GFS - 0801

Cost-Savings Study for Union Station Parking Garage

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

Submitted by:

Sandro R. Pani

____

Patrick Sheehan

____

Submitted to:

Advisor: Guillermo F. Salazar

Co-Advisor: Jayachandran Paramasivam

February 29, 2008

Abstract

Construction of the Union Station Parking Garage was observed through the documentation and analysis of the project management team. Methods to reduce the construction cost were performed by evaluating the impacts of a union-only project labor agreement, and by conducting a cost estimate that analyzes and compares the use of a union workforce opposed to a nonunion workforce. A proposed alternative layout and design was developed using a cast-in-place reinforced concrete structure opposed to the original precast concrete.

Acknowledgements

As we complete our work for our Major Qualifying Project, we realize that there are various people that we would like to thank, and without their contributions we would not have been able to complete this report.

We would like to start by thanking our project advisors Professor Guillermo Salazar, and Professor Jayachandran Paramasivam for their guidance as well as their continuous comments and revisions through our work until the completion of the project.

We would like to extend our sincerest gratitude to Albert E. Abdella, Jr. and Thomas J. Place from Gilbane Building Co. who in spite of the their busy schedule still found time to answer our questions concerning the construction of the Union Station Parking Garage, and allowing us to attend the site meetings.

We would also like to give thanks to Meghan Hogan, intern for Gilbane Building Co., who was our main liaison within Gilbane and helped us obtain all the information we required for the analysis and completion of our report.

Authorship

Equal contributions were given to the research for the background (*Section 2*). The majority of the labor cost estimation (*Section 4*) research was completed by Patrick Sheehan and edited by Sandro Pani. The majority of project management (*Section 3*) and the alternative design (*Section 5*) write-up and design was completed by Sandro Pani and edited by Patrick Sheehan. Conclusions for both capstone design and construction project management were completed equally.

Capstone Design Statement

Our capstone design experience consisted of an alternative design for the Union Station Parking Garage. The original design of the parking garage is a concrete precast structure and is highly aesthetically pleasing. The owner required it to have a significant aesthetic appeal as it was part of the major reconstruction of the Worcester Union Station. This requirement increased the overall cost of the structure. Therefore, our main objective was to propose an alternative design, mainly focusing on using a substitute for the concrete precast structure as well as developing the layout of parking and the type of circulation system.

The alternate design that was prepared was broken down into two major sections: The development of a new parking layout and selection of a circulation system, and the structural design of the new proposed layout using a different type of structure. The original design consisted of a half-helix, which provided vertical circulation, separate from the main body of the structure. The new layout of the building features a single threaded helix system with two-way traffic. The height of the structure is increased by approximately 5 feet, it is important to note that this was due to the threaded helix system that was chosen. The selection was based on the fact that it would increase capacity and decrease the cost of the structure

There are various considerations when designing the layout of a parking structure. First, it is important that parking spaces are large enough to accommodate all vehicles. Secondly, the widths of lanes, and the slopes of floors are important both for convenience and safety. As in any building construction accessibility is extremely important. Finally, it is important that the design meets requirements for Americans with Disabilities Act (ADA). All this was considered in developing the alternative layout design for the parking structure.

The second part of the design of the alternative structure was to determine the type of structure to be used. Cast-in-place reinforced concrete was chosen opposed to the precast concrete structure. The original proposal detailed that the alternative design would be steel framing with concrete slabs. This was changed due to the fact that the spans necessary for the structure were to large and would require very large steel members. These steel members would be inefficient and too costly for the proposed layout. Therefore, the alternative design is composed of reinforced cast-in-place concrete.

The design and analysis of the structure was completed by first determining the required design loads for the structure. This was done by referring to the ASCE design requirements for parking structures as well as the Massachusetts Building Code. After finding the appropriate design loads one-way slabs were designed. The structure consisted of 48.5’ x 60’ bays, with beams running every 12.125 feet. Once the beams and girders for the bays were designed, the columns were designed. These were developed by performing a structural analysis of the frame system. This was required since the beams and girders have fixed connections to the columns, and therefore it is necessary to check for moments. A full description of the design process and final results can be found in **Section 5**.

Table of Contents

List of Figures

List of Equations

List of Tables

1. Introduction

The Union Station Parking Garage is an important component to the extensive project of the Worcester Union Station renovation in Worcester, Massachusetts. Although the development and construction of the project was delayed for almost a decade since the beginning of the renovation of Union Station began (Sutner, June 26 2007). Union Station is a very important part of Worcester's infrastructure since it serves as its train and bus station. The station offers bus service for Greyhound, Peter Pan, and other local and regional buses. The Massachusetts Bay Transportation Authority (MBTA) operates 10 round-trip trains daily between Union Station and Boston, and Amtrak operates daily service to Albany, Chicago, New York, and Washington, D.C. Since parking is limited in downtown Worcester, a parking garage is necessary to serve commuters and visitors.

The parking garage is owned by the Worcester Redevelopment Authority (WRA), designed by Maguire Group Inc. and the construction project manager in charge of construction is Gilbane Building Company. The parking garage has been designed to hold 500 parking spaces, and 10,000 square feet of retail space. The total cost of the project is estimated at $21.5 million dollars, approximately $40,000 dollars per parking space. The actual design of the parking garage was an important factor in the development of the project since it was required to go in conjunction with Union Station.

Space for development is limited in downtown Worcester and the site for the parking garage is not very large (approximately 1 acre). In addition, the geometry of the site also restricts the options for the layout of the structure. For these reasons a single-helix ramp type of garage is being used instead of the more common ramp type garage. The city also did not want a garage that was too tall since it would block the view of Union Station, a historical landmark (Union Station, 2007). The proposed design does increase the height of the building, but is still low enough as to not block the view of Union Station. Therefore, from the beginning there were various constraints on the design of the project.

Another important factor in the construction of the project was it was signed under a union-only project labor agreement (PLA). In 2001, an Executive Order from the President of the United States banned the use of PLAs on federally funded projects. Even though the City of Worcester argues that the project is tied to the Union Station renovation, which includes a PLA which was signed in 1997. This causes controversy since the project is using federal funds. These funds provided by the Federal Transit Authority (FTA) consist of $8.5 million dollars which is approximately 40% of the project's budget (Sutner, June 26 2007). Construction continued although many people oppose the use of a PLA, mostly since it is generally thought to raise the cost of construction. In this project, a selective comparative cost analysis between using union labor and nonunion labor was conducted. This was accomplished by taking different work packages, which included activities that were both labor intensive and not labor intensive. By concentrating on the cost of labor it is possible to approximate the percentage of labor cost for the project and compare these with wages for union and nonunion workers.

As the station was constructed, it was not only important to look at the cost, but also how the project was managed to keep construction moving forward and the cost below budget. Analysis was done by observing the actual construction progress and comparing it to the proposed schedule. Analysis was also done by attending site meetings and observing management practices in terms of the organization, relationships between the concerned parties and document handling.

Finally, to fulfill the Capstone Design Experience requirement an alternative design was developed. The original design consists of a precast concrete design. The main objective of preparing an alternative design was to choose a different type of system for the structure as well as redesigning the original parking layout. The original layout called for a half-helix ramp at one end of the building as to avoid sloped floors. The alternative design consists of a single-threaded helix system with two-way traffic, as to increase capacity and decrease cost of the structure. Although the system is not as aesthetically pleasing as the original design, the purpose of the alternative is to propose a substitute structure that would decrease costs by maximizing capacity. Therefore, a cast-in-place reinforced concrete structure was used for the new design.

2. Background

2.1 Union Station Parking Garage

The focus for this project was the Union Station Parking Garage project. Union Station at Worcester, MA was in great need of adequate parking space since its renovation and reopening in July of 2000. Union Station not only serves as Worcester's transportation hub serving train and bus stations, but also has retail space including: Union Station The Restaurant. As this area of downtown Worcester starts to redevelop, a parking garage to serve the area becomes a necessity. The Union Station Parking Garage is therefore an important part in the completion of the revitalization of the Union Station area. The parking garage was designed by Maguire Group Inc. It will provide 500 parking spaces and 10,000 square feet of retail space, and the rehabilitation of a tunnel going under the railroads, connecting directly to Union Station. An architectural rendering of the parking garage can be observed in **Figure 1**.

Figure 1 - Architectural rendering of the Union Station Parking Garage

The owner, being the City of Worcester, is represented by Worcester Redevelopment Authority (WRA), who is in charge of overseeing the construction of the project. The WRA hired Maguire Group Inc. to develop the design of the project. Both the owner and the designer worked closely together to develop a design that fitted the owner's needs. After the design was completed the owner decided on choosing a delivery system. It was agreed to have Construction Management at Risk delivery system to perform the construction. The project was bid out and Gilbane Building Co. was awarded the project and hired under a Guaranteed Maximum Price (GMP) contract of $17 million dollars. Gilbane performed an extensive value engineering and constructability review, before construction began.

The Union Station Parking Garage began construction in May 2007 and its scheduled completion is in June of 2008. The total cost of the project including design and construction is estimated at $21.5 million dollars.

2.2 Construction Management at Risk

Project Management as Oberlender (2000) states it, is: "The art and science of coordinating people, equipment, materials, money, and schedules to complete a specified project on time and within approved cost." Project management is needed to organize three principal contracting parties in construction projects, these parties are: the owner, the designer, and the contractor. There are various types of contractual agreements that exist for managing and delivering construction projects. Some of the major contractual agreements include: Design/Bid/Build, Design/Build, Construction Management (CM), or Owner/Agent.

The Construction Management contract is a four-party agreement between the owner, the designer, the CM firm, and the sub-contractors. The basis of a CM contract is that the owner hires a CM firm to manage and coordinate all aspects of the project's construction. CM at Risk is a variation of CM where the CM bears the financial risk of the project. For a public agency, such as the Worcester Redevelopment Authority (WRA) there are various benefits for the use of CM at Risk.

Some of these benefits include:

- The ability to pre-qualify and select a CM on the basis of its reputation and record in controlling costs, meeting deadlines, and satisfying customers.

- The CM's ownership of the construction budget through early cost estimating leading to a Guaranteed Maximum Price (GMP) for the work.
- The ability to "fast-track" the start of construction by bidding early trade contracts which the CM will ultimately incorporate into the final GMP.
- The right and responsibility to monitor and audit the construction costs of the project to ensure the city pays only the costs of work plus the agreed fee to the CM.
- A spirit of cooperation between the owner, architect, CM and trade contractors due to a defined allocation of project responsibilities and CM's interest in obtaining strong references for future work. (DCAM/IG, 2005).

In the Commonwealth of Massachusetts, the CM at risk practice has just recently become legal for use in public projects. In 2004, "*An Act Further Regulating Public Construction in the Commonwealth*" went into effect, stating that for public projects totaling over $5 million dollars the CM at risk practice could be used pending approval of an application by the Inspector General (Massachusetts Office of the Inspector General, 2006).

The concept of using a CM for the Union Station Parking Garage was not discussed until the design was completed and ready for a conventional Chapter 149 Bid. Chapter 149 is part of the Massachusetts General Law; the specific chapter includes sections specifically focused on "Fair Competition for Bidders on Construction, Etc., of Public Works". Due to the logistics of the project along with the very long lead time for precast concrete, Paul Moosey, who is Assistant Commissioner to the City of Worcester and the owner's representative, believed that the project was a good candidate for a CM delivery system. The City of Worcester also wanted to try using a CM on this project as it believed that there would be potential benefits in terms of schedule. Worcester is one of the first communities to receive approval from the State to use this method. For this reason, the City also wanted to try this method on a smaller project and not a large one such as a new school.

The agreement for the Union Station Parking Garage is a CM at Risk contract with a Guaranteed Maximum Price (GMP). The GMP is a fixed amount, meaning the CM guarantees this cost as the total cost of the project, and any additional cost is covered by the CM. The Worcester Redevelopment Authority has contracted Gilbane Building Co. as a CM at Risk for a GMP of $17 million dollars. **Figure 2** in **Section 3.1** details the internal organization for the construction of the Union Station Parking Garage.

2.3 Gilbane Building Company

The Gilbane Building Company has been family owned and operated since it was founded in 1873. Gilbane is a national real-estate development and construction company, and continues to be so to this day. Originally known as William Gilbane and Brother, the current incarnation of the Gilbane Building Company began in 1970, after a major expansion. Today, Gilbane generates over $3 billion dollars in revenue annually and has 25 offices around the United States with over 1800 employees (Gilbane: About Us, n.d.).

Forbes ranked the Gilbane Building Company as the 108th largest privately held company in the world. Engineering News Record ranked Gilbane Building Co. as the 5th largest construction manager in the United States in 2007. Some of Gilbane's self-imposed core values include integrity, tough mindedness and loyalty. Gilbane Building Co. has experience in a variety of building projects in both the private and public sector. Some notable projects include: the President's House at Brown University, the National Air and Space Museum, and the Vietnam War Memorial (Gilbane: About Us, n.d.).

In the past three years Gilbane has worked on several projects in Worcester, including the new Worcester Court House, the Gateway Park project, and buildings at the Worcester Polytechnic Institute (WPI) campus such as the Bartlett Center and a new residence hall currently under construction. As far as experience in parking garages, in the New England region, Gilbane has worked on parking garages for Cambridge Hospital, the modernization of the Central Parking Garage at Logan International Airport, the construction of a 650-vehicle parking garage for the Lawrence Transportation Center, as well as the parking garage for the Gateway Park project in Worcester (Gilbane: About Us, n.d.). The Gilbane's project management team for the Union Station Parking Garage has also worked on parking structure's in Worcester. The Project Manager (PM), Albert

Abdella was also PM for the construction of a 1500 parking structure for Allmerica Financial, as well as being PM for the Gateway Park parking structure.

2.4 The Union Factor

There are many reasons why a company like Gilbane might choose to work with a unionized group as opposed to a non-union group. The main reason that a company might choose to use union workers is because unions claim to have superior craftsmanship and better quality of skills than non-unionized workers. There is a great amount of debate on whether this is correct or not, but unions tend to support this opinion. Another reason might be to benefit the workers in a certain area. Many public projects are located in areas where large percentages (>50%) of all workers are unionized. Therefore by awarding contracts to the union, the company is providing jobs locally (Mishel & Walters, 2003).

A secondary reason to negotiate with a unionized labor force could also be to preemptively guard against strikes. It is common for a union work contract to have a "no strike" and "no lockout" clauses. What this says is that the workers agree not to strike for any reason so long as the employer agrees not to lockout the workers. This essentially guarantees constant work throughout the duration of the project. This is a huge point for projects that are working on a tight deadline (Industrial Workers of the World (IWW), n.d.).

There are many benefits to joining a union as a worker. First and foremost is the wage benefit. Union laborers typically make $5 per hour more than their nonunion counterparts. This gap is shrinking, however, due to the Davis-Bacon act, which guarantees local prevailing wages to all public project workers. Working under a union contract also serves to set the definitions for overtime, seniority, and worker breaks during the day. There are also options for healthcare, dental care, as well as life insurance.

2.5 Project Labor Agreement (PLA)

Project Labor Agreement (PLA), as defined in the General Services Administration Acquisition Manual (GSAM), "means an agreement between the contractor, subcontractors, and the union(s) representing workers. Under a PLA, the contractor and subcontractors on a project and the union(s) agree on terms and conditions of employment for the project, establishing a framework for labor-management cooperation to advance the Government's procurement interest in cost, efficiency, and quality." (U.S. GSA & OAP, 2004).

Since the establishment of PLAs there has been great opposition towards this type of agreement. The main controversy is that a PLA requires all contractors, whether they belong to union or not, to subject themselves to union collective bargaining agreements (CBAs) to be able to work on government-funded construction projects. Collective bargaining as defined by the U.S. Department of Labor is the

> "Method whereby representatives of employees (unions) and employers negotiate the conditions of employment, normally resulting in a written contract setting forth the wages, hours, and other conditions to be observed for a stipulated period (e.g., 3 years). The term also applies to union-management dealings during the term of the agreement." (BLS, 2007)

For the above reason nonunion contractors are dissuaded from bidding on PLA based projects. Although the use of PLAs for federally funded projects was stopped with an Executive Order from the President of the United States in 2001, the Union Station Parking Garage is still under a PLA.

In Worcester, Massachusetts, 80% of contractors do not belong to unions, therefore having a PLA project with federal funding has caused major controversy within the Worcester population. (Cogliano, June 4 2007) Not only is there controversy because of the selectiveness of a PLA, but also there are many examples where having a PLA increased the cost of construction. One case is the Beacon Hill Institute that reports that PLAs increase the cost of school construction by as much as 20% (Cogliano, June 4 2007).

A large part of the cost associated with a PLA comes from the Davis-Bacon Act of 1931. This act states that for government contracts of $2000 or higher, the workers must be paid the prevailing local wages. It also includes fringe benefits into its calculation of fair wage. There was much opposition to the act mainly by minorities stating that it originally started as a Jim Crow law. Jim Crow laws are, “in U.S. history, any of the laws that enforced racial segregation…”(Jim Crow law, 2007) Therefore, it is believed that it intended to keep African Americans out of civil projects, the law now ensures that all workers receive fair pay for their work. The act has been suspended and reinstated by multiple Presidents; most recently reinstated by George W. Bush in the areas affected by hurricane Katrina by declaring the disaster to be a “national emergency”.

2.6 Preliminary Cost Estimating

Preliminary cost estimation is done before any detailed specifications for a project are known. What this means is most of the estimation is rough, (+ or – 25% accuracy) and it is important to know that future estimations will be based on preliminary estimations; therefore they should still be performed with careful analysis. As a result, early estimates will tend to have a range of accuracy assigned in percentages. As the more information on a project is developed the estimate can be made more and more accurate lowering the percent error.

Although there is a general process for estimating, all cost estimates are done differently, depending on the project and who is performing the estimation. For this reason, to understand how the given estimate was calculated it is important to always define what process was followed. As mentioned before, there are various ways to perform preliminary cost estimates; some examples include: comparing the current project to similar projects, calculating costs by square foot, calculating indirect/direct costs, and many others (Oberlender, 2000).

For this project cost estimation was performed following a similar process to that for preliminary cost estimation. The difference is that the total estimated cost is already known, as well as the percent of total cost for each of the work packages. Therefore, the best way to generate an accurate preliminary estimate is to use the largest sections of the project that are unlikely to change along the way, such as the structure. The cost estimation completed was mainly performed by looking at the difference in costs between union labor and nonunion labor. Since the project is already under construction and the specifications are already defined, it was not important to give an exact estimate. What is important is to determine the difference between union labor and nonunion labor in terms of costs.

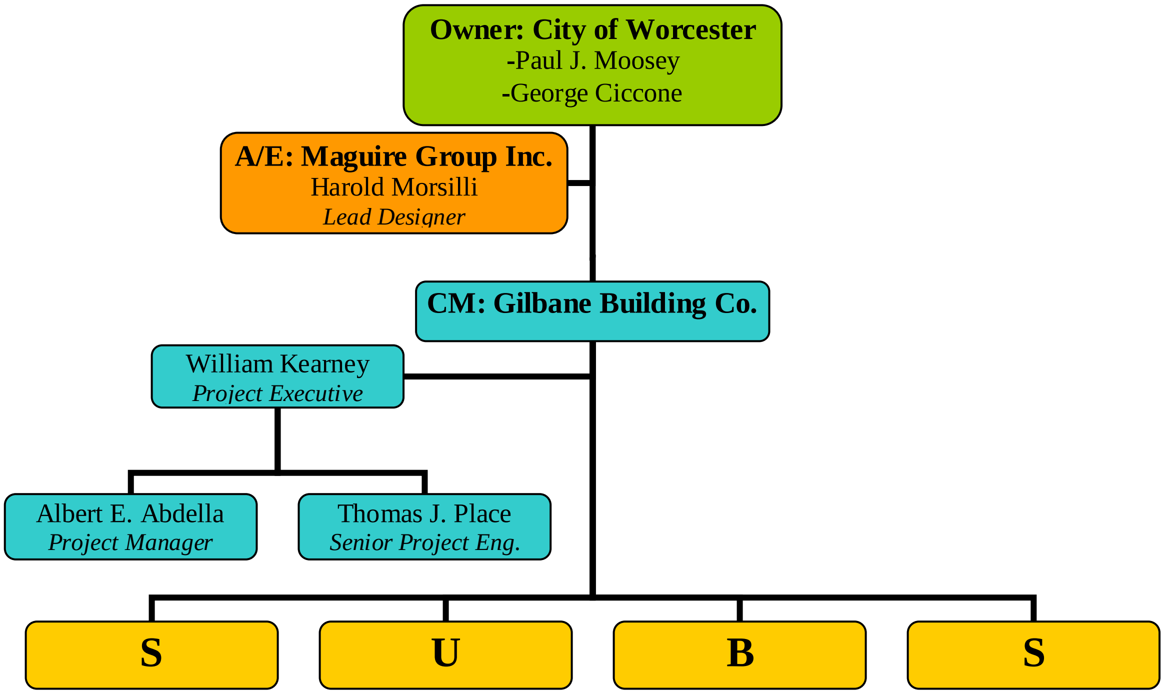
3. Project Management & Communication

The Union Station Parking Garage is a small project compared to other projects that have been developing in the Worcester area in the past five years, such as the Worcester Trial Courthouse, and the WPI Gateway complex. However, this does not reduce the importance of having a good project management team. The relationship and communication between the three major parties, the owner, the designer and construction manager, is critical to completing the project on schedule and within the budget. Throughout the construction of the parking garage, the relationship between the parties was observed. This was done in an attempt to gather information on how the responsibilities are divided, how the parties work together, and how conflicts and change orders are resolved.

3.1 Project Organization

The Union Station Parking Garage is owned by the City of Worcester, yet the Worcester Redevelopment Authority (WRA) is in charge of overseeing the project. The WRA is one of the boards & commissions of the City of Worcester and its main goal, as stated on their website, is to identify and implement Urban Renewal Area Plans and corresponding amendments in Worcester. The WRA's main functions are urban renewal planning, land acquisition, business relocation, demolition of obsolete structures, site testing/preparation, and public improvements. (WRA, 2008)

Throughout the design process, the WRA was intimately involved in the development of the final design. As observed by Paul Moosey, Assistant Commissioner to the City of Worcester and in charge of overseeing the construction of the parking structure, the WRA wanted a design that would compliment the work that took place to renovate the Worcester Union Station. For this reason, it was requested that the parking layout not include sloped floors or be higher than the station. This determined the shape of the structure as well as the need to use a section of the street. The final architectural treatment was selected by the WRA after several options were presented by and reviewed with Maguire Group Inc. As mentioned earlier, Gilbane Building Co. was the Construction Manager at Risk. Although Gilbane Building Co. was not involved during the design of the project they did provide an extensive value engineering effort and constructability review, and assisted with the bidding process. A Project Organization Chart can be found in **Figure 2.**



*A list of subcontractors can be found in Appendix C

Figure 2 - Project Organization Chart for the Union Station Parking Garage

From this it is possible to observe that the three parties were deeply involved and committed to the project. An interesting point is how Gilbane works with the subcontractors, the owner, and the designer. There are various examples that help understand how Gilbane works and its commitment to the project. One example is that Gilbane even before having finalized and signed a contract with the WRA, they were already placing an order with the precast subcontractor, Blakeslee Prestress Inc., who would be manufacturing the precast and erecting it. In the past 45 years, Blakeslee Prestress has worked on the design and construction of over 200 parking garages (Parking Structures, n.d.). Gilbane has worked with Blakeslee previously on various projects including the recently completed Gateway Parking Garage, in the expansion and modernizing of the Central Parking Garage at Logan Airport, and currently Blakeslee is also a subcontractor of the new WPI Residence Hall for which Gilbane is a PM.

Nevertheless, placing the order before finalizing an agreement with the owner is extremely interesting since the precast is the major lead item in the project and accounts for approximately 40% of the GMP. By doing this Gilbane was taking considerable risk by entering in a $7 million dollar contract with the subcontractor without having a signed contract with the owner. In spite of that, this proved to be a gain for Gilbane since it allowed for an early finish of the precast erection.

3.2 Schedule maintenance

Maintaining and following a predetermined construction schedule is crucial throughout the project. All constructions have two main constraints that can determine the completion of the project and these are cost and date of completion. Both cost and date of completion are correlated and a change in one can cause a dramatic change in the other. Therefore, maintaining a schedule is extremely important. For this reason, Gilbane had the responsibility to maintain a schedule and make sure it was being followed. If changes did occur the concerned parties were notified, and that proper actions were taken to make sure the project was completed on time.

Gilbane kept a day to day schedule that was updated as construction progressed. Therefore, it was possible to easily report accurate estimated dates of completion of tasks as well as when other tasks were to begin. By doing this not only was Gilbane able to better manage the project, Gilbane was also able to report to the owner and the designer any delays or early completions. Although Gilbane does update their schedule on a day to day basis, they also have a bi-monthly review of the full schedule (**Appendix B**). This means that Gilbane has a scheduler come on to the project site who will review construction, its current progress and develop a more complete schedule. This is done not only to maintain the project on time, but also it helps the Gilbane as a construction company review and keep track of its current projects.

3.3 Communication

Communication between the concerned parties was crucial for the completion of the project. As a result, Gilbane followed a specific communication procedure as to keep in touch with all the parties, as well as convey the necessary information in the appropriate manner. Throughout the project bi-weekly meetings were held at the site. These formal meetings were held to update the owner and the designer of the project's current progress. The owner and designer also posed concerns and present any information concerning the project. The purpose and general procedure throughout the site meetings is further explained in **Section 3.4**.

Although the parties attended bi-weekly meetings, more frequent communication was necessary. For this reason all three parties were in constant contact. Phone calls were standard practice and daily calls were made between Gilbane, the WRA, and Maguire Group. This type of communication is informal, and contracts require formal documents, to keep track of costs and changes to the project scope. These types of documentation include: Requests for Information (RFIs), Change Orders, and Cash Flow, Construction Submittals and Meeting Minutes.

3.3.1 RFIs & Change Orders

RFIs are submitted by Gilbane to either the designer or the owner, requesting information pertaining to the scope of the project or the design. These are submitted on a regular basis as construction progresses and inquiries are made. Change Orders are submitted by Gilbane when changes are made to the scope of the project or to the original design. These changes may be due to circumstances that could not be predicted until construction had begun or when Gilbane suggested a change in the design to save money, for alternate materials to be used, among other changes to the building's design. It is important to note that these changes are frequent especially when the design is not 100% complete before construction begins.

Change Orders many times contain various items. An example of a Change Order can be seen in **Appendix A**. The reason for it to contain many items is that Change Orders usually can take a long time to be approved, especially when on a public project. This is due to the fact that it has to go through various levels of approval. Therefore, Gilbane would request verbal approval of the changes by the owner and designer as they came up, and would then compile the items at the end of the month or as needed by the owner. This way construction could continue without needing a formal written approval of the change order.

A simple example for an item in a change order is the following. The parking garage includes retail space for 3 different establishments. The retail space, which is located on the ground floor, was to have the concrete slab placed with the rest of the ground floor, taking place in October, 2007. Gilbane proposed to establish a credit for the owner with the subcontractor for the section of slab for the retail space. This meant that the owner would pay the subcontractor for the concrete slabbing, but the subcontractor would perform the work at a later date. It was proposed by Gilbane to have this section of concrete slabbing done in the spring of 2008 near the completion of the project because the owner had yet to find tenants. Each tenant might have certain needs for utilities. If the concrete slab were to be placed, the most probable outcome would be that the tenants would request the owner to remove portions of the slab to relocate the utilities as required by the tenant. Therefore, the owner would save time by postponing the concrete slabbing of this specific area to a later date as well as the hassle of having to schedule the relocating of utilities, and having Gilbane do the work twice. In **Figure 3**, it can be observed how a section of the site did not have the concrete slab placed. Allowing to have the slab placed at a later date also helped with logistics concerning the placement of the crane that was erecting the precast structure. By not placing the slab the crane could move back and forth on that section of the site allowing the possibility to save space for arrival of precast sections and storage of other materials.

Figure 3 - Photo of construction site depicting retail space to be slabbed.

3.3.2 Cash Flow

All construction projects have one main concern and that is cost. Therefore, it is very important that throughout the construction of a project all parties understand perfectly, what is being constructed, how much it costs and who has to pay for it. All three major parties were concerned in costs, and therefore every site meeting made one of the last items to be reviewed was the overall budget and cash flow.

At each site meeting would hand out a Change Log, where construction items would be listed with their costs. If any new items were added those would be addressed there, as well as any changes in costs that had occurred in the last two weeks. This was an easy way to view any changes and discuss them. Gilbane would give the reasons for changes in the log, and the owner and the designer would either approve or disapprove. Although this was not an official statement of costs, it was an important document to better follow construction costs.

Cash Flow is the document that Gilbane submitted to the owner as a bill for costs of construction completed in the past month. This document was originally required for submission every two weeks. Gilbane requested permission to submit every month instead of every two weeks. This was due to the fact that preparing and reviewing the cash flow is a timely task, since Gilbane required documentation from the subcontractors as well. Therefore, it proved to be more efficient to keep up a monthly cash flow than a bi-weekly one.

3.3.3 Construction Submittals

Construction submittals are a very important aspect of a construction project. Construction submittals are documents that are transmitted from the contractor to the owner or the designer for their review and/or approval (Oberlender, 2000). For the Union Station Parking Garage, Gilbane was in charge of managing the submittals and making sure they were reviewed on time. An example of pending Submittals can be found in **Appendix A**.

As it can be observed in the example at that moment there were three outstanding submittals that had been submitted with the designer, Maguire Group, for approval. It also shows the date the submittal was sent and when it is due. The log that can be observed in the Appendix was handed out during a site meeting and served as a reminder for the designer, as well as notifying the owner on where submittals stand and what is the next step for construction. Receiving the submittals on time is extremely important for the subcontractor, since various preparations need to be made and design considerations need to be taken.

3.3.4 Meeting Minutes

Minutes of the meeting, also known as Meeting Minutes, record items discussed, decisions made, and actions to be taken. For site meetings, which are formal meetings with the owner and the designer, Gilbane followed a different path. Gilbane would hand out a detailed outline of the topics to be discussed that day, this memo were the Meeting Minutes (**Appendix A**). Each member took notes, and all the items were discussed yet there wasn’t a formal record of what was agreed on. This is an interesting approach since no formal minutes were kept and then later sent to the owner and the designer. Therefore, it can be understood that the three parties understood their responsibilities, and what had to be done so the project could be completed without any major conflict between the owner, the designer and the PM. As can be seen in Appendix A the Meeting Minutes, usually also included an RFI Log, a Submittal Log, and any other document that may be necessary such as a copy of the most recent Change Order.

3.4 Site Meeting Dynamics

Throughout the project the biweekly site meetings were held. It was required that all three main parties be represented by at least one person. Usually this included two representatives from the City of Worcester (Paul Moosey and George Ciccone), the architect from Maguire Group (Harold Morsilli), and representatives from Gilbane: the project executive (William Kearney), the project manager (Albert Abdella), and the senior project engineer (Thomas Place). These meetings were held to discuss progress of the construction, any changes or conflicts that may need addressing, current costs, schedule updates, Requests For Information (RFIs), Change Orders, and any other information concerning the project. It is important to understand, that although these were official meetings, required by the contract, all three parties were in constant contact in between meetings, and were well aware of construction progress.

The dynamics of the site meetings was very interesting since it was clear that it was a team that was working together, each having their responsibilities and concerns. The meeting followed a set of Meeting Minutes (MM) that was provided by Gilbane. An example of these can be found in **Appendix A**. As can be observed in the MM, the project manager, Albert Abdella, would start-out the meeting by addressing different items that had come up in the past 2 weeks. Questions were addressed to the items, and both the architect and the owner brought up points, and answered any questions Gilbane may have. If there were any major items that required further discussion they were left to the end of the meeting as to better address them. After addressing these items the project manager would go around the table asking those present if there were any questions or items they wished to discuss.

The end of the meeting usually was followed by walk through the site, where the owners and the architects would observe progress, and address any questions they had of the current work. At times while walking through the construction site, the architect or the owner would identify details concerning the work being completed that may seem to be incongruent with the plans. A simple example of this was during a walk-through through the corridor (which connects the garage to the station) that is being remodeled, it was observed by the owner that the sprinklers seemed not to be aligned correctly. Shop drawings were reviewed on the spot, and it was observed that they had been installed incorrectly. Although this is not a major item, and it was easy to address, it demonstrated that although each party has their own priorities they understand and are cooperative throughout the project as to successfully complete the project.

4. Labor Cost Estimation

To perform effective labor cost estimation it is important to take various aspects of the project into consideration. The cost estimation done as part of this project concentrated exclusively on labor costs, with the final goal to compare union labor costs with nonunion labor costs. To accomplish this, the list of work packages provided by Gilbane Building Co. was used, as well as the percent of total cost for each of the packages. The reason percentages are used here instead of actual monetary values is because of a confidentiality policy imposed by Gilbane preventing us from displaying the necessary data. They were, however, able to provide us with useful approximate percentages pertaining to each work package.

Having the total estimated cost of the project and the percentages for each of the work packages it was then possible to reverse-calculate a rough price for each work package. Next, the work packages with the highest cost were chosen, focusing on major items such as site construction (which accounts for 5.2% of the total cost), concrete (39.7%), and masonry (4.20%).

To determine labor costs for the project it was necessary to first determine material costs. This was done by using R.S. Means's 2007 Building Construction Cost Data (R.S. Means, 2006). Having a material cost percentage, and assuming a 25% in contractor fees, a percentage for labor costs for each work package was established. Since the project is a union-only PLA, it was assumed that these prices reflected labor costs for union workers.

To establish labor costs and create a comparison between union labor and nonunion labor, a table was created to determine the necessary work crews needed to complete the tasks. The table also included the number of shifts needed for each crew to complete its task. By doing this it was possible to determine the productivity of each crew. The crew composition and shifts were determined by using the PLA for the Union Station Parking Garage project, as well as cost estimating references such as R.S. Means Building Cost Data.

Using the table and **Equation 1**, where quantity of work is the total work needed to be completed and productivity is how fast the crew can complete the work, it is possible to determine the labor hours it will take to complete the item.

Equation 1 - Labor hours

$$Labor\ Hours = \frac{Quality\ of\ Work}{Productivity} \Rightarrow \left(\frac{(Square\ Feet)}{\left(\frac{Square\ Feet}{Hour}\right)}\right)$$

Having determined the labor hours, the hourly rate was established. This was accomplished by comparing basic rates, the local prevailing wages, and the Davis-Bacon act wages. Then by using **Equation 2**, where cost is the labor cost for the particular work item, it was possible to determine the labor costs for each of the items

Equation 2 - Labor Cost

$$Cost = Labor\ Hours * Hourly\ Rate$$

This whole process was done for both nonunion labor and union labor. By following this procedure it was possible not only to compare union and nonunion labor by the hourly rates, but also it was possible to include an important variable in construction work: productivity. The calculations and data used, can be found in **Appendix E & F**

4.1 Cost Comparison

4.1.1 Introduction

There are many benefits and drawbacks to using union labor for any given construction project. The attribute most thought of when union labor is involved is quality of work. Most unions are well known for the quality of their work, their thoroughness, thoughtfulness and experience. While this is certainly an asset on any project, it comes with some cost. The cost is the increased price associated with union labor. There are numerous other pros and cons to using union labor, but we will focus on the cost aspect associated with them. Therefore, we will discuss the total cost of three of the work packages that are a part of the construction process on the Union Station parking garage. Those packages are concrete, site construction, and masonry.

4.1.2 Information Gathering and Development of Results

The primary way in which we gathered data pertaining to both the work packages and their monetary value was by asking Gilbane's on site project manager, Al Abdella directly. Mr. Abdella was able to provide is with a percentage based representation of all of the existing work packages. He was unable to provide is with hard numbers due to a confidentiality issue. However, we were able to get approximate numbers from the percentages given. For example, the concrete work package represents approximate 7.6% of the total cost of the project, or approximately $1.6 million dollars. Compared to the non-union labor, this is a lower number. However, this is the exception and not the rule.

4.1.3 Results

The results mostly speak for themselves. The union labor has a higher cost in two of the three cases that we evaluated. The only exception is in the concrete work package, in which the cost for a non-union contract would be higher.

The prices in **Table 1** reflect the estimated cost for each work package for a non-union contract.

Work Package	Cost
Concrete	$2,100,000
Site Construction	$551,500
Masonry	$11,500
Total Cost	**$2,663,000**

Table 1 – Cost, non-union

Comparatively, the union prices, reflected in **Table 2**, are approximately 28% higher than their non-union counterparts overall.

Work Package	Cost
Concrete	$1,634,000
Site Construction	$1,118,000
Masonry	$946,000
Total Cost	**$3,698,000**

Table 2 – Cost, union

As you can clearly see, the cost of union labor for these three work packages adds up to a little over one million dollars in costs. This is only a thin slice representation of the total cost of the project, though one can see the immediate increase in total cost. A full table with actual labor costs and percentages of the project can be found in **Appendix E**. The full table of estimated non-union labor costs can be found in **Appendix F**.

As can be observed in **Figure 4** below, the distribution of cost is much skewed toward the pre-stressed concrete production work package. Overall it accounts for almost 40% of the cost of the project, according to Gilbane. **Figure 5** shows the total number of man hours being used by each work package. Concrete work and precast concrete work again represent the overwhelming majority of the total. Finally, **Figure 6** shows the approximate percentage of the total cost of each work package that is represented by labor. This essentially shows that J.L. Marshall and Sons, the concrete subcontractor for the project, has a very labor intensive work package. These graphs are representations based solely on the data provided by Gilbane, and do not represent the estimate according to a non-union contract.

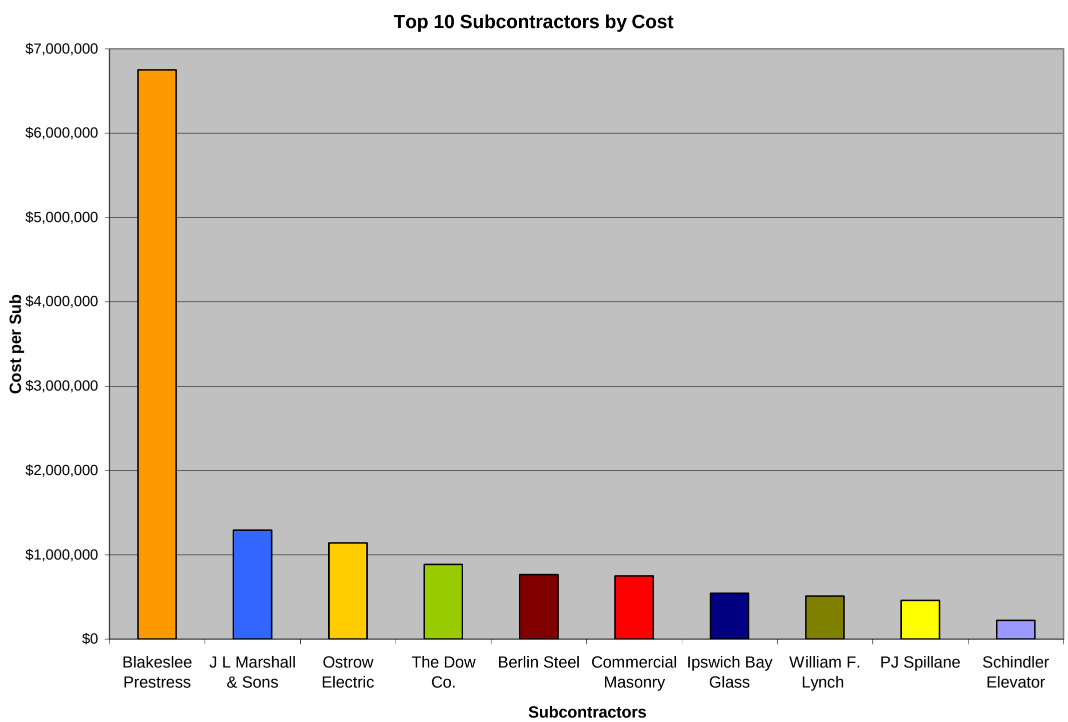


Figure 4 - Top 10 Subcontractors by Cost

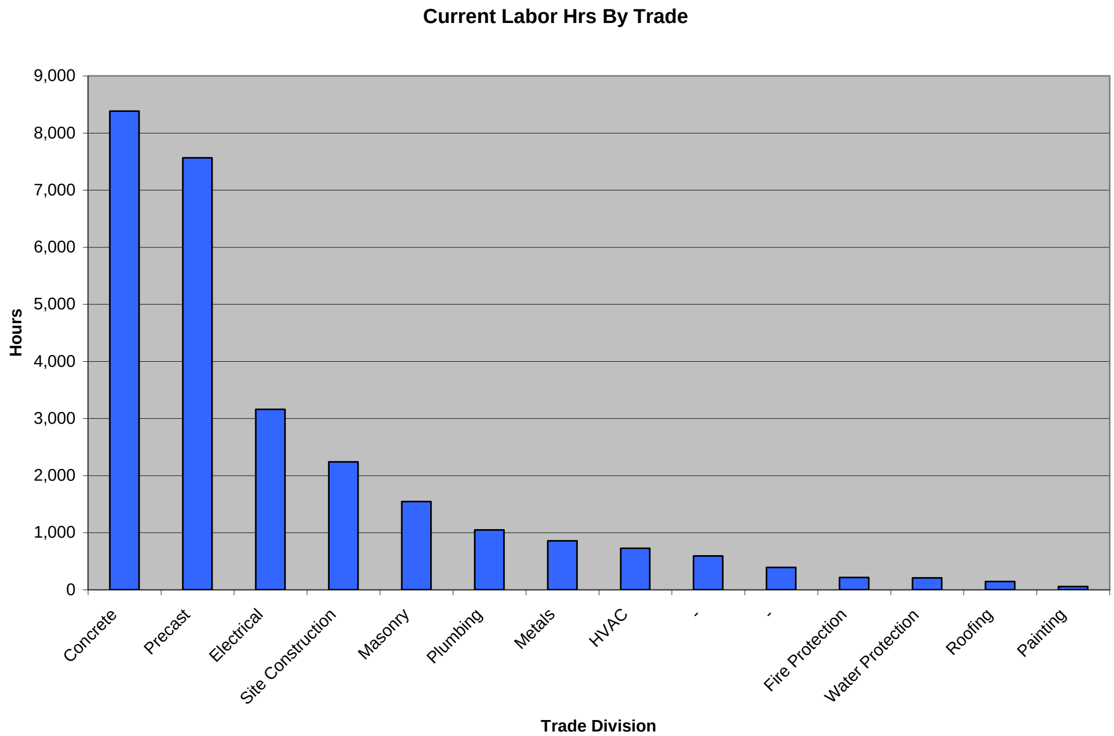


Figure 5 - Current Labor Hrs by Trade (as of Dec. 3, 2007)

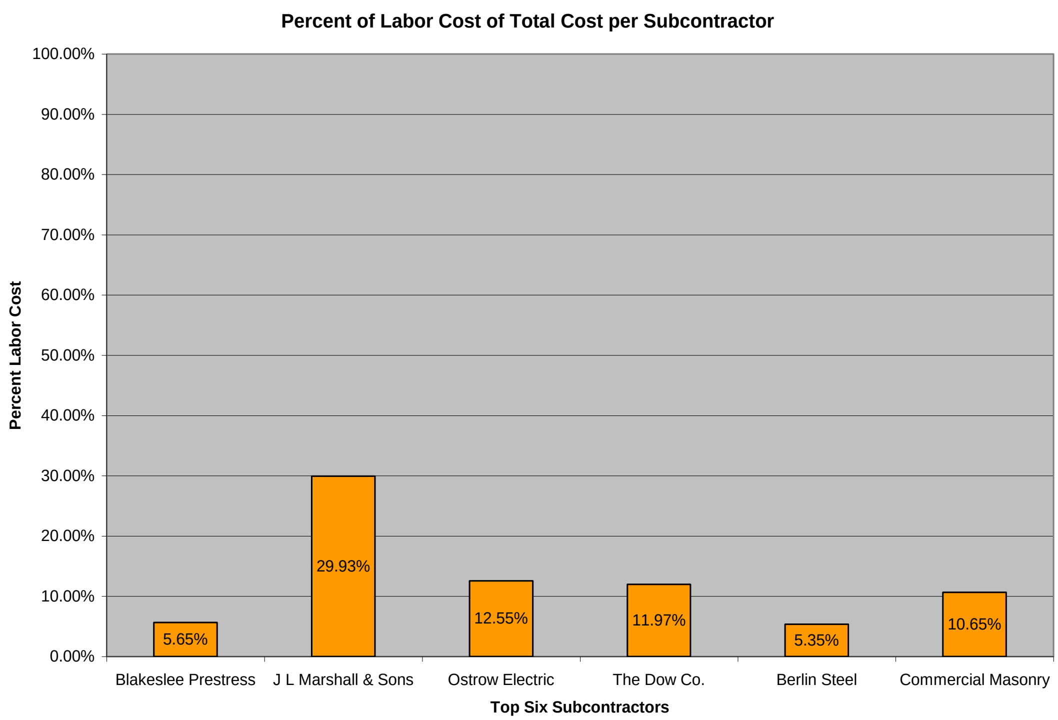


Figure 6 - Percent of Labor Cost of Total Cost per Subcontractor

5. Alternative Design of Parking Structure

The design of a building is a lengthy process in which the input of the owner, architect and engineers is essential for the completion of the design. The final design of the building is therefore determined by the input of these parties and any constraints that may exist. To fulfill the capstone design requirement, an alternative design for the Union Station Parking Garage was developed. To do this it was necessary to understand the constraints that existed on the project such as use, site layout, owner need and requirements, and design constraints. The design was developed in two separate parts. The first part of the design was dedicated to developing a new functional design for the parking structure this required creating a new layout for the parking spaces as well as redesigning the main structure of the building. The second part of the alternative design was the structural analysis of the parking garage, which was designed to be reinforced cast-in-place concrete opposed to the original precast concrete structure.

5.1 Alternative Layout Design

Our main objective was to propose an alternative design, mainly focusing on using a substitute for the precast structure that was originally designed, as well as using a different type of circulation system. The original design called for a half-helix separate from the main body of the building, this was used because of owner originally preferred not to have sloped floors. After researching and considering different circulation systems a single threaded helix system with two-way traffic (**Figure 7**) was chosen for the alternative design. Although sloped floors tend not to be the most aesthetically appealing for parking structures, it would increase capacity and decrease the cost of the structure. In addition, this design allowed the retail space, which is an important aspect of the design, to remain without any major changes.

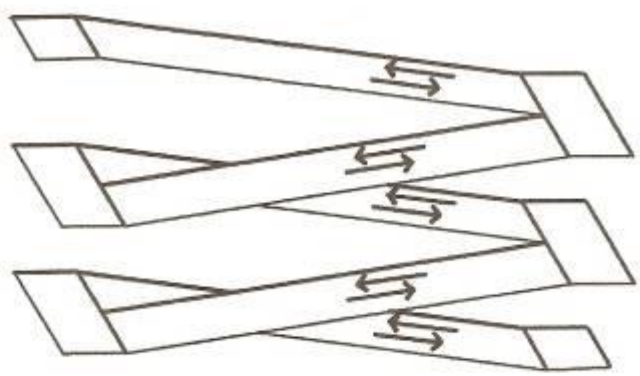


Figure 7 - Single Threaded Helix (Two-way traffic) (National Parking Association, 2000)

Throughout the process of choosing a circulation system the drawings of the original design were reviewed, and it was observed for changes could be made and how to better use the space provided by the site. By doing this a new structure could be developed to fit the site as well as the new functional design.

In addition, to complete the design of the alternative it was necessary to understand the different design requirements for a parking structure. These include: size of parking spaces, maximum grades for ramps, clearance requirements, as well as complying with the Americans with Disability Act (ADA) requirements. The final structure could not be completed without addressing these points. For example it was necessary to verify that the height between floors to ensure that all standard vehicles including handicap vans could access the parking garage. The minimum vertical clearance required to comply with ADA requirements is 8’2’’ (Chrest et al, 1996). For this reason the floors are 10’8” high.

Another aspect of designing the layout for the parking garage was determining the number of handicap parking spaces. ADA requirements state that for a parking structure with 501 to 1000 spaces, 2% of the total number of spaces are required to be accessible stalls. The proposed design is comprised of 509 typical parking stalls with an additional 11 accessible stalls, thus complying with ADA requirements. Of the 11 accessible stalls 2 of them are van-accessible stalls, since ADA also requires that for every 9 to 16 accessible stalls 2 of them to be van-accessible (Chrest et al, 1996).

The accessible stalls also have a minimum required size being 18'x 8' and having and access aisle of at least 5'. For van-accessible stalls the access aisle must be at least 8 ft. wide. All other typical parking stalls were 8'-6"x 18'. **Figure 8** depicts ADA minimum requirements for accessible parking stalls.

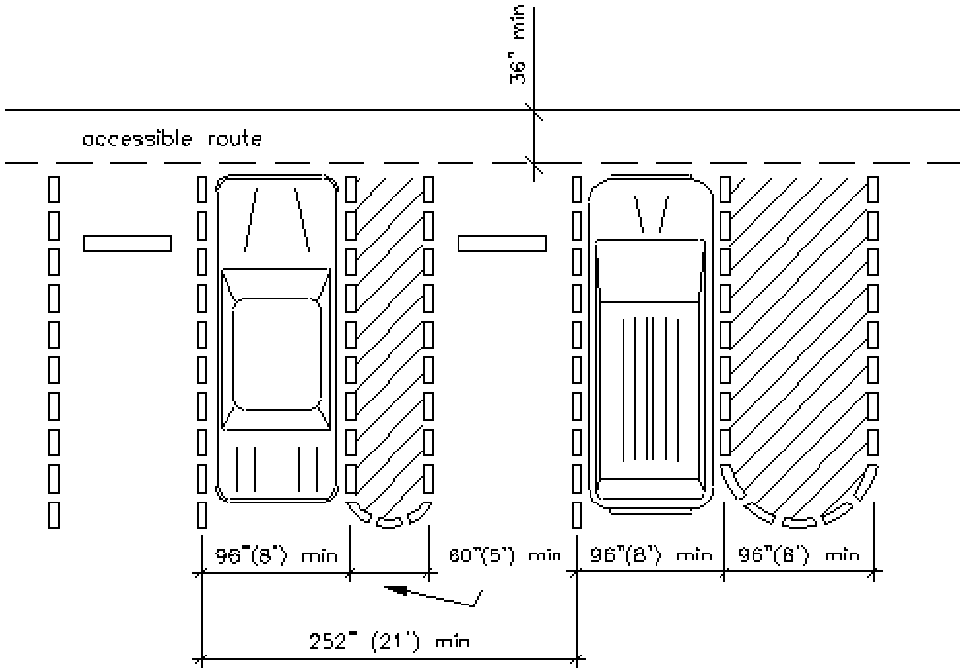


Figure 8 – ADA Minimum Dimensions for Accessible Parking Stalls

After estimating the number of spaces it was important to determine where the accessible spaces could be placed. This is important since there are various aspects that need to be considered when placing accessible spaces. They require accessible routes, from the parking stall to elevators and exits. For this reason the accessible stalls were not placed on the ramps, but rather on the horizontal slabs nearest to the elevators. In addition, by placing the accessible stalls on the horizontal slabs, the slope of the ramps did not become a concern for the design and could be allowed to be as sloped as necessary. It is important though to note that the slope of the ramps is only 6.2%, which allows it to be pedestrian friendly, and make it comfortable to reach the stairs or elevators from any point on the ramp. By distributing the parking spaces and arriving to final dimensions for the parking structure the layout design of the structure is complete. Final general layout plans for the alternative design were developed using AutoCAD 2007 software figures of these can be found in **Appendix H.**

5.2 Alternative Structural Design

To complete the design of the proposed alternative, it was necessary to design a structural frame capable of serving our proposed layout. To accomplish this, research was performed to determine the appropriate structural system. After researching references dedicated to the design of parking structures (i.e. *Parking Structures: Planning, Design, Construction, Maintenance, and Repair by A.P. Chrest* and *The Dimensions of Parking by the National Parking Association*) it was decided that a steel frame with cast-in-place post-tension concrete floor would be appropriate.

After deciding on what structural frame to use, a proposal detailing our alternative layout and how we planned to perform the structural design and analysis was developed. (**Appendix G**). The proposal was submitted to Professor Jayachandran Paramasivam, our co-advisor. The proposal was then discussed with Prof. Paramasivam, who approved of the layout and the process for the design began.

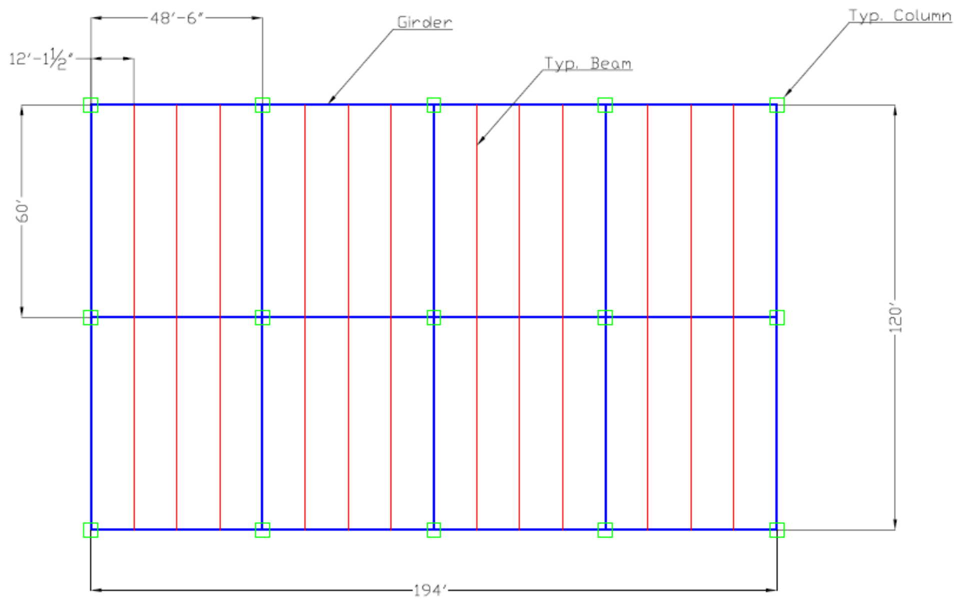


Figure 9 - Structural Layout

The first step in the design was to determine the size of the structural bays, including locations for girders and columns, and estimated number of beams. It here was that it was decided that only the section including the ramps would be used to determine the design. This was decided since a great majority of the parking spaces are located on the ramps these carry most of the loads. **Figure 9** shows the general structural layout of a typical floor.

Next the design of the slab was begun. The proposed design called for composite beams and a one-way slab. As the design for the slab began concerns over how to analyze the loads since the slabs would be sloped. After researching in various design guides for reinforced concrete, no specifics were found for sloping slabs. For this reason, Prof. Paramasivam was consulted. After discussing the options with him, it was concluded that the slab could be designed as a regular horizontal slab. And that the slope was only important when doing a frame analysis of the girders and columns.

The design of the slabs continued, yet another problem arose when the design for the beams and girders began. This included how the layout of sloping steel girders and beams would be. As well as the concern that 60' spans would give very large W sections for the girders. For this reason the design was once again discussed, and it was decided that the whole structure would be design as a reinforced concrete structure. This way the slabs would have a simpler design, being one-way slabs with imbedded continuous beams. The two main design aids that were used throughout the process were guides for reinforced concrete, J. Macgregor's Reinforced Concrete: Mechanics and Design, was used mainly for the design of the slab and continuous beams, while Chu-Kia Wang's Reinforced Concrete Design was used for the design of girders and columns.

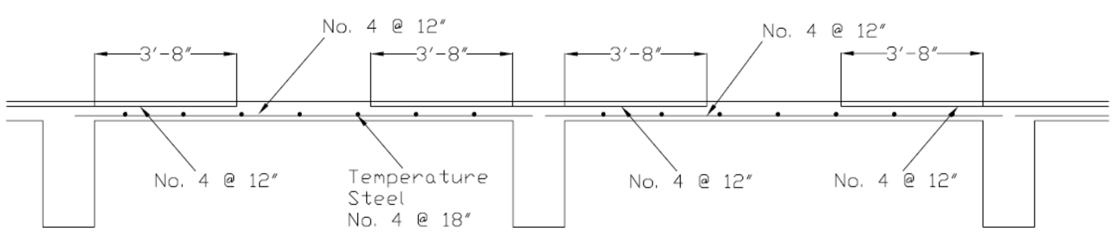


Figure 10 - Cross-section of Reinforced Concrete Slab

The slab was designed to be a 6in slab with reinforcement for flexure being No. 4 reinforcement bars at 12" o.c, and with shrinkage and temperature reinforcement being provided by No. 4 bars at 15" o.c. Calculations can be found in **Appendix I**. The beams were placed every 12.125 ft, giving 3 beams per bay. The beams are 14"x39" reinforced concrete beams with the stem extending 33” below the slab and with a d=36.5”. 4 (four) No. 11 steel reinforcement bars will be used for the negative-moment region, and 6 (four) No. 10 bars will be used for positive moment (**Appendix I**). **Figures 10** and **11** show detailed cross-sections for the concrete slabs and beams.

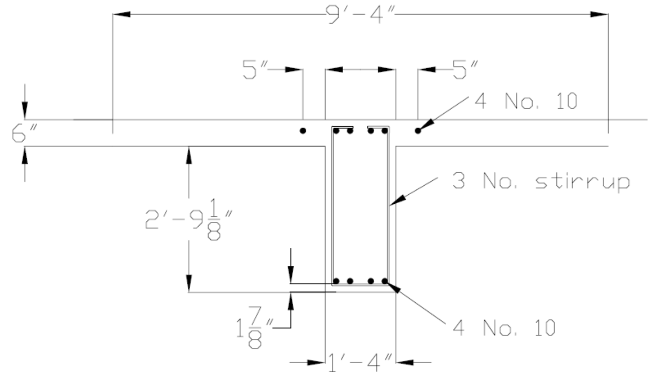


Figure 11 - Cross-section of Typical Continuous Beam

After designing the slabs and beams, the girders and columns were designed. The girders were designed by first determining a web size, which resulted in an 18”x 42” stem web. After doing this it was possible to analyze the girder as a continuous frame, this was done to calculate fixed-end-moments. Following this it was possible to determine the longitudinal reinforcement for the girder at different sections. **Figure 12** shows the resulting detail reinforcement, and calculations can be found in **Appendix I**.

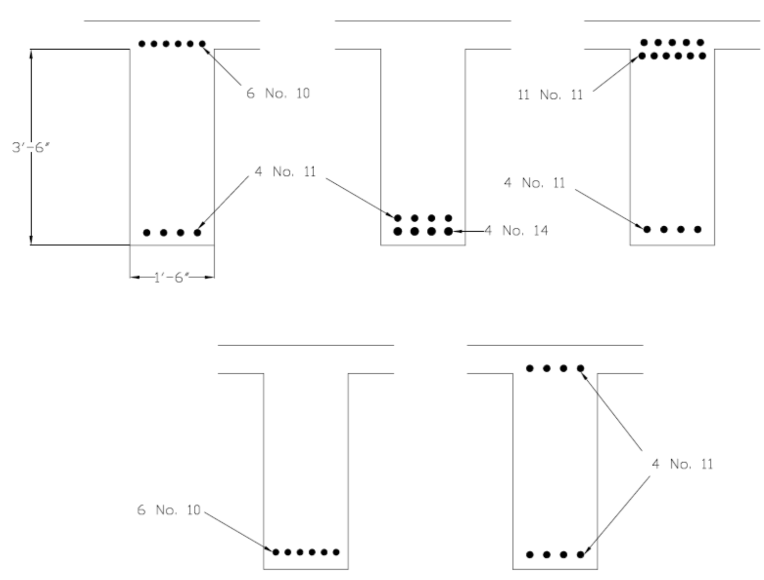


Figure 12 - Reinforcement Detail at Girder Sections

After reaching a girder size the columns for the structure could be designed. The design for the columns followed the process of Design for Ultimate Strength – Region II, Region II meaning that compression controls. Therefore, a 17"x17" column was designed, with 8 No.9 bars, and with No. 3 ties spaced at 17". **Figure 13** depicts the section of a typical column, calculations for the design can be found in **Appendix I**.

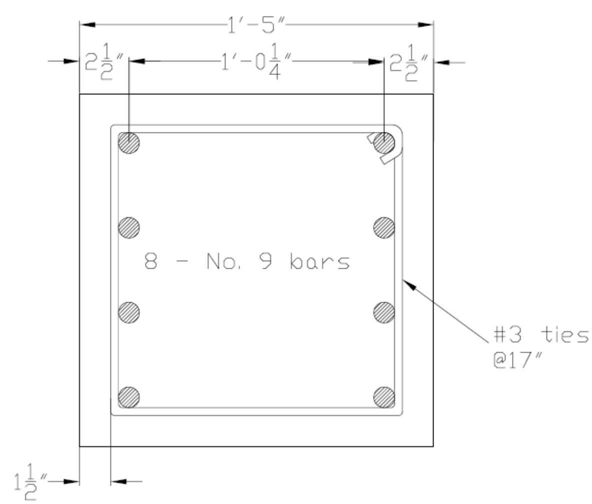


Figure 13 - Cross-section of Typical Column

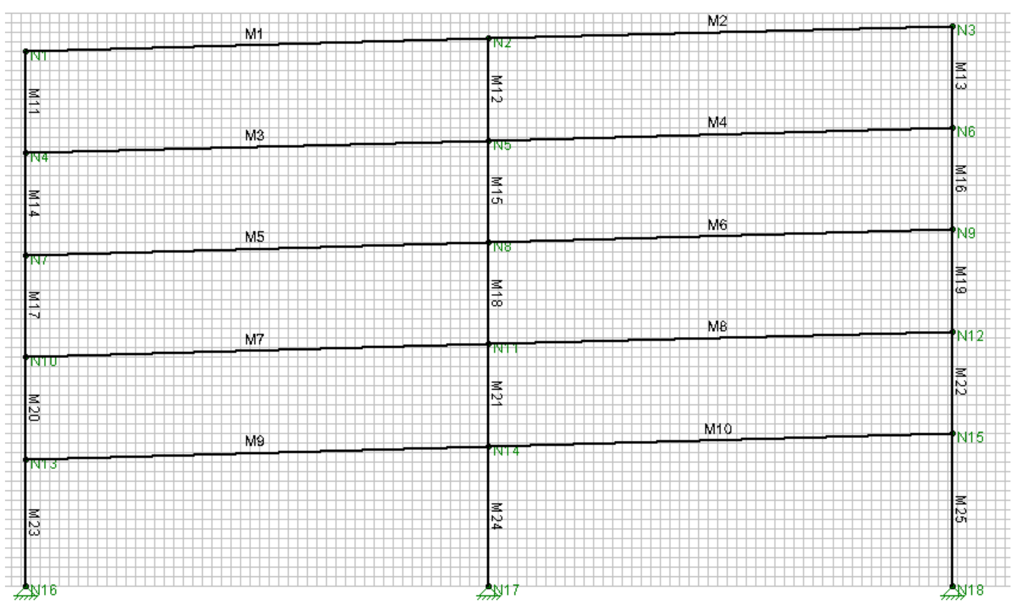


Figure 14 - Frame Section used in RISA 2D

Finally a frame analysis was performed on the structure to verify the structure for end moments and deflections. The analysis was done on two bays using RISA 2D software to simplify the analysis. **Figure 14** shows the typical two bays, consisting in a total of 25 different members, which were used through out the analysis. Four different loading cases (LC) were used as well, these were divided into: *LC 1- Dead Loads only, LC 2 – Live Loads only*, *LC 3 – Dead Loads and partial LL*, *LC 4 – full Live and Dead Loads*. **Appendix J** contains figures showing all four loading cases, as well as the moment and shear force diagrams for each loading case. **Appendix K** contains tables showing actual values for deflections and forces in all directions.

6. Conclusions

As with any project, there are a number of concerns that emerge throughout the design and building phases. Of course, there are specific problems related to this project. Being owned by the Worcester Redevelopment Authority, managed by Gilbane, and designed by the Maguire Group, there are many decisions that must run through all three parties before taking any effect on the project.

Another concern is of course the cost of the project. Having calculated the cost of three work packages of the project, a good portion of the project is represented here.

6.1 Project Management

Having the opportunity to observe the project management team throughout major construction of the Union Station Parking Garage, was a unique experience that gave a clear idea of how project management should be handled on site. The project management team did an exceptional job at coordinating the construction, as well as all of those involved. The project manager was always up to speed and was well aware of what was occurring at the site. The project manager not only was looking at what was occurring currently on-site but was planning well ahead what had to be done in the next couple of weeks.

A perfect example of this was coordinating with the subcontractor in charge of the masonry weeks before the subcontractor was due on site. By doing this the subcontractor could look at the layout of the site, and coordinate the work with the project manager and other subcontractors, as well as plan where the materials could be stored for easy access and without disturbing other construction. This is always important especially on sites, such as this one, where space is limited, and coordination between the subcontractors is crucial.

It was also interesting to observe how conscientious the project management team was concerning safety. The team always made sure that all laborers and visitors had proper safety gear (i.e. safety goggles and hard hats). Providing a safe work environment is important not only because it keeps workers, visitors, and people passing by from incurring injuries, but also shows the commitment the team has for the well being of the workers. Other examples of safety on the site were making sure welders were using their face shields when welding, or just the simple task of insuring that the site was clean of garbage or construction debris.

Also as the project began, it was believed that at some point the project management team might confront a major problem during construction. One of the reasons for this was that as construction began the project was criticized for having a union-only Project Labor Agreement. However, the project management team worked very well and no major set backs occurred, and construction was allowed to progress smoothly. On the contrary to having setbacks, the project gained a very important achievement which was completing the erection of the precast structure approximately a week ahead of schedule (**Appendix B**). This was achieved by both the work done by the project management team and the subcontractor in charge of its erection. This was a great gain, since it allowed the necessary caulking to be done so that utility and elevator subcontractors could work inside the building during the winter months. The speed in which the erection was completed can be observed the photographs below (**Figure 15**), which were taken two weeks apart.

Figure 15 - Erection of Precast Structure: Oct. 10th, 2007 (left) & Oct 23rd, 2007 (right)

6.2 Cost Estimating

While going over the cost of individual work packages for the project, we found some large differences in final cost when looking at a union vs. non-union contract. In the case of both the site construction and the masonry work packages, the cost of the project was greatly increased by using a union labor force. However, for the concrete work package, the cost of non-union labor was significantly higher. This could be for any number of reasons, but in the end it was not enough to save the union contract a significant amount. In the end, the union contract was almost a million dollars more expensive (**Table 3**).

Non-union contract	$2,663,000
Union contract	$3,698,000

Table 3 - Total cost of work packages

However, this data is not 100% accurate. As stated previously, Gilbane was only able to provide us with a percentage of the final cost of the project for each work package. This was of course inherently less accurate than simply using a final cost generated by each work package. Also, the non-union contract cost was calculated using R.S. Means, and was based on the total number of hours predicted for the given tasks. This number of hours will obviously differ from the number of hours estimated by the union, and therefore a large difference will crop up in the final calculations.

6.3 Alternative Design

The final design of the proposed alternative consists of two major parts, one is the layout of the parking spaces and the other is the structural design of the parking garage. The final design is comprised of a single-threaded helix reinforced concrete structure, with 5 floors, and a total count of 520 parking stalls. The main difference between the proposed alternative and the original design is the circulation system. The original design is composed of a half-helix compared to the single-threaded helix. This change in the design takes better advantage of the site, meaning more of the site area is used for the building. Also there is an increase in the number of parking stalls, although not a dramatic increase. The proposed layout adds only approximately 20 parking stalls. Also the use of the proposed circulation system raises the final height of the structure approximately 5 feet.

Although the proposed layout may contribute in providing more parking stalls, there are some shortcomings to the proposed design. The first one being that generally sloped floors are not aesthetically pleasing. The owner of the parking garage requested that the structure be aesthetically pleasing since it was being design as part of the redevelopment of the Worcester Union Station. Therefore once, the both structures are compare it is noticeable that the proposed design and the original design suite different needs. The proposed design would be advantageous if the owner's expectations were to obtain the highest number of parking stalls possible, however the owner also required certain aesthetic requirements out of the design, that were not considered for the alternative. It was concluded that the original design, fits the owner's needs not only aesthetically but also in function. Since the proposed design only increases the capacity of the parking structure by approximately 4%, and does not provide all of the owner's aesthetic requirements.

The structural design of the proposed layout had been proposed with a steel frame, as the design for the structure began, it was made clear that the steel design could not be economically feasible. This is due to the fact that since the beams would be spanning 60' the size required would make the whole structure inefficient since the floor heights would have to be increased and total height of the building would increase dramatically. Therefore, it was settle upon to use a reinforced concrete design for the proposed structure. Although there were some concerns as to the difficulty of designing sloped floors, the slope for the ramps was not very high; approximately 6%, (as a reference, 5% is the maximum slope for ADA requirements) and thus the slabs could be designed without any extra design requirements.

The main difference between our proposed structure and the original design, in terms of structural design, is that the original design is prestressed concrete. The proposed design is cast-in-place. This is a significant design difference in terms of construction, and scheduling. Precast sections can be designed for and constructed while site construction is still underway. For this reason if the structural design is completed in time, the owner may save a lot of time and therefore money during construction. Other benefits to precast concrete are that when constructing the floors, it is not necessary to wait for the concrete to set to remove the forms and begin construction on the next floor. It is however, very important that the precast subcontractor have an efficient and knowledgeable erecting crew, as well as having a well-organized system in delivering the precast sections. If sections do not arrive on time, erection will be delayed. In addition, many times sites do not have a lot of room to store large precast sections, therefore, if erection is delayed, sections may be backed up and cause problems in terms of where to store them. At the same time cast-in-place depends on the punctual arrival of concrete to have it placed and set in time for construction to flow.

Glossary

cash flow - Cash flow is cash receipts minus cash disbursements from a given operation or asset for a given period. A cash flow statement shows all sources and uses of cash reflected in the balance sheet cash account from one period to the next.

fringe benefits – an employment benefit (as a pension or a paid holiday) granted by an employer that has a monetary value but does not affect basic wage rates

Jim Crow law - in U.S. history, any of the laws that enforced racial segregation in the South between the end of the formal Reconstruction period in 1877 and the beginning of a strong civil rights movement in the 1950s.

LRFD – Load and Resistance Factor Design

precast - being concrete that is cast in the form of a structural element (as a panel or beam) before being placed in final position

prevailing wages – the rate paid to a majority of people engaged in a particular craft, classification, or type of work within a geographic area. If there is no single rate paid to a majority of the workers, then it is the common rate being paid to the greatest number of workers.

Project Labor Agreement (PLA) – an agreement between the contractor, subcontractors, and the union(s) representing workers. Under a PLA, the contractor and subcontractors on a project and the union(s) agree on terms and conditions of employment for the project, establishing a framework for labor-management cooperation to advance the Government's procurement interest in cost, efficiency, and quality

subcontractor – a specialty contractor who enters into an agreement with a general contractor. The subcontractor has no contractual agreement with the owner.

labor union – an organization of workers formed for the purpose of advancing its members' interests in respect to wages, benefits, and working conditions

value engineering (VE)- an organized, creative approach which has for its purpose the effective identification of unnecessary costs, i.e., costs which provide neither quality nor use nor life nor appearance nor customer features

Bibliography

Barrie, D. S., & Paulson, B. C. (1992). *Professional Construction Management: Including CM, Design-Construct, and General Contracting*. New York, NY: McGraw Hill.

Chrest, A. P., Smith, M. S., Bhuyan, S. (1996). *Parking Structures: Planning, Design, Construction, Maintenance, and Repair.* New York, NY: International Thomson Publishing.

Cogliano, R. N. (2007, June 4). Project labor agreements are the bane of taxpayers, budgets. *Worcester Telegram & Gazette*, p. A7.

Dell'Isola, Alphonse. (1997). *Value Engineering: Practical Applications… for Design, Construction, Maintenance, & Operations.* Kingston, MA: R.S. Means CMD Group.

Division of Capital Asset Management (DCAM) & the Inspector General (IG). (2005). *Frequently Asked Questions Regarding the New Public Construction Reform Law*. Retrieved November 4, 2007, from http://www.mass.gov/cam/Creform/CRLFAQS.pdf

Ferguson, P.M., Breen, J.E., Jirsa, J.O. (1988) *Reinforced Concrete Fundamentals*. New York, NY: John Wiley & Sons.

Gilbane: About Us. (n.d.) Gilbane Building Company. Retrieved October 4, 2007, from http://www.gilbanebuilding.com/inside/about.aspx

Hinze, J. (2001). *Construction Contracts*. Boston, MA: McGraw-Hill.

Industrial Workers of the World (IWW). (n.d.) Typical Benefits of Union Contract. Retrieved October 7, 2007 from http://www.iww.org/organize/laborlaw/contract1.shtml

Jim Crow law. (2007). In *Encyclopædia Britannica*. Retrieved October 31, 2007, from Encyclopædia Britannica Online: http://www.britannica.com/eb/article-9043641

MacGregor, J.G., Wight, J.K. (2005). *Reinforced Concrete: Mechanics and Design*. Upper Saddle River, NJ: Pearson Prentice Hall.

Massachusetts Office of the Inspector General. (2006). *Public Construction Reform Information*. Retrieved October 3, 2007, from http://www.mass.gov/ig/creform/refinfo.htm

Mishel, L., & Walters, M. (2003). How unions help all workers. *Economic Policy Institute*. Retrieved October 7, 2007 from http://www.epinet.org/content.cfm/briefingpapers_bp143

National Parking Association. (2000). *The Dimensions of Parking*. Washington D.C.: Urban Land Institute.

Oberlender, G. D. (2000). *Project Management for Engineering and Construction*. Boston, MA: McGraw Hill.

R.S. Means Company. (2006) *2007 Building Construction Cost Data*. R.S. Means Company.

Parking Structures. (n.d.). Blakeslee Prestress Incorporated. Retrieved February 16, 2008 from: http://www.blakesleeprestress.com/solutions/parking/index.cfm

Sutner, S. (2007, June 26). Feds want city to justify union-only construction. *Worcester Telegram & Gazette*. Retrieved October 24, 2007 from http://www.telegram.com/article/20070626/NEWS/706260534&SearchID=73285556988663

The White House, George W. Bush. (2001). *Executive order: Preservation of Open Competition and Government Neutrality Towards Government Contractors' Labor Relations on Federal and Federally Funded Construction Projects.* Retrieved October 3, 2007 from: http://www.whitehouse.gov/news/releases/2001/02/20010221.html

Union Station. (2007). Architectural Record, McGraw Hill Construction. Retrieved October 3, 2007, from http://archrecord.construction.com/projects/bts/archives/transportation/unionStation/overview.asp

U.S. Department of Labor: Bureau of Labor Statistics (BLS). (2007). *Glossary*. Retrieved October 4, 2007, from http://www.bls.gov/bls/glossary.htm

U.S. Department of Labor: Employment Standards Administration Wage and Hour Division. (n.d.). *Davis-Bacon Act*. Retrieved October 4, 2007, from http://www.dol.gov/esa/regs/statutes/whd/dbra.htm

U.S. General Services Administration, & Office of Acquisition Policy. (2004). *General Services Administration Acquisition Manual (GSAM).* Retrieved October 3, 2007, from http://www.acqnet.gov/GSAM/current/pdf/GSAM.pdf

Wang, C., Salmon C. G. (1979). *Reinforced Concrete Design*. New York, NY: Harper & Row Publishers

What is a Project Labor Agreement and how does it affect workers? (2007). *National Right to Work Legal Defense Foundation, Inc.* Retrieved October 3, 2007 from, http://www.nrtw.org/neutrality/na_6.htm

Winter, G., Nilson A.H. (1979). *Design of Concrete Structures*. New York, NY: McGraw-Hill Book Company.

Worcester Redevelopment Authority (WRA). (2008). Boards & Commissions for the City of Worcester. Retrieved January 24, 2008 from, http://www.ci.worcester.ma.us/boards/profiles/wra.htm

Appendix A – Example of Gilbane Meeting Minutes

Gilbane

Meeting Minutes

Detailed, Grouped by Topic for each Meeting and by 'Old Business' and 'New Business'

Union Station Parking Garage 18 Grafton Street 4th Floor Worcester MA 01604	**Project # 114220000** Tel: 508 767-1115 Fax: 508 767-1116	**Gilbane Building Company**

Owner, Architect, Contractor Meeting 11

Date	Start	End	Next Meeting	Next Time	Prepared By	Company
11/7/2007	08:00 AM	09:00 AM	11/27/2007	08:00 AM	Place, Thomas	Gilbane Building Company

Purpose	Location	Next Location	General Notes
Union Station Parking Garage Progress Meeting	GBCO Filed Office 18 Grafton Street 4th Floor	GBCO Filed Office 18 Grafton Street 4th Floor	

Attended By	Non-Attendees
City of Worcester - Moosey, Paul	City of Worcester - O'Neil, Steve
Maguire Group Inc. - Morsilli, Harold	
Gilbane Building Company - Kearney, William	
Gilbane Building Company - Abdella, Albert	
Gilbane Building Company - Place, Thomas	
City of Worcester - Ciccone, George	
Gilbane Building Company - Hogan, Meghan	

Item	Meeting Item Description	Resp	Status	Due Date	Compl'd	Cls'd
010 Safety						
Old Business						
004-005	Safety -9/12/07 Ongoing. Every day is to be a safe day. New Project Safety Officer is Jim Barnett. - Safety Orientation and Drug Testing is required for all tradespeople working on site.					No

Item	Meeting Item Description	Resp	Status	Due Date	Compl'd	Cls'd
020 Schedule						
Old Business						
006-001	Remaining items to be bought out - Parking Equipment - Package to be sent out today. - Signage - Waiting for scope of work.					No

Item	Meeting Item Description	Resp	Status	Due Date	Compl'd	Cls'd
030 Quality						
Old Business						
003-002	-10/31/07 Received a visit from Ken Haywood and was informed that the City has reviewed and amended the WRA Responsible Employer & Inclusionary Participation Policy. Ken stated that revision now includes Worcester					No

Prolog Manager Printed on: 11/27/2007 NENG Union Station Parking Garage Page 1

Gilbane

Meeting Minutes
Detailed, Grouped by Topic for each Meeting and by 'Old Business' and 'New Business'

Item	Meeting Item Description	Resp	Status	Due Date	Compl'd	Cls'd
	County Residents and not Minority Worcester County Residents in achieving 20% goal.					

Item	Meeting Item Description	Resp	Status	Due Date	Compl'd	Cls'd
040 Issue/Concerns						
Old Business						
010-001	Issues: -Overhead Door at Entrance -Reopening of Corridor -Concrete work at Helix / garage to allow access for required trades. - Paint Odor in corridor and Union Station - Cash Flow update and submission - Change Order to be issued					No

Item	Meeting Item Description	Resp	Status	Due Date	Compl'd	Cls'd
050 Changes						
Old Business						
004-002	Change Log is attached -					No

Item	Meeting Item Description	Resp	Status	Due Date	Compl'd	Cls'd
060 Submittals						
Old Business						
004-003	Submittal Log in Review is attached					No

Item	Meeting Item Description	Resp	Status	Due Date	Compl'd	Cls'd
070 RFI						
Old Business						
004-004	RFI Log is attached					No

Cc:	Company Name	Contact Name	Copies	Notes
	Gilbane Building Company	Read File	1	
	Gilbane Building Company	Correspondence	1	
	City of Worcester	Haywood, Kendrick	1	

These meeting minutes reflect the writer's understanding of the issues discussed. Please notify the writer within five (5) days of any errors, omissions or corrections otherwise, they remain as written.

Gilbane

Request for Information

Summary Log of all Outstanding RFIs Grouped by Company

Union Station Parking Garage
18 Grafton Street
4th Floor
Worcester MA 01604

Project # 114220000
Tel: 508 767-1115 Fax: 508 767-1116

Gilbane Building Company

RFI #	Subject	Submitted	In Review	Date Req'd	Days Late	Amount	Delay
Maguire Group Inc.							
0028	Water lines at G08 - not heated or insulated	9/26/2007	62	10/3/2007	55		

Gilbane

Submittal Packages

Summary Log In Review, Grouped by To Company

Union Station Parking Garage
18 Grafton Street
4th Floor
Worcester MA 01604

Project # 114220000
Tel: 508 767-1115 Fax: 508 767-1116

Gilbane Building Company

Number-Rev	From Company	Description	To Company	Sent	Due	Rec'd	Days +/-	Action
Maguire Group Inc.								
0001-09511-0	Gilbane Building Company	Acoustical Ceiling Panels	Maguire Group Inc.	10/1/2007	10/15/2007		43	
0008-04200-0	Gilbane Building Company	Ground Face Block Samples	Maguire Group Inc.	10/10/2007	10/24/2007		34	
0011-05500-1	Gilbane Building Company	Aluminum Grills & Grill Sample	Maguire Group Inc.	11/27/2007	12/11/2007		-14	

Number of Submittal Packages in this Project: 3

‹ILBANE BUILDING COMPANY
CHANGE ORDER

CONTRACT FOR:	Union Station Parking Garage	**PROJECT NUMBER:**	114220000
OWNER:	City of Worcester	**CHANGE ORDER NO:**	1
ADDRESS:	20E Worcester Street	**DATE OF ISSUANCE:**	11/27/07
	Worcester , MA 01604	**SUBMITTED BY:**	GILBANE
		CONTRACT DATED:	6/18/07
ARCHITECT:	Maguire Group	**ARCHITECT PROJ NO:**	17150

The Contract changes as follows:

DESCRIPTION: This Change Order is for the following CCA as listed CCA Number's 17, 19, 20, 22, 25, 26, 29, 30, 34, 36, 46, 47, 49, 50, 52, 53, 55, 56, 58, 67 and 74

CCA Number	Change Request	Change Request Description	Amount
17	17	Bulletin No 3 Dated 6/08/07	8,349.00
19	19	Out of Sequence due to obstrtn	1,097.00
20	20	Bulletin No 4 dated 6/21/07	16,527.00
22	22	Millbrook IssuesforFoundation	15,513.00
25	25	Screening gravel	2,519.00
26	26	Bulletin No. 5 6/29/07	55,482.00
29	29	RFI 006 Union St. Sprinklers	4,122.00
30	30	San. and Drain Lines 6 & 12	7,051.00
34	34	Galvanized piping Corridor	1,575.00
36	36	Corridor WP Elimination	11,520.00-
46	46	Cores thru helix for telephone	630.00
47	47	Stone and fabric filter @ per	6,083.00
49	49	Bulletin # 8 8/23/07	15,995.00
50	50	Water to Snowmelter	10,305.00
52	52	Vent/trap for AD to tunnel	1,621.00
53	53	Bull # 9 S S Supports	11,867.00
55	55	Add Valve Area Drain B	1,401.00
56	56	Exit Signs at Corridor/Tunnel	2,212.00
58	58	Cut Cap Hydrant at A6 line	6,591.00
67	67	Paving along North Side	13,075.00
74	74	Credit for CR GMP Adjustment	17,075.00-

Signature of the Owner indicates agreement herewith, including any adjustment in the Contract Sum or the Contract Time

The original Guaranteed Maximum Price was	17,000,000.00
Net change by previously authorized Change Orders	.00
Guaranteed Maximum Price prior to this Change Order	17,000,000.00
Guaranteed Maximum Price will be increased by this Change Order in the Amount	153,420.00
The new Guaranteed Maximum Price including this Change Order will be	17,153,420.00
The Contract Time will be unchanged by	0 days
The date of Substantial Completion for construction as of the date of this Change Order therefore is	7/01/08

Architect: ______________________________ Date: ______________

Owner: ______________________________ Date: ______________

Company: ______________________________ Date: ______________

GILBANE BUILDING COMPANY

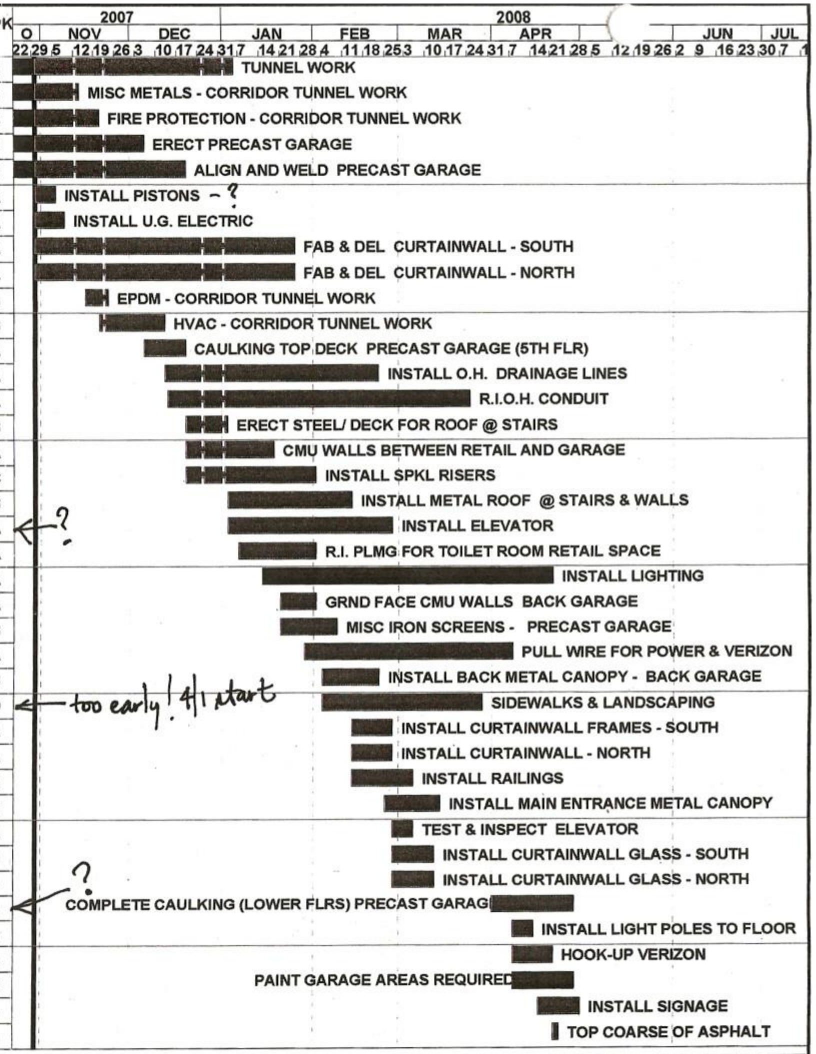
Distribution: Owner Architect CR File CO File Other

CO114220000-1.DOC

Page 1 of 1

Appendix B – Gilbane Construction Schedule

Activity ID	Activity Description	Rem Dur	Early Start	Early Finish	3DPK
4032	TUNNEL WORK	45	23JUL07A	04JAN08	03A
4097	MISC METALS - CORRIDOR TUNNEL WORK	10	13AUG07A	13NOV07	05B
4099	FIRE PROTECTION - CORRIDOR TUNNEL WORK	15	17SEP07A	20NOV07	15C
4200	ERECT PRECAST GARAGE	25*	17SEP07A	05DEC07	03B
4205	ALIGN AND WELD PRECAST GARAGE	35*	19SEP07A	19DEC07	03B
4066	INSTALL PISTONS ?	5	30OCT07	05NOV07	14A
4100	INSTALL U.G. ELECTRIC	8	30OCT07	08NOV07	16A
4245	FAB & DEL CURTAINWALL - SOUTH	60	30OCT07	25JAN08	08A
4255	FAB & DEL CURTAINWALL - NORTH	60	30OCT07	25JAN08	08A
4098	EPDM - CORRIDOR TUNNEL WORK	5	16NOV07	23NOV07	07B
4101	HVAC - CORRIDOR TUNNEL WORK	15	21NOV07	12DEC07	15B
4207	CAULKING TOP DECK PRECAST GARAGE (5TH	10	06DEC07	19DEC07	07A
4340	INSTALL O.H. DRAINAGE LINES	50	13DEC07	22FEB08	15A
4300	R.I.O.H. CONDUIT	70	14DEC07	24MAR08	16A
4210	ERECT STEEL/ DECK FOR ROOF @ STAIRS	8	20DEC07	02JAN08	05B
4209	CMU WALLS BETWEEN RETAIL AND GARAGE	20	20DEC07	18JAN08	04A
4335	INSTALL SPKL RISERS	30	20DEC07	01FEB08	15C
4215	INSTALL METAL ROOF @ STAIRS & WALLS	30	03JAN08	13FEB08	05B
4270	INSTALL ELEVATOR	40	03JAN08	27FEB08	14A
4211	R.I. PLMG FOR TOILET ROOM RETAIL SPACE	20	07JAN08	01FEB08	15A
4310	INSTALL LIGHTING	70	15JAN08	21APR08	16A
4222	GRND FACE CMU WALLS BACK GARAGE	10	21JAN08	01FEB08	04A
4233	MISC IRON SCREENS - PRECAST GARAGE	15	21JAN08	08FEB08	05B
4305	PULL WIRE FOR POWER & VERIZON	50	29JAN08	07APR08	16A
4224	INSTALL BACK METAL CANOPY - BACK GARAGE	15	04FEB08	22FEB08	05B
4228	SIDEWALKS & LANDSCAPING	40	04FEB08	28MAR08	02D
4248	INSTALL CURTAINWALL FRAMES - SOUTH	10	14FEB08	27FEB08	08A
4258	INSTALL CURTAINWALL - NORTH	10	14FEB08	27FEB08	08A
4232	INSTALL RAILINGS	15	14FEB08	05MAR08	05B
4226	INSTALL MAIN ENTRANCE METAL CANOPY	15	25FEB08	14MAR08	05B
4272	TEST & INSPECT ELEVATOR	5	28FEB08	05MAR08	14A
4249	INSTALL CURTAINWALL GLASS - SOUTH	10	28FEB08	12MAR08	08A
4259	INSTALL CURTAINWALL GLASS - NORTH	10	28FEB08	12MAR08	08A
4220	COMPLETE CAULKING (LOWER FLRS) PRECAST	20	01APR08*	28APR08	07A
4312	INSTALL LIGHT POLES TO FLOOR	5	08APR08	14APR08	16A
4315	HOOK-UP VERIZON	10	08APR08	21APR08	16A
4320	PAINT GARAGE AREAS REQUIRED	15	08APR08	28APR08	09C
4617	INSTALL SIGNAGE	10	17APR08	30APR08	10A
4325	TOP COARSE OF ASPHALT	2	22APR08	23APR08	02A



Start Date 15AUG06
Finish Date 01JUL08
Data Date 30OCT07
Run Date 30OCT07 11:41

Early Bar
Progress Bar
Critical Activity

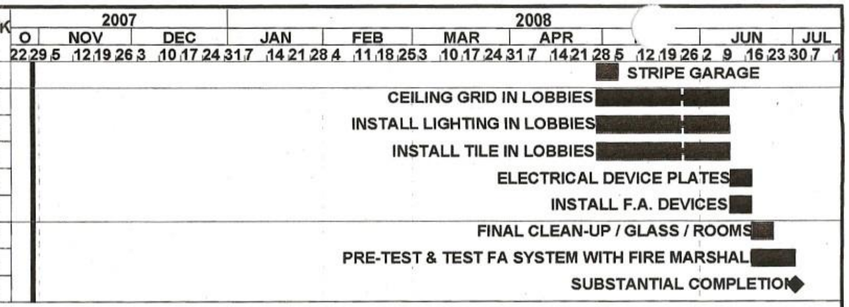
US08
Sheet 1 of 2
UNION STATION PARKING GARAGE (US08)
GILBANE BUILDING COMPANY
CONSTRUCTION ACTIVITIES BY ES EF

Gilbane

CONST			
Date	Revision	Checked	Approved
30OCT0	Schedule Update		

Figure 16 - Gilbane Construction Schedule 1 (Data from: Oct. 20, 2007)

Activity ID	Activity Description	Rem Dur	Early Start	Early Finish	3DPK
4330	STRIPE GARAGE	5	29APR08	05MAY08	02A
4326	CEILING GRID IN LOBBIES	30	29APR08	10JUN08	09B
4327	INSTALL LIGHTING IN LOBBIES	30	29APR08	10JUN08	16A
4328	INSTALL TILE IN LOBBIES	30	29APR08	10JUN08	09B
4322	ELECTRICAL DEVICE PLATES	5	11JUN08	17JUN08	16A
4324	INSTALL F.A. DEVICES	5	11JUN08	17JUN08	16A
4999	FINAL CLEAN-UP / GLASS / ROOMS	5	18JUN08	24JUN08	99D
4400	PRE-TEST & TEST FA SYSTEM WITH FIRE	10	18JUN08	01JUL08	16A
4405	SUBSTANTIAL COMPLETION	0		01JUL08	99D



Start Date	15AUG06
Finish Date	01JUL08
Data Date	30OCT07
Run Date	30OCT07 11:42

Early Bar
Progress Bar
Critical Activity

US08 Sheet 2 of 2

UNION STATION PARKING GARAGE (US08)

GILBANE BUILDING COMPANY

CONSTRUCTION ACTIVITIES BY ES EF

Gilbane

CONST

Date	Revision	Checked	Approved
30OCT0	Schedule Update		

Figure 17 - Gilbane Construction Schedule 2 (Data from: Oct. 20, 2007)

Appendix C – List of Sub/Trade Contractors

Table 4 – List of Sub/Trade Contractors *

Code	*Name*	*City*	*Division*	*Percentage of Total Cost***
03B	Blakeslee Prestress Inc.	Branford	Precast	39.70%
03A	J L Marshall & Sons, Inc.	Seekonk	Concrete	7.60%
16A	Ostrow Electric Co.	Worcester	Electrical	6.70%
02A	The Dow Co., Inc.	Dracut	Site Construction	5.20%
05A	Berlin Steel Co.	Oxford	Metals	4.50%
04A	Commercial Masonry Corp.	Plymouth	Masonry	4.40%
08A	Ipswich Bay Glass Co., Inc.	Rowley	Glazing	3.20%
15A	William F. Lynch Co.	Worcester	Plumbing	3.00%
07A	PJ Spillane Co.	Everett	Water Protection	2.70%
14A	Schindler Elevator Corp.	West Springfield	Elevator	1.30%
15B	Royal Steam & Heater Co.	Gardner	HVAC	1.10%
15C	Carlysle Engineering Inc.	Boston	Fire Protection	0.60%
09C	John W Egan Co., Inc.	West Newton	Painting	0.60%
-	Commercial Door & Hardware	-	-	0.20%
09B	K&K Acoustical Ceilings, Inc.	Tewksbury	Ceiling	0.10%

*Percentages do not include design costs.
**Percentages correspond to approximately 81% of cost, and do not include percentages for Gilbane Building Co. and General Trades.

Appendix D – Total Labor Hours & Crew Composition

Table 5 - Labor Hours & Crews

Contractor	*Total Labor Hrs**	*Crew Composition*
Berlin Steel Co.	856 hrs	Iron Workers
Blakeslee Prestress Inc.	7,564 hrs	Equipment Operator Iron Workers Laborer Mason
Carlysle Engineering, Inc.	216 hrs	Sprinkler Fitter
Century Drywall, Inc.	392 hrs	Carpenter Laborer
Commercial Masonry Corp.	1,544 hrs	Equipment Operator Laborer Mason
Francis Harvey & Sons, Inc.	594 hrs	Carpenter Laborer
J. L. Marshall & Sons, Inc.	8,384 hrs	Carpenter Laborer Iron Workers
John W. Egan Co., Inc.	56 hrs	Painter
Ostrow Electric Co.	3,160 hrs	Electrician
PJ Spillane Co.	208 hrs	Caulker
Royal Steam & Heater Co.	728 hrs	Sheet Metal Workers
Silktown Roofing, Inc.	144 hrs	Roofer
The Dow Company, Inc.	2,240 hrs	Equipment Operator Laborer
William F. Lynch Co.	1,048 hrs	Pipe Fitter

*Labor Hours as of December 3, 2007.

Appendix E – Actual Labor Costs and Percentages

Table 6 – Actual Labor Costs and Percentages per Subcontractor

Name	Division	Percentage of Total Cost*	Total Cost per Sub	Total Labor Hrs**	Crew Composition	Hours per laborer***	Wages ($/hr)	Labor Cost	% Labor Cost per Sub
Blakeslee Prestress Inc.	Precast	39.70%	$6,749,000.00	7,564	Equip. Operator	1891.0	$54.69	$103,418.79	5.65%
					Iron Workers	1891.0	$47.82	$90,427.62	
					Laborer	1891.0	$40.35	$76,301.85	
					Mason	1891.0	$58.74	$111,077.34	
J L Marshall & Sons, Inc.	Concrete	7.60%	$1,292,000.00	8,384	Carpenter	2794.7	$50.47	$141,048.83	29.93%
					Laborer	2794.7	$40.10	$112,066.13	
					Iron Workers	2794.7	$47.82	$133,640.96	
Ostrow Electric Co.	Electrical	6.70%	$1,139,000.00	3,160	Electrician	3160.0	$45.25	$142,990.00	12.55%
The Dow Co., Inc.	Site Construction	5.20%	$884,000.00	2,240	Equip. Operator	1120.0	$54.39	$60,916.80	11.97%
					Laborer	1120.0	$40.10	$44,912.00	
Berlin Steel Co.	Metals	4.50%	$765,000.00	856	Iron Workers	856.0	$47.82	$40,933.92	5.35%
Commercial Masonry Corp.	Masonry	4.40%	$748,000.00	1,544	Equip. Operator	514.7	$54.69	$28,147.12	10.65%
					Laborer	514.7	$40.35	$20,766.80	
					Mason	514.7	$59.79	$30,771.92	
Ipswich Bay Glass Co., Inc.	Glazing	3.20%	$544,000.00					$0.00	0.00%
William F. Lynch Co.	Plumbing	3.00%	$510,000.00	1,048	Pipe Fitter	1048.0	$49.27	$51,634.96	10.12%
PJ Spillane Co.	Water Protection	2.70%	$459,000.00	208	Caulker	208.0	$59.79	$12,436.32	2.71%
Schindler Elevator Corp.	Elevator	1.30%	$221,000.00					$0.00	0.00%
Royal Steam & Heater Co.	HVAC	1.10%	$187,000.00	728	Sheet Metal Workers	728.0	$45.03	$32,781.84	17.53%
Carlysle Engineering Inc.	Fire Protection	0.60%	$102,000.00	216	Sprinkler Fitter	216.0	$46.53	$10,050.48	9.85%
John W Egan Co., Inc.	Painting	0.60%	$102,000.00	56	Painter	56.0	$45.76	$2,562.56	2.51%
Commercial Door & Hardware	-	0.20%	$34,000.00					$0.00	0.00%
K&K Acoustical Ceilings, Inc.	Ceiling	0.10%	$17,000.00					$0.00	0.00%
Silktown Roofing, Inc.	Roofing	-		144	Roofer	144.0	$46.88	$6,750.72	-
Francis Harvey & Sons, Inc.	-	-		594	Carpenter	297.0	$50.47	$14,989.59	-
					Laborer	297.0	$40.10	$11,909.70	
Century Drywall, Inc.	-	-		392	Carpenter	196.0	$50.47	$9,892.12	-
					Laborer	196.0	$40.10	$7,859.60	
TOTAL		80.90%	$13,753,000.00	27134		27134		$1,298,285.97	

Total Cost of Construction = $17,000,000.00

*Percentages correspond to approximately 81% of cost, and do not include percentages for Gilbane Building Co. and General Trades.

**Labor Hours as of December 3, 2007.

***Assume equal amount of hrs per laborer in each crew

Appendix F – Cost Estimate Calculations

						Concrete									
	Crew	Daily Output	labour hrs	unit	material	labor	equipment	total	total o & P	Total Area	Total Days	Total Hours	Total Tons	Total Cost	**Total Union Cost**
Slab on grade	C -14F	3184	0.023	SF	2.75	0.76	0.01	3.52	4.16	26433.25	8.301900126	607.96475		2529.1334	**$1.8mil**
Reinforcement Bars	4 Rodmen	2.3	13.913	Ton	850	575		1425	1875		34.7826087	1113.04	80	2086950	
Welded wire														0	
6x6 w4xw4 58lb/csf	2 rodmen	27	0.593	CSF	28	24.5		52.5	70.5	264.3325	9.790092593	156.7491725		8229.3316	
Forms														2097708.5	
Foundations	C-2	160	0.3	CFCA	2.59	10.7		13.29	19.55						
Footings	C-1	375	0.085	SFCA	2.64	2.96		5.6	7.5						
Slab on Grade	C-1	510	0.063	LF	0.87	2.18		3.05	4.35	755	1.480392157	47.565			

Reinforcement Bar Calculations

	Spaces	Length of slab	Total Length	Weight per LF	Total Lgth Long + Short	Total LBS	**Total Tons**
Long Bar	200	227	45400	2.67	59800	159666	**79.833**
Short Bar	120	120	14400	2.67			

					Masonry								
	Crew	Daily Output	labour hrs	unit	material	labor	equipment	total	total o & P	Total Area	Total Days	Hours	**Total Cost**
Concrete Block, Column, 8"x16", 4" thick	D-8	460	0.087	SF	1.29	2.98		4.27	5.95	1170	2.543478261	101.79	605.6505
Concrete Block, Decorative, 8"x16", 4"thick, Ground Face	D-8	345	0.116	SF	3.82	3.98		7.8	10.25	9190	26.63768116	1066.04	10926.91
													11532.5605

	Crew	Daily Output	labour hrs	unit	material	labor	equipment	total	total o & P	Total Area (or length, etc)	Total Days	Total Hours	Total Cost
						Site Construction							
	Crew	Daily Output	labour hrs	unit	material	labor	equipment	total	total o & P	Total Area (or length, etc)	Total Days	Total Hours	**Total Cost**
Excavation & Fill 4'-6', 3/4 CY Excavator	B-12F	300	0.53	BCY		1.83	1.72	3.55	4.68	4403	14.67666667	2333.59	10921.2012
Demo of Pavement/Curb 4-6" thick	B-38	640	0.063	SY		2.04	1.41	3.45	4.69	1000	1.5625	63	295.47
Wells 10'-20' deep w/2' diameter	B-6	165	0.145	VLF	39	4.57	1.47	45.04	51.5	2	0.012121212	0.29	14.935
Wellpoints pump operation 4@6 hr sh	4 Eqlt	1.27	25.197	Day		930		930	1400	10	7.874015748	251.97	352758
Structural Excavation 6'-12' deep,	1 Clab	5	1.6	BCY		46		46	71.5	720	144	1152	82368
Hay bales, staked	A-2	2500	0.01	LF	6.05	0.28	0.06	6.39	7.15	720	0.288	7.2	51.48
Water Supply, Ductile Iron Pipe 6" diar	B-21A	160	0.25	LF	16.45	9	3.6	29.05	36	10560	66	2640	95040
												0	0
Plant-mix asphalt paving 3" thick	B-25	4905	0.18	SY	7.85	0.57	0.46	8.88	10	2400	0.489296636	432	4320
Sanitary Utility Sewage Piping 10" dian	B-21	330	0.085	LF	14.3	2.85	0.5	17.65	20.5	1000	3.03030303	85	1742.5
Sewage/Drainage pipe collection, cond	B-14	216	0.222	LF	5.9	6.75	1.13	13.78	18.15	1000	4.62962963	222	4029.3
													551540.886
Excavation Calculations	Length in ft		**Perimeter of construction site**	(220+10)*2									
Southern Boundary	280			(120+10)*2									
Western Boundary	90			**720**									
Northwestern Boundary	200												
North Central Cutout (south direction)	20		**Water Supply**										
North Central Cutout (NE direction)	27		Length of building	220									
Northeastern Boundary	130		Width of building	120									
Eastern Boundary	100		Number of pipelines	12									
28,175			number of floors	4									
8575			Total Pipe Length Needed	10560									
2875													
39,625	SF												
4403	SY												
Sanitary Utility/Sewage+Drainage													
Assume 1000'													

Appendix G – Capstone Design Experience Proposal

To fulfill the Capstone Design Experience we are proposing an alternative design for the parking structure. Our main objective was to propose an alternative design, mainly focusing on using a substitute for the precast structure that was originally designed, as well as using a different type of circulation system. The original design called for a half-helix separate from the main body of the building, this was used because of owner originally preferred not to have sloped floors. In our design we chose to use a single threaded helix system with two-way traffic (**Figure 18**), since we believed that although it may not be the most aesthetically appealing parking structure, it will increase capacity and decrease the cost of the structure.

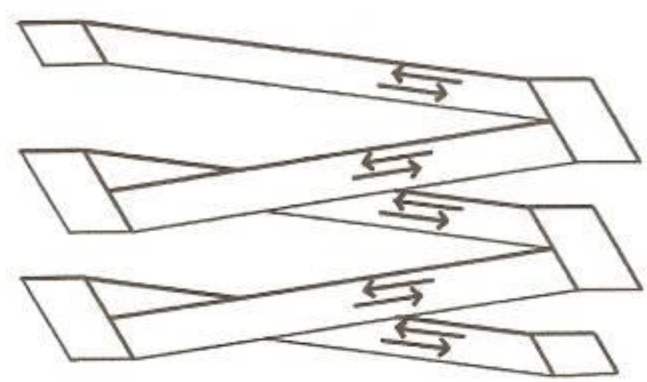


Figure 18 - Single Threaded Helix (Two-way traffic) (National Parking Association, 2000)

The first step was to go over the drawings of the actual design that is being constructed, and observe what changes could be made and how to better use the space provided by the site. In addition, to complete the design of the alternative it was necessary to understand the different design requirements for a parking structure. These include: size of parking spaces, maximum grades for ramps, clearance requirements, as well as complying with the Americans with Disability Act (ADA) requirements. By studying the provided design in addition to code requirements it was possible to develop a general layout for the parking structure **(Appendix H).**

After developing a general layout, the type of structural frame is to be determined. A steel frame has been decided on opposed to a concrete structure. Subsequently, preliminary structural drawings will be developed to determine the placement of columns, beams, and bays. We will be using the Load and Resistance Factor Design (LRFD) method for the design and analysis of the steel structure. First it will be necessary to determine the gravity loads that will be acting on the structure. Dead loads will be determined as the design progresses, while the original specifications and plans called for the following live loads:

Floor Live Loads:

- Garage – 50 psf
- Stairs – 100 psf

Roof Live Load

- Snow – 35 psf (Zone 3)

The floor system will consist of a cast-in-place post-tension concrete floor or of precast double tees. Following the LRFD method, we will continue the design of the structure by continuing the path the gravity loads as they are carried down into the foundations. (Maximum soil bearing capacity 4.0 kips psf). After the floor system the beams and girders will be designed. Next the column sizes will be determined, and finally we will ensure that the design of the original foundations will have the capacity to hold the new designed structure. After the general design is completed, a structural analysis of the design will be performed, mainly by determining any lateral loads the building might be subjected to. Some of the loads have been provided in the original specifications and drawings. These include the following:

Basic Wind Speed – 80mph Zone 2

Wind Exposure Category B

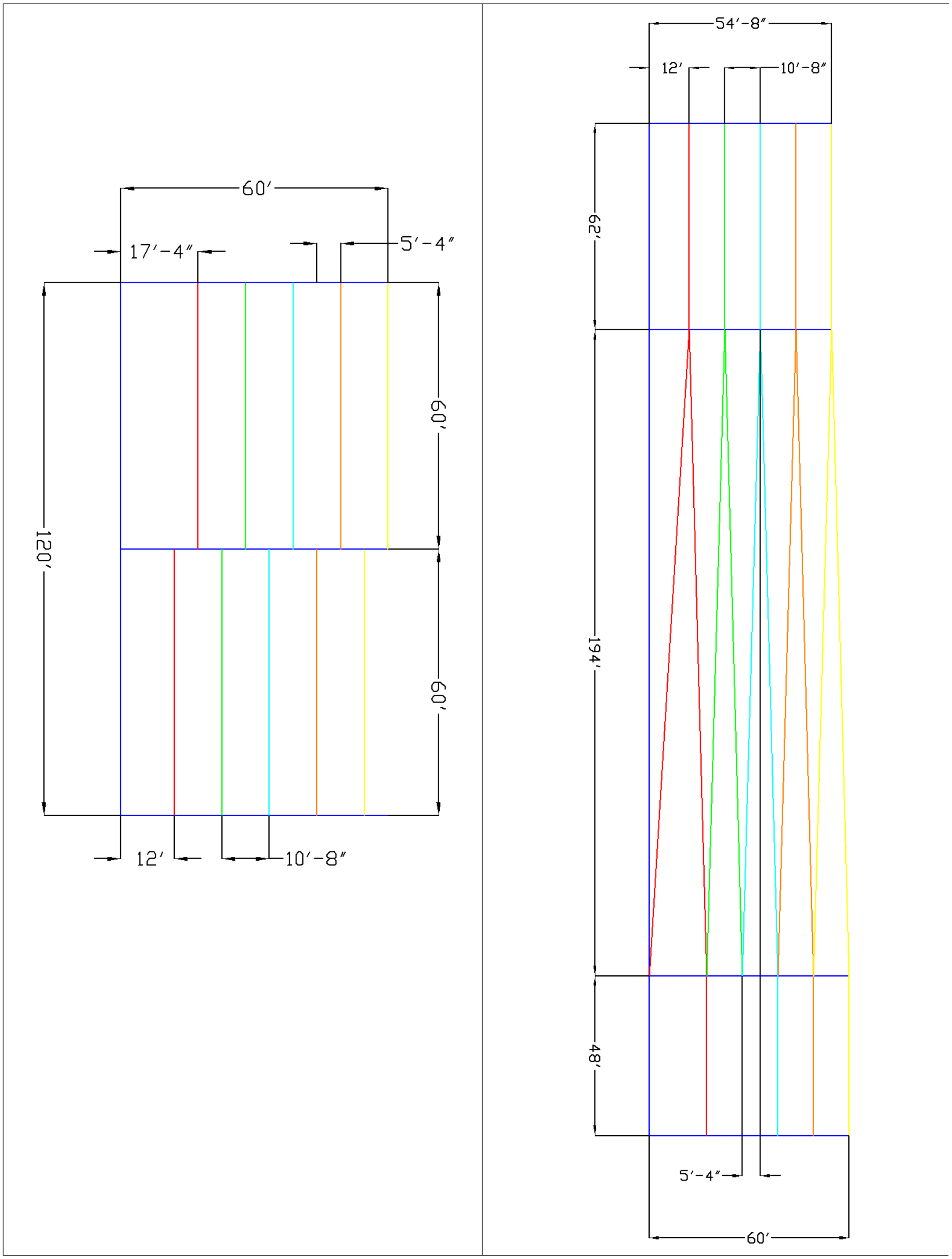
Wind Design Pressure Pv= 17.0psf

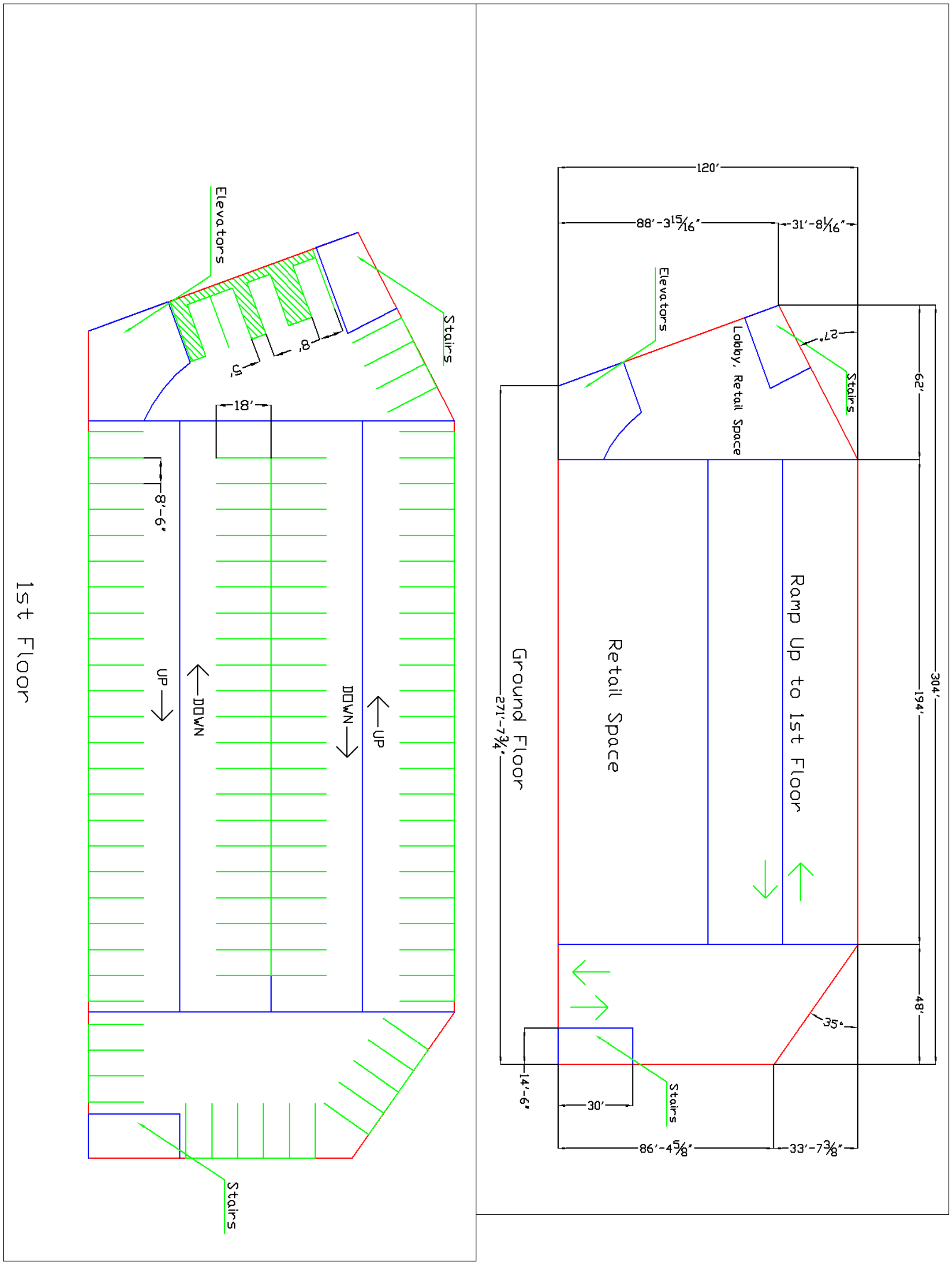
Earthquake Loads

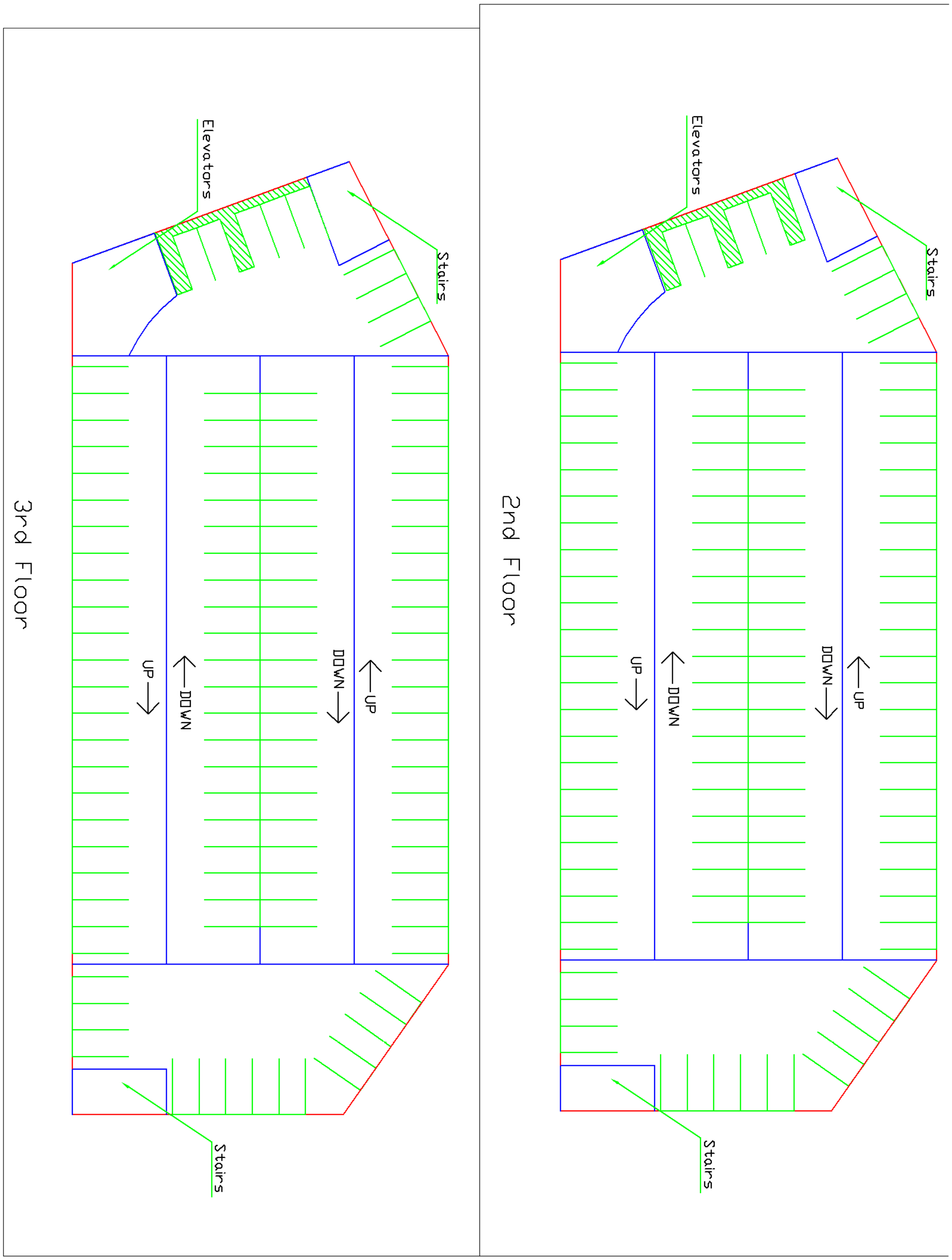
- Peak Velocity related acceleration Av=0.12
- Peak Acceleration Aa=0.12
- Seismic Hazard Exposure Group I
- Seismic Performance Category C
- Soil profile type S=1.0

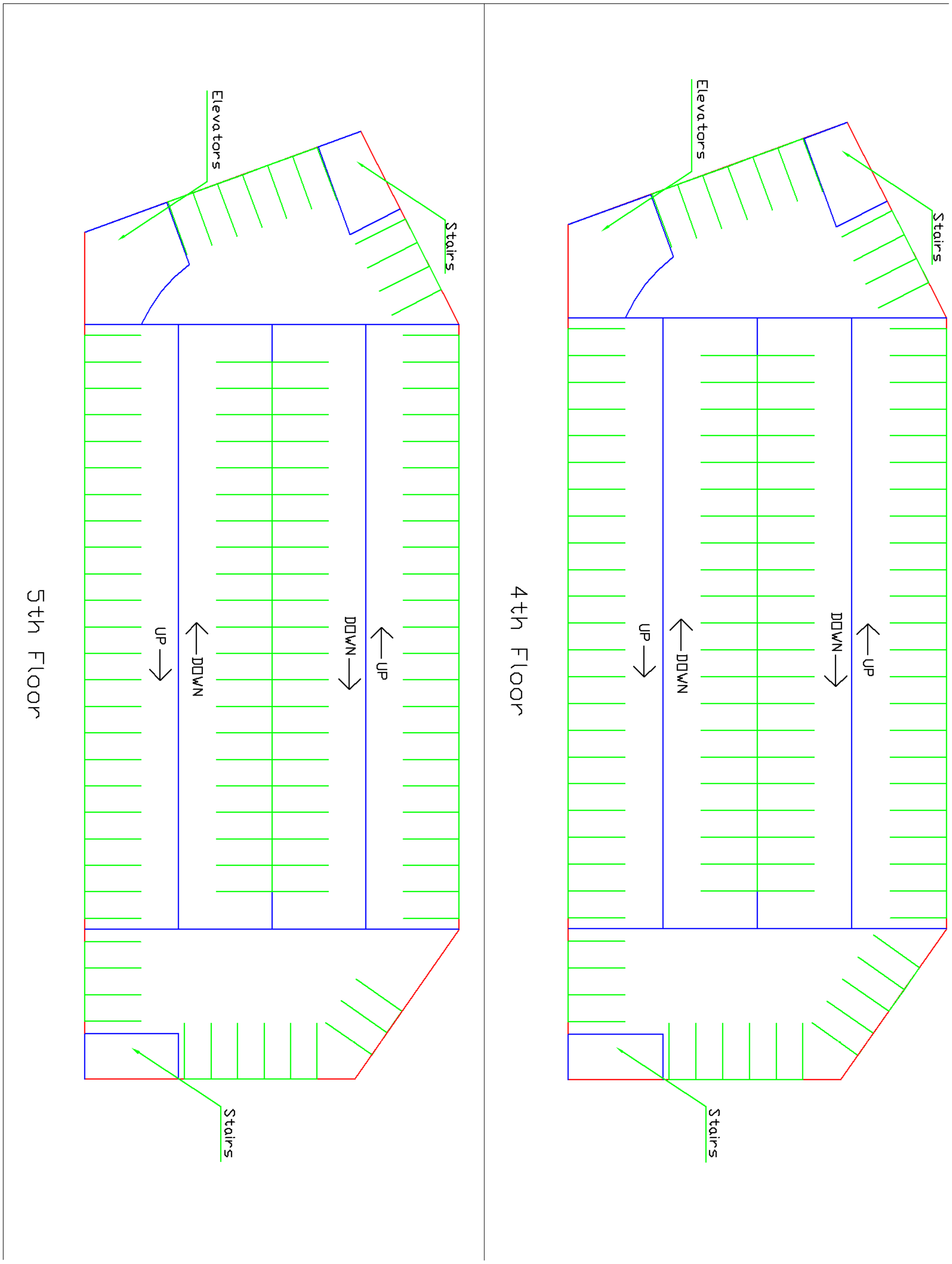
Building codes will be used throughout the analysis to ensure that the design is accurate and up to code (Massachusetts State Building Code, AISC Steel Construction Manual, ACI Building Code).

Appendix H – Layout Design Drawings




1st Floor
Elevators
Stairs
8'
5'
18'
8'-6"
UP
DOWN
DOWN
UP
Stairs
Ground Floor
120'
88'-3 15/16"
31'-8 1/16"
Elevators
Lobby, Retail Space
27°
Stairs
62'
304'
194'
Retail Space
Ramp Up to 1st Floor
271'-7 3/4"
48'
35°
14'-6"
30'
Stairs
86'-4 5/8"
33'-7 3/8"


3rd Floor
Elevators
Stairs
UP
DOWN
DOWN
UP
Stairs
2nd Floor
Elevators
Stairs
UP
DOWN
DOWN
UP
Stairs


5th Floor
Elevators
Stairs
UP
DOWN
DOWN
UP
Stairs
4th Floor
Elevators
Stairs
UP
DOWN
DOWN
UP
Stairs

Appendix I – Structural Design Calculations

Slabs

Clear span of 12.125'
Service live load of 50 psf.

4000 psi concrete
60,000 psi steel

Estimate slab thickness:

$h = \frac{l}{28} = \frac{12.125 \times 12}{28} = 5.20$ Use trial h of 6"

$w = 150 \times \frac{6}{12} = 75$ psf

Using load factors we determine

$1.2(DL) + 1.6(LL) = 1.2(75) + 1.6(50) = 170$ psf

Design moments at critical section using moment coefficients

$M_u = \frac{wl^2}{10} = \frac{(170\,psf)(12.125)^2}{10} = 2499$ ft·lbs $= 2.49$ ft-kips

$M_u = \frac{wl^2}{11} = \frac{(170\,psf)(12.125)^2}{11} = 2272$ ft·lbs $= 2.27$ ft-kips

Maximum steel ratio permitted by ACI Code

$0.75\rho_b = 0.75 \times 0.85\beta_1 \frac{f'_c}{f_y} \frac{87{,}000}{87{,}000 + f_y}$

$\beta_1 = 0.85$
$f'_c = 4000$
$f_y = 60{,}000$

$= 0.75 \times 0.85^2 \left(\frac{4}{60}\right)\left(\frac{87}{87+60}\right) = 0.0211$

b = 12 in

Minimum required effective depth:

$d^2 = \frac{M_u}{\phi \rho f_y b(1 - 0.59\rho f_y/f'_c)} = \frac{2.49 \times 12}{[(0.9)(0.021)(60)(12)](1 - 0.59(0.021)(\frac{60}{4}))}$

$= \frac{29.88}{11.07895} = 2.70\,in^2$

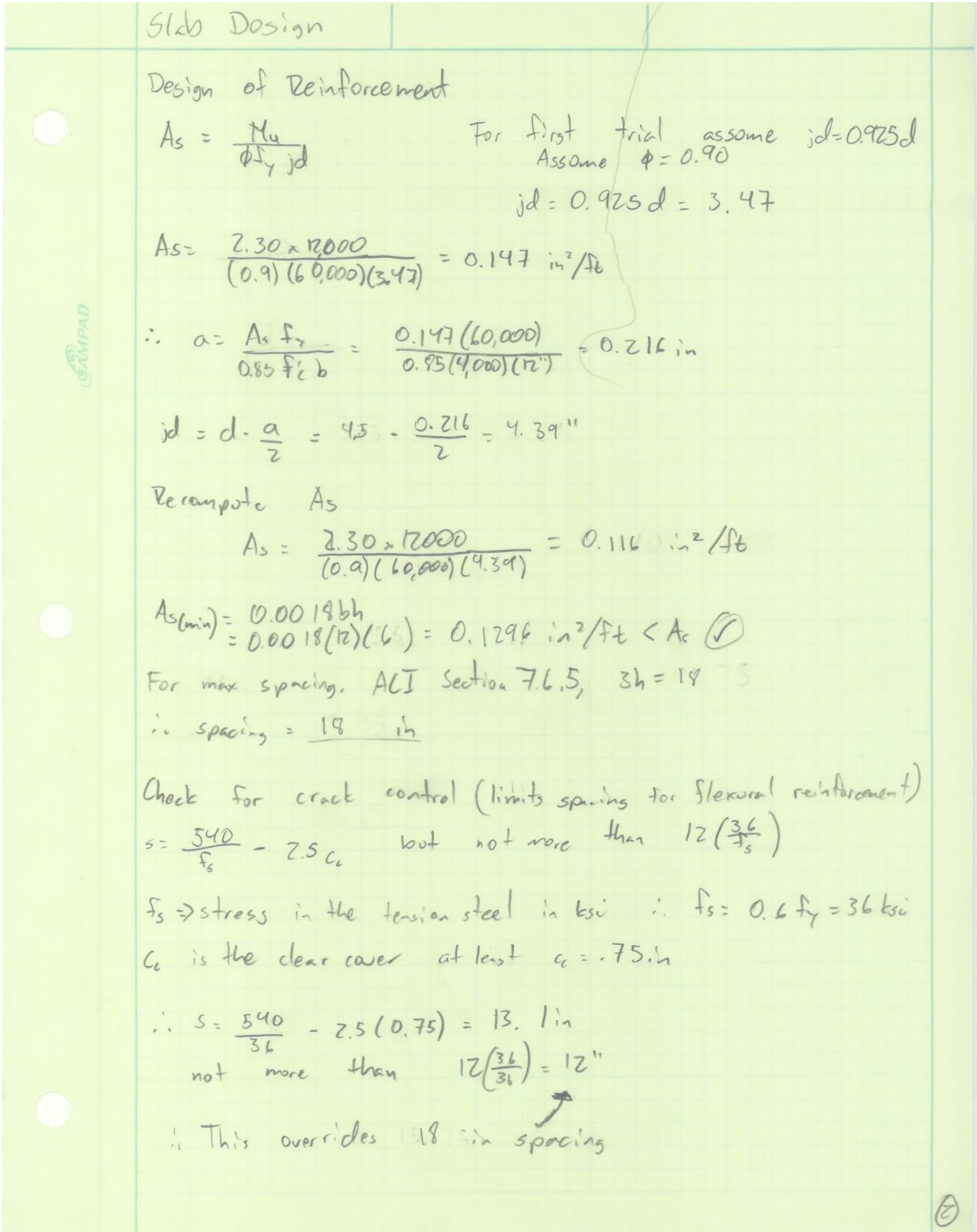
$d = 1.64$ in

Less than the effective depth of 6.0" − 1.5 = 4.5"

∴ use h = 6.00", d = 4.5"

①

Figure 19 - Design Calculations for Slab (1)



Slab Design

Design of Reinforcement

$A_s = \frac{M_u}{\phi f_y \, jd}$ For first trial assume $jd = 0.925d$

Assume $\phi = 0.90$

$jd = 0.925d = 3.47$

$A_s = \frac{2.30 \times 12{,}000}{(0.9)(60{,}000)(3.47)} = 0.147 \text{ in}^2/\text{ft}$

$\therefore a = \frac{A_s f_y}{0.85 f'_c b} = \frac{0.147(60{,}000)}{0.85(4{,}000)(12")} = 0.216 \text{ in}$

$jd = d - \frac{a}{2} = 4.5 - \frac{0.216}{2} = 4.39"$

Recompute A_s

$A_s = \frac{2.30 \times 12000}{(0.9)(60{,}000)(4.39)} = 0.116 \text{ in}^2/\text{ft}$

$A_{s(min)} = 0.0018bh$
$= 0.0018(12)(6) = 0.1296 \text{ in}^2/\text{ft} < A_s$ ✓

For max spacing, ACI Section 7.6.5, $3h = 18$

$\therefore$ spacing = 18 in

Check for crack control (limits spacing for flexural reinforcement)

$s = \frac{540}{f_s} - 2.5c_c$ but not more than $12\left(\frac{36}{f_s}\right)$

$f_s \Rightarrow$ stress in the tension steel in ksi $\therefore f_s = 0.6 f_y = 36$ ksi

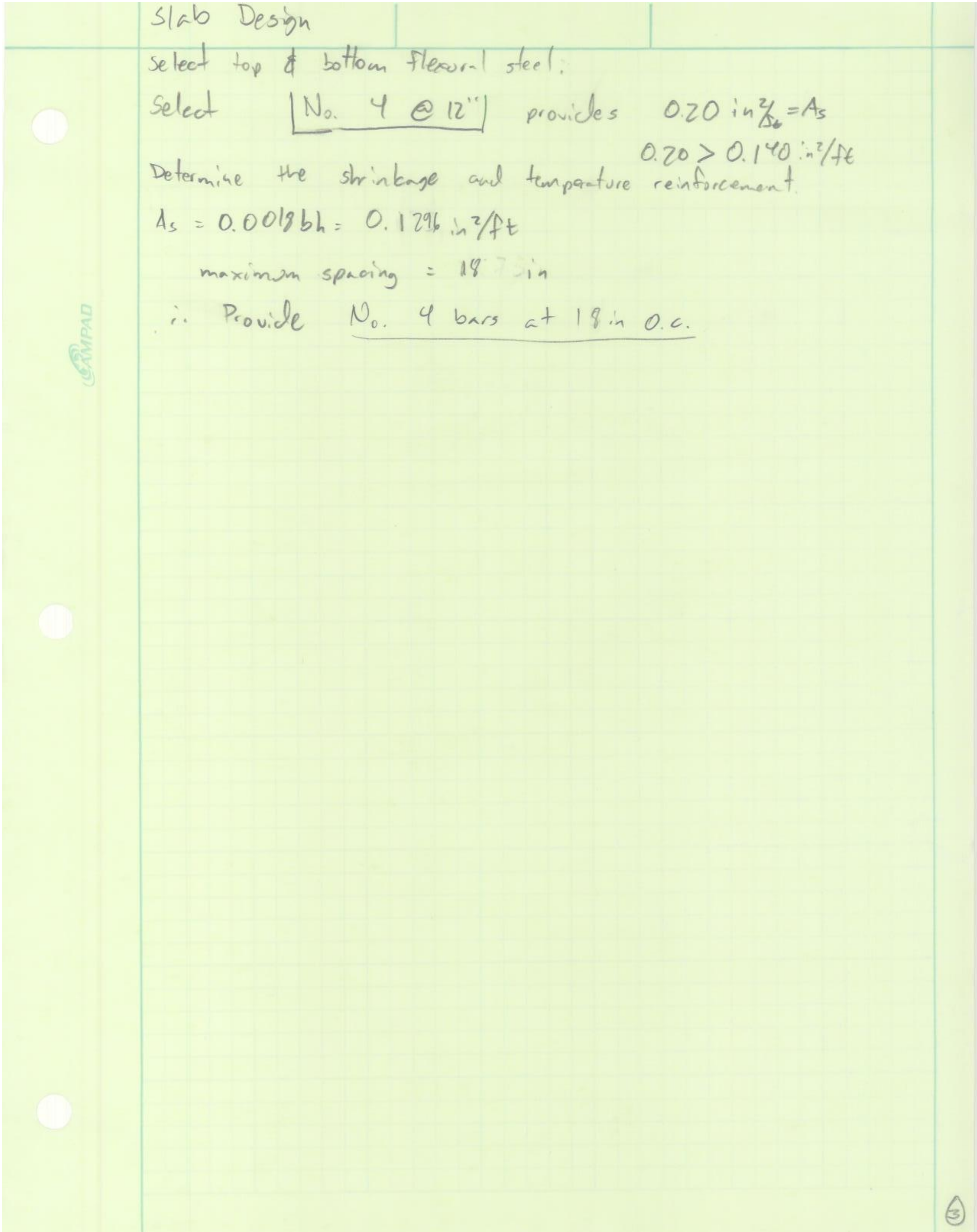
c_c is the clear cover at least $c_c = .75$ in

$\therefore s = \frac{540}{36} - 2.5(0.75) = 13.1$ in

not more than $12\left(\frac{36}{36}\right) = 12"$

$\therefore$ This overrides 18 in spacing

Figure 20 - Design Calculations for Slab (2)



Slab Design

select top & bottom flexural steel:

Select No. 4 @ 12" provides $0.20\ in^2/ft = A_s$

$0.20 > 0.140\ in^2/ft$

Determine the shrinkage and temperature reinforcement.

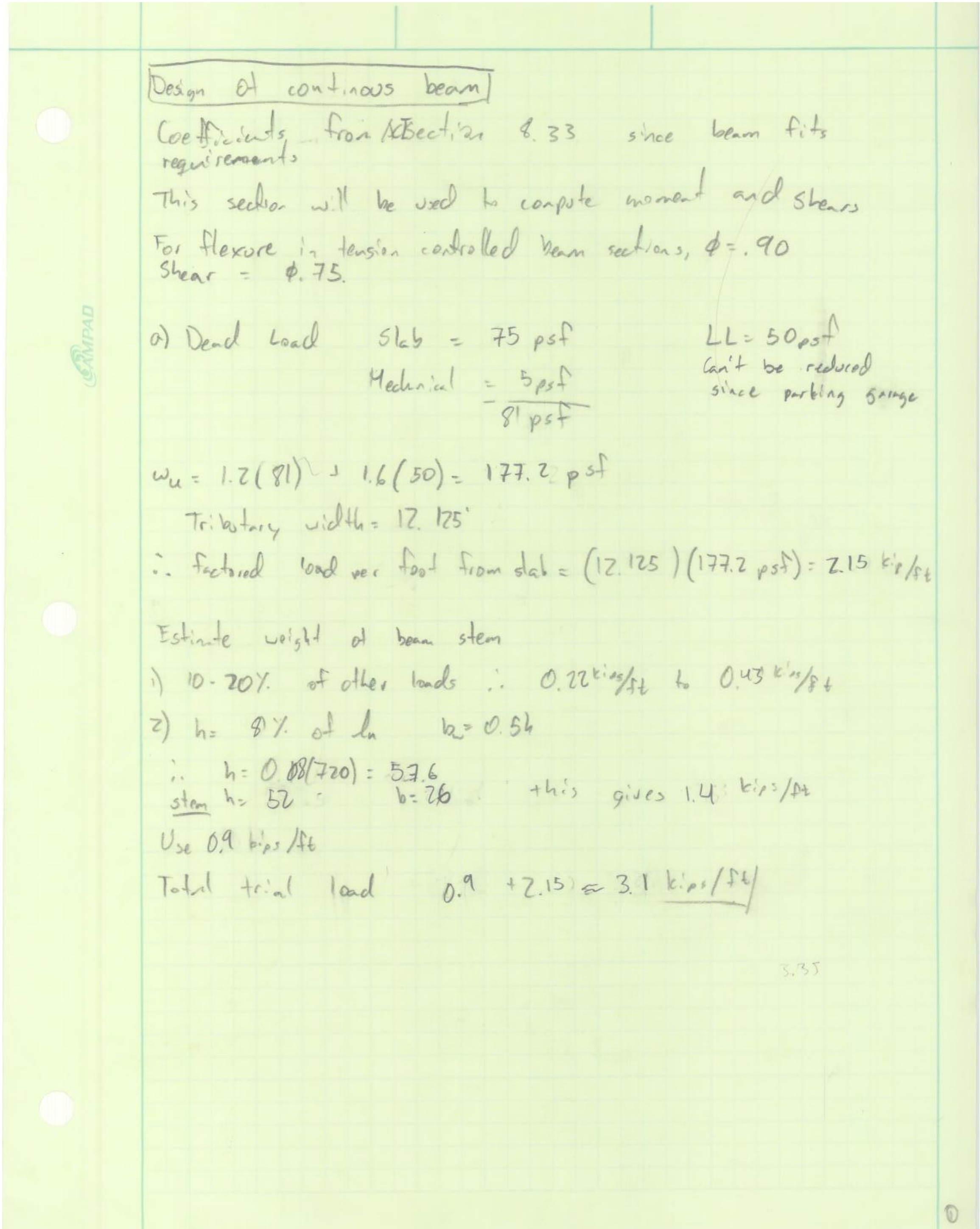
$A_s = 0.0018bh = 0.1296\ in^2/ft$

maximum spacing = 18 in

∴ Provide No. 4 bars at 18 in o.c.

(3)

Figure 21 - Design Calculations for Slab (3)



Design of continuous beam

Coefficients from ACI Section 8.33 since beam fits requirements

This section will be used to compute moment and shears

For flexure in tension controlled beam sections, $\phi = .90$
Shear = ϕ .75

a) Dead Load   Slab = 75 psf
Mechanical = 5 psf
81 psf

LL = 50 psf
Can't be reduced since parking garage

$w_u = 1.2(81) + 1.6(50) = 177.2$ psf

Tributary width = 12.125'

∴ factored load per foot from slab = (12.125)(177.2 psf) = 2.15 kip/ft

Estimate weight of beam stem

1) 10-20% of other loads ∴ 0.22 kips/ft to 0.43 kips/ft

2) h = 8% of l_n b_w = 0.5h

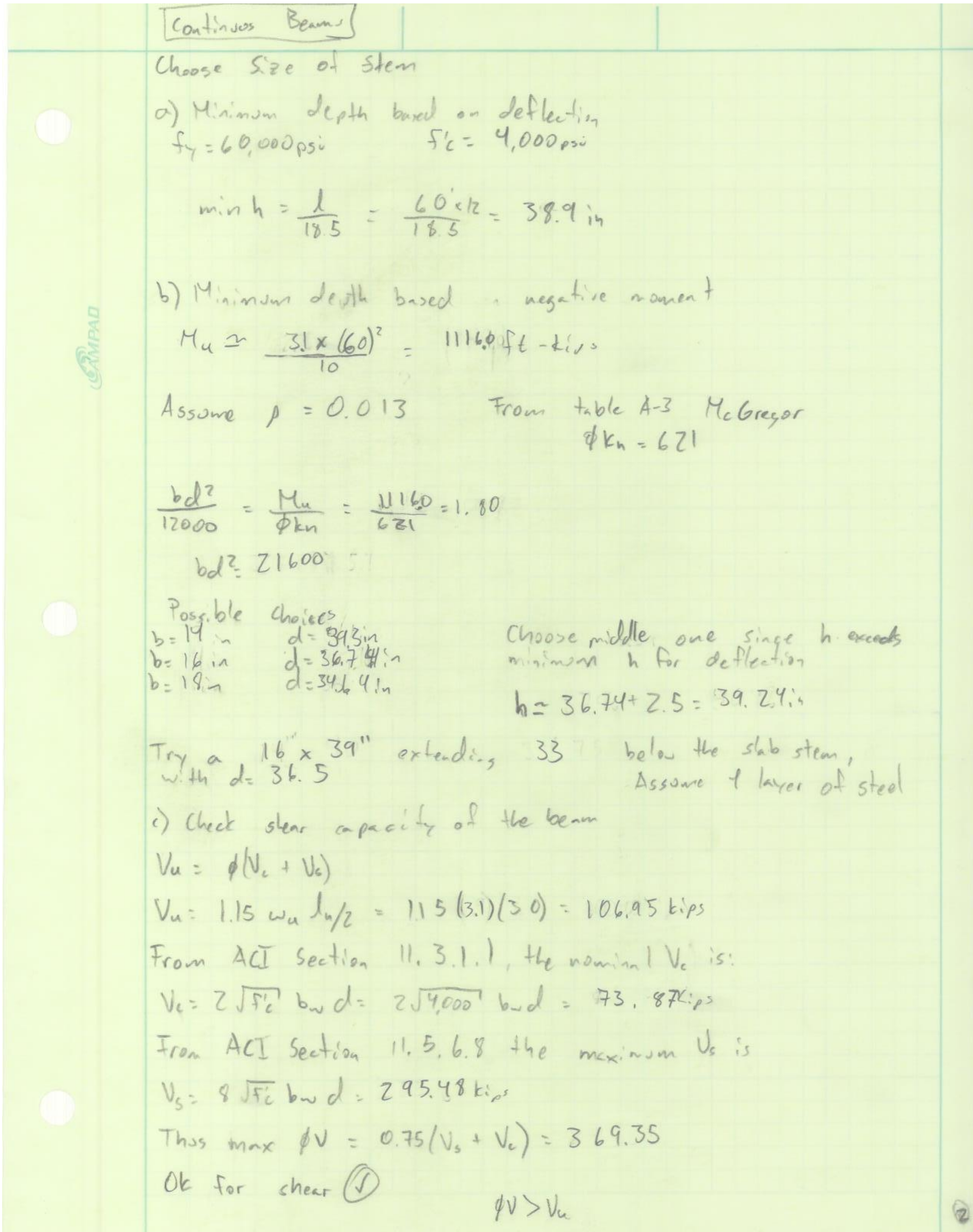
∴ h = 0.08(720) = 57.6
stem h = 52   b = 26   this gives 1.4 kips/ft

Use 0.9 kips/ft

Total trial load   0.9 + 2.15 ≈ 3.1 kips/ft

3.35

Figure 22 - Design Calculations for Beam (1)


Continuous Beam

Choose Size of Stem

a) Minimum depth based on deflection

$f_y = 60{,}000\,psi$ $\quad f'_c = 4{,}000\,psi$

$\min h = \frac{l}{18.5} = \frac{60' \times 12}{18.5} = 38.9\,in$

b) Minimum depth based on negative moment

$M_u \approx \frac{3.1 \times (60)^2}{10} = 1116.0\,ft\text{-}kips$

Assume $\rho = 0.013$ From table A-3 McGregor $\phi k_n = 621$

$\frac{bd^2}{12000} = \frac{M_u}{\phi k_n} = \frac{1116.0}{621} = 1.80$

$bd^2 = 21600$

Possible choices
$b = 14\,in$ $\quad d = 39.3\,in$
$b = 16\,in$ $\quad d = 36.74\,in$
$b = 18\,in$ $\quad d = 34.64\,in$

Choose middle one since h exceeds minimum h for deflection

$h = 36.74 + 2.5 = 39.24\,in$

Try a $16'' \times 39''$ extending 33 below the slab stem, with $d = 36.5$

Assume 1 layer of steel

c) Check shear capacity of the beam

$V_u = \phi(V_c + V_s)$

$V_u = 1.15\, w_u\, l_n/2 = 1.15(3.1)(30) = 106.95\,kips$

From ACI Section 11.3.1.1, the nominal V_c is:

$V_c = 2\sqrt{f'_c}\, b_w d = 2\sqrt{4{,}000}\, b_w d = 73.87\,kips$

From ACI Section 11.5.6.8 the maximum V_s is

$V_s = 8\sqrt{f'_c}\, b_w d = 295.48\,kips$

Thus max $\phi V = 0.75(V_s + V_c) = 369.35$

Ok for shear ✓ $\quad \phi V > V_u$

②

Figure 23 - Design Calculations for Beam (2)

Continuos Beams 3.1

Compute dead load of the stem

$w_D = 0.081\ ksf \times 12.125\ ft + w_{DBeam} = 1.53$

$w_{DBeam} = \frac{16 \times 33.5 \times 12}{1728} \times 0.15 = 0.55$

$w_u = 1.2(1.53) + 1.6(0.05 \times 12.125) = 2.81\ kips/ft$

Calculate the flange width for the positive-moment region (ACI section 8.10.2)

$0.25\, l_n = 0.25(60 \times 12) = 180\ in$

$b_w + 2(8 \times 6) = 112\ in$

$b_w + \frac{12.125 \times 12}{2} + \frac{12.125 \times 12}{2} = 161.5\ in$

The effective flange width is 112 in

- Design of the flexural reinforcement

Computing moments for the beam

(There can be no reduction in live loads since it is a parking garage)

Positive moment

$\frac{w_u l_n^2}{14} = \frac{(2.81)(60^2)}{14} = 722.57\ ft\text{-}kips$

Negative moment

$\frac{w_u l_n^2}{10} = \frac{(2.81)(60^2)}{10} = 1011.6\ ft\text{-}kips$

Compute As for negative moment.

$A_s = \frac{M_u}{\phi f_y j d} \times 12000$ (f_y in psi)

$A_s = \frac{939.6 \times 12000}{0.9 \times 60000(0.875 \times 31.5)} = 7.04\ in^2$

(3)

Figure 24 - Design Calculations for Beam (3)

Continuos Beams

If this much is used

$$a = \frac{7.04 \text{ in}^2 \times 60{,}000 \text{ psi}}{0.85 \times 4000 \times 16} = 7.76$$

$$\frac{a}{d} = \frac{a}{d_t} = \frac{7.76}{36.5} = 0.213$$

since $0.213 < \frac{a_b}{d} = .503$ $\quad f_s = f_y$ at ultimate

since $0.213 < \frac{a_{tcl}}{d_t} = 0.319$ $\quad$ section is tension controlled and $\phi = 0.9$

$$\therefore \quad A_s = \frac{M_u \text{ (ft-kips) } 12000}{0.9 \times 60{,}000(36.5 - \frac{7.76}{2})} = 0.0068\, M_u$$

$\therefore$ $A_{s_{req}}$ for negative flexure $\quad A_s = 0.0068\ (1012)$

$\boxed{A_s = 6.88 \text{ in}^2}$

Compute As for positive moment

assume $j = 0.95$

$$A_s = \frac{722.57 \times 12000}{0.9 \times 60{,}000(0.95 \times 36.5)} = 4.63$$

Assume a is less than h_f then,

$$a = \frac{A_s f_y}{0.85 (f'_c)\, b} = \frac{4.63 \times 60000}{0.85 \times 4000 \times 112} = 0.73 \text{ in} < h_f = 6 \text{ in}$$

$\frac{a}{d} = \frac{a}{d_t} = 0.02 < \frac{a}{d} = 0.503$ $\quad \therefore f_s = f_y$ $\quad$ From Table A-4 McGregor Text

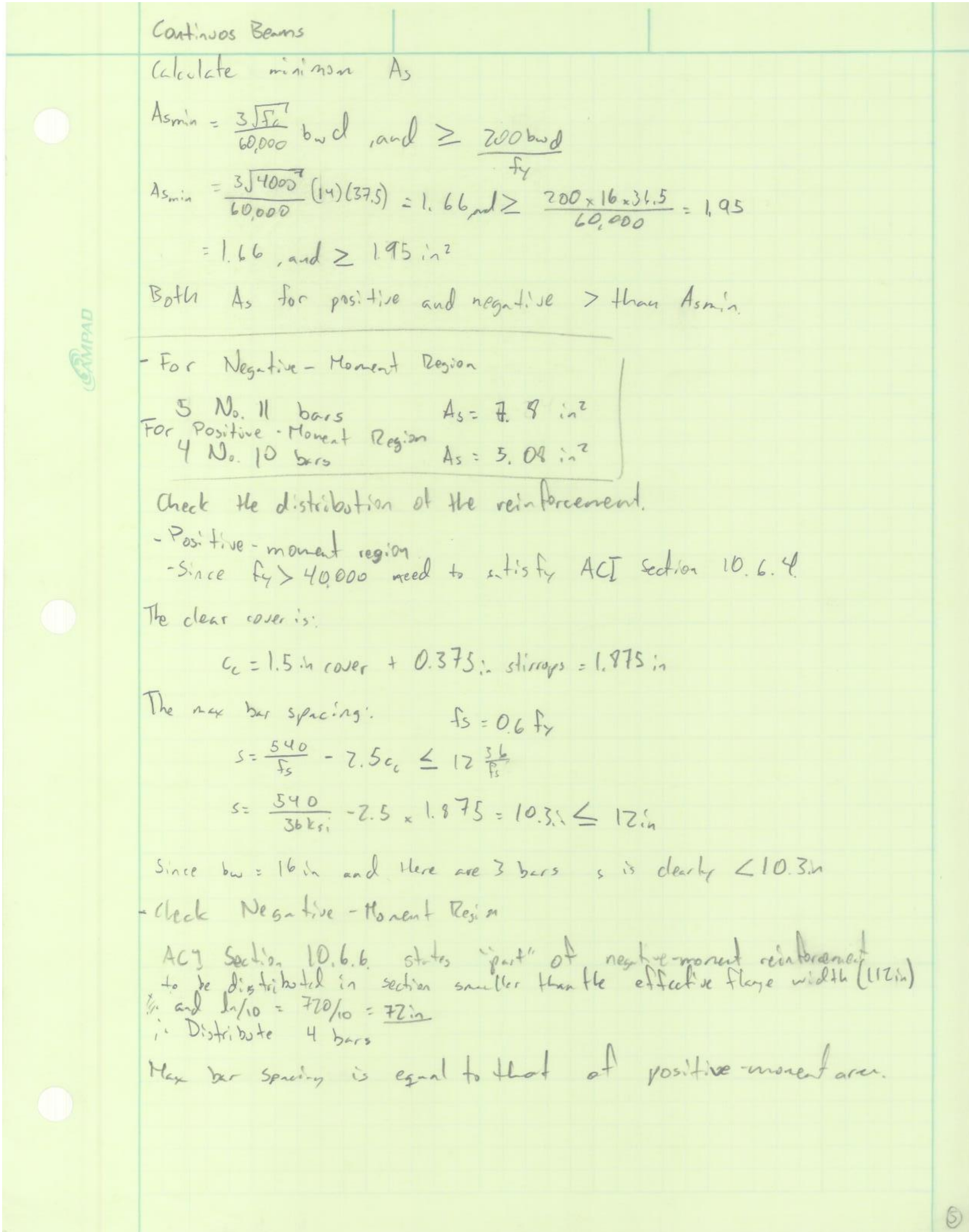
$0.02 < 0.319$ $\quad \therefore$ Tensioned controlled $\Rightarrow \phi = 0.9$

$$A_s = \frac{M_u \times 12{,}000}{0.9 \times 60{,}000 \times (36.5 - 0.73/2)} = 0.00615\, M_u$$

$A_s = 722.57' \,(0.00615) = \boxed{4.44 \text{ in}}$

(4)

Figure 25 - Design Calculations for Beam (4)



Continuous Beams

Calculate minimum A_s

$A_{s,min} = \frac{3\sqrt{f_c'}}{60{,}000} b_w d$, and $\geq \frac{200 b_w d}{f_y}$

$A_{s,min} = \frac{3\sqrt{4000}}{60{,}000}(14)(37.5) = 1.66$, and $\geq \frac{200 \times 16 \times 36.5}{60{,}000} = 1.95$

$= 1.66$, and $\geq 1.95 \text{ in}^2$

Both A_s for positive and negative > than $A_{s,min}$

- For Negative-Moment Region
  5 No. 11 bars $A_s = 7.8 \text{ in}^2$
- For Positive-Moment Region
  4 No. 10 bars $A_s = 5.08 \text{ in}^2$

Check the distribution of the reinforcement.

- Positive-moment region
  - Since $f_y > 40{,}000$ need to satisfy ACI Section 10.6.4

The clear cover is:

$c_c = 1.5 \text{ in cover} + 0.375 \text{ in stirrups} = 1.875 \text{ in}$

The max bar spacing: $f_s = 0.6 f_y$

$s = \frac{540}{f_s} - 2.5 c_c \leq 12 \frac{36}{f_s}$

$s = \frac{540}{36 \text{ ksi}} - 2.5 \times 1.875 = 10.3 \text{ in} \leq 12 \text{ in}$

Since $b_w = 16$ in and there are 3 bars, s is clearly < 10.3 in

- Check Negative-Moment Region

ACI Section 10.6.6 states "part" of negative-moment reinforcement to be distributed in section smaller than the effective flange width (112 in) and $l_n/10 = 720/10 = 72$ in

∴ Distribute 4 bars

Max bar spacing is equal to that of positive-moment area.

(5)

Figure 26 - Design Calculations for Beam (5)

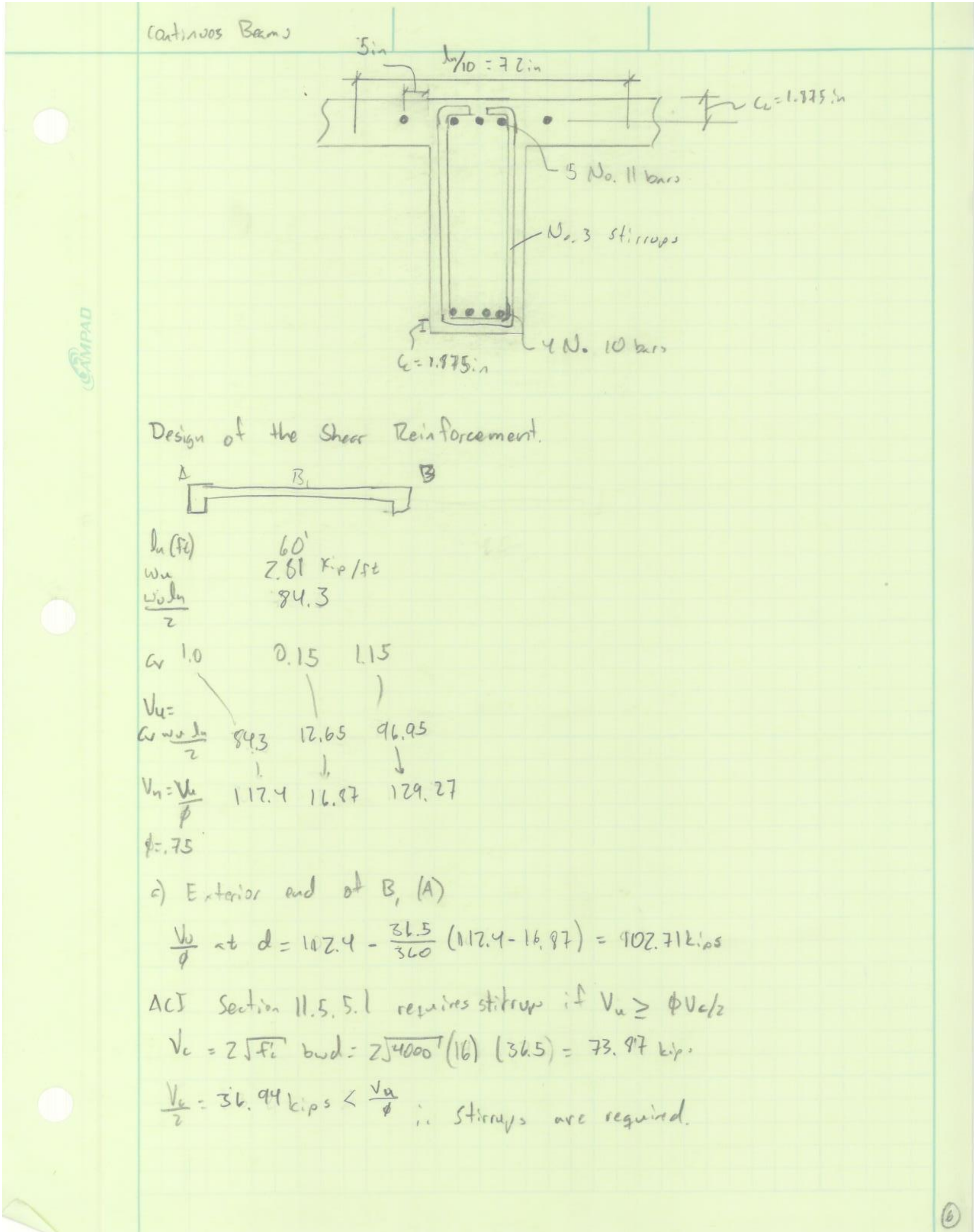
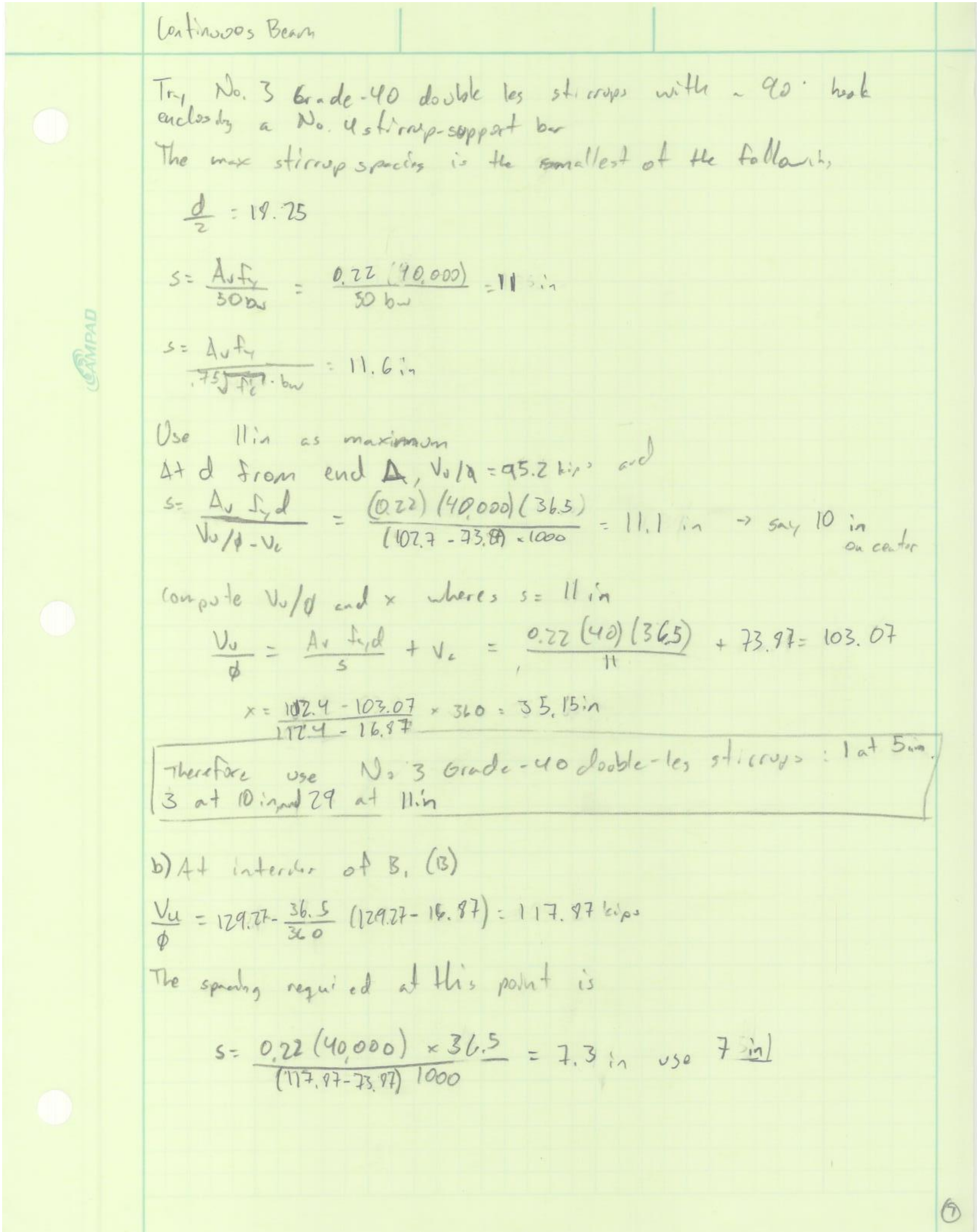


Figure 27 - Design Calculations for Beam (6)



Continuous Beam

Try No. 3 Grade-40 double leg stirrups with a 90° hook enclosing a No. 4 stirrup-support bar

The max stirrup spacing is the smallest of the following

$\frac{d}{2} = 18.25$

$s = \frac{A_v f_y}{50 b_w} = \frac{0.22\,(40{,}000)}{50\, b_w} = 11 \text{ in}$

$s = \frac{A_v f_y}{.75\sqrt{f'_c} \cdot b_w} = 11.6 \text{ in}$

Use 11 in as maximum

At d from end A, $V_u/\phi = 95.2$ kips and

$s = \frac{A_v f_y d}{V_u/\phi - V_c} = \frac{(0.22)(40{,}000)(36.5)}{(102.7 - 73.89) \cdot 1000} = 11.1 \text{ in} \rightarrow$ say 10 in on center

Compute V_u/ϕ and x where s = 11 in

$\frac{V_u}{\phi} = \frac{A_v f_y d}{s} + V_c = \frac{0.22\,(40)(36.5)}{11} + 73.97 = 103.07$

$x = \frac{102.4 - 103.07}{112.4 - 16.87} \times 360 = 35.15 \text{ in}$

Therefore use No. 3 Grade-40 double-leg stirrups: 1 at 5 in, 3 at 10 in and 29 at 11 in

b) At interior of B, (B)

$\frac{V_u}{\phi} = 129.27 - \frac{36.5}{360}(129.27 - 16.87) = 117.87$ kips

The spacing required at this point is

$s = \frac{0.22\,(40{,}000) \times 36.5}{(117.87 - 73.97)\,1000} = 7.3 \text{ in}$ use 7 in

7

Figure 28 - Design Calculations for Beam (7)

Continuous Beam

Change spacing to 9 in and then to 11 in

$\frac{V_u}{\phi}$ where $s = 9$ in

$$\frac{V_u}{\phi} = \frac{0.22 \times 40 \times 36.5}{9} + 73.87 = 109.56$$

$s = 9$ in occurs at

$$x = \frac{129.27 - 109.56}{129.27 - 16.87} \times 360 = 63.1 \text{ in}$$

$$\frac{V_u}{\phi} = \frac{0.22 \times 40 \times 36.5}{11} + 73.87 = 103.07$$

$s = 11$ occurs at

$$x = \frac{129.27 - 103.07}{129.27 - 16.87} \times 360 = 83.91 \text{ in}$$

At the interior end of B, (B) use No. 3 Grade-40 double-leg stirrups: one at 3.5 in, 9 at 7 in, 2 at 9 in, 25 at 11 in

(8)

Figure 29 - Design Calculations for Beam (8)

Design of Girders

Concentrated reactions from beams

$DL = 1.2(60)[(0.081)(12.125) + (0.55)] = 110$ kips

$LL = 1.6(60)(0.05)(12.125) = 58.2$ kips

$T_L = 110$ kips $+ 58.2$ kips $= 168.2$ kips

Assuming 18×38 web uniform loads are:

Uniform $DL = 1.2\left[\frac{18(44)(0.15)}{144}\right] = 0.99$ kips/ft

Uniform $LL = 1.6(0.05)(15) = 0.12$ kips/ft

Total Uniform $= 0.12 + 0.99 = 1.11$ kips/ft

Max positive moment on a simple span

$$M_u = 168.2(12.125) + \frac{1}{8}(1.11)(48.5')^2 = 2039 + 326 =$$

$$M_u = 2365 \text{ ft-kips}$$

The estimated max negative moment in the girder at the exterior face of the first interior support, is

$0.8(2365) = 1892$ ft-kips say 1895 ft-kips

Estimate $d_{neg} = 44 - 5 = 38$ in

$d_{pos} = 44 - 3.5 = 41.5$ in

The neg moment requirement is

$$R_u = \frac{M_u}{\phi b d^2} = \frac{1895(12000)}{0.9(18)(38)^2} = 972 \text{ psi}$$

Max R_u for $\rho = 0.75$ where $\rho_b = 0.0241$

$$m = \frac{f_y}{0.85 f'_c} = 17.65$$

$$R_u = \rho f_y\left(1 - \frac{1}{2}\rho m\right) = 1139$$

therefore. $R_u = 972$ is an acceptable value.

required A_s for $(-M) \approx 0.75\rho_b\left(\frac{972}{1139}\right)bd = (0.75)(0.0241)\left(\frac{972}{1139}\right)(18)(38)$

$A_s = 10.55$ sq in

For $+M$ using ACI - 8.33 coefficients to obtain approx. proportion

estimated $(+M) \approx \frac{10}{14}(-M) = \frac{10}{14}(1895) = 1355$ ft-kips

①

Figure 30 - Design Calculations for Girder (1)

Design of Girders

required $A_s \approx \frac{M_u}{\phi f_y (arm)} = \frac{1355(12)}{0.9(60)(\approx 37)} = 9.14$ sq in

For shear requirement

max $V_u = 1.15(168.2 + 1.11(24.25)) = 224.4$ kips

$v_n = \frac{224{,}000}{0.85(18)(37)} = 385$ psi

Stem could be smaller $\therefore$ use 42 in × 18 in

$d_{neg} = 36$
$d_{pos} = 38.5$

revised girder weight $= 1.2\left[\frac{18 \times 36}{144}\right]0.15 = 0.81$

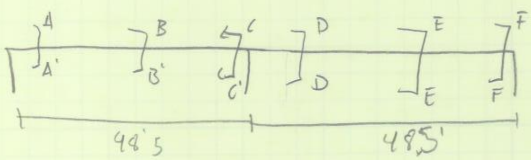
$W_u = W_D + W_L = 0.12 + 0.81 = 0.93$

revised M_u (simple beam) $= 2039 + (\frac{1}{8})(0.93)(48.5)^2 = 2312$ ft-kips

req. $R_u = \frac{0.8(2312)(12{,}000)}{0.9(18)(36^2)} = 1057 < 1139$ psi max OK

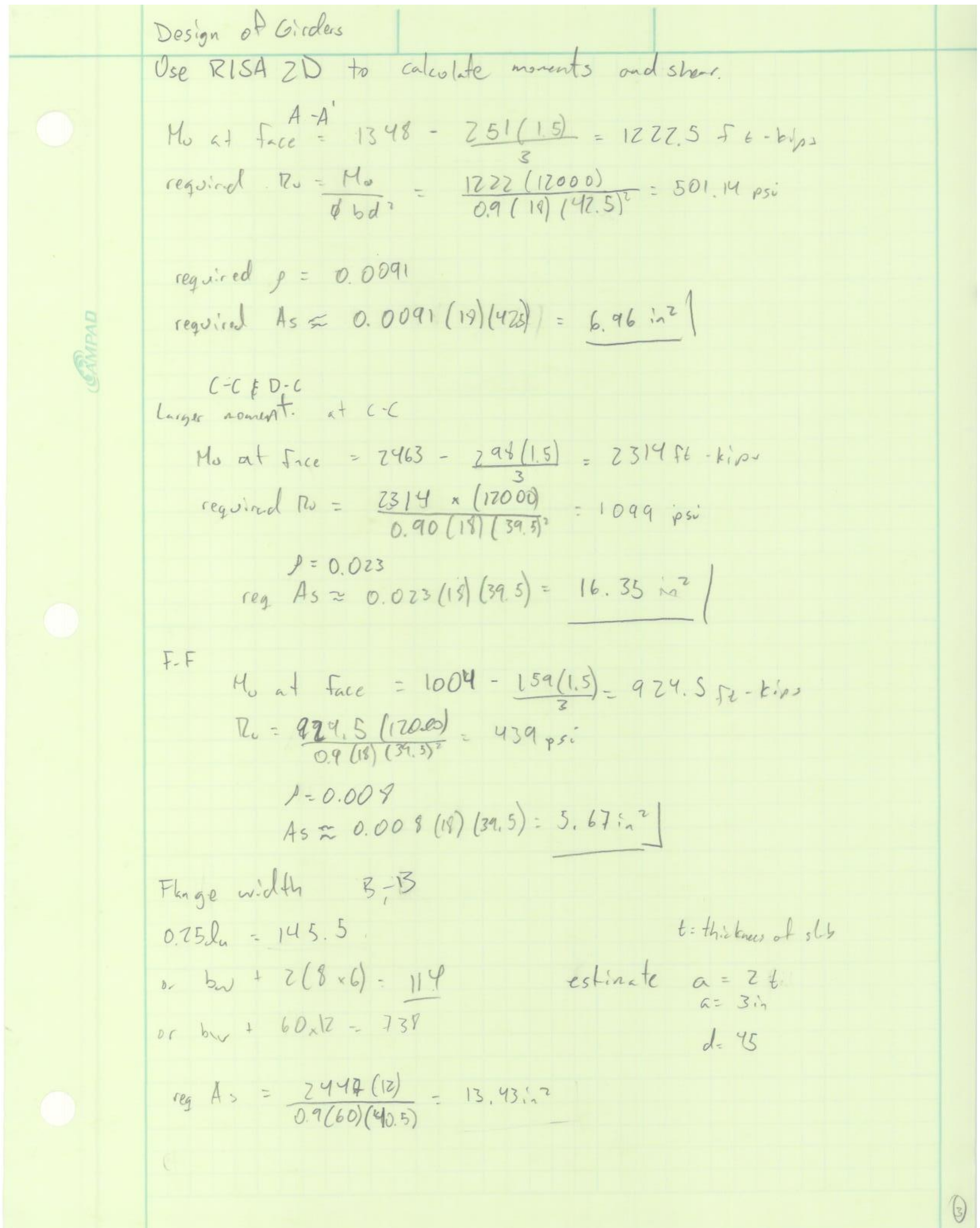
v_n at support $= \frac{219365}{0.85(18)(36)} = 398$ psi

Use 18×42 stem section



②

Figure 31 - Design Calculations for Girder (2)



Design of Girders

Use RISA 2D to calculate moments and shear.

A-A'

M_u at face $= 1348 - \frac{251(1.5)}{3} = 1222.5$ ft-kips

required $R_u = \frac{M_u}{\phi b d^2} = \frac{1222(12000)}{0.9(18)(42.5)^2} = 501.14$ psi

required $\rho = 0.0091$

required $A_s \approx 0.0091(18)(42.5) = 6.96\ in^2$

C-C & D-C

Larger moment at C-C

M_u at face $= 2463 - \frac{298(1.5)}{3} = 2314$ ft-kips

required $R_u = \frac{2314 \times (12000)}{0.90(18)(39.5)^2} = 1099$ psi

$\rho = 0.023$

req $A_s \approx 0.023(18)(39.5) = 16.35\ in^2$

F-F

M_u at face $= 1004 - \frac{159(1.5)}{3} = 924.5$ ft-kips

$R_u = \frac{924.5(12000)}{0.9(18)(39.5)^2} = 439$ psi

$\rho = 0.008$

$A_s \approx 0.008(18)(39.5) = 5.67\ in^2$

Flange width B₁-B

$0.25 l_n = 145.5$

or $b_w + 2(8 \times 6) = 114$

or $b_w + 60 \times 12 = 738$

t: thickness of slab

estimate $a = 2t$

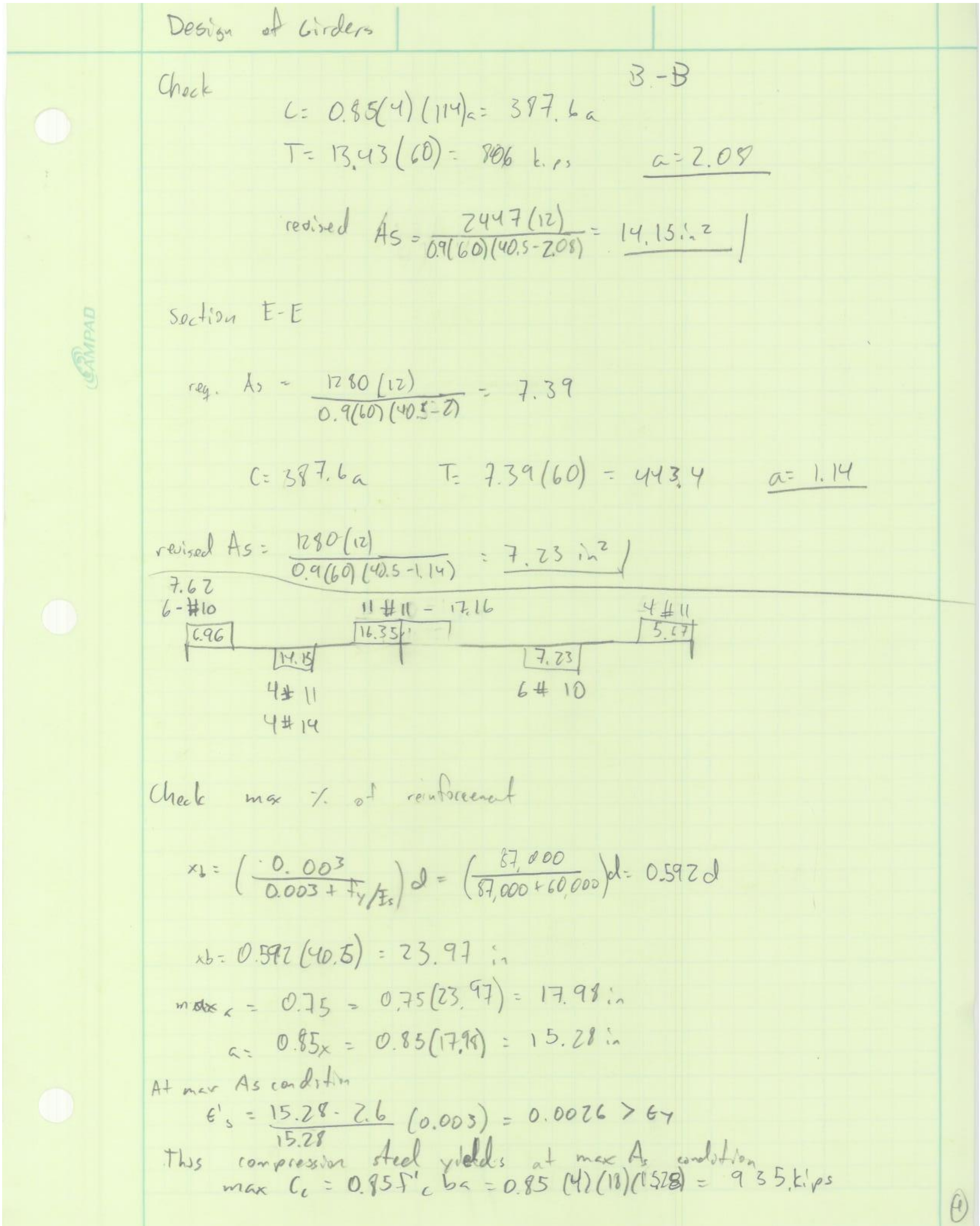
$a = 3$ in

$d = 45$

req $A_s = \frac{2447(12)}{0.9(60)(40.5)} = 13.43\ in^2$

(3)

Figure 32 - Design Calculations for Girder (3)



Design of Girders

Check B-B

$C = 0.85(4)(114)a = 387.6a$

$T = 13.43(60) = 806$ kips $\quad a = 2.08$

revised $A_s = \frac{2447(12)}{0.9(60)(40.5-2.08)} = 14.15 in^2$

Section E-E

req. $A_s = \frac{1280(12)}{0.9(60)(40.5-2)} = 7.39$

$C = 387.6a \quad T = 7.39(60) = 443.4 \quad a = 1.14$

revised $A_s = \frac{1280(12)}{0.9(60)(40.5-1.14)} = 7.23 in^2$

Check max % of reinforcement

$x_b = \left(\frac{0.003}{0.003 + f_y/E_s}\right)d = \left(\frac{87,000}{87,000+60,000}\right)d = 0.592d$

$x_b = 0.592(40.5) = 23.97$ in

$max_x = 0.75 = 0.75(23.97) = 17.98$ in

$a = 0.85x = 0.85(17.98) = 15.28$ in

At max As condition

$\epsilon'_s = \frac{15.28-2.6}{15.28}(0.003) = 0.0026 > \epsilon_y$

This compression steel yields at max A_s condition

$max\ C_c = 0.85f'_c ba = 0.85(4)(18)(15.28) = 935$ kips

Figure 33 - Design Calculations for Girder (4)

Design Column

Design of Column using Ultimate Strength Method - Region II, Compression Controls.

Square tied column about 3% reinf.

Dead Load axial - 449 kips   155.83 bending
Live Load axial - 117 kips   40.6 bending

Determine req'd nominal strength

$$P_n = \frac{P_u}{\phi} = \frac{449 + 117}{0.70} = 809 \text{ kips}$$

$$M_n = \frac{M_u}{\phi} = \frac{156 + 41}{0.7} = 281 \text{ ft-kips}$$

Eccentricity $\quad e = \frac{M_n}{P_n} = \frac{281(12)}{809} = 4.2 \text{ in}$

Determine approximate size if $P_n = 70$ kips equals P_b

$$x_b = \left(\frac{\epsilon_c}{\epsilon_c + \epsilon_y}\right) d = \left(\frac{0.003}{0.003 + 60/29{,}000}\right) d = 0.592d$$

$$P_b = C_c + C_s - T = 0.85 f'_c\, b\, \beta_1 x_b + A'_s f_y \text{ (approx)} - A_s f_y$$

Column is symmetrical $\therefore A'_s = A_s$

$$P_b \approx 0.85 f'_c\, b\, \beta_1\, x_b = 0.85(4.0)b(0.85)(0.592d) = 1.711\, bd$$

For $P_b = 706$ kips

$$\text{balanced } bd \approx \frac{809}{1.711} = 473 \text{ in}^2$$

Assuming $d \approx 0.9h$

$$A_s \text{ (balanced)} = \frac{473}{0.9} = 526 \text{ sq in } (22.9 \text{ in square})$$

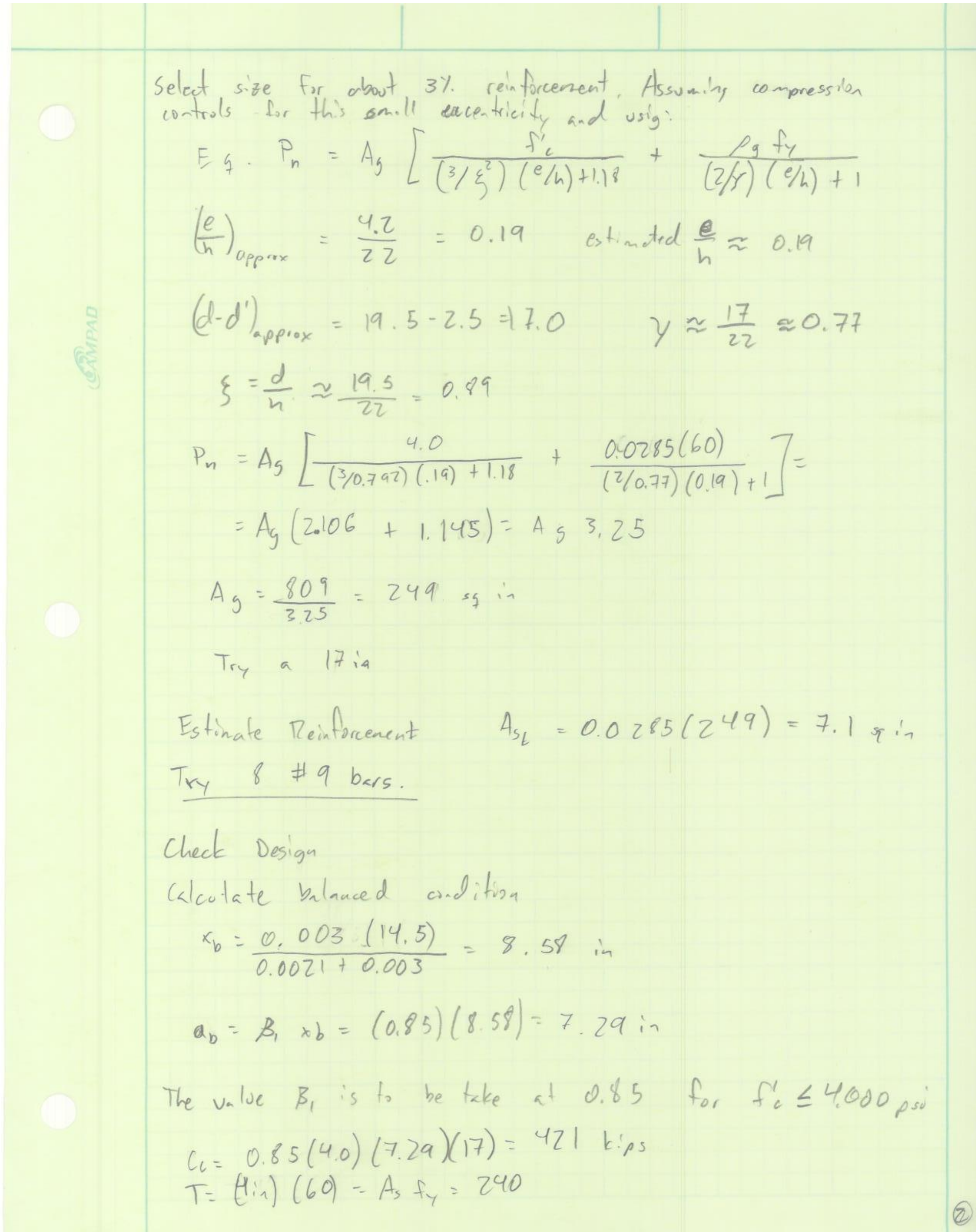
If area less than 526 sq in will be compression controlled.

It is preferred to use smaller size than that of the balance size. This way will be in compression controls.

Assume section of 22 in square

①

Figure 34 - Design Calculations for Column (1)



Select size for about 3% reinforcement. Assuming compression controls for this small eccentricity and using:

$$\text{Eq. } P_n = A_g \left[\frac{f'_c}{(3/\xi^2)(e/h) + 1.18} + \frac{\rho_g f_y}{(2/\gamma)(e/h) + 1} \right]$$

$$\left(\frac{e}{h}\right)_{approx} = \frac{4.2}{22} = 0.19 \quad \text{estimated } \frac{e}{h} \approx 0.19$$

$$(d-d')_{approx} = 19.5 - 2.5 = 17.0 \quad \gamma \approx \frac{17}{22} \approx 0.77$$

$$\xi = \frac{d}{h} \approx \frac{19.5}{22} = 0.89$$

$$P_n = A_g \left[\frac{4.0}{(3/0.792)(.19) + 1.18} + \frac{0.0285(60)}{(2/0.77)(0.19) + 1} \right] =$$

$$= A_g (2.106 + 1.145) = A_g \, 3.25$$

$$A_g = \frac{809}{3.25} = 249 \text{ sq in}$$

Try a 17 in

Estimate Reinforcement $A_{st} = 0.0285(249) = 7.1$ sq in

Try 8 #9 bars.

Check Design

Calculate balanced condition

$$x_b = \frac{0.003(14.5)}{0.0021 + 0.003} = 8.58 \text{ in}$$

$$a_b = \beta_1 x_b = (0.85)(8.58) = 7.29 \text{ in}$$

The value β_1 is to be take at 0.85 for $f'_c \leq 4{,}000$ psi

$$C_c = 0.85(4.0)(7.29)(17) = 421 \text{ kips}$$

$$T = (4 \text{ in})(60) = A_s f_y = 240$$

②

Figure 35 - Design Calculations for Column (2)

$\epsilon_s = 0.003\left(\frac{8.58 - 2.5}{8.58}\right) = 0.00212 > \frac{f_y}{E_s}$ compression steel yields

$C_s = 60(4) - 0.85(4)(4) = 240 - 13.6 = 226.4$ kips

Compute P_b and e_b

$P_b = C_c + C_s - T = 421 + 240 - 226 = \underline{435 \text{ kips}}$

For rotational equilibrium about plastic centroid

$P_b \cdot e_b = [421(14.5 - 3.645) + 226(12 - 2.5) + 240(12 - 2.5)]/12$

$= 381 + 179 + 190 = 750$ ft-kips

$e_b = \frac{750(12)}{435} = \underline{20.7}$

Since $P_n > 435$ kips and $e < 20.7$ in it is verified that compression controls.

The approximate equation gives nominal strength

$P_n = \frac{b h f'_c}{3he/d^2 + 1.18} + \frac{A'_s f_y}{e/(d-d') + 0.5}$

$= \frac{289(4)}{3(17)(4.2)/(14.56)^2 + 1.18} + \frac{4(60)}{4.2/12.12 + 0.5} = 528 + 284$

$= 811$ kips > 809 kips req'd $\underline{OK}$

Use 17-in square column and 8 #9 bars, with 4 bars in each face.

Use #3 ties, 2 ties per set at 17 in spacing

(6)

Figure 36 - Design Calculations for Column (3)

Appendix J – Loading Cases Analyzed in RISA 2D

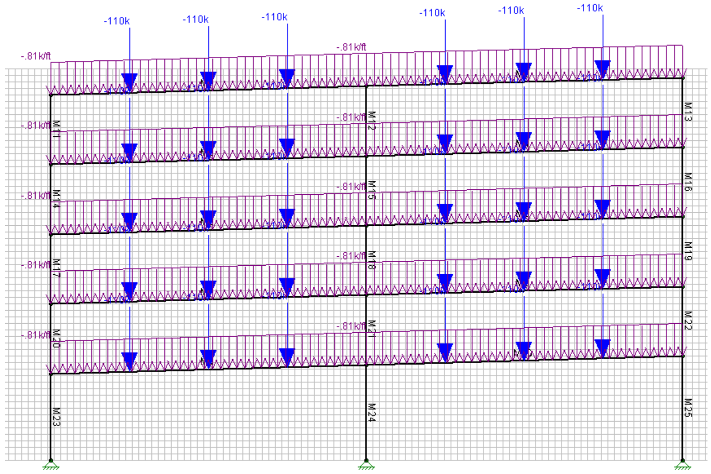


Figure 37 - Loading Case 1 - Dead Loads Only

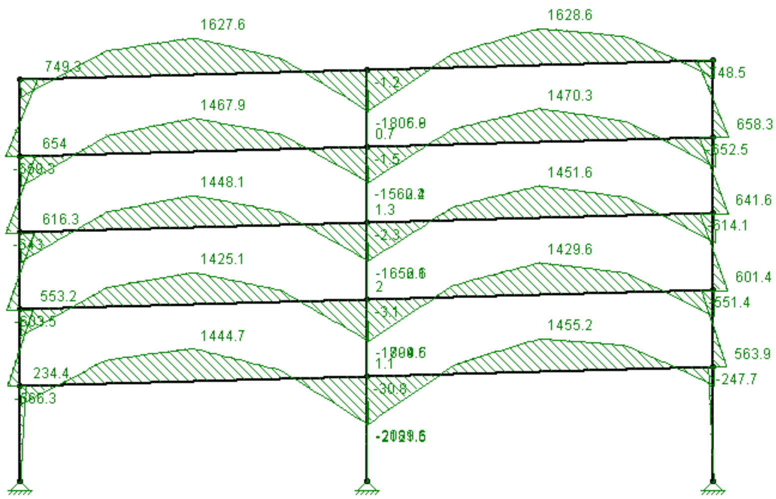


Figure 38 - Loading Case 1 – Moment Forces

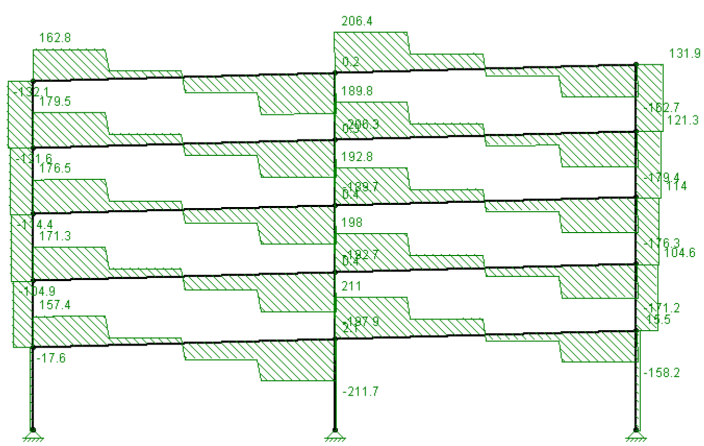


Figure 39 - Loading Case 1 - Shear Forces

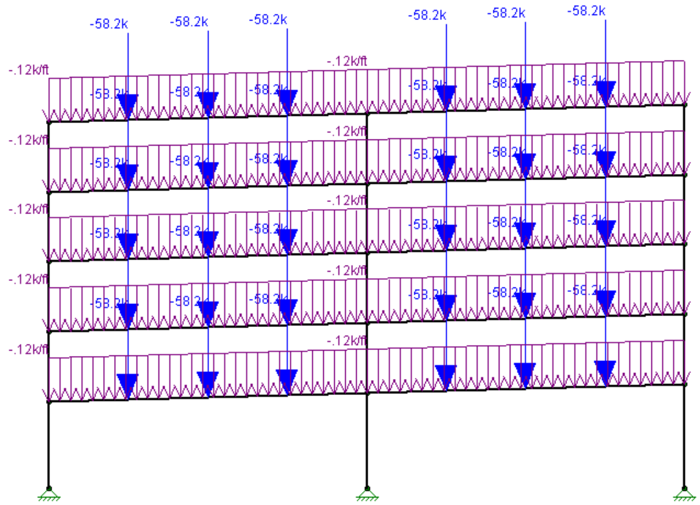


Figure 40 - Loading Case 2 - Live Loads Only

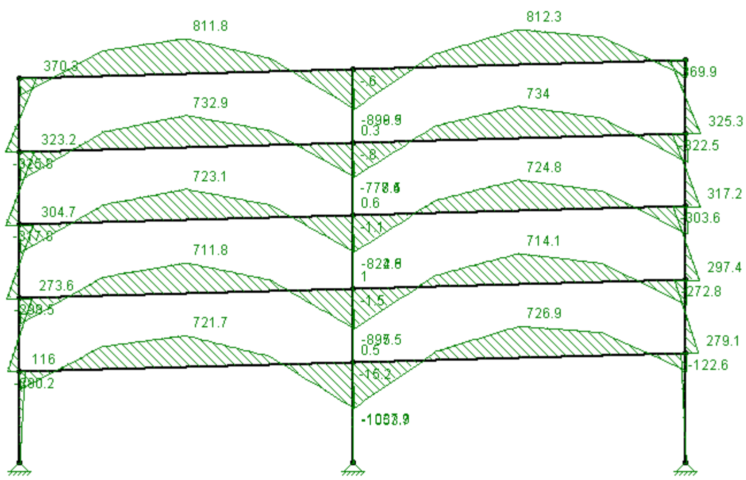


Figure 41 - Loading Case 2 - Moment Forces

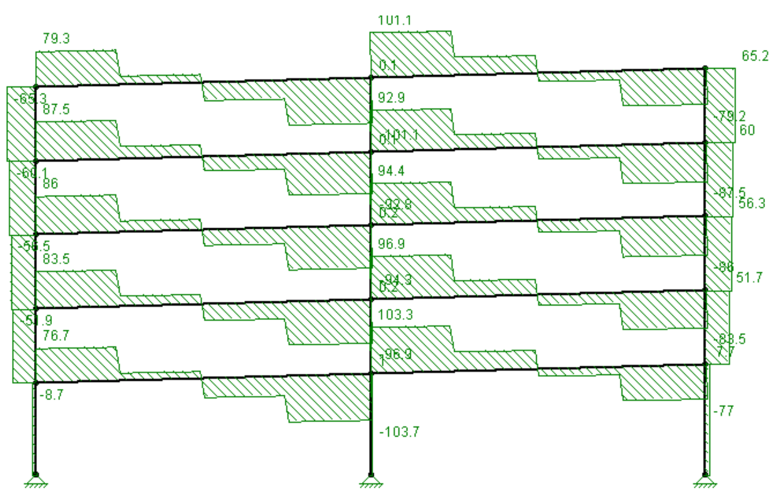


Figure 42 - Loading Case 2 - Shear Forces

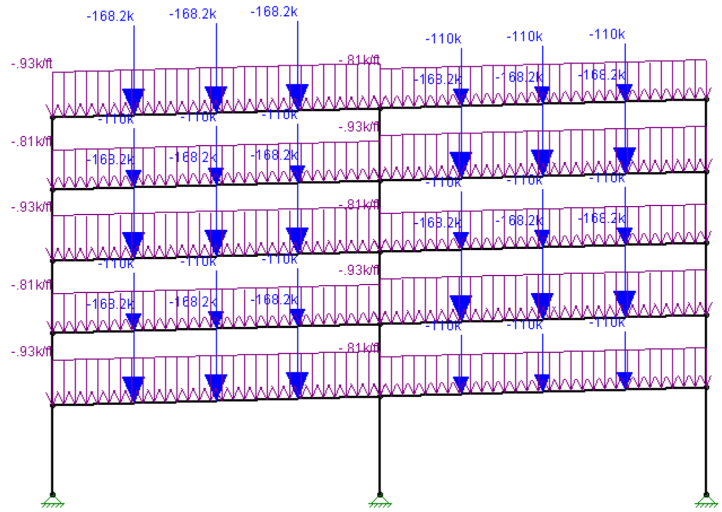


Figure 43 - Loading Case 3 - DL & Partial LL

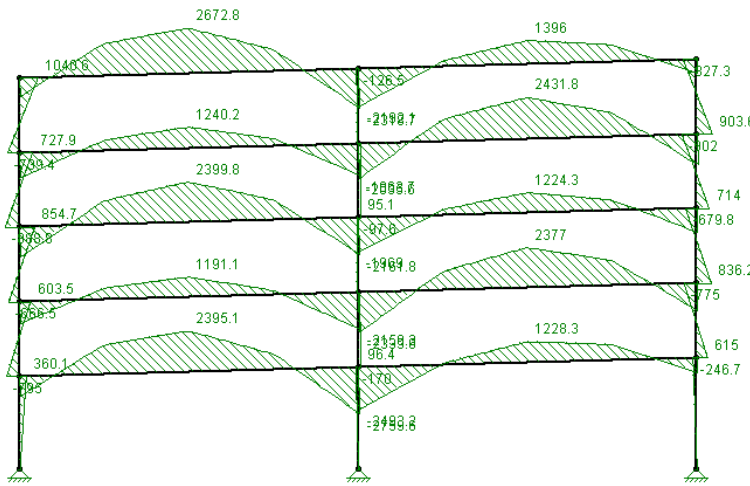


Figure 44 - Loading Case 3 - Moment Forces

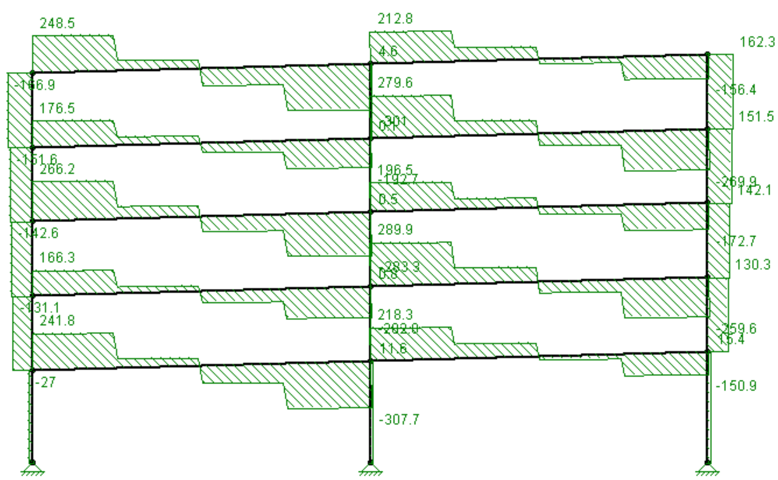


Figure 45 - Loading Case 3 - Shear Forces

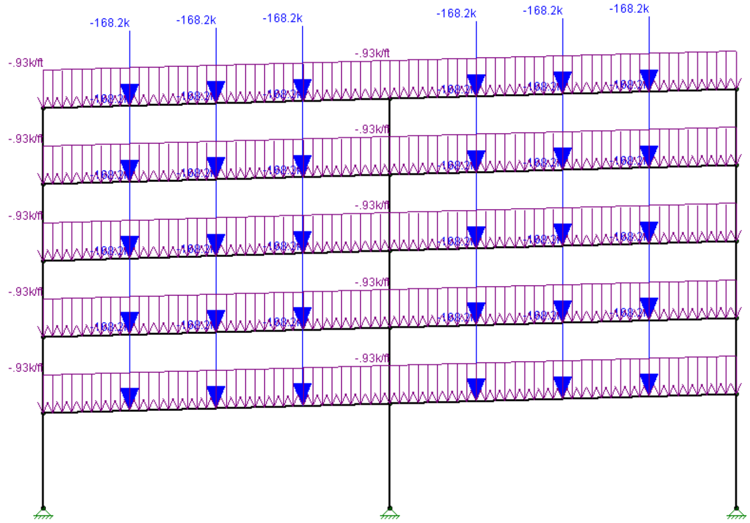


Figure 46 - Loading Case 4 - Full DL and LL

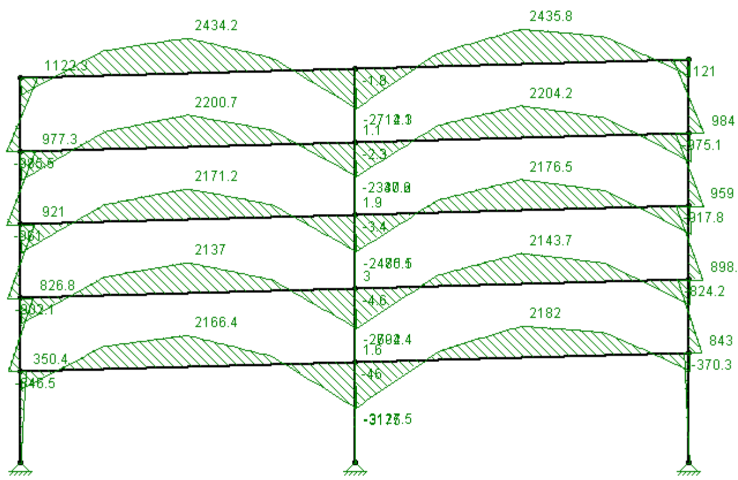


Figure 47 - Loading Case 4 - Moment Forces

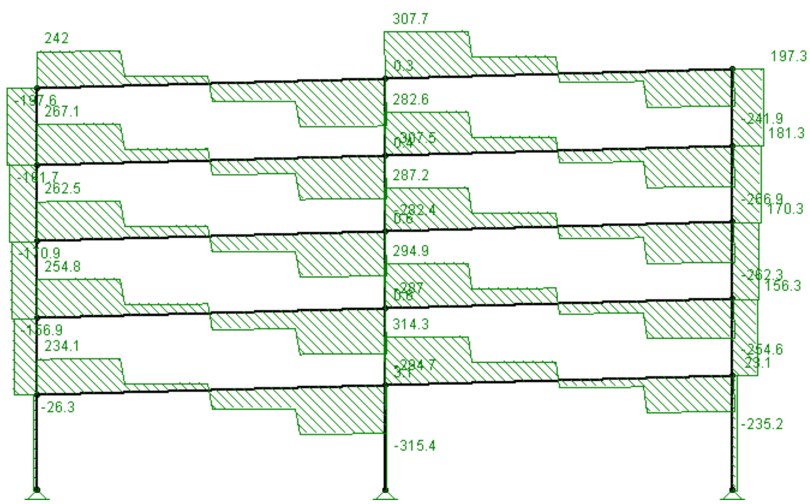


Figure 48 - Loading Case 4 - Shear Forces

Appendix K – RISA 2D Result Tables

Table 7 - Member Forces and Deflections - Loading Case 1

Deflections	Sec	X (in)	Y(in)
M1	1	0.066	-0.341
	2	0.059	-0.694
	3	0.052	-0.902
	4	0.045	-0.891
	5	0.038	-0.817
M2	1	0.038	-0.817
	2	0.031	-0.896
	3	0.024	-0.912
	4	0.017	-0.71
	5	0.01	-0.362
M3	1	0.034	-0.32
	2	0.035	-0.613
	3	0.035	-0.816
	4	0.036	-0.826
	5	0.037	-0.767
M4	1	0.037	-0.767
	2	0.037	-0.833
	3	0.038	-0.829
	4	0.038	-0.631
	5	0.039	-0.343
M5	1	0.034	-0.278
	2	0.035	-0.555
	3	0.035	-0.741
	4	0.035	-0.736
	5	0.036	-0.67
M6	1	0.036	-0.67
	2	0.036	-0.743
	3	0.036	-0.754
	4	0.037	-0.574
	5	0.037	-0.302
M7	1	0.034	-0.214
	2	0.034	-0.471
	3	0.035	-0.63
	4	0.035	-0.602
	5	0.036	-0.527
M8	1	0.036	-0.527
	2	0.036	-0.61
	3	0.037	-0.644
	4	0.037	-0.491
	5	0.038	-0.239
M9	1	0.017	-0.13
	2	0.022	-0.377
	3	0.027	-0.498

Forces	Sec	Axial (k)	Shear (k)	Moment (k-ft)
M1	1	136.588	162.844	-749.333
	2	133.295	43.065	1165.834
	3	130.002	-76.715	1627.619
	4	126.709	-196.495	636.023
	5	126.439	-206.316	-1806.939
M2	1	137.61	206.434	-1805.762
	2	134.317	86.654	638.129
	3	131.024	-33.125	1628.638
	4	127.731	-152.905	1165.766
	5	127.461	-162.726	-748.473
M3	1	-5.542	179.507	-1313.282
	2	-8.835	59.727	803.996
	3	-12.128	-60.052	1467.891
	4	-15.421	-179.832	678.406
	5	-15.691	-189.653	-1562.446
M4	1	-5.346	189.783	-1560.2
	2	-8.639	70.003	681.723
	3	-11.932	-49.776	1470.265
	4	-15.225	-169.556	805.425
	5	-15.495	-179.377	-1310.782
M5	1	-2.38	176.463	-1259.275
	2	-5.673	56.683	821.079
	3	-8.966	-63.096	1448.052
	4	-12.259	-182.876	621.644
	5	-12.529	-192.697	-1656.13
M6	1	-2.074	192.821	-1652.56
	2	-5.367	73.041	626.209
	3	-8.66	-46.738	1451.597
	4	-11.953	-166.518	823.604
	5	-12.223	-176.339	-1255.755
M7	1	-4.707	171.289	-1156.707
	2	-8	51.509	860.886
	3	-11.293	-68.271	1425.097
	4	-14.586	-188.05	535.927
	5	-14.856	-197.871	-1804.61
M8	1	-3.955	197.971	-1799.493
	2	-7.248	78.191	541.747
	3	-10.541	-41.588	1429.605
	4	-13.834	-161.368	864.082
	5	-14.104	-171.189	-1152.808
M9	1	-83.074	157.42	-800.659
	2	-86.367	37.64	1048.71
	3	-89.66	-82.14	1444.697

	4	0.031	-0.429
	5	0.036	-0.335
M10	1	0.036	-0.335
	2	0.041	-0.439
	3	0.045	-0.514
	4	0.05	-0.399
	5	0.055	-0.156
M11	1	0.339	0.075
	2	0.334	0.038
	3	0.329	0.048
	4	0.324	0.064
	5	0.319	0.043
M12	1	0.816	0.061
	2	0.803	0.06
	3	0.791	0.059
	4	0.778	0.058
	5	0.765	0.058
M13	1	0.362	0.02
	2	0.357	0.057
	3	0.352	0.045
	4	0.347	0.028
	5	0.342	0.048
M14	1	0.319	0.043
	2	0.308	0.022
	3	0.298	0.041
	4	0.287	0.061
	5	0.277	0.042
M15	1	0.765	0.058
	2	0.741	0.057
	3	0.717	0.056
	4	0.693	0.055
	5	0.669	0.054
M16	1	0.342	0.048
	2	0.332	0.068
	3	0.322	0.048
	4	0.311	0.028
	5	0.301	0.046
M17	1	0.277	0.042
	2	0.261	0.022
	3	0.245	0.039
	4	0.229	0.057
	5	0.213	0.039
M18	1	0.669	0.054
	2	0.633	0.053
	3	0.597	0.052
	4	0.561	0.051
	5	0.526	0.05
M19	1	0.301	0.046

	4	-92.953	-201.919	387.303
	5	-93.223	-211.74	-2121.458
M10	1	-83.313	210.984	-2089.613
	2	-86.606	91.204	409.469
	3	-89.899	-28.575	1455.169
	4	-93.191	-148.355	1047.488
	5	-93.461	-158.176	-811.559
M11	1	166.536	-132.062	749.333
	2	166.536	-132.062	397.169
	3	166.536	-132.062	45.005
	4	166.536	-132.062	-307.16
	5	166.536	-132.062	-659.324
M12	1	412.901	0.177	-1.178
	2	412.901	0.177	-0.706
	3	412.901	0.177	-0.234
	4	412.901	0.177	0.238
	5	412.901	0.177	0.71
M13	1	159.162	131.885	-748.473
	2	159.162	131.885	-396.781
	3	159.162	131.885	-45.089
	4	159.162	131.885	306.603
	5	159.162	131.885	658.295
M14	1	345.823	-121.588	653.958
	2	345.823	-121.588	329.722
	3	345.823	-121.588	5.487
	4	345.823	-121.588	-318.749
	5	345.823	-121.588	-642.985
M15	1	792.478	0.263	-1.536
	2	792.478	0.263	-0.834
	3	792.478	0.263	-0.132
	4	792.478	0.263	0.57
	5	792.478	0.263	1.272
M16	1	338.897	121.325	-652.486
	2	338.897	121.325	-328.953
	3	338.897	121.325	-5.419
	4	338.897	121.325	318.114
	5	338.897	121.325	641.648
M17	1	522.154	-114.36	616.291
	2	522.154	-114.36	311.331
	3	522.154	-114.36	6.372
	4	522.154	-114.36	-298.587
	5	522.154	-114.36	-603.546
M18	1	1178.138	0.407	-2.298
	2	1178.138	0.407	-1.214
	3	1178.138	0.407	-0.129
	4	1178.138	0.407	0.955
	5	1178.138	0.407	2.04
M19	1	515.505	113.953	-614.107

	2	0.285	0.065
	3	0.27	0.046
	4	0.254	0.027
	5	0.238	0.044
M20	1	0.213	0.039
	2	0.192	0.019
	3	0.171	0.032
	4	0.15	0.044
	5	0.129	0.021
M21	1	0.526	0.05
	2	0.478	0.049
	3	0.43	0.048
	4	0.382	0.046
	5	0.334	0.045
M22	1	0.238	0.044
	2	0.217	0.064
	3	0.197	0.05
	4	0.176	0.037
	5	0.155	0.059
M23	1	0.129	0.021
	2	0.097	-0.023
	3	0.065	-0.034
	4	0.032	-0.023
	5	0	0
M24	1	0.334	0.045
	2	0.251	0.04
	3	0.167	0.03
	4	0.084	0.016
	5	0	0
M25	1	0.155	0.059
	2	0.116	0.103
	3	0.077	0.097
	4	0.039	0.057
	5	0	0

	2	515.505	113.953	-310.233
	3	515.505	113.953	-6.358
	4	515.505	113.953	297.517
	5	515.505	113.953	601.391
M20	1	693.249	-104.947	553.161
	2	693.249	-104.947	273.301
	3	693.249	-104.947	-6.558
	4	693.249	-104.947	-286.418
	5	693.249	-104.947	-566.278
M21	1	1574.13	0.388	-3.077
	2	1574.13	0.388	-2.042
	3	1574.13	0.388	-1.007
	4	1574.13	0.388	0.028
	5	1574.13	0.388	1.063
M22	1	687.017	104.559	-551.416
	2	687.017	104.559	-272.592
	3	687.017	104.559	6.233
	4	687.017	104.559	285.057
	5	687.017	104.559	563.882
M23	1	848.326	-17.579	234.381
	2	848.326	-17.579	175.786
	3	848.326	-17.579	117.191
	4	848.326	-17.579	58.595
	5	848.326	-17.579	0
M24	1	1996.968	2.099	-30.782
	2	1996.968	2.099	-23.086
	3	1996.968	2.099	-15.391
	4	1996.968	2.099	-7.695
	5	1996.968	2.099	0
M25	1	847.702	15.48	-247.677
	2	847.702	15.48	-185.758
	3	847.702	15.48	-123.839
	4	847.702	15.48	-61.919
	5	847.702	15.48	0

Table 8 - Member Forces and Deflections - Loading Case 2

Deflections	Sec	X (in)	Y(in)
M1	1	0.033	-0.166
	2	0.029	-0.341
	3	0.026	-0.443
	4	0.022	-0.437
	5	0.019	-0.4
M2	1	0.019	-0.4
	2	0.015	-0.44
	3	0.012	-0.448
	4	0.009	-0.349
	5	0.005	-0.176
M3	1	0.017	-0.156
	2	0.017	-0.301
	3	0.018	-0.401
	4	0.018	-0.405
	5	0.018	-0.375
M4	1	0.018	-0.375
	2	0.018	-0.408
	3	0.019	-0.407
	4	0.019	-0.31
	5	0.019	-0.167
M5	1	0.017	-0.135
	2	0.017	-0.273
	3	0.017	-0.364
	4	0.018	-0.361
	5	0.018	-0.328
M6	1	0.018	-0.328
	2	0.018	-0.364
	3	0.018	-0.371
	4	0.018	-0.282
	5	0.018	-0.147
M7	1	0.017	-0.105
	2	0.017	-0.232
	3	0.017	-0.31
	4	0.017	-0.296
	5	0.018	-0.258
M8	1	0.018	-0.258
	2	0.018	-0.299
	3	0.018	-0.317
	4	0.018	-0.241
	5	0.019	-0.117
M9	1	0.009	-0.063
	2	0.011	-0.186
	3	0.013	-0.245
	4	0.015	-0.211
	5	0.018	-0.164

Forces	Sec	Axial (k)	Shear (k)	Moment (k-ft)
M1	1	67.469	79.303	-370.306
	2	65.829	19.67	582.521
	3	64.19	-39.963	811.758
	4	62.55	-99.596	317.405
	5	62.51	-101.051	-899.472
M2	1	67.981	101.113	-898.892
	2	66.342	41.48	318.478
	3	64.702	-18.153	812.259
	4	63.063	-77.786	582.45
	5	63.023	-79.241	-369.884
M3	1	-2.759	87.542	-649.073
	2	-4.398	27.909	403.685
	3	-6.038	-31.724	732.853
	4	-7.677	-91.357	338.431
	5	-7.717	-92.812	-778.516
M4	1	-2.654	92.88	-777.412
	2	-4.294	33.247	340.099
	3	-5.933	-26.386	734.02
	4	-7.573	-86.019	404.35
	5	-7.613	-87.474	-647.843
M5	1	-1.187	86.047	-622.556
	2	-2.827	26.414	412.068
	3	-4.466	-33.219	723.101
	4	-6.106	-92.852	310.545
	5	-6.146	-94.307	-824.536
M6	1	-1.029	94.372	-822.782
	2	-2.668	34.739	312.826
	3	-4.308	-24.894	724.843
	4	-5.947	-84.527	413.27
	5	-5.987	-85.982	-620.827
M7	1	-2.328	83.504	-572.117
	2	-3.968	23.871	431.657
	3	-5.607	-35.762	711.84
	4	-7.247	-95.395	268.434
	5	-7.287	-96.85	-897.497
M8	1	-1.95	96.904	-894.983
	2	-3.589	37.271	271.33
	3	-5.229	-22.362	714.053
	4	-6.868	-81.995	433.186
	5	-6.908	-83.45	-570.206
M9	1	-41.134	76.66	-396.25
	2	-42.773	17.027	524.518
	3	-44.412	-42.606	721.697
	4	-46.052	-102.239	195.285
	5	-46.092	-103.694	-1053.651

M10	1	0.018	-0.164
	2	0.02	-0.216
	3	0.022	-0.254
	4	0.025	-0.197
	5	0.027	-0.076
M11	1	0.165	0.037
	2	0.163	0.019
	3	0.16	0.024
	4	0.158	0.032
	5	0.155	0.021
M12	1	0.399	0.03
	2	0.393	0.03
	3	0.387	0.029
	4	0.381	0.029
	5	0.375	0.028
M13	1	0.176	0.01
	2	0.174	0.028
	3	0.172	0.022
	4	0.169	0.014
	5	0.167	0.024
M14	1	0.155	0.021
	2	0.15	0.011
	3	0.145	0.02
	4	0.14	0.03
	5	0.135	0.021
M15	1	0.375	0.028
	2	0.363	0.028
	3	0.351	0.028
	4	0.339	0.027
	5	0.328	0.027
M16	1	0.167	0.024
	2	0.162	0.034
	3	0.157	0.024
	4	0.152	0.014
	5	0.147	0.022
M17	1	0.135	0.021
	2	0.127	0.011
	3	0.119	0.019
	4	0.112	0.028
	5	0.104	0.02
M18	1	0.328	0.027
	2	0.31	0.026
	3	0.292	0.026
	4	0.275	0.025
	5	0.257	0.025
M19	1	0.147	0.022
	2	0.139	0.032
	3	0.131	0.023

M10	1	-41.249	103.323	-1037.907
	2	-42.889	43.69	206.272
	3	-44.528	-15.943	726.861
	4	-46.168	-75.576	523.86
	5	-46.208	-77.031	-401.665
M11	1	81.128	-65.264	370.306
	2	81.128	-65.264	196.269
	3	81.128	-65.264	22.232
	4	81.128	-65.264	-151.805
	5	81.128	-65.264	-325.841
M12	1	202.238	0.087	-0.58
	2	202.238	0.087	-0.348
	3	202.238	0.087	-0.115
	4	202.238	0.087	0.117
	5	202.238	0.087	0.349
M13	1	77.479	65.177	-369.884
	2	77.479	65.177	-196.079
	3	77.479	65.177	-22.275
	4	77.479	65.177	151.53
	5	77.479	65.177	325.335
M14	1	168.561	-60.1	323.231
	2	168.561	-60.1	162.964
	3	168.561	-60.1	2.697
	4	168.561	-60.1	-157.57
	5	168.561	-60.1	-317.838
M15	1	387.999	0.129	-0.755
	2	387.999	0.129	-0.41
	3	387.999	0.129	-0.065
	4	387.999	0.129	0.28
	5	387.999	0.129	0.625
M16	1	165.129	59.971	-322.509
	2	165.129	59.971	-162.586
	3	165.129	59.971	-2.664
	4	165.129	59.971	157.258
	5	165.129	59.971	317.18
M17	1	254.543	-56.549	304.718
	2	254.543	-56.549	153.922
	3	254.543	-56.549	3.126
	4	254.543	-56.549	-147.67
	5	254.543	-56.549	-298.467
M18	1	576.748	0.2	-1.129
	2	576.748	0.2	-0.596
	3	576.748	0.2	-0.064
	4	576.748	0.2	0.469
	5	576.748	0.2	1.002
M19	1	251.242	56.349	-303.646
	2	251.242	56.349	-153.383
	3	251.242	56.349	-3.12

	4	0.124	0.013
	5	0.116	0.022
M20	1	0.104	0.02
	2	0.094	0.009
	3	0.083	0.016
	4	0.073	0.022
	5	0.063	0.01
M21	1	0.257	0.025
	2	0.234	0.024
	3	0.21	0.024
	4	0.187	0.023
	5	0.164	0.022
M22	1	0.116	0.022
	2	0.106	0.031
	3	0.096	0.025
	4	0.086	0.018
	5	0.075	0.029
M23	1	0.063	0.01
	2	0.047	-0.012
	3	0.031	-0.017
	4	0.016	-0.011
	5	0	0
M24	1	0.164	0.022
	2	0.123	0.02
	3	0.082	0.015
	4	0.041	0.008
	5	0	0
M25	1	0.075	0.029
	2	0.057	0.051
	3	0.038	0.048
	4	0.019	0.028
	5	0	0

	4	251.242	56.349	147.144
	5	251.242	56.349	297.407
M20	1	337.951	-51.926	273.65
	2	337.951	-51.926	135.18
	3	337.951	-51.926	-3.29
	4	337.951	-51.926	-141.76
	5	337.951	-51.926	-280.23
M21	1	770.576	0.19	-1.512
	2	770.576	0.19	-1.005
	3	770.576	0.19	-0.499
	4	770.576	0.19	0.008
	5	770.576	0.19	0.514
M22	1	334.851	51.736	-272.798
	2	334.851	51.736	-134.835
	3	334.851	51.736	3.129
	4	334.851	51.736	141.093
	5	334.851	51.736	279.056
M23	1	413.452	-8.701	116.02
	2	413.452	-8.701	87.015
	3	413.452	-8.701	58.01
	4	413.452	-8.701	29.005
	5	413.452	-8.701	0
M24	1	977.648	1.038	-15.23
	2	977.648	1.038	-11.423
	3	977.648	1.038	-7.615
	4	977.648	1.038	-3.808
	5	977.648	1.038	0
M25	1	413.122	7.663	-122.609
	2	413.122	7.663	-91.957
	3	413.122	7.663	-61.304
	4	413.122	7.663	-30.652
	5	413.122	7.663	0

Table 9 - Member Forces and Deflections - Loading Case 3

Deflections	Sec	X (in)	Y(in)
M1	1	0.112	-0.443
	2	0.103	-0.986
	3	0.095	-1.286
	4	0.086	-1.223
	5	0.077	-1.018
M2	1	0.077	-1.018
	2	0.068	-1.004
	3	0.06	-0.975
	4	0.051	-0.764
	5	0.042	-0.432
M3	1	0.073	-0.411
	2	0.074	-0.678
	3	0.074	-0.885
	4	0.075	-0.934
	5	0.076	-0.955
M4	1	0.076	-0.955
	2	0.077	-1.133
	3	0.077	-1.165
	4	0.078	-0.872
	5	0.078	-0.414
M5	1	0.076	-0.359
	2	0.076	-0.796
	3	0.077	-1.067
	4	0.077	-1.018
	5	0.078	-0.835
M6	1	0.078	-0.835
	2	0.078	-0.825
	3	0.079	-0.796
	4	0.079	-0.611
	5	0.08	-0.363
M7	1	0.077	-0.274
	2	0.078	-0.499
	3	0.078	-0.652
	4	0.079	-0.655
	5	0.08	-0.657
M8	1	0.08	-0.657
	2	0.08	-0.856
	3	0.081	-0.937
	4	0.082	-0.701
	5	0.082	-0.291
M9	1	0.058	-0.169
	2	0.063	-0.572
	3	0.069	-0.762
	4	0.075	-0.634
	5	0.08	-0.418
M10	1	0.08	-0.418
	2	0.086	-0.449

Forces	Sec	Axial (k)	Shear (k)	Moment (k-ft)
M1	1	173.768	248.51	-1040.558
	2	168.836	69.097	1904.605
	3	163.903	-110.316	2672.797
	4	158.971	-289.728	1264.017
	5	158.661	-301.004	-2318.653
M2	1	168.184	212.773	-2192.142
	2	164.891	92.994	328.641
	3	161.598	-26.786	1396.042
	4	158.305	-146.566	1010.063
	5	158.035	-156.387	-827.283
M3	1	-10.457	176.473	-1467.351
	2	-13.75	56.693	613.127
	3	-17.043	-63.086	1240.223
	4	-20.336	-182.866	413.939
	5	-20.606	-192.687	-1863.712
M4	1	-3.084	279.591	-2035.587
	2	-8.016	100.178	1286.577
	3	-12.948	-79.234	2431.771
	4	-17.881	-258.647	1399.992
	5	-18.191	-269.923	-1805.677
M5	1	-1.644	266.231	-1743.502
	2	-6.577	86.819	1416.616
	3	-11.509	-92.594	2399.762
	4	-16.441	-272.007	1205.937
	5	-16.751	-283.283	-2161.779
M6	1	-3.985	196.498	-1969.035
	2	-7.278	76.719	354.342
	3	-10.571	-43.061	1224.337
	4	-13.864	-162.841	640.951
	5	-14.134	-172.662	-1393.802
M7	1	-6.931	166.314	-1270.043
	2	-10.224	46.534	687.206
	3	-13.516	-73.246	1191.074
	4	-16.809	-193.025	241.56
	5	-17.079	-202.846	-2159.32
M8	1	-3.845	289.865	-2339.61
	2	-8.778	110.452	1107.167
	3	-13.71	-68.961	2376.972
	4	-18.642	-248.374	1469.807
	5	-18.952	-259.65	-1611.25
M9	1	-97.496	241.783	-1155.078
	2	-102.429	62.37	1708.486
	3	-107.361	-117.043	2395.079
	4	-112.293	-296.455	904.701
	5	-112.603	-307.731	-2759.568
M10	1	-108.941	218.27	-2493.203
	2	-112.234	98.491	94.258

	3	0.092	-0.501
	4	0.098	-0.397
	5	0.104	-0.187
M11	1	0.44	0.124
	2	0.432	0.06
	3	0.424	0.068
	4	0.417	0.094
	5	0.409	0.084
M12	1	1.015	0.105
	2	1	0.124
	3	0.984	0.128
	4	0.968	0.121
	5	0.953	0.102
M13	1	0.431	0.054
	2	0.426	0.082
	3	0.421	0.063
	4	0.417	0.048
	5	0.412	0.09
M14	1	0.409	0.084
	2	0.396	0.075
	3	0.383	0.104
	4	0.37	0.124
	5	0.357	0.086
M15	1	0.953	0.102
	2	0.923	0.085
	3	0.893	0.078
	4	0.863	0.084
	5	0.833	0.101
M16	1	0.412	0.09
	2	0.399	0.131
	3	0.386	0.112
	4	0.374	0.082
	5	0.361	0.089
M17	1	0.357	0.086
	2	0.336	0.045
	3	0.315	0.062
	4	0.293	0.091
	5	0.272	0.085
M18	1	0.833	0.101
	2	0.788	0.117
	3	0.743	0.122
	4	0.699	0.116
	5	0.654	0.098
M19	1	0.361	0.089
	2	0.343	0.098
	3	0.325	0.071
	4	0.306	0.053
	5	0.288	0.09

	3	-115.527	-21.289	1228.338
	4	-118.82	-141.069	909.037
	5	-119.09	-150.89	-861.63
M11	1	253.191	-166.873	1040.558
	2	253.191	-166.873	595.563
	3	253.191	-166.873	150.568
	4	253.191	-166.873	-294.427
	5	253.191	-166.873	-739.422
M12	1	513.845	4.6	-126.511
	2	513.845	4.6	-114.244
	3	513.845	4.6	-101.977
	4	513.845	4.6	-89.71
	5	513.845	4.6	-77.443
M13	1	151.985	162.273	-827.283
	2	151.985	162.273	-394.555
	3	151.985	162.273	38.173
	4	151.985	162.273	470.901
	5	151.985	162.273	903.629
M14	1	429.311	-151.57	727.929
	2	429.311	-151.57	323.742
	3	429.311	-151.57	-80.446
	4	429.311	-151.57	-484.633
	5	429.311	-151.57	-888.821
M15	1	986.426	0.063	94.432
	2	986.426	0.063	94.601
	3	986.426	0.063	94.77
	4	986.426	0.063	94.939
	5	986.426	0.063	95.107
M16	1	422.306	151.507	-902.048
	2	422.306	151.507	-498.029
	3	422.306	151.507	-94.011
	4	422.306	151.507	310.008
	5	422.306	151.507	714.027
M17	1	695.396	-142.61	854.681
	2	695.396	-142.61	474.387
	3	695.396	-142.61	94.093
	4	695.396	-142.61	-286.2
	5	695.396	-142.61	-666.494
M18	1	1466.377	0.486	-97.637
	2	1466.377	0.486	-96.339
	3	1466.377	0.486	-95.042
	4	1466.377	0.486	-93.745
	5	1466.377	0.486	-92.448
M19	1	595.291	142.124	-679.775
	2	595.291	142.124	-300.779
	3	595.291	142.124	78.218
	4	595.291	142.124	457.215
	5	595.291	142.124	836.211

M20	1	0.272	0.085
	2	0.246	0.075
	3	0.22	0.097
	4	0.194	0.107
	5	0.167	0.063
M21	1	0.654	0.098
	2	0.595	0.08
	3	0.535	0.072
	4	0.475	0.076
	5	0.416	0.092
M22	1	0.288	0.09
	2	0.262	0.131
	3	0.236	0.119
	4	0.21	0.098
	5	0.184	0.109
M23	1	0.167	0.063
	2	0.126	-0.013
	3	0.084	-0.037
	4	0.042	-0.027
	5	0	0
M24	1	0.416	0.092
	2	0.312	0.103
	3	0.208	0.085
	4	0.104	0.047
	5	0	0
M25	1	0.184	0.109
	2	0.138	0.141
	3	0.092	0.122
	4	0.046	0.069
	5	0	0

M20	1	861.457	-131.112	603.549
	2	861.457	-131.112	253.918
	3	861.457	-131.112	-95.713
	4	861.457	-131.112	-445.344
	5	861.457	-131.112	-794.975
M21	1	1959.266	0.798	87.842
	2	1959.266	0.798	89.969
	3	1959.266	0.798	92.096
	4	1959.266	0.798	94.223
	5	1959.266	0.798	96.351
M22	1	855.363	130.314	-775.039
	2	855.363	130.314	-427.535
	3	855.363	130.314	-80.031
	4	855.363	130.314	267.473
	5	855.363	130.314	614.977
M23	1	1100.469	-27.008	360.103
	2	1100.469	-27.008	270.077
	3	1100.469	-27.008	180.051
	4	1100.469	-27.008	90.026
	5	1100.469	-27.008	0
M24	1	2485.169	11.592	-170.014
	2	2485.169	11.592	-127.511
	3	2485.169	11.592	-85.007
	4	2485.169	11.592	-42.504
	5	2485.169	11.592	0
M25	1	1009.468	15.416	-246.653
	2	1009.468	15.416	-184.99
	3	1009.468	15.416	-123.327
	4	1009.468	15.416	-61.663
	5	1009.468	15.416	0

Table 10 - Member Forces and Deflections - Loading Case 4

Deflections	Sec	X (in)	Y(in)
M1	1	0.099	-0.507
	2	0.089	-1.038
	3	0.078	-1.349
	4	0.068	-1.33
	5	0.057	-1.217
M2	1	0.057	-1.217
	2	0.047	-1.338
	3	0.036	-1.365
	4	0.025	-1.062
	5	0.015	-0.538
M3	1	0.051	-0.476
	2	0.052	-0.913
	3	0.053	-1.217
	4	0.054	-1.232
	5	0.055	-1.142
M4	1	0.055	-1.142
	2	0.056	-1.241
	3	0.056	-1.236
	4	0.057	-0.94
	5	0.058	-0.511
M5	1	0.051	-0.413
	2	0.052	-0.828
	3	0.052	-1.105
	4	0.053	-1.097
	5	0.053	-0.998
M6	1	0.053	-0.998
	2	0.054	-1.107
	3	0.055	-1.124
	4	0.055	-0.856
	5	0.056	-0.449
M7	1	0.05	-0.319
	2	0.051	-0.703
	3	0.052	-0.94
	4	0.053	-0.898
	5	0.053	-0.785
M8	1	0.053	-0.785
	2	0.054	-0.909
	3	0.055	-0.961
	4	0.055	-0.732
	5	0.056	-0.356
M9	1	0.026	-0.193
	2	0.033	-0.563
	3	0.04	-0.743
	4	0.047	-0.639
	5	0.054	-0.499
M10	1	0.054	-0.499
	2	0.061	-0.654

Forces	Sec	Axial (k)	Shear (k)	Moment (k-ft)
M1	1	204.335	242.044	-1122.257
	2	199.403	62.631	1744.478
	3	194.47	-116.781	2434.241
	4	189.538	-296.194	947.033
	5	189.228	-307.47	-2714.066
M2	1	205.874	307.651	-2712.306
	2	200.942	128.238	950.213
	3	196.01	-51.174	2435.761
	4	191.077	-230.587	1744.337
	5	190.767	-241.863	-1120.978
M3	1	-8.558	267.067	-1962.842
	2	-13.49	87.654	1207.412
	3	-18.422	-91.758	2200.695
	4	-23.355	-271.171	1017.007
	5	-23.665	-282.447	-2340.572
M4	1	-8.258	282.646	-2337.22
	2	-13.19	103.233	1021.995
	3	-18.123	-76.18	2204.239
	4	-23.055	-255.593	1209.511
	5	-23.365	-266.868	-1959.107
M5	1	-3.584	262.518	-1882.009
	2	-8.516	83.105	1233.063
	3	-13.449	-96.308	2171.164
	4	-18.381	-275.72	932.293
	5	-18.691	-286.996	-2480.468
M6	1	-3.12	287.186	-2475.142
	2	-8.052	107.773	939.141
	3	-12.985	-71.64	2176.452
	4	-17.917	-251.053	1236.792
	5	-18.227	-262.329	-1876.758
M7	1	-7.037	254.796	-1728.893
	2	-11.969	75.383	1292.518
	3	-16.902	-104.029	2136.957
	4	-21.834	-283.442	804.426
	5	-22.144	-294.718	-2701.997
M8	1	-5.907	294.871	-2694.364
	2	-10.839	115.459	813.143
	3	-15.771	-63.954	2143.679
	4	-20.704	-243.367	1297.244
	5	-21.014	-254.643	-1723.081
M9	1	-124.212	234.082	-1196.943
	2	-129.144	54.669	1573.217
	3	-134.077	-124.743	2166.406
	4	-139.009	-304.156	582.624
	5	-139.319	-315.432	-3175.049
M10	1	-124.567	314.306	-3127.458
	2	-129.499	134.893	615.779

	3	0.068	-0.768
	4	0.075	-0.596
	5	0.082	-0.232
M11	1	0.505	0.113
	2	0.497	0.057
	3	0.49	0.072
	4	0.482	0.096
	5	0.474	0.064
M12	1	1.215	0.091
	2	1.196	0.09
	3	1.178	0.088
	4	1.159	0.087
	5	1.14	0.086
M13	1	0.538	0.029
	2	0.531	0.084
	3	0.523	0.067
	4	0.516	0.042
	5	0.509	0.072
M14	1	0.474	0.064
	2	0.459	0.033
	3	0.443	0.061
	4	0.428	0.091
	5	0.412	0.062
M15	1	1.14	0.086
	2	1.104	0.085
	3	1.068	0.084
	4	1.032	0.082
	5	0.997	0.081
M16	1	0.509	0.072
	2	0.494	0.102
	3	0.478	0.072
	4	0.463	0.041
	5	0.448	0.068
M17	1	0.412	0.062
	2	0.388	0.032
	3	0.365	0.058
	4	0.341	0.086
	5	0.317	0.059
M18	1	0.997	0.081
	2	0.943	0.079
	3	0.89	0.078
	4	0.836	0.076
	5	0.783	0.075
M19	1	0.448	0.068
	2	0.424	0.097
	3	0.401	0.069
	4	0.378	0.041
	5	0.354	0.066

	3	-134.431	-44.52	2182.044
	4	-139.364	-223.933	1571.338
	5	-139.674	-235.209	-1213.258
M11	1	247.568	-197.606	1122.257
	2	247.568	-197.606	595.307
	3	247.568	-197.606	68.357
	4	247.568	-197.606	-458.593
	5	247.568	-197.606	-985.543
M12	1	615.346	0.264	-1.76
	2	615.346	0.264	-1.055
	3	615.346	0.264	-0.35
	4	615.346	0.264	0.355
	5	615.346	0.264	1.06
M13	1	236.529	197.342	-1120.978
	2	236.529	197.342	-594.733
	3	236.529	197.342	-68.488
	4	236.529	197.342	457.757
	5	236.529	197.342	984.002
M14	1	514.299	-181.712	977.299
	2	514.299	-181.712	492.733
	3	514.299	-181.712	8.167
	4	514.299	-181.712	-476.399
	5	514.299	-181.712	-960.965
M15	1	1180.649	0.393	-2.291
	2	1180.649	0.393	-1.244
	3	1180.649	0.393	-0.197
	4	1180.649	0.393	0.85
	5	1180.649	0.393	1.897
M16	1	503.939	181.32	-975.105
	2	503.939	181.32	-491.586
	3	503.939	181.32	-8.067
	4	503.939	181.32	475.452
	5	503.939	181.32	958.971
M17	1	776.619	-170.915	921.043
	2	776.619	-170.915	465.269
	3	776.619	-170.915	9.495
	4	776.619	-170.915	-446.279
	5	776.619	-170.915	-902.053
M18	1	1755.042	0.607	-3.428
	2	1755.042	0.607	-1.81
	3	1755.042	0.607	-0.193
	4	1755.042	0.607	1.425
	5	1755.042	0.607	3.043
M19	1	766.669	170.309	-917.787
	2	766.669	170.309	-463.631
	3	766.669	170.309	-9.475
	4	766.669	170.309	444.682
	5	766.669	170.309	898.838

M20	1	0.317	0.059
	2	0.286	0.028
	3	0.255	0.047
	4	0.223	0.065
	5	0.192	0.031
M21	1	0.783	0.075
	2	0.712	0.073
	3	0.64	0.071
	4	0.569	0.069
	5	0.498	0.067
M22	1	0.354	0.066
	2	0.323	0.095
	3	0.292	0.075
	4	0.261	0.055
	5	0.23	0.088
M23	1	0.192	0.031
	2	0.144	-0.035
	3	0.096	-0.051
	4	0.048	-0.034
	5	0	0
M24	1	0.498	0.067
	2	0.373	0.06
	3	0.249	0.044
	4	0.124	0.023
	5	0	0
M25	1	0.23	0.088
	2	0.173	0.154
	3	0.115	0.145
	4	0.058	0.085
	5	0	0

M20	1	1031.126	-156.879	826.84
	2	1031.126	-156.879	408.497
	3	1031.126	-156.879	-9.847
	4	1031.126	-156.879	-428.19
	5	1031.126	-156.879	-846.534
M21	1	2344.855	0.578	-4.59
	2	2344.855	0.578	-3.048
	3	2344.855	0.578	-1.506
	4	2344.855	0.578	0.036
	5	2344.855	0.578	1.578
M22	1	1021.793	156.301	-824.244
	2	1021.793	156.301	-407.442
	3	1021.793	156.301	9.36
	4	1021.793	156.301	426.161
	5	1021.793	156.301	842.963
M23	1	1261.706	-26.281	350.41
	2	1261.706	-26.281	262.807
	3	1261.706	-26.281	175.205
	4	1261.706	-26.281	87.602
	5	1261.706	-26.281	0
M24	1	2974.76	3.137	-46.014
	2	2974.76	3.137	-34.51
	3	2974.76	3.137	-23.007
	4	2974.76	3.137	-11.503
	5	2974.76	3.137	0
M25	1	1260.752	23.143	-370.295
	2	1260.752	23.143	-277.721
	3	1260.752	23.143	-185.148
	4	1260.752	23.143	-92.574
	5	1260.752	23.143	0