	3.70
306.01	22.25	19.75	0.15	546.90	6714.44	17.22	161.30	88.98	113.22	120.24	3.63	0.72	0.04	3.51
315.11	22.25	19.75	0.15	546.90	6914.07	17.73	166.10	88.98	113.73	124.56	3.73	0.74	0.04	3.61
297.67	22.25	19.75	0.15	546.90	6531.45	16.75	156.91	88.98	112.75	116.28	3.53	0.70	0.04	3.41
254.96	22.25	19.75	0.15	546.90	5594.31	14.35	134.39	88.98	110.35	96.00	3.02	0.60	0.03	2.91
254.96	22.25	19.75	0.15	546.90	5594.31	14.35	134.39	88.98	110.35	96.00	3.02	0.60	0.03	2.91
115.99	16.88	14.38	0.15	546.90	2544.97	12.32	83.98	67.50	108.32	77.52	1.89	0.49	0.03	1.82
124.79	16.88	14.38	0.15	546.90	2738.08	13.25	90.35	67.50	109.25	84.84	2.03	0.53	0.04	1.97
611.00	16.88	14.38	0.15	546.90	13406.47	64.88	442.38	67.50	160.88	84.84	9.94	2.60	0.18	10.38
138.21	16.88	14.38	0.15	546.90	3032.50	14.68	100.07	67.50	110.68	96.00	2.25	0.59	0.04	2.18
134.31	16.88	14.38	0.15	546.90	2947.02	14.26	97.24	67.50	110.26	92.76	2.19	0.57	0.04	2.12
136.19	16.88	14.38	0.15	546.90	2988.18	14.46	98.60	67.50	110.46	94.32	2.22	0.58	0.04	2.15
146.57	16.88	14.38	0.15	546.90	3216.12	15.56	106.12	67.50	111.56	102.96	2.39	0.62	0.04	2.32

As (min1)	As (min2)	As required	Cc	spacing max	Steel Req(in^3)	Concrete Req(in^3)
0.61	0.65	1.80	1.88	10.31	467.21	37453.91
1.17	1.23	3.46	1.88	10.31	1211.14	105738.31
2.43	2.56	7.47	1.88	10.31	2614.80	220483.62
1.08	1.14	3.16	1.88	10.31	1106.13	97831.70
0.60	0.63	1.75	1.88	10.31	650.16	58600.46
0.14	0.15	0.42	1.88	10.31	156.04	14132.41
0.80	0.85	2.35	1.88	10.31	873.07	78378.77
0.60	0.63	1.75	1.88	10.31	650.16	58600.46
0.14	0.15	0.42	1.88	10.31	156.04	14132.41
1.09	1.15	3.20	1.88	10.31	1120.13	99075.76
1.15	1.22	3.38	1.88	10.31	1183.14	104546.15
1.09	1.15	3.20	1.88	10.31	1120.13	99075.76
0.60	0.63	1.75	1.88	10.31	650.16	58600.46
0.14	0.15	0.42	1.88	10.31	156.04	14132.41
0.80	0.85	2.35	1.88	10.31	873.07	78378.77
0.60	0.63	1.75	1.88	10.31	650.16	58600.46
0.14	0.15	0.42	1.88	10.31	156.04	14132.41
1.08	1.14	3.16	1.88	10.31	1106.13	97831.70
1.17	1.23	3.46	1.88	10.31	1211.14	105738.31
2.43	2.56	7.47	1.88	10.31	2614.80	220483.62
0.61	0.65	1.80	1.88	10.31	467.21	37453.91
1.26	1.33	3.70	1.88	10.31	1316.90	116491.38
1.08	1.13	3.51	1.88	10.31	1249.28	99578.98
1.11	1.17	3.61	1.88	10.31	1284.87	102539.57
1.05	1.10	3.41	1.88	10.31	1213.69	96865.10
0.90	0.94	2.91	1.88	10.31	1035.73	82966.78
0.90	0.94	2.91	1.88	10.31	1035.73	82966.78
0.56	0.59	1.82	1.88	10.31	491.40	36162.61
0.60	0.63	1.97	1.88	10.31	531.90	38906.65
2.95	3.11	10.38	1.88	10.31	2802.60	190498.63
0.67	0.70	2.18	1.88	10.31	588.60	43090.18
0.65	0.68	2.12	1.88	10.31	572.40	41875.61
0.66	0.69	2.15	1.88	10.31	580.50	42460.40
0.71	0.75	2.32	1.88	10.31	626.40	45699.27

9.3. Pod Labeling Conventions



Middle Pod Beams and Columns



North/South Pod Beams and Columns

9.4. Frame Program Results Example

Beam 28

NUMBER OF JOINTS = 12
NUMBER OF MEMBERS = 15
NUMBER OF MATERIALS = 1
NUMBER OF SUPPORT JOINTS = 2
NUMBER OF LOADED JOINTS = 5

JOINT DATA

JOINT	X	Y	RESTRAINTS
1	.000	.000	1 1 1
2	.000	156.000	0 0 0
3	.000	276.000	0 0 0
4	.000	396.000	0 0 0
5	.000	516.000	0 0 0
6	.000	636.000	0 0 0
7	270.000	636.000	0 0 0
8	270.000	516.000	0 0 0
9	270.000	396.000	0 0 0
10	270.000	276.000	0 0 0
11	270.000	156.000	0 0 0
12	270.000	.000	0 1 1

MEMBER DATA

MEMBER	J1	J2	AX	IZ	E
1	1	2	256.000	5461.000	29000.0
2	11	12	144.000	1728.000	29000.0
3	2	11	324.000	8748.000	29000.0
4	2	3	256.000	5461.000	29000.0
5	10	11	144.000	1728.000	29000.0
6	3	10	324.000	8748.000	29000.0
7	3	4	256.000	5461.000	29000.0
8	9	10	144.000	1728.000	29000.0
9	4	9	324.000	8748.000	29000.0
10	4	5	256.000	5461.000	29000.0
11	8	9	144.000	1728.000	29000.0
12	5	8	324.000	8748.000	29000.0

13	5	6	256.000	5461.000	29000.0
14	7	8	144.000	1728.000	29000.0
15	6	7	432.000	20736.000	29000.0

JOINT LOADS

JOINT	WX	WY	MZ
2	76.130	.000	.00
3	61.670	.000	.00
4	47.400	.000	.00
5	33.040	.000	.00
6	18.670	.000	.00

JOINT DISPLACEMENTS

JOINT	X-DISP	Y-DISP	Z-ROT
1	.00000	.00000	.00000
2	.78437	.00421	-.00399
3	1.17798	.00614	-.00177
4	1.40869	.00707	-.00118
5	1.53860	.00744	-.00058
6	1.59320	.00755	-.00019
7	1.59299	-.01342	-.00010
8	1.53816	-.01323	-.00037
9	1.40826	-.01257	-.00061
10	1.17603	-.01092	-.00134
11	.78748	-.00748	.00004
12	.79097	.00000	.00000

MEMBER END LOADS

MEMBER	JOINT	AXIAL FORCE	SHEAR FORCE	MOMENT
1	1	-200.277	236.903	22527.69
1	2	200.277	-236.903	14429.16
2	11	200.277	.000	14.39
2	12	-200.277	.000	-14.39
3	2	-108.180	-80.541	-14662.83
3	11	108.180	80.541	-7083.11
4	2	-119.737	52.600	233.66
4	3	119.737	-52.600	6078.27
5	10	119.737	108.176	5912.36
5	11	-119.737	-108.176	7068.73
6	3	68.081	-62.384	-8830.17

6	10	-68.081	62.384	-8013.38
7	3	-57.353	59.017	2751.90
7	4	57.353	-59.017	4330.19
8	9	57.353	40.092	2709.96
8	10	-57.353	-40.092	2101.02
9	4	15.287	-34.277	-5158.95
9	9	-15.287	34.277	-4095.73
10	4	-23.076	26.914	828.77
10	5	23.076	-26.914	2400.97
11	8	23.076	24.792	1589.23
11	9	-23.076	-24.792	1385.77
12	5	15.420	-16.593	-2440.85
12	8	-15.420	16.593	-2039.19
13	5	-6.484	9.299	39.85
13	6	6.484	-9.299	1076.01
14	7	6.484	9.371	674.58
14	8	-6.484	-9.371	449.95
15	6	9.365	-6.484	-1076.04
15	7	-9.365	6.484	-674.58

REACTIONS

JOINT	RX	RY	MZ
1	-236.903	-200.277	22527.69
12	.000	200.277	-14.39

9.5. *Beams Cost Estimate Example*

Beam #	length (ft)	h (min) (in)	d (min) (in)	bw (min) (in)	h (in)	d (in)	bw (in)	Side Forms (sfca)	Bottom Forms (sfca)
6	29.66	22.25	19.75	19.17	24	21.5	24	118.64	59.32
7	29.66	22.25	19.75	18.19	24	21.5	24	118.64	59.32
8	29.66	22.25	19.75	18.74	24	21.5	24	118.64	59.32
9	29.66	22.25	19.75	17.69	30	27.5	24	148.30	59.32
10	29.66	22.25	19.75	15.13	30	27.5	24	148.30	59.32
11	29.66	22.25	19.75	15.13	24	21.5	18	118.64	44.49
22	22.50	16.88	14.38	13.08	18	15.5	18	67.50	33.75
23	22.50	16.88	14.38	14.08	18	15.5	18	67.50	33.75
24	22.50	16.88	14.38	15.62	18	15.5	18	67.50	33.75
25	22.50	16.88	14.38	15.17	18	15.5	18	67.50	33.75
26	22.50	16.88	14.38	15.39	24	21.5	18	90.00	33.75
27	22.50	16.88	14.38	16.57	24	21.5	18	90.00	33.75
28	22.50	16.88	14.38	14.82	24	21.5	18	90.00	33.75
29	22.50	16.88	14.38	13.08	18	15.5	18	67.50	33.75
16	17.00	12.75	10.25	8.37	18	15.5	12	51.00	17.00
34	17.00	12.75	10.25	8.37	18	15.5	12	51.00	17.00
1	17.00	12.75	10.25	8.37	18	15.5	12	51.00	17.00
17	17.00	12.75	10.25	8.37	18	15.5	12	51.00	17.00
15	17.00	12.75	10.25	14.92	18	15.5	18	51.00	25.50
33	17.00	12.75	10.25	14.92	18	15.5	18	51.00	25.50
2	17.00	12.75	10.25	14.92	18	15.5	18	51.00	25.50
18	17.00	12.75	10.25	14.92	18	15.5	18	51.00	25.50
4	22.40	16.80	14.30	17.29	18	15.5	18	67.20	33.60
20	22.40	16.80	14.30	17.29	18	15.5	18	67.20	33.60
13	22.40	16.80	14.30	17.29	18	15.5	18	67.20	33.60
31	22.40	16.80	14.30	17.29	18	15.5	18	67.20	33.60
+30	24.00	18.00	15.50	10.86	24	21.5	12	96.00	24.00
-30	1.79								
+21	24.00	18.00	15.50	10.86	24	21.5	12	96.00	24.00
-21	1.79								
+12	31.45	23.59	21.09	12.44	24	21.5	18	125.80	47.18
-12	1.79								
+5	31.45	23.59	21.09	12.44	24	21.5	18	125.80	47.18
-5	1.79								

3	22.40	22.25	19.75	13.17	24	21.5	18	89.60	33.60

Total Forms (sfca)	Unit Price Side Forms	Unit Price Bottom Forms	Forms Cost	Concrete CY	Unit Price Concrete	Concrete Cost
177.96	$9.55	$9.90	$1,720.28	4.39	$190	$834.87
177.96	$9.55	$9.90	$1,720.28	4.39	$190	$834.87
177.96	$9.55	$9.90	$1,720.28	4.39	$190	$834.87
207.62	$9.55	$9.90	$2,003.53	5.49	$190	$1,043.59
207.62	$9.55	$9.90	$2,003.53	5.49	$190	$1,043.59
163.13	$9.55	$9.90	$1,573.46	3.30	$190	$626.16
101.25	$9.55	$9.90	$978.75	1.88	$190	$356.25
101.25	$9.55	$9.90	$978.75	1.88	$190	$356.25
101.25	$9.55	$9.90	$978.75	1.88	$190	$356.25
101.25	$9.55	$9.90	$978.75	1.88	$190	$356.25
123.75	$9.55	$9.90	$1,193.63	2.50	$190	$475.00
123.75	$9.55	$9.90	$1,193.63	2.50	$190	$475.00
123.75	$9.55	$9.90	$1,193.63	2.50	$190	$475.00
101.25	$9.55	$9.90	$978.75	1.88	$190	$356.25
68.00	$9.55	$9.90	$655.35	0.94	$190	$179.44
68.00	$9.55	$9.90	$655.35	0.94	$190	$179.44
68.00	$9.55	$9.90	$655.35	0.94	$190	$179.44
68.00	$9.55	$9.90	$655.35	0.94	$190	$179.44
76.50	$9.55	$9.90	$739.50	1.42	$190	$269.17
76.50	$9.55	$9.90	$739.50	1.42	$190	$269.17
76.50	$9.55	$9.90	$739.50	1.42	$190	$269.17
76.50	$9.55	$9.90	$739.50	1.42	$190	$269.17
100.80	$9.55	$9.90	$974.40	1.87	$190	$354.67
100.80	$9.55	$9.90	$974.40	1.87	$190	$354.67
100.80	$9.55	$9.90	$974.40	1.87	$190	$354.67
100.80	$9.55	$9.90	$974.40	1.87	$190	$354.67
120.00	$9.55	$9.90	$1,154.40	1.78	$190	$337.78
120.00	$9.55	$9.90	$1,154.40	1.78	$190	$337.78
172.98	$9.55	$9.90	$1,668.42		$190	$0.00
172.98	$9.55	$9.90	$1,668.42	3.49	$190	$663.94
123.20	$9.55	$9.90	$1,188.32	2.49	$190	$472.89

As required (sq in)	# of Bars	Bars Used	Total Rebar (ft)	Rebar Weights (lbs/ft)	Total Steel (tons)	Bars Unit Cost ($/ton)	Bars Total Cost
3.94	7	7	207.62	2.044	0.212	$2,325	$493.34
3.71	7	7	207.62	2.044	0.212	$2,325	$493.34
3.85	7	7	207.62	2.044	0.212	$2,325	$493.34
12.41	8	11	237.28	5.313	0.630	$2,325	$1,465.53
10.17	7	11	207.62	5.313	0.552	$2,325	$1,282.34
3.07	6	7	177.96	2.044	0.182	$2,325	$422.86
1.94	4	7	90	2.044	0.092	$2,325	$213.85
2.09	4	7	90	2.044	0.092	$2,325	$213.85
2.33	4	7	90	2.044	0.092	$2,325	$213.85
2.26	4	7	90	2.044	0.092	$2,325	$213.85
4.84	9	7	202.5	2.044	0.207	$2,325	$481.17
6.3	5	11	112.5	5.313	0.299	$2,325	$694.84
5.33	4	7	90	2.044	0.092	$2,325	$213.85
1.94	4	7	90	2.044	0.092	$2,325	$213.85
0.89	3	5	51	1.043	0.027	$2,325	$61.84
0.89	3	5	51	1.043	0.027	$2,325	$61.84
0.89	3	5	51	1.043	0.027	$2,325	$61.84
0.89	3	5	51	1.043	0.027	$2,325	$61.84
1.59	3	7	51	2.044	0.052	$2,325	$121.18
1.59	3	7	51	2.044	0.052	$2,325	$121.18
1.59	3	7	51	2.044	0.052	$2,325	$121.18
1.59	3	7	51	2.044	0.052	$2,325	$121.18
2.57	5	7	112	2.044	0.114	$2,325	$266.13
2.57	5	7	112	2.044	0.114	$2,325	$266.13
2.57	5	7	112	2.044	0.114	$2,325	$266.13
2.57	5	7	112	2.044	0.114	$2,325	$266.13
1.73	3	7	72	2.044	0.074	$2,325	$171.08
0.45	2	5	3.58	1.043	0.002	$2,325	$4.34
1.73	3	7	72	2.044	0.074	$2,325	$171.08
0.45	2	5	3.58	1.043	0.002	$2,325	$4.34
2.69	5	7	157.25	2.044	0.161	$2,325	$373.65
0.41	2	5	3.58	1.043	0.002	$2,325	$4.34
2.69	5	7	157.25	2.044	0.161	$2,325	$373.65
0.41	2	5	3.58	1.043	0.002	$2,325	$4.34
2.69	5	7	112	2.044	0.114	$2,325	$266.13

	Forms		Concrete		Reinforcement
	$80,549.39		$31,844.02		$21,247.56
Worcester Adj.	1.29	Worcester Adj.	1.125	Worcester Adj.	1.206
Per Floor	$103,908.71		$35,824.52		$25,624.55
				Add 10% Waste	$28,187.01
				Total for Roof Beams	$167,920.24

9.6. Slab Design Hand Calculations

SLAB

Design of typica strip

1) Select slab thickness

longest span = $11'-4\frac{1}{2}''$ $(17+10-1'4''+4-7\frac{1}{4}''-1'6'')$

= $136.5''$ $(345.25'') = 28'-9.25''$

Asume 12" beams

$\beta = (E\text{-}W\,\ell_n\ ')/(N\text{-}S\,\ell_n\ ) =$

$(346-12)\ /\ (137-12)$

$= 334\ /\ 125$

$= 2.67$

$\beta_s = 1$

$$h_{min} = \frac{\ell_n(800 + [(.005)(f_y)])}{36000 + 5000\beta(1+\beta_s)}$$

$$h_{min} = \frac{334[800 + ((.005)(60000))]}{36000 + (5000 \times 2.67 \times 2)}$$

$$h_{min} = 5.86''$$

$$h_{max} = \frac{\ell_n(800 + .005 \times f_y)}{36\,000}$$

$$h_{max} = \frac{334(800 + (.005 \times 60{,}000))}{36\,000}$$

$$= 10.2''$$

Try $h = 6''$

One way slab reinforcement

Maximum spacing = 18" or 3x slab thickness

$= 18"$

$d = 6" - (.75 + \frac{.5}{2})$ Assume #4 bars

$d = 6"$

Unfactored loads

$w_D = \frac{6.00\,in}{12\,in/ft} \times 150\,lb/ft^3$

$w_D = 75\,lbs/ft^2$

floor cover = .5 psf
Ceilings = 5 psf
MEP = 10 psf
Partitions = 20 psf
Green roof = 40 psf

Total $D_L = (75 + .5 + 5 + 10 + 20) = 110.5\,psf$

$L_L = 100\,psf$ Public places (max)

load combinations

$U = 1.4(D_L) = 1.4(110.5) = 154.7$

$U = 1.2(D_L) + 1.6(L_L) = 1.2(110.5) + 1.6(100) = 292.6$

Select reduction factor

Assume tension controlled beam [illegible]
$\phi = .9$

Check slab thickness for moment

$\frac{b d^2}{12,000} = \frac{M_u}{\phi k_n}$ ft-kips

$f'_c = 4000 psi$
$f_y = 60,000 psi$

$w = \frac{.01 \times 60,000}{4,000} = .15$

$\phi k_n = [.9[4000 \times .15(1-.59 \times .15)]] = 492$

negative moment at first or second span

$M_u = \frac{w_u l_n^2}{10}$ $M_u = \frac{w_u l_n^2}{11}$

l_n = Average of adjacent spans

$l_n = 7'1''$ $l_n = \frac{7'1'' + 9'2.5''}{2}$

$l_n = 85'' = 7.08'$ $l_n = 97.75'' = 8.15'$

$M_u = \frac{(293 lb/ft)(7.08^2)}{10}$ $M_u = \frac{(293)(8.15^2)}{11}$

$M_u = 1469$ $M_u = 1769$
$= 1.47$ ft-kips/ft $= 1.77$ ftkips/ft

$$bd^2 = \frac{M_u \times 12000}{\phi k_n}$$

$$bd^2 = \frac{1.77 \times 12000}{492}$$

12 in test

$$bd^2 = 43.17$$

$$d^2 = \frac{43.17}{12}$$

$$d^2 = 3.60$$

$d = 1.90''$ = $d_{minimum}$

$d = 5''$ so slab is ok for flexure

Check slab for thickness for shear.

Exterior face of first interior support:

$$V_u = 1.15\, w_u l_n / 2$$
$$= \frac{1.15(293)(7.08)}{2}$$
$$= 1193 \text{ lb/ft}$$

Typical interior:

$$V_u = \frac{(293)(8.15)}{2}$$
$$= 1194.$$

$\phi V_c = 0.75(2\sqrt{f'_c}\, b_w d)$
$= .75(2\sqrt{4000} \times 12 \times 5)$
$= 5692$ lb/ft

$\phi V_c > V_u$ so slab is adequate for shear

7) Design of reinforcement

End bay $l_n = 85"$
Interior bay $l_n = 98"$

$M_u = w_u l_n^2 \times$ moment coef
$= \frac{293(8.15^2)}{10}$
$= 1.95$ ft-kip/ft

$A_s = \frac{M_u}{\phi f_y jd}$ Assume $jd = 0.925d$ $\phi = .9$

$A_s = \frac{1.95 \times 12000}{.9(66,000)(.925 \times 5)}$

$A_s = .0937$

$a = \frac{.0937 \times 60,000}{.85 \times 4000 \times 12}$

$= .1378$ in

$jd = d - \frac{a}{2}$
$= 5 - \frac{.1378}{2}$
$= 4.93$

$$A_s = \frac{M_u \times 12000}{.9 \times 60000 \times 4.93} = .045 \times M_u$$

$$= .0877$$

$$A_{s\,min} \overset{\text{Flexural}}{=} .0018\,bh$$

$$= .0018 \times 12 \times 6$$

$$= .1296 \text{ in}^2/\text{ft}$$

Spacing = 18"

8) Check reinforcement spacing for crack control

$$s = \frac{540}{f_s} - 2.5\,c_c \quad \text{no more than} \quad 12\left(\frac{36}{f_s}\right)$$

$c_c = .75 \qquad f_s = .6\,f_y = 36\text{ ksi}$

$$s = \frac{540}{.6 \times 60} - 2.5 \times .75 = 13.1\text{ in}$$

but no more than

$$12\left(\frac{36}{36}\right) = 12\text{ in}$$

use 12in for spacing

9) Select the top and bottom flexural steal

#4 bars are sufficient
follow A-5c for bar lengths

10) Determine the shrinkage and temperature reinforcement

A_s = .0018bh = 0.1296
Max space 18"

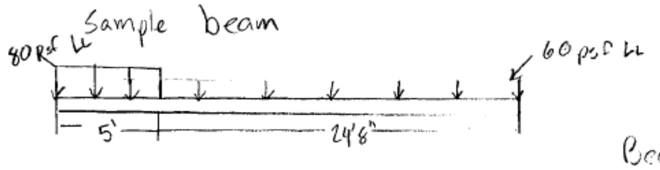
Use #4 bars @ 15" o.c. look at bay size

11) Design the traverse top steel at Girders

This will be designed with girders.

9.7. Beam Design Hand Calculations

Beam design



Beam length
3'2" + 17'10" + 10'-0" − 1'-4"
29' 8"

Trib width
$D_L = 8' \times (5 + 10 + 20 + (150 \times 5))$

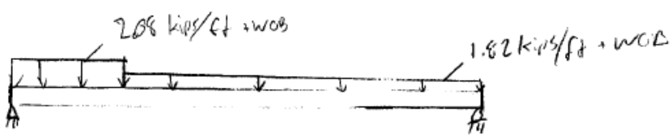
Ceilings = 5psf
MEP = 10psf
Partitions = 20psf

$D_L = 8' \times 110'$
$D_L = 880$ plf

Factored Loads from slab

$w_u = 1.2 \times (880) + 1.6(8 \times 80)$
$= 1056 + 1024$
$= 2.08$ kips/ft

$w_u = 1.2 \times (880) + 1.6(8 \times 60)$
$= 1056 + 768$
$= 1.82$ kips/ft



WOB

10%-20% of factored load
.21 kips/ft − .42 kips/ft

h = 8% - 10% ln

$bw = .5h$

$L = 356"$ [illegible]

8–10 per inch

$h = 28" \rightarrow 36"$

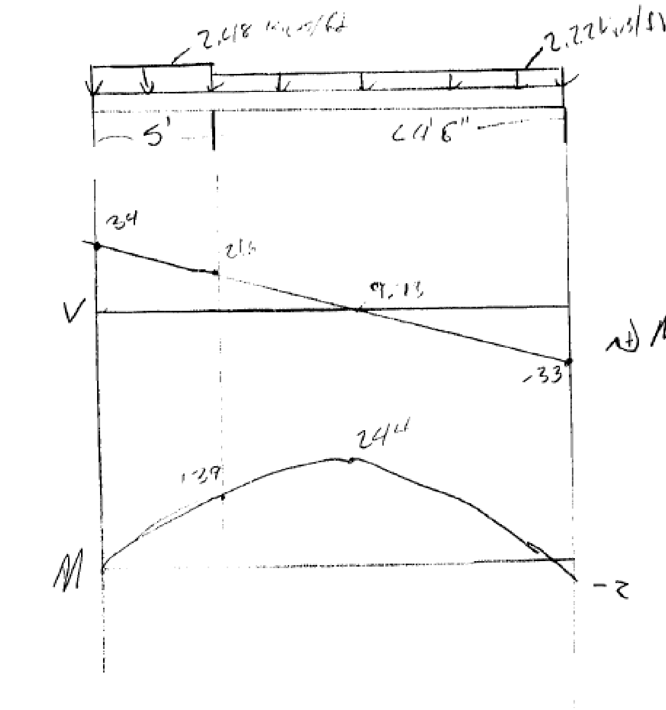
$bw = 14" - 18"$

Factored loads

$\left(\frac{14}{12}\right)\left(\frac{28}{12}\right)(150) = .41 \text{ kips/ft}$

$\left(\frac{36}{12}\right)\left(\frac{18}{12}\right)(150) = .68 \text{ kips/ft}$

Try .4 kips/ft



$F_y = 0 = -(5 \times 2.48) - (24.66 \times 2.22) + A_y + B_y$

$A_y = 67 - B_y$

$\circlearrowleft + M_A = 0 = (5 \times 2.48 \times 2.5) + (24.66 \times 2.22 \times 17.33) - B_y(29.66)$

$B_y = 33$

$A_y = 34$

Calculate the minimum depth based on deflection

Table A-14

$$\min h = \frac{l}{16} = \frac{29.66''}{16} = 1.85' = 22.2''$$

b) minimum depth based on negative moment

$$Moment = \frac{w_u l_n^2}{10} - \frac{2.48(5^2) + 222(24.66)}{10}$$

$$= 141 \text{ ft} \cdot \text{kips}$$

Table A-5

$\rho_{TCL} = .0181$

Table A-3

$\phi k_n = 817$

$$\frac{bd^2}{12000} = \frac{M_u}{\phi k_n}$$

$bd^2 = 2071$

$d_{min} = 22.2'' - 2.5'' = 19.7''$ $b = 5.3''$

$b_{min} = 5.5''$

Check shear capacity of T beam

$$V_u = \phi(V_c + V_s)$$

$V_u = 1.15 w_u l_n / 2 = \frac{1.15 \times 2.48 \times 29.66}{2} = 42.3$ kips

$V_c = 2\sqrt{f'_c}\, b_w d = 2\sqrt{4000}\,(5.5)(19.7) = 13.7$ kips

$V_s = 8\sqrt{f'_c}\, b_w d = 8\sqrt{4000}\,(5.5)(19.7) = 54.8$ kips

$\phi V_n = .75(54.8 + 13.7) = 51.4$ kips

Beam stem has ample capacity

Design Reinforcement for T beam

effective flange width

$29.66/4 = 7.415' = 89''$

$8 \times 6'' = 48''$ $48'' + 48'' + 5.5'' = 101.5''$

$8 \times 12 + 5.5'' = 101.5''$

Use $89''$

compute d and d_t

$d = 19.3$
$d_t = 19.3$

Compute A_s

$$A_s = \frac{M_u}{\phi f_y j d} \qquad j = .95$$

$$= \frac{244 \times 12000}{.9 \times 60000 \times (.95 \times 19.3)}$$

$$= 2.96$$

check $A_s \geq A_{s,min}$

$$A_{smin} \quad \frac{3\sqrt{f'_c}}{f_y} b_w d \quad \text{and} \geq \frac{200 b_w d}{f_y}$$

$$\frac{3\sqrt{4000}\, 89 \times 19.3}{60,000} \quad \text{and} \geq \frac{200 (89)(19.3)}{60,000}$$

$$5.43 \quad \text{and} \geq \quad 5.73$$

Use $A_s = 5.73$

Design Rectangular Beam

compute b and d

$$\frac{M_u}{\phi K_n} = \frac{bd^2}{12000}$$

$K_n = f'_c\omega(1-.59\omega)$ $\omega = \rho f_y/f'_c$

$$\omega = .01 \times \frac{60{,}000}{4000} = .15$$

$$k_n = 4000 \times .15(1-.59 \times .15) = 547$$

assume $\phi = .9$

$$\frac{bd^2}{12000} = \frac{244}{.9(547)}$$

$$bd^2 = 5947$$

$$d_{min} = \frac{l}{16} = \frac{29.66}{16} = 1.85' = 22.3''$$

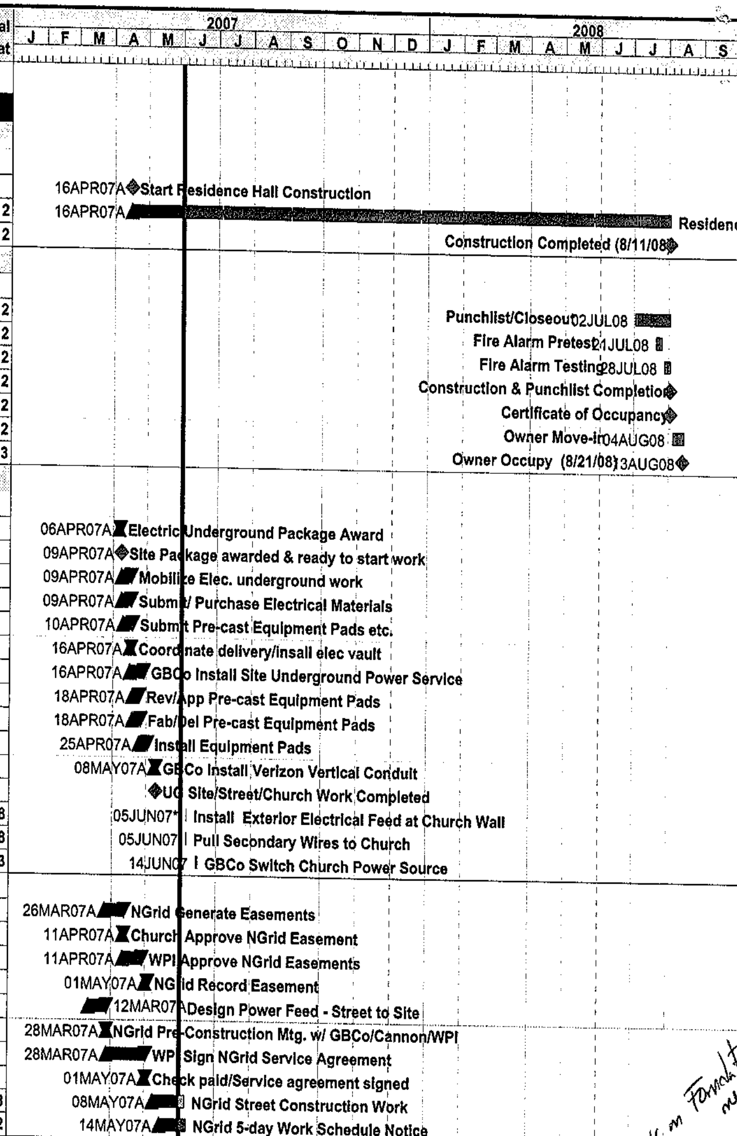
Try d/b between 1.5 – 2

$$\phi V_n = .75\left(2\sqrt{f'_c}\, b_w d + 8\sqrt{f'_c}\, b_w d\right)$$

$$\phi V_n = .75(2)\left(\sqrt{4000}\right)(b_w)(d + 4d)$$

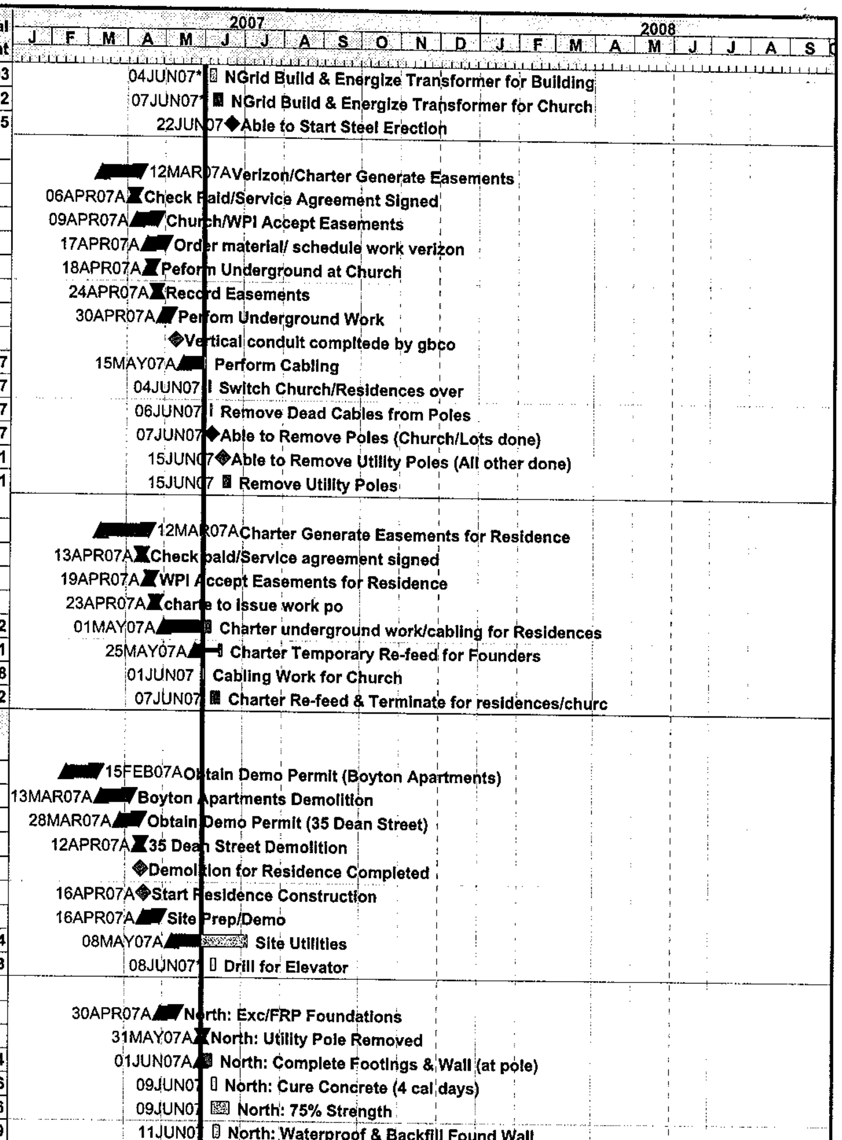
9.8. Gilbane Schedule

Activity ID	Activity Description	Orig Dur	Rem Dur	Early Start	Early Finish	Total Float
CONSTRUCTION						
Residence Hall						
Summary						
4100	Start Residence Hall Construction	0	0	16APR07A		
4000	Residence Hall Construction	333*	299*	16APR07A	01AUG08	2
4002	Construction Completed (8/11/08)	0	0		01AUG08	2
Project Close-out						
6230	Punchlist/Closeout	22	22	02JUL08	01AUG08	2
MS1	Fire Alarm Pretest	5	5	21JUL08	25JUL08	2
MS2	Fire Alarm Testing	5	5	28JUL08	01AUG08	2
MS10	Construction & Punchlist Completion	0	0		01AUG08	2
MS3	Certificate of Occupancy	0	0		01AUG08	2
6240	Owner Move-in	8	8	04AUG08	13AUG08	2
6250	Owner Occupy (8/21/08)	0	0	13AUG08		3
Utility Work						
GBCo Power Utility (on-site work)						
6420	Electric Underground Package Award	1	0	06APR07A	06APR07A	
6350	Site Package awarded & ready to start work	0	0	09APR07A		
6430	Mobilize Elec. underground work	7	0	09APR07A	16APR07A	
6440	Submit/ Purchase Electrical Materials	7	0	09APR07A	16APR07A	
6370	Submit Pre-cast Equipment Pads etc.	5	0	10APR07A	17APR07A	
6630	Coordinate delivery/insall elec vault	1	0	16APR07A	16APR07A	
6360	GBCo Install Site Underground Power Service	15	0	16APR07A	27APR07A	
6380	Rev/App Pre-cast Equipment Pads	5	0	18APR07A	24APR07A	
6390	Fab/Del Pre-cast Equipment Pads	10	0	18APR07A	25APR07A	
6400	Install Equipment Pads	1	0	25APR07A	01MAY07A	
6640	GBCo Install Verizon Vertical Conduit	3	0	08MAY07A	08MAY07A	
6410	UG Site/Street/Church Work Completed	0	0		08MAY07A	
6570	Install Exterior Electrical Feed at Church Wall	1	1	05JUN07*	05JUN07	8
6650	Pull Secondary Wires to Church	1	1	05JUN07	05JUN07	8
6510	GBCo Switch Church Power Source	1	1	14JUN07	14JUN07	3
National Grid						
6300	NGrid Generate Easements	20	0	26MAR07A	11APR07A	
6320	Church Approve NGrid Easement	3	0	11APR07A	11APR07A	
6310	WPI Approve NGrid Easements	3	0	11APR07A	27APR07A	
6340	NGrid Record Easement	2	0	01MAY07A	02MAY07A	
6260	Design Power Feed - Street to Site	10	0	12MAR07A	28MAR07A	
6270	NGrid Pre-Construction Mtg. w/ GBCo/Cannon/WPI	1	0	28MAR07A	28MAR07A	
6280	WPI Sign NGrid Service Agreement	10	0	28MAR07A	01MAY07A	
6282	Check paid/Service agreement signed	2	0	01MAY07A	01MAY07A	
6330	NGrid Street Construction Work	14	2	08MAY07A	04JUN07	8
6480	NGrid 5-day Work Schedule Notice	5	4	14MAY07A	06JUN07	2



Start Date 30OCT06 Finish Date 15AUG08 Data Date 01JUN07 Run Date 13JUN07 06:35 © Primavera Systems, Inc.	Early Bar Progress Bar Critical Activity	WP16 GILBANE BUILDING COMPANY WPI RESIDENCE HALL	Sheet 1 of 13 Constuction Updated 01JUN07

Activity ID	Activity Description	Orig Dur	Rem Dur	Early Start	Early Finish	Total Float
6491	NGrid Build & Energize Transformer for Building	5	5	04JUN07*	08JUN07	303
6490	NGrid Build & Energize Transformer for Church	10	5	07JUN07*	13JUN07	2
6600	Able to Start Steel Erection	0	0	22JUN07		5
Verizon						
6610	Verizon/Charter Generate Easements	10	0	12MAR07A	10APR07A	
6800	Check Paid/Service Agreement Signed	1	0	06APR07A	06APR07A	
6620	Church/WPI Accept Easements	2	0	09APR07A	24APR07A	
6820	Order material/ schedule work verizon	15	0	17APR07A	30APR07A	
6900	Peform Underground at Church	3	0	18APR07A	20APR07A	
6810	Record Easements	1	0	24APR07A	24APR07A	
6830	Perfom Underground Work	10	0	30APR07A	04MAY07A	
6850	Vertical conduit compltede by gbco	0	0		08MAY07A	
6840	Perform Cabling	5	1	15MAY07A	01JUN07	7
6860	Switch Church/Residences over	2	2	04JUN07	05JUN07	7
6870	Remove Dead Cables from Poles	1	1	06JUN07	06JUN07	7
6880	Able to Remove Poles (Church/Lots done)	0	0	07JUN07		7
6580	Able to Remove Utility Poles (All other done)	0	0	15JUN07		1
6590	Remove Utility Poles	5	5	15JUN07	21JUN07	1
Charter						
6740	Charter Generate Easements for Residence	10	0	12MAR07A	18APR07A	
6752	Check paid/Service agreement signed	1	0	13APR07A	13APR07A	
6750	WPI Accept Easements for Residence	2	0	19APR07A	20APR07A	
6762	charte to issue work po	1	0	23APR07A	23APR07A	
6770	Charter underground work/cabling for Residences	10	4	01MAY07A	06JUN07	2
6790	Charter Temporary Re-feed for Founders	10	2	25MAY07A	14JUN07	1
6890	Cabling Work for Church	1	1	01JUN07	01JUN07	308
6780	Charter Re-feed & Terminate for residences/churc	5	5	07JUN07	13JUN07	2
Structure						
General						
2024	Obtain Demo Permit (Boyton Apartments)	20	0	15FEB07A	09MAR07A	
2080	Boyton Apartments Demolition	25	0	13MAR07A	04APR07A	
2025	Obtain Demo Permit (35 Dean Street)	20	0	28MAR07A	11APR07A	
2007	35 Dean Street Demolition	11	0	12APR07A	13APR07A	
2082	Demolition for Residence Completed	0	0		13APR07A	
5000	Start Residence Construction	0	0	16APR07A		
5010	Site Prep/Demo	10	0	16APR07A	27APR07A	
5030	Site Utilities	40	25	08MAY07A	06JUL07	284
5023	Drill for Elevator	2	2	08JUN07*	11JUN07	13
Foundation						
5020	North: Exc/FRP Foundations	15	0	30APR07A	11MAY07A	
5040	North: Utility Pole Removed	5	0	31MAY07A	01JUN07A	
5050	North: Complete Footings & Wall (at pole)	7	6	01JUN07A	08JUN07	4
5060	North: Cure Concrete (4 cal days)	4	4	09JUN07	12JUN07	16
5062	North: 75% Strength	14	14	09JUN07	22JUN07	6
5070	North: Waterproof & Backfill Found Wall	5	5	11JUN07	15JUN07	9



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Early Bar
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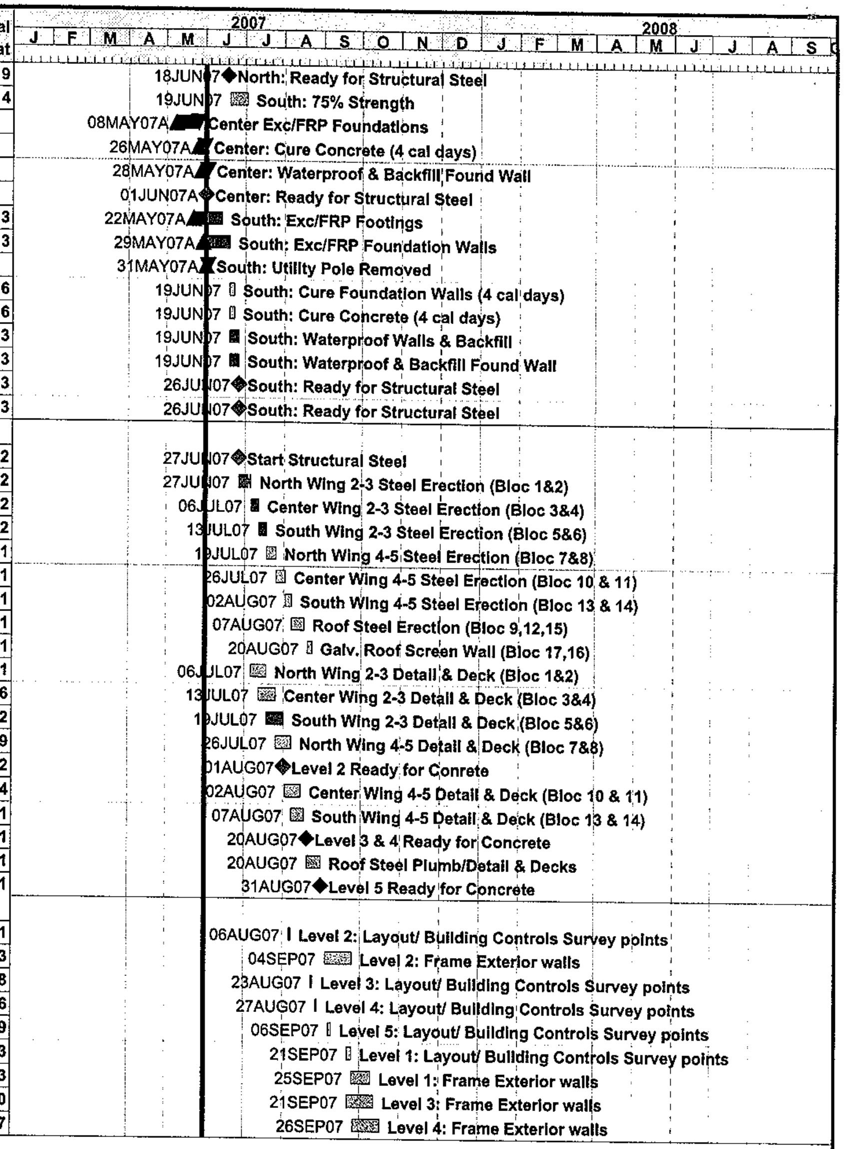
GILBANE BUILDING COMPANY

WPI RESIDENCE HALL

Constuction
Updated 01JUN07

Activity ID	Activity Description	Orig Dur	Rem Dur	Early Start	Early Finish	Total Float
5080	North: Ready for Structural Steel	0	0	18JUN07		9
5037	South: 75% Strength	14	14	19JUN07	02JUL07	14
5021	Center Exc/FRP Foundations	15	0	08MAY07A	25MAY07A	
5090	Center: Cure Concrete (4 cal days)	4	0	26MAY07A	29MAY07A	
5100	Center: Waterproof & Backfill Found Wall	5	0	28MAY07A	01JUN07A	
5110	Center: Ready for Structural Steel	0	0	01JUN07A		
5022	South: Exc/FRP Footings	28	8	22MAY07A	12JUN07	3
5024	South: Exc/FRP Foundation Walls	20	12	29MAY07A	18JUN07	3
5130	South: Utility Pole Removed	5	0	31MAY07A	01JUN07A	
5035	South: Cure Foundation Walls (4 cal days)	4	4	19JUN07	22JUN07	6
5150	South: Cure Concrete (4 cal days)	4	4	19JUN07	22JUN07	6
5045	South: Waterproof Walls & Backfill	5	5	19JUN07	25JUN07	3
5160	South: Waterproof & Backfill Found Wall	5	5	19JUN07	25JUN07	3
5120	South: Ready for Structural Steel	0	0	26JUN07		3
5170	South: Ready for Structural Steel	0	0	26JUN07		3
Structural Frame						
7050	Start Structural Steel	0	0	27JUN07		2
7060	North Wing 2-3 Steel Erection (Bloc 1&2)	6	6	27JUN07	05JUL07	2
7062	Center Wing 2-3 Steel Erection (Bloc 3&4)	5	5	06JUL07	12JUL07	2
7064	South Wing 2-3 Steel Erection (Bloc 5&6)	4	4	13JUL07	18JUL07	2
7066	North Wing 4-5 Steel Erection (Bloc 7&8)	5	5	19JUL07	25JUL07	11
7068	Center Wing 4-5 Steel Erection (Bloc 10 & 11)	5	5	26JUL07	01AUG07	11
7070	South Wing 4-5 Steel Erection (Bloc 13 & 14)	3	3	02AUG07	06AUG07	11
7116	Roof Steel Erection (Bloc 9,12,15)	9	9	07AUG07	17AUG07	11
7117	Galv. Roof Screen Wall (Bloc 17,16)	3	3	20AUG07	22AUG07	251
7061	North Wing 2-3 Detail & Deck (Bloc 1&2)	9	9	06JUL07	18JUL07	11
7063	Center Wing 2-3 Detail & Deck (Bloc 3&4)	9	9	13JUL07	25JUL07	6
7065	South Wing 2-3 Detail & Deck (Bloc 5&6)	9	9	19JUL07	31JUL07	2
7067	North Wing 4-5 Detail & Deck (Bloc 7&8)	9	9	26JUL07	07AUG07	19
7082	Level 2 Ready for Conrete	0	0	01AUG07		2
7069	Center Wing 4-5 Detail & Deck (Bloc 10 & 11)	9	9	02AUG07	14AUG07	14
7071	South Wing 4-5 Detail & Deck (Bloc 13 & 14)	9	9	07AUG07	17AUG07	11
7108	Level 3 & 4 Ready for Concrete	0	0	20AUG07		11
7118	Roof Steel Plumb/Detail & Decks	9	9	20AUG07	30AUG07	11
7119	Level 5 Ready for Concrete	0	0	31AUG07		11
Exterior Wall Framing						
7152	Level 2: Layout/ Building Controls Survey points	2	2	06AUG07	07AUG07	41
7104	Level 2: Frame Exterior walls	15	15	04SEP07	24SEP07	23
7154	Level 3: Layout/ Building Controls Survey points	2	2	23AUG07	24AUG07	38
7156	Level 4: Layout/ Building Controls Survey points	2	2	27AUG07	28AUG07	36
7160	Level 5: Layout/ Building Controls Survey points	2	2	06SEP07	07SEP07	29
7158	Level 1: Layout/ Building Controls Survey points	2	2	21SEP07	24SEP07	13
7130	Level 1: Frame Exterior walls	10	10	25SEP07	08OCT07	13
7126	Level 3: Frame Exterior walls	15	15	21SEP07	11OCT07	20
7128	Level 4: Frame Exterior walls	15	15	26SEP07	16OCT07	17



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GILBANE BUILDING COMPANY

WPI RESIDENCE HALL

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Constuction
Updated 01JUN07

Activity ID	Activity Description	Orig Dur	Rem Dur	Early Start	Early Finish	Total Float
Level 1						
General Floor Area						
8011	Level-1: Cure Slab (7 cal)	7	7	14SEP07	20SEP07	19
8000	Level-1: Plumbing Underslab Utilities	15	15	06AUG07	24AUG07	13
8002	Level-1: Electrical Underslab	10	10	20AUG07	31AUG07	13
8010	Level-1: Prepare & Place SOG	8	8	04SEP07	13SEP07	13
8032	Level-1: Layout/Building Controls Survey Points	2	2	21SEP07	24SEP07	21
8034	Level-1: Layout Walls/Top Track	10	10	25SEP07	08OCT07	21
8035	Level-1: Install MEP Hangers	10	10	25SEP07	08OCT07	21
8036	Level-1: Spray Fireproofing	3	3	09OCT07	11OCT07	21
8044	Level-1: Receive OH HVAC/Equip	0	0	12OCT07		29
8038	Level-1: Receive & Install Door Frames	3	3	12OCT07	16OCT07	21
8042	Level-1:Frame & Top-off Corridor & Support Walls	5	5	17OCT07	23OCT07	21
8030	Level-1: Ready to Start MEP Roughin	0	0	24OCT07		21
8050	Level-1: Fire Protection Mains/Branches	10	10	24OCT07	06NOV07	21
8040	Level-1: Overhead HVAC Ductwork	15	15	07NOV07	28NOV07	21
8046	Level-1: OH Electrical Roughin	15	15	19NOV07	10DEC07	21
8045	Level-1: Overhead Pipe/Duct Insulate	15	15	07DEC07	28DEC07	33
8060	Level-1: Frame Remaining Walls/ Door Frames	10	10	11DEC07	24DEC07	21
8080	Level-1: Fire Alarm Roughin	15	15	18DEC07	09JAN08	26
8070	Level-1: Electrical In-wall Roughin	20	20	18DEC07	16JAN08	21
8090	Level-1: In-wall Inspections	2	2	17JAN08	18JAN08	21
Bedroom & Common Areas						
8102	Level-1: Frame Hard Ceilings	15	15	21JAN08	08FEB08	21
8103	Level-1: Electrical Drops	8	8	11FEB08	20FEB08	21
8104	Level-1: OH Inspections	2	2	21FEB08	22FEB08	21
8100	Level-1: Sheetrock Walls & Ceilings	25	25	21MAR08	24APR08	2
8110	Level-1: Tape/ Finish Walls & Ceilings	20	20	11APR08	08MAY08	2
8105	Level-1: Electrical Panel Terminations	6	6	25APR08	02MAY08	38
8120	Level-1: Prime Paint	8	8	09MAY08	20MAY08	2
8130	Level-1: ACT ceiling grid	8	8	21MAY08	02JUN08	2
8140	Level-1: Millwork/ Counter/Cab	6	6	03JUN08	10JUN08	2
8180	Level-1: Fire Protection Drops	8	8	03JUN08	12JUN08	10
8150	Level-1: Doors & Hardware	10	10	03JUN08	16JUN08	25
8160	Level-1: HVAC drops/ Diffusers	10	10	03JUN08	16JUN08	8
8190	Level-1: Electrical Fixtures & Finishes	10	10	03JUN08	16JUN08	8
8142	Level-1: MEP Tie-in & Trim	10	10	11JUN08	24JUN08	2
8200	Level-1: Acoustical Tile corridor	5	5	25JUN08	01JUL08	2
8210	Level-1: Finish Paint	10	10	27JUN08	11JUL08	2
8220	Level-1: Vinyl Flooring	5	5	01JUL08	08JUL08	10
8230	Level-1: MEP Trim/ Finishes	10	10	02JUL08	16JUL08	4
8240	Level-1: Carpet Flooring	5	5	14JUL08	18JUL08	2
8250	Level-1: Clean Floor	0	0	21JUL08	18JUL08	2
8255	Level-1: Ready for Fire Alarm Test	0	0	21JUL08		2
8260	Level-1: A/E Punchlist Floor	5	5	21JUL08	25JUL08	2

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GILBANE BUILDING COMPANY

WPI RESIDENCE HALL

Constuction
Updated 01JUN07

9.9. Scheduling Durations

Floor and Pod	Beams and Girders (CY)	Beams and Girders(Days)	Columns (CY)	Columns (Days)	Slabs (SF)	Slabs (Days)
1st Floor Middle	N/A	N/A	12.73	0.21	6261	2.42
1st Floor N/S (each)	N/A	N/A	13.05	0.22	6682	2.58
2nd Floor Middle	91.50	1.53	9.79	0.16	6261	2.42
2nd Floor N/S (each)	100.42	1.67	10.04	0.17	6682	2.58
3rd Floor Middle	91.50	1.53	9.79	0.16	6261	2.42
3rd Floor N/S (each)	100.42	1.67	10.04	0.17	6682	2.58
4th Floor Middle	91.50	1.53	9.79	0.16	6261	2.42
4th Floor N/S (each)	100.42	1.67	10.04	0.17	6682	2.58
5th Floor Middle	91.50	1.53	9.79	0.16	6261	2.42
5th Floor N/S (each)	100.42	1.67	10.04	0.17	6682	2.58
Roof Middle	100.71	1.68	N/A	N/A	6261	2.42
Roof N/S (each)	89.80	1.50	N/A	N/A	6682	2.58

	RS Means Daily Output
Slabs	2585 SF Per Day
Beams	60 CY Per Day
Columns	60 Per Day

9.10. *Footings Schedule*

Mark	Width(ft)	Length(ft)	Area(sq-in)	Allowable Load(Kips)
F3	3	3	1296	5184
F3.5	3.5	3.5	1764	7056
F4	4	4	2304	9216
F4.5	4.5	4.5	2916	11664
F5	5	5	3600	14400
F5.5	5.5	5.5	4356	17424
F6	6	6	5184	20736
F6-42	6	41.66	35994.24	143976.96
F6.5	6.5	6.5	6084	24336
F7	7	7	7056	28224
F7.5	7.5	7.5	8100	32400
F8	8	8	9216	36864
F8.5	8.5	8.5	10404	41616
F9	9	9	11664	46656
F9-18	9	18.2	23587.2	94348.8
F9.5	9.5	9.5	12996	51984
F10	10	10	14400	57600
F10-18	10	17.58	25315.2	101260.8
F10.5	10.5	10.5	15876	63504
F11	11	11	17424	69696
F11.5	11.5	11.5	19044	76176
F12	12	12	20736	82944
F12.5	12.5	12.5	22500	90000
F13	13	13	24336	97344