

St. Elizabeth Hospital Boardman Campus Inpatient Facility

Boardman, Ohio



Josh Behun
Structural Option

Final Report
April 9, 2008

Faculty Consultant: Dr. Linda Hanagan, P.E.



**Humility of Mary Health Partners
St. Elizabeth Boardman Campus
Inpatient Facility
Boardman, Ohio**

Project Team:

Owner: Humility of Mary Health Partners
Structural Engineer: Atlantic Engineering
Mechanical Engineer: Scheeser, Buckley, Mayfield, LLC
Lead Architect: Moody-Nolan, Inc
Local Architect: Strollo Architects
General Contractors: Boardman Construction Partners, LLC
(a joint venture between) - Alex Downie & Sons Co.
- The Albert M. Higley Co.

General Project Information:

Location: Boardman, Ohio
Size: 7 stories / 250,000 ft² + Penthouse
Occupancy: Hospital
Cost: \$65 Million
Construction Dates: Oct 2005 –Aug 2007
Delivery Method: Design-Bid-Build

Structural System:

- Foundation of 16" auger cast piles with pile caps and grade beams with cast in place concrete piers.
- Wide flange structural steel framing with 4" light weight concrete floor slabs on composite steel decking.
- Steel chevron, knee, and cross bracings on all floors for lateral force resistance.

Electrical System:

- Emergency backup 2000 kw diesel generator.
- Standard distribution supplied through 480/277 Volt 3 phase, 4 wire system
208/120 Volt 3 phase, 4 wire system
- Linear fluorescent fixtures on 277 volt system with local line volt switching.
- Visual voice fire alarm evacuation system with nurse calling and telecommunication systems throughout building.

Architecture:

- Primarily brick façade.
- 14'-8" typical floor to floor height.
- Curvilinear wall on north elevation with aluminum panel curtain wall system.
- Flat roof system similar to floor structure with light weight concrete slab for contained HVAC units and penthouse.

Mechanical System:

- Roof top units controlling air quality within seven story addition.
- Two mechanical rooms on 2nd and 3rd floors including boilers and chillers regulating heating, cooling, and air quality for entire building.

Josh T. Behun

Architectural Engineering
Structural Option

The Pennsylvania State University

www.engr.psu.edu/AE/thesis/portfolios/2008/jtb217

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Executive Summary

The St. Elizabeth Hospital in Boardman, Ohio has recently built a relatively large addition to its preexisting hospital facility. The new addition is primarily a 19,000 square foot, seven story patient tower that consists mainly of patient rooms and nursing stations for more effective treatment of the patients as they briefly reside within the hospital walls, plus a 5,000 square foot, three story area that typically contains mechanical rooms and central distribution equipment. Also, within this renovation is an additional 36,000 square foot, two story area that houses operating and recovery rooms as well as a kitchen and cafeteria area.

The goal of this thesis project is to prepare a redesign of the current steel structure as a reinforced concrete framed structure. After an extensive evaluation of the state of the current building, it has been concluded that the structural steel design method chosen for the building was most likely the most efficient option. Thus, the redesign analysis at hand is based solely on an educational basis, and is intended to provide insight into the design of concrete structures and produce a more knowledgeable thesis experience.

Along with the structural modifications for the hospital building, an analysis of the affects that the new design variation places upon the schedule, construction sequence, cost breakdown, and material usage for the building will also be evaluated to determine, aside from structural characteristics, which construction method is the more efficient building process. The investigation of these managerial aspects of the hospital building will be assessed dealing exclusively with comparisons of the two different framing structures.

In addition, the hospital will be evaluated using the standards of the LEED rating system, to determine if the building could potentially meet the parameters of a sustainable “green” building. Among other assessments, a green roof will be added the roof of the 36,000 square foot operating room / kitchen-cafeteria area, and a more in depth investigation of the roofing systems in place will be conducted to assess the summertime cooling demands placed upon the building with a green roof as opposed to the cooling demands of a typical EPDM roofing system.

Conclusions

For this particular project, the original steel design for the building is most likely the better design for the hospital’s structural system. The alternative concrete structure that was evaluated for this project, while it has own evident disadvantages, can also certainly provide a number of benefits as well. Though, effectively incorporating an efficient concrete framing system into this project would likely require further architectural planning from the initial conception stages. Also, though the steel framing system currently in place appears to remain the more effective structural system, there are numerous ways that the building could be improved to achieve a LEED status, as well as produce a more sustainable existence and more efficiently functioning systems throughout the building.

“The mission of Humility of Mary Health Partners is to extend the healing ministry of Jesus by improving the health of our communities, with emphasis on people who are poor and under-served”

Acknowledgements

Thank you to all of the Architectural Engineering faculty for assisting with my education and professional development, as well as providing so very much of your time, energy, patience, instruction, and guidance throughout the thesis process and the past four years; especially:

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Don Harley, The Albert M. Higley Company

A special thanks goes out to my family and friends for all of the support, assistance, and inspiration they have provided over the years.

Building Description

The St. Elizabeth Hospital Boardman Campus Inpatient Facility is a 65 million dollar renovation to an already existing two story building located in Boardman, Ohio. The renovation consists primarily of a seven story, 19,000 square foot patient tower addition, as well as some modifications to the pre-existing two story diagnostic wing. The patient tower is constructed using a steel framing system, which includes a façade system that is constructed using a brick veneer and a curvilinear aluminum panel curtain wall system that exists on the north facing elevation of the hospital. The remainder of the building, including the preexisting areas, is primarily masonry construction. The total height of the new building tops off at around 104 feet, plus a penthouse that contains a stairway for access to the rooftop HVAC equipment. The hospital began the construction for the new patient tower addition during October of 2005, and has just recently finished construction in August of 2007. Figure 1.1 shows an aerial view of the hospital's original facilities with the renovation project's footprint superimposed over it in red.



Figure 1.1 – Aerial view of original hospital structure courtesy of Google Maps.

Introduction to Structural System

Foundation

The foundation for the St. Elizabeth Hospital Inpatient Facility consists of 16" diameter auger cast grout injected piles with a capacity of 50 tons and an f'_c of 4000 psi, including (4) #6 vertical bars for the top 20' of the piles and #3 ties spaced at 16" on center. The vertical reinforcement from each pile is to extend 18" into its corresponding pile cap or grade beam with a 90° hook of 2'-0" in length. Several of the column piers will be constructed on existing footings, subsequent reinforcement bars are to be drilled and grouted into the existing footing with Hilti epoxy adhesives, providing a minimum embedment of 8".

Super Structure

The framing for the structural system consists typically of wide flange structural steel members. The typical column size for the building is within the range of W12x40 to W12x136 members, while there are a minimal number of W10 and W14 columns throughout the atypical areas of the new addition. The girders for the building are on average W30x90 members where the façade is brick and W18x40 members where the outer façade is the aluminum panel curtain wall system. The floor to floor height of each story two through seven is 14'-8" tall, while the floor to floor height for the first floor is 15'-4" in height. An architectural layout and floor plans for the patient tower renovation are shown in figure 1.3 and figure 1.4, respectively.

Roofing

The roofing system for the hospital is a flat roof which consists of structural steel members similar to that of the floor system. The area where the HVAC units rest has a slab of 4½" light weight concrete on 2" - 20 gage galvanized composite decking with 6x6-W2.1xW2.1 welded wire fabric reinforcement. While the remainder of the roof area, including the penthouse roof, is constructed with 1½"-20 gage galvanized wide ribbed steel roof deck. The outermost membrane of the roofing system is constructed of a durable sheet of EPDM fabric for superior weather resistance.

Floor System

The floor system of the St. Elizabeth Hospital Inpatient Facility is a concrete slab system comprised of a 4" light weight concrete topping slab on 2" - 20 gage galvanized composite decking with 5" long ¾" diameter shear studs and a 6x6-W2.1xW2.1 welded wire fabric reinforcement system. The majority of the beams for the floor framing are 21" in depth with a typical span of 34'. On the first two floors, the new addition's floor systems are connected to the existing floor slabs as well as the masonry walls by ½" diameter Hilti adhesive anchors spaced at 24" on center, with a minimum embedment of 4½".

Lateral Bracing System

The lateral resisting system in place at the St. Elizabeth Boardman Hospital consists of a number of braced frames strategically placed throughout the superstructure of the building. The majority of the bracing frames used along the exterior of the building contain chevron type bracings, or K braces, and are located against the eastern most side of the building, where the aluminum panel curtain wall system meets the brick façade. There is also a large section of bracings amongst the elevator shafts that consist primarily of chevron style bracings as well, except for a two column section along the western most side of the elevators that is constructed using a set of singular cross bracings. Aside from the typical bracings throughout the building, there are also a small number of interior framed sections that contain knee bracings for added lateral support. All of the bracing members used throughout the framing system are square HSS members ranging in size from 5x5x3/8" to 9x9x1/2".

Expansion Joints

The connections between the new addition and the pre-existing portion of the hospital are separated using expansion joints containing Teflon slide bearings. The expansion joints have been constructed along the seams which separate the individual sections of the hospital, allowing the patient tower renovation to react to lateral forces independently of the original hospital building. The Teflon slide bearings consist of two 3/32" pads of 100% virgin polytetrafluoroethylene polymer resin and reinforcing aggregates of ground glass fibers bonded to stainless steel plates. The compression creep of the slide bearing's Teflon pad should be able to withstand temperatures of up to 400 degrees Fahrenheit, while the entire bearing assembly shall have a working load capacity of 2000 psi. These features will allow the different materials used along the wall sections of the two conjoined buildings to expand and react to forces independent of each other, so as not to damage one another during extreme load cases.

Building Background

Project Team

Owner: Humility of Mary Health Partners
www.HMpartners.org

Structural Engineer: Atlantic Engineering Services
www.aespj.com

Mechanical Engineers: Scheeser, Buckley, Mayfield, LLC
www.sbmce.com

Civil Engineers: Lynn, Kittinger & Noble, Inc.

Lead architect: Moody-Nolan, Inc
www.moodynolan.com

Local architect: Strollo Architects
www.strolloarchitects.com

General Contractors: Boardman Construction Partners, LLC – a joint venture between

- Alex Downie & Sons Co.
alexdownie.com
- The Albert M. Higley Co.
www.amhigley.com

Geotechnical Engineer: Cernica Engineering, Inc

Construction

The delivery method for the St. Elizabeth Hospital addition is described as Design-Bid-Build; with the Alex Downie & Sons Company and The Albert M. Higley Company serving as the general contractors in a joint venture known as the Boardman Construction Partners. The site around the original existing building was cleared and prepared for construction beginning in November of 2005 with a scheduled completion date set for August of 2007. There was an existing building to work around, with an existing foundation that was tied into and used to help support the foundation of the new addition. The construction began by correctly situating the new foundations amongst the existing foundation, making note not to disturb the current system in place. Following the subsurface construction, the cranes were brought in and the erection of the steel framing for the seven story addition could begin.

The initial plans for the hospital addition have also included a second tower, similar to the one that is being analyzed in this thesis, which does not currently have a projected time frame to be built within, but has been anticipated if the needs of the current building call for another large expansion.

Mechanical

The mechanical system of the new hospital is comprised of three local systems contained within different areas of the building for handling the building's indoor environment. The most noticeable system is a set of enclosed roof top units that control the heating and air conditioning for the seven story addition. There are also two mechanical rooms housed within the building for more localized air quality control. The first of which is located on the second floor and consists of three air handling units for controlling air quality throughout the entire building, while the other mechanical room is housed on the third floor and contains one air handling unit as well as two large chillers and 6 boilers to provide comfortable heating and cooling environments for their patients through all seasons. Each air handling unit is equipped with ultraviolet light emitters downstream from the cooling coils and upstream of the tail water coil. These ultraviolet light emitters are provided to help clean the surfaces of the air handling units and reduce the spread of airborne bacteria, viruses, mold spores, and other microorganisms that may endanger the health and recovery of the hospitals patients. All localized air quality is controlled in each room by VAV boxes, in order to meet minimum air quality standards required by code.

Transportation

The transportation system for the new hospital addition is made up of a localized collection of elevators as well as two sets of stairs at either end of the building. The elevators are located at the far eastern side of the building and are separated into two groupings. The first set of elevators are 6'x 6', while the second set of elevators are 6'x 8'. Each elevator has an open shaft directly adjacent to it, which leaves room for a future elevator to be installed, making the grand total for planned elevators to eventually be four 6'x 6' and four 6'x 8'. The elevator's mechanical system is controlled by a hoist method that consists of a counter weight on a pulley with a motor driving the system.

Lighting

The lighting system in the hospital consists primarily of linear fluorescent fixtures running on a 277 volt system with local line volt switching. All exit signs utilize LED technology to minimize input wattage.

Electrical

The electrical scheme for the hospital is run from a local line supplied by First Energy through an underground system into the building. It runs from an initial 12470 volt system with standard distribution through two substations, one with a 480/277 volt, 3 phase, 4 wire secondary and another with a 208/120 volt, 3 phase, 4 wire secondary. The hospital also utilizes a backup 2000 kilowatt diesel generator system with 3 transfer switches comprising the essential power distribution for the critical power, life safety, and equipment branches in case of emergency.

Fire Protection

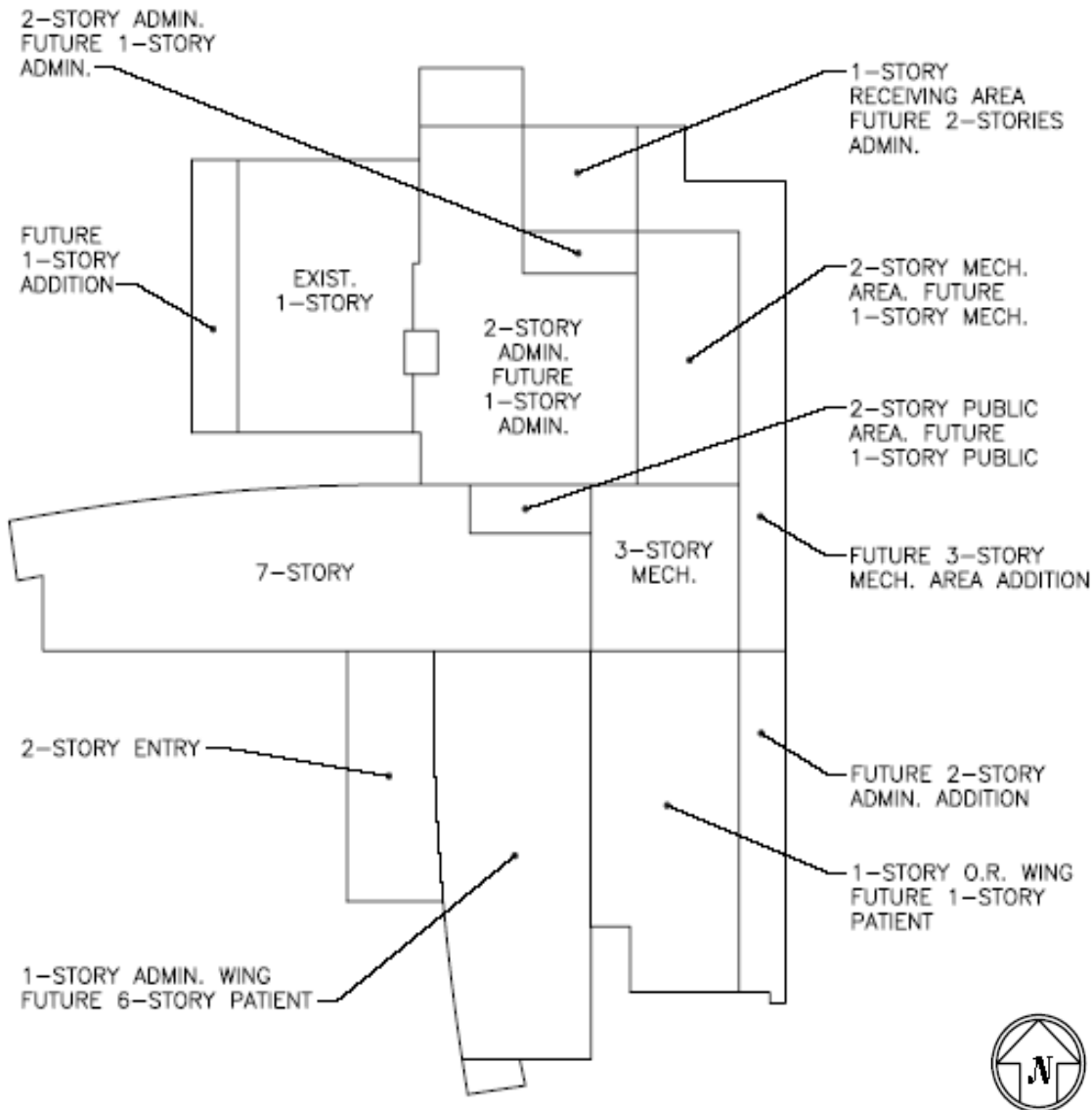
One of the fire protection systems in use in the building is a visual voice fire alarm evacuation system. It is required by Ohio state law that all high rise buildings utilize an evacuation system based on actual voice prompting instead of the old style of bells or lights. For this system the hospital contains a fire command center where, in case of emergency, a chief fire fighter can view visual displays of where smoke or a fire is located in a building and instruct his team on how to effectively extinguish the problem, as well as provide the public with evacuation information for quickly and safely exiting the building. In addition to the command center, there are input jacks near every stairwell where a fire fighter can input a handset and communicate directly with the fire command center. For any hearing impaired visitor who may be in the building there is also a system of strobe lights throughout the hallways, spaced at every 100 feet along the path of egress, as well as in every restroom to help aid the evacuation process. Aside from informational systems the building is also equipped with an engineered smoke control system in every stairwell that, in case of emergency, will pump pressurized air into the stairwell to keep smoke from billowing into the stairwell as visitors are escaping into them.

Telecommunications

There are several telecommunications systems in place throughout the building to help make the patients stay more comfortable, and the doctors and nurses jobs a bit easier. The first of which is a nurse calling system. This system, located throughout the building, has several call points in every patient room and connects back to a central nurses station on every floor, keeping the nurses more connected to their patient's needs. Each patient's room has a "pillow speaker" that allows for two-way communication with the nurses, as well as a one-way call button located in the bathroom which will contact a nurse in case of an emergency. A call to the nurse can only be turned off in the patient's room, making it possible to keep track of the amount of calls placed by a patient or the time lapse between a call and the nurse's attention. In addition to the central nurse's station at every floor, the call system also gets directed straight to the nurse's pager, so that if the nurses are away from their station or with other patients when an emergency arises they can be notified immediately. Another key telecommunications system in the hospital is the phone system that allows calls to be made within the building, from any incorporated phone, by simply entering a person's extension number and also allows an official within the hospital make announcements over the intercom system that projects throughout the building.

Complete Plan for Building Renovation

Figure 1.2 shows the renovation plans for the hospital with the current modifications that have been recently constructed, plus a second renovation addition that will most likely take place at some time in the undetermined future. The main focus of this thesis project is based around the seven story tower, as well as the accompanying three story mechanical area and the two story operating room / kitchen cafeteria wing.



FUTURE EXPANSION KEY PLAN

Figure 1.2

Typical Plans for new Inpatient Facility

Typical Floor Plan for Seven Story Addition

- Showing **patient rooms**, **nurse's station**, **elevator core**, and **corridors**.

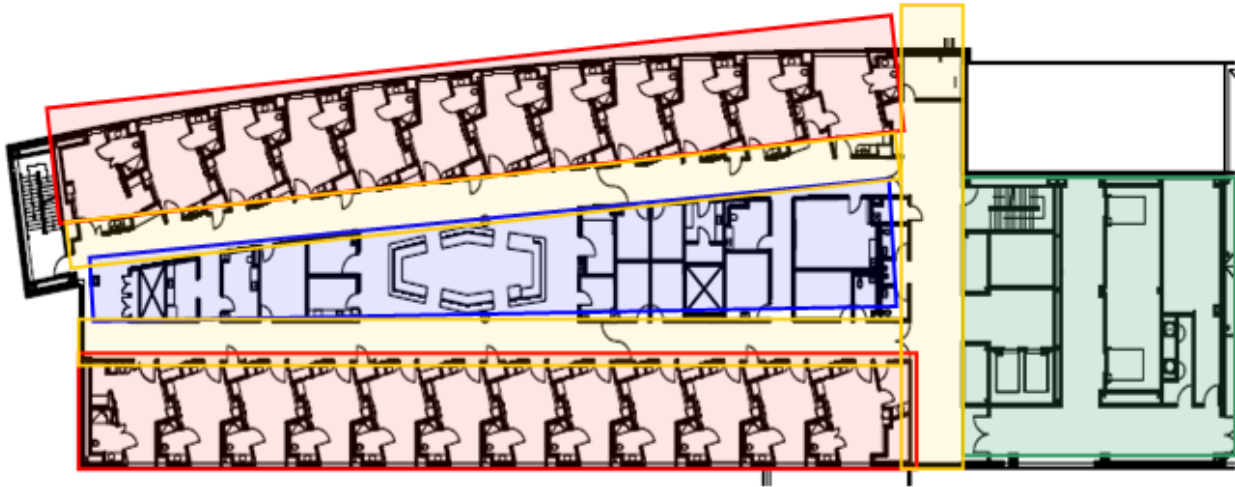


Figure 1.3

Typical Framing Plan for Seven Story Addition

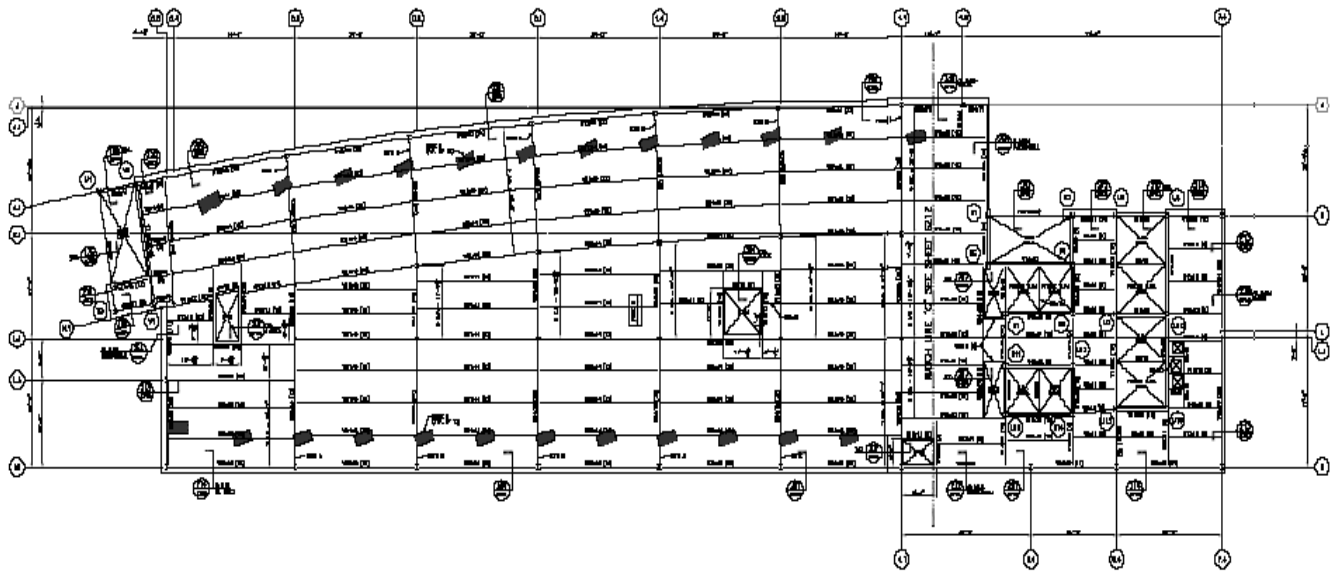


Figure 1.4

Problem Statement

Based on all of the analysis performed for the building, the structural system for the St. Elizabeth Hospital Inpatient Facility as it currently stands has been designed adequately enough to resist all of the loading combinations that it would receive in the northern Ohio region. Though, in order to evaluate the possibility of improvements that could be made to the building, the structure will be redesigned using a cast in place concrete structural system. In the essence of designing a building that is meant to provide assistance for maintaining public health, it is only natural that the building itself should be made to reduce the strain it places upon the environment it occupies. With that, the hospital must be evaluated to meet the standards of a LEED certified “green” building, which practices sustainable methods and ideals while promoting a healthier and more efficient existence.

Problem Solution

The hospital’s new patient tower renovation project was originally designed using steel framing members. The focus of this study will be to redesign the building’s structure in order to investigate the validity of using a concrete structural system instead of the original steel framing system that is currently in place at the hospital. Though, since the use of a concrete system stands to impose any number of implications upon the current building, the constraints it then creates upon the cost, schedule, and building sequence of the construction management aspects of the hospital will be inspected and evaluated as well. Plus, with the use of structural concrete, the current steel lateral bracing system will no longer be valid, thus the necessity to construct shear walls for resisting lateral forces will be investigated. While physical changes are underway, the building will be evaluated for its environmental impact and utilization of sustainable practices, in order to obtain a clear vision for the path to be taken to progress the hospital toward a LEED certifiable status.

Structural Depth Study

After a rather extensive evaluation of the original structure, it was determined that the initial steel framed structure was indeed an efficient design. Though for educational purposes, a concrete framed structure will be analyzed as an alternative fit for the hospital's main structural system. The main structural components of a concrete system that are involved with this redesign include columns, slabs (with drop panels and/or beams where necessary), and concrete shear walls to replace the steel chevron bracings that aided in resisting the lateral forces. The overall floor thickness of the structural system is able to be reduced with the redesign from 36" to 22.5", a difference of 13.5". Though, since this redesign did not intend on reducing the height of the stories or the overall height of the building this extra foot plus of ceiling area can be used as mechanical space, making an easier fit for piping, ductwork, electrical cables, or anything else that may need to be run throughout a ceiling.

Figure 2.1 shows the distinct areas of the building, as determined with the original renovation. The essential areas of redesign for this thesis project are areas C, D, and E, the remaining areas A and B include pre-existing sections of the hospital. Area E is the seven story patient tower addition and is the largest area of concern for the renovation project. Area C is split between the elevator system that runs up the entire seven story addition and a three story section of the hospital that houses primarily the mechanical and central distribution equipment, as well as a pharmacy and a kitchen. Finally, area D is a two story area of the new addition that contains a kitchen / cafeteria area and some surgery and patient recovery rooms as well. In addition, the eastern portion of area D is the area of the hospital that has been designated for a future renovation that would mirror the seven story tower of this current renovation project.

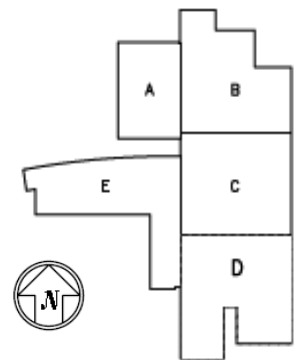


Figure 2.1

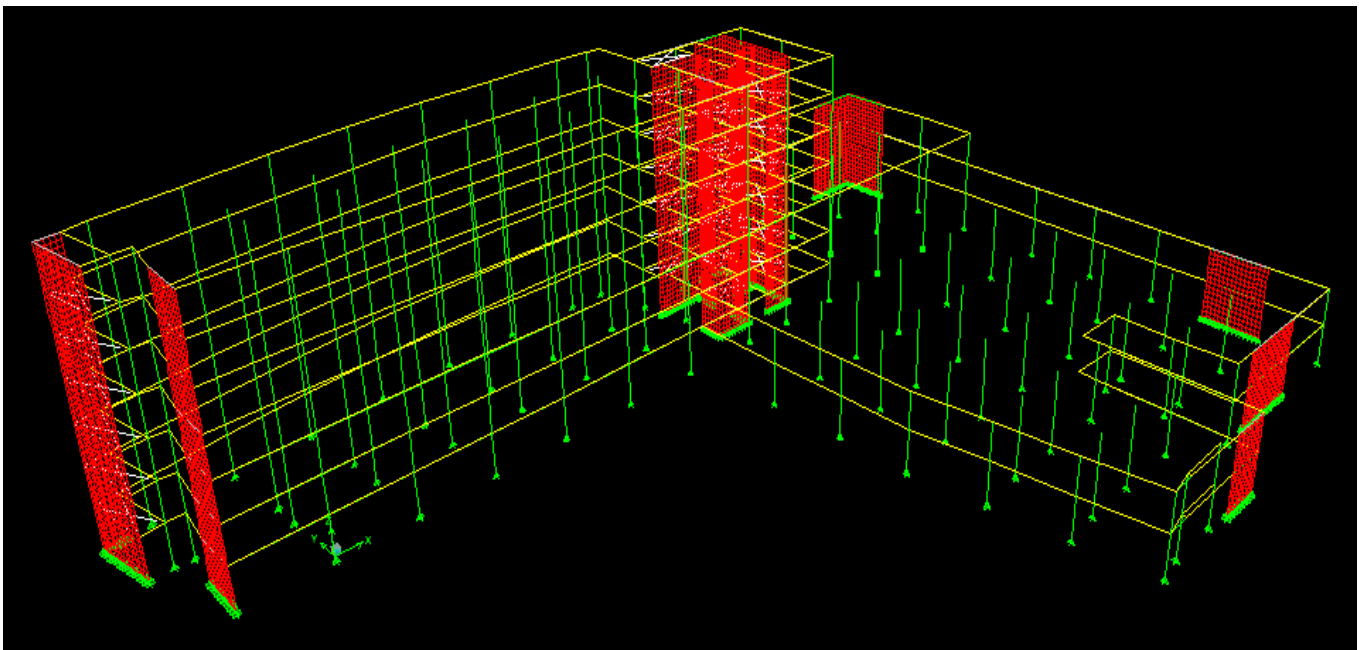


Figure 2.2 - 3D image of building framing and shear wall location courtesy of E-tabs

Gravity Loadings

The gravity loading for the building consists primarily of the weight of the materials that have been used to construct the building, plus the weight of the all of the objects that are being housed within the building. The necessary and permanent materials used to construct the building and support the structure are known as the dead load, while everything else within the building including furniture, fixtures, machinery and people are all considered live load. The live loads used for typical designs can be found within the IBC specifications, and the specific loadings used with the design of the St. Elizabeth Hospital project are shown below:

Roof.....	30 psf	Patient Rooms.....	60 psf
Public Areas.....	100 psf	Light Storage.....	125 psf
Lobbies.....	100 psf	Catwalks.....	25 psf
First Floor Corridors.....	100 psf	Mechanical.....	175 psf
Corridors Above First Floor.....	80 psf	Stairs.....	100 psf

There are several load combinations that are calculated to determine which possible arrangement of significantly factored loads will produce the largest effect upon the building at any given point in time. The combinations typically used for the analysis of concrete structures can be found in the ACI Building Code requirements specified by the American Concrete Institute, and are shown as follows, with the combinations most commonly used throughout this design analysis shown in bold print.

- (1) 1.4 Dead
- (2) 1.2 Dead + 1.6 Live + 0.5 (Roof Live, Snow, or Rain)**
- (3) 1.2 Dead + 1.6 (Roof Live, Snow, or Rain) + (1.0 Live or 0.8 Wind)
- (4) 1.2 Dead + 1.6 Wind + 1.0 Live + 0.5 (Roof Live, Snow, or Rain)**
- (5) 1.2 Dead + 1.0 Earthquake + 1.0 Live + 0.2 Snow**
- (6) 0.9 Dead + 1.6 Wind + 1.6 (Soil or Water Pressure)
- (7) 0.9 Dead + 1.0 Earthquake + 1.6 (Soil or Water Pressure)

Building Weight

The building components that are factored into the project's weight assessment are those that are considered with the dead load, including but not limited to the building's structural framing, the façade system, and the roofing structure. In general, concrete structures tend to weight significantly more than a typical steel designed structure will. That is certainly not an exception with the alternative concrete structural design for this particular project. The original building weight for the steel structure was estimated at a load of about 36,000 kips, while the alternative concrete design has been determined to have an estimated weight of around 51,300 kips, which is nearly 1.5 times the original loading. This extra weight is a very important factor when determining the effects that seismic activity would have on the building. A more massive building will result in a lower period, which means the building will oscillate less when impacted by the lateral forces of an earthquake.

The following items listed are the key components of the building that were analyzed and designed to resist the loadings caused by gravity and compose the hospital's alternative concrete structural system.

Column Design

In accordance with the current architectural layout for the hospital, and to help resist punching shear failures in the slab, the columns have been designed to be 24"x 24" square columns, which is the typical column encasement sizing shown in the architectural plans. The columns have been designed using the computer software PCA Column, with loadings determined using the computer program E-tabs. The majority of the columns throughout the building are 14' - 8" in height, though the first floor story height is 15' - 4", which produces many larger column designs. The columns that carry the largest loads within the building are the ones located along with the slabs that contain drop panels, and will be situated throughout area D of the building, in the first floor operating room / kitchen and cafeteria area. There are numerous sizing and design configurations for the steel reinforcement that would support the loading for the columns. The typical column reinforcement design used throughout the building is (8) #8 reinforcing bars arranged symmetrically about the square column, providing a steel reinforcement area of 6.32 square inches, with a provided confinement of #3 ties. There are a few select columns, typically on the first floor, which do not fall into the typical prescribed column design parameters. The steel reinforcement for these larger columns are comprised of designs ranging from (8) #9 bars to (8) #11 bars to even one column which has (20) #10 bars. The design calculations and software output for a few select column designs used throughout the building are provided in Appendix D, and the building plans for the second floor area D are located in Appendix A.1.

Beam Design

There are two types of beams associated with the slab designs that will assist in carrying loads and help support the slab. The beams most frequently used throughout the building are the edge beams that run along the perimeter of the two-way slab with drop panels. These beams are typically known as spandrel beams, and are cast monolithically with the slab, making the beam and slab one solid component. The second type of beam used throughout the building are the ones located within the one-way slab that is situated in the vicinity of the elevator shafts. These beams, known as T-beams, will also be cast monolithically with the slabs. Both beam types will be reinforced using (6) #6 rebar with one inch of clear spacing between the bars. The design calculations used for the beams are provided in Appendix C.

Slab Design

The updated slab design will vary throughout the floor plan. Though there are only two distinctly different design styles used; one a two-way slab with drop panels and edge beams and the other a one-way slab with beams, the use of either does tend to switch back and forth throughout the floor plan on each story. The designs for the slabs have been conducted using the computer software PCA Slab and verified with hand calculations using the direct design method. The design calculations and software output, including reinforcement specifications, for each of these slab design layouts are provided in Appendix B.

The majority of the floor area throughout the patient room region of the new seven story tower will utilize the two-way slab with drop panels and edge beams. The slab in this area will be 9.5" in thickness with an additional 7.5" of thickness for the drop panels, which run a typical size of 9' x 11.33', to withstand punching shear. The rebar used throughout these drop panel slabs will often vary; though tend to stay in a range between #6 to #8 bars, typically spaced at eight to twelve inches on center. There is typically a minimum required slab thickness that is used for an average design to ensure that the slab's deflection will not pose serious issue. Though, this is not a mandatory design regulation, yet only a precautionary task to save time in calculating the actual slab deflections. In this case, with an average span of 34 feet, the required slab is calculated to be 10.25 inches in depth. Although the slab designed at 9.5 inches is slightly under this deflection requirement, the largest deflections determined fall well within the allowable limits of $L/360$ for live load and $L/240$ for total loading. The beams that run the perimeter of the building will be spandrel beams with a width of 16" and a total depth of 22.5". Due to the frequency of large openings in the slab around the vicinity of the elevator shafts, the one-way slab with beams will be located in this area. The slab thickness for the one-way slab, having much smaller spans, will be slightly thinner at 8" in thickness. The interior beams designed for this area will meet the specifications of a T-beam, which will also provide a width of 16", and a total depth of 22.5", as well as an effective width of 68". Lastly, the two-way slab with drop panels will also be implemented in the mechanical area of the third floor, the kitchen and cafeteria area on the second floor, and all of the roof areas as well, seeing as the majority of the roofs house a fair amount of mechanical equipment or are designed to be built upon with another renovation at some point in the future.

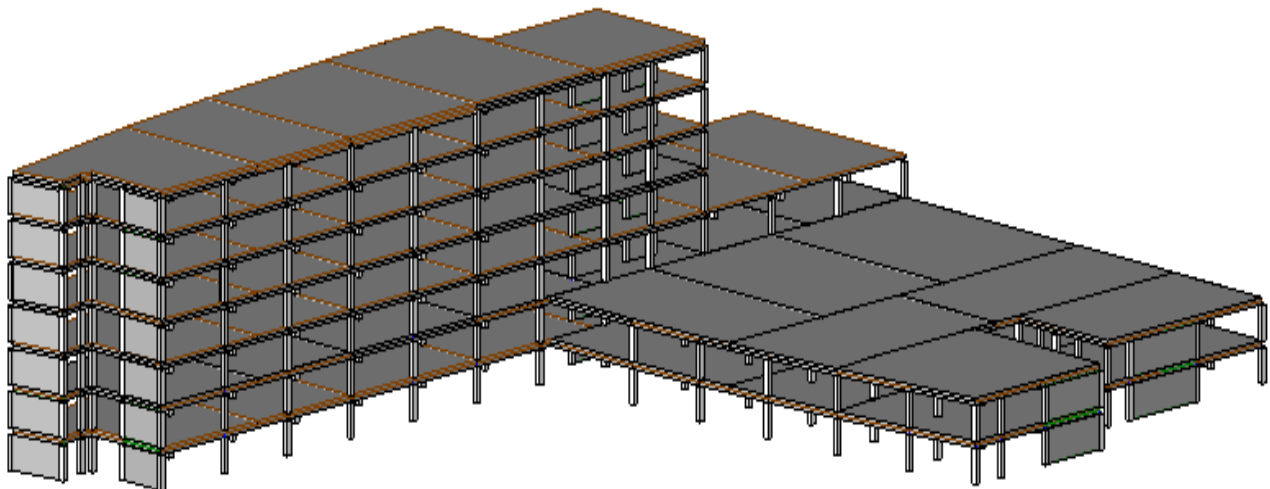


Figure 2.3

Lateral Loadings

The two main forces that need to be considered when analyzing the lateral loadings are the wind forces and the seismic forces. Though this particular building is located in northern Ohio, a place that will rarely be hit by an earthquake, seismic considerations are very important factors that affect a building's structure, and knowing how it would react in such a situation will often be a controlling element for the building's design. Also, though it may not always be noticeable at ground level, taller buildings can be largely affected by gusts of wind that hit the structure at higher altitudes, especially when dealing with storming weather conditions.

The majority of the calculations performed for the lateral loadings are based upon the building's period; the amount of time it would take for the building to complete one full sway back and forth, in a seconds, when acted upon by lateral forces. When analyzed with only the structure's frame absorbing the lateral forces, the period for the building was calculated to be around 1.7 seconds. Though, as shear walls are added to the building, the stiffness of the structure can be manipulated, which in turn will affect the building's period, reducing the resulting sway and lessening the effects that the lateral forces inflict upon the building and its inhabitants. The original period of 1.7 seconds places the building into a category of flexible structures. Though, with the alternative concrete design and the utilization of shear walls, the building could exhibit a period of around 0.4 seconds, which would place the building into a rigid structure category.

Wind Load Analysis

The wind load for the hospital renovation was determined using the analysis illustrated in method 2 of the ASCE7-05 specifications. The majority of the calculations performed were based upon the original documented design properties for a hospital structure located in the Northern Ohio region, which include an average wind velocity of 90 mph, an importance factor of 1.15, and a “C” classification for the exposure category, as well as the numerous tables and charts provided within the ASCE7-05 specifications. In order to ease the calculations involved, the shape of the seven story tower addition was normalized from its original form to a standard rectangular shape, disregarding the curvilinear figure of the northern wall and all indentations on the western side of the patient tower. The connections between the patient tower renovation and the existing hospital building contain expansion joints that include Teflon slide bearings, allowing the buildings to react to lateral loading as separate identities. Thus, in this analysis, since the tower addition will absorb the largest amount of lateral wind force, it will be the main area of concern. The variables calculated for the wind analysis are shown in table 2.1 and the resulting wind forces that are inflicted upon the building at each story level, for the north-south direction and the east-west direction, are shown in figure 2.4 with contributing values shown in table 2.2 and table 2.3 respectively. The design pressures used as well as some of the necessary design charts referenced from the ASCE7-05 specifications are shown in Appendix F.

Building Properties		
	N-S	E-W
B	87'	318'
L	318'	87'
n1	2.5	2.5
h	104'	104'
$h_{min} = 0.6h$	62.4	62.4'
g_R	4.4	4.4
g_Q & g_v	3.40	3.40
R_n	0.025	0.025
I_z	0.18	0.18
V_z	94.64	94.64
R_h	0.076	0.076
ηh	12.64	12.64
β	5%	5%

	N-S Direction	E-W Direction
ηL	35.39	129.4
R_L	0.028	0.008
ηB	38.64	10.57
R_B	0.026	0.09
Q	0.81	0.871
R	0.2	0.043
Gf	0.84	0.86

Table 2.1

North – South Wind Loading								
Floor	Height (ft)	Tributary Height (ft)	Windward Pressure (psf)	Leeward Pressure (psf)	Total (psf)	Story Force (k)	Total Shear (k)	Overturning Moment (ft-k)
Ground	0	0	0	0	0	0	V = 980	M = 56468
2	15.33	15	9.64	-11.8	29.12	138.88	978.66	2129.04
3	30	14.67	10.53	-11.8	29.64	138.26	839.78	4147.83
4	44.67	14.67	11.7	-11.8	31.33	146.14	701.52	6528.12
5	59.33	14.67	12.74	-11.8	32.75	152.76	555.38	9063.29
6	74	14.67	13.63	-11.8	33.74	157.40	402.62	11647.72
7	88.67	14.67	14.21	-11.8	34.89	162.77	245.22	14433.09
Roof	103.33	7.33	14.95	-11.8	35.37	82.45	82.45	8519.14

Table 2.2

East – West Wind Loading								
Floor	Height (ft)	Tributary Height (ft)	Windward Pressure (psf)	Leeward Pressure (psf)	Total (psf)	Story Force (k)	Total Shear (k)	Overturning Moment (ft-k)
Ground	0	0	0	0	0	0	V = 795	M = 45759
2	15.33	15	9.64	-13.8	23.44	111.81	793.72	1714.03
3	30	14.67	10.53	-13.8	24.33	113.50	681.92	3405.03
4	44.67	14.67	11.7	-13.8	25.5	118.96	568.42	5313.90
5	59.33	14.67	12.74	-13.8	26.54	123.81	449.46	7345.69
6	74	14.67	13.63	-13.8	27.43	127.96	325.65	9469.23
7	88.67	14.67	14.21	-13.8	28.01	130.67	197.68	11586.36
Roof	103.33	7.33	14.95	-13.8	28.75	67.01	67.01	6924.61

Table 2.3

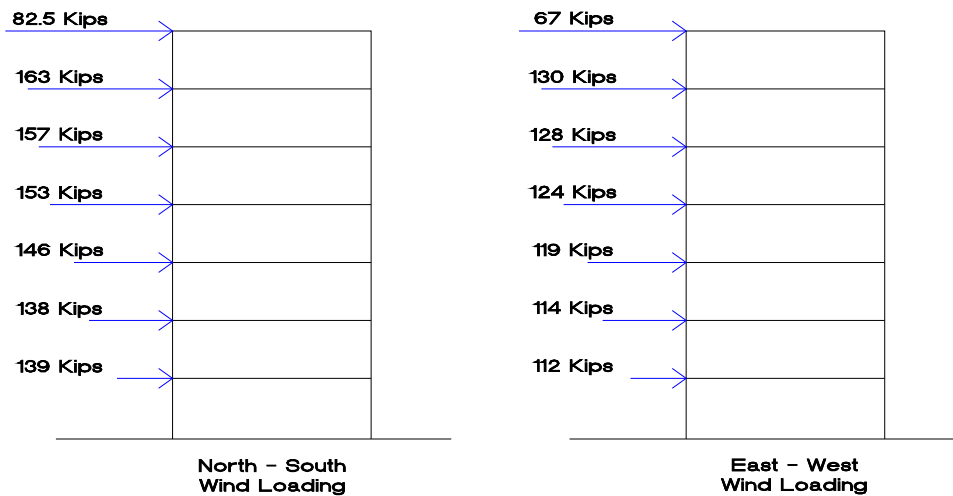


Figure 2.4

Seismic Load Analysis

The seismic analysis for the hospital was determined using the base shear calculations derived from the equivalent lateral force procedure from the ASCE7-05 specifications. The calculations performed for this section were evaluated using the “seismic design values for buildings” determined by the USGS motion parameter calculator, as well as the original documented design properties for a hospital structure and the soil on which the foundations are constructed. The basic seismic resisting system that has been chosen for the building is “special reinforced concrete shear walls”, which produces a response modification coefficient of 6. Due to the height of the building, this system is one of only a few options that are available from table 12.2-1 of the ASCE7-05 specifications. The section of table 12.2-1 which was referenced is available in Appendix G. The period used for the seismic calculations was determined using the structural analysis computer program Etabs, and was calculated to be about 0.4 seconds for the concrete framing structure with shear walls. The seismic analysis calculations performed for this section and the tables referenced from the ASCE7-05 specifications are shown in Appendix G.

The location of the hospital for the seismic considerations is at:

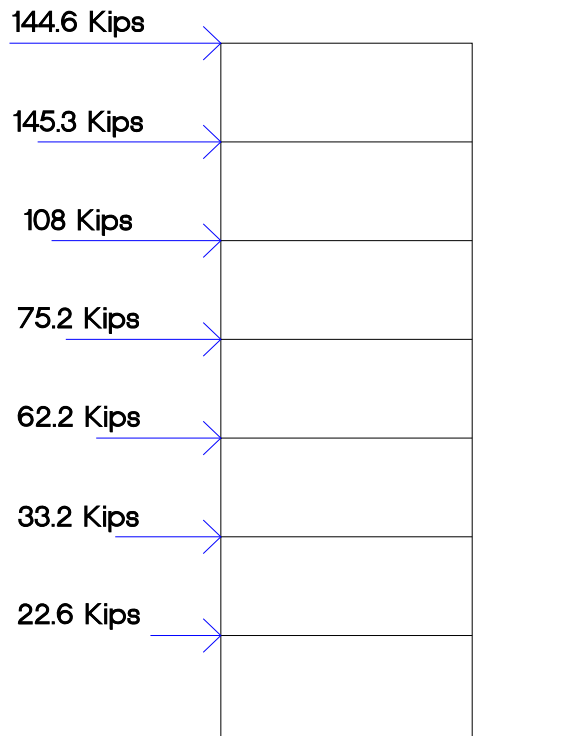
Latitude: 40° 59' 35”
Longitude: -80° 39' 35”

The design properties used for the seismic evaluation:

Velocity – Related Acceleration (SS).....	0.143
Peak Acceleration (S1).....	0.049
Seismic Hazard Exposure Group.....	III
Seismic Performance Category.....	C
Seismic Importance Factor (IE).....	1.5
Site Class.....	D

Lateral Seismic Force Distribution								
Level	Weight (kips)	Story Height h (ft)	Exponent k	$W_x \cdot h_x^k$ (kips)	C_{vx}	Story Force F_x (kips)	V_x (kips)	M_x (ft-kips)
Ground	16,689	0	-	-	-	-	-	-
2	11,104	15.33	1.64	976717	0.0382	22.55	22.55	345.77
3	5,429	30	1.64	1436146	0.0561	33.16	55.72	994.93
4	5,297	44.67	1.64	2691883	0.1052	62.16	117.88	2776.81
5	4,022	59.33	1.64	3255457	0.1272	75.18	193.06	4460.26
6	4,022	74	1.64	4677158	0.1828	108.01	301.07	7992.59
7	4,022	88.67	1.64	6292104	0.2459	145.30	446.37	12883.87
Roof	3,115	103.33	1.64	6263101	0.2447	144.63	591.00	14944.78
Sum	53,700	104		25592566	1	V = 591		M = 44399

Table 2.4



Seismic Loading

Figure 2.5

Lateral Resisting Systems

In order to effectively control the lateral wind and seismic forces affecting the building, a series of shear walls will be designed for the patient tower. The new reinforced concrete shear walls will be placed in the same locations as the original steel bracing systems, minus a few that were deemed unnecessary for the rigidity of a concrete system. Since the building is classified as a D level site class, there are many restrictions placed upon the design of the seismic resisting system. Due to these restriction requirements, the building will need to follow the ACI design code for “special reinforced concrete shear walls”. In all, there are sixteen remaining shear wall locations that exist throughout the building, the majority of them are centered about the elevator shafts, though there are also a number of walls scattered along the outer frames of the building in a few select locations and along the stairwell area in the far western corner of the building. The computer program E-tabs has been used to determine the effects that the seismic and wind forces would place upon the building, and the distribution of the forces amongst the several walls, as well as the natural frequency and period used for evaluating these forces. The shear walls were designed to be 8 inches in thickness, and have been determined to require boundary elements at the edge where each wall interacts with a column. The reinforcement for the shear walls were designed to contain one curtain of #5 reinforcing bars that span in both directions, utilizing a spacing of at most 15.5 inches on center. Figure 2.6 shows the shear wall locations that are in use throughout the building. The design calculations for the shear walls labeled in figure 2.6 are provided in Appendix E.

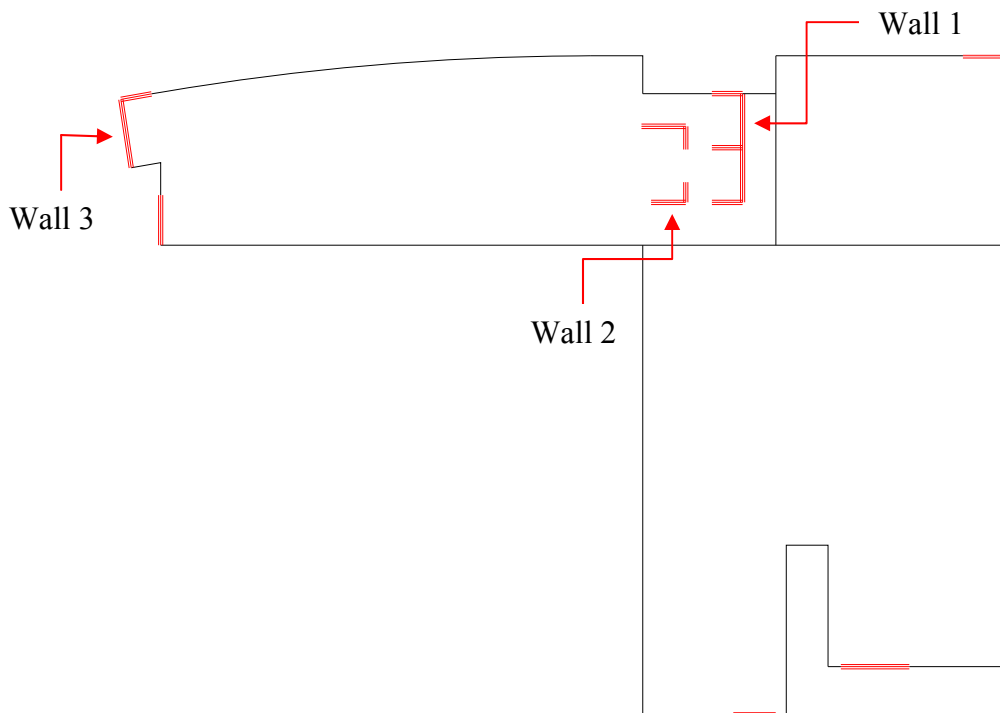


Figure 2.6

Structural Depth Conclusions

Throughout the study and redesign of the structural system of the St. Elizabeth Boardman Hospital project, various objectives and goals have been assumed and concluded to attain the most effective understanding of the project at hand. The main goals of this redesign study were to efficiently evaluate and compare the differences between the steel framing system and a concrete system, while providing personal insight into the analysis and design of concrete systems and their design methods.

After completing the analysis of the proposed alternative concrete system it has been concluded that the original steel system in place is the more efficient system to use with this specific building design. Though concrete systems do have their benefits for certain regional locations or specific aspects of a building's design, it seems as though for the hospital project at hand a steel system would provide more flexible design capabilities as well as possibilities for a more open architectural layout. The slab spans for instance, though completely reasonable for a steel design, were approaching a limit in length that would eventually produce slabs of unreasonable thickness for a structural concrete frame. One benefit that the concrete system did have over the steel design for this particular project was the ability to reduce the overall thickness of the flooring system. The steel framing system, with beams, girders, and a 4 inch slab has an overall depth of 36 inches, while the alternative concrete system designed for this evaluation has been sized at 22.5 inches in overall depth, a reduction of a little over a foot. This excess of ceiling area in the design could be used to create more space for mechanical systems and ductwork to run throughout the building, or added up, could lower the height of the building by seven to eight feet if desirable. Another beneficial outcome of altering the structure to a concrete system would be the added stiffness that concrete systems can possess. Due to this additional stiffness that is provided with a concrete framing system, the effects that the lateral forces inflict upon the hospital's structure would be largely decreased, with lateral drift displacements for the concrete design being calculated at a around a half an inch, falling well within the allowable limit of $H/400$, which amounts to a little over 3 inches.

Of course, if the project had been designed as a concrete building from the beginning, the architectural design, floor plan, and overall building schematics could have been planned differently and most likely much more accommodatingly. Therefore, it is not to say that steel structures are superior, or that this thesis evaluation was in any way unsuccessful. A concrete system, having been accounted for as the main structural system from the beginning of the project, could have worked just as well as the steel system that was inevitably put into place, if not slightly better.

Finally, the overlying goal of gaining more comprehensive knowledge and understanding of the design of concrete systems, their construction methods, and the tools that are available to aid with all aspects of the building design processes has certainly been a principle objective throughout this thesis study, and a seemingly successful endeavor.

Breadth Topics

Aside from the intrinsic changes produced throughout the building, this structural redesign of the St. Elizabeth Boardman Hospital will inherently cause an impact on other areas of the building's characteristics, the construction process, and likely other features of the hospital's campus. There are two additional areas of study that have been associated with the redesign of the hospital and the impact of modifying the structure from a steel framed system to a concrete framed system.

Most obviously affected by the structural modifications of a new framing design method are the managerial aspects of the construction process. First, an updated construction sequence and schedule will need to be prepared to determine how to most efficiently coordinate the construction of the building in a timely fashion. Secondly, a cost breakdown, which will determine the anticipated costs of material, equipment, and labor that needs to be put into the building's construction, will also be prepared. Each of which will be compared to the initial schedule and cost for the steel design to further understand some of the unseen differences between the two construction methods.

The other area of concern within the building procedure that will be evaluated is the process of declaring a building as "sustainable", though the LEED certification program. The building's sustainable aspects will be evaluated and its degree of sustainability will be reviewed. Among the numerous factors that decide the degree of a building's sustainability, this report will evaluate the effects of constructing a green roof atop the two story operating room / kitchen-cafeteria area, as opposed to the current EPDM roof membrane that is currently in place.

Construction Management

There are many variables that contribute to the construction decisions that get made during the pre-construction process that may determine the way a building is designed and/or eventually constructed. Many of these initial decisions will lie within the owner's hands, though it is also typically the architect and general contractor's responsibility to help guide the owner into the most efficient design possibility. Often, the overall costs of a project will be the determining factor that drives a project's final construction, though in many cases the scheduling process can be a key factor in choosing building methods for a significant building such as a hospital, where a quicker erection time may hold significance over the general building costs.

To properly determine the effects that the redesign will place upon the management of the hospital's construction renovation, the schedule and construction sequence, as well as the specific structural framing costs, for the entire renovation project will need to be evaluated and manipulated to effectively atone for the construction process using concrete construction techniques.

Scheduling

The scheduling process is a very important factor controlling the progress of a building's construction. The timing and sequence for a project's construction is often reliant on the overlapping of trade work as it moves throughout the building. It's important to correctly account for the time frames of each activity, in order be sure that none of the trades conflict with another's ability to work or is too reliant on the progression of another trades operations to accomplish their own scheduled tasks.

The scheduling process for the seven story patient tower phase alone was estimated to endure a time span stretching from June 2006 to September 2007, with trade work processes overlapping each other as the building continued to progress more and more stories skyward. Though, the only section of the schedule that will be examined for this thesis will be the erection of the concrete framing system, once evaluated it can then be comparatively contrasted with an estimated general schedule. A sample section of the original schedule obtained from the general contractor, highlighting the time spent erecting the steel framing, is provided in Appendix H.

A large aspect of deciding how aggressive a schedule can be is determining the amount of workers assumed to be on the job in a given work period. Each scheduled activity will require a specific labor crew to properly assemble each portion of the project's construction. Typical crews have an average daily output that can be produced in a given work day, though too many crews on site at one time will make the job site congested and unmanageable, making work more difficult to effectively complete. As a method of expediting the projected schedule, with the bottom floor's framing completed and the concrete nearing full structural capacity, the building's façade system and interior construction work can begin, thus involving other trades as early in the project as possible. The proposed scheduling update for the construction process involved with the erection of the alternative concrete framing system is provided in Appendix H.

The concrete system itself, structural framing components only, has been estimated to take in the area of seven months to construct. Whereas the structural steel erection schedule, even with time lapses between floor and wing erection sequences that last several days, only accounts for about four months of the project's schedule. Though each construction method requires various different construction processes and schedule manipulation. The main components of concern for the structural concrete framing system's slab construction scheduling process; the columns, the slab forming and shoring, the respective rebar, and the necessary reshoring are shown and labeled in the following figure 3.1

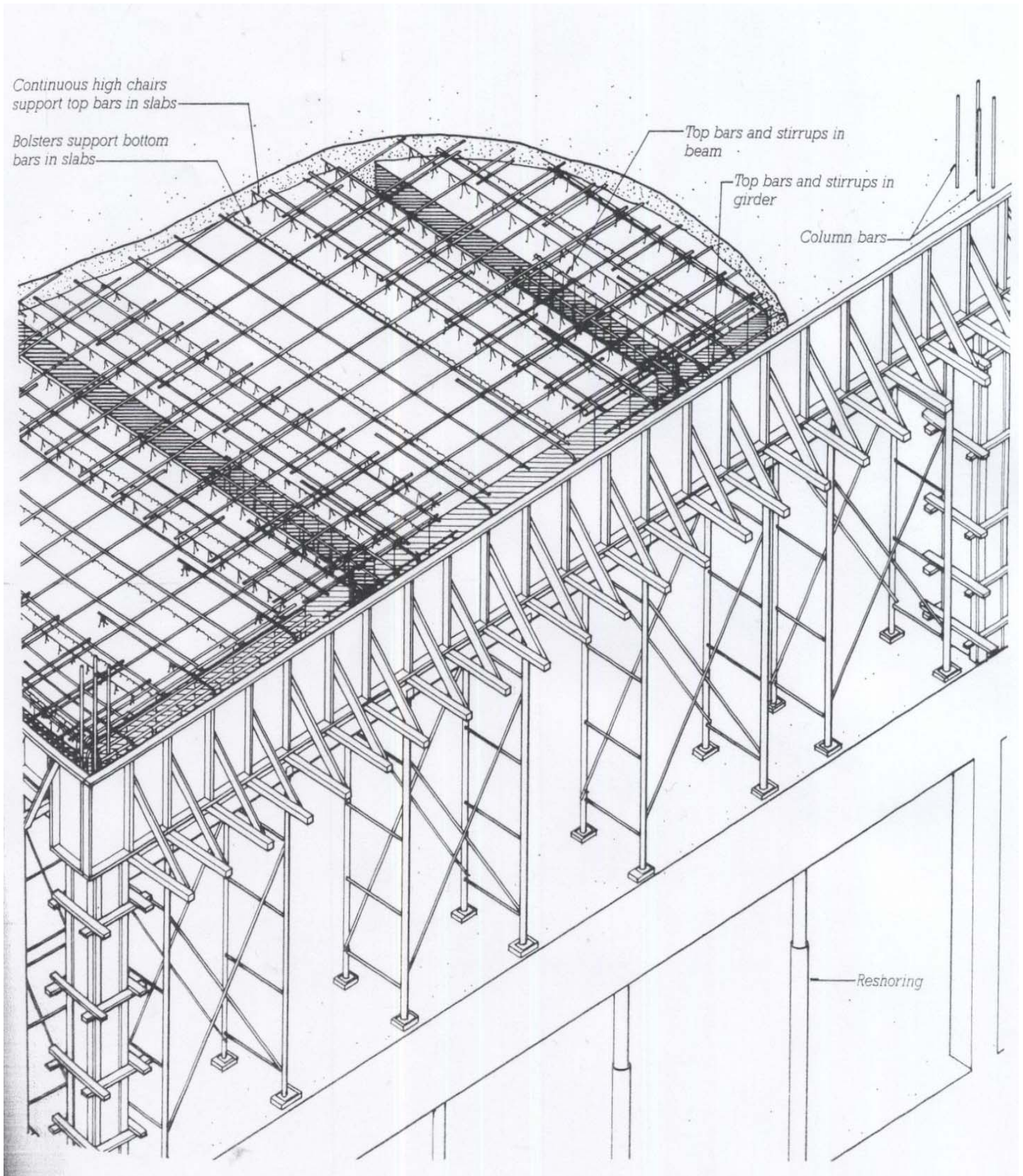


Figure 3.1

Sequencing

Along with establishing the scheduling for a project, is the erection sequence that must be determined to construct the building in the most efficient progression. There are many activities that must be accounted for when creating and adjusting a project's schedule. This thesis will simply examine the construction processes of the alternative concrete framing structure, and the main activities used to develop the schedule. The general sequence that is followed for the hospital's renovation begins with the two story operating room / kitchen-cafeteria area, and continues on with the patient tower and mechanical room portions of the building, once substantial construction is underway. With this approach, the structure for the two story section of the building can be completed, and work with the other trades can begin as the patient tower starts to rise skyward. This approach is beneficial because the building's more intricate areas, such as the lobby and the kitchen, are contained within this portion of the building, and getting the more complicated, non-repetitive, trade work underway early in the project is certainly an advantage.

A more specific description of the sequencing process can be examined with the construction process for the patient tower. With a more repetitive floor plan, the basic construction of this portion of the building will move much quicker as the construction workers become more accustomed to the project and its sequencing. The schedule and sequencing will commence where the alternative concrete framing system begins, with the erection of the superstructure. The initial tasks will be to form, set rebar, and place the concrete for the first floor columns. While the columns are being constructed, the forming and rebar for the shear walls will need to begin as well, in order to be able to place the shear wall concrete monolithically with the columns that border them, due to the need for boundary elements at the edges of the shear walls. Once these activities are accomplished, the formwork for the second floor slabs can be built and the respective rebar can be added to prepare to place the concrete for the first elevated slab. Figure 3.2 shows how the slab sections will need to be divided to effectively complete each pour in a reasonable time frame. In the meantime, the formwork for the columns and shear walls can begin to be stripped away from the concrete. An average concrete structural member should remain in the forms for two to seven days after placing the concrete, with this project the forming will typically remain in place for three to four days before stripping. After the slab is set, the process can be repeated for the next floor; forming the columns, with rebar placement lagging slightly behind, and shear wall construction to follow. As the building levels advance, and become ready to place the next elevated slab, the formwork and shoring will be stripped away from the floor below, and reshoring will be set in its place. The responsibility of the reshoring is to provide added support to the slab, which hasn't yet cured to full structural capacity, as more floors are added and thus more weight is placed upon the weakened concrete. The reshoring is typically used for the two stories directly under the floor slab which is being constructed, and will be spaced at about 10 feet on center between the columns. Figure 3.3 shows an example of a concrete framed building with shoring and forming on the top and progressing floors, and reshoring in place between the middle two floors.

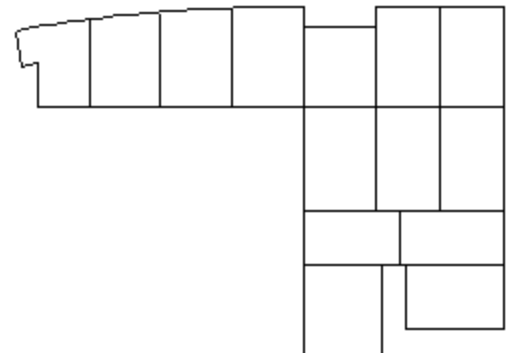


Figure 3.2

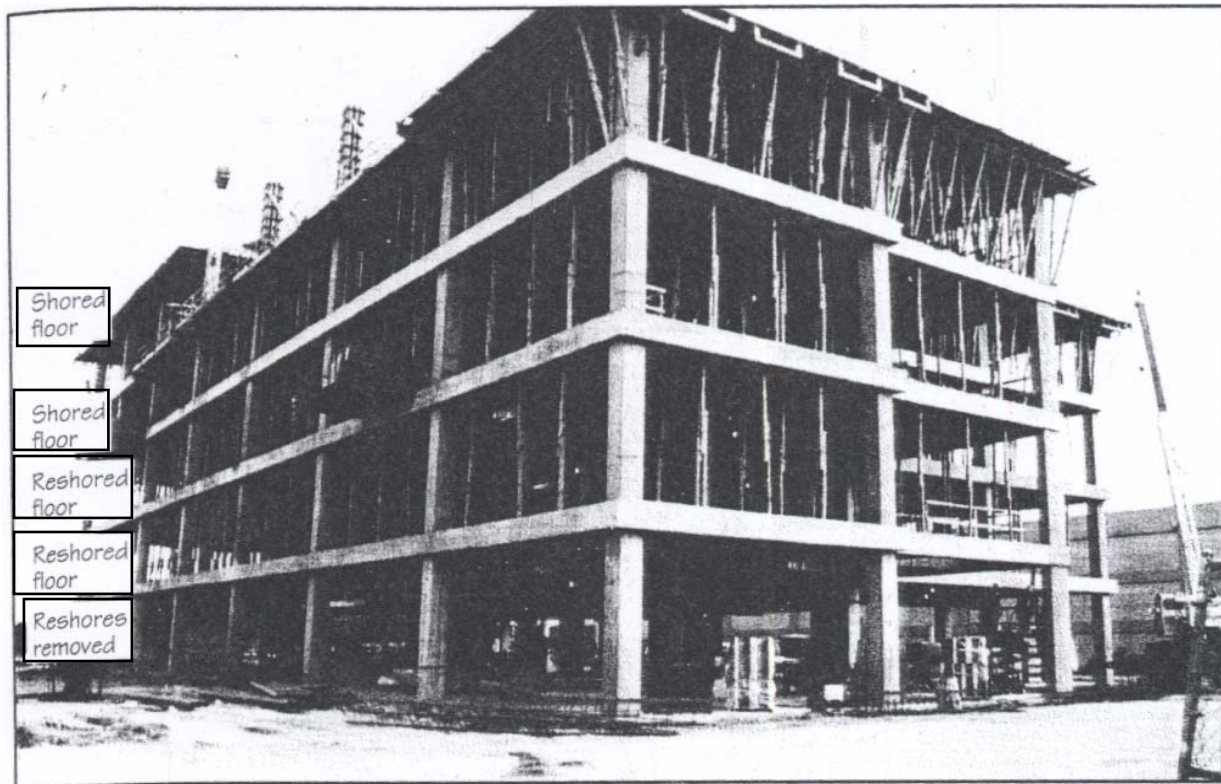


Figure 3.3

Cost Analysis

To fully understand the financial differences between the original steel design and the concrete alternative proposed in this thesis document, the individual costs of both structural systems will need to be analyzed and broken down into the separate categories that contribute substantially to the total cost. The majority of the expenses for a project are derived from the costs of materials, equipment, and labor, plus the costs of job site facilities, resources, and rentals as well as some necessary documentation required for legal purposes. There are numerous general costs associated with the design and erection of a structure that contributes greatly to a project's overall cost. Though, due to availability of information and time constraints, this fundamental cost analysis will be based solely on the raw material, labor, and equipment used to construct the building's structural framing system.

Original Steel Framing System

The basic overall costs of the steel structural system for the hospital renovation's original design have been obtained from the general contractor, The Albert M. Higley Company, and are shown broken down by building area and material or process in the following table 3.1.

Original Steel Structural Cost Breakdown			
	Area C	Area D	Area E
Structural Raw Materials	601,800	88,500	920,400
Structural Fabrication	401,200	59,000	613,600
Structural Erection	102,290	27,350	156,440
Structural Detailing	83,690	10,000	128,000
Metal Deck Material	68,000	10,000	9,000
Metal Deck Labor	24,820	3,650	5,000
Hung Lintel Final Adjustments	40,800	6,000	104,000
Joist Material	-----	-----	38,000
Joist Labor	-----	-----	52,860
Subtotals	\$ 1,322,600	\$ 204,500	\$ 2,027,300
Allowance		\$ 15,000	
Close-Out Documents		\$ 3,000	
Total Cost of Steel Structural System		\$ 3,572,400	

Table 3.1

Alternative Concrete Framing System

The cost information, shown in table 3.2, for the concrete framing system and its components was evaluated using the data provided in the 2006 RS Means catalogs. The concrete material pricing figures used in this analysis are based upon placement via pumping systems with the material amounts measured in cubic yards, while the rebar costs associated with the concrete quantities used are measured in pounds of steel, and the forming necessary to mold the concrete correctly into place is measured in units of square feet. Plywood is the most commonly used material to construct formwork for concrete placement, and the RS Means estimating resources for formwork are based on the assumption that the majority of the pieces of plywood will be used four times throughout the concrete's construction process

Alternative Concrete Structural Cost Breakdown				
	Material	Equipment	Labor	Total
Concrete				
Slabs	676,950	88,525	34,590	800,055
Drop Panels	27,300	1,395	3,570	32,265
Columns	102,875	23,175	9,160	135,210
Beams	43,407	5,915	15,026	64,348
Shear Walls	114,660	9,387	23,940	147,987
Shoring / Re-shoring	500	-----	3,300	3,800
Rebar				
Slabs	416,420	-----	194,920	611,340
Columns	76,248	-----	46,790	123,038
Beams	34,500	-----	31,363	65,863
Shear Walls	9,512	-----	4,540	14,052
Forming				
Slabs	100,500	-----	196,480	296,980
Columns	6,335	-----	34,415	40,750
Beams	62,505	-----	312,545	375,050
Shear Walls	8,940	-----	53,760	62,700
Subtotals	\$ 1,680,640	\$ 128,400	\$ 964,400	\$ 2,773,440
Allowance			\$ 15,000	
Close-Out Documents			\$ 3,000	
Estimated Total Cost of Concrete Structural System			\$ 2,791,440	
Location Adjustment Factor			0.955	
Projected Total Cost of Concrete Structural System			\$ 2,665,825	

Table 3.2

Aside from the outright costs of material, labor, and equipment that are calculated within the initial cost analysis, the lengthening of the schedule to account for the extended construction process, due to lengthy concrete building methods, will undoubtedly accrue numerous general costs for necessary job-site items such as trailers, dumpsters, port-o-johns, and fencing, as well as worker salaries and equipment rentals, plus several other elements that have not been efficiently accounted for within this basic cost breakdown analysis, but must be mentioned as key project expense driving factors.

It must also be mentioned that material availability and pricings do vary throughout different areas of the country, though there are location factors that are provided within the RS Means estimate resources to compensate for these economic differences. The table of factors used for the northern Ohio region where the St. Elizabeth Hospital is located, along with a few other major surrounding regions, is provided in Appendix H.

Material Usage

Any large construction project will undoubtedly consume mass amounts of resources to efficiently construct. For instance, due to the hospital's use of rather large spans between columns, the resulting floor slabs designed are required to be fairly thick to effectively support the estimated occupancy loading and meet code standards.

Some of the projected material amounts used to construct the alternative concrete system are as follows:

Concrete – measured in cubic yards of concrete

Slabs (including beams and drop panels) – 8,300 cubic yards

Columns – 1,130 cubic yards

Shear Walls – 630 cubic yards

Rebar – measured in tons of steel

Slabs – 485 tons

Columns – 87 tons

Shear Walls – 15 tons

Formwork – measured in square feet of plywood, used four times

Slabs – 123,950 square feet

Columns – 7,630 square feet

Shear Walls – 12,800 square feet

Construction Conclusions

As with the conclusions of the structural depth analysis, it seems as though the original steel framing design may still be the better construction method for this particular project design. Though, based on material usage alone, it does appear as if the concrete system would turn out to be the slightly less expensive construction process for the hospital. Although, as the schedule becomes a little more lagged behind, due to the slower construction methods available for concrete structures, the costs associated with the other trades and the deceleration of the extended schedule could add up quickly and cause general costs, like rentals or worker salaries, to rise rather quickly.

Though the schedule produced for the concrete section is simply the tasks involved with the structural framing system, it appears quite evident that the overall resultant schedule would be extended substantially to account for the prolonged framing construction and the time associated with curing concrete to its full, or at least adequately acceptable, structural capacity. If an accelerated turnover rate would be an essential element for the completion of the project, a more aggressive schedule could be formulated to make this achievable by use of additional labor crews, extended work periods, or larger daily material installations. The relevant portions of the original building schedule, the updated version of the alternative concrete construction schedule, as well as an example of unit pricings and output from the RS Means estimating resources are available in Appendix H.

Due to the nature of this building evaluation, many aspects of the hospital renovation project could have been planned for and designed very differently, given a concrete system in the preliminary design stages, to make a concrete system more applicable to the constraints of the project and its scheduling demands.

As with the overlying goal of insight and education, this evaluation of the scheduling and sequencing process for concrete structures has indeed provided numerous amounts of insight into the methodology and complexity of managerial procedures involved with the construction industry. Lastly, it must be understood that pricing will vary with the economy as well as from location to location, and that the estimating resources used to develop these initial cost comparisons are exactly that, estimates.

Sustainability / LEED Rating



Sustainability, the ability to “meet the needs of the present without compromising the ability of future generations to meet their own needs,” is quickly becoming a large factor in the business world, and it certainly holds a strong place in the building industry as well. The LEED rating system, since developed by the U.S. Green Building Council (USGBC) in 2001, has served as a design guide to help professionals improve the quality of our buildings and their systems, as well as their impact on the environment. The LEED rating system is broken down into six essential categories of environmentally responsible aspects of buildings. Each category is then broken down into available “points” that can be earned for utilizing sustainable processes and/or providing environmentally friendly alternative methodologies. Once a minimum of 26 points are achieved, out of a total of 69 possible credit points, the basic certification level can be assigned to the building, with different levels of achievement available to more extraordinarily sustainable buildings. The categories that are involved with the LEED system are as follows:

Sustainable Sites

This first category of the LEED program contains eight sections, which offer a total of fourteen available points relating to site development. An initial requirement for gaining any points within this category is to provide an erosion and sedimentation control plan for the construction activities that are to be associated with the project, in order to reduce pollution from stormwater runoff and airborne dust or particulates. Once the initial requirements of this section are accomplished, the remaining sections each provide one of the available points through areas such as restoring or protecting habitats, preserving greenfields by redeveloping abandoned sites or polluted sites, developing in densely populated areas, minimizing the building’s footprint, providing alternative public transportation or bicycle storage facilities, providing more efficient stormwater management, reducing the heat island effect caused by dark reflecting roof surfaces, or by reducing light pollution by using more efficient exterior lighting fixtures.

SS Credit 7.1: Heat Island Effect: Roof

With the addition of a vegetated green roof over the two story operating room / kitchen-cafeteria area of the building, the amount of reflective roofing surface could be greatly reduced, thus minimizing the heat island effects on the building’s summertime cooling load, as well as the effects of elevated climate temperatures on surrounding communities and habitats. Typical heat island effects can be seen in figure 4.2.

Water Efficiency

This next category, though arguably one of the more important areas of concern, is the smallest category in the LEED system, containing only five available points for water conservation efforts, and is the only category in the LEED system that does not require any pre-requisite obligations to earn its points. The points that are available for consideration deal mainly with water use reduction within the building and its surrounding landscaping. Points can be earned in this category by reducing landscaping demands by 50 percent or by using no potable water at all to landscape, only recycled wastewater or rainwater. The other available points can be earned by reducing the buildings water usage by 20% or 30% and by finding innovative ways to recycle wastewater.

WE Credit 2: Innovative Wastewater Technologies

There are various applicable ways to conserve the use of potable water within a building. By taking a deeper look into the systems that are currently used, a few standout opportunities may arise. The first potential subject would concern an upgrade of the restroom facilities systems to include waterless urinals. A single waterless urinal can save up to 45,000 gallons of water every year. By simply installing waterless urinal systems into the two public restrooms, let alone the 24 private patient restrooms, located on each floor of the patient tower, the hospital would be capable of possibly conserving an average of 540,000 gallons of potable water every year.

Energy and Atmosphere

The largest category in the LEED rating system, this section of the program contains seventeen available points and has three necessary pre-requisite conditions that must be met to achieve other energy related points. The initial requirements of this category involve verifying that the building's energy systems are up to code standards, establishing a minimum level of energy efficiency, and reducing ozone effects by eliminating the use of chlorofluorocarbon based refrigerants in the HVAC systems. The available points within this section involve issues such as on-site renewable energy options, enhanced refrigerant materials, the use of ongoing energy consumption management systems, and up to ten points for advanced levels of energy performance optimization.

Materials and Resources

This category consists primarily of the reuse of existing building materials as well as the management and recycling of waste products. The only pre-requisite that is required to earn points throughout these sections is to provide facilities to recycle waste and reduce the amount of materials that get hauled off to landfills. The available points that are described throughout this category dictate specific required amounts of reusable structural and non-structural materials, amounts of construction waste diverted from disposal, and usage of recycled / post-consumer content. In addition to use recycled material for building supplies, points can also be earned by utilizing materials produced and manufactured within the local region, materials that are produced from rapidly renewable resources, and wood which is produced from local timber yards or is certified in accordance with the Forest Stewardship Council.

Indoor Environmental Quality

This category deals with the air quality and personal health of the inhabitants of our buildings. There are two pre-requisites that must first be met to further obtain any of the other fifteen available points that are offered throughout the eight sections of this category. The first required pre-requisite states that the minimum indoor air quality of the building must meet the standards specified by specific sections of the ASHRAE 62.1-2004 code, and be properly ventilated to all updated codes as well. While the second pre-requisite, for environmental tobacco smoke control, simply pertains to prohibiting smoking within the building, and being sure to locate any designated exterior smoking areas at least 25 feet away from any entrances, outdoor air intakes, or operable windows.

Some of the available points offered throughout these sections come from topics that pertain to the buildings life before occupancy, such as the quality of the air during construction and the amount of ventilation time performed before occupancy is allowed. Other points come directly from the materials being used for the interior finishes within the building. The use of low-emitting materials is strongly suggested for a variety of points. Many materials commonly used for paints, adhesives, sealants, carpets, or other composite products often release Volatile Organic Compounds (VOC's) that may be odorous, irritating, and/or harmful to the comfort and well-being of the building's installers and/or occupants, and should be avoided if possible. Yet, a few of the other points available pertain specifically to the comfort levels maintained for the building's occupants, including temperature, day-lighting, ventilation, the amounts of fresh air run through the building's air conditioning units, and the ability to have localized control over all of these special climate conditions.

IEQ Credit 1: Outdoor Air Delivery Monitoring

The hospital does have a system that monitors the properties of the air as it is distributed through the air handling units, plus each of the particular areas of the building that the specific air handling unit supplies air to. The operating rooms alone are monitored for temperature, humidity, actual heating and cooling, discharge air temperature, and supply flow, plus systems such as exhaust fan output, occupancy, damper control, and all of the respective control settings as they exist in real time.

Innovation and Design Process

Lastly, the LEED rating system leaves an available one to five points to be awarded to projects or design teams that exude exceptional performance of any of the fore mentioned requirements set by the USGBC or any innovative categories that had not been specifically mentioned within the LEED rating system. In particular, one easy point acquired from this category can be achieved by employing at least one LEED accredited professional to work as a principle participant on the project.

Vegetated Green Roof Systems

Another option worth exploring, which may even be worth a few LEED points from a few various categories, is the installation of a green roof on the 36,000 square foot, two story operating room / kitchen-cafeteria area of the building. Although this portion of the building is set to have a second renovation project eventually constructed upon it, in the mean time a green roof could offer considerable assistance with the summertime cooling demands placed upon the hospital's HVAC system.

Composition

The elements that compose a green roof system are not all that complex or different from the materials used for a typical roofing system, aside from the plants and substrate of course. The typical layers of a green roof system, from the plants down to the actual building structure, begin of course, with the plants and vegetation of your choice. Though, the selection of the plant life used will be governed by the typical plant height and root spread, which will in turn regulate the depth of the substrate used. Based upon plant size, the typical roof layer design and general substrate depth can be determined using the chart provided in figure 4.5. The substrate, which is the next layer in the progression, is the "soil" of the green roof. Though due to wind and erosion, plain soil cannot be used, but a heavier, granular medium is required to hold the plants firmly in place. After the substrate layer is the filtration and root barrier layers. The root barrier is generally a porous filtering fabric that will allow water to seep through but not permit the roots of the plants to penetrate, thus protecting the roof membrane and insulation. Lastly, before the roof membrane and actual building structure, is the drainage material. There are a few different types of available drainage systems, the most typically used systems are shown in figure 4.5. A general section of the composition of a standard green roof is shown in figure 4.1.

There are generally two types of green roofs. An extensive green roof, which is a roof system with a typical substrate depth of between two and five inches that typically grows small, hardy, drought tolerable plants that require little to no maintenance. Additionally are the intensive green roofs, which utilize fairly deeper amounts of substrate, typically between six and twelve inches, and can therefore maintain much larger plants, though the intensive green roofs do typically require a bit more maintenance to sustain, thus the name intensive. Figure 4.5 shows a variety of green roof variables and their respective characteristics.



Figure 4.1

Benefits

There are numerous benefits to using a green roof system in comparison to an average flat roof system. The first advantageous characteristic of a green roof is its ability to assist with reducing stormwater runoff, because the majority of the stormwater will get soaked up into the roots of the plants that reside on the roof, less water is inevitably pouring through the gutter systems toward the local municipal treatment center or watershed. Another valuable function of green roofs is the simple and natural, yet very important function of plants. A thriving, well vegetated green roof can perform various natural functions such as oxygen production, carbon sequestration, the availability of habitats for local wildlife, and even food production for both wildlife and human consumption. A third application of green roofs is the absorption of and protection from direct sunlight, keeping the surface of the roof a great deal cooler. This now cooler roof surface can benefit the building in a variety of ways. First of all, the roof's outermost membrane would become protected from the damaging ultra violet rays of the sun which tend to deteriorate a typical roofing material, as well as remain insulated from the extreme fluctuations in temperature that occur in a seasonal climate, thus extending the life of the roof system. Secondly, the heat-island effect, which tends to contribute to a lot of heat in urban and suburban areas, can be significantly reduced. Though the hospital is not located in a directly urban area, any amount of heat island reduction is always a benefit. Figure 4.2 shows a graph of the effects that the heat island effect can produce on the climate a community. Lastly, and possibly most importantly for this project, the lower temperature roof system can help reduce the demands that are imposed upon the building's HVAC system for combating the necessary summertime cooling loads, while optimizing the energy performance of the mechanical system.

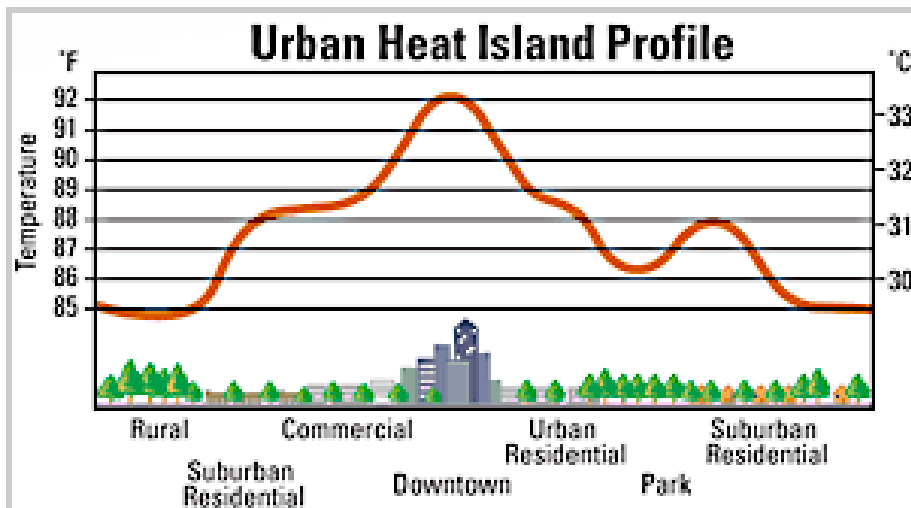


Figure 4.2 – Heat Island Effects Courtesy of the US EPA (www.epa.gov)

Vegetated Green Roof Systems vs. EPDM Roof Membranes

The current roofing system of the St. Elizabeth Hospital uses an exterior layer of single ply, 60 mils (thousandths of an inch) thick, white, reflective EPDM (ethylene propylene diene terpolymer) rubber roofing membrane for superior resistance to extreme weather conditions, ultraviolet light, hail, and the seasonal freeze-thaw cycle of the northern Ohio region. The use of this material for roofing purposes has demonstrated superior performance against harsh weather as well as excellent characteristics for water-proofing and leak control when compared to other traditional roof surfaces. But when the factors of building cooling loads and heat absorption are accounted for, it seems that there may be other considerations to be concerned with before deciding to use a reflective roof membrane surface. Figure 4.3 shows a photo of the roof section where the EPDM roof membrane would be converted to the proposed green roof system.

With the current architectural layout of the hospital, the two story section of the building, where the proposed green roof would be installed, is fully exposed to sunlight without any shading, gaining full southern exposure. Figure 4.4 shows the building plan with the story heights and green roof area labeled plus a north arrow distinguishing south facing areas. The key problem with this plan initially deals with the sunlight shinning upon the rooftop of the two story operating room / kitchen-cafeteria area, and the resulting surface heat acquired on the roof. The EPDM membrane's fundamental cooling solution is to reflect this light away from the building, in order to help lower the surface temperatures of the roof. Though, due to the actual angles of the sun, the light is not being reflected straight up, but is essentially being reflected toward the taller portions of the building, raising the surface temperature of the exterior walls instead. With typical buildings that have utilized a similar plan, the surface temperatures of the EPDM membrane and adjacent walls have been measured to reach temperatures as high as 160° F, even during cloudy days which produce indirect sunlight.

A green roof, on the other hand, offers numerous cooling techniques to naturally and effectively lower summertime cooling demands, while incorporating storm water management procedures and aesthetics into the roof system as well. With a green roof system, all of the direct sunlight shinning upon the roof would be absorbed and consumed by the plants, not reflected toward other nearby building structures. In addition, with the thick layer of substrate and organic material, moisture tends to stay trapped within the vegetated roof system, and the surface of the roof is cooled as this water slowly evaporates. More importantly, the roofing surface no longer has large peaks or drops in temperature, the layers of substrate and moisture are able to regulate the temperature of the roof, maintaining it to an average temperature range of 40° to 80° F year round.



Figure 4.3

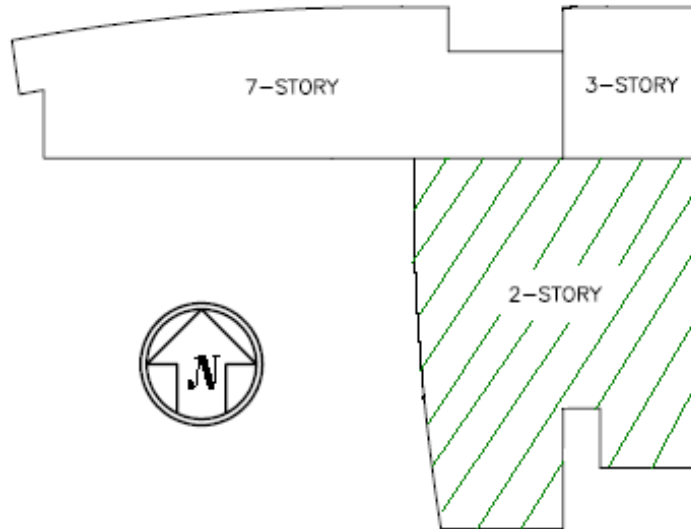


Figure 4.4

Installation

The average cost of a green roof system in the United States is estimated between \$15 and \$20 per square foot, including material, labor, and maintenance fees. The green roofing system that will be utilized for the St. Elizabeth Hospital project will be an extensive green roof, with a substrate depth of about four inches and a typical granular drainage system to alleviate excess storm water. The additional weight that the green roof system will impose upon the roofing structure would be a live load of around 28 psf dry and about 41 psf wet. Since this section of the building has already accounted for a future renovation and a live load of 100 psf, the necessary strength to support the green roof already exists, and seeing as the current roofing materials would have to be demolished to construct the future addition anyway, removing a green roof would not be a very arduous task, and its effects on the demands of the HVAC system would more than justify this temporary green roof addition.

Additional Complimenting Systems

In conjunction with the vegetated green roof system, a grey water system could be utilized to occasionally water and maintain the green roof, when necessary. Keeping the substrate moist, in order to help sustain healthy plant life and allow evaporation to take place, will inherently help cool the surface of the roof, in turn reducing the cooling load for the building. A basic grey water system could be constructed by simply collecting the wastewater produced by the hospital's laundry system or restroom sinks, collecting and storing the water for later use, then pumping the water throughout the green roof, as needed, to sprinkler systems strategically placed throughout the roof. The grey water system could easily be controlled mechanically using hydrometers, with a system of sensors placed in the substrate that measure the moisture levels. As the water in the green roof evaporates past an effective moisture level, the sprinkler system could become activated and distribute the recycled grey water throughout the roofing system.

GREEN ROOF SYSTEMS		SYSTEMS WITH GRANULAR DRAINAGE				SYSTEMS WITH DRAINAGE PLATES				SYSTEMS WITH DRAINAGE MATS	
		G1	G2	G3	G4	P1	P2	P3	P4	M1	M2
system designation		G1	G2	G3	G4	P1	P2	P3	P4	M1	M2
typical plants		sedum herbs	sedum herbs perennials	perennials grasses shrubs	grasses shrubs trees	sedum herbs	sedum herbs perennials	perennials grasses shrubs	grasses shrubs trees	sedum herbs	sedum herbs perennials
extensive soil mix		2"	4"	-	-	3"	5"	-	-	3"	5"
intensive soil mix		-	-	6"	9"	-	-	8"	12"	-	-
separation fabric		1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	-	-
granular drainage		2"	2"	4"	6"	-	-	-	-	-	-
drainage plate		-	-	-	-	1"	1-1/2"	1-1/2"	2-1/2"	-	-
drainage mat		-	-	-	-	-	-	-	-	3/8"	3/8"
protection mat		1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	-	-
nominal thickness		4"	6"	10"	15"	4"	7"	10"	15"	3"	5"
dry weight		19 lbs/ft ²	28 lbs/ft ²	45 lbs/ft ²	69 lbs/ft ²	14 lbs/ft ²	23 lbs/ft ²	34 lbs/ft ²	52 lbs/ft ²	14 lbs/ft ²	22 lbs/ft ²
saturated weight		26 lbs/ft ²	41 lbs/ft ²	70 lbs/ft ²	105 lbs/ft ²	23 lbs/ft ²	37 lbs/ft ²	57 lbs/ft ²	85 lbs/ft ²	23 lbs/ft ²	37 lbs/ft ²
minimum slope		0:12	0:12	0:12	0:12	1/4:12	1/4:12	1/4:12	1/4:12	1:12	1:12
maximum slope		1:12	1:12	1:12	1:12	1:12	1:12	1:12	1:12	3:12	3:12
water retention		50%	60%	70%	80%	50%	60%	70%	80%	50%	60%
irrigation system		-	-	subsurface	subsurface	-	-	surface	surface	-	-

Skyland USA LLC Certified Green Roof Media for all Green Roof Systems www.skylandusa.us p: 1.877.268.0017 © Resource Conservation Technology Inc.

Figure 4.5

Sustainability Conclusions

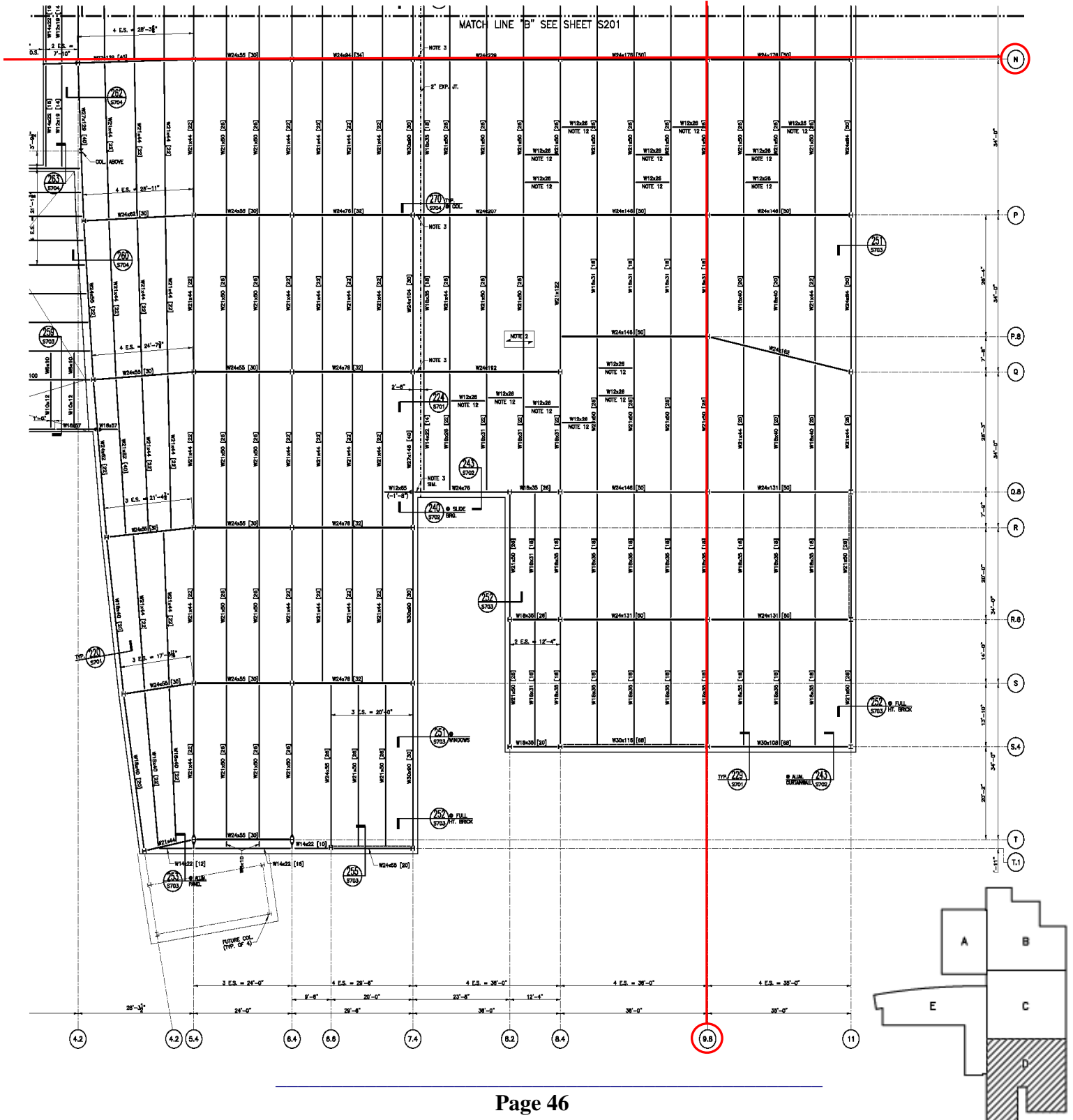
In all, the St. Elizabeth Hospital project does appear to have the potential to reach a LEED certified status. There are numerous opportunities to gain more credits toward a basic or higher level of certification that would be easily achievable, as well as beneficial for the building and its occupants. Many of the points that are available throughout the LEED program are features that have already been met due to the requirements and standards that most health care facilities must be built to. Though there was seemingly no intent by the hospital, or their associates, to investigate the building's actual LEED status, thus many already existing building features worthy of LEED points have been established out of necessity, while other easily obtainable points were not required to operate and maintain the hospital and were therefore simply overlooked.

The application of a green roof to the two story operating room / kitchen-cafeteria area is certainly a practical opportunity to achieve a number of available points from several categories throughout the LEED program. Some of the noteworthy characteristics portrayed by a green roof system and the possible credits available include; reducing the heat island effect by absorbing heat and minimizing reflective surfaces, reducing the surface temperature of the roof while minimizing the summertime cooling demands and optimizing the performance of the HVAC system, and utilizing a grey water system to recycle wastewater and maintain the roofs moisture levels. Also, since the structure of this section of the building is already built to withstand 100 psf of live load and the weight of an additional renovation that mirrors the proportions of the patient tower, the added weight of a temporary green roof system, in the mean time, would not require any additional structural reinforcement to account for this minimal live load application.

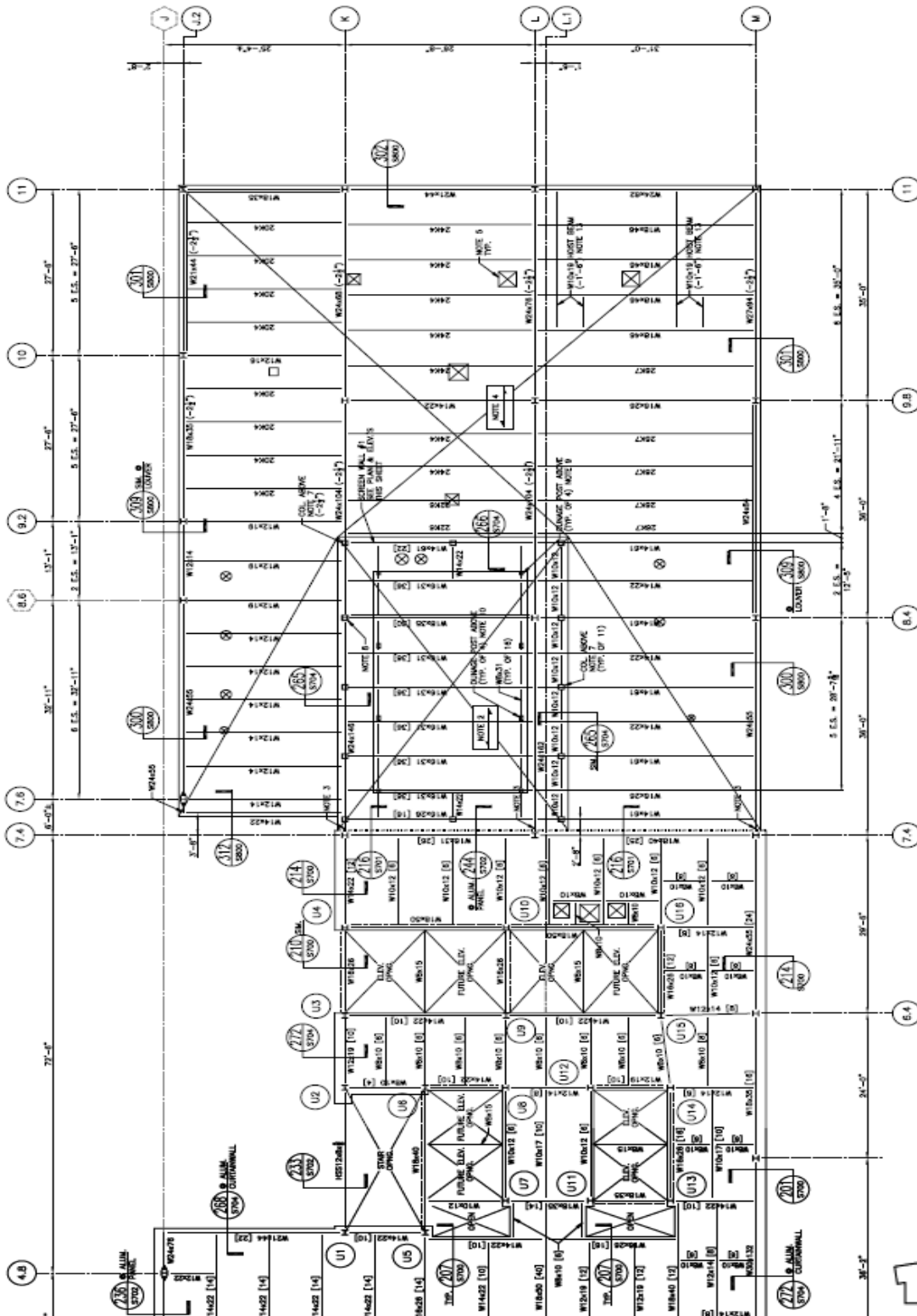
Appendix

Appendix A – Building Plans

Appendix A.1 – Sheet S202 – Second Floor Framing Plan – Area D



Appendix A.2 – Sheet S207 – Fourth Floor Framing Plan – Area C



Appendix B – Slab Designs

Appendix B.1 – One-way Slab Design Calculations

Josh Behun One-way slab page 1

One-way slab with beams

$f'_c = 4000 \text{ psi}$
 Columns @ 24 x 24

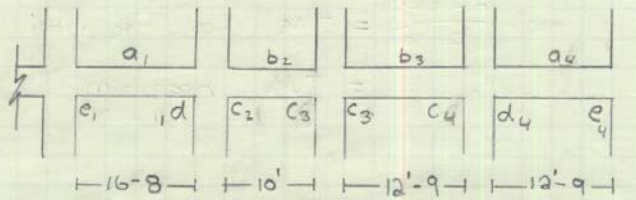
Slab thickness (both ends continuous)
 $\frac{L}{28} = \frac{16.67(12)}{28} = 7.14$ $\frac{12.5(12)}{28} = 5.5''$
 + try 8'' slab

$D_L = 8/12(150) = 100 + 20 = 120 \text{ psf}$
 $L_L = 100 \text{ psf}$
 $W_U = 1.2(120) + 1.6(100) = 304 \text{ psf}$

assume #9 bars
 $d = 8 - 3/4 - 1/2 = 6.75''$

One-way slab page 2

Frame A
critical moments



assume
24 x 24 columns

$$M = \frac{w_0 L_n^2}{x}$$

$$L_{avg1} = 13.34 \quad L_{avg2} = 11.38 \quad L_{avg3} = 12'-9''$$

midspan M^+

$$a_1 = \frac{.304(16.67)^2}{14} = 6.03 \text{ 'K}$$

$$a_4 = \frac{.304(12.75)^2}{14} = 3.5 \text{ 'K}$$

$$b_2 = \frac{.304(10)^2}{16} = 1.9 \text{ 'K}$$

$$b_3 = \frac{.304(12.75)^2}{16} = 3.09 \text{ 'K}$$

supports M^-

$$d_1 = \frac{.304(13.34)^2}{10} = 5.4 \text{ 'K}$$

$$d_4 = \frac{.304(12.75)^2}{10} = 4.9 \text{ 'K}$$

$$c_2 = \frac{.304(13.34)^2}{11} = 4.9 \text{ 'K}$$

$$c_3 = \frac{.304(11.38)^2}{11} = 3.58 \text{ 'K}$$

$$c_4 = \frac{.304(12.95)^2}{11} = 4.63 \text{ 'K}$$

beams

$$e_1 = \frac{.304(16.67)^2}{24} = 3.52 \text{ 'K}$$

$$e_4 = \frac{.304(12.75)^2}{24} = 2.06 \text{ 'K}$$

column

$$e_1 = \frac{.304(16.67)^2}{16} = 5.28 \text{ 'K}$$

$$e_4 = \frac{.304(12.75)^2}{16} = 3.09 \text{ 'K}$$

One-way Slab page 3

thickness check

$$\frac{bd^2}{12,000} = \frac{Mu}{\phi k_n}$$

$$\omega = \frac{.01(60000)}{4000} = 0.15$$

$$\phi k_n = \phi f'_c \omega (1 - .59\omega) = 492$$

$$bd^2 = \frac{6.03(12000)}{492} = 147 \text{ in}^3$$

$$d = \sqrt{\frac{147}{12}} = 3.5$$

$$d = 6.75 > 3.5 \quad \underline{\text{ok}} \text{ for flexure}$$

shear

$$V_u = \frac{1.15(.304)(6.67)}{2} = 2.91 \text{ k/ft}$$

$$\phi V_c = .75(2)\sqrt{4000}(6.75)(12) = 7.68 \text{ k/ft}$$

$$\phi V_c > V_u \quad \underline{\text{ok}}$$

One-way Slab page 4

Reinforcement

$$A_s = \frac{M_u}{\phi f_y j d} = \frac{6.03(12)}{.9(60)(.925)(6.75)} = 0.215 \text{ in}^2/\text{ft}$$

$$a = \frac{0.215(60)}{.85(4)12} = 0.316 \text{ in}$$

$$j d = d - \frac{a}{2} = 6.75 - \frac{.316}{2} = 6.59 \text{ in}$$

$$A_{smin} = .0018bh = .0018(8)(12) = 0.173 \text{ in}^2$$

$$A_s = \frac{M_u(12000)}{.9(60000)6.59} = .0337 M_u$$

also on page 2

	-	+	-	+	-	+	-	+	-
(1) L_n (ft)	16.67	16.67	13.34	10'	11.38	12.75	12.75	12.75	12.75
(2) $W_u L_n^2$	93.1	93.1	59.6	33.5	43.4	54.5	54.5	54.5	54.5
(3) M_u	5.28	6.03	5.4	1.9	3.58	3.09	4.9	3.75	3.09
(4) $A_{s req'd}$	.178	.203	.182	.064	.121	.104	.165	.118	.104
(5) A_{smin}	.173	.173	.173	.173	.173	.173	.173	.173	.173
(6) steel	#4@12"	#5@12"	#4@12"						
(7) A_s Provided	.2	.31	.2						

crack control

$$S = 15 \left(\frac{40000}{.67(60000)} \right) - 2.5(.75) = 13.1$$

∴ cannot use #5 bars @ 18"
must use #5 bars @ 12" oc
making A_s provided .31 in²

temperature/shrinkage

$$A_s = .0018bh = .0018(8)12 = 0.173 \text{ in}^2/\text{ft}$$

use #4 bars @ 12" oc

Appendix B.2 – Two-way Slab with Drop Panels – Hand Calculations

Drop Panels page 1

column sizes 24x24
interior panel
 $L_c = 100$ psf
 $S_{ID} = 20$ psf
 $f'_c = 4000$ psi
 $f_y = 60,000$ psi
slab thickness = 9.5"
drop panel thickness = 7.5"

$$D_L = \frac{9.5}{12}(150) = 120 \text{ psf}$$

$$W_U = 1.2(140) + 1.6(100) = 330 \text{ psf}$$

$$M_o = \frac{W_U L_n^2 L_2}{8} = \frac{.33(34)(24 - \frac{24}{12})^2}{8} = 680 \text{ 'K}$$

$$M^+ = .35(680) = 238 \text{ 'K}$$

$$M^- = .65(680) = 442 \text{ 'K}$$

$$M_S \quad M^- = .25(442) = 110.5$$

$$M^+ = .4(238) = 95.2$$

$$C_S \quad M^- = .75(442) = 331.5$$

$$M^+ = .6(238) = 142.8$$

$d = 9.5 - \frac{3}{4} - 1\frac{1}{2} = 7.25$
assume #8 bars

frame B

$$M_o = \frac{.33(24)(34 - \frac{24}{12})^2}{8} = 1015 \text{ 'K}$$

$$M^+ = .35(1015) = 355$$

$$M^- = .65(1015) = 660$$

$d = 9.5 - \frac{3}{4} = 8.25$

$$M_S \quad M^- = .25(660) = 165$$

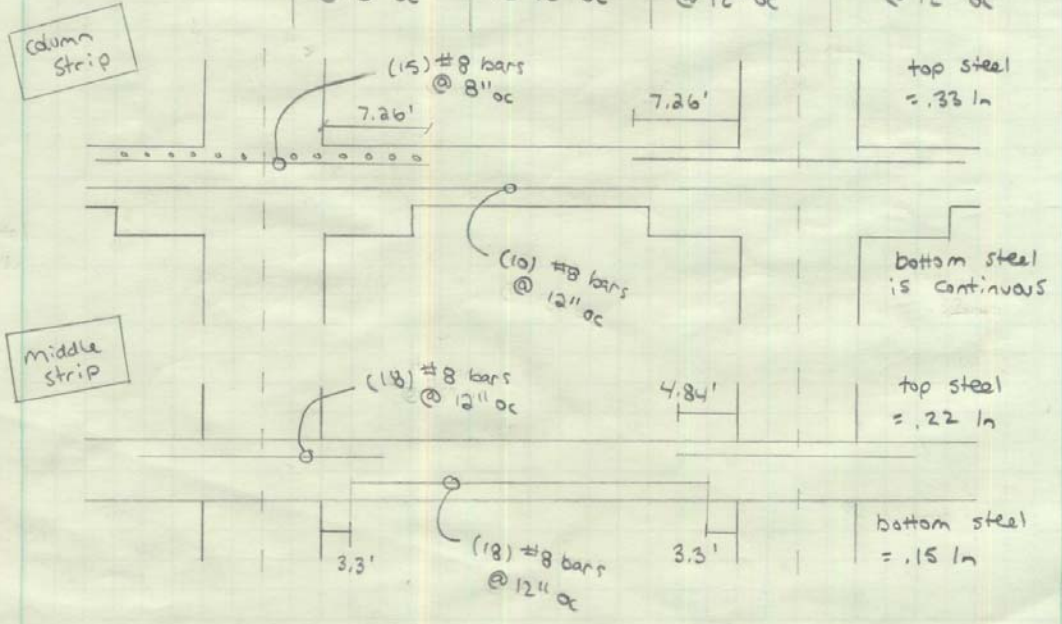
$$M^+ = .4(355) = 142$$

$$C_S \quad M^- = .75(660) = 495$$

$$M^+ = .6(355) = 213$$

Drop Panels page 2

Frame A	CS		MS	
	M-	M+	M-	M+
(1) moment	331.5	142.8	110.5	95.2
(2) width b drop panels	11.33' = 136"	12' = 144"	22' = 264"	264"
(3) effective d	7.25	7.25	7.25	7.25
(4) $M_N = \frac{M_U}{.9}$	368	159	123	106
(5) $R = \frac{M_N (12000)}{bd^2}$	618	252	106	92
(6) ϕ table A.5	.0115	.0044	.0017	.0015
(7) $A_s = \phi db$	11.34	4.6	3.25	2.87
(8) $A_{s \text{ min}} = .002bt$	2.58	2.74	5.02	5.02
(9) $N = \frac{A_s}{A_b}$	$\frac{11.34}{.79} = 15 \text{ bars}$	6 bars	7 bars	7 bars
(10) $N_{\text{min}} = \frac{b}{2t}$	7.15 = 9 bars	7.59 = 10 bars	13.89 = 18 bars	13.89 = 18 bars
(11) bars used	(15) #8 bars @ 8" oc	(10) #8 bars @ 12" oc	(18) #8 bars @ 12" oc	(18) #8 bars @ 12" oc



Drop Panels page 3

bar cutoff

with drop panels

column strip

$$\text{top steel} = .33 l_n = .33 (22) = 7.26'$$

$$\text{bottom steel is continuous } .33 (32) = 10.56' \text{ (frame B)}$$

middle strip

$$\text{top steel} = .22 l_n = .22 (22) = 4.84'$$

$$\text{bottom steel} = .15 l_n = .15 (22) = 3.3'$$

$$.22 (32) = 7.04' \text{ (frame B)}$$

$$.15 (32) = 4.8'$$

$$17 - 3/4 - 1 1/2 = 14.75 = d$$

column shear

$$V_c = 4 \sqrt{f'_c} b_o d$$

$$= 4 \sqrt{4000} (155) (14.75) = 578$$

$$b_o = \left[24 + \frac{14.75 (2)}{2} \right] 4 = 155''$$

$$\beta_c = \frac{b_c}{b_s} = \frac{34}{24} = 1.42$$

$$V_c = \left(2 + \frac{4}{\beta_c} \right) \sqrt{f'_c} b_o d \quad \leftarrow \text{governs}$$

$$= \left(2 + \frac{4}{1.42} \right) \sqrt{4000} (155) (14.75) = 697 \text{ K}$$

$\alpha_c = 40$
for interior columns

$$V_c = \left(\frac{\alpha_c d}{b_o} + 2 \right) \sqrt{f'_c} b_o d$$

$$= \left(\frac{40 (14.75)}{155} + 2 \right) \sqrt{4000} (155) (14.75) = 840 \text{ K}$$

punching shear

$$V_u = w_u A$$

$$= .33 \left[34(24) - \left(24 + \frac{14.75 (2)}{2} \right)^2 \right] = 270$$

$$\phi V_c = .75 (578) = 435$$

$$\phi V_c > V_u \quad \underline{\text{OK}}$$

drop panel

$$V_c = 4 (\sqrt{4000}) (1015) (9.5) = 2440$$

$$\phi V_c = .75 (2440) = 1830$$

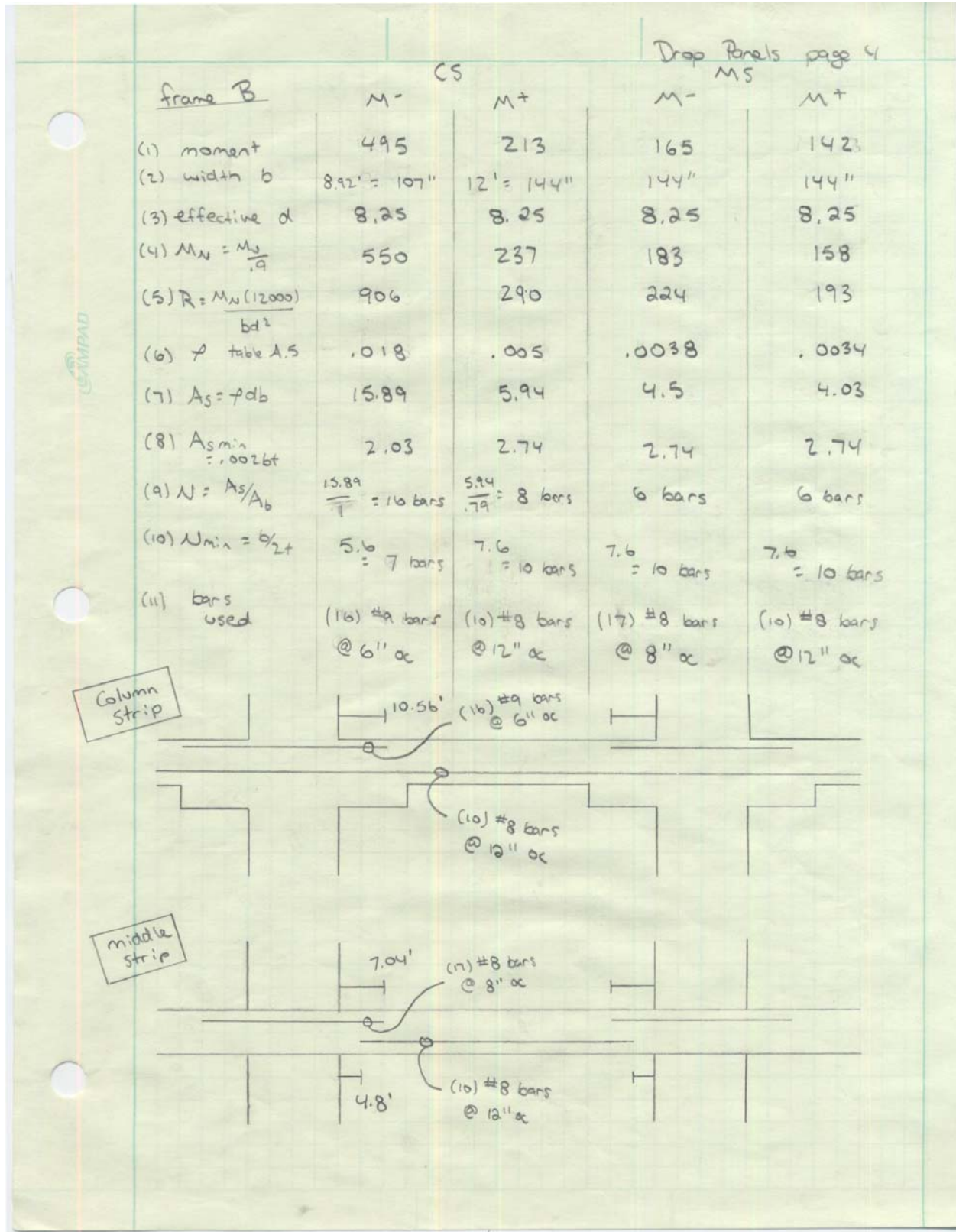
$$V_u = .33 [34(24)] = 270$$

$$\phi V_c > V_u \quad \underline{\text{OK}}$$

$$b_o = \left[(2) 12 (11.33) + 9.5 \right] 2$$

$$+ \left[(2) 12 (8.92) + 9.5 \right] 2$$

$$= 565 + 450 = 1015$$



**Appendix B.3 – Two-way Slab with Drop Panels – PCA Slab Calculations
Column Line K in Mechanical Room Slab**



Top Reinforcement:

Units: Width (ft), Mmax (k-ft), Xmax (ft), As (in²), Sp (in)

Span	Strip	Zone	Width	Mmax	Xmax	AsMin	AsMax	SpReq	AsReq	Bars	
2	Column	Left	13.00	503.88	1.000	2.668	23.246	7.800	15.145	20-#8	
		Middle	13.00	0.00	18.000	0.000	23.599	0.000	0.000	---	
		Right	13.00	843.90	35.000	4.072	29.586	9.176	12.788	17-#8	
	Middle	Left	13.00	22.38	1.000	2.668	23.599	15.600	0.596	10-#6	
		Middle	13.00	0.00	18.000	0.000	23.599	0.000	0.000	---	
		Right	13.00	281.31	35.000	2.668	23.423	11.143	7.951	14-#7	
	3	Column	Left	13.00	728.70	1.000	4.072	29.586	9.176	10.924	17-#8
			Middle	13.00	0.00	18.000	0.000	23.599	0.000	0.000	---
			Right	13.00	710.19	35.000	4.072	29.586	9.750	10.629	16-#8
Middle		Left	13.00	242.90	1.000	2.668	23.423	11.143	6.809	14-#7	
		Middle	13.00	0.00	18.000	0.000	23.599	0.000	0.000	---	
		Right	13.00	236.73	35.000	2.668	23.599	9.176	6.573	17-#6	
4		Column	Left	13.00	801.83	1.000	4.072	29.586	9.750	12.102	16-#8
			Middle	13.00	0.00	17.500	0.000	23.599	0.000	0.000	---
			Right	13.00	445.16	34.000	2.668	23.246	9.176	13.182	17-#8
	Middle	Left	13.00	267.28	1.000	2.668	23.599	9.176	7.469	17-#6	
		Middle	13.00	0.00	17.500	0.000	23.599	0.000	0.000	---	
		Right	13.00	42.59	34.000	2.668	23.599	15.600	1.139	10-#6	

Top Bar Details:

Units: Length (ft)

Span	Strip	Left				Continuous		Right			
		Bars	Length	Bars	Length	Bars	Length	Bars	Length	Bars	Length
2	Column	10-#8	12.22	10-#8	7.80	---	---	9-#8	16.03	8-#8	11.31
	Middle	10-#6	8.48	---	---	---	---	15-#7	15.13	---	---
3	Column	9-#8	15.86	8-#8	9.91	---	---	8-#8	15.74	8-#8	10.22
	Middle	15-#7	15.10	---	---	---	---	17-#6	13.87	---	---
4	Column	8-#8	16.01	8-#8	11.34	---	---	9-#8	11.89	8-#8	7.60
	Middle	17-#6	13.83	---	---	---	---	10-#6	8.26	---	---

Bottom Reinforcement:

```

=====
Units: Width (ft), Mmax (k-ft), Xmax (ft), As (in^2), Sp (in)
Span Strip   Width      Mmax      Xmax      AsMin     AsMax     SpReq     AsReq     Bars
-----
2 Column     13.00      254.70    16.080    2.668     23.599    9.176     7.099    17-#6
  Middle     13.00      169.80    16.080    2.668     23.599    14.182    4.652    11-#6

3 Column     13.00      178.59    18.000    2.668     23.599    13.000    4.901    12-#6
  Middle     13.00      119.06    18.000    2.668     23.599    15.600    3.230    10-#6

4 Column     13.00      240.21    19.635    2.668     23.599    9.750     6.675    16-#6
  Middle     13.00      160.14    19.635    2.668     23.599    15.600    4.379    10-#6

```

Bottom Bar Details:

```

=====
Units: Start (ft), Length (ft)
Span Strip   Long Bars      Short Bars
            Bars Start Length Bars Start Length
-----
2 Column     17-#6  0.00  36.00  ---
  Middle     7-#6  0.00  36.00  4-#6  0.00  30.60

3 Column     12-#6  0.00  36.00  ---
  Middle     7-#6  0.00  36.00  3-#6  5.40  25.20

4 Column     16-#6  0.00  35.00  ---
  Middle     7-#6  0.00  35.00  3-#6  5.25  29.75

```


Slab Shear Capacity:

Units: b, d (in), Xu (ft), PhiVc, Vu(kip)

Span	b	d	Vratio	PhiVc	Vu	Xu
2	312.00	8.25	1.000	244.19	159.94	34.31
3	312.00	8.25	1.000	244.19	143.41	1.69
4	312.00	8.25	1.000	244.19	155.55	1.69

Flexural Transfer of Negative Unbalanced Moment at Supports:

Units: Width (in), Munb (k-ft), As (in^2)

Supp	Width	GammaF*Munb	Comb	Pat	AsReq	AsProv	Additional Bars
2	75.00	241.96	U2	Even	3.506	6.457	---
3	75.00	223.10	U2	Even	3.226	6.077	---
4	52.50	376.30	U2	All	14.305	4.520	13-#8

Punching Shear Around Columns:

Units: Vu (kip), Munb (k-ft), vu (psi), Phi*vc (psi)

Supp	Vu	vu	Munb	Comb	Pat	GammaV	vu	Phi*vc
2	331.62	132.4	-170.15	U2	All	0.400	156.1	189.7
3	325.78	130.1	135.79	U2	All	0.400	149.0	189.7

Punching Shear Around Drops:

Units: Vu (kip), vu (psi), Phi*vc (psi)

Supp	Vu	Comb	Pat	vu	Phi*vc
2	296.46	U2	All	67.9	124.5
3	291.12	U2	All	67.2	124.7

Maximum Deflections:

Units: Dz (in)

Span	Frame			Column Strip			Middle Strip		
	Dz (DEAD)	Dz (LIVE)	Dz (TOTAL)	Dz (DEAD)	Dz (LIVE)	Dz (TOTAL)	Dz (DEAD)	Dz (LIVE)	Dz (TOTAL)
2	-0.326	-0.613	-0.938	-0.473	-0.890	-1.363	-0.178	-0.335	-0.512
3	-0.151	-0.284	-0.434	-0.203	-0.383	-0.586	-0.098	-0.184	-0.282
4	-0.282	-0.546	-0.828	-0.404	-0.782	-1.186	-0.161	-0.311	-0.471

Appendix C – Beam Designs

Josh Behun
Beam Design page 1

$f'_c = 4000 \text{ psi}$
 $f_y = 60000 \text{ psi}$

slab thickness $h_f = 8''$ $L_c = 100 \text{ psf}$
 positive moment area $S_{xL} = 20 \text{ psf}$

$A_T = 22.5'(14.75') = 332 \text{ ft}^2$

$L = L_c \left(.25 + \frac{15}{\sqrt{K_{LL} A_T}} \right)$ $K_{LL} = 2.0$ for interior beam

$= 100 \left(.25 + \frac{15}{\sqrt{2(332)}} \right) = 83 \text{ psf}$ $83 > .4L$ ok

negative moment area

$A_T = 22.5(14.75) + 23.67(7.4) = 507 \text{ ft}^2$

$L = 100 \left(.25 + \frac{15}{\sqrt{2(507)}} \right) = 72 \text{ psf}$

conservatively use 83 psf throughout

$D_L = \frac{8}{12}(150) = 100 + 20 = 120 \text{ psf}$

$W_u = 120(1.2) + 83(1.6) = 280 \text{ psf}$

$\left(14.75' + \frac{24}{12} \right) 280 \text{ psf} = 4.7 \text{ klf}$

assume initial beam sizes

$h = .12l_n = .1(14.75) = 18''$ $D_L = \frac{110}{12} \left(\frac{9}{12} \right) 150 = 94 \text{ plf}$
 $bw = .5h = .5(18) = 9''$ $+ 4.7 \text{ klf}$

total trial load = 4.8 klf

Beam Design page 2

actual dimensions

$$\min h = \frac{l}{18.5} = \frac{22.5(12) + 12}{18.5} = 15.3''$$

$$l_n = \frac{(22.5 + 23.67)12}{2} = 23'-1''$$

$$M_u^- = \frac{4.8(23.08)^2}{10} = 256 \text{ 'K}$$

assuming ϕ is limited to 0.013

$$\phi k_N = 621$$

$$\frac{bd^2}{12000} = \frac{M_u}{\phi k_N} \Rightarrow bd^2 = \frac{256(12000)}{621} = 4950 \text{ in}^3$$

possible sizes for bd^2

$$b = 9 \text{ in} \quad d = 23.5 \text{ in}$$

$$b = 10 \text{ in} \quad d = 22.3 \text{ in}$$

$$b = 12 \text{ in} \quad d = 20.3 \text{ in}$$

$$b = 14 \text{ in} \quad d = 18.8 \text{ in}$$

$$b = 16 \text{ in} \quad d = 17.5 \text{ in}$$

try 16" wide beam
 $h = 17.5 + 2.5 = 20$
20" depth and $d = 17.5$

shear check

$$V_u = \frac{1.15(4.8)22.5'}{2} = 62.1 \text{ K}$$

$$V_c = 2\sqrt{4000}(16)(17.5) = 35.4 \text{ K}$$

$$V_s = 8\sqrt{4000}(16)(17.5) = 141.7 \text{ K}$$

$$\phi V_N = .75(35.4 + 141.7) = 132.8 \text{ K}$$

$$V_u < \phi V_N \quad \underline{\text{ok}}$$

Beam Design page 3

new stem weight

$$D_L = \frac{16(12)(12)}{1728}(150) = .2 \text{ K/ft}$$

$$W_D = 120(14.75' + 2') + 200 \text{ lb/ft} = 2210 \text{ Klb/ft}$$

$$W_L = 83(14.75 + 2) = 1390 \text{ lb/ft}$$

$$W_U = 1.2(2210) + 1.6(1390) = 4.9 \text{ K/ft}$$

flange width

$$b_{eff} = \frac{1}{4} \text{ span} = \frac{1}{2}(22.5)12 = 68'' \leftarrow \text{governs}$$

$$b_w + 16h_f = 16 + 16(8) = 144''$$

$$b_w + \frac{1}{2} \text{ distance} = \frac{1}{2}(14.75)12 = 89''$$

Beam moments

		-	+	-	+	-	+	-
(1) l_n	22.5'	22.5	23.09	23.67	18.3	21.3	13	
(2) W_U	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
(3) $W_U l_n^2$	2481	2481	2612	2745	1641	828	828	
(4) C_m	$\frac{1}{16}$	$\frac{1}{14}$	$\frac{1}{10}$	$\frac{1}{16}$	$\frac{1}{10}$	$\frac{1}{14}$	$\frac{1}{16}$	
(5) M_U	155	177	261	172	164	59	52	

negative steel reinforcement

assume $j = .875$

$$A_s = \frac{M_U(12000)}{\phi f_y j d} = \frac{261(12000)}{.9(60000)(.875)(17.5)} = 3.79 \text{ in}^2$$

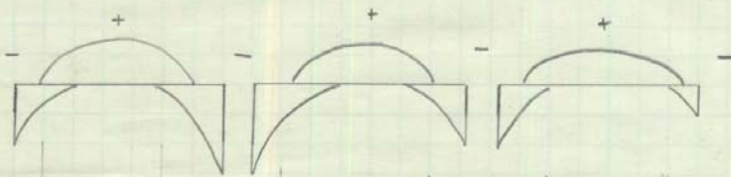
$$a = \frac{3.79(60)}{.85(4)16} = 4.18''$$

$$\frac{a}{d} = \frac{a}{d} = \frac{4.18}{17.5} = 0.239$$

$$\frac{a}{d} < \frac{a_b}{d} = .503 \therefore f_s = f_y \text{ at ultimate}$$

$$\frac{a}{d} < \frac{a_{tcl}}{d} = .309 \text{ section is tension controlled, } \phi = .9$$

Beam Design page 4



(5) M_U	155	177	261	172	164	59	52
(6) $A_{s, req'd}$	2.23	2.30	3.76	2.24	2.36	0.77	0.75
(7) $A_{s, min}$	.504	.504	.504	.504	.504	.504	.504
(8) bars	(6) #6	(6) #6	(5) #8	(6) #6	(6) #6	(4) #4	(4) #4
(9) $A_{s, prov}$	2.64	2.64	3.95	2.64	2.64	0.8	0.8
(10) $b_w d$	13.25" ok	—	12.75" ok	—	13.25" ok	—	8.75" ok @ 2" spacing = 11.75" ok

(all @ 1" spacing)

$$A_s = \frac{M_U (12000)}{.9 (60000) (17.5 - \frac{4.18}{2})} = .0144 M_U$$

$$A_{s, min} = .0018 b h = .0018 (16) (17.5) = 0.504$$

positive steel reinforcement

assume $j = .95$

$$A_s = \frac{177 (12000)}{.9 (60000) .95 (17.5)} = 2.37 \text{ in}^2$$

#3 stirrup

$$a = \frac{2.37 (60)}{.85 (4) (68)} = 0.615 < h_f = 8$$

$$C_c = 1.5" + \frac{3.75}{2} = 1.875 \text{ in}$$

cover stirrup

$$\frac{a}{d} = \frac{a}{d_t} = \frac{.615}{17.5} = 0.035$$

$$S = 15 \left(\frac{40000}{.16 (60000)} \right) - 2.5 (1.875) = 12"$$

max bar spacing

$$A_s = \frac{M_U (12000)}{.9 (60000) (17.5 - \frac{.615}{2})} = 0.013 M_U$$

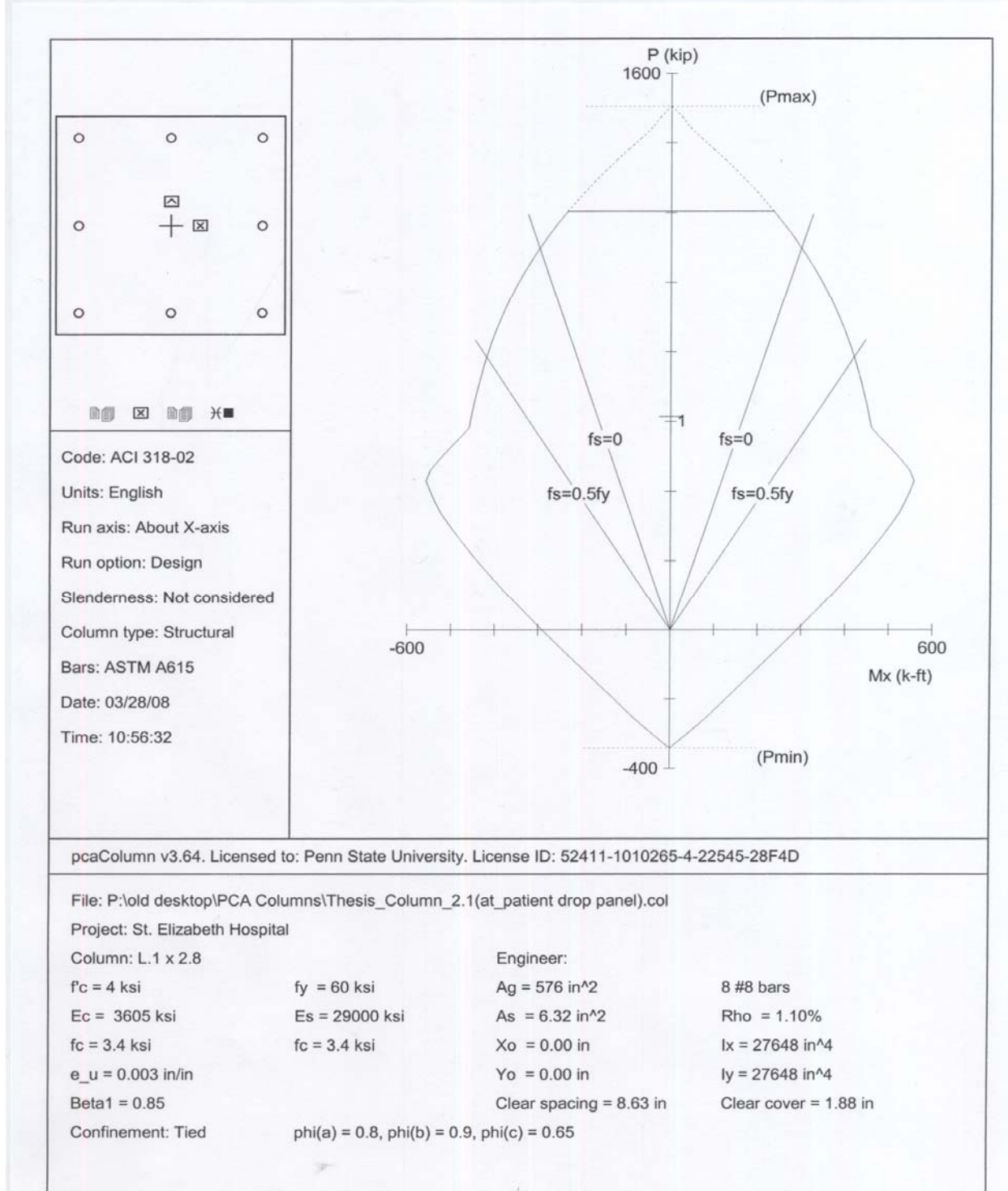
$b_w = 16$ w/ 3 bars
 \therefore max bar spacing will not be met

$$A_{s, min} = \frac{3 \sqrt{f'_c}}{f_y} b_w d = \frac{3 \sqrt{4000} (16) (17.5)}{60000} = 0.885$$

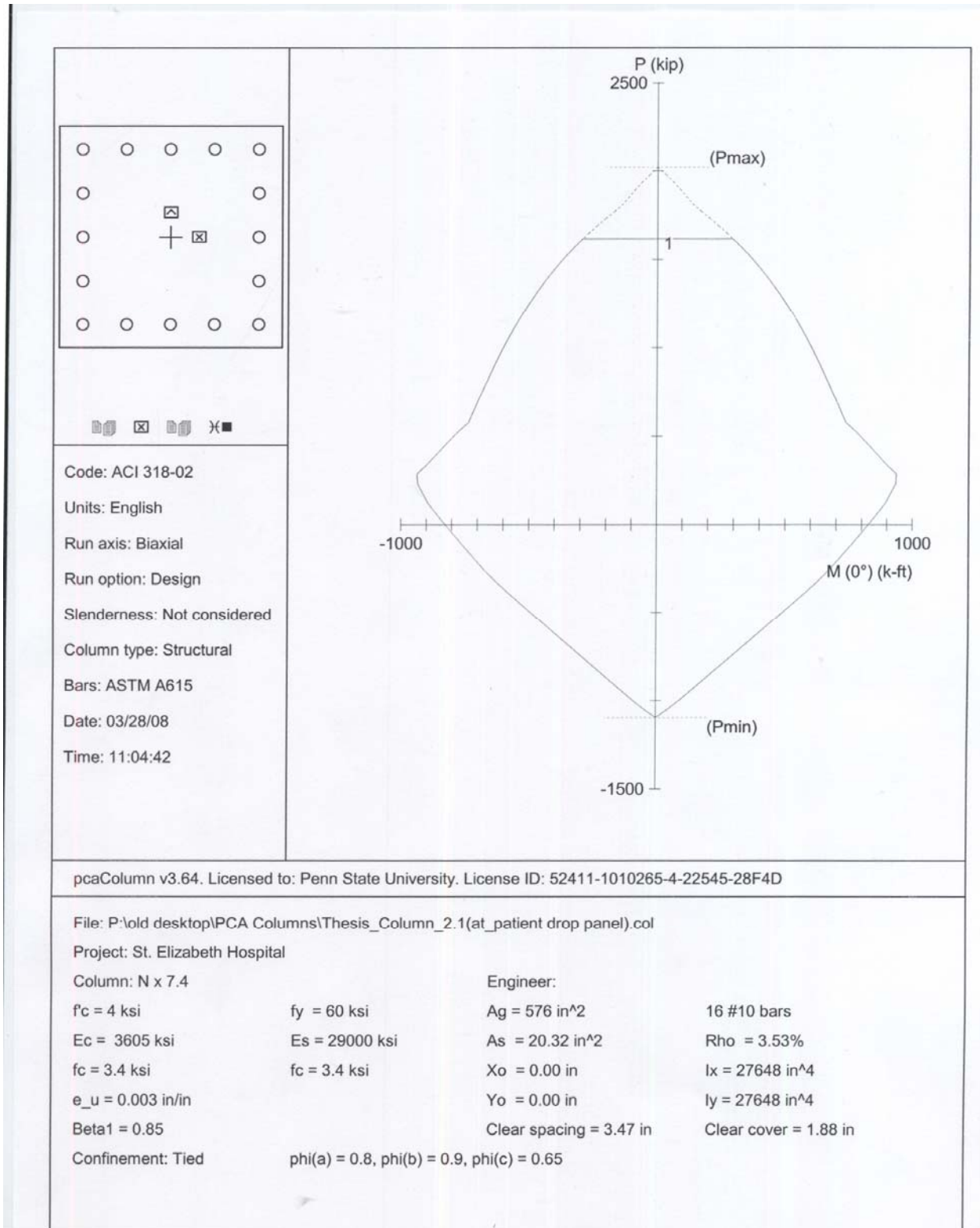
$$= \frac{200 b_w d}{f_y} = \frac{200 (16) (17.5)}{60000} = 0.933$$

Appendix D – Column Designs

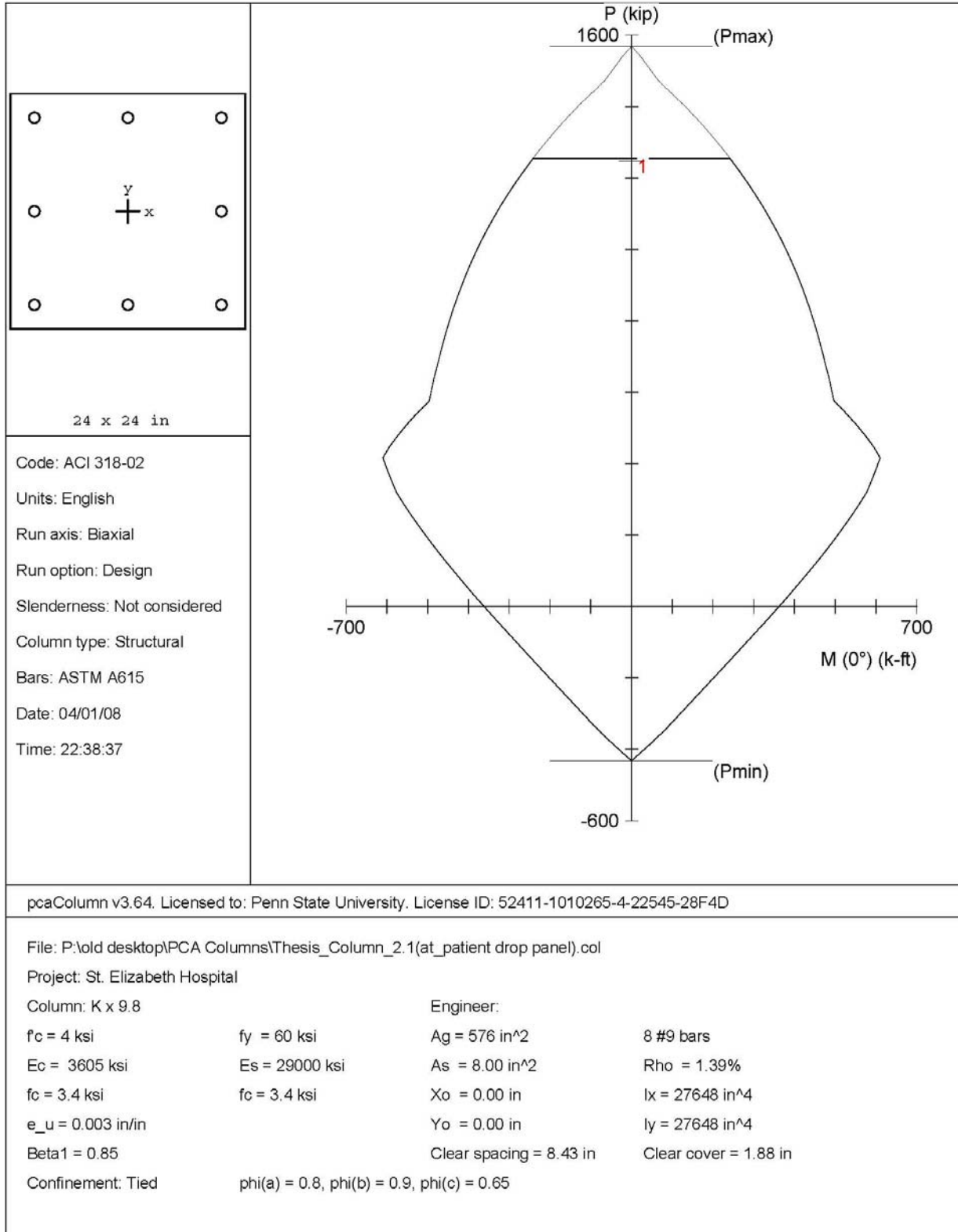
Appendix C.1 – Column Located on Fifth Floor at L.1 & 2.8 – Typical Design



Appendix C.2 – Column Located on First Floor at N & 7.4



Appendix C.3 – Column Located on First Floor at K & 9.8



Appendix C.4 – Columns Designs Located on First Floor

Location	Length x Width	Drop Panel Area	Weight	Factored Load	Rebar	# of Bars	As	% Steel
EW x NS	EW x NS	sqft	kips	kips			in ²	
L.1 x 0.2	34 x 23	102	786	1103	# 8	8	6.32	1.097
L.1 x 0.1	34 x 24.5	102	829	1154	# 8	8	6.32	1.097
L.1 x 1.4	34 x 25.75	102	865	1198	# 8	8	6.32	1.097
L.1 x 2.8	34 x 26.5	102	886	1223	# 9	8	8	1.389
L.1 x 4.1	33 x 26.75	102	871	1205	# 9	8	8	1.389
M x 0.3	35 x 14.75	-	496	756	# 8	8	6.32	1.097
M x 6.4	7 x 26.75	-	220	424	# 8	8	6.32	1.097
M x 9.8	35.5 x 15.5	154	625	910	# 8	8	6.32	1.097
L.C x 6.4	7.5 x 22	-	201	401	# 8	8	6.32	1.097
K x 9.8	35.5 x 26	104	905	1247	# 9	8	8	1.389
N x 6.4	26.75 x 38.5	113	1001	1362	# 11	8	12.48	2.167
N x 7.4	32.75 x 38.5	141	1213	1616	# 10	16	20.32	3.528
N x 8.4	36 x 38.5	154	1327	1753	# 10	20	25.4	4.41
N x 9.8	35.5 x 38.5	154	1311	1734	# 11	16	24.96	4.333
N x 11	17.5 x 38.5	-	628	914	# 8	8	6.32	1.097
P x 6.4	26.75 x 34	100	892	1230	# 9	8	8	1.389
P X 9.8	35.5 x 30	136	1046	1415	# 10	12	15.24	2.646
Q x 6.4	26.75 x 34	102	893	1232	# 9	8	8	1.389
Q x 11	17.5 x 34	-	562	834	# 8	8	6.32	1.097
Q.8 x 9.8	35.5 x 31	120	1065	1438	# 10	12	15.24	2.646
R.6 x 9.8	35.5 x 28	110	970	1324	# 11	8	12.48	2.167
S x 6.4	26.75 x 34	102	893	1232	# 9	8	8	1.389
S.4 x 11	17.5 x 14	-	268	481	# 8	8	6.32	1.097

Appendix E – Shear Wall Designs

For Right wall against elevators
Shear Wall Design
page 1

Floor 3
Wall 1

$V_u = \text{shear} = 56.26 \text{ K}$
 $M_u = \text{moment} = 2042 \text{ K}$
 $P_u = \text{weight} = 5430 \text{ K}$

$L = 46' - 2''$
 $w = 8''$

$I_g = \frac{8/12 (46.17 + 24/12)^3}{12} = 9314 (8/12) = 6210$

$A_g = 8/12 (48.17) = 32.1$

$f_c = \frac{P_u}{A_g} + \frac{M_u y}{I_g} = \frac{5430}{32.1} + \frac{2042 (46.17/2)}{6210} = \frac{176.75}{144} = 1.23$

$.2 f'_c = .2(4) = .8 < 1.23$
 \therefore Need Boundary Elements

Reinforcement

$V_n = 2 A_{cv} \sqrt{f'_c} = 2 (32.1) (8) 12 \frac{\sqrt{4000}}{1000} = 390$
 $V_u = 56.3 < V_n = 390$
 \therefore Need only One Curtain

use $\rho_L \ \& \ \rho_T \geq 0.0025$

$A_{s \text{ req'd}} = A_{cv} \rho = 12(8)(0.0025) = 0.24 \text{ in}^2/\text{ft}$
 try #5 bars @ 0.31 in² $\rho_T = \frac{.31}{12(8)} = 0.00323$

$\frac{.24}{12} = \frac{.31}{5}$ spacing = 15.5" < 18" ok

shear

$V_n = A_{cv} (\alpha_c \sqrt{f'_c} + \rho_T f_y)$
 $= 12(32.1)(8) (2 \frac{\sqrt{4000}}{1000} + .00323(60000)) = 987$

$\phi V_n = .6(987) = 592$
 $592 > 56.3 \text{ ok}$

$\frac{h_w}{L_w} = \frac{104}{32.1} = 3.2 \therefore \alpha_c = 2.0$

Shear Wall Design
page 2

Bottom wall along elevators
Floor 6

Wall Z
 $V_u = \text{shear} = 120 \text{ K}$
 $M_u = \text{moment} = 937 \text{ 'K}$
 $P_u = \text{weight} = 4022 \text{ K}$

$L = 18' - 6''$
 $w = 8''$

$I_g = \frac{8}{12} \frac{(18.5 + 2 \cdot \frac{1}{2})^3}{12} = 478.6$

$A_g = \frac{8}{12} (18.5) = 12.33$

$f_c = \frac{P_u}{A_g} + \frac{M_u y}{I_g} = \frac{4022}{12.33} + \frac{937 (\frac{18.5}{2})}{478.6} = \frac{344.3}{144} = 2.4$

$.2 f'_c = .2 (4) = .8 < 2.4$
 \therefore Need Boundary Elements

Reinforcement

$V_n = 2 A_{cv} \sqrt{f'_c} = 2 (12.33) (8) \frac{12 \sqrt{4000}}{1000} = 150$

use $\rho_L \text{ \& } \rho_T \geq 0.0025$
 $A_s \text{ long req'd} = A_{cv} \rho = 12 (8) .0025 = 0.24 \text{ in}^2_{ft}$
 try #5 bars @ 0.31 in^2

$\rho_T = \frac{.31}{12(8)} = 0.00323$

$\frac{.24}{12} = \frac{.31}{5}$ Spacing = $15.5'' < 18''$ ok

Shear

$V_n = A_{cv} (\alpha_c \sqrt{f'_c} + \rho_T f_y)$
 $= 12 (12.33) (8) (2 \sqrt{4000} + .00323 (60000))$
 $\frac{\hspace{10em}}{1000} = 380$

$\frac{h_w}{L_w} = \frac{104}{12.3} = 8.5$
 $\therefore \alpha_c = 2$

$\phi V_n = .6 (380) = 227$
 $227 > 120$ ok

Far eastern wall along stairwell

Shear Wall Design
Page 3

floor 2

Wall 3

$V_u = \text{shear} = 88.7 \text{ k}$
 $M_u = \text{moment} = 3927 \text{ k}$
 $P_u = \text{weight} = 11,105 \text{ k}$

$L = 28' - 0''$
 $w = 8''$
 $I_g = \frac{8/12 (28 + 24/2)^3}{12} = 1500$
 $A_g = 8/12 (30) = 20$
 $f_c = \frac{P_u}{A_g} + \frac{M_u y}{I_g} = \frac{11,105}{20} + \frac{3927 (24/2)}{1500} = \frac{592}{744} = 4.1$
 $.2 f'_c = .8 < 4.1$
 \therefore Need Boundary Elements

Reinforcement

$V_n = \frac{2 A_{cv} \sqrt{f'_c}}{1000} = \frac{2 (20)(8) 12 \sqrt{4000}}{1000} = 243$
 $V_u = 88.7 < V_n = 243$
 \therefore Need Only One Curtain

use $\rho_c \text{ \& } \rho_t \geq 0.0025$
 $A_s \text{ req'd} = A_{cv} \rho = 12(8) .0025 = 0.24 \text{ in}^2/\text{ft}$
 try #5 bars @ 0.31 in^2
 $\rho_t = \frac{.31}{12(8)} = 0.00323$
 $\frac{.24}{12} = \frac{.31}{5}$ spacing = $15.5'' < 18''$ ok

Shear

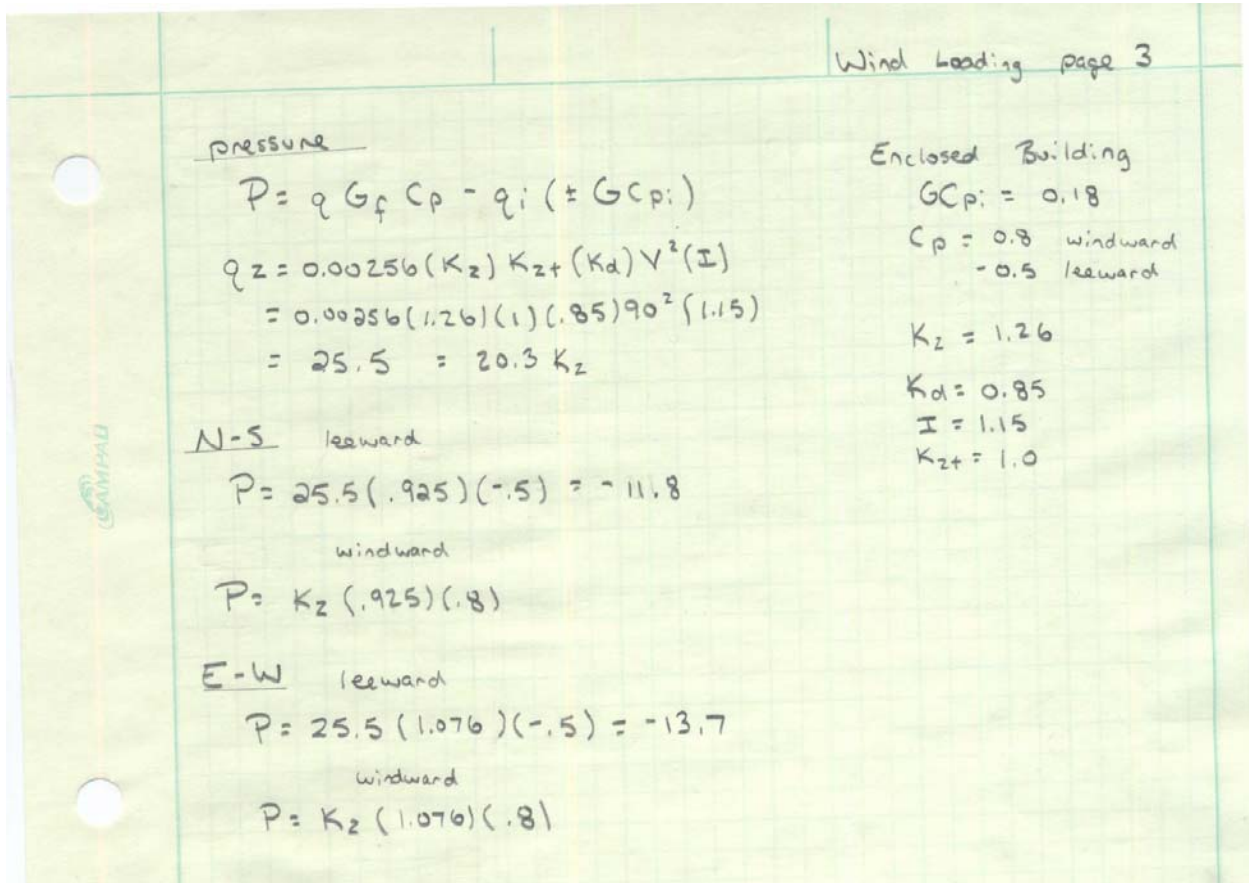
$\frac{h_w}{L_w} = \frac{104}{20} = 5.2$
 $\therefore \alpha_c = 2$

$V_n = \frac{A_{cv} (\alpha_c \sqrt{f'_c} + \rho_t f_y)}{1000} = \frac{12 (20)(8) (2 \sqrt{4000} + .00323(60000))}{1000} = 615$
 $\phi V_n = .6(615) = 369$
 $369 > 88.7$ ok

Appendix F – Wind Forces

North – South Wind Pressures					
Height (ft)	Kz	qz	Windward Pressure (psf)	Leeward Pressure (psf)	Total (psf)
0-15	0.85	21.68	16.04	-11.8	27.84
20	0.9	22.95	16.98	-11.8	28.78
25	0.94	23.97	17.74	-11.8	29.54
30	0.98	24.99	18.49	-11.8	30.29
40	1.04	26.52	19.62	-11.8	31.42
50	1.09	27.80	20.57	-11.8	32.37
60	1.13	28.82	21.32	-11.8	33.12
70	1.17	29.84	22.08	-11.8	33.88
80	1.21	30.86	22.83	-11.8	34.63
90	1.24	31.62	23.40	-11.8	35.20
110	1.26	32.13	23.78	-11.8	35.58
120	1.31	33.41	24.72	-11.8	36.52

East – West Wind Pressures					
Height (ft)	Kz	qz	Windward Pressure (psf)	Leeward Pressure (psf)	Total
0-15	0.85	21.68	18.66	-13.7	32.36
20	0.9	22.95	19.76	-13.7	33.46
25	0.94	23.97	20.63	-13.7	34.33
30	0.98	24.99	21.51	-13.7	35.21
40	1.04	26.52	22.83	-13.7	36.53
50	1.09	27.80	23.93	-13.7	37.63
60	1.13	28.82	24.80	-13.7	38.50
70	1.17	29.84	25.68	-13.7	39.38
80	1.21	30.86	26.56	-13.7	40.26
90	1.24	31.62	27.22	-13.7	40.92
110	1.26	32.13	27.66	-13.7	41.36
120	1.31	33.41	28.76	-13.7	42.46



Building properties utilized in method 2 calculations for exposure C
 Table 6-2 from ASCE7-05

Exposure	α	z_g (ft)	\hat{a}	\hat{b}	$\bar{\alpha}$	\bar{b}	c	ℓ (ft)	$\bar{\epsilon}$	z_{min} (ft)*
B	7.0	1200	1/7	0.84	1/4.0	0.45	0.30	320	1/3.0	30
C	9.5	900	1/9.5	1.00	1/6.5	0.65	0.20	500	1/5.0	15
D	11.5	700	1/11.5	1.07	1/9.0	0.80	0.15	650	1/8.0	7

Appendix G – Seismic Forces

Josh Behun Lateral Loading page 1

Lat = 40.9930556
Long = -80.6597222

from USGS Ground Motion Calculator
Site Class D

$S_s = 0.143$ $F_a = 1.6$
 $S_1 = 0.049$ $F_v = 2.4$

$S_{m_s} = F_a (S_s) = 1.6(0.143) = 0.2288$
 $S_{m_1} = F_v (S_1) = 2.4(0.049) = 0.1176$
 $S_{D_s} = \sqrt[2]{3} S_{m_s} = 0.15253$
 $S_{D_1} = \sqrt[2]{3} S_{m_1} = 0.0784$

from table 12.8-1 ASCE 7-05
 $S_{D_1} \leq 0.1$ $C_u = 1.7$

from table 12.8-2
concrete moment-resisting frames
 $C_t = 0.016$ $\alpha = 0.9$
all other structural systems
 $C_t = 0.02$ $\alpha = 0.75$

$T_a = C_t (\text{height})^\alpha = 0.016 (104')^{0.9} = 1.046$
~~period = $T = C_u T_a = 1.7(1.046) = 1.78$~~
~~frequency = $\frac{1}{1.78} < 1$ \therefore Flexible~~

from chart 22-15
 $T_L = 12$ sec

from table 12.2-1
Building frame system - special reinforced concrete shear walls
 $R = 6$
 $I_E = 1.5$

The period and frequency shown for this calculation are incorrect. They had been based on the concrete frame without the inclusion of shear walls. The period for the building with shear walls included was calculated at 0.4, making the building frame rigid, and was determined using the Etabs computer program.

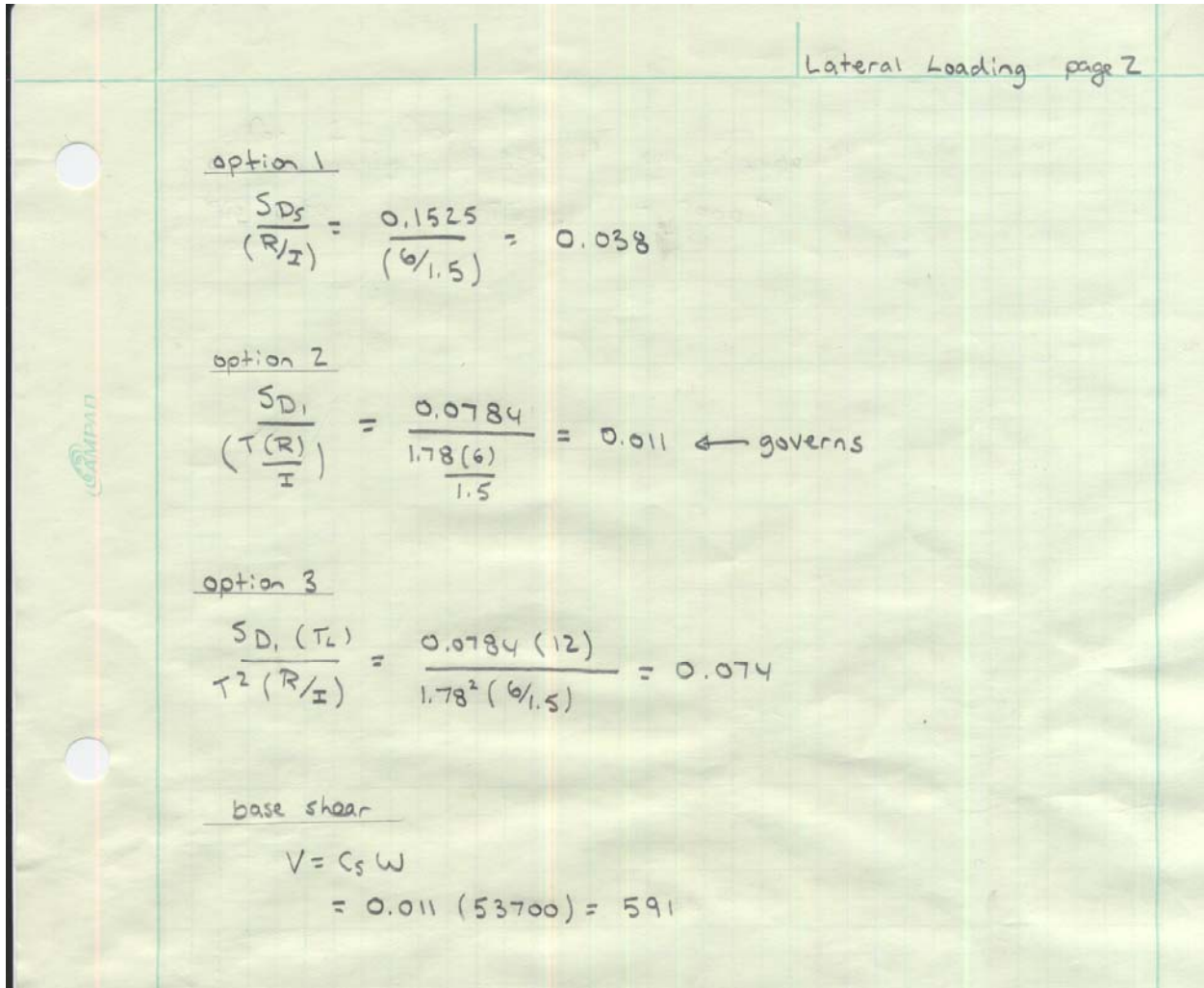


TABLE 12.8-2 VALUES OF APPROXIMATE PERIOD PARAMETERS C_t AND x

Structure Type	C_t	x
Moment-resisting frame systems in which the frames resist 100% of the required seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting where subjected to seismic forces:		
Steel moment-resisting frames	0.028 (0.0724) ^a	0.8
Concrete moment-resisting frames	0.016 (0.0466) ^a	0.9
Eccentrically braced steel frames	0.03 (0.0731) ^a	0.75
All other structural systems	0.02 (0.0488) ^a	0.75

^aMetric equivalents are shown in parentheses.

TABLE 12.2-1 DESIGN COEFFICIENTS AND FACTORS FOR SEISMIC FORCE-RESISTING SYSTEMS

Seismic Force-Resisting System	ASCE 7 Section where Detailing Requirements are Specified	Response Modification Coefficient, R^a	System Overstrength Factor, Ω_0^b	Deflection Amplification Factor, C_d^d	Structural System Limitations and Building Height (ft) Limit ^c				
					Seismic Design Category				
					B	C	D ^e	E ^e	F ^e
A. BEARING WALL SYSTEMS									
1. Special reinforced concrete shear walls	14.2 and 14.2.3.6	5	2½	5	NL	NL	160	160	100
2. Ordinary reinforced concrete shear walls	14.2 and 14.2.3.4	4	2½	4	NL	NL	NP	NP	NP
3. Detailed plain concrete shear walls	14.2 and 14.2.3.2	2	2½	2	NL	NP	NP	NP	NP
4. Ordinary plain concrete shear walls	14.2 and 14.2.3.1	1½	2½	1½	NL	NP	NP	NP	NP
5. Intermediate precast shear walls	14.2 and 14.2.3.5	4	2½	4	NL	NL	40 ^k	40 ^k	40 ^k
6. Ordinary precast shear walls	14.2 and 14.2.3.3	3	2½	3	NL	NP	NP	NP	NP
7. Special reinforced masonry shear walls	14.4 and 14.4.3	5	2½	3½	NL	NL	160	160	100
8. Intermediate reinforced masonry shear walls	14.4 and 14.4.3	3½	2½	2¼	NL	NL	NP	NP	NP
9. Ordinary reinforced masonry shear walls	14.4	2	2½	1¾	NL	160	NP	NP	NP
10. Detailed plain masonry shear walls	14.4	2	2½	1¾	NL	NP	NP	NP	NP
11. Ordinary plain masonry shear walls	14.4	1½	2½	1¼	NL	NP	NP	NP	NP
12. Prestressed masonry shear walls	14.4	1½	2½	1¾	NL	NP	NP	NP	NP
13. Light-framed walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1, 14.1.4.2, and 14.5	6½	3	4	NL	NL	65	65	65
14. Light-framed walls with shear panels of all other materials	14.1, 14.1.4.2, and 14.5	2	2½	2	NL	NL	35	NP	NP
15. Light-framed wall systems using flat strap bracing	14.1, 14.1.4.2, and 14.5	4	2	3½	NL	NL	65	65	65
B. BUILDING FRAME SYSTEMS									
1. Steel eccentrically braced frames, moment resisting connections at columns away from links	14.1	8	2	4	NL	NL	160	160	100
2. Steel eccentrically braced frames, non-moment-resisting, connections at columns away from links	14.1	7	2	4	NL	NL	160	160	100
3. Special steel concentrically braced frames	14.1	6	2	5	NL	NL	160	160	100
4. Ordinary steel concentrically braced frames	14.1	3¼	2	3¼	NL	NL	35 ^j	35 ^j	NP ^j
5. Special reinforced concrete shear walls	14.2 and 14.2.3.6	6	2½	5	NL	NL	160	160	100
6. Ordinary reinforced concrete shear walls	14.2 and 14.2.3.4	5	2½	4½	NL	NL	NP	NP	NP
7. Detailed plain concrete shear walls	14.2 and 14.2.3.2	2	2½	2	NL	NP	NP	NP	NP
8. Ordinary plain concrete shear walls	14.2 and 14.2.3.1	1½	2½	1½	NL	NP	NP	NP	NP

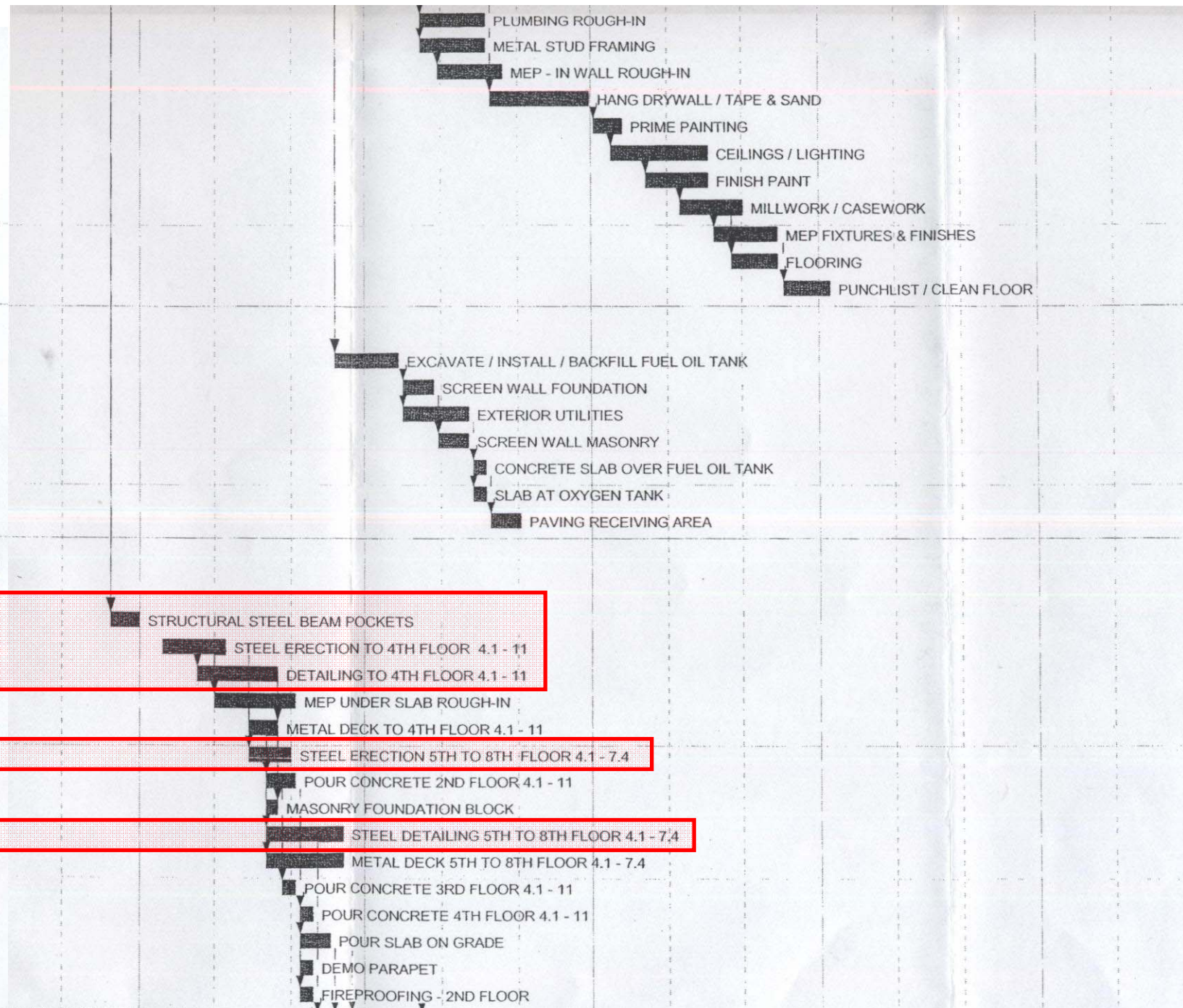
TABLE 12.8-1 COEFFICIENT FOR UPPER LIMIT ON CALCULATED PERIOD

Design Spectral Response Acceleration Parameter at 1 s, S_{D1}	Coefficient C_u
≥ 0.4	1.4
0.3	1.4
0.2	1.5
0.15	1.6
≤ 0.1	1.7

Appendix H – Construction Management

Appendix H.1 – Original Steel Building Schedule

1470	METAL STUD FRAMING	20	24JUL06	18AUG06
1480	MEP - IN WALL ROUGH-IN	20	31JUL06	25AUG06
1490	HANG DRYWALL / TAPE & SAND	30	21AUG06	29SEP06
1510	PRIME PAINTING	10	02OCT06	13OCT06
1520	CEILINGS / LIGHTING	30	09OCT06	17NOV06
1530	FINISH PAINT	20	23OCT06	17NOV06
1540	MILLWORK / CASEWORK	20	06NOV06	01DEC06
1560	MEP FIXTURES & FINISHES	20	20NOV06	15DEC06
1550	FLOORING	15	27NOV06	15DEC06
1570	PUNCHLIST / CLEAN FLOOR	15	18DEC06	05JAN07
EXTERIOR ACTIVITIES				
1620	EXCAVATE / INSTALL / BACKFILL FUEL OIL TANK	20	19JUN06	14JUL06
1630	SCREEN WALL FOUNDATION	10	17JUL06	28JUL06
1650	EXTERIOR UTILITIES	20	17JUL06	11AUG06
1640	SCREEN WALL MASONRY	10	31JUL06	11AUG06
1660	CONCRETE SLAB OVER FUEL OIL TANK	5	14AUG06	18AUG06
1680	SLAB AT OXYGEN TANK	5	14AUG06	18AUG06
1670	PAVING RECEIVING AREA	10	21AUG06	01SEP06
AREA C				
SHELL				
2000	STRUCTURAL STEEL BEAM POCKETS	10	20MAR06	31MAR06
2010	STEEL ERECTION TO 4TH FLOOR 4.1 - 11	20	10APR06*	05MAY06
2020	DETAILING TO 4TH FLOOR 4.1 - 11	25	24APR06	26MAY06
2190	MEP UNDER SLAB ROUGH-IN	25	01MAY06	02JUN06
2030	METAL DECK TO 4TH FLOOR 4.1 - 11	10	15MAY06	26MAY06
2720	STEEL ERECTION 5TH TO 8TH FLOOR 4.1 - 7.4	13	15MAY06	31MAY06
2060	POUR CONCRETE 2ND FLOOR 4.1 - 11	10	22MAY06	02JUN06
2150	MASONRY FOUNDATION BLOCK	5	22MAY06	26MAY06
2730	STEEL DETAILING 5TH TO 8TH FLOOR 4.1 - 7.4	23	22MAY06	21JUN06
2740	METAL DECK 5TH TO 8TH FLOOR 4.1 - 7.4	23	22MAY06	21JUN06
2070	POUR CONCRETE 3RD FLOOR 4.1 - 11	5	29MAY06	02JUN06
2080	POUR CONCRETE 4TH FLOOR 4.1 - 11	5	05JUN06	09JUN06
2110	POUR SLAB ON GRADE	10	05JUN06	16JUN06
2120	DEMO PARAPET	5	05JUN06*	09JUN06
2200	FIREPROOFING - 2ND FLOOR	5	05JUN06	09JUN06

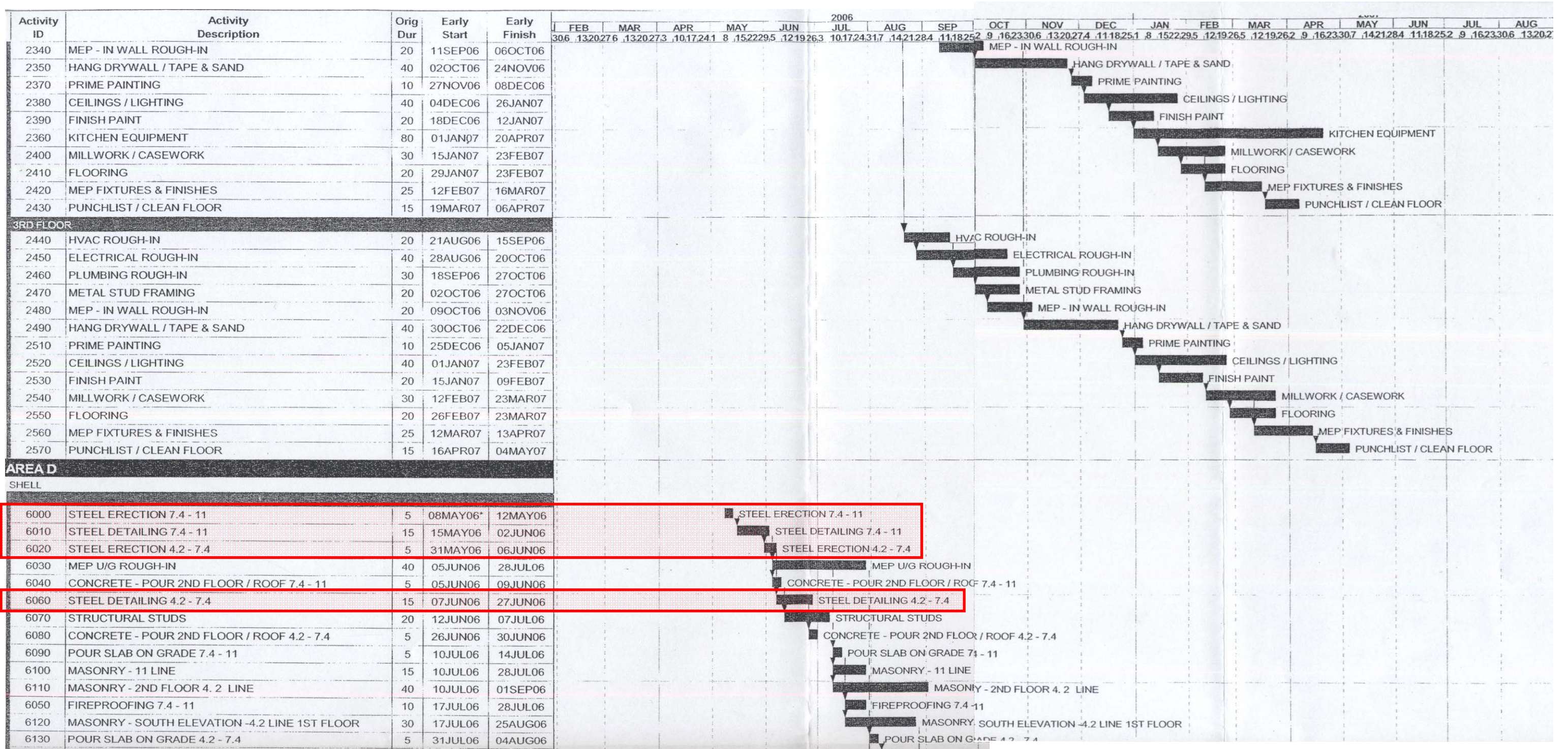


Start Date	17JAN06	Early Bar
Finish Date	17AUG07	Progress Bar
Start Date	17JAN06	Critical Activity
Finish Date	21FEB06 17:22	

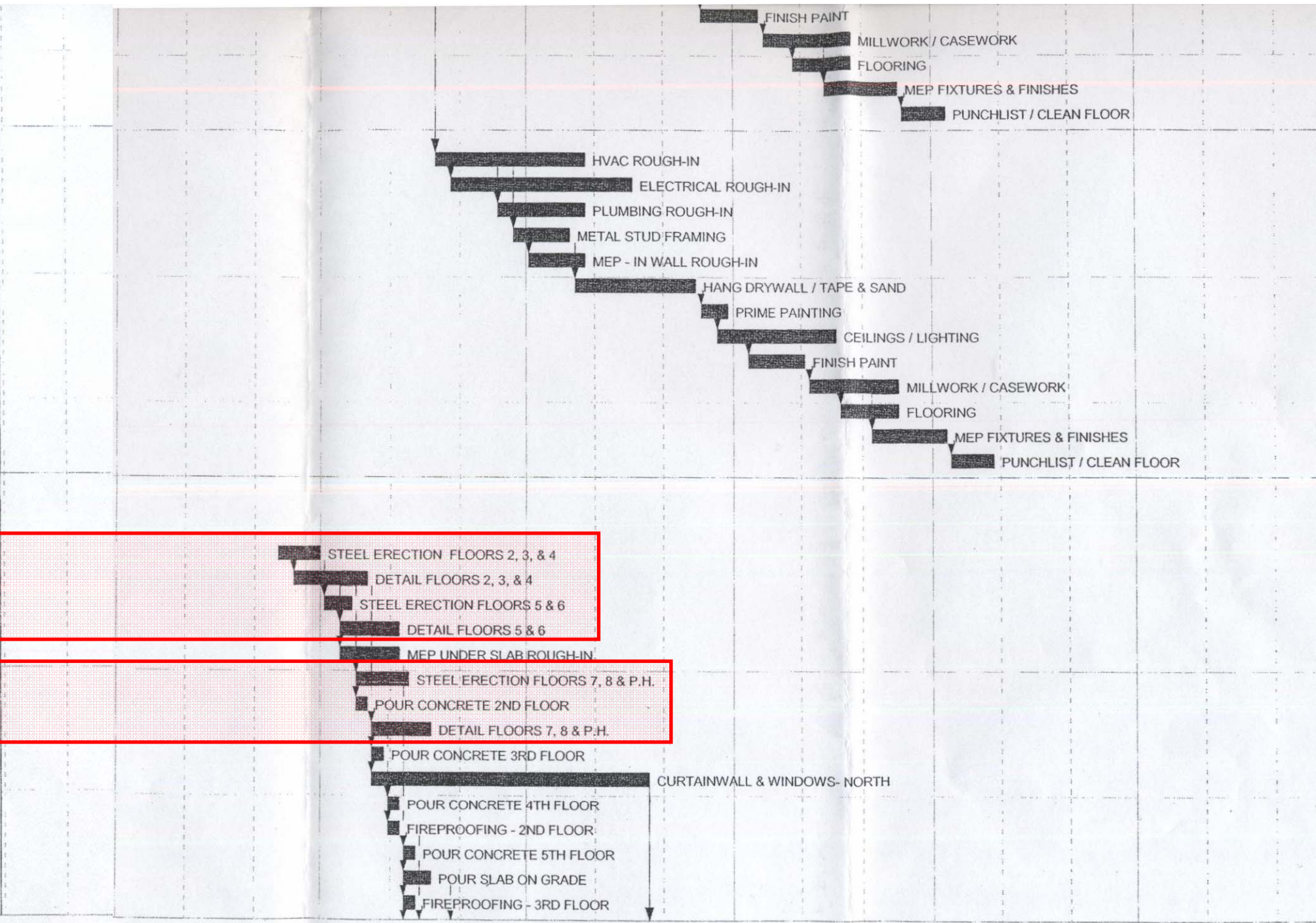
SES1 Sheet 2 of 10

ST ELIZABETH'S HOSPITAL
PRELIMINARY SCHEDULE

Date	Revision
21FEB06	REVISED DRAFT



6260	FINISH PAINT	20	18DEC06	12JAN07
6270	MILLWORK / CASEWORK	30	15JAN07	23FEB07
6280	FLOORING	20	29JAN07	23FEB07
6290	MEP FIXTURES & FINISHES	25	12FEB07	16MAR07
6300	PUNCHLIST / CLEAN FLOOR	15	19MAR07	06APR07
1ST FLOOR 4.2 TO 7.4				
6320	HVAC ROUGH-IN	50	21AUG06	27OCT06
6330	ELECTRICAL ROUGH-IN	60	28AUG06	17NOV06
6340	PLUMBING ROUGH-IN	30	18SEP06	27OCT06
6350	METAL STUD FRAMING	20	25SEP06	20OCT06
6360	MEP - IN WALL ROUGH-IN	20	02OCT06	27OCT06
6370	HANG DRYWALL / TAPE & SAND	40	23OCT06	15DEC06
6380	PRIME PAINTING	10	18DEC06	29DEC06
6390	CEILINGS / LIGHTING	40	25DEC06	16FEB07
6400	FINISH PAINT	20	08JAN07	02FEB07
6410	MILLWORK / CASEWORK	30	05FEB07	16MAR07
6420	FLOORING	20	19FEB07	16MAR07
6430	MEP FIXTURES & FINISHES	25	05MAR07	06APR07
6440	PUNCHLIST / CLEAN FLOOR	15	09APR07	27APR07
AREA E				
SHELL				
3000	STEEL ERECTION FLOORS 2, 3, & 4	15	12JUN06*	30JUN06
3030	DETAIL FLOORS 2, 3, & 4	25	19JUN06	21JUL06
3010	STEEL ERECTION FLOORS 5 & 6	10	03JUL06	14JUL06
3040	DETAIL FLOORS 5 & 6	20	10JUL06	04AUG06
3160	MEP UNDER SLAB ROUGH-IN	20	10JUL06	04AUG06
3020	STEEL ERECTION FLOORS 7, 8 & P.H.	17	17JUL06	08AUG06
3060	POUR CONCRETE 2ND FLOOR	5	17JUL06	21JUL06
3050	DETAIL FLOORS 7, 8 & P.H.	20	24JUL06	18AUG06
3070	POUR CONCRETE 3RD FLOOR	5	24JUL06	28JUL06
3270	CURTAINWALL & WINDOWS- NORTH	90	24JUL06	24NOV06
3080	POUR CONCRETE 4TH FLOOR	5	31JUL06	04AUG06
3170	FIREPROOFING - 2ND FLOOR	5	31JUL06	04AUG06
3090	POUR CONCRETE 5TH FLOOR	5	07AUG06	11AUG06
3130	POUR SLAB ON GRADE	10	07AUG06	18AUG06
3180	FIREPROOFING - 3RD FLOOR	5	07AUG06	11AUG06



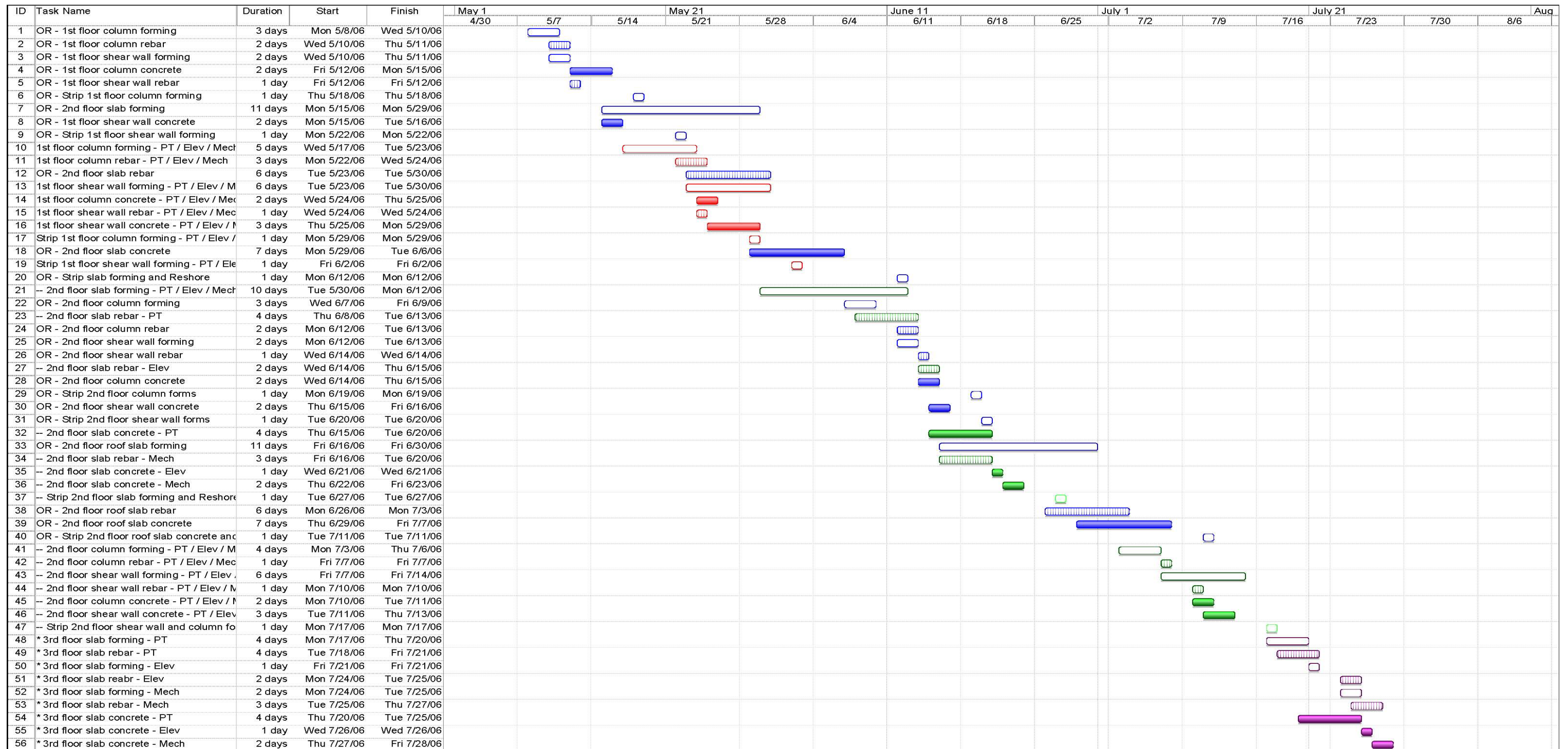
Start Date	17JAN06	Early Bar	SES1
Finish Date	17AUG07	Progress Bar	
Data Date	17JAN06	Critical Activity	
Run Date	21FEB06 17:22		

ST ELIZABETH'S HOSPITAL
PRELIMINARY SCHEDULE

Sheet 5 of 10

Date	Revision	Checked	Approved
21FEB06	REVISED DRAFT		

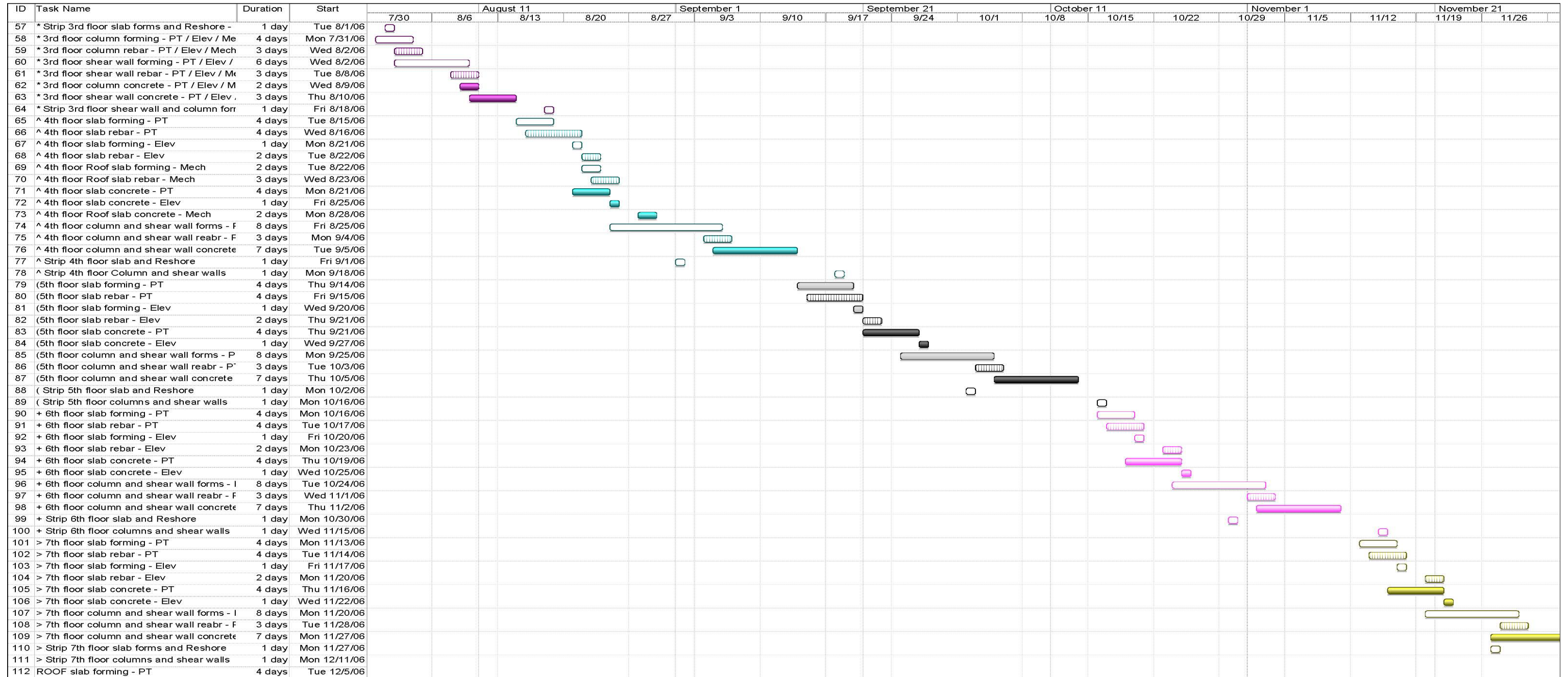
Appendix H.2 – Alternative Concrete Building Schedule



Project: Thesis_Scheduling_Gantt
Date: Fri 4/4/08

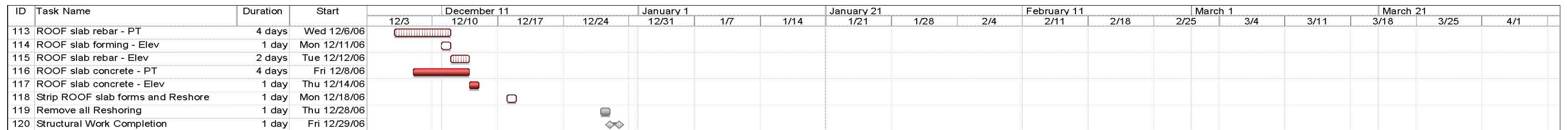
Task: Progress Summary External Tasks Deadline

Split: Milestone Project Summary External Milestone



Project: Thesis_Scheduling_Gantt
Date: Sat 4/5/08

Task Progress Summary External Tasks Deadline
Split Milestone Project Summary External Milestone



Location Factors				
STATE/ZIP	CITY	MAT.	INST.	TOTAL
OHIO				
430-432	Columbus	97.3	89.6	93.9
433	Marion	93.9	88.4	91.5
434-436	Toledo	97.6	100.0	98.7
437-438	Zanesville	94.3	86.1	90.6
439	Steubenville	95.2	95.1	95.1
440	Lorain	96.9	97.1	97.0
441	Cleveland	97.2	104.3	100.4
442-443	Akron	97.8	98.0	97.9
444-445	Youngstown	97.2	93.3	95.5
446-447	Canton	97.3	88.4	93.4
448-449	Mansfield	94.6	93.8	94.2
450	Hamilton	94.5	89.6	92.3
451-452	Cincinnati	94.9	90.2	92.8
453-454	Dayton	94.6	87.0	91.2
455	Springfield	94.6	87.9	91.6
456	Chillicothe	93.5	94.2	93.8
457	Athens	96.3	79.9	89.0
458	Lima	96.8	87.9	92.8

03300 | Cast-In-Place Concrete												
03310 | Structural Concrete				CREW	DAILY OUTPUT	LABOR HOURS	UNIT	2006 BARE COSTS				T/INC
								MAT.	LABOR	EQUIP.	TOTAL	
700	0010	PLACING CONCRETE										
	0020	Includes labor and equipment to place and vibrate	R033105 -70									
	0050	Beams, elevated, small beams, pumped		C-20	60	1.067	C.Y.	31.50	12.40	43.90		
	0100	With crane and bucket		C-7	45	1.600		48	22.50	70.50		
	0200	Large beams, pumped		C-20	90	.711		21	8.25	29.25		
	0250	With crane and bucket		C-7	65	1.108		33	15.55	48.55		
	0400	Columns, square or round, 12" thick, pumped		C-20	60	1.067		31.50	12.40	43.90		
	0450	With crane and bucket		C-7	40	1.800		54	25.50	79.50		
	0600	18" thick, pumped		C-20	90	.711		21	8.25	29.25		
	0650	With crane and bucket		C-7	55	1.200		20.50	18.40	57.90		
	0800	24" thick, pumped		C-20	92	.696		20.50	8.10	28.60		
	0850	With crane and bucket		C-7	70	1.029		31	14.45	45.45		
	1000	36" thick, pumped		C-20	140	.457		13.55	5.30	18.85		
	1050	With crane and bucket		C-7	100	.720		21.50	10.10	31.60		
	1400	Elevated slabs, less than 6" thick, pumped		C-20	140	.457		13.55	5.30	18.85		
	1450	With crane and bucket		C-7	95	.758		22.50	10.65	33.15		
	1500	6" to 10" thick, pumped		C-20	160	.400		11.90	4.65	16.55		
	1550	With crane and bucket		C-7	110	.655		19.65	9.20	28.85		
	1600	Slabs over 10" thick, pumped		C-20	180	.356		10.55	4.13	14.68		
	1650	With crane and bucket		C-7	130	.554		16.60	7.80	24.40		
	1900	Footings, continuous, shallow, direct chute		C-6	120	.400		11.55	.36	11.91		
	1950	Pumped		C-20	150	.427		12.65	4.96	17.61		
	2000	With crane and bucket		C-7	90	.800		24	11.25	35.25		
	2100	Footings, continuous, deep, direct chute		C-6	140	.343		9.90	.31	10.21		
	2150	Pumped		C-20	160	.400		11.90	4.65	16.55		
	2200	With crane and bucket		C-7	110	.655		19.65	9.20	28.85		
	2400	Footings, spread, under 1 C.Y., direct chute		C-6	55	.873		25	.78	25.78		
	2450	Pumped		C-20	65	.985		29	11.45	40.45		
	2500	With crane and bucket		C-7	45	1.600		48	22.50	70.50		
	2600	Over 5 C.Y., direct chute		C-6	120	.400		11.55	.36	11.91		
	2650	Pumped		C-20	150	.427		12.65	4.96	17.61		
	2700	With crane and bucket		C-7	100	.720		21.50	10.10	31.60		

Appendix I – References

The following sources were referenced throughout the duration of the project, to aid with design and/or analysis of the St. Elizabeth Hospital's alternative concrete framing system.

Building Code Requirements for Structural Concrete. Farmington Hills, MI:
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