Eight Tower Bridge

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Structural Option
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Eight Tower Bridge

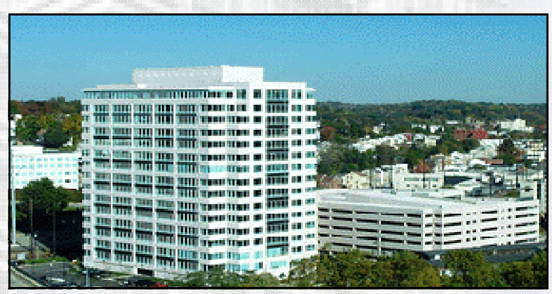
161 Washington Street
Conshohocken, PA

Project Team:

Owner/Developer:
-Oliver Tyrone Pulver Corporation
Architect:
-Skidmore, Owings & Merril, LLP
General Contractor:
-R.M. Shoemaker Company
Structural Engineers:
-Skidmore, Owings & Merril, LLP
MEP Engineers:
-Jaros, Baum & Bolles
Geotechnical Engineer:
-Schnabel Engineering Associates, Inc.
Corporate Partners:
-Brandywine Realty Trust
-Union Labor Life Insurance Co.

Project Information:

Size:
-16 stories plus mechanical penthouse
-345,000 square feet
Use:
-High-rise office building
-48 car parking garage at lobby level
Construction:
-Design-Bid-Build
-Constructed from February 2001– April 2002
-$43,000,000 total project cost



Architecture:

-Facade matches other Tower Bridge projects with green tinted windows and precast concrete
-Scenic views of Schuylkill River
-2 story lobby with marble walls and floors
-Four terraces located at the 15th story

MEP:

-Mechanical penthouse on rooftop
-Two rooftop fan cooling towers
-VAV system capable of 70,000 CFM fresh air

Electrical:

-120/208 3 phase, 4 wire house panelboards
-200 AMP 277/480V 3 phase, 4 wire lighting panels on each floor
- 1'x2' fluorescent luminaires typical lighting

Structural:

Foundation:
-Auger cast piles with 100 ton capacity
-36"-54" normal weight concrete pile caps
-4'3" thick Mat foundation at building core

Superstructure:
-W-shape floor beams and columns
-Lateral resisting system combination of braced and moment frames

Floor System:
-Composite concrete slab on metal deck
-4000 psi normal weight concrete

Table of Contents

Executive Summary

EXECUTIVE SUMMARY

The building being analyzed in this report is Eight Tower Bridge, a high rise office tower located in Conshohocken, Pennsylvania. The building is a 16 story steel frame structure with a rooftop mechanical penthouse for HVAC equipment. The total area of the building is approximately 345,000 square feet, with an average of 21,500 square feet of rentable space per floor. Construction of Eight Tower Bridge began on February 12th, 2001 and was completed in April of 2002. The total cost of the building was $43 million, with nearly $4.8 million dollars stemming from the steel superstructure of the building. The steel frame is supported by a combination of pile and mat foundations, and allows for the slab-on-grade on the first floor to be used for vehicle parking. The lateral loads of the building are resisted with a combination of steel braced frames and moment resisting connections.

This report contains a study to see if the superstructure of Eight Tower Bridge could be alternately designed in concrete. Due to the desire to maintain an open floor plan, longer span concrete beams were required, which lent the structure to be post-tensioned. Two alternate post-tensioned floor systems were designed and compared in regards to deflection performance and costs. Both of these systems employed the same cast-in-place concrete column and shear wall designs.

The first flooring system was a one-way beam and slab system incorporating post-tensioning in the beams only. The beam members were sized to a typical 20"x 20", including the 6" reinforced concrete slab. This system saw a maximum deflection of 0.57" under sustained loading and costs an estimated $14.51/square foot to construct. The second system was also a one-way beam and slab post-tensioned system, although the 6" slab was also post-tensioned. This system allowed for further spacing between beams, but resulted in more post-tensioning. The system saw sustained service load deflections of 0.55" and costs an estimated $14.21 to construct.

Columns were designed for the structure using PCA COL. Columns were first designed for axial loading, and then checked for resistance to lateral loads. Although

not designed as the main lateral force resisting system, these concrete frames will act in concert with the eight, 12" thick shear walls designed to resist lateral loading. These walls were designed using ETABS, and considered under multiple load cases to find a maximum deflection of 4.66", which meets the L/400 limit.

A construction management study was done regarding the cost and building duration for an alternate concrete superstructure. Cost and schedule analysis were done considering both flooring system options, which were found to impact the building cost only, and not the overall construction schedule. The construction duration for both systems was found to be 28 weeks if concrete was placed by crane, and 23 weeks if concrete was pumped into place. These were both comparable to the 28 week construction duration for the original steel building.

A non-structural related mechanical system study was also conducted. This study evaluated the feasibility of replacing the current chilled water loop system that uses rooftop cooling towers to chill or heat water (depending on the season) with a ground source heat pump. A ground source heat pump that uses the earth relatively unvarying temperature as thermal reservoir, was found to reduce to building heating and cooling loads, but resulted in a payback period of over 8 years for the heating cycle and nearly 19 years for the cooling cycle.

This report begins with a building background and existing conditions summary to acquaint the reader with the project. The problem development and proposal of work is then introduced. This is followed by the depth of the report, which includes discussion on problem solutions, post-tensioned concrete and finally, the presentation of the alternate concrete design and how the solution was obtained. Finally, the two shorter breadth studies completed on construction management and the building's mechanical systems are presented, with final conclusions and summaries following.

Building Statistics

BUILDING STATISTICS

BUILDING AREA HISTORY AND BACKGROUND

Eight Tower Bridge is a 16 story steel high-rise office tower located outside of Philadelphia in Conshohocken, Pennsylvania. Completed in April of 2002, Eight Tower Bridge sits on the shore of the Schuylkill River, next to the Fayette Street Bridge, leading to both interstates I-476 and I-76. The building was designed by Skidmore, Owings and Merrill, and is the most recent of the Tower Bridge building projects to be constructed in the area by the partnership of Oliver Tyrone Pulver Corporation and Brandywine Reality Trust.

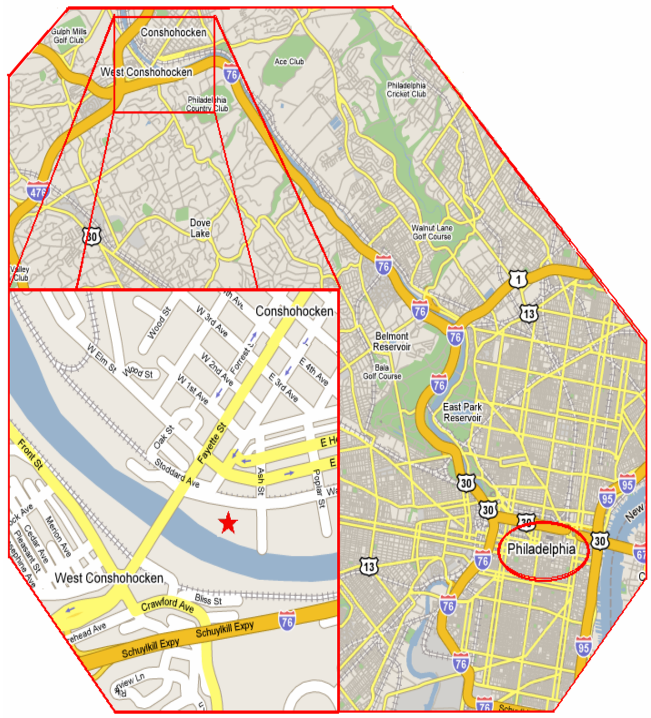


Figure 1: Map of Eight Tower Bridge site and surrounding Philadelphia area

The multi-tenant high rise office tower is the sister project of the existing Tower Bridge projects located in Conshohocken. Over the past fifteen years, the Tower Bridge building projects have transformed the once run-down industrial town into one of the most desirable office, commercial and retail riverfront properties in the greater Philadelphia-metro region.

The city of Conshohocken was founded during the late 1600's by William Penn; the riverfront location being the areas most attractive attribute. Through the 1800's and 1900's, the area was known largely as a booming "Iron town" and was consequently given the clever nickname due to the local success of the industry. With the progression of the century and the slow decrease in demand for iron and steel work, the Conshohocken area began to fall into disrepair, both aesthetically and economically.

By the mid-1980's, the town was considered by most to be a complete loss of riverfront property. In attempt to attract business and commerce to the area again, the state of Pennsylvania declared Conshohocken as an "Enterprise Zone" in 1987. The Oliver Tyrone Pulver Corporation capitalized on this opportunity to rebuild the Conshohocken area with the beginning of the Tower Bridge projects, and has since added 1.3 million square feet of office space with two hotels to the area sitting on 37 acres.

Eight Tower Bridge is the largest of the building projects with 345,000 square feet of office space across its 16 stories, averaging 21,500 square feet of usable space per floor. The ground level features a two story entrance lobby finished with marble walls and floors, wood paneled elevator doors, and stainless steel entry doors with glazing. The ground level also features a "drive through" parking facility that can accommodate up to 48 vehicles. There is also a small space located on the ground floor for a retail tenant.

Figure 2: Elevator Lobby

The architectural program of Eight Tower Bridge had been previously established by the preceding Tower Bridge projects constructed. The office tower features the signature clean cut and professional Tower Bridge building façade, consisting of architectural precast concrete panels with stone trim, and tinted green glass windows. Eight Tower Bridge blends in nicely with the surrounding buildings,

Figure 3: Building facade

yet stands out slightly due to it being the tallest building in the area. Tenants of Eight Tower Bridge can enjoy views of the scenic riverfront and ever expanding downtown Conshohocken area. Tenants on the sixteenth floor are graced with the luxury of working atop one of the tallest buildings in Montgomery County.

PRIMARY DESIGN TEAM

The key players involved in the design, construction and funding of Eight Tower Bridge can all be considered highly experienced in their respective roles. As previously mentioned, this project was a joint venture between Oliver Tyrone Pulver Corporation and Brandywine Reality Trust, two well experienced land development companies. The project delivery method was design-bid-build. Both the architectural and structural design work was completed by Skidmore, Owings and Merrill, a much respected design firm in both disciplines. The mechanical systems consultant on this project was Jarros, Baum & Bolles, a firm that has worked with both SOM and Oliver Tyrone Pulver Corporation on previous projects. The steel erection contract was awarded to Samuel Grossi & Sons, and the general contractor for the project was the R.M. Shoemaker Company. Eight Tower Bridge cost a reported $43 million to construct. Construction began on February 12, 2001 and was completed substantially by April of 2002.

Figure 4: Construction of Eight Tower Bridge

ZONING

The downtown Conshohocken was previously zoned as commercial and light industrial. In an effort to rebuild the area, Conshohocken was recently declared an "Enterprise Zone" to attract businesses to the area, in exchange for monetary subsidies. Eight Tower Bridge is located on a plot zoned as "Class A Commercial".

Existing Structural System

EXISTING STRUCTURAL SYSTEM

Eight Tower Bridge currently employs a composite steel frame structural system, supporting 16 above grade stories that stretch 192' into the air. The superstructure also supports a mechanical penthouse level that rises 22' above the lower roof, topping the building out at 214'. The mechanical penthouse contains two cooling towers, a fan room, and an elevator machine room that controls the six general access elevators. The framing layout was designed to maximize the open floor plan of the building, creating nearly 21,500 square feet of usable space per floor. In addition to mechanical roof loads, gravity floor loads, and lateral forces, the perimeter of the building must support a façade of pre-cast concrete panels and glazing.

BUILDING FOUNDATION

The building foundation system of Eight Tower Bridge consists of reinforced normal weight concrete pile caps ranging from 36" to 54" in depth. The pile caps range in dimension from square 6'10" size to a nearly square 10'10" x 9'10" size.

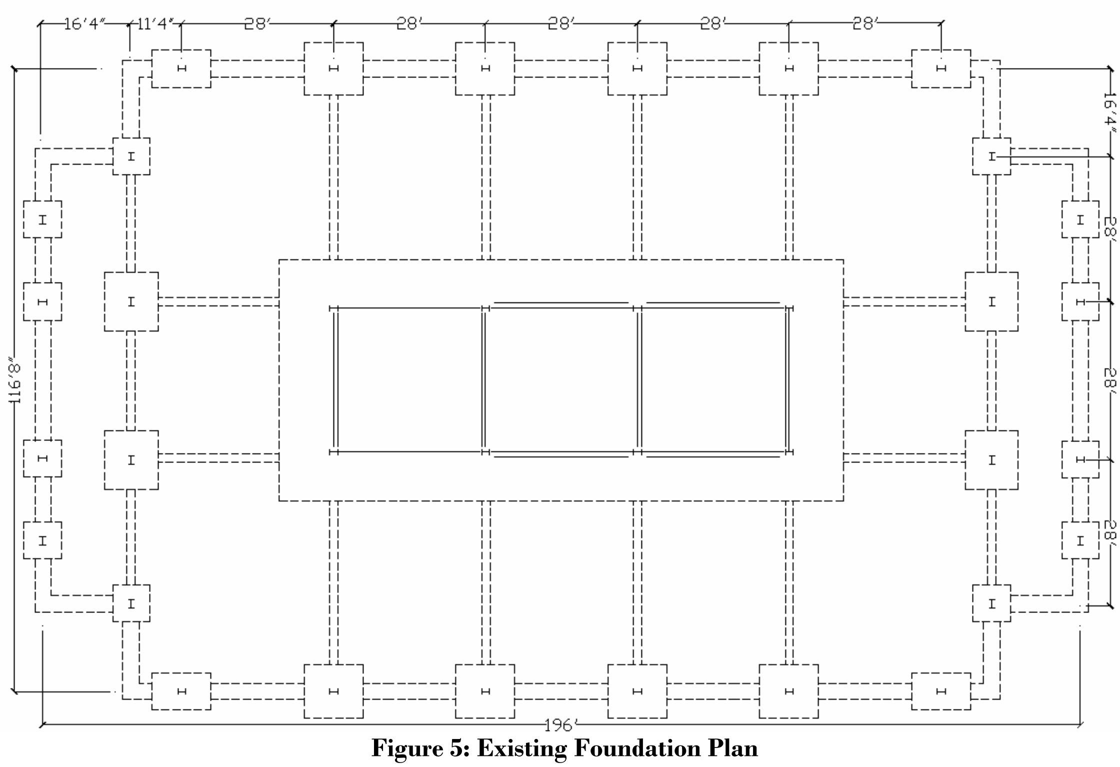


Figure 5: Existing Foundation Plan

These pile caps are supported by four to eight 16” diameter auger–cast piles driven to an average bearing depth of thirteen feet below grade. The piles are made of normal weight concrete with a compressive strength of 4,000psi, and have been designed to a capacity of 100 tons. A foundation plan can be seen above.

The core of the building is supported by a 4’3” reinforced concrete mat foundation, supported by additional auger-cast piles. The entire building is supported by a total of 328 piles. Reinforced concrete grade beams typically 18” wide by 30” deep, connect all of the pile caps, as well as the interior core mat foundation.

The slab at the lobby level is a 5” concrete slab-on-grade with one layer of welded wire fabric reinforcement. The slab sits over a loose granular fill, which sits over compacted sub-grade soil. The inner core slab-on-grade is similar, but is cast 8” thick and has two layers of welded wire fabric as reinforcement. The lobby level also functions as a parking garage, designed with a 50psf live load.

SUPERSTRUCTURE FRAMING

Eight Tower Bridge is a composite steel framed structure. The simple design

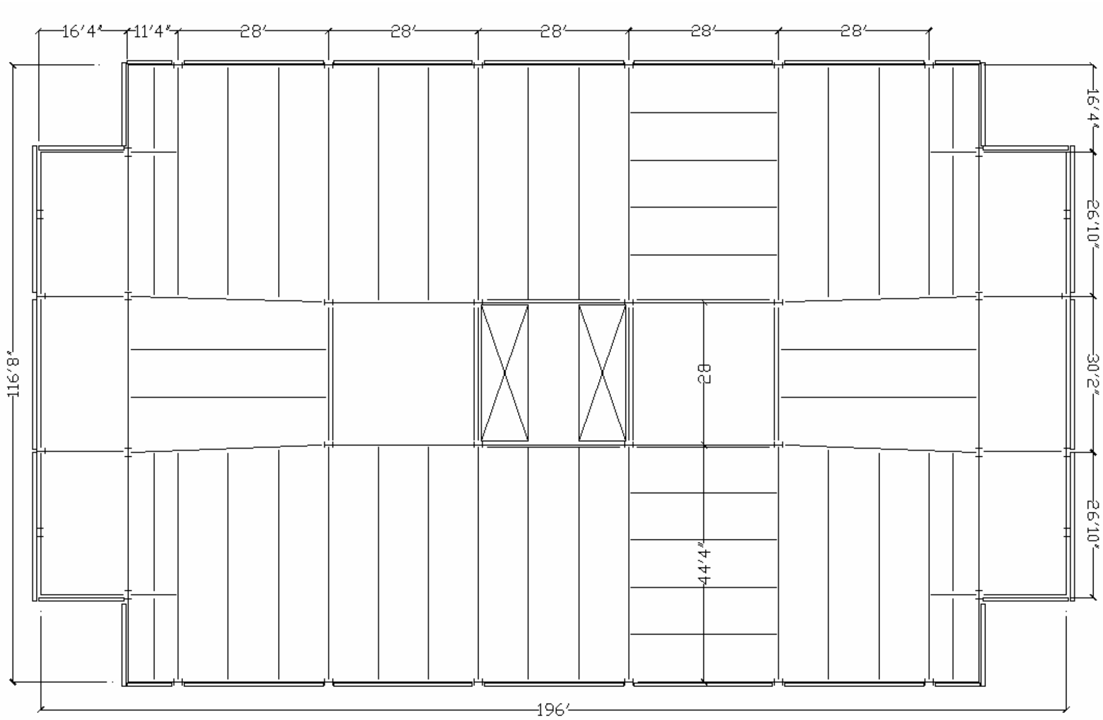


Figure 6: Typical Framing Plan for Floors 4-14

and layout of the framing system has allowed for 13 of the 16 stories to be designed with a typical framing plan. The typical frame in the east-west building dimension consists of a 3 bay bent, with two external spans of 44'4" and an interior span of 28'. Beam sizes for this system are most commonly W18x40 and typically spanning the 44'4" length and spaced at 9'4".

Variations in this framing system occur at the extreme north and south end of the building, as well as in the buildings core due to mechanical system loads, and the insertion of six elevator towers through the height of the building. Exterior girders have been sized to W21x44 with spans ranging from 28' to 12'. Interior girders are primarily sized as W18 shapes with weights ranging from 26 to 86 pounds per linear foot. All beams spanning over 35' in length have been designed with a varying upward camber.

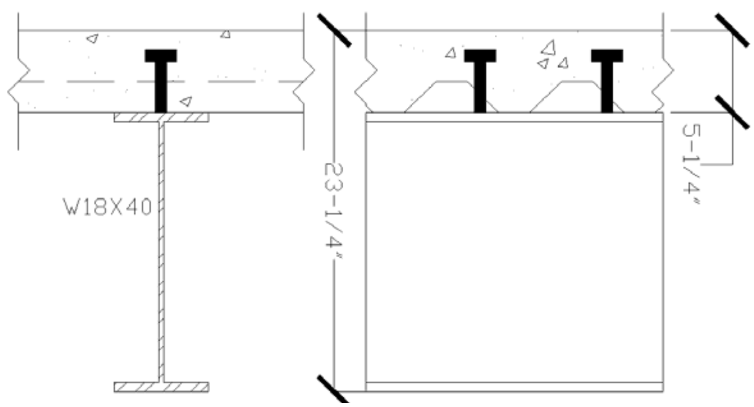


Figure 7: Composite steel floor system section

The columns supporting each floor are all W14x shapes, ranging from 550 to 90 lbs per linear foot at the bottom and top of the frame, respectively. Columns have been designed with a floor to floor story height of 12'1" and typically span two stories. Since Eight Tower Bridge was designed as a multi-tenant office tower with no set floor plan, an important design consideration was to maintain a floor space uninterrupted by columns. In order to span the 44'4" direction, a composite steel system was really the only feasible steel frame design option, as the composite action between the slab and beam increases the moment capacity of the section, and thus allows for longer spans. The steel W-shapes act in composite with a 5-1/4" normal weight concrete slab cast over a 2" steel deck. The total system floor system depth is 23-1/4". There is an additional 13-3/4" mechanical plenum space provided, which brings the floor-to-floor height from 12'1" to a floor to ceiling height of 9'0".

Interior beam-to-column and beam-to-girder connections are typically simple shear connections. Beam-to-column connections in the moment resisting frames within the building are fully welded moment connections, or as an alternate, have bolted end-plate moment resisting connections. All structural steel beams and columns have been specified to ASTM A992 grade 50 steel.

LATERAL SYSTEM

The lateral system of Eight Tower Bridge is actually two separate concentric

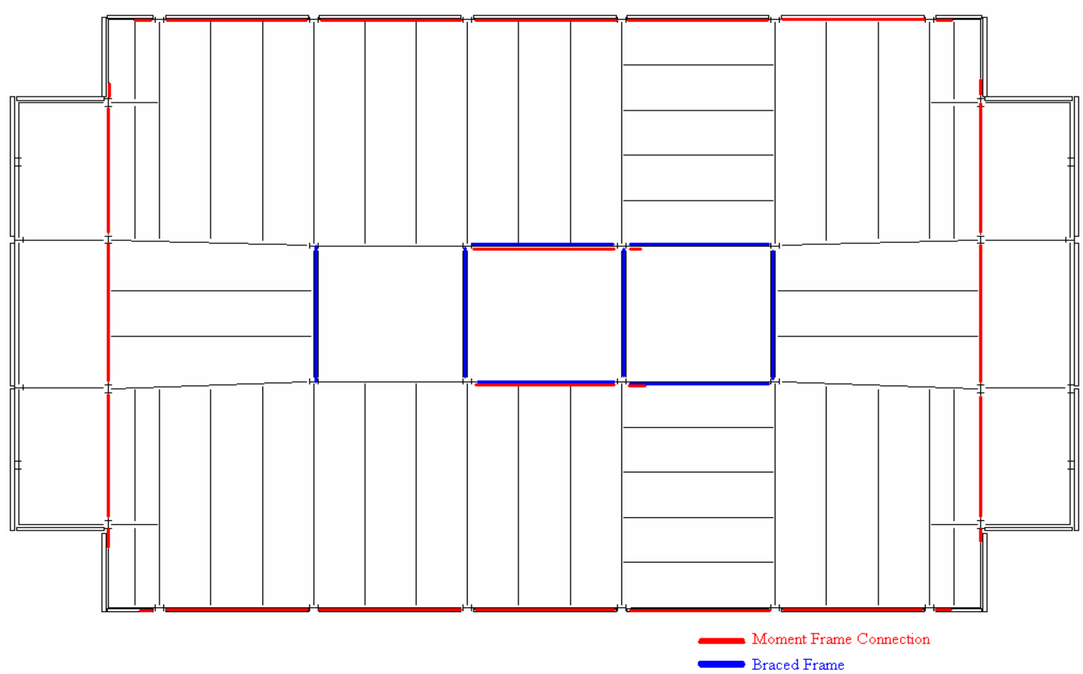


Figure 8: Lateral system framing plan, with moment frames in red and braced frames shown in blue

frame systems. The inner lateral resisting frame is an 18-story tower located around the buildings elevator, mechanical and stairwell spaces. It is comprised of a combination of moment and braced frames. The braced frames span 28' along column lines D, E, F and G in the east-west dimension of the building. Additional braced frames span 56' along column lines 4.1 and 4.9 in the north-south direction between column lines D and F. The lateral system framing schematic can be seen in the framing plan above.

The outer frame is comprised of structural steel moment resisting frames located around the building perimeter. All structural steel is specified as ASTM A992 grade. These moment connections have been designed with single shear plate slip-critical connections in order for the beam to resist lateral and gravity loads and develop the total designed beam end reaction.

The combination of both moment resisting and braced frames limited the overall drift of the building to a maximum of 3.26" under direct wind loading perpendicular to the long dimension of the building. It should be noted that the "long dimension" of the Eight Tower Bridge is also referred to as the "y-dimension" and the "x-direction". The above drift was determined in a previous inspection to be the maximum drift of the steel framed structure as modeled in ETABS.

Proposal

PROPSAL

PROBLEM DEVELOPMENT

It is typical practice in most design offices to evaluate multiple structural systems for any given project the office is approached with. This report acknowledges and respects the design professional's original steel structure design for Eight Tower Bridge. However, there are obviously multiple solutions to the design of a high-rise office building, with the most feasible being dependant of several factors. A few of these factors include site location, material availability, practicality of design and overall system cost, with the last two items being weighted most heavily in the ultimate design choice. While the composite steel system may have been rated highly among these criteria, it is possible that an alternate concrete structural system for Eight Tower Bridge could be designed. Being a completely different material, a concrete system would require a different design method than a steel system, as well an analysis to determine the performance under both gravity and lateral loadings. Whenever a part of building system is altered, such as the building superstructure, there will invariably be consequences in the other disciplines related to building design, especially construction cost and management issues.

PROBLEM STATEMENT

Two alternate concrete structural systems will be designed for Eight Tower Bridge in this report and evaluated for Eight Tower Bridge and compared to the existing composite steel superstructure. The first design will be a reinforced concrete slab and post-tensioned beam concrete system, with post-tensioning in beams spanning both principle building directions. Beam spacing in this system will increase from the current 9'4" found in the steel system to 14' on center, with a 6" slab reinforced in the orthogonal direction.

The second alternate system will be very similar to the first, although the reinforced concrete slab will be replaced with a post-tensioned slab. The intermediate beam spacing of this design will be increased from 14' in the first concrete design, to 28' on center, creating a typical bay size of 44'4"x 28'. The slab thickness will remain the same. Columns will be designed to carry both flooring systems, as the overall system weight is expected to be comparable.

Once the elements of the gravity system have been designed, the building's lateral system will be designed. Concrete shear walls, with an expected thickness of 10"-12" will be placed within the building core. The same lateral system will be employed by both floor system designs.

SOLUTION METHOND

As described above, altering the material of the building will require the redesign of all structural elements, including concrete beams, columns and shear walls. These elements will be designed in accordance with ACI 318-05.

The design loads will be updated from ASCE7-98 and the BOCA 96 code used in the original design, to the more current ASCE7-02 and IBC 2000. The loads governing the design of the alternate systems are given in the table to the right. The mechanical room live load of 125 psf and rooftop mechanical system live load of 200 psf used in the original steel system design will still be used. A schematic of this loading plan can be found in Appendix A. The derivation of roof live and snow loads can also be found here.

Building Loads		
Live		80 psf
Dead		
	Slab	75 psf
	Exterior Wall	60 psf
	SI Dead	20 psf
	MEP/Finishes	10 psf
Roof Live		10 psf
Snow Load		22 psf

Several computer design and analysis programs will be used for the alternate system design for Eight Tower Bridge. The first program used will be RAM Con*cept*, a concrete design program that allows you to design both regularly reinforced and post-tensioned concrete sections. Beam reinforcement from this program will be verified by manual hand calculations.

Once the floor framing member sizes have been determined, column loads and moments will be determined in order obtain preliminary column sizes. These columns will be designed using the program PCACOL. It should be noted that this program designs concrete sections referencing ACI 318-89.

With initial column sizes determined, an ETABS model of the concrete structure will be constructed in order to design the lateral force resisting shear walls. The program will be run using various models with the placement of the walls in different locations in order to find an economical and satisfactory placement. The column moments created from these lateral loads in this model will be re-entered in to PCACOL to verify the initial column sections designed have enough capacity to resist sway.

Both of these systems will be compared to each other, as well as the original steel structure in regards to system performance and efficiency. The overall story height possible by each system will be reviewed to determine if the building could be shortened or additional stories added without increasing the building height.

BREADTH STUDY PROPOSALS

CONSTRUCTION MANAGEMENT BREADTH

A breadth study will be conducted regarding the construction management issues involved with altering the superstructure of Eight Tower Bridge from steel to concrete. A superstructure cost estimate will be conducted for the new concrete system, and a construction schedule will also be formed. The cost estimates and construction schedules of both systems will be compared to the steel bid package and construction duration obtained from Grossi & Sons Steel, the steel contractor for this project. It should be noted that the 2005 Edition of RS Means will be used through the computer software Cost Works to conduct an estimate for the new concrete systems. The estimated for the alternate concrete systems will then be converted to 2001 dollars, the time the structural package was received by Gross & Sons.

MECHANICAL BREADTH

The current mechanical system for Eight Tower Bridge will be redesigned to incorporate a ground source heat pump for used for heating and cooling fluid currently in the chilled water loop found in Eight Tower Bridge. A closed loop system containing water or refrigerant will run through the bore holes in the ground, using the constant temperature of the earth as a thermal reservoir for extracting heat from and discharging heat to. This system would be used in replacement of the current cooling towers located on the roof of the building. This system will largely be evaluated for feasibility while still attempting to reduce the cooling loads of the tower and mechanical system operating costs. It will be based on the period to positive return length, which will ideally fall between 3 and 5 years.

Structural System Design

STRUCTURAL SYSTEM DESIGN

DESIGN CRITERIA

The primary goals and criteria governing the alternate concrete superstructure design are as follows:

-maintain an open office layout, free of column obstructions
-maintain an overall floor system depth equal to or less than the existing steel floor system depth of 23-1/4"
-limit live load deflection of floor to ℓ/360
-limit the total building drift to ℓ/400 or 6.42"

DESIGN PROCESS

The alternate concrete structural system for Eight Tower Bridge was designed keeping in mind several of the same performance and design criteria that the original steel system was designed under. A desirable attribute of any office tower design, especially a multi-tenant office tower, is to maintain an open floor plan with minimal interruption from columns. An open floor plan allows for the space to be configured to suite the tenant's needs as the space is rented. A multi-tenant office tower also means there is little to no set floor plan prior to or during construction, again requiring flexibility of the space to be modified once rented.

In order to preserve the open floor span of the existing steel structure, the long spans of 44'4" from the building exterior columns to the building core columns must be preserved without adding additional column lines. The bay size of 44'4"x28' starts to approach the upper limits for allowable two-way concrete action (a length to width ratio less than two is required). Even though this bay size is below the *l/w* ratio of two, it still may not be a very economical design.

A one-way beam and slab system will carry the floor loads in a similar fashion to the existing steel system, which will keep the long spans of the bay in tact. A T-beam design would be possible, with the added flange width allowing for the decrease of the depth of the concrete stress block, a. The moment capacity of a T-beam section is given by the equation below:

$$M_n = (.85f'c(b-b_w)h_f)(d-h_f/2) + (.85f'cb_wa)(d-a/2)$$

When the depth of the stress block a is reduced, the overall moment capacity of the section will increase. While this seems like the optimum solution to the concrete design problem, T-beam design is only possible at midspan, as negative moments at the end span won't be resisted by forces in the flange. A solution to this problem would be to increase the effective depth, d, thus increasing the overall system depth. While this may be a viable design solution for applications where structure depth may not be a limiting criterion such as a bridge span, minimizing the structure depth in building design is an important design factor. Additionally, with an increase in beam size, controlling deflection will also become difficult due to an increase in beam self weight. A design solution that will decrease the beam depth and provide adequate flexural strength is to introduce post tensioning to the section.

POST TENSIONING DISCUSSION

Post tensioning of concrete sections involves balancing a certain percentage of the floors permanent load dead load with an external tension force at the end of the beam transferred to the concrete through a stressing tendon. These tendons are laid inside the concrete formwork, usually protected by plastic duct work or sheathing to prevent the concrete from bonding to the tendons initially. The tendons are anchored at one end of section, and tensioned using a hydraulic jack at the other, or in long span cases (longer than 120') are tensioned at both ends once the concrete has cured to a specified strength, usually taken to be 0.6f'c. The tendon ducts are sometimes injected with a grout in order for the tendons to more effectively transfer the prestressing force to the concrete section. These tendons are known as bonded tendons. Post-tensioned systems that don't use this method are said to have unbonded tendons.

Figure 9: Post tensioned slab
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Pulling on the end of the anchored tendon creates a compression force at either end of the beam, inducing a compression force in area of section where tension would occur in the concrete element under dead loading. If designed properly, this compression force will create a camber of the concrete element, which is then balanced by the addition of finishing loads,

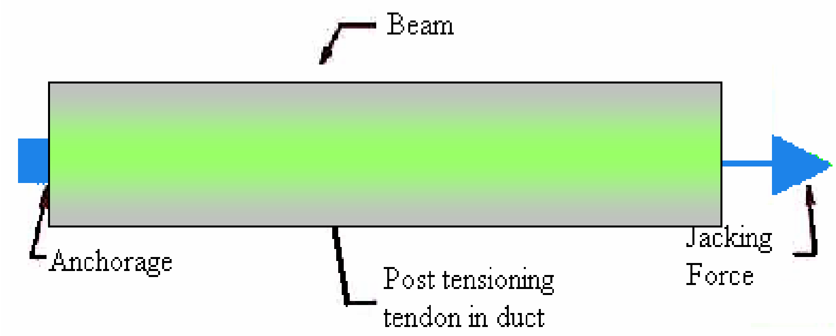
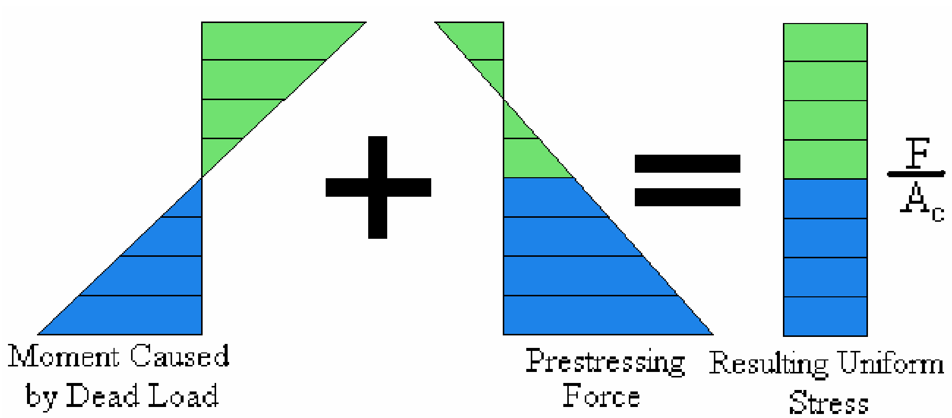


Figure10: Post-tensioned beam



miscellaneous MEP system loads and live loading after the concrete has cured. This additional loading on the beam or slab will act against the upward camber, yielding minimum deflections across the member length. Prestressing tendons are usually draped across the section in a parabolic profile in order to evenly balance the dead load along the length of the beam. The tendon profile and magnitude can be designed to create a member that is uniformly stressed under flexural forces.

The floor system design of any building has the most significant impact on the rest of the building's structure, and additionally the building's overall cost. The weight of each floor ultimately determines the size of the columns, walls and foundations. The depth of the structural system determines the overall building height, thereby affecting the total quantities of cladding components as well as mechanical, electrical and plumbing work. Additionally, in areas of high wind forces, a 6" reduction of flooring system depth over 20 stories would result in a 10' reduction in building height, thus reducing the total area the wind has to act on the building. This results in reduced story shears, base shears and overturning moment. In seismic controlled areas, a reduction of floor system weight could ultimately reduce the lateral force resisting system of the building.

There are both advantages and disadvantages of post-tensioning concrete. In general practice, post-tensioning concrete can result in thinner, more aesthetic sections without sacrificing strength. Post-tensioning concrete allows for greater span/depth ratios, thus decreasing the total material impacting both cost and weight. When concrete is post-tensioned in buildings, it is possible to strip formwork earlier than regularly reinforced concrete once the slab or beam has been post-tensioned, thus decreasing the lag time between floor construction cycles. In systems where a considerable amount of the load is reduced by post-tensioning, the amount of regular steel reinforcing is decreased, reducing raw steel tonnage and material handling costs.

Figure 11: Post-tensioned bridge span

Disadvantages of post-tensioned system are largely construction related. You must wait for the concrete to cure to a specified strength before the tendons can be stressed. This can prolong the floor construction duration, despite the ability to speedily remove formwork shortly after the tendons are stressed. When post-tensioning slabs, additional labor is required to actually tension each of the strands which can slow construction time if not done properly. This usually requires hiring a special post-tensioning subcontractor. Post-tensioning tendons can also wreak havoc on a site if they are not tensioned to the proper strength or placed incorrectly. Too little tensioning can drastically reduce the effectiveness of the tendon. This can create increased deflections seen under wet concrete loads or over the course of the building's life. If a tendon is over stressed, it can snap, ripping through an entire concrete slab or beam, ruining the section, in addition to threatening the safety of crews on site. Also, a contractor can only perform post-tensioning when the temperature is above 45˚F. If a post-tensioning structure falls behind schedule into the winter months, concrete heaters will be required, adding to equipment costs. It is essential the contractor hired to perform post-tensioning in any building be experience to ensure safety and quality.

FLOOR SYSTEM DESIGN #1

Multiple types of post-tensioned systems were reviewed to determine what concrete flooring system would be most suitable for Eight Tower Bridge. After weighing possible options, a one-way post-tensioned beam and slab design alternative was selected. A typical bay spans 28’x44’4” with beams spaced at 14” on center. A 6” thick concrete slab with reinforcement in the orthogonal direction was found to be adequate with regard to ACI 318-05, Table 9.5(a). The flexural reinforcement for the

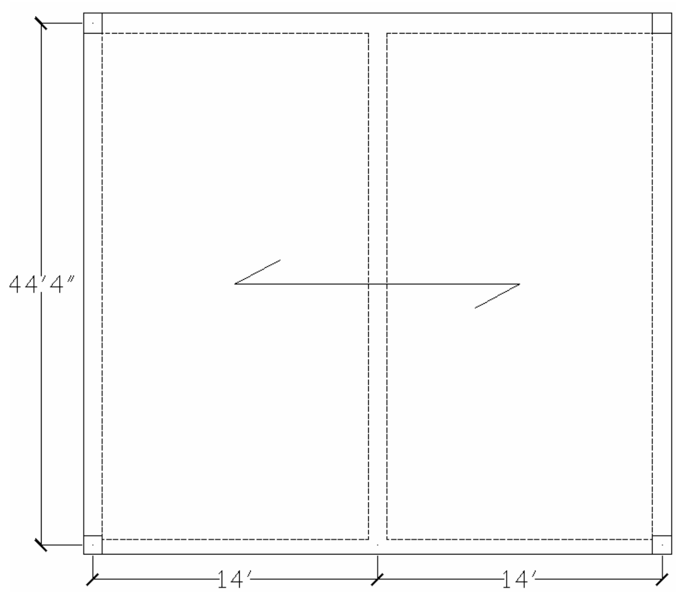


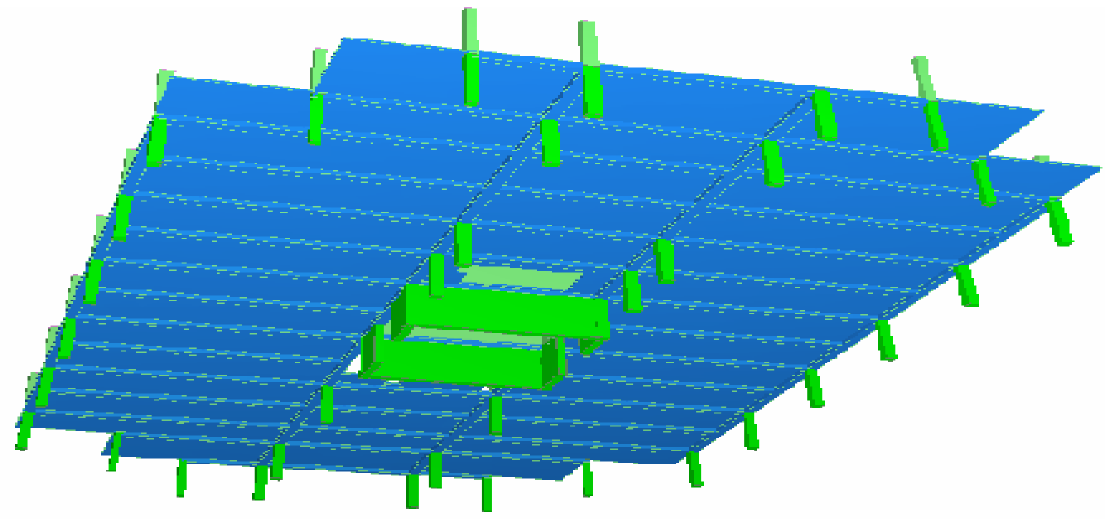
Figure 12: Typical concrete bay

slab was found to be #5@12” on center through the hand calculations found in Appendix B.

Due to the rather complex nature of calculating post-tensioning by hand, the structural software package RAM Conc*ept* was used to model the beam and slab floor system. RAM Conc*ept* allows the user to model a single floor of a building and either design or analyze post-tensioning system for the flooring system. A basic model for the program would include a floor slab, beams, drop panels if necessary and any columns or shear walls above and below the floor. However, at this point in the design, there was no trial section for either columns or beams to be entered into Conc*ept*.

In order to obtain a trial size for modeling the floor system in the program, a moment distribution based on relative stiffness with E and I held constant was performed on each bent of the proposed concrete frame to determine the approximate magnitude of the moments each frame would need to be designed for. Alternate and adjacent bay loadings were used to determine maximum and minimum design moments. The upper limit of any size beam selected, trial or final, was set at 24" deep, including the 6" slab in attempt to keep the total system design under the existing 23-1/4". A trial beam size of 20x20 was selected, and seeing as both E and I were kept constant for both columns and beams in the moment distribution, a 20x20 trial column size was also selected. The moment distribution tables can be found in Appendix B.

With trial sizes selected for the flooring system, an initial model could be



2-D rendering of post-tensioned beam and slab system

constructed in Conc*ept*. Shear walls were also placed in the model, but were not designed, as Concept does not consider lateral loads in design. A 3-D rendering of the floor system and supporting columns can be seen above. Please refer to Appendix B for more views the flooring system.

Post-tensioning tendons were added to beams spanning both directions, and the following design assumptions were made:

1. The concrete beams were designed as "T Class" sections, with an allowable extreme fiber stress of $7.5\sqrt{f'c} < f_t < 12\sqrt{f'c}$ in precompressed tensile zone at service loads (ACI 318-05, 18.3.3b.)

2. The design strips that Concept uses to design concrete elements were designed as T or L beams in the column strip, and as elevated slabs in the middle strip

3. All slabs and beams are 5000psi normal weight concrete

4. Tendons are unbonded, 270 ksi, ½"ø 7-wire stands with an effective force of 26.6kip/tendon after losses. Loss calculations can be found in Appendix B

The model was then run to test the initial section size, number of tendons and tendon profiles in each element. Through multiple trial and error design iterations, final beam member sizes were assigned and appropriate number of tendons and tendon profiles were placed in each section. The deepest section was found to be 20" including the 6" slab. This system had an overall depth 3-1/4" less than the existing steel system. The final framing plan can be found below with member sizes noted.

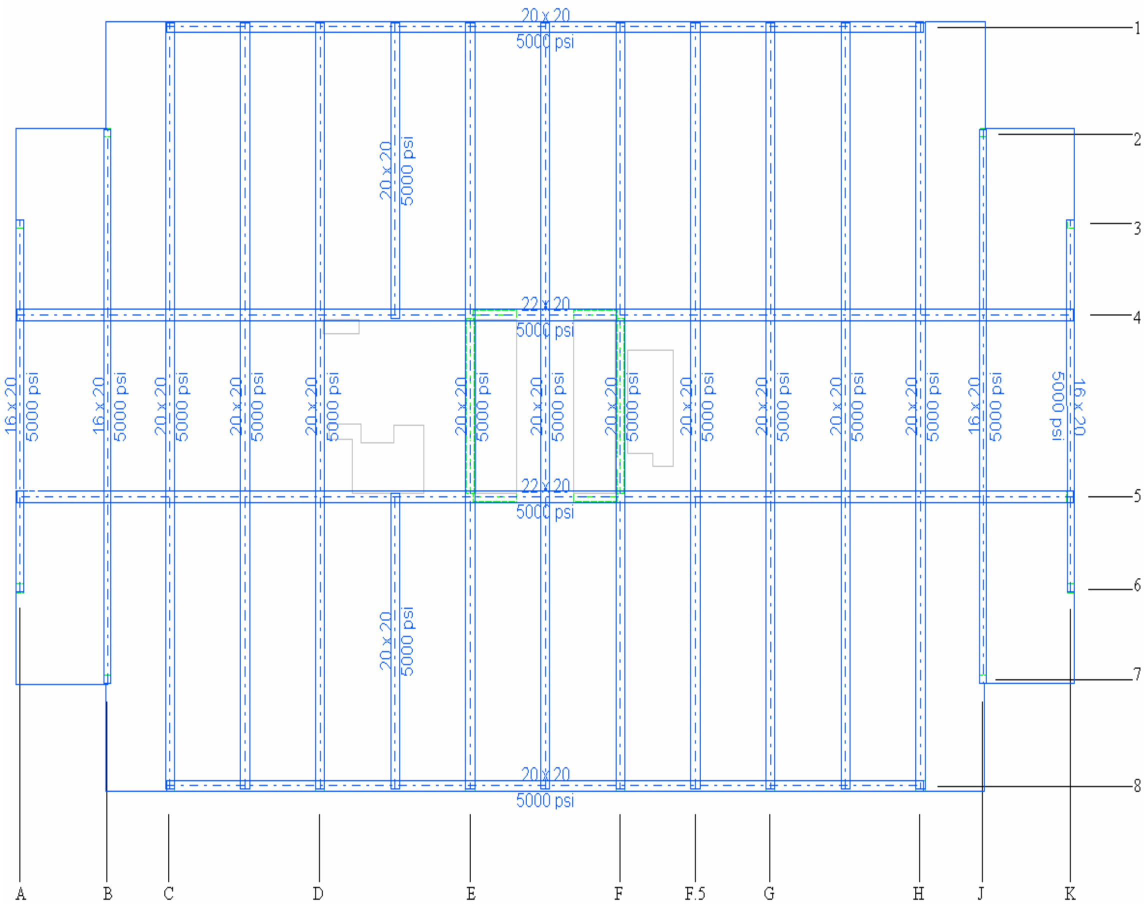


Figure 13: Concrete framing plan of typical floor

Post-tensioning tendons were originally placed in each of the beams in the above framing plan. However, in order to reduce post-tensioning costs, tendons were entirely removed from beams along column lines 1, 8, A, B, J and K, as well as along column lines 4 and 5 between lines A and C, and between lines H and K. All of these spans are under 28' in length and can be designed as regularly reinforce concrete sections. Although RAM Conc*ept* designs regularly reinforced concrete sections, the design was verified through hand calculations which can be found in Appendix B.

In the design of post-tensioned concrete beams, the load balanced in by the post-tensioning force tends to be in the range of 80%-110% of the dead load. The design of a tendon spanning multiple lengths like the spans found in the system depicted above, the longest span is usually designed first and labeled as the "critical span". For the design in this system, the critical span was 44'4" in the longitudinal direction. Using the maximum possible drape in the section as one limiting criterion, and the minimum precompression force (7.5√f'c by assumption #1) as the other, an efficient number of tendons and tendon profile should be designed for this span.

For the 28' span adjacent to the critical span, it is practical to design for a smaller percentage of the dead load because less upward force in this adjacent span reduces the design of the critical span. This can be done by either reducing the number tendons in the section, or decreasing the tendon drape. It is usually preferred to design using the latter method, as it simplifies the constructability of the system. The overall goal of modifying the tendon drape profile through a section over a varying length is to find a constant jacking force that will be applied throughout the length of the tendon and will resist an acceptable percentage of the design dead load. For an illustration of the effect sag has on tendon tension, see Appendix B.

The tendon drape profile and number of tendons in each beam were designed using the method above in order to maximize strength of each tendon over varying spans. The depth of the drape or "sag" of each tendon is related to the tensioning force required through the equation $F = w_{pre}L^2/8s$, where the term "s" is the sag of the tendon in inches. The other terms, "w_{pre}" and "L" are the balanced load in design and length of span, respectively. The final tendon profile for a typical beam spanning the longitudinal building direction can be seen below. Beams in the latitude direction were designed using the iterative process. Tendon plans for both directions can be found in Appendix B.

The tendon profile below uses 16 unbonded ½"ø 7-wire stands throughout the

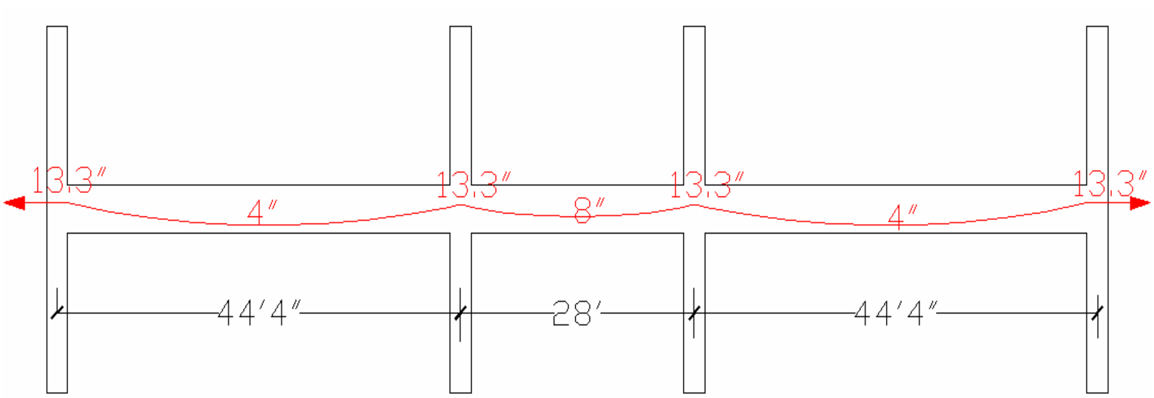


Figure 14: Tendon profile for typical beam in longitudinal direction. Drape dimensions are from bottom of concrete soffit.

entire profile with a capacity 26.6kips/strand, resulting in a total jacking force of 425kips. The total span of this tendon is 116'8", which falls under the 120' maximum length for jacking a tendon from one side only. This will allow for simplified constructability by the post-tensioning contractor.

As previously mentioned, one advantage of post-tensioning concrete is the ability to minimize deflections due to the upward camber created by the compressive forces created from tensioning the tendon. For this design, the deflection of the floor system was limited by $\ell/360$ from ACI 318. This equates to a maximum deflection of 1.47" in the 44'4" spans; a limitation which the system meets. It should also be noted that designing the beams of this system as a "Class T" member allows for higher precompression stresses, but also uses the cracked section as the basis for deflection calculations. The cracked moment of inertia for any section tends to be around half the uncracked section, effectively doubling any deflections using the cracked section. This is a serious design consideration, and would have to be counteracted by adding strands to the section or increasing the tension force in the strand. Below are the deflection plans for the flooring system design. The plans include deflection under initial service loading, sustained service loading, and long term loading. The long term loading plan takes into account creep in the concrete and the post-tensioning tendons over a considerable length of the building's lifetime. While it important to minimize the deflection under long term loads and know how the building reacts under long term loads, deflections are expected to be slightly higher and may slightly exceed deflection design criteria. However, over the lifetime of the building, a deflection of 1.6" will be noticeable, but not incredibly uncomfortable to the tenant.

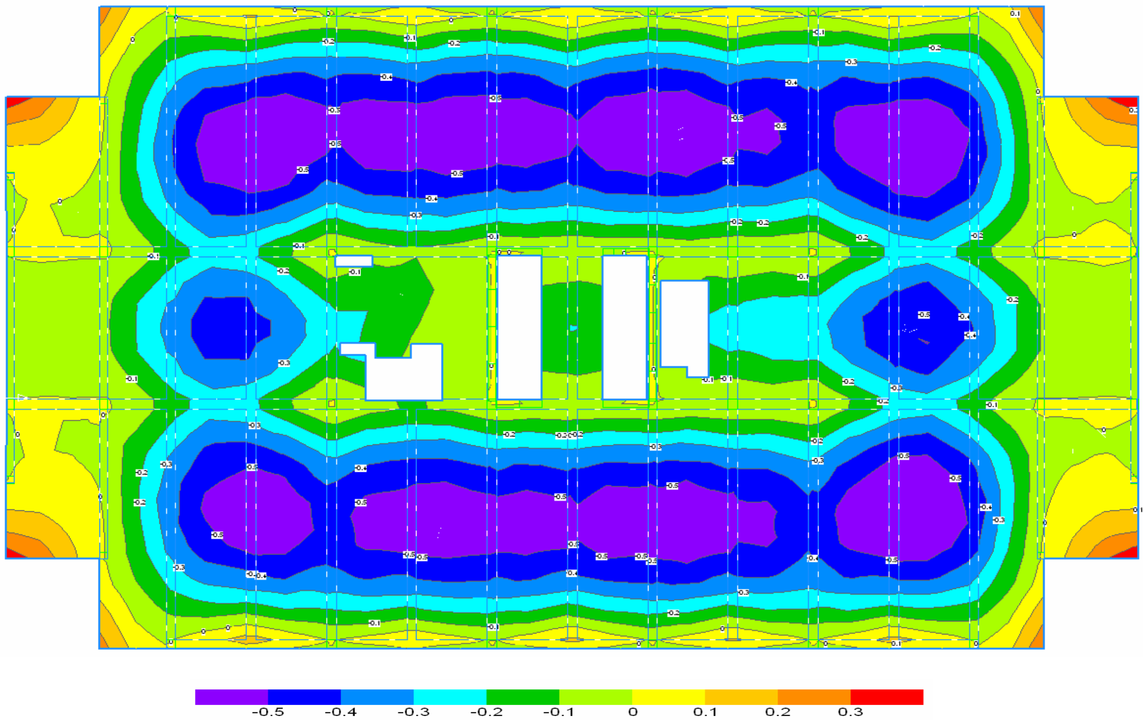


Figure 15: Deflection plan under initial service loading

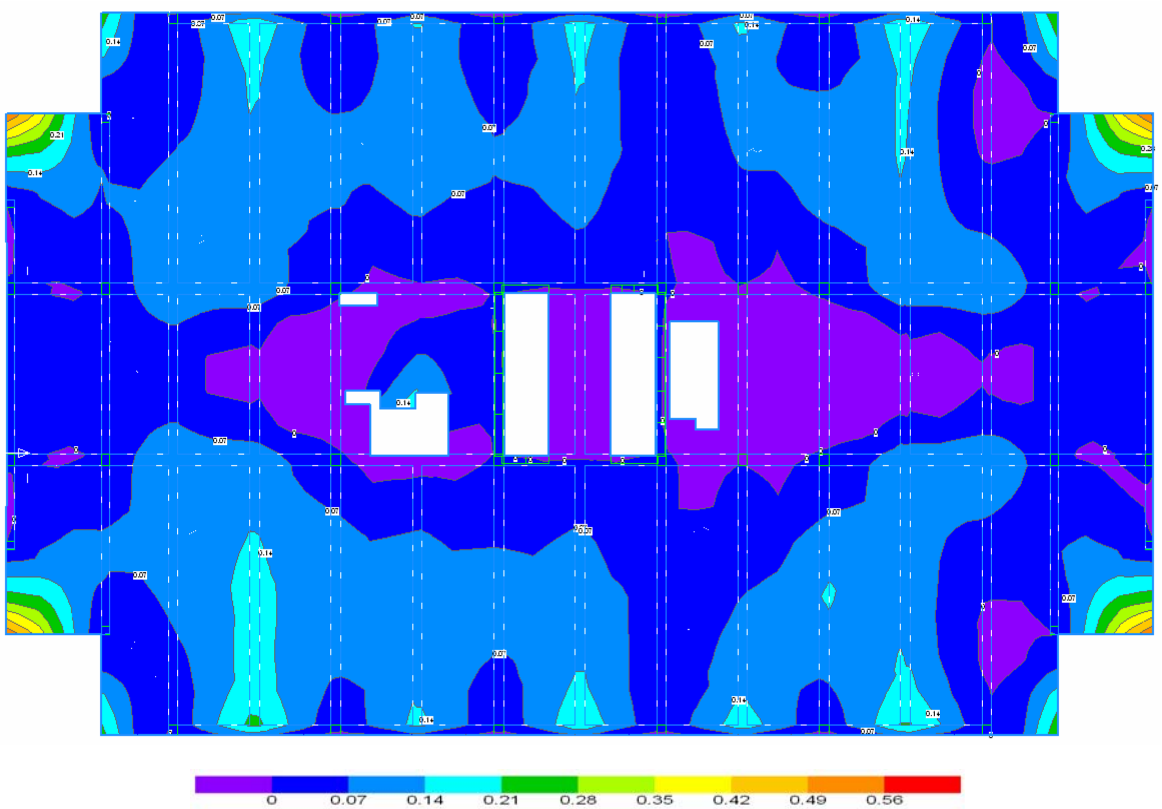


Figure 16: Deflection plan under sustained load

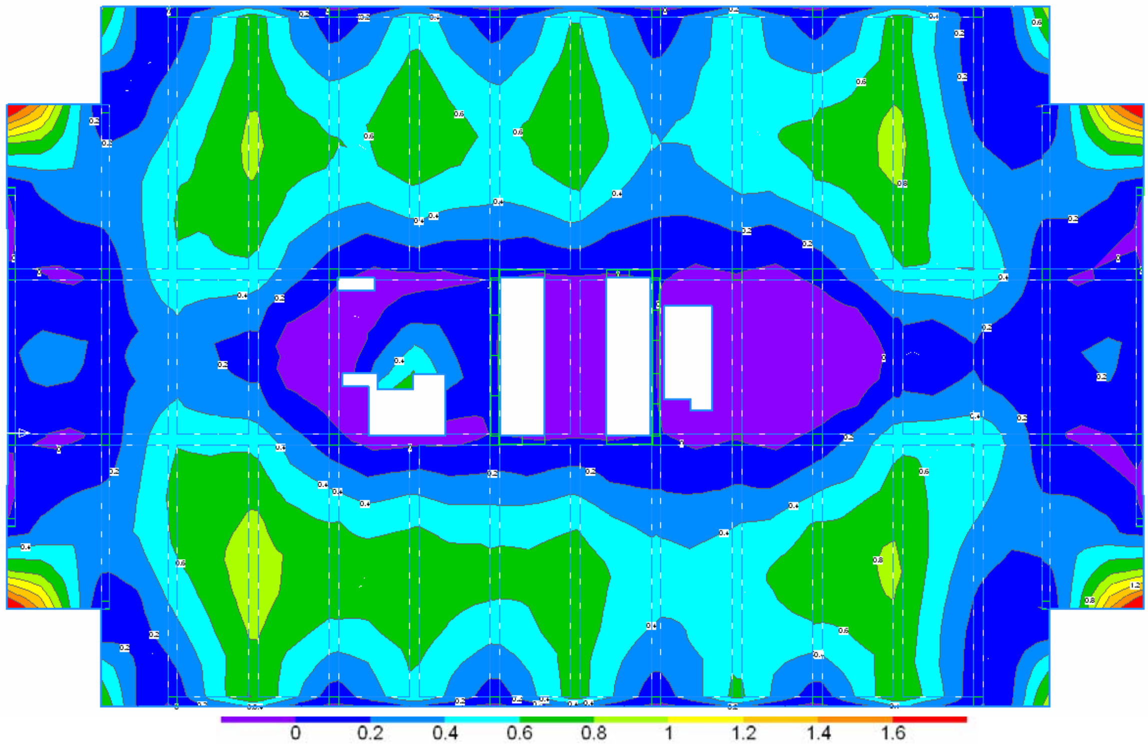
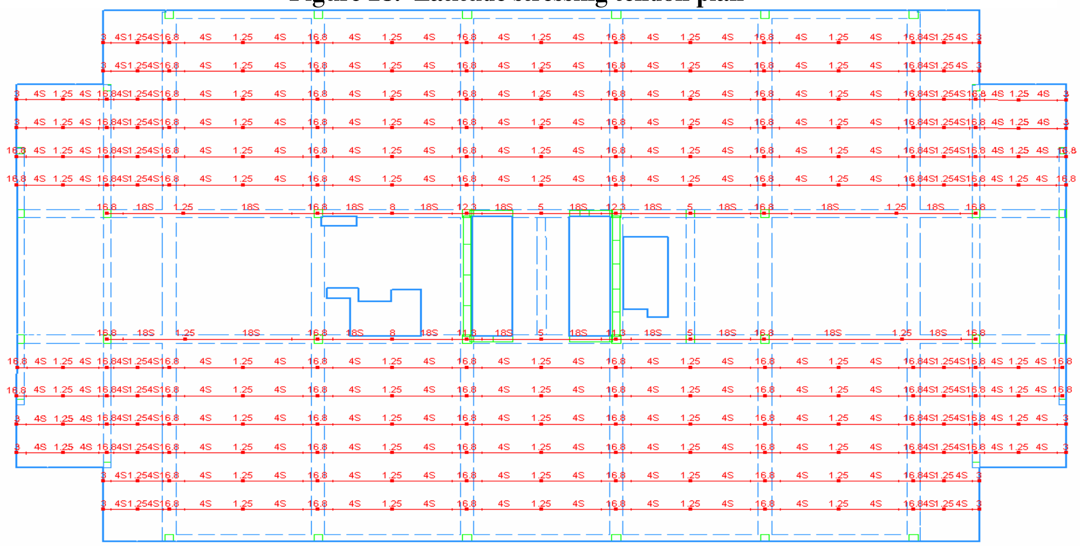


Figure 17: Deflection plan under long term loading

FLOOR SYSTEM DESIGN #2

Once an acceptable flooring system was designed in RAM Conc*ept*, and a better understanding of how post-tensioning works was obtained, it became evident that a design with post-tensioning found only in the beams could be altered to include post-tensioning in the slab and beam a spacing of twice the distance. These beams would need to be designed as wide beams, and additional post-tensioning tendons would needed to be added to resist the dead load from the increased self weight of the wide beams, as well as the concrete weight being carried from double the tributary area. As the number of design iterations increased, it was found that a wider beam with additional post-tensioning added could resist the same loads as a deeper section with less post-tensioning. A wide beam design would decrease the depth of the system, thus shortening the floor to floor height of the building and overall height. This design required bundles of 4 ½"ø 7-wire stands spaced a little over 6' apart in the slab, and an average of 26 strands in the 18"x30" wide beams spanning in the

Figure 18: Latitude stressing tendon plan



longitudinal direction. The latitude tendon plan is shown in the diagram above. The final depth of the post-tensioned slab floor system was found to be 18" including a 6" slab; a reduction of 5-1/4" from the original steel system and a decrease of 2" from the first post-tensioned flooring system. The post-tensioned beam and slab design adequately met the L/360 deflection rating, and even only slightly exceeded the rating over long term loading, which speaks well for the strength of the system over the life of the building. Below are the initial, sustained and long term service load deflection plans for a post-tensioned beam and slab system.

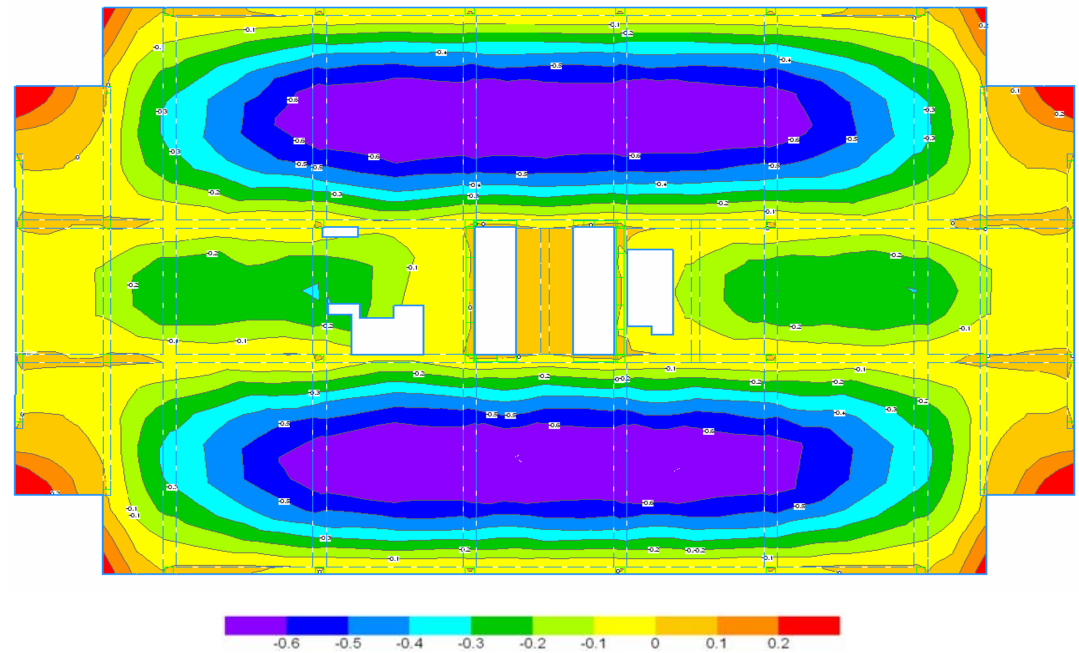


Figure 20: Deflection plan under initial service load

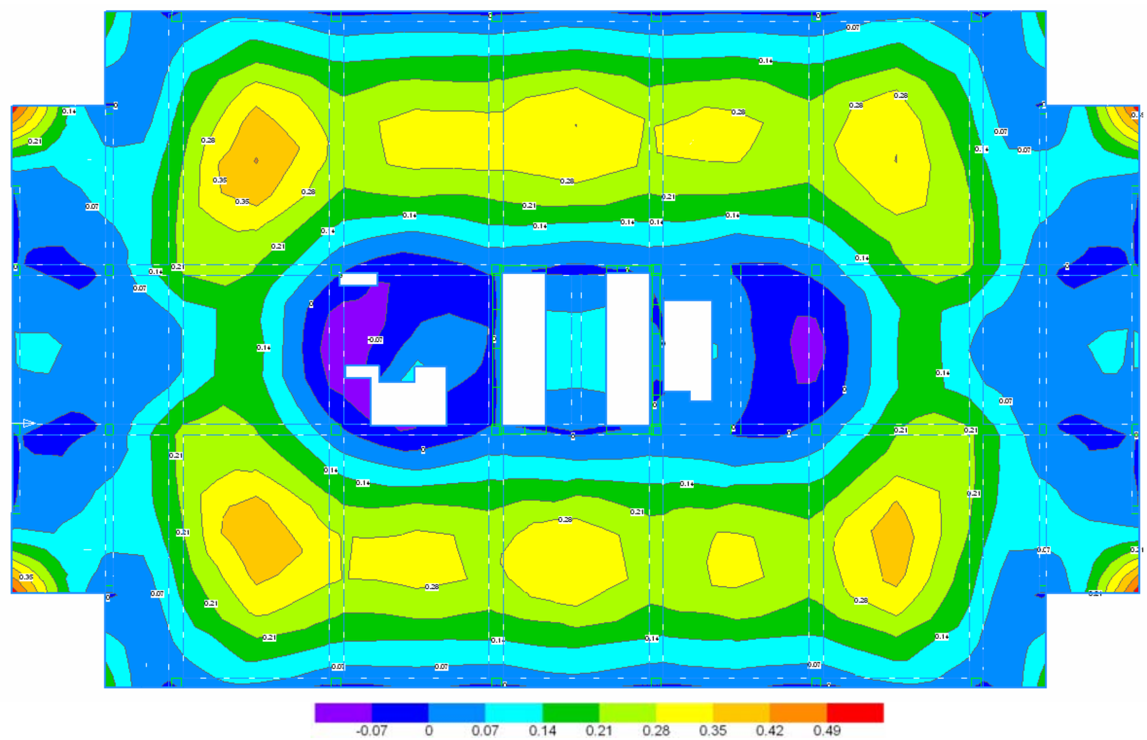


Figure 21: Deflection plan under sustained service loads

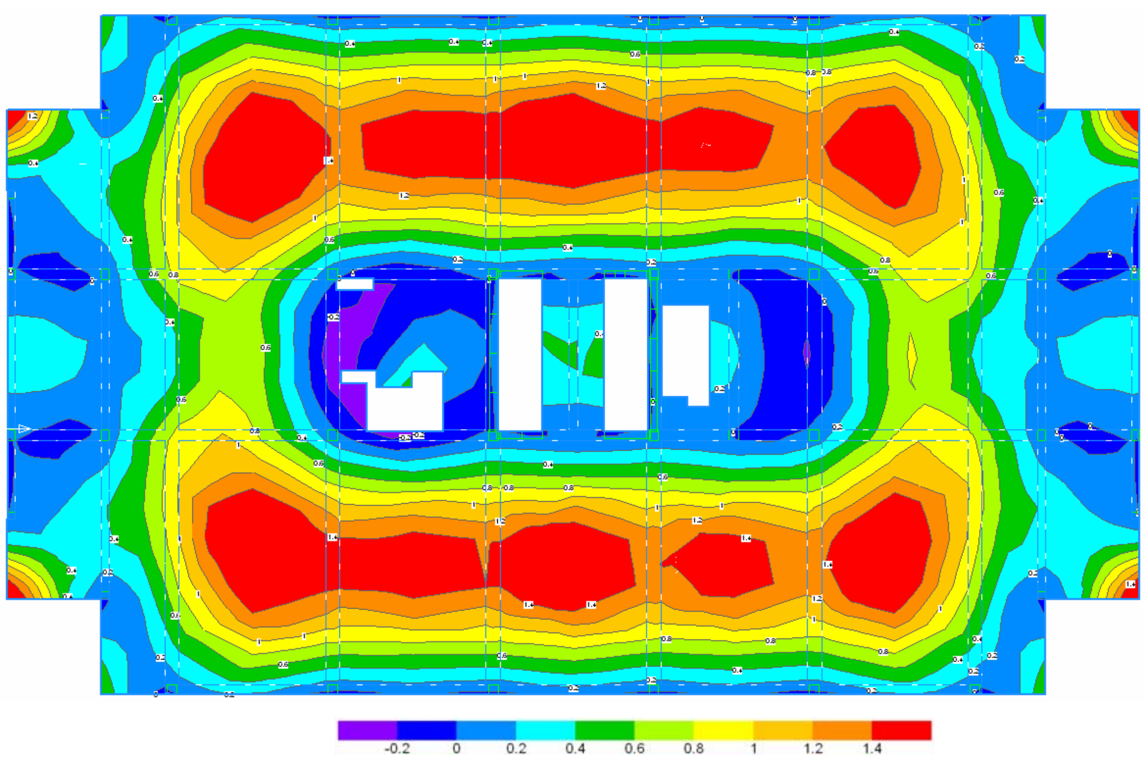


Figure 22: Deflection plan under long term loading

CONCRETE COLUMN DESIGN

As previously mentioned, columns were assigned a trial section of 20" x 20" in order to create a post-tensioned floor system model in RAM Con*cept*. Again, this section was determined by finding the end moments on the beams from a moment distribution, initially estimating a beam size, and then keeping the dimensions of the column the same as the beam to keep a constant moment of inertia. However, it is evident by inspection that a base column with dimensions of 20"x20" wouldn't be nearly large enough to support 15 stories of weight above it given the current column layout of Eight Tower Bridge.

To get a better idea of the axial forces carried in each column at every level, a simple spreadsheet was created that factored in tributary area, dead load, reduced live load, roof load and mechanical rooftop loading. The weight of the concrete slab was also taken into account over the tributary area. These spreadsheets can be found in Appendix C.

The columns must also be designed to resist bending moment about both axes. In order to obtain bending moments due to gravity loads, a reaction plan created by RAM Con*cept* was used. The moments from this plan were determined to be more accurate than the moments derived through the moment distribution spreadsheets created. However, it was recognized that the moment outputs from this plan were for 20"x20" columns only, and did not take into account that a larger column would take more moment from the beams in a distribution. In order to estimate the increased moment a larger column size would take, the moment distribution spread sheet used to determine the trial section size was run with a constant beam size and an increasing column size. Although the distribution of moments is not on a linear scale, a rough "moment multiplier" was determined for columns larger and smaller than the 20"x20" column moments obtained from RAM Con*cept*.

With both axial loads and bending moments obtained for all columns, the program PCA column was used to obtain column sizes and reinforcement that could withstand the given moments. The columns loads were entered as service loads, and the load cases of 1.2D+1.6L and 1.4D were used. Below are the service loads entered into and an output from PCA COL for the base columns at D4 and D5. These two column marks carried the largest load, having the largest tributary area and supporting half of the load created from the mechanical system room located on every floor.

D4, D5	Axial (kips)	M_{x-x} (ft-kips)	M_{y-y} (ft-kips)
Dead	2051	271	125
Live	803	185	78

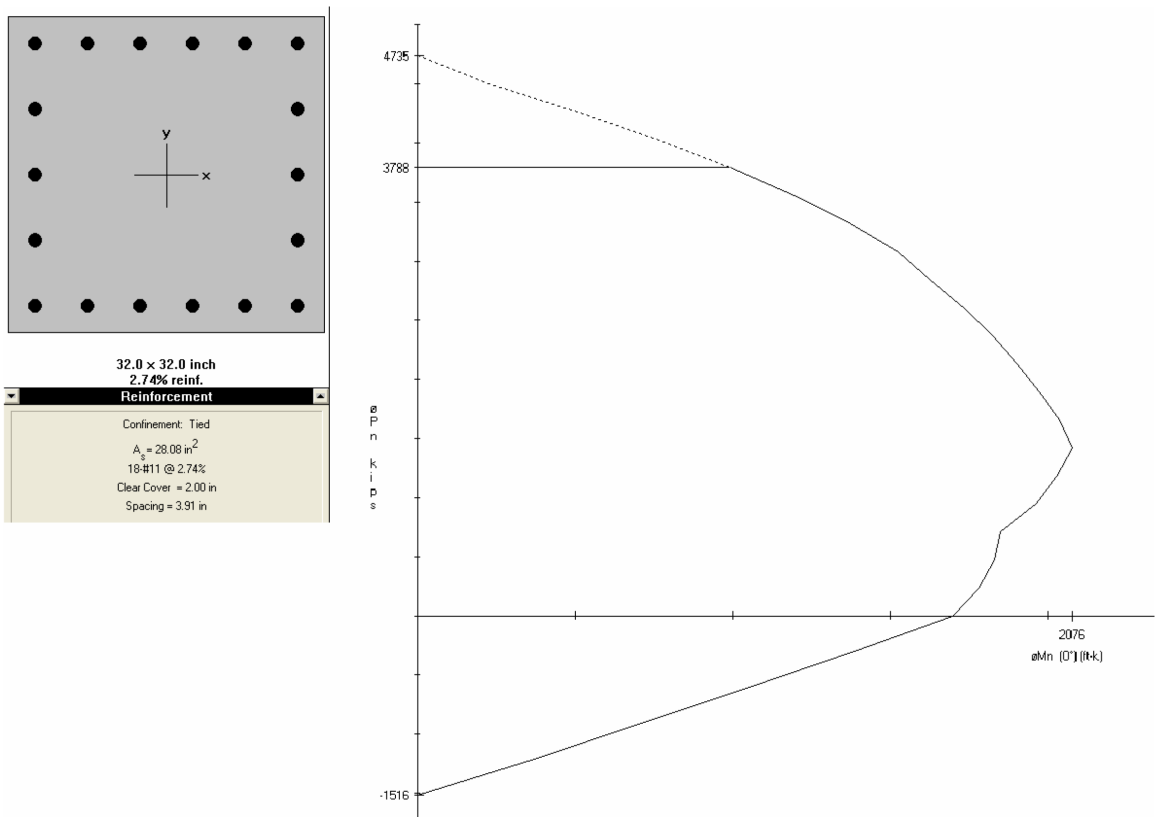


Figure 23: Initial PCA COL output with interaction chart

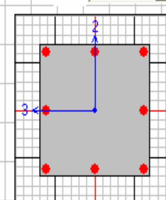
The output suggests that a 32"x32" 6000psi concrete column reinforced with 18-#11 bars be used to resist the given moments. From discussion with design professionals and referencing similar sized concrete office building plans, it was determined that a column size of 32"x32" for the given tributary area is common. It was also previously mentioned that RAM Conc*ept* does not take into account lateral forces, so the moments caused by both gravity and lateral loads needed to be obtained. However, the initial 32"x32" column size seems to work well for the given axial loads, so the reinforcement will need to be verified for bending.

The above design process was used for each column mark, changing the loads every three levels. For contractibility, it is more efficient to re-size columns every few floors rather than at every level. Column sizes were obtained for every level using PCA COL.

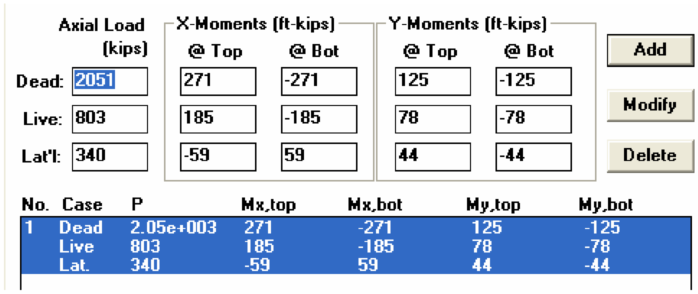
With the floor system designed and a tentative column schedule, a complete building model could now be constructed using ETABS. This model took into account moments created from lateral loads, and helped refine the column sizes and reinforcement obtained through PCA COL. There is also a design feature on ETABS that outputs the suggested area of steel to include in each column. This feature was used as a check against the PCA COL output as well. Below flexural summary from the concrete design feature used in ETABS.

```
ACI 318-99 COLUMN SECTION DESIGN  Type: Sway Special  Units: Kip-ft  (Flexural Details)

Level        : LEVEL 2              L=11.000
Element      : C26                  B=2.667          D=2.667          dc=0.150
Station Loc  : 10.167               E=518400.000     fc=864.000       Lt.Wt. Fac.=1.000
Section ID   : 6KSI-32X32COL        fy=8640.000      fys=8640.000
Combo ID     : DCON18               RLLF=1.000

Phi(Compression-Spiral): 0.750      Overstrength Factor: 1.25
Phi(Compression-Tied):   0.700
Phi(Tension):            0.900
Phi(Bending):            0.900
Phi(Shear/Torsion):      0.850

AXIAL FORCE & BIAXIAL MOMENT DESIGN FOR PU, M2, M3
                          Rebar     Rebar    Design     Design     Design
                           Area         %        Pu        Mu2        Mu3
                          0.071     1.000   339.217    -58.105     44.098

Factored & Minimum Biaxial Moments
                       Non-Sway      Sway  Factored    Minimum    Minimum
                            Mns        Ms        Mu       Mmin Eccentrcty
    Major Bending(M3)    18.772     0.235    19.007     44.098      0.130
    Minor Bending(M2)    -7.210   -50.894   -58.105     44.098      0.130

Axial Force & Biaxial Moment Factors
                             Cm  Delta_ns   Delta_s          K          L
                         Factor    Factor    Factor     Factor     Length
    Major Bending(M3)     0.600     1.000     1.000      1.000     10.167
    Minor Bending(M2)     0.600     1.000     1.000      1.000     10.167
```

Units Kip-ft



These moments were added to the gravity moments in PCA COL to verify that the reinforcement in the column will be enough to resist later loads. Below is a view of the loads that were put into PCA COL as well as an output with these loads.



Above: Table output of loads input to PCA COL
Below: Output and interaction diagram from PCA COL

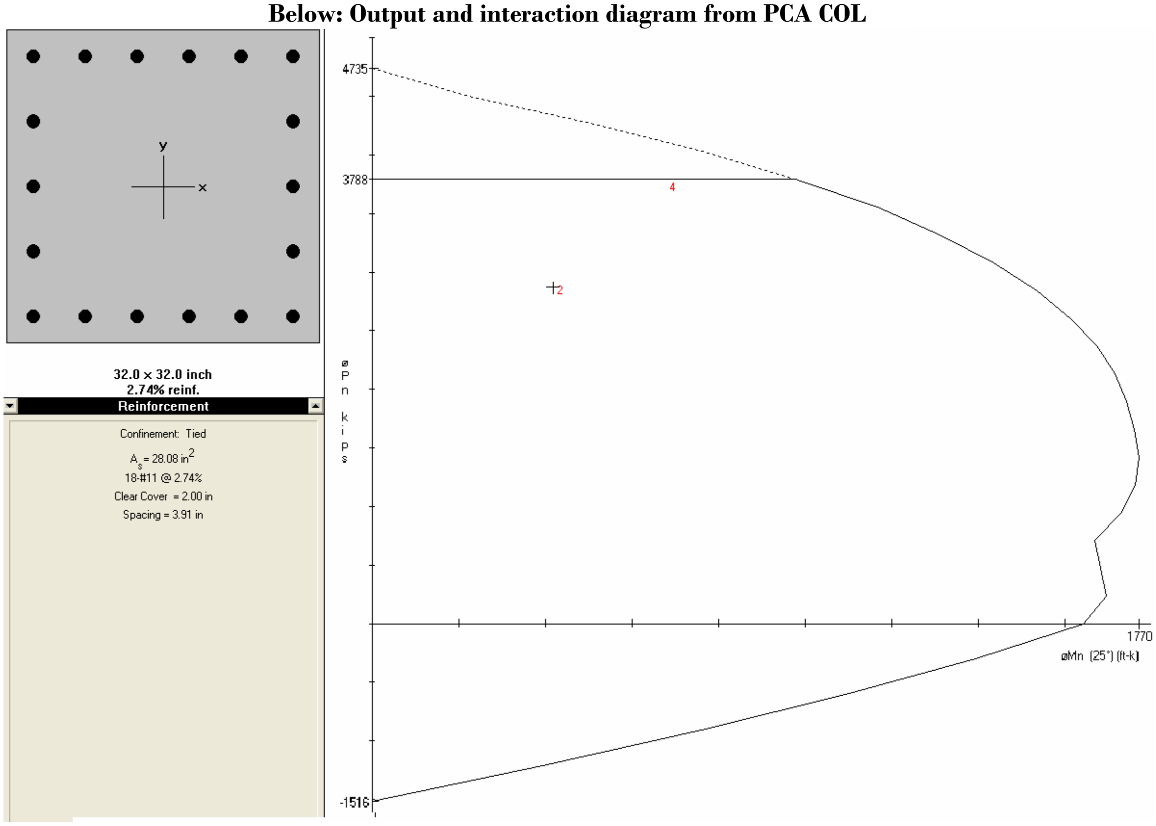


Figure 24: Refined PCA COL output using lateral loads from ETABS

The input of lateral loads for this design shows that a 32"x32" column with 18-#11 bars is adequate reinforcement for this column. The process was repeated for the rest of the columns, and a full column schedule was produced. This schedule can be found in Appendix C. It was found that the strength of the concrete could be reduced at the 10th level to 5000psi, which is the same strength as the other structural elements, making concrete placement easier for construction crews.

It should be noted that the columns were not designed as the main lateral force resisting members, even though the concrete frames will act as rigid frames and take moment. The shear wall design is discussed in the next section of this report.

SHEAR WALL DESIGN

The main wind lateral force resisting system of this alternate concrete design is comprised of 8, 12" thick shear walls located around the building core throughout the entire building height. The lateral system was modeled using ETABS.

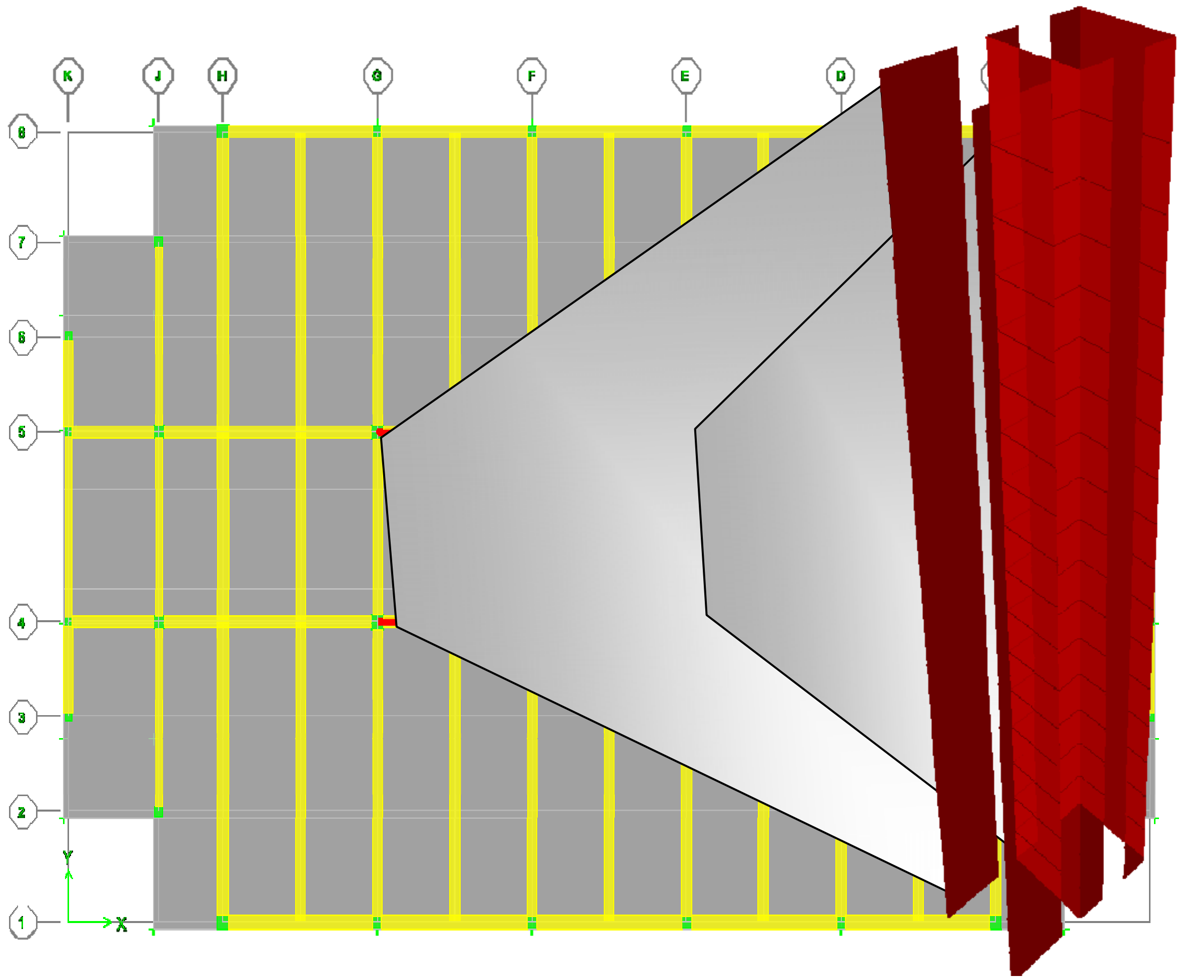


Figure 25: 3-D view of shear walls over building plan

The first design model run included 2 more shear walls along column lines D and G. They were removed after it was found that the shear wall plan above was enough to resist the lateral loads on the building. The two shear walls resisting load in the Y-direction are 28' long, while the four short walls in the X-direction are each 9'4". The two additional walls in the X-direction span 20' and have been intentionally cut short of the full 28' bay length in order to allow for doorway openings to the stair tower found within that bay. All walls are 5000psi normal weight concrete.

There were five main load cases input into ETABS to obtain the deflection of the building and the forces on each shear wall. They are as follows:

1. Seismic in both X and Y directions
2. ASCE7-02 Wind Case 1
3. ASCE7-02 Wind Case 2
4. ASCE7-02 Wind Case 3
5. ASCE7-02 Wind Case 4

Wind Case 2 and Case 3 were input into ETABS without eccentricity. An eccentricity of 15% of the building length was then added by hand to account for the torsion created from eccentric loading. Please refer to Appendix D for the ASCE7-02 description of load cases, as well as additional load cases run in ETABS.

The deflection found in each of these load cases is summarized in the table below:

Lateral Load Deflection Summary		
	△ X	△ Y
Wind Case 1X	1.76"	-
Wind Case 1Y	-	1.65"
Seismic X	4.66"	-
Seismic Y	-	4.55"
Wind Case 2X	1.32”	-
Wind Case 2Y	-	1.23"
Wind Case 3	1.29"	1.23"
Wind Case 4	0.98"	0.93"

The controlling deflection case in both directions was found to be seismic. This differs from the controlling cases found for the original steel building (both were wind) due to the increased weight of the building. However, the building is not located in a very heavy seismic region, so the deflections resulting from earthquake loads will be at a minimum. Below is an elevation along column line D of the deflected shape of the building under the Seismic X loading.

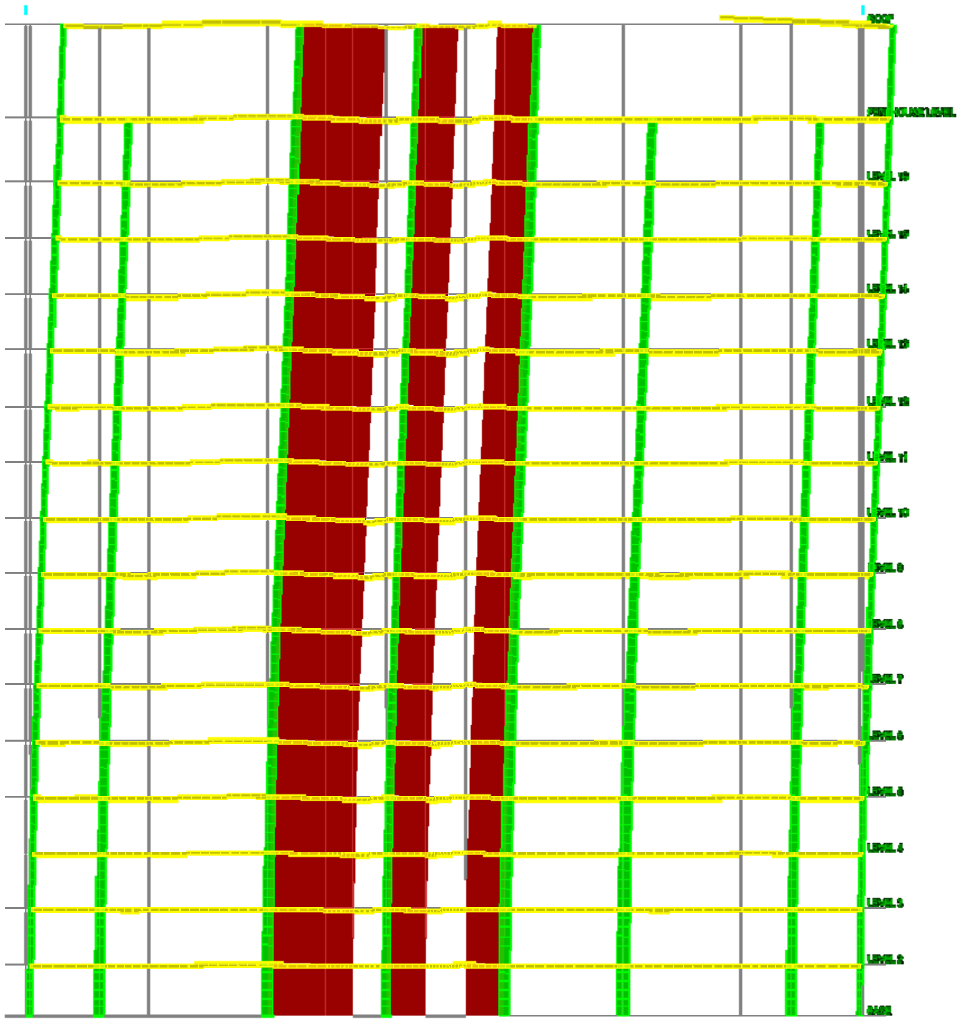


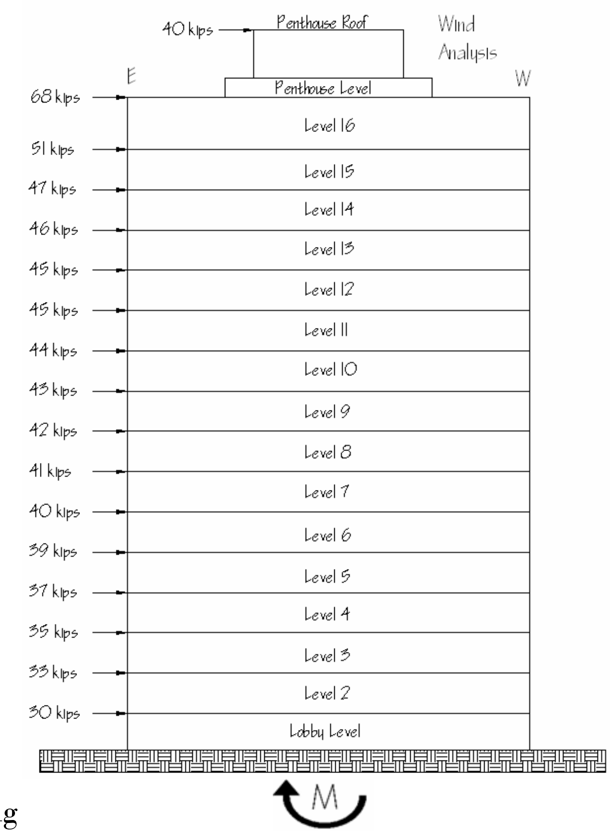
Figure 26: Deflection under seismic loading in the X-direction

The base force for each shear wall under the above loading is summarized in the table below. The shear wall forces for the remaining load cases considered can be found in Appendix D. These forces were verified by spreadsheet calculations, also found in Appendix D.

Shear Wall Forces under Seismic X Loading (kips)								
	Wall							
Level	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Level 2	99.95	N/A	99.36	97.15	N/A	97.77	266	264.8

Shear wall reinforcement ratios were also designed in ETABS and fell between 2.34% and 2.92% at the wall base and .25% at the top story of the wall.

Although the largest deflection was found to be under seismic loading, Eight Tower Bridge will be primarily resisting wind loads, as it is not located in an area of high seismic activity. The wind story forces acting in the y-dimension are shown below. The total of these forces added to a total overturning moment 84,320 ft-k at the base. This overturning moment is resisted by a total building dead weight of 38,733 kips, which performs adequate resistance. It should also be noted that these calculations were also performed for a reduced story height for both alternative flooring systems. The first alternative flooring system, which reduced the overall building height 4'8" (3-1/4" per floor) reduced the overturning moment by 4,400 ft-kips. The second floor system, which reduced the overall building height by 7' (5-1/4" per floor) subtracted over 7,700 ft-kips from the overturning moment.



FOUNDATION DISCUSSION

Although the foundation was not redesigned for the alternate concrete system, it should be noted that the foundation would need to be redesigned slightly. Concrete buildings are generally heavier structures despites a 3:1 ration in weight per cubic foot of steel to concrete, which results in an overall increased building dead load. The increased dead load was seen when performing seismic calculations. Increasing the foundation strength capacity could be done by increasing the concrete strength from 4000psi to 5000psi, increase the dimensions of the pile caps or increase the quantity of piles driven. All of these foundation design options could be explored independently at critical locations or in combination to increase foundation performance.

OTHER CONSIDERATIONS

There are a few other considerations involving the design of Eight Tower Bridge in concrete, specifically post-tensioned concrete rather than steel. The first issue concerns the post-tensioning. When the concrete is being post-tensioned, there are increased forces formed from pulling on the tendons. This could be a serious problem if not designed for, especially at points on the structure that are not as laterally stable. For example, in the first concrete flooring system, post-tensioning tendons would have to be run through beams in between column line, falling at the mid span of the perimeter beams. This could result in added torsion and lateral bending effects in the beam during construction. Moments can also be created in columns when post-tensioning tendons run through column-beam joints.

Another general concern when designing any concrete structure is rebar crowding. This issue can become particularly difficult when dealing with post-tensioning tendons that vary their profile throughout the member section. This design concern was evaluated in the design of this concrete system, as additional space was left towards the bottom of each beam in the longitudinal direction. Even without rebar crowding, this space will still allow for easier concrete placement to the soffit and in between tendon bundles

A third concern is the rooftop mechanical penthouse located on the roof of Eight Tower Bridge. While it is possible to construct a rooftop penthouse out of concrete, they are more easily constructed out of steel. A RAM Concept model was run with point loads placed along the length of beams to model transfer columns from a penthouse design, and met strength requirements after additional post-tensioning tendons were added to the beam. Moving the penthouse HVAC equipment to the basement was considered for the concrete system, but with the close site proximity to the Schuylkill River, even the slightest flood could costs million of dollars in HVAC equipment damage, eliminating the feasibility of this move.

Finally, Philadelphia is not particularly well known as a “high post-tensioned building” area, and contractors are not prominent from the searches that were conducted. Therefore, a post-tensioning contractor would have to be carefully selected if this were to become a post-tensioned concrete project.

ALTERNATE SYSTEM SUMMARY

An alternate concrete superstructure was designed for Eight Tower Bridge. The structure will be comprised of a post-tensioned concrete beam and slab system. Two alternate systems were designed. The first system employs a 6” reinforced concrete slab cast monolithically with post tensioned beams spaced 14’ apart. The second system involves a 6” post-tensioned concrete slab cast monolithically with post-tensioned beams spaces 28’ apart. A summary of both systems can be seen in the table above. More information about these systems can be found in Appendix B.

	Typical Beam Size	Overall Depth	Sustained Deflection	2 hour fire rating?
System #1	20"x20"	20"	.57"	✔
System #2	18"x30"	18"	.55"	✔

Cast in place concrete columns were designed to support both of these floor systems. The largest of these columns was found to be a 32” square column reinforced with 18-#11 bars, and was found at the building base. The most prominent column selection was a 20” square column with varying amounts of reinforcement, decreasing as level location increases. A complete column schedule can be found in Appendix C.

The main lateral force resisting system is comprised of 8, 12” thick shear walls. Six of these shear walls are arranged in a “channel” formation around the building elevator core, while the additional two walls span along the building’s y-directions. This shear wall formation yielded a maximum deflection of 4.66” under seismic loading in the X-direction. Calculations and computer output related the design of these shear walls can be found in Appendix D.

Construction Management Study

CONSTRUCTION MANAGEMENT STUDY

A construction management study of the alternate concrete system was done to examine the impact that changing the building's superstructure material had on both cost and construction schedule. Cost analysis and construction schedules had been completed based on material quantity take offs for the concrete structural system. Material quantities for concrete found in beams and slabs, steel reinforcing tonnage, total post-tensioning weight and formwork areas were all obtained through the very helpful RAM Conc*ept* output. Similar material quantities were found for columns and shear walls by hand. These takeoffs can be found in Appendix E. Material and labor cost information was taken from RS Means 2005 via Cost Works. Construction schedules were created Microsoft Project.

The estimate for the existing steel system was obtained from Grossi & Sons Steel. This estimate included detailing, material and fabrication of steel beams, steel erection and metal deck furnishing and instillation. The additional cost of slab concrete was added by multiplying 2/3 the slab thickness (accounting for voids created by deck flutes) by the average area of 21,000 square feet per floor. This was then added to the estimate provided, which brought the total cost for the steel superstructure to $4,814,455. The steel estimate can be seen in the itemized list above. The total superstructure cost per square foot was found to be $13.95 per square foot based on a total area of 345,000 square feet.

Steel Estimate For Eight Tower Bridge			
Steel	**QTY**		
Beams	3200		
Columns	350		
Angle Braces	280		$2,300,000
Moment Conncetions	834		
Instalation			$1,125,000
		TOTAL	$3,425,000
Decking	**QTY**		
Metal Deck			
Shear Studs	48000		$450,000
Instalation			$525,000
		TOTAL	$975,000
Concrete	**QTY**		
4000psi	3451 C.Y.		$310,590
Placing			$103,865
		TOTAL	$414,455
		TOTAL	**$4,814,455**

Figure 28: Steel superstructure building cost

The total construction duration for the steel system was reported by Grossi & Sons to be 28 weeks, totaling steel erection and connections and metal deck installation. A crane was on site for 20 weeks of the total time Grossi & Sons was on site, and was owned by the company. An additional cost that will not be factored into the building total cost, but is of considerable note is the $500,000 worth of change orders placed.

The concrete estimates carried out for the concrete structural system took into account total cubic yards of concrete pf varying strengths in columns, beams and shear walls. It was also assumed that formwork would be reused a minimum (or maximum by RS Means) of four times each. It was also assumed that adjustable steel shoring would be rented for the duration of the construction, and each floor would be reshored. Finally, the appropriate adjustment factors were applied for construction projects in the Philadelphia area. Detailed estimates for both of these systems can be found in Appendix E.

Estimates for the concrete superstructure were conducted, using formwork, post-tensioning, and concrete totals for both floor systems designed. The same quantities for columns and shear walls were used. The total costs for system #1, using less post-tensioning and more concrete beams came to $5,338,047. The total cost for the post-tensioned slab system totaled $5,242,839, slightly less than the first system. Both of these costs were based on crane placement of concrete.

However, both of these costs are based on average cost estimates for materials in 2005. The steel contract was received by Grossi & Sons in February of 2001, so all building costs are in 2001 dollars. In order to create a similar cost comparison to the one a design engineer or owner would have gone through at the time, the total costs mentioned above were converted into 2001 dollars. This was done by using the following equation:

$$(P/F) = (1 + i)^{n}$$

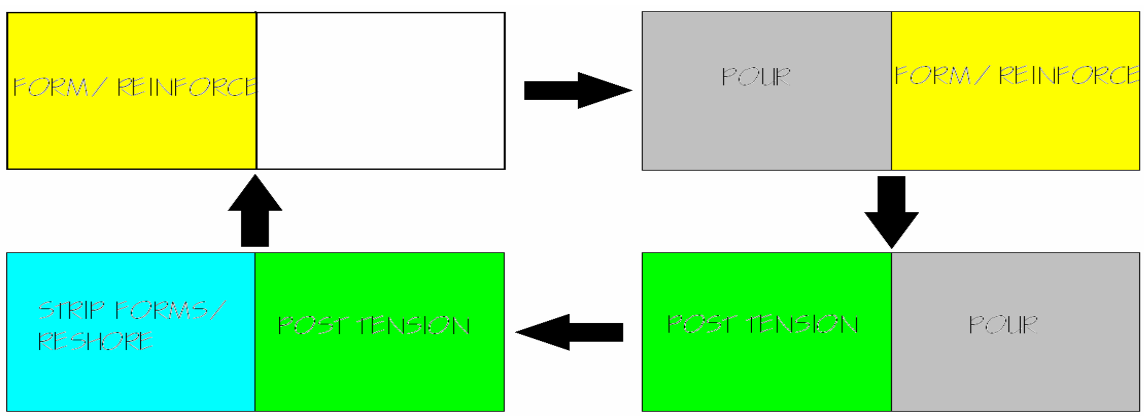
This equation is used to calculate the future value of money given the present value. However, the “future” value is actually the present value for the concrete structure designed, so the reciprocal equation will be used. With an assumed constant interest rate of 3% and a time period, n=4 years, the resulting cost for system #1 is $5,004,943 and the cost for system #2 is $4,903,700. This equates to a total cost per square foot of $14.51/sq. ft. and $14.21/sq. ft. respectively. On a side note, this proves that every cent an engineer can save in a design can add up to a good sum of money, even if it is only $.30/square foot.

Costs estimates for placing the concrete with a pump were also conducted. While it is not standard practice to pump concrete 16 stories, it is still possible, and estimates for this delivery method came in almost a full dollar less than a crane placing method. However, this may be outweighed by costs incurred by the added difficulty of pump placement.

The construction schedule for both systems was also formed using the estimated quantities of material and crew output from RS Means. It was assumed that the daily output of any crew has not significantly changed since 2001. The duration of each task can be seen below:

Construction Duration/Floor					
Task	**Crew**	**QTY**	**# of crews**	**Output**	**Duration**
Shoring	C1	21000	5	1400	3
Formwork					
Beams/Slabs	C1	21570	5	545	7.92
Columns	C1	3070	5	240	2.56
Shear Walls	C2	2288	4	395	1.45
				Total	**11.92**
Reinforce				**MAX**	8
Beams/Slabs	4 Rdmn	9.96	3	2.2	1.51
Columns	4 Rdmn	5.75	3	2.3	0.83
Slabs	4 Rdmn	19.9	4	2.9	1.72
				Total	**4.06**
Placing Conc				**MAX**	2
Beams	C7	114	5	65	0.35
Slabs	C7	398	5	110	0.72
Shear Walls	C7	44	5	90	0.10
Columns	C7	48	5	63	0.15
				Total	**1.32**
				MAX	1
Post Tensioning	C4	16100	4	1650	2.44
Reshoring	2 CARP	21000	3	1400	5.00
				Total	**17.79**

The maximum duration was taken for the tasks of shoring, formwork and reinforcement, assuming that shoring and formwork could take place simultaneously on parts of each level, and crews of rodmen could follow formwork crews laying reinforcement. It was derived that placing all concrete on a given level would take two days, so the each level would be placed in two separate pours with a construction joint placed between them. An assumption was made that post-tensioning could take place two days after the concrete has been placed, and formwork could be removed the day two days following that. It was also assumed that reshoring crews would work behind concrete and post tensioning crews. Below is a construction sequence schematic.



The durations calculated were found to be nearly identical for both flooring systems, as only the amount of concrete and post-tensioning differ. However, these amounts differ in a proportional relationship that evens the construction time. The only difference is in the total labor hours used. A final construction duration of 197 days was determined, equating to 28 weeks and 1 day for the concrete system using a crane to place the concrete. This is very comparable to the steel system's 28 week duration. However, like all schedules, this system requires 100% efficiency and flawless execution of each trade. A construction schedule was also created for concrete placed by pump. This construction duration came out to 163 days, or 23 weeks and 2 days. The same number of crews were used for this schedule, and resulted in an expedited construction schedule.

Below is a summary for the steel system and both concrete systems with both placement methods.

Superstructre System Summary						
	Cost per square foot			Duration (weeks)		
System		Crane	Pump		Crane	Pump
Steel	$13.94	-	-	28	-	-
Concrete System #1	-	$14.51	$13.75	-	28.14	23.7
Concrete System #2	-	$14.21	$13.51	-	28.14	23.7

Mechanical System Study

MECHANICAL SYSTEM STUDY

The existing mechanical system of Eight Tower Bridge employs a chilled water loop to cool the building through evaporative cooling. Evaporative cooling is a process by which moisture is added to air with a relative humidity less than 100% in order to reduce air temperature and increase relative humidity. The lower the relative humidity, the greater the cooling affect possible when moisture is added. The chilled water loop in Eight Tower Bridge is an example of indirect evaporative cooling. Indirect systems cool air without adding moisture. In operation, an indirect evaporative process cools air or water on one side of an impermeable heat-exchanger. The wet side cools the dry side without adding moisture to the air because there is no direct contact between the water and the air stream. They are more expensive and use more energy than direct systems, but they can provide energy efficiency in applications where direct evaporative cooling may not be practical.

The system in Eight Tower Bridge currently takes water pulled from the water main and pumps it through a loop to the rooftop, where heat is removed by two cooling towers. The water is then sent through a chilled water pump back down the building where it meets a heat exchanger within the "package" air handling units found on each floor. These air handling units use the chilled water to indirectly cool return air that is being circulated throughout each floor. Each of these units has a cooling capacity of 80 tons and can take 160 GPM of chilled water. Fresh air is provided to the spaces through rooftop louvers capable of taking in 475 CFM/ft length of louver.

Eight Tower Bridge is located directly next to the Schuylkill River; a body of water that maintains an average winter temperature of 31 ˚F and a summer temp of 72 ˚F. A feasibility study was conducted regarding the practicality of using a Ground source heat pump as the primary heating and cooling source for this loop, eliminating the need for rooftop cooling towers.

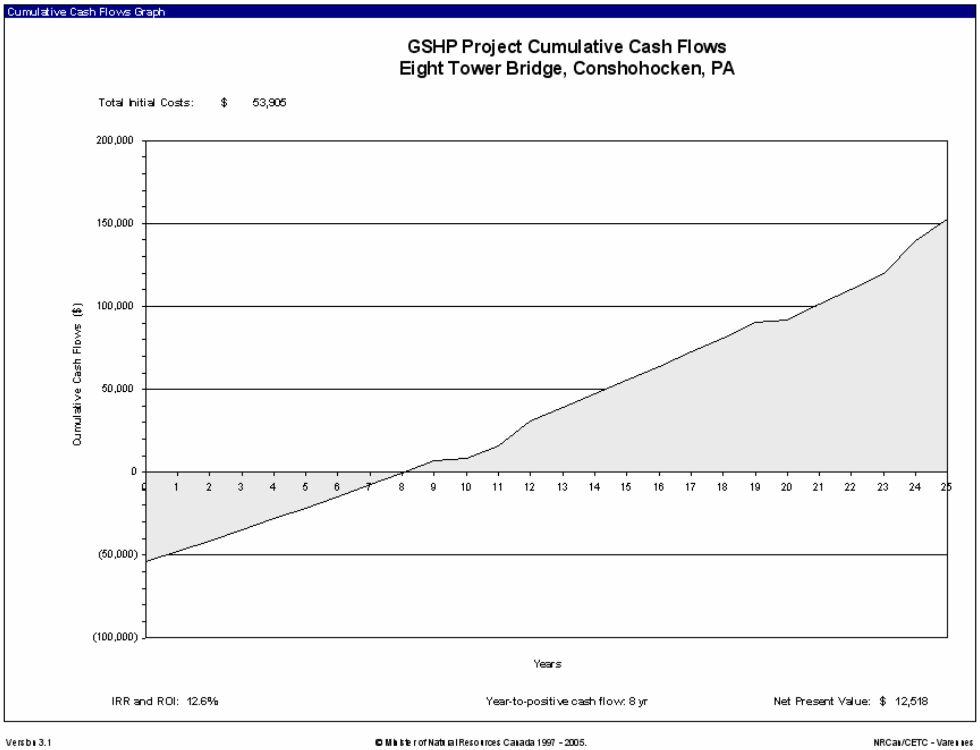
Ground source heat pumps use the heat in the ground as a thermal reservoir to take heat from in the heating case or discharge heat to in a cooling case. Water or refrigerant is pumped through a series of tubes bored into the ground. The refrigerant gains heat from the ground and is then pumped through the same loop described up above. The process is run in reverse for cooling, using the ground as a discharge for heat extracted from the building.

Heat pumps have generally been found to be very efficient, and can cut heating and cooling costs by nearly 40% given the right set of characteristics. The life of the system is generally longer than conventional systems because the units are housed indoors (in most applications) and the pipe work used for heat exchanging is buried underground. There are generally fewer components involved in a heat pump system, making installation easier and less prone to failure. However, these are an added start up costs (boring hundreds of holes on site) as well as the units themselves. The goal is to have a system that pays for itself in energy savings over the shortest time period.

The feasibility of installing a ground source heat pump as a cooling source for water or refrigerant in the chilled water loop described above was carried out using a ground source heat pump project model obtained through RETscreen International. This model allows the user to enter the desired location characteristics, average earth temperatures, equipment specifications and building size. Initial costs and payback periods for the system are then calculated.

The project model was run for both heating and cooling cycles. It was assumed that there would be a 200'x200' (3,176 m^2) space available to bore holes for the piping involved in heating exchanging for the heat pump. The temperature date was obtained from NASA's Surface Meteorology and Solar Energy Data site. Finally, the equipment selected for this Trane model was a high efficiency vertical WPVJ060 heat pump with a standard heating COP of 3.2 and standard cooling COP of 4.5. More specifications on this equipment can be found in Appendix F.

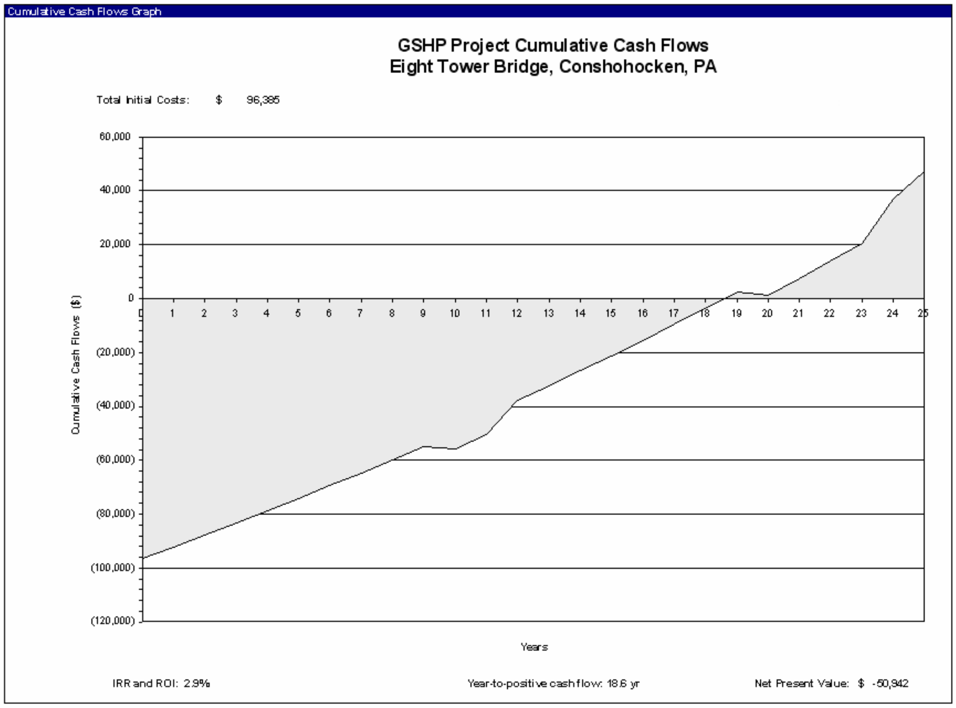
The model was run with the above assumptions and equipment selection. Below is the cumulative cash flow graph for the heating cycle.



Year #	Pre-tax $	After-tax $	Cumulative $
0	(53,905)	(53,905)	(53,905)
1	6,238	6,238	(47,666)
2	6,363	6,363	(41,304)
3	6,490	6,490	(34,813)
4	6,620	6,620	(28,193)
5	6,752	6,752	(21,441)
6	6,887	6,887	(14,554)
7	7,025	7,025	(7,529)
8	7,166	7,166	(363)
9	7,309	7,309	6,946
10	1,360	1,360	8,306
11	7,604	7,604	15,910
12	15,366	15,366	31,276
13	7,911	7,911	39,188
14	8,070	8,070	47,257
15	8,231	8,231	55,488
16	8,396	8,396	63,884
17	8,564	8,564	72,448
18	8,735	8,735	81,182
19	8,910	8,910	90,092
20	1,658	1,658	91,750
21	9,270	9,270	101,020
22	9,455	9,455	110,474
23	9,644	9,644	120,118
24	19,488	19,488	139,606
25	13,315	13,315	152,921

The initial cost of this system is $53,905 with a "year-to-positive" cash flow of 8 years. This cash flow does not take into account taxes. The system will see an annual life cycle savings of $1,379 dollars. A yearly cash flow for the system in heating can be seen to the right. Please refer to Appendix F for the full model report.

As previously mentioned, the ground source heat pump model was also run for the system in cooling to see what the cost of the system would be under cooling conditions. The same heat pump model was selected and all assumptions were kept the same. Below is the cash flow graph for the same system in cooling.



The initial cost of the system used for cooling would be $96,385 with a payback period of 18.6 years. The additional costs stem from the total depth of boring holes required, which nearly tripled under the cooling condition. A full report for the cooling model can be found in Appendix F.

It is important to mention that the effects of having a large body of water like the Schuylkill River next to a ground source heat pump reduce the average ground temperature that is reported for the area. This could add considerable efficiency to the system in cooling. A more accurate model including these affects could be created using ground temperature data collected on site.

Using a ground source heat pump to heat the building in cooler months appears to be a feasible mechanical system option. Although the payback period was determined to be a little over eight years, it still falls on the fringe of the acceptable return on investment time. However, when the system was run for cooling loads, it was found that the initial investment to employ this system is not worth the nearly 19 year return period, a period considerably higher than the ideal 3 to 4 year period. Therefore, it is suggested that the existing system be used over a possibly more expensive, yet more efficient system.

Conclusions and Recommendations

CONCLUSIONS AND FINAL RECCOMENDATIONS

The goal of this report was to design and evaluate an alternative superstructure design for Eight Tower Bridge, a high-rise office tower located in Conshohocken, Pennsylvania. The existing composite steel superstructure does adequately resist gravity and lateral loads, but the question still exists: could this building have been designed as a concrete structure?

The long spans that currently exist in Eight Tower Bridge were maintained by designing a one-way, post-tensioned beam and slab floor design. Using post-tensioning allowed for longer concrete spans, which kept the floor plan of the building open and without very many column intrusions. Two post-tension systems were designed. The system employs post-tensioning in the beams that support a 6" reinforced concrete. This system saw a maximum deflection of 0.57" under sustained loading. The second alternative flooring system increased the spacing between beams by adding post-tensioning to the slab. The maximum deflection under sustained loading of this system was found to be 0.55". The original steel system was found to have a deflection of 1.03" after a 1-3/4" camber was subtracted from the total deflection. Both of the concrete systems reduced the overall floor system depth by 3-1/4" and 5-1/4", respectively. However, this reduction in floor system depth did not correlate to a reduction in dead load, as the building's total weight actually increased.

Both concrete systems used the same columns and the same shear wall lateral force resisting system. The shear wall system designed is comprised of 8, 12" shear walls arranged around the building core. The building sees a maximum deflection of 4.66" under seismic loading in the x-direction. Under wind loading, the deflection was found to be 1.76", nearly half the deflection found under the same loading for the steel system.

A construction management study was conducted to see how changing the material of the building would affect the overall cost and construction schedule. The first concrete system resulted in a $14.51/ square foot, while the second system came in at $14.21/square foot. These totals are in 2001 dollars, and include material, placement, formwork and shoring. The total steel system was totaled $13.94/square foot, but did not include the $500,000 dollars in change orders reported. The construction duration of both concrete systems was found to be comparable, and totaled 28 weeks when concrete was placed using a crane and bucket. If the engineer or concrete contractor could arrange to have the concrete placed by pump (a feat uncommon in high-rise construction, but not out of the question entirely), then the construction duration would only last 23 weeks. This would be a reduction of 5 weeks from the steel construction time of 28 weeks.

An unrelated mechanical systems study was conducted to explore the used of a ground source heat pump for use in heating and cooling of Eight Tower Bridge. The system currently runs a chilled water loop system that uses rooftop mounted cooling towers to chill the liquid in the loop. The ground source pump would use the earth's natural temperature as a reservoir for heat exchange of the liquid in the loop. However, it was found that the initial investment to implement this system heavily outweighed the payback period, which was found to be nearly 19 years for the cooling loop.

Final Recommendation:

Although the alternative concrete design results in an overall thinner floor system, which could allow for reduction in overall building height, saving money on cladding components and MEP costs, it is still suggested that Eight Tower Bridge be constructed out of steel for the following reasons:

1. The cost per square foot of the steel system is lower than the concrete systems ($13.94/sq ft)
2. Interior finishes (i.e. drop ceiling) are more difficult to install in concrete systems, and are the desired finish for most office buildings
3. The Philadelphia region does not have very many experienced post-tensioning contractors, which could potentially cause construction issues
4. The owner, engineer and architect all have experience designing and constructing steel office buildings
5. The rooftop mechanical penthouse is most easily constructed in steel, and is strategically placed on the roof due to flood concerns, eliminating the possibility of placing equipment in the basement

ACKNOWLEDGEMENTS

I would like to extend my sincere gratitude to the people who have helped me make this senior thesis project a success. Without the help of everyone below, I would not have been able to complete this project.

Firstly, I would like to thank Skidmore, Owings & Merrill specifically Shaun Mason and Jim for their help in obtaining Eight Tower Bridge for my senior thesis project. Without their fast action in the face of disaster, I would have been in trouble.

I would also like to thank Oliver Tyrone Pulver Corporation and Brandywine Realty Trust for allowing me to conduct my research on their property.

I would like to thank the AE faculty, specifically Professor Parfitt and Dr. Hanagan, for all their work this year not just with me, but with all the students working in thesis projects. They have been a great source of guidance, more than they will know.

Next, I would like to thank all of my classmates for all their help this year. Everyone was incredibly helpful, weather it was helping to learn a computer program, getting an opinion about design options or for a good laugh late at night. All of these things contributed to my success this year.

Finally, I would like to thank all of my friends for their support this year, especially the staff of 419 Old Main. All of your endless support and cheering is what has gotten me through this challenging year. And of course, thanks to both of my parents for being my biggest supporters from day one. I could not have done life without the two of you, let alone this project. Thanks for all your encouragement and love.

REFERENCES

Aalami, Bijan O., and Jennifer D. Jurgens. Guidelines for the Design of Post-Tensioned Floors. Concrete International, March 2003.

Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (ACI318R-05). Farmington Hills, MI: American Concrete Institute, 2005.

Darwin, David, Charles Dolan, and Arthur Nilson. Design of Concrete Structures, 13th Edition. Boston, MA: McGraw Hill, 2004.

Load and Resistance Factor Design, 3rd Edition, American Institute of Steel Construction, 2001.

Naaman, Antoine E. Prestressed Concrete Analysis and Design, 2nd Edition. Ann Arbor, MI: Techno Press, 2004.

Two-Way Post-Tension Design. 12 February, 2006. Portland Cement Association. www.cement.org/buildings.

Appendix A: Existing Conditions

Roof Live Load [From ASCE7-02, section 4.9]

$L_r = 20R_1R_2$ where $12 \leq L_r \leq 20$

$R_1 = 1.2\text{-}0.001A_t$ for $200ft^2 \leq A_t \leq 600ft^2$

Average Atrib= $700ft^2$, use R_1=0.5

$R_2 = 1.0$ (flat roof)

$L_r = 20(0.5)(1.0) = 10$ psf

Snow Load [From ASCE7-02, section 7.3]

$P_f = 0.7C_eC_tIp_g$

$C_e = 0.9$
$I = 1.0$
$p_g = 20$ psf
$C_t = 1.0$

$P_f = 0.7(0.9)(1.0)(1.0)(20psf) = 22psf$

Assume average total roof load of 30 psf

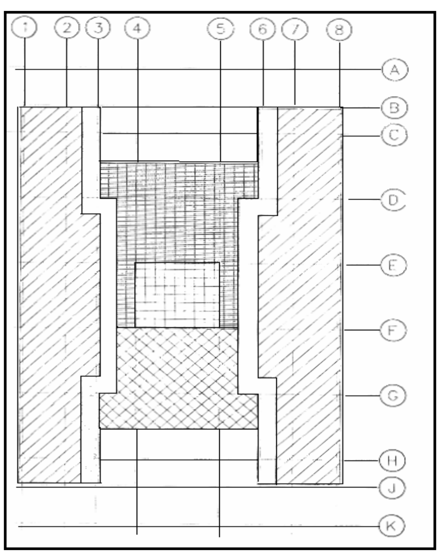
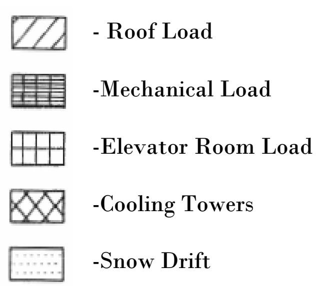


Figure A1- Shows the load distribution over the penthouse level of the structure. This distribution was used to determine the weight of the roof for the seismic analysis.



(Drawings not to scale)

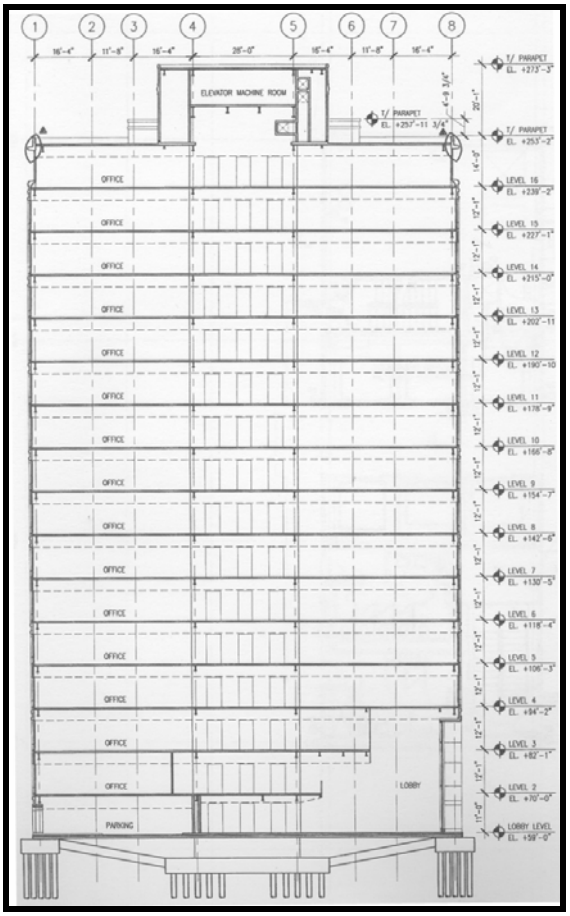


Figure A2- East/West Section

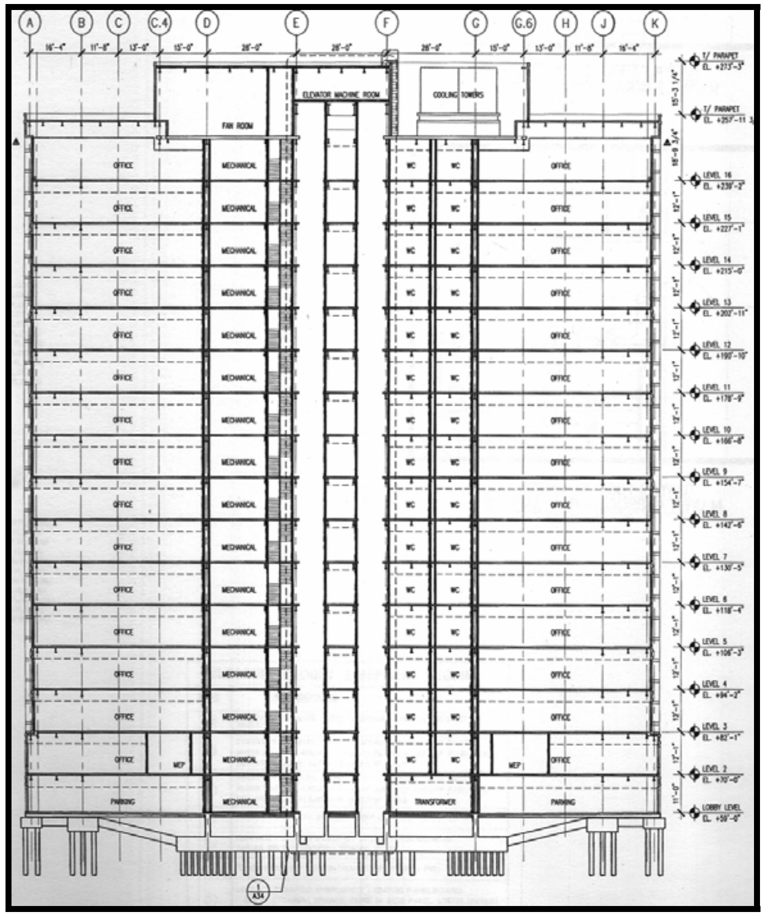


Figure A3- North/South Section

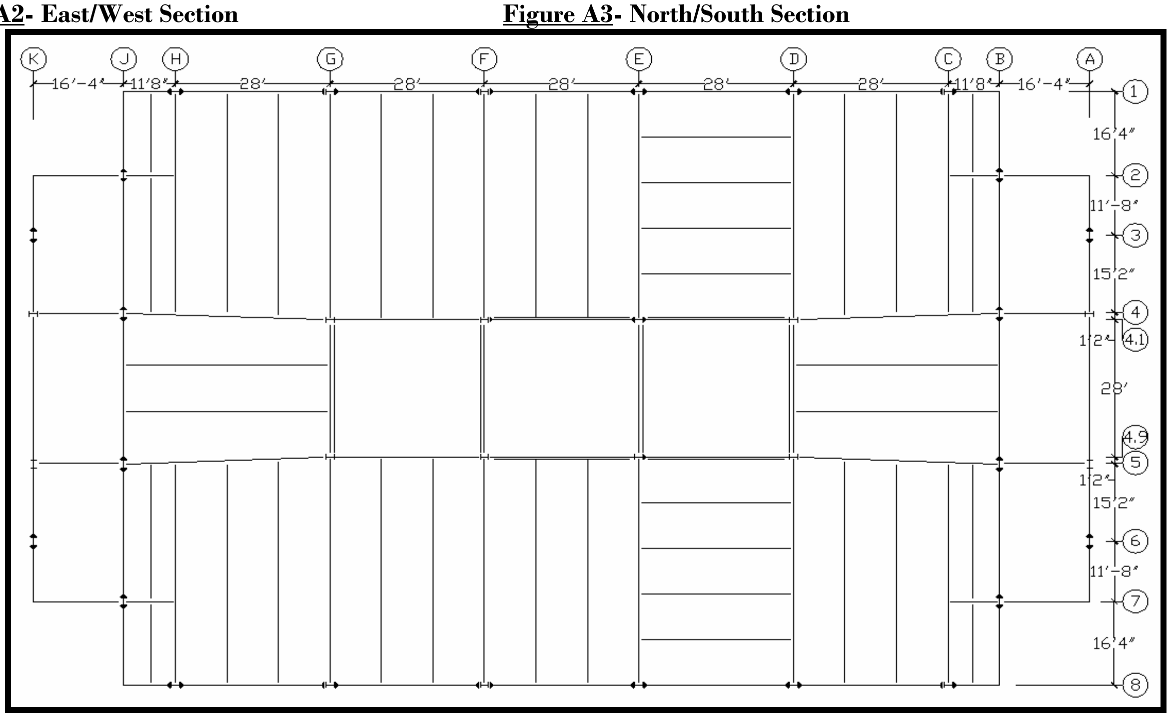


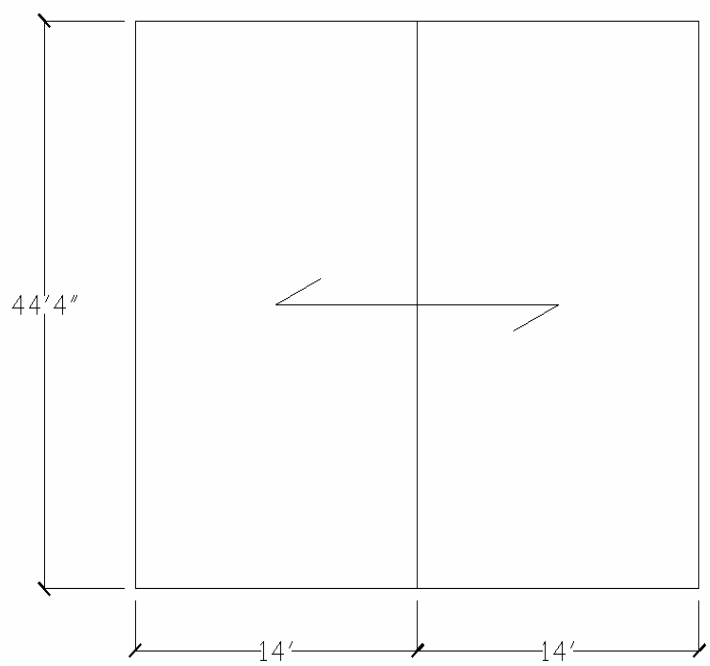
Figure A4: Typical framing plan with moment connections shown

Appendix B: Floor System

Reinforced Concrete Slab Calculation

Material Properties
F'c=5000 psi
Fy= 60ksi

Loads:
Live: Office: 80psf
Dead
Superimposed: 20psf
MEP: 5 psf
Finish/Misc: 5psf
Total: 30 psf



Estimate of thickness: l/28 [ACI 318-05, table 9.5(a)]

(14' x 12"/ft) / 28 = 6"

Design Load:

1.6(80psf) + 1.2(30psf+ ((6"/12)*150pcf)= 254 psf

Design Moments: [ACI 318-05 8.3]

$-M_1$ Interior Support: $w_n l_n^2/11 = (1/11)*.254ksf*14^2 = 4.53$ k-ft
$+M_1$ Interior Support: $w_n l_n^2/16 = (1/16)*.254ksf*14^2 = 3.11$ k-ft
$-M_1$ Interior Support: $w_n l_n^2/11 = (1/11)*.254ksf*14^2 = 4.53$k-ft

Minimum Reinforcing: estimate d = 6"- 3/4" - 4/16" =4.875"

$A_{smin} = .003\ b_w d$
$A_{smin} = .003\ (12in)(4.875in)$
$A_{smin} = .1755\ in^2$
→ can use #4 bars, resize d to 5"
$A_{smin} = .003\ (12in)(5in) = .18\ in^2 < .20 in^2$

Flexure Check:

a= As*fy/(.85)(f'c)b = .235 in c = .235in/.85 = .277 < 1.875 ∴φ=.9

Flexure Check (cont)

$\varphi Mn = \varphi As^*fy(d-a/2)$
$\varphi Mn = (.9)(.20in^2)(60ksi)(5in- .235/2)$
$\varphi Mn = 52.73$ in-k = 4.39 ft-k < 4.53 ft-k

∴ No Good, use #5's

(a= .365in)
$\varphi Mn = \varphi As^*fy(d-a/2)$
$\varphi Mn = (.9)(.31in^2)(60ksi)(4.94in- .365/2)$
$\varphi Mn = 79.64$ in-k = 6.64 ft-k > 4.53 ft-k

∴OK, use #5's@12" o.c.

Shrinkage and Temperature Check

[ACI 318-05 7.12.2.1] Grade 60 steel, $\rho min = .0018$

$A_{smin} = .0018(6")(12")$
$A_{smin} = .1296\ in^2 < .20in^2$ ∴ OK

USE #5 BARS SPACED @ 12" o.c FOR SLAB REINFORCMENT

Estimate of Prestress Losses

-Unbonded Tendons

½"φ, 7-wire strands, $A=0.153\ in^2$
$F_{pu} = 270$ ksi

-Esitmated prestress losses = 15 ksi (ACI 18.6)

$F_{se} = .7(270\ ksi)-15\ ksi = 174\ ksi$ (ACI 18.5.1)
$P_{eff} = A^*f_{se} = (0.153)^*(174\ ksi) = 26.6$ kips/tendon

Moment Distribution Spreadsheets

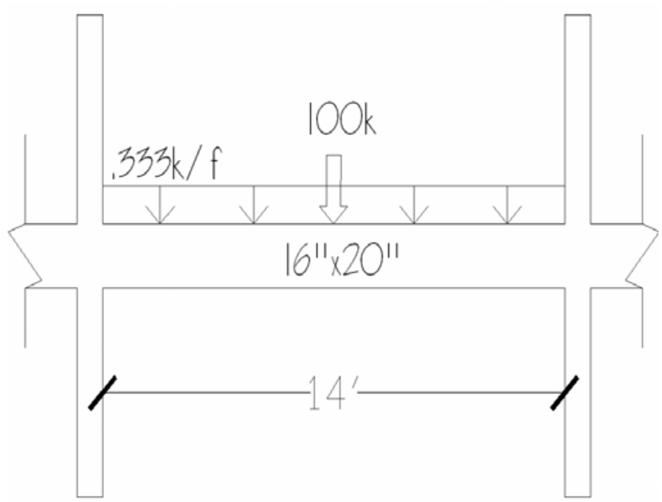
Available upon request

The table on the left shows equal cable forces for profiles adjusted across different span lengths. The table on the right has aconstant sag regardless of span.

		% DL	80%DL	90%DL	95%DL	100%DL	110%DL
		m	1.07	1.21	1.27	1.34	1.48
Span	L	Sag (in)	Fc (kips)				
1	44.33	10.00	316.39	355.94	375.71	395.49	435.03
2	28	4	315.56	355.01	374.73	394.45	433.90
3	44.33	10.00	316.39	355.94	375.71	395.49	435.03
Span	1	# Tendons	12	13	14	15	16
		precomp	369.61	415.81	438.92	462.02	508.22
	2	# Tendons	12	13	14	15	16
		precomp	368.64	414.73	437.77	460.81	506.89
	3	# Tendons	12	13	14	15	16
		precomp	369.61	415.81	438.92	462.02	508.22

		% DL	80%DL	90%DL	95%DL	100%DL	110%DL
		m	1.07	1.21	1.27	1.34	1.48
Span	L	Sag (in)	Fc (kips)				
1	44.33	10.00	316.39	355.94	375.71	395.49	435.03
2	28	10	126.22	142.00	149.89	157.78	173.56
3	44.33	10.00	316.39	355.94	375.71	395.49	435.03
Span	1	# Tendons	12	13	14	15	16
		precomp	369.61	415.81	438.92	462.02	508.22
	2	# Tendons	5	5	6	6	7
		precomp	147.46	165.89	175.11	184.32	202.75
	3	# Tendons	12	13	14	15	16
		precomp	369.61	415.81	438.92	462.02	508.22

Moment Capacity Check for Reinforced Beam



Material Properties
F'c=5000 psi
Fy= 60ksi

Loads:
Live: Office: 80psf
Dead
Superimposed: 20psf
MEP: 5 psf
Finish/Misc: 5psf
Total: 30 psf

As= 4-#8 bars (3.16in^2) → taken from Concept output

Load from Beam

Live Load: 80psf (14') = 1120lb/ft
Dead Load: 30psf(14') = 420lb/ft
Slab Load: (6"/12)*150 lb/cu. ft * 14' = 1050lb/ft
Beam self weight: (16'*20")/144in^2 *150lb/cu.ft. = 333.3lb/ft

Point Load: [1.2(833.3+1050+420) + 1.6(1120)]*22/1000 = 100k

Beam Self weight: (16"x16")/144*150lb/cu.ft =266.6*1.2= .333k/ft

Moments at Ends [LRFD Table 5-17]

Fixed End, Uniform Load: M= wl^2/12= 5.39k-ft
Fixed End, Point Load: M=Pl/8= 175 ft-k Total: 180.4 ft-k

Moments at Middle

Fixed End, Uniform Load: M= wl^2/24= 2.7k-ft
Fixed End, Point Load: M=Pl/8= 175 ft-k Total: 177.7 ft-k

Capacity Check

a= As*fy/(.85)(f'c)b = 2.78 in

Mn=.9* As*fy(d-a/2) =224 ft-k > 180.4ft-k
∴ OK

Floor System #1

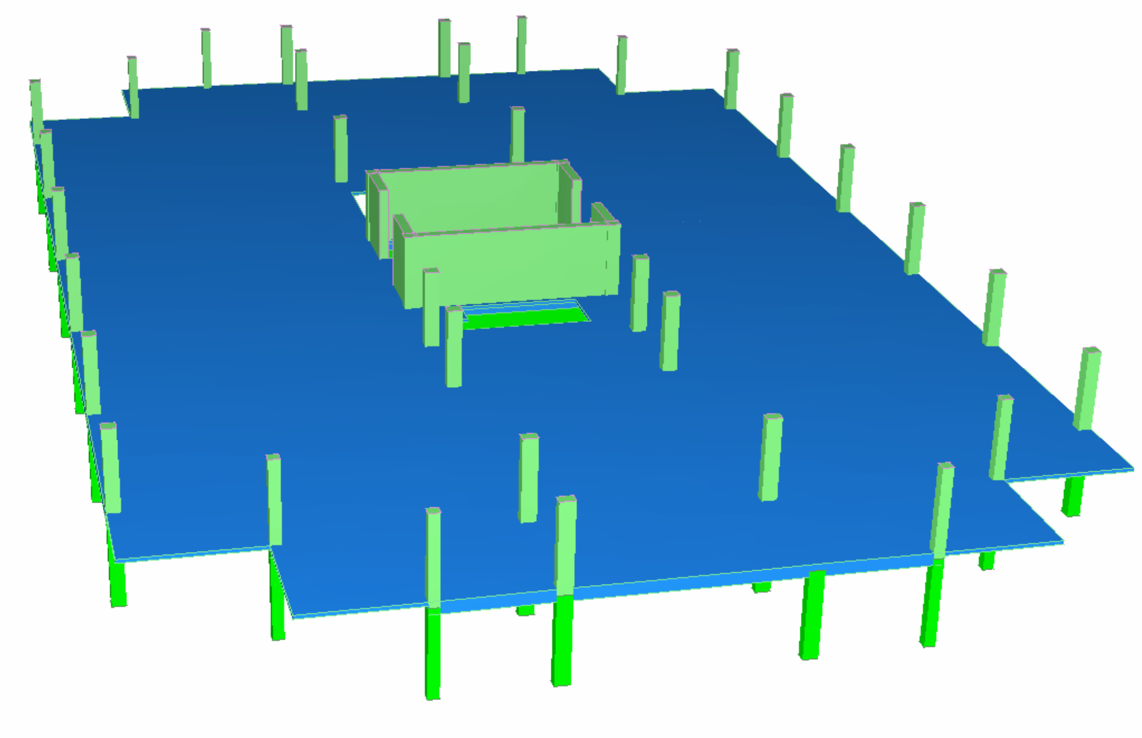


Figure B1: Floor system overhead view

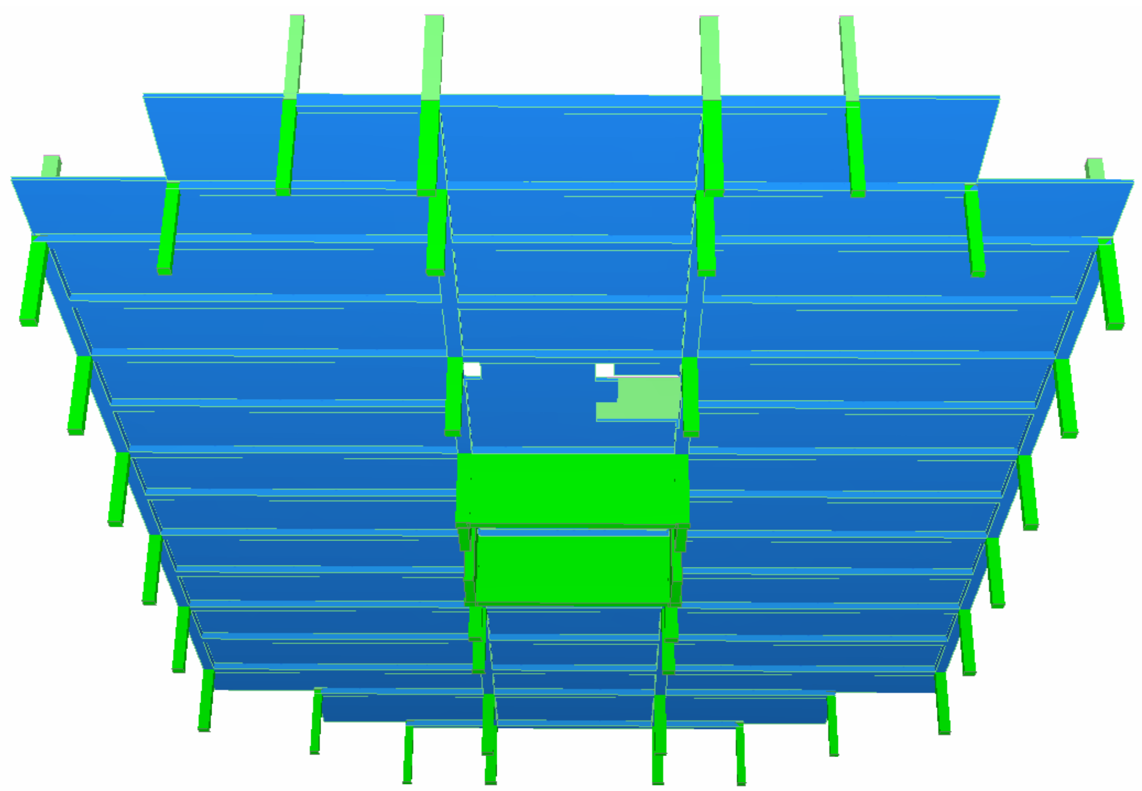


Figure B2: Floor system #1 underside view

Floor System #1

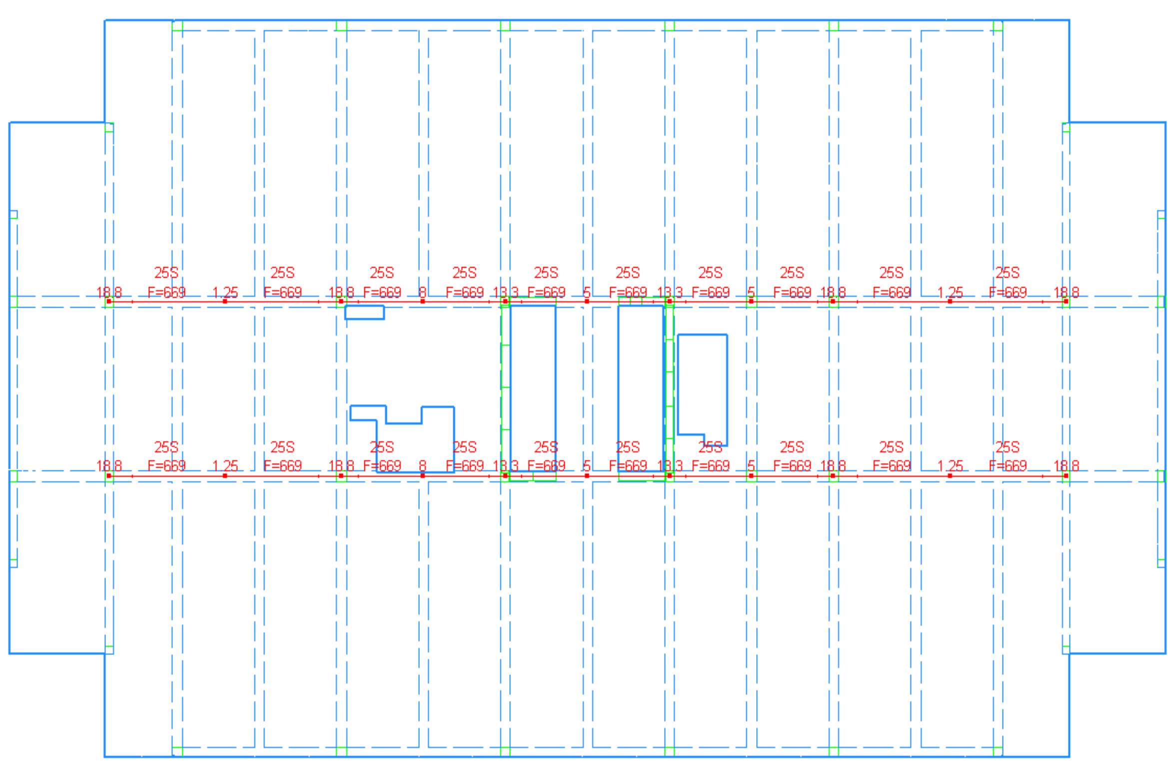


Figure B3 Latitude tendon plan view with tendon forces labeled

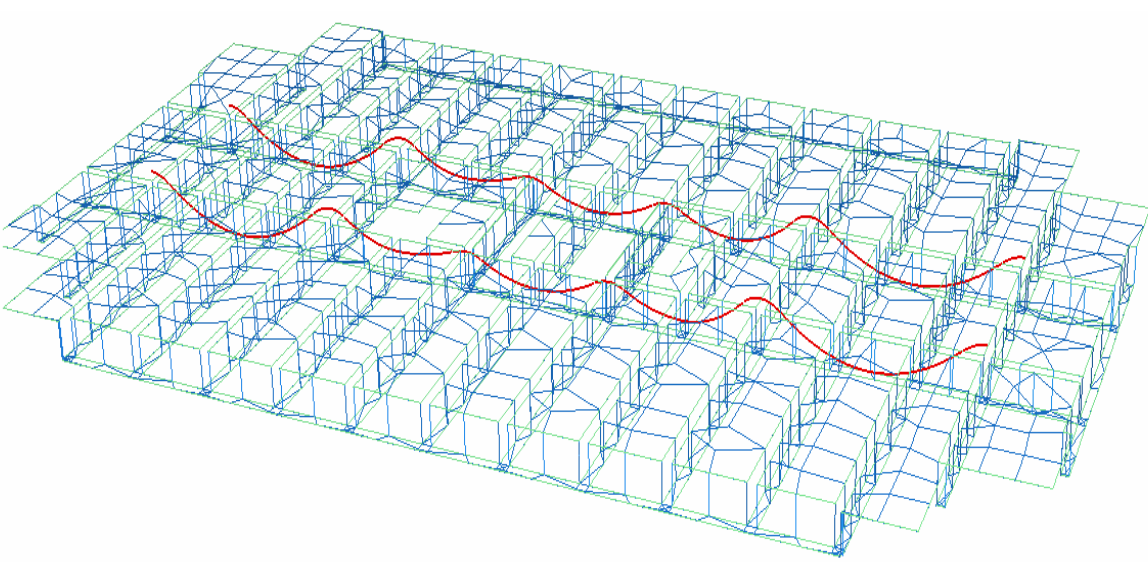


Figure B4: 3-D View of lateral tendon profiles

Floor System #1

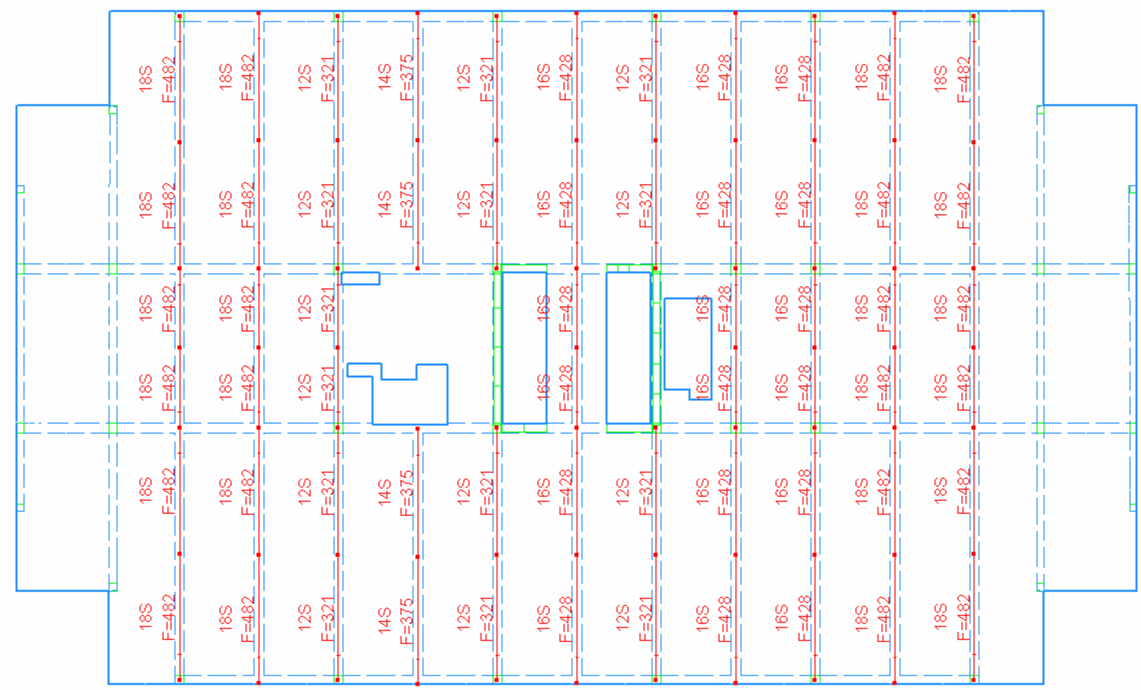


Figure B5: Longitude tendon plan view with tendon forces labeled

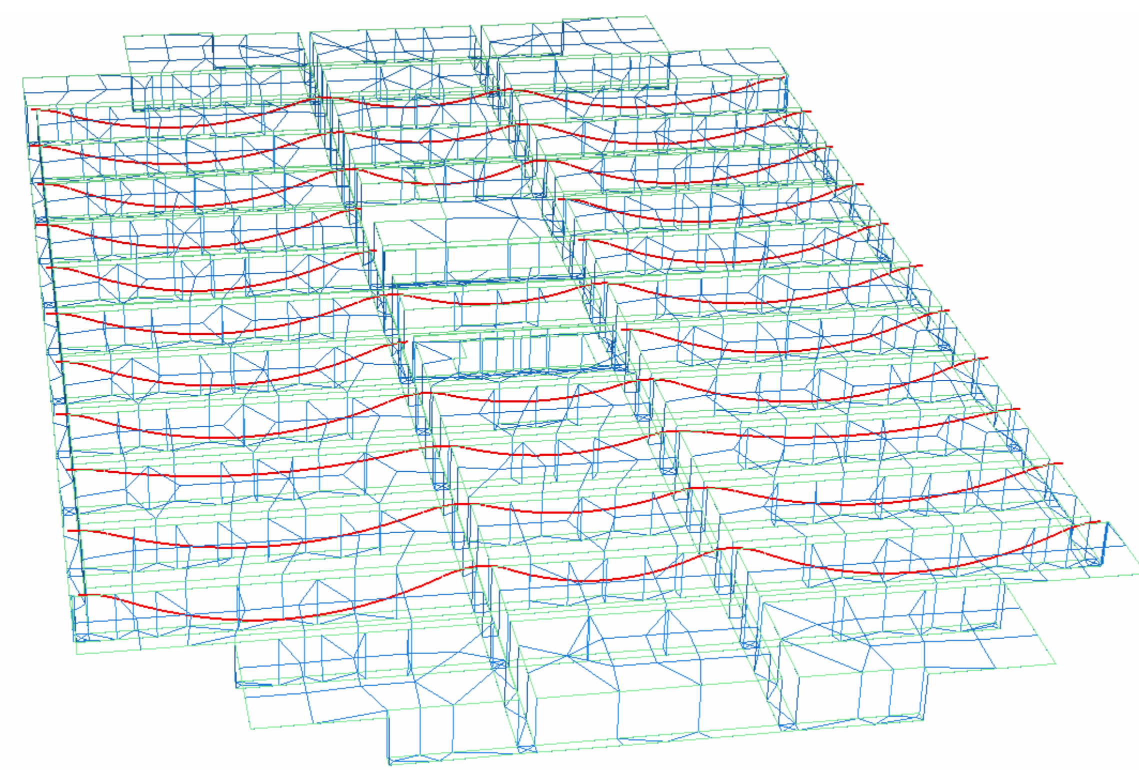


Figure B6: 3-D View of longitudinal tendon profiles

Floor System #2

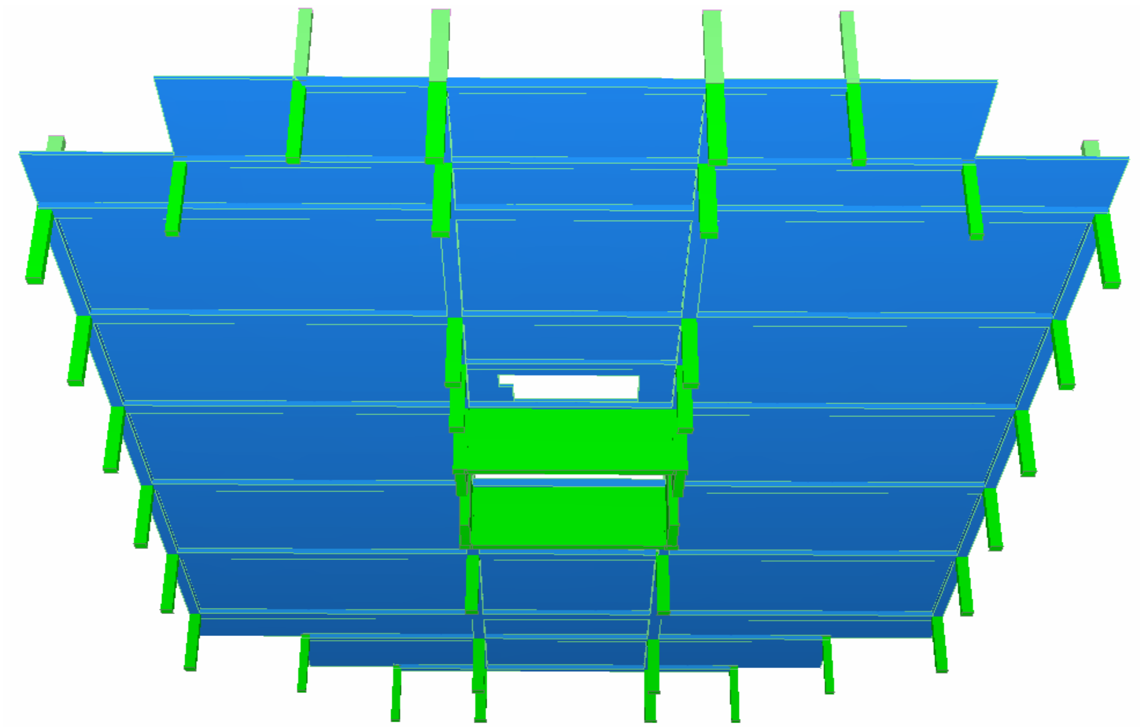


Figure B7: Underside of flooring system #2

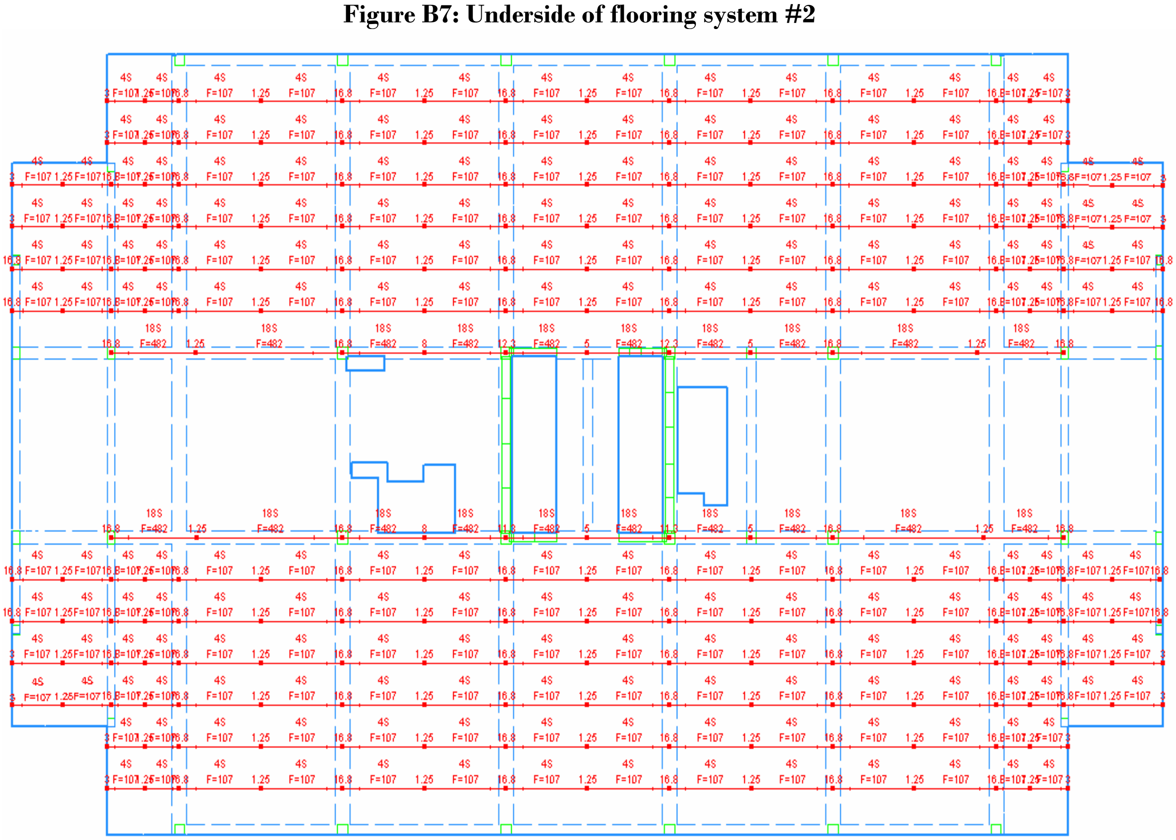


Figure B8: Latitude tendon plan view with tendon forces labeled

Floor System #2

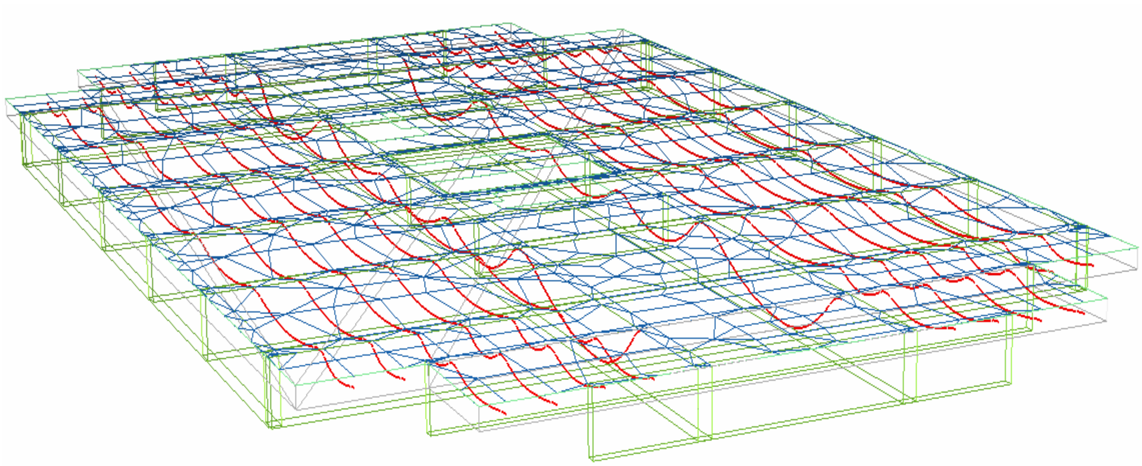


Figure B9: 3-D View of lateral tendon profiles

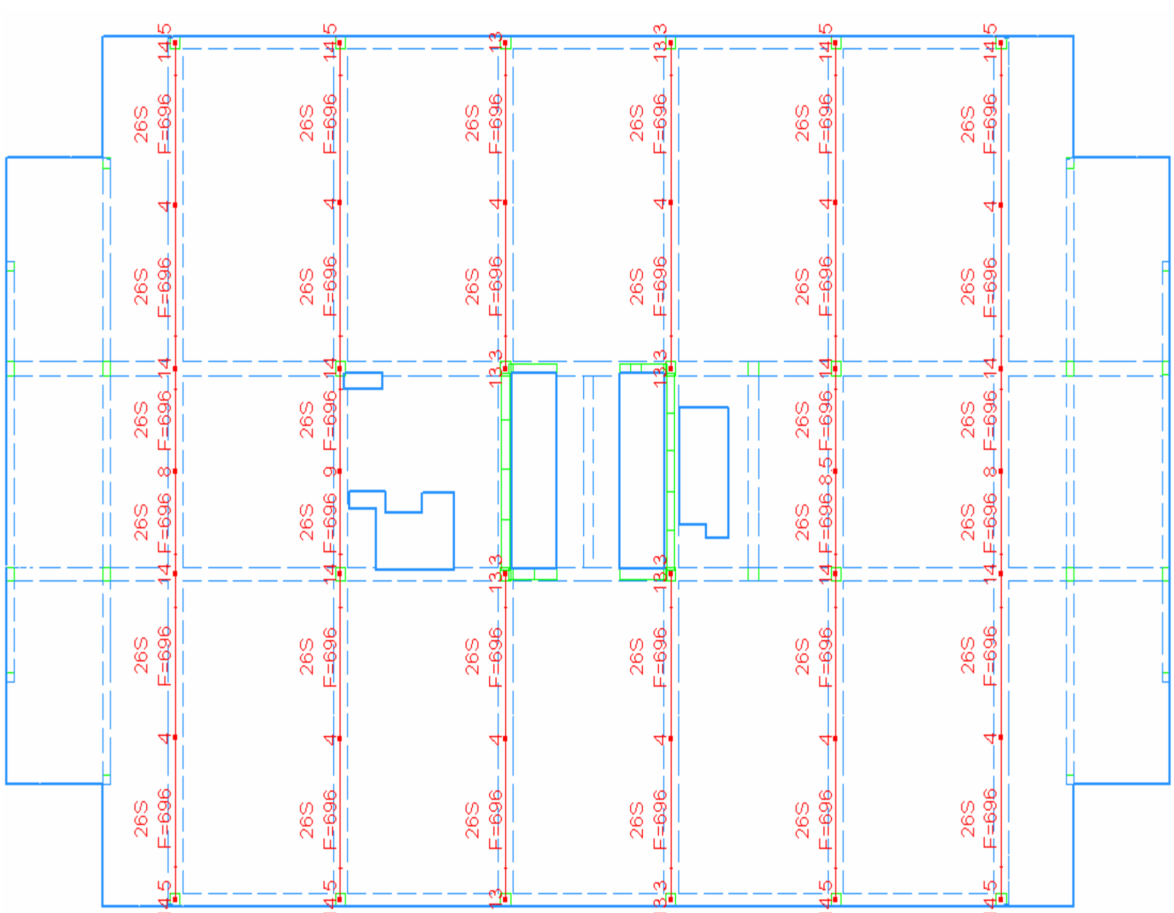


Figure B10: Longitudinal tendon plan view with tendon forces labeled

Quantity Estimates

Floor System #1

Concrete Costs

Materials:	1	per	cu. yds	x	552.1	cu. yds	=	552.1
Labor:	1	per	cu. yds	x	552.1	cu. yds	=	552.1
Total:	2	per	cu. yds	x	552.1	cu. yds	=	1104

Post-Tensioning Costs

Materials:	1	per	pounds	x	14070	pounds	=	14070
Labor:	1	per	pounds	x	14070	pounds	=	14070
Total:	2	per	pounds	x	14070	pounds	=	28150

Formwork Costs

Materials:	1	per	sq. ft.	x	21570	sq. ft.	=	21570
Labor:	1	per	sq. ft.	x	21570	sq. ft.	=	21570
Total:	2	per	sq. ft.	x	21570	sq. ft.	=	43140

Mild Steel Reinforcing Costs

Materials:	1	per	tons	x	31.36	tons	=	31.36
Labor:	1	per	tons	x	31.36	tons	=	31.36
Total:	2	per	tons	x	31.36	tons	=	62.72

Total Costs

Materials:	1.68	per	sq. ft.	x	21570	sq. ft.	=	36230
Labor:	1.68	per	sq. ft.	x	21570	sq. ft.	=	36230
Total:	3.359	per	sq. ft.	x	21570	sq. ft.	=	72450

Floor System #2

Concrete Costs

Materials:	1	per	cu. yds	x	520.5	cu. yds	=	520.5
Labor:	1	per	cu. yds	x	520.5	cu. yds	=	520.5
Total:	2	per	cu. yds	x	520.5	cu. yds	=	1041

Post-Tensioning Costs

Materials:	1	per	pounds	x	16430	pounds	=	16430
Labor:	1	per	pounds	x	16430	pounds	=	16430
Total:	2	per	pounds	x	16430	pounds	=	32870

Formwork Costs

Materials:	1	per	sq. ft.	x	21570	sq. ft.	=	21570
Labor:	1	per	sq. ft.	x	21570	sq. ft.	=	21570
Total:	2	per	sq. ft.	x	21570	sq. ft.	=	43140

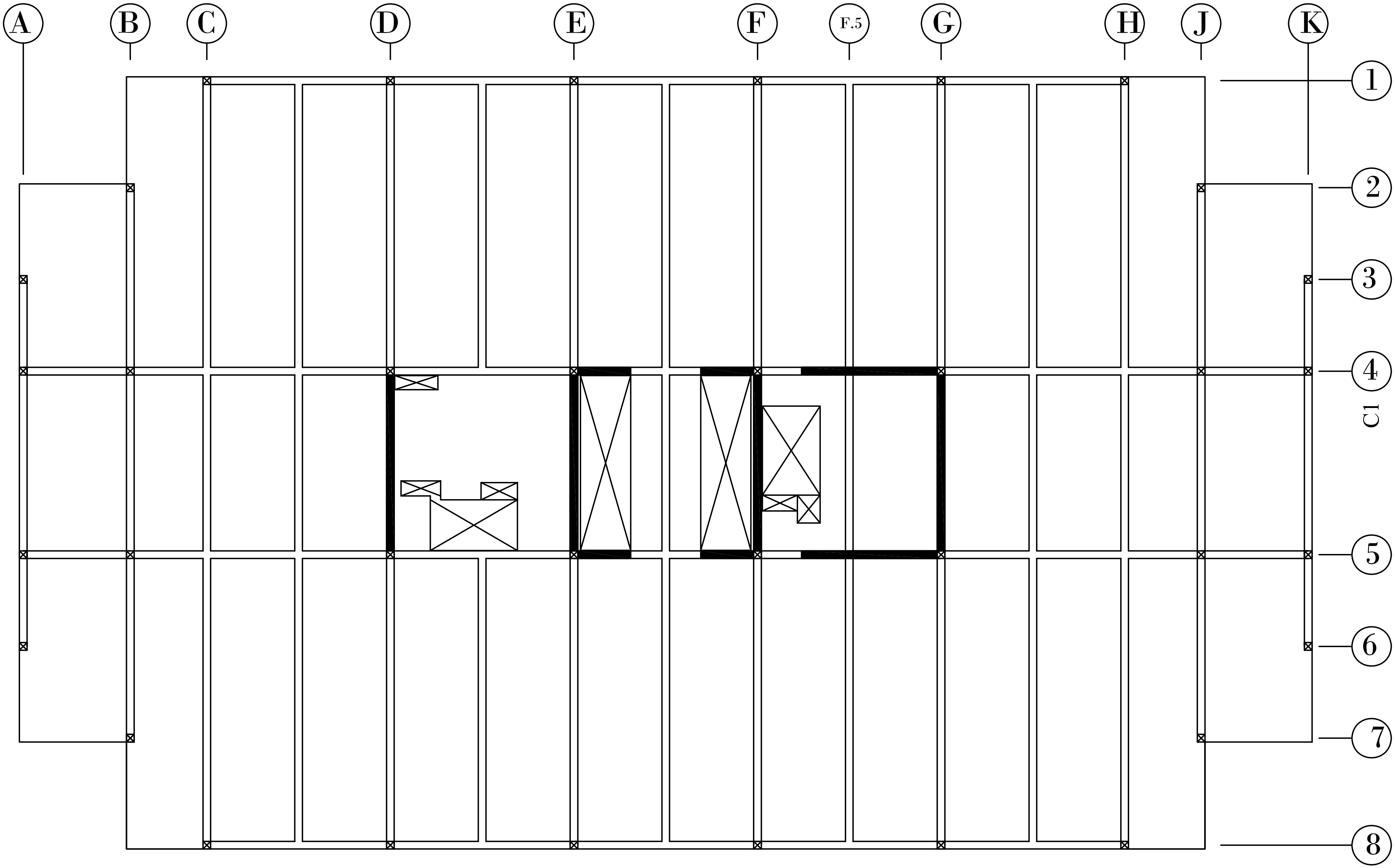
Mild Steel Reinforcing Costs

Materials:	1	per	tons	x	29.9	tons	=	29.9
Labor:	1	per	tons	x	29.9	tons	=	29.9
Total:	2	per	tons	x	29.9	tons	=	59.79

Total Costs

Materials:	1.787	per	sq. ft.	x	21570	sq. ft.	=	38550
Labor:	1.787	per	sq. ft.	x	21570	sq. ft.	=	38550
Total:	3.575	per	sq. ft.	x	21570	sq. ft.	=	77110

Appendix C: Column Design



Concrete framing plan with grid

A_{trib}	662
K_{LL}	4
A_I	2648

DEVELOPMENT OF AXIAL COLUMN LOADS

Couln D1, E1, F1, G1, D8, E8, F8, G8													
Level	Floor	LL (psf)	LL_R (psf)	DL (psf)	DL_R (psf)	Wt_{slab} (psf)	A_{trib} (sq ft)	A_I (sq ft)	LL_{red}	LL (kip)	DL (kip)	Slab Load (kip)	Total Axial (kip)
1	roof	---	30	---	15	---	662	---	---	19.86	9.93		29.79
2	16	80	---	30	---	75	662	2648	0.54	28.68	19.86	49.65	127.98
3	15	80	---	30	---	75	1324	5296	0.46	48.31	39.72	99.3	217.12
4	14	80	---	30	---	75	1986	7944	0.42	66.46	59.58	148.95	304.78
5	13	80	---	30	---	75	2648	10592	0.40	83.84	79.44	198.6	391.67
6	12	80	---	30	---	75	3310	13240	0.40	105.92	99.3	248.25	483.26
7	11	80	---	30	---	75	3972	15888	0.40	127.10	119.16	297.9	573.95
8	10	80	---	30	---	75	4634	18536	0.40	148.29	139.02	347.55	664.65
9	9	80	---	30	---	75	5296	21184	0.40	169.47	158.88	397.2	755.34
10	8	80	---	30	---	75	5958	23832	0.40	190.66	178.74	446.85	846.04
11	7	80	---	30	---	75	6620	26480	0.40	211.84	198.6	496.5	936.73
12	6	80	---	30	---	75	7282	29128	0.40	233.02	218.46	546.15	1027.42
13	5	80	---	30	---	75	7944	31776	0.40	254.21	238.32	595.8	1118.12
14	4	80	---	30	---	75	8606	34424	0.40	275.39	258.18	645.45	1208.81
15	3	80	---	30	---	75	9268	37072	0.40	296.58	278.04	695.1	1299.51
16	2	80	---	30	---	75	9930	39720	0.40	317.76	297.9	744.75	1390.20
	Base	---	---	---	---		---	---					

A_{trib}	174
K_{LL}	4
A_I	696

DEVELOPMENT OF AXIAL COLUMN LOADS

Couln A3, A6, K3, K6													
Level	Floor	LL (psf)	LL_R (psf)	DL (psf)	DL_R (psf)	Wt_{slab} (psf)	A_{trib} (sq ft)	A_I (sq ft)	LL_{red}	LL (kip)	DL (kip)	Slab Load (kip)	Total Axial (kip)
1	roof	---	30	---	15	---	174	---	---	5.22	2.61		7.83
2	16	80	---	30	---	75	174	696	0.82	11.39	5.22	13.05	37.49
3	15	80	---	30	---	75	348	1392	0.65	18.15	10.44	26.10	62.52
4	14	80	---	30	---	75	522	2088	0.58	24.15	15.66	39.15	86.79
5	13	80	---	30	---	75	696	2784	0.53	29.75	20.88	52.20	110.66
6	12	80	---	30	---	75	870	3480	0.50	35.10	26.1	65.25	134.28
7	11	80	---	30	---	75	1044	4176	0.48	40.27	31.32	78.30	157.72
8	10	80	---	30	---	75	1218	4872	0.46	45.30	36.54	91.35	181.02
9	9	80	---	30	---	75	1392	5568	0.45	50.23	41.76	104.40	204.22
10	8	80	---	30	---	75	1566	6264	0.44	55.06	46.98	117.45	227.32
11	7	80	---	30	---	75	1740	6960	0.43	59.83	52.2	130.50	250.36
12	6	80	---	30	---	75	1914	7656	0.42	64.53	57.42	143.55	273.33
13	5	80	---	30	---	75	2088	8352	0.41	69.18	62.64	156.60	296.25
14	4	80	---	30	---	75	2262	9048	0.41	73.78	67.86	169.65	319.12
15	3	80	---	30	---	75	2436	9744	0.40	78.33	73.08	182.70	341.94
16	2	80	---	30	---	75	2610	10440	0.40	83.52	78.3	195.75	365.40
	Base	---	---	---	---		---	---					

A_{trib}	665
K_{LL}	4
A_I	2660

DEVELOPMENT OF AXIAL COLUMN LOADS

Coulmns C1, C8, H1, H8													
Level	Floor	LL (psf)	LL_R (psf)	DL (psf)	DL_R (psf)	Wt_{slab} (psf)	A_{trib} (sq ft)	A_I (sq ft)	LL_{red}	LL (kip)	DL (kip)	Slab Load (kip)	Total Axial (kip)
1	roof	---	30	---	15	---	665	---	---	19.95	9.975		29.93
2	16	80	---	30	---	75	665	2660	0.54	28.77	19.95	49.88	128.52
3	15	80	---	30	---	75	1330	5320	0.46	48.48	39.9	99.75	218.06
4	14	80	---	30	---	75	1995	7980	0.42	66.70	59.85	149.63	306.10
5	13	80	---	30	---	75	2660	10640	0.40	84.15	79.8	199.50	393.37
6	12	80	---	30	---	75	3325	13300	0.40	106.40	99.75	249.38	485.45
7	11	80	---	30	---	75	3990	15960	0.40	127.68	119.7	299.25	576.56
8	10	80	---	30	---	75	4655	18620	0.40	148.96	139.65	349.13	667.66
9	9	80	---	30	---	75	5320	21280	0.40	170.24	159.6	399.00	758.77
10	8	80	---	30	---	75	5985	23940	0.40	191.52	179.55	448.88	849.87
11	7	80	---	30	---	75	6650	26600	0.40	212.80	199.5	498.75	940.98
12	6	80	---	30	---	75	7315	29260	0.40	234.08	219.45	548.63	1032.08
13	5	80	---	30	---	75	7980	31920	0.40	255.36	239.4	598.50	1123.19
14	4	80	---	30	---	75	8645	34580	0.40	276.64	259.35	648.38	1214.29
15	3	80	---	30	---	75	9310	37240	0.40	297.92	279.3	698.25	1305.40
16	2	80	---	30	---	75	9975	39900	0.40	319.20	299.25	748.13	1396.50
	Base	---	---	---	---		---	---					

A_{trib}	998
K_{LL}	4
A_I	3992

DEVELOPMENT OF AXIAL COLUMN LOADS

Coulmns G4, G5													
Level	Floor	LL (psf)	LL_R (psf)	DL (psf)	DL_R (psf)	Wt_{slab} (psf)	A_{trib} (sq ft)	A_I (sq ft)	LL_{red}	LL (kip)	DL (kip)	Slab Load (kip)	Total Axial (kip)
0	roof	---	30	---	15	---	998	---	---	29.94	14.97		44.91
1	pent	175	---	15	---	75	998	---	---	174.65	14.97	74.85	189.62
2	16	91.25	---	30	---	75	998	3992	0.49	44.39	29.94	74.85	338.80
3	15	91.25	---	30	---	75	1996	7984	0.42	76.11	59.88	149.7	475.31
4	14	91.25	---	30	---	75	2994	11976	0.40	109.28	89.82	224.55	613.27
5	13	91.25	---	30	---	75	3992	15968	0.40	145.71	119.76	299.4	754.49
6	12	91.25	---	30	---	75	4990	19960	0.40	182.14	149.7	374.25	895.71
7	11	91.25	---	30	---	75	5988	23952	0.40	218.56	179.64	449.1	1036.92
8	10	91.25	---	30	---	75	6986	27944	0.40	254.99	209.58	523.95	1178.14
9	9	91.25	---	30	---	75	7984	31936	0.40	291.42	239.52	598.8	1319.36
10	8	91.25	---	30	---	75	8982	35928	0.40	327.84	269.46	673.65	1460.57
11	7	91.25	---	30	---	75	9980	39920	0.40	364.27	299.4	748.5	1601.79
12	6	91.25	---	30	---	75	10978	43912	0.40	400.70	329.34	823.35	1743.01
13	5	91.25	---	30	---	75	11976	47904	0.40	437.12	359.28	898.2	1884.22
14	4	91.25	---	30	---	75	12974	51896	0.40	473.55	389.22	973.05	2025.44
15	3	91.25	---	30	---	75	13972	55888	0.40	509.98	419.16	1047.9	2166.66
16	2	91.25	---	30	---	75	14970	59880	0.40	546.41	449.1	1122.75	2307.88
	Base	---	---	---	---		---	---					

A_{trib}	494
K_{LL}	4
A_I	1976

DEVELOPMENT OF AXIAL COLUMN LOADS

Coulmns F.5 4, F.5 5													
Level	Floor	LL (psf)	LL_R (psf)	DL (psf)	DL_R (psf)	Wt_{slab} (psf)	A_{trib} (sq ft)	A_I (sq ft)	LL_{red}	LL (kip)	DL (kip)	Slab Load (kip)	Total Axial (kip)
0	roof	---	30	---	15	---	494	---	---	14.82	7.41		22.23
1	pent	175	---	15	---	75	494	---	---	86.45	7.41	37.05	93.86
2	16	91.25	---	30	---	75	494	1976	0.59	26.48	14.82	37.05	172.21
3	15	91.25	---	30	---	75	988	3952	0.49	44.05	29.64	74.1	241.65
4	14	91.25	---	30	---	75	1482	5928	0.44	60.15	44.46	111.15	309.62
5	13	91.25	---	30	---	75	1976	7904	0.42	75.50	59.28	148.2	376.84
6	12	91.25	---	30	---	75	2470	9880	0.40	90.36	74.1	185.25	443.57
7	11	91.25	---	30	---	75	2964	11856	0.40	108.19	88.92	222.3	513.27
8	10	91.25	---	30	---	75	3458	13832	0.40	126.22	103.74	259.35	583.17
9	9	91.25	---	30	---	75	3952	15808	0.40	144.25	118.56	296.4	653.07
10	8	91.25	---	30	---	75	4446	17784	0.40	162.28	133.38	333.45	722.97
11	7	91.25	---	30	---	75	4940	19760	0.40	180.31	148.2	370.5	792.87
12	6	91.25	---	30	---	75	5434	21736	0.40	198.34	163.02	407.55	862.77
13	5	91.25	---	30	---	75	5928	23712	0.40	216.37	177.84	444.6	932.67
14	4	91.25	---	30	---	75	6422	25688	0.40	234.40	192.66	481.65	1002.57
15	3	91.25	---	30	---	75	6916	27664	0.40	252.43	207.48	518.7	1072.47
16	2	91.25	---	30	---	75	7410	29640	0.40	270.47	222.3	555.75	1142.38
	Base	---	---	---	---		---	---					

A_{trib}	741
K_{LL}	4
A_I	2964

DEVELOPMENT OF AXIAL COLUMN LOADS

Coulmns F4, F5													
Level	Floor	LL (psf)	LL_R (psf)	DL (psf)	DL_R (psf)	Wt_{slab} (psf)	A_{trib} (sq ft)	A_I (sq ft)	LL_{red}	LL (kip)	DL (kip)	Slab Load (kip)	Total Axial (kip)
0	roof	---	30	---	15	---	741	---	0.53	22.23	11.115		33.35
1	pent	---	175	---	15	---	741	---	---	129.675	11.115		140.79
2	16	80	---	30	---	75	741	2964	0.53	31.15	22.23	55.58	249.75
3	15	80	---	30	---	75	1482	5928	0.44	52.74	44.46	111.15	349.14
4	14	80	---	30	---	75	2223	8892	0.41	72.75	66.69	166.73	446.95
5	13	80	---	30	---	75	2964	11856	0.40	94.85	88.92	222.30	546.86
6	12	80	---	30	---	75	3705	14820	0.40	118.56	111.15	277.88	648.38
7	11	80	---	30	---	75	4446	17784	0.40	142.27	133.38	333.45	749.89
8	10	80	---	30	---	75	5187	20748	0.40	165.98	155.61	389.03	851.41
9	9	80	---	30	---	75	5928	23712	0.40	189.70	177.84	444.60	952.93
10	8	80	---	30	---	75	6669	26676	0.40	213.41	200.07	500.18	1054.44
11	7	80	---	30	---	75	7410	29640	0.40	237.12	222.3	555.75	1155.96
12	6	80	---	30	---	75	8151	32604	0.40	260.83	244.53	611.33	1257.48
13	5	80	---	30	---	75	8892	35568	0.40	284.54	266.76	666.90	1358.99
14	4	80	---	30	---	75	9633	38532	0.40	308.26	288.99	722.48	1460.51
15	3	80	---	30	---	75	10374	41496	0.40	331.97	311.22	778.05	1562.03
16	2	80	---	30	---	75	11115	44460	0.40	355.68	333.45	833.63	1663.55
	Base	---	---	---	---		---	---					

A_{trib}	988
K_{LL}	4
A_I	3952

DEVELOPMENT OF AXIAL COLUMN LOADS

Coulmns E4, E5													
Level	Floor	LL (psf)	LL_R (psf)	DL (psf)	DL_R (psf)	Wt_{slab} (psf)	A_{trib} (sq ft)	A_I (sq ft)	LL_{red}	LL (kip)	DL (kip)	Slab Load (kip)	Total Axial (kip)
0	roof	---	30	---	15		988	---	---	2.69	14.82		17.51
1	mech	150	---	---	15	75	988	---	---	148.2	14.82	74.1	163.02
2	16	80	---	30	---	75	988	3952	0.49	38.62	29.64	74.1	305.38
3	15	80	---	30	---	75	1976	7904	0.42	66.19	59.28	148.2	436.69
4	14	80	---	30	---	75	2964	11856	0.40	94.85	88.92	222.3	569.09
5	13	80	---	30	---	75	3952	15808	0.40	126.46	118.56	296.4	704.44
6	12	80	---	30	---	75	4940	19760	0.40	158.08	148.2	370.5	839.80
7	11	80	---	30	---	75	5928	23712	0.40	189.70	177.84	444.6	975.16
8	10	80	---	30	---	75	6916	27664	0.40	221.31	207.48	518.7	1110.51
9	9	80	---	30	---	75	7904	31616	0.40	252.93	237.12	592.8	1245.87
10	8	80	---	30	---	75	8892	35568	0.40	284.54	266.76	666.9	1381.22
11	7	80	---	30	---	75	9880	39520	0.40	316.16	296.4	741	1516.58
12	6	80	---	30	---	75	10868	43472	0.40	347.78	326.04	815.1	1651.94
13	5	80	---	30	---	75	11856	47424	0.40	379.39	355.68	889.2	1787.29
14	4	80	---	30	---	75	12844	51376	0.40	411.01	385.32	963.3	1922.65
15	3	80	---	30	---	75	13832	55328	0.40	442.62	414.96	1037.4	2058.00
16	2	80	---	30	---	75	14820	59280	0.40	474.24	444.6	1111.5	2193.36
	Base	---	---	---	---		---	---					

A_{trib}	1245
K_{LL}	4
A_I	4980

DEVELOPMENT OF AXIAL COLUMN LOADS

Coulmns D4, D5													
Level	Floor	LL (psf)	LL_R (psf)	DL (psf)	DL_R (psf)	Wt_{slab} (psf)	A_{trib} (sq ft)	A_I (sq ft)	LL_{red}	LL (kip)	DL (kip)	Slab Load (kip)	Total Axial (kip)
0	roof	---	30	---	15	---	1245	---	---	37.35	18.675		56
1	mech	200	---	---	---	75	1245	---	0.46	57.27	---	93.38	207
2	16	80	---	30	---	75	1245	4980	0.46	46.07	37.35	93.38	233
3	15	80	---	30	---	75	2490	9960	0.40	79.74	74.7	186.75	397
4	14	80	---	30	---	75	3735	14940	0.40	119.52	112.05	280.13	568
5	13	80	---	30	---	75	4980	19920	0.40	159.36	149.4	373.50	738
6	12	80	---	30	---	75	6225	24900	0.40	199.20	186.75	466.88	909
7	11	80	---	30	---	75	7470	29880	0.40	239.04	224.1	560.25	1079
8	10	80	---	30	---	75	8715	34860	0.40	278.88	261.45	653.63	1250
9	9	80	---	30	---	75	9960	39840	0.40	318.72	298.8	747.00	1421
10	8	80	---	30	---	75	11205	44820	0.40	358.56	336.15	840.38	1591
11	7	80	---	30	---	75	12450	49800	0.40	398.40	373.5	933.75	1762
12	6	80	---	30	---	75	13695	54780	0.40	438.24	410.85	1027.13	1932
13	5	80	---	30	---	75	14940	59760	0.40	478.08	448.2	1120.50	2103
14	4	80	---	30	---	75	16185	64740	0.40	517.92	485.55	1213.88	2273
15	3	80	---	30	---	75	17430	69720	0.40	557.76	522.9	1307.25	2444
16	2	80	---	30	---	75	18675	74700	0.40	597.60	560.25	1400.63	2615
	Base	---	---	---	---		---	---					

A_{trib}	174
K_{LL}	4
A_I	696

DEVELOPMENT OF AXIAL COLUMN LOADS

Couln A4,A5, K4, K5													
Level	Floor	LL (psf)	LL_R (psf)	DL (psf)	DL_R (psf)	Wt_{slab} (psf)	A_{trib} (sq ft)	A_I (sq ft)	LL_{red}	LL (kip)	DL (kip)	Slab Load (kip)	Total Axial (kip)
1	roof	---	30	---	15	---	174	---		5.22	2.61		7.83
2	16	80	---	30	---	75	174	696	0.82	11.39	5.22	13.05	37.49
3	15	80	---	30	---	75	348	1392	0.65	18.15	10.44	26.1	62.52
4	14	80	---	30	---	75	522	2088	0.58	24.15	15.66	39.15	86.79
5	13	80	---	30	---	75	696	2784	0.53	29.75	20.88	52.2	110.66
6	12	80	---	30	---	75	870	3480	0.50	35.10	26.1	65.25	134.28
7	11	80	---	30	---	75	1044	4176	0.48	40.27	31.32	78.3	157.72
8	10	80	---	30	---	75	1218	4872	0.46	45.30	36.54	91.35	181.02
9	9	80	---	30	---	75	1392	5568	0.45	50.23	41.76	104.4	204.22
10	8	80	---	30	---	75	1566	6264	0.44	55.06	46.98	117.45	227.32
11	7	80	---	30	---	75	1740	6960	0.43	59.83	52.2	130.5	250.36
12	6	80	---	30	---	75	1914	7656	0.42	64.53	57.42	143.55	273.33
13	5	80	---	30	---	75	2088	8352	0.41	69.18	62.64	156.6	296.25
14	4	80	---	30	---	75	2262	9048	0.41	73.78	67.86	169.65	319.12
15	3	80	---	30	---	75	2436	9744	0.40	78.33	73.08	182.7	341.94
16	2	80	---	30	---	75	2610	10440	0.40	83.52	78.3	195.75	365.40
	Base	---	---	---	---		---	---					

A_{trib}	309
K_{LL}	4
A_I	1236

DEVELOPMENT OF AXIAL COLUMN LOADS

Couln B2, B7, J2, J7													
Level	Floor	LL (psf)	LL_R (psf)	DL (psf)	DL_R (psf)	Wt_{slab} (psf)	A_{trib} (sq ft)	A_I (sq ft)	LL_{red}	LL (kip)	DL (kip)	Slab Load (kip)	Total Axial (kip)
1	roof	---	30	---	15	---	309	---		9.27	4.635		13.91
2	16	80	---	30	---	75	309	1236	0.68	16.73	9.27	23.18	63.08
3	15	80	---	30	---	75	618	2472	0.55	27.28	18.54	46.35	106.07
4	14	80	---	30	---	75	927	3708	0.50	36.81	27.81	69.53	148.05
5	13	80	---	30	---	75	1236	4944	0.46	45.81	37.08	92.70	189.50
6	12	80	---	30	---	75	1545	6180	0.44	54.48	46.35	115.88	230.61
7	11	80	---	30	---	75	1854	7416	0.42	62.91	55.62	139.05	271.49
8	10	80	---	30	---	75	2163	8652	0.41	71.16	64.89	162.23	312.18
9	9	80	---	30	---	75	2472	9888	0.40	79.27	74.16	185.40	352.74
10	8	80	---	30	---	75	2781	11124	0.40	88.99	83.43	208.58	394.90
11	7	80	---	30	---	75	3090	12360	0.40	98.88	92.7	231.75	437.24
12	6	80	---	30	---	75	3399	13596	0.40	108.77	101.97	254.93	479.57
13	5	80	---	30	---	75	3708	14832	0.40	118.66	111.24	278.10	521.90
14	4	80	---	30	---	75	4017	16068	0.40	128.54	120.51	301.28	564.23
15	3	80	---	30	---	75	4326	17304	0.40	138.43	129.78	324.45	606.57
16	2	80	---	30	---	75	4635	18540	0.40	148.32	139.05	347.63	648.90
	Base	---	---	---	---		---	---					

A_{trib}	743
K_{LL}	4
A_I	2972

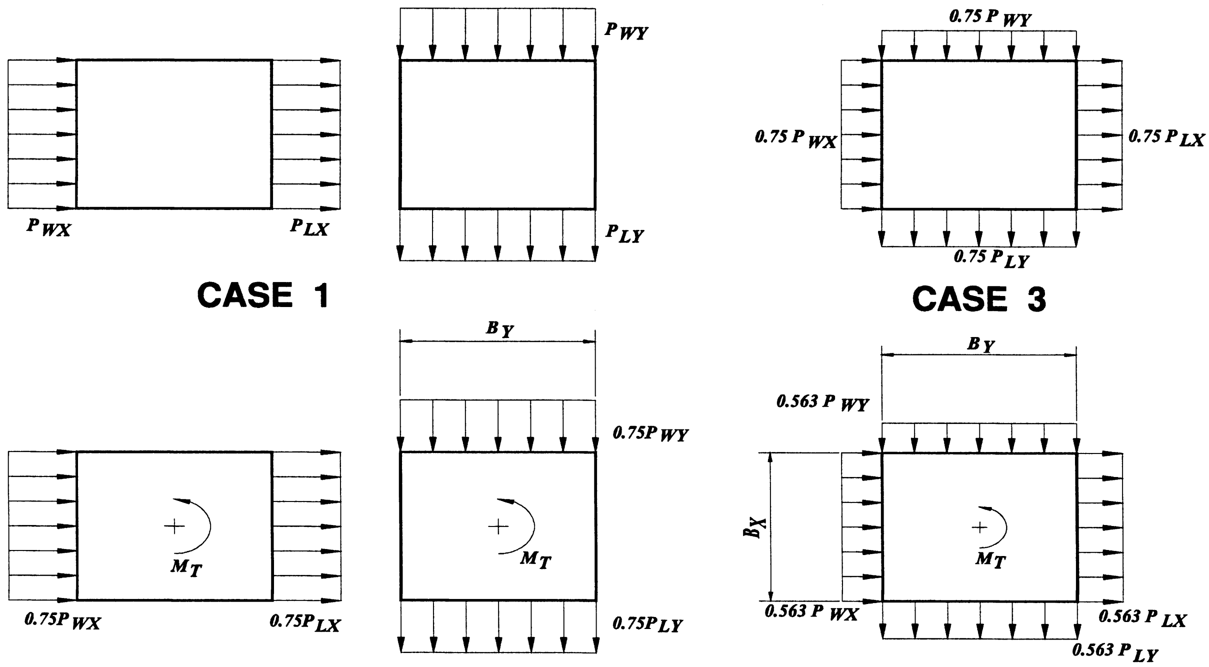
DEVELOPMENT OF AXIAL COLUMN LOADS

Couln B4, B5, J4, J5													
Level	Floor	LL (psf)	LL_R (psf)	DL (psf)	DL_R (psf)	Wt_{slab} (psf)	A_{trib} (sq ft)	A_I (sq ft)	LL_{red}	LL (kip)	DL (kip)	Slab Load (kip)	Total Axial (kip)
1	roof	---	30	---	15	---	743	---	---	22.29	11.145		33.44
2	16	80	---	30	---	75	743	2972	0.53	31.21	22.29	55.73	142.66
3	15	80	---	30	---	75	1486	5944	0.44	52.85	44.58	111.45	242.31
4	14	80	---	30	---	75	2229	8916	0.41	72.91	66.87	167.18	340.39
5	13	80	---	30	---	75	2972	11888	0.40	95.10	89.16	222.90	440.60
6	12	80	---	30	---	75	3715	14860	0.40	118.88	111.45	278.63	542.39
7	11	80	---	30	---	75	4458	17832	0.40	142.66	133.74	334.35	644.18
8	10	80	---	30	---	75	5201	20804	0.40	166.43	156.03	390.08	745.97
9	9	80	---	30	---	75	5944	23776	0.40	190.21	178.32	445.80	847.76
10	8	80	---	30	---	75	6687	26748	0.40	213.98	200.61	501.53	949.55
11	7	80	---	30	---	75	7430	29720	0.40	237.76	222.9	557.25	1051.35
12	6	80	---	30	---	75	8173	32692	0.40	261.54	245.19	612.98	1153.14
13	5	80	---	30	---	75	8916	35664	0.40	285.31	267.48	668.70	1254.93
14	4	80	---	30	---	75	9659	38636	0.40	309.09	289.77	724.43	1356.72
15	3	80	---	30	---	75	10402	41608	0.40	332.86	312.06	780.15	1458.51
16	2	80	---	30	---	75	11145	44580	0.40	356.64	334.35	835.88	1560.30
	Base	---	---	---	---		---	---					

MARK / LEVEL	A3 A6 K3 K6	A4 A5 K4 K5	B2 B7 J2 J7	B4 B5 J4 J5	C1 C8 H1 H8	D1 D8 E1 E8 F1 F8 G1 G8	D4 D5	E4 E5	F4 F5	F.5 4 F.5 5	G4 G5	f'c (psi)
PENTHOUSE ROOF	14 x 14 45k 6-#6	14 x 14 45k 6-#6					18 x 18 82k 4-#11	18 x 18 22k 4-#8	18 x 18 57k 4-#10	18 x 18 33k 4-#8	18 x 18 65k 4-#10	5000
PENTHOUSE	14 x 14 45k 6-#6	14 x 14 45k 6-#6	18 x 18 20k 4-#9	18 x 18 49k 4-#10	18 x 18 44k 4-#10	18 x 18 44k 4-#10	20 x 20 293k 4-#11	24 x 24 419k 8-#8	18 x 18 221k 4-#10	20 x 20 147k 6-#8	20 x 20 387k 6-#10	5000
LEVEL 16	14 x 14 53k 6-#6	14 x 14 53k 6-#6	18 x 18 88k 8-#9	18 x 18 197k 4-#10	20 x 20 178k 4-#10	18 x 18 177k 4-#10	20 x 20 321k 4-#11	24 x 24 447k 8-#8	18 x 18 368k 4-#10	20 x 20 255k 6-#8	20 x 20 500k 6-#10	5000
LEVEL 15	14 x 14 85k 6-#6	14 x 14 85k 6-#6	18 x 18 144k 8-#9	18 x 18 325k 4-#10	20 x 20 293k 4-#10	18 x 18 292k 4-#10	20 x 20 531k 4-#11	24 x 24 616k 8-#8	18 x 18 496k 4-#10	20 x 20 345k 6-#8	20 x 20 677k 6-#10	5000
LEVEL 14	14 x 14 117k 6-#6	14 x 14 117k 6-#6	18 x 18 198k 6-#9	18 x 18 451k 4-#10	20 x 20 406k 4-#10	18 x 18 404k 4-#10	20 x 20 751k 6-#11	24 x 24 786k 8-#8	18 x 18 622k 4-#10	20 x 20 493k 6-#8	20 x 20 855k 6-#10	5000
LEVEL 13	14 x 14 148k 6-#6	14 x 14 148k 6-#6	18 x 18 251k 6-#9	20 x 20 580k 4-#10	20 x 20 518k 4-#10	20 x 20 515k 4-#10	20 x 20 972k 6-#11	24 x 24 961k 8-#8	18 x 18 750k 6-#10	20 x 20 520k 4-#10	20 x 20 1040k 6-#10	5000
LEVEL 12	14 x 14 178k 6-#6	14 x 14 178k 6-#6	18 x 18 304k 6-#9	20 x 20 712k 4-#10	20 x 20 637k 4-#10	20 x 20 634k 4-#10	20 x 20 1193k 6-#11	24 x 24 1136k 8-#8	18 x 18 882k 6-#10	20 x 20 606k 4-#10	20 x 20 1224k 6-#10	5000
LEVEL 11	14 x 14 208k 6-#6	14 x 14 208k 6-#6	18 x 18 357k 6-#9	20 x 20 843k 4-#10	20 x 20 755k 4-#10	20 x 20 752k 4-#10	20 x 20 1413k 6-#11	24 x 24 1311k 8-#8	20 x 20 1013k 6-#10	20 x 20 697k 4-#10	20 x 20 1408k 6-#10	5000
LEVEL 10	14 x 14 238k 6-#6	14 x 14 238k 6-#6	18 x 18 409k 4-#9	20 x 20 975k 4-#10	20 x 20 873k 4-#10	20 x 20 869k 4-#10	24 x 24 1634k 6-#11	24 x 24 1486k 8-#10	20 x 20 1144k 4-#10	20 x 20 788k 6-#10	24 x 24 1592k 6-#10	6000
LEVEL 9	14 x 14 268k 6-#6	14 x 14 268k 6-#6	18 x 18 461k 4-#9	20 x 20 1107k 4-#10	20 x 20 991k 4-#10	20 x 20 986k 4-#10	24 x 24 1855k 6-#11	24 x 24 1661k 8-#10	20 x 20 1276k 4-#10	20 x 20 879k 6-#10	24 x 24 1776k 6-#10	6000
LEVEL 8	14 x 14 298k 6-#6	14 x 14 298k 6-#6	18 x 18 515k 4-#9	20 x 20 1238k 4-#10	20 x 20 1108k 4-#10	20 x 20 1103k 4-#10	24 x 24 2075k 6-#11	24 x 24 1836k 8-#10	20 x 20 1407k 4-#10	20 x 20 970k 6-#10	24 x 24 1960k 6-#10	6000
LEVEL 7	16 x 16 327k 6-#6	16 x 16 327k 6-#6	18 x 18 570k 4-#9	24 x 24 1370k 6-#10	24 x 24 1226k 6-#10	20 x 20 1221k 6-#10	28 x 28 2296k 8-#11	28 x 28 2012k 10-#10	24 x 24 1538k 8-#10	20 x 20 1061k 8-#10	28 x 28 2144k 6-#11	6000
LEVEL 6	16 x 16 357k 6-#6	16 x 16 357k 6-#6	18 x 18 625k 4-#9	24 x 24 1502k 6-#10	24 x 24 1344k 6-#10	20 x 20 1338k 8-#10	28 x 28 2516k 8-#11	28 x 28 2187k 10-#10	24 x 24 1670k 8-#10	20 x 20 1152k 8-#10	28 x 28 2328k 6-#11	6000
LEVEL 5	16 x 16 386k 6-#6	16 x 16 386k 6-#6	18 x 18 679k 4-#9	24 x 24 1633k 6-#10	24 x 24 1462k 6-#10	20 x 20 1455k 8-#10	28 x 28 2737k 8-#11	28 x 28 2362k 10-#10	24 x 24 1801k 8-#10	20 x 20 1243k 8-#10	28 x 28 2512k 6-#11	6000
LEVEL 4	16 x 16 416k 6-#6	16 x 16 416k 6-#6	18 x 18 734k 4-#9	24 x 24 1765k 8-#10	24 x 24 1580k 8-#10	20 x 24 1573k 10-#10	32 x 32 2958k 10-#11	28 x 28 2537k 10-#11	24 x 24 1932k 10-#11	24 x 24 1334k 6-#10	32 x 32 2696k 8-#11	6000
LEVEL 3	16 x 16 445k 6-#6	16 x 16 445k 6-#6	18 x 18 789k 4-#9	24 x 24 1897k 10-#10	24 x 24 1698k 8-#10	20 x 24 1690k 10-#10	32 x 32 3178k 14-#11	28 x 28 2712k 10-#11	24 x 24 2064k 12-#11	24 x 24 1425k 6-#10	32 x 32 2880k 8-#11	6000
LEVEL 2	16 x 16 475k 6-#6	16 x 16 475k 6-#6	18 x 18 844k 8-#8	24 x 24 2028k 12-#10	24 x 24 1851k 8-#10	20 x 24 1807k 10-#10	32 x 32 3399k 18-#11	28 x 28 2887k 10-#11	24 x 24 2195k 12-#11	24 x 24 1517k 6-#10	32 x 32 3064k 8-#11	6000
BASE (Dowels)	6-#6	6-#6	8-#8	10-#10	8-#10	10-#10	14-#11	10-#11	12-#11	6-#10	8-#11	

Appendix D: Lateral System

Main Wind Force Resisting System– Method 2		All Heights
Figure 6-9	Design Wind Load Cases	



$M_T = 0.75\ (P_{WX}+P_{LX})B_X e_X$
$e_X = \pm\ 0.15\ B_X$

$M_T = 0.75\ (P_{WY}+P_{LY})B_Y e_Y$
$e_Y = \pm\ 0.15\ B_Y$

CASE 2

$M_T = 0.563\ (P_{WX}+P_{LX})B_X e_X + 0.563\ (P_{WY}+P_{LY})B_Y e_Y$
$e_X = \pm\ 0.15\ B_X$ $e_Y = \pm\ 0.15\ B_Y$

CASE 4

Case 1. Full design wind pressure acting on the projected area perpendicular to each principal axis of the structure, considered separately along each principal axis.

Case 2. Three quarters of the design wind pressure acting on the projected area perpendicular to each principal axis of the structure in conjunction with a torsional moment as shown, considered separately for each principal axis.

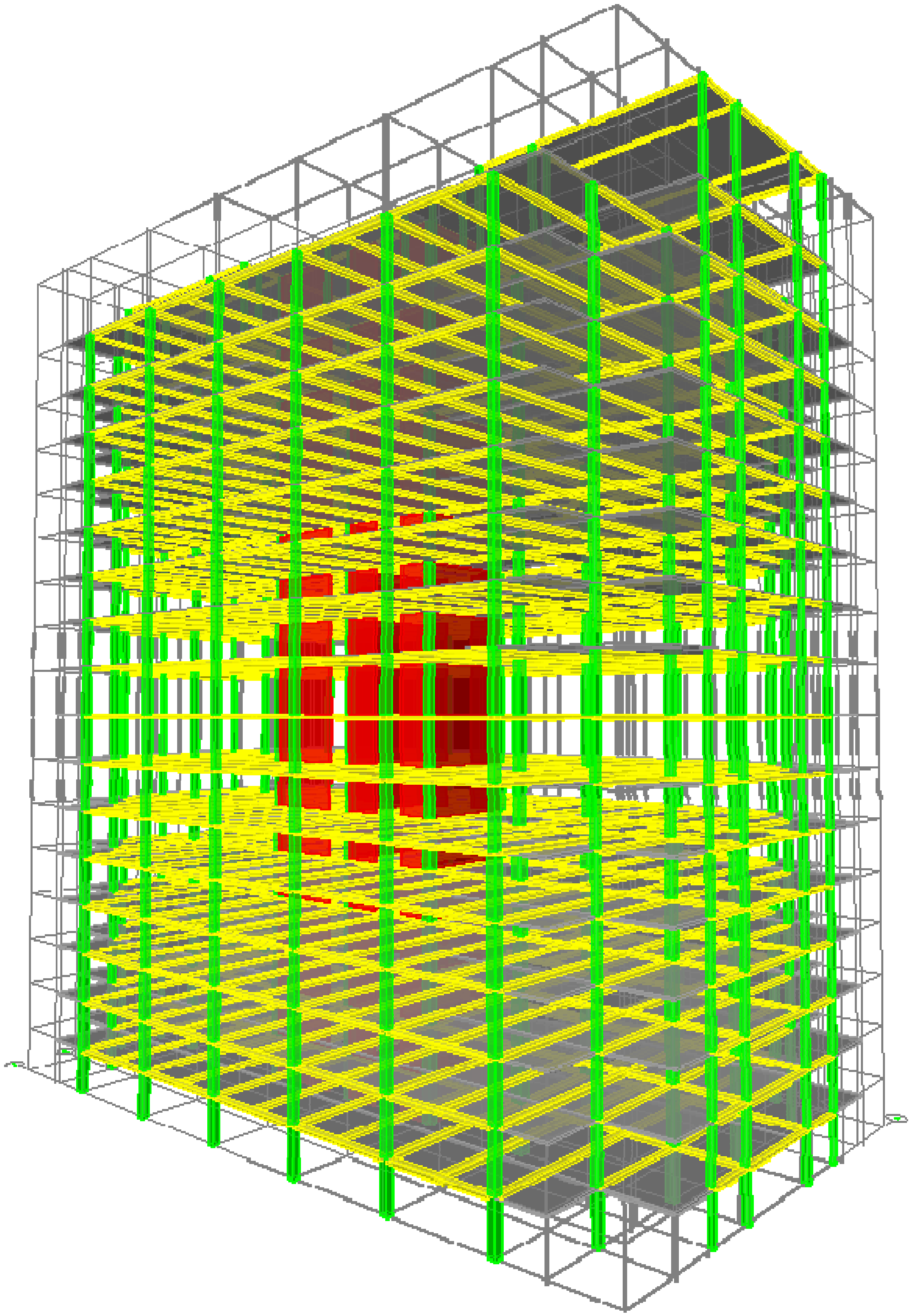
Case 3. Wind loading as defined in Case 1, but considered to act simultaneously at 75% of the specified value.

Case 4. Wind loading as defined in Case 2, but considered to act simultaneously at 75% of the specified value.

Notes:

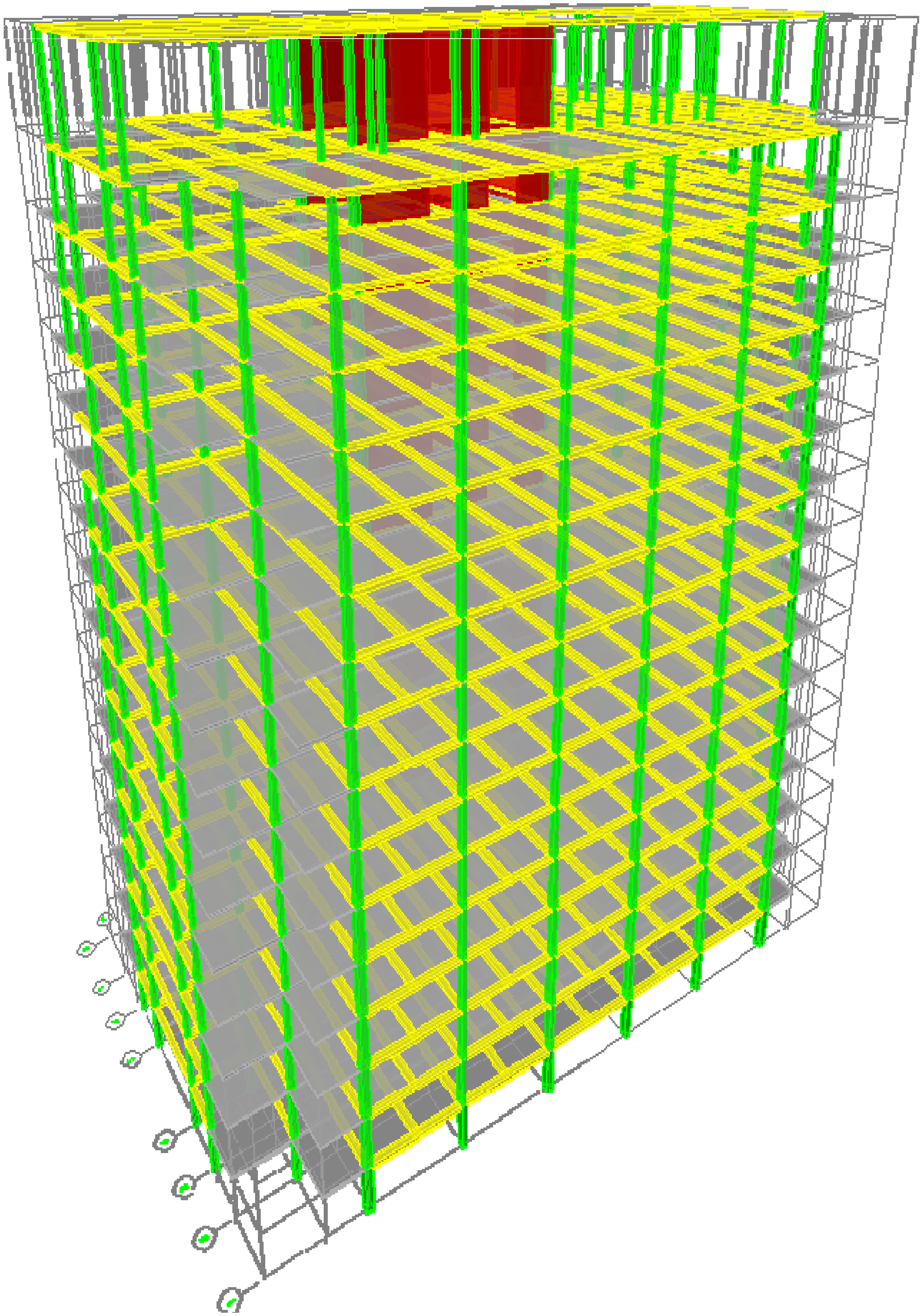
1. Design wind pressures for windward and leeward faces shall be determined in accordance with the provisions of 6.5.12.2.1 and 6.5.12.2.3 as applicable for building of all heights.
2. Diagrams show plan views of building.
3. Notation:

   P_{WX}, P_{WY}: Windward face design pressure acting in the x, y principal axis, respectively.
   P_{LX}, P_{LY}: Leeward face design pressure acting in the x, y principal axis, respectively.
   $e\ (e_X, e_Y)$: Eccentricity for the x, y principal axis of the structure, respectively.
   M_T: Torsional moment per unit height acting about a vertical axis of the building.



ETABS Concrete Model

ETABS Concrete model



Location:	Conshohocken, PA			
				Penthouse
Dimension	N-S	196 ft	N-S	114 ft
	E-W	118 ft	E-W	44 ft
	Total Height, h	209 ft	Height	22 ft
	Inter-story Height, h_s	12.03 ft		

Velocity Pressure			
	K_{zt}	1.0	(Table 6-4) Assumed area is flat
	K_d	0.85	(Table 6-4)
	V	90 mph	(Figure 6-1)
	Group	II	Office Building
	Importance Factor, I	1.0	(Table 6-1)
	Exposure	B	Assumed area is flat
	$q_z/K_z = 0.00256K_{zt}K_dV^2I =$	17.6256	

	N-S	E-W
Gust Factor Effect, G	0.832	0.821

Location:	Conshohocken, PA			
				Penthouse
Dimension	N-S	118 ft	N-S	114 ft
	E-W	196 ft	E-W	44 ft
	Total Height, h	209 ft	Height	22 ft
	Inter-story Height, h_s	12.03 ft		

Velocity Pressu			
	K_{zt}	1.0	(Table 6-4) Assume area is flat
	K_d	0.85	(Table 6-4)
	V	90 mph	(Figure 6-1)
	Group	II	Office Building
	Importance Factor, I	1.0	(Table 6-1)
	Exposure	B	Assume area is flat
	$q_z/K_z = 0.00256K_{zt}K_dV^2I =$	17.6256	

ASCE7-02 Chapter 6: Wind Analysis
Method 2- Analytical Procedure

External Pressure Coefficients, C_p		Resultant pressure N-S	Resultant pressure E-W
	Windward	0.8	0.8
	Leeward	-0.368	-0.50

ASCE7-02 Chapter 6: Wind Analysis
Method 2- Analytical Procedure

Story No.	z (ft)	K_z	q_z (lb/ft²)	q_h (lb/ft²)	N-S $q_zC_pG - q_hC_pG$ (lb/ft²)	E-W $q_zC_pG - q_hC_pG$ (lb/ft²)	Story Forces N-S (kips)	Story Forces E-W (kips)	Story Shear N-S (kips)	Story Shear E-W (kips)	Moment N-S (ft-kips)	Moment E-W (ft-kips)
Penthouse Roof	209	1.214	21.405	21.405	20.812	22.851	10.07	28.65			2,105.26	5,988.88
Penthouse Level	187	1.181	20.814	21.405	20.419	22.463	26.75	30.06	10.07	28.65	5,008.61	5,628.68
16	176	1.161	20.463	21.405	20.185	22.232	28.65	52.42	36.82	58.71	5,028.73	9,199.98
15	164	1.138	20.049	21.405	19.909	21.960	28.26	51.78	65.47	111.14	4,627.93	8,478.96
14	152	1.114	19.635	21.405	19.634	21.688	27.87	51.14	93.74	162.92	4,236.33	7,773.02
13	140	1.091	19.221	21.405	19.358	21.416	27.48	50.50	121.61	214.05	3,853.93	7,082.16
12	129	1.061	18.705	21.405	19.014	21.077	26.99	49.70	149.09	264.55	3,468.42	6,386.20
11	117	1.032	18.187	21.405	18.670	20.737	26.50	48.90	176.08	314.25	3,094.12	5,708.61
10	105	1.003	17.670	21.405	18.325	20.397	26.01	48.09	202.58	363.15	2,731.33	5,049.87
9	93.3	0.970	17.092	21.405	17.940	20.018	25.47	47.20	228.59	411.24	2,374.79	4,401.38
8	81.5	0.935	16.471	21.405	17.527	19.610	24.88	46.24	254.06	458.44	2,027.69	3,768.35
7	69.8	0.889	15.669	21.405	16.992	19.083	24.12	45.00	278.94	504.68	1,682.47	3,138.41
6	58	0.842	14.841	21.405	16.441	18.539	23.34	43.71	303.06	549.67	1,353.62	2,535.29
5	46.3	0.791	13.946	21.405	15.845	17.951	22.49	42.33	326.40	593.38	1,040.29	1,957.59
4	34.5	0.727	12.814	21.405	15.091	17.207	21.42	40.57	348.89	635.71	739.06	1,399.74
3	22.8	0.642	11.316	21.405	14.093	16.223	20.01	38.25	370.31	676.28	455.13	870.22
2	11	0.570	10.047	21.405	13.248	15.389	18.81	36.29	390.32	714.53	206.87	399.14
Base	0	0.570	10.047	21.405	13.248	15.389		Total Shear	409.13	750.82		
										Total Moment	44,034.56	79,766.47

ASCE7-02 Chapter 9- Seismic Analysis

Reference				
	Building Location :			**Conshohocken, Pennsylvania**
	Number of Stories :	N		16
	Inter-story Height	h_s		12.08
	Building Height :	h_n		192 ft
Table 1.1	Seismic Use Group :	I		I
Table 9.1.4	Occupany Importance Factor :			1.00
	Site Classification :			**D**
Figure 9.4.1.1a	0.2s Acceleration :	S_S		0.31 g-s
Figure 9.4.1.1b	1s Acceleration :	S_1		0.08 g-s
Table 9.4.1.2.4a	Site Class Factor :	F_a		1.55
Table 9.4.1.2.4b	Site Class Factor :	F_v		2.40
	Adjusted Accelerations :	S_{MS}	$= F_a S_S$	0.481 g-s
		S_{M1}	$= F_v S_1$	0.180 g-s
	Design Spectral Response Accelerati	S_{DS}	$= (2/3)S_{MS}$	0.320 g-s
		S_{D1}	$= (2/3)S_{M1}$	0.120 g-s
Table 9.4.2.1a	Seismic Design Category :			**B**
Table 9.4.2.1b	Both design category B			
	N-S Direction			
Table 9.5.2.2	Response Modification Factor :	R_{N-S}		3
	Seismic Response Coefficient :	$C_{s, N-S}$	$= S_{DS}/(R_{N-S}/I)$	**0.107**
Table 9.5.5.3.2		$C_{T, N-S}$		0.028
Table 9.5.5.3.2	(moment frames only)	x		0.80
	Approximate Period of Structure :	T_{N-S}	$= C_{T, N-S} h_n^{x}$	1.88
	Seismic Response Coefficient need			
	not greater than	$C_{S\,max, N-S}$	$S_{D1}/T(R_{N-S}/I)$	**0.021**
	and	$C_{S\,min}$	$= 0.044 I S_{DS}$	**0.0141**
	Seismic Response Coefficient ($C_{s, N-S}$)			**0.021**
	E-W Direction			
Table 9.5.2.2	Response Modification Factor :	R_{N-S}		3
	Seismic Response Coefficient :	$C_{s, E-W}$	$= S_{DS}/(R_{E-W}/I)$	**0.107**
Table 9.5.5.3.2		$C_{T, E-W}$		0.02
Table 9.5.5.3.2	(moment and braced frame)	x		0.75
	Approximate Period of Structure :	T_{N-S}	$= C_{T, E-W} h_n^{x}$	1.03
	Seismic Response Coefficient need			
	not greater than	$C_{S\,max, N-S}$	$S_{D1}/T(R_{E-W}/I)$	**0.039**
	and	$C_{S\,min}$	$= 0.044 I S_{DS}$	**0.0141**
	Seismic Response Coefficient ($C_{s, E-W}$)			**0.039**

Table 1 : Vertical Distribution of Seismic Forces (X-direction)

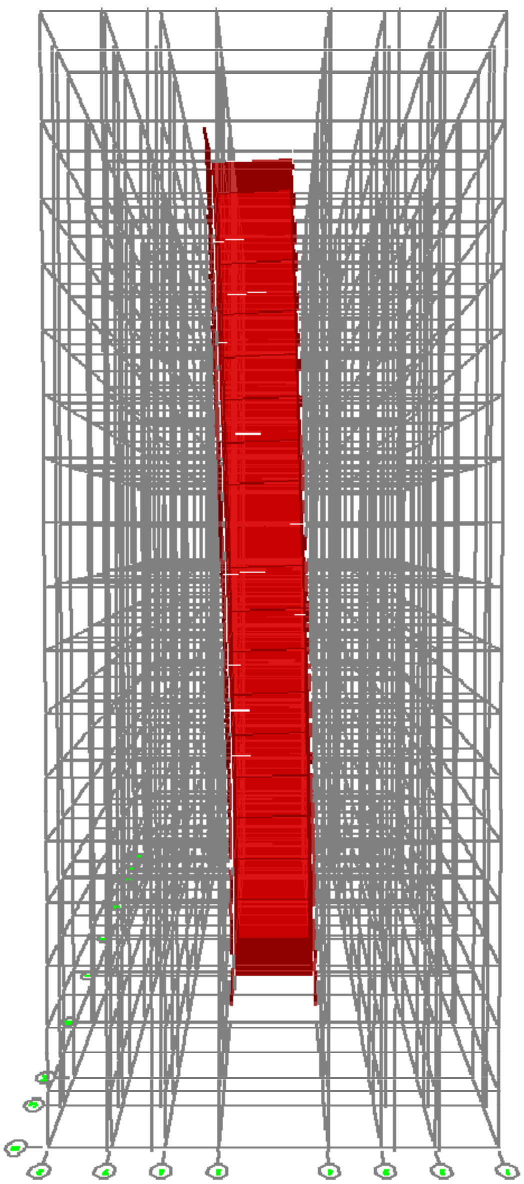
Seismic Base Shear, $V_{N-S} = C_{s,N-S} W =$ **873** kips

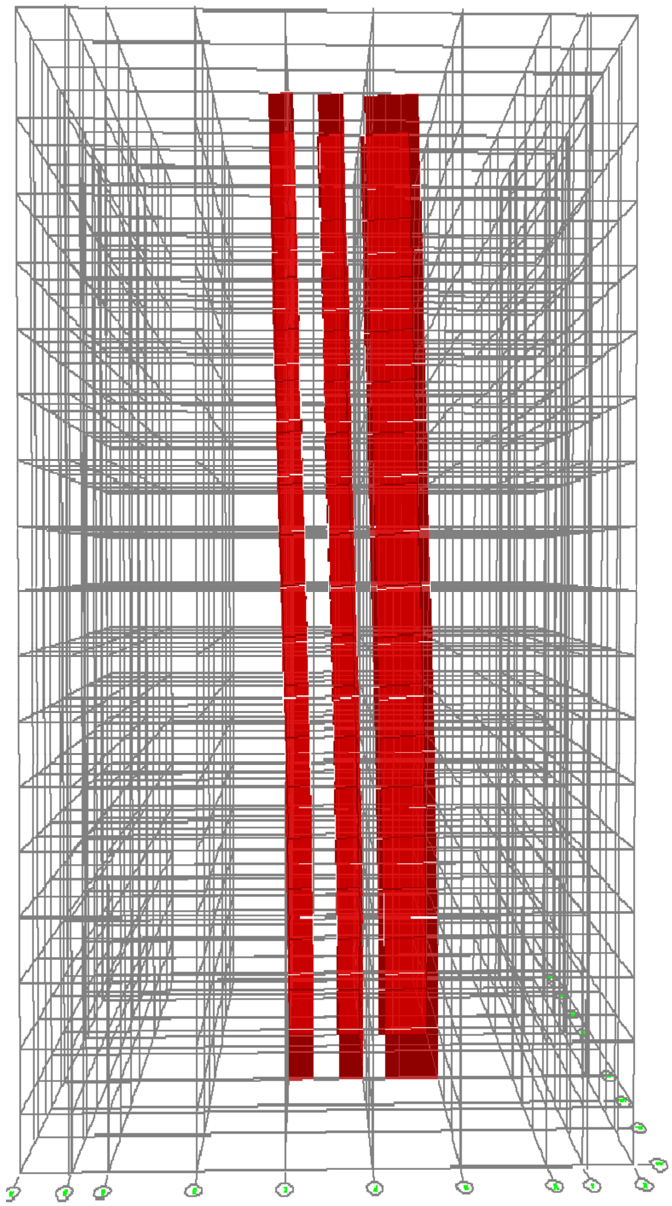
Exponent $k_{N-S} = 1 + (T_{N-S} - 0.5)/(2.5 - 0.5) =$ **1.689**

Level, x	w_x	h_x	$w_x h_x^k$	C_{vx}	F_x	V_x	M_x
	(kips)	(ft)			(kips)	(kips)	(ft-kips)
Roof	3100	192	22,342,508	0.136	118.4		22,760
16	3641	180	23,517,831	0.143	124.7	118.4	22,452
15	3641	168	20,915,508	0.127	110.9	243.1	18,628
14	3641	156	18,439,049	0.112	97.7	353.9	15,242
13	3641	144	16,091,409	0.098	85.3	451.7	12,271
12	3641	132	13,875,861	0.084	73.5	536.9	9,693
11	3641	120	11,796,062	0.072	62.5	610.5	7,485
10	3641	108	9,856,137	0.060	52.2	673.0	5,623
9	3641	96	8,060,797	0.049	42.7	725.3	4,083
8	3641	83	6,415,510	0.039	34.0	768.0	2,839
7	3641	71	4,926,739	0.030	26.1	802.0	1,864
6	3641	59	3,602,318	0.022	19.1	828.1	1,133
5	3641	47	2,452,068	0.015	13.0	847.2	614
4	3641	35	1,488,919	0.009	7.9	860.2	277
3	3641	23	731,238	0.004	3.9	868.1	89
2	3641	11	209,119	0.001	1.1	872.0	12
BASE						873.1	
	Σ = 57719		Σ = 164721074	Σ = 1.000	Σ = 873.1		Σ = 125067

BASED ON A DEAD WEIGHT OF 39,000 kips

Shear Wall deflection under Seismic Y loading





Shear Wall deflection under Seismic X loading

Shear Forces Wall A (kips)								
	Wind X	Wind Y	Case 2X	Case 2Y	Case 3	Case 4	Seismic X	Seismic Y
ROOF	5.62	-1	4.22	-0.75	3.47	2.61	12.47	1.95
PENTHOUSE LEVEL	10.97	0.21	8.23	0.16	8.38	6.29	31.85	3.49
LEVEL 16	15.31	-2.49	11.48	-1.87	9.61	7.22	45.41	-7.06
LEVEL 15	18.06	-4.93	13.55	-3.7	9.85	7.39	54.47	-16.25
LEVEL 14	20.39	-6.69	15.29	-5.02	10.28	7.71	61.42	-23.17
LEVEL 13	22.62	-8.17	16.97	-6.13	10.84	8.13	67.26	-28.55
LEVEL 12	24.9	-10.13	18.68	-7.6	11.08	8.32	72.41	-34.31
LEVEL 11	27.09	-12.36	20.32	-9.27	11.05	8.29	76.6	-40.66
LEVEL 10	29.04	-14.44	21.78	-10.83	10.95	8.22	79.46	-45.96
LEVEL 9	30.59	-16.48	22.95	-12.36	10.58	7.95	80.71	-50.61
LEVEL 8	30.88	-13.93	23.16	-10.45	12.71	9.54	77.77	-41.7
LEVEL 7	30.74	-14.95	23.06	-11.21	11.84	8.89	74.02	-42.3
LEVEL 6	32.32	-20.82	24.24	-15.62	8.62	6.47	75.11	-56.95
LEVEL 5	30.31	-22.95	22.74	-17.21	5.52	4.15	66.37	-60.22
LEVEL 4	29.98	-24.86	22.48	-18.64	3.84	2.88	61.98	-62.65
LEVEL 3	32.34	-26.05	24.26	-19.53	4.72	3.55	63.51	-63.23
LEVEL 2	52.28	-13.71	39.21	-10.28	28.93	21.72	99.95	-38.85

Shear Forces Wall B (kips)								
	Wind X	Wind Y	Case 2X	Case 2Y	Case 3	Case 4	Seismic X	Seismic Y
ROOF	N/A	23.66	N/A	17.75	17.47	13.11	N/A	7.82
PENTHOUSE LEVEL	N/A	48.67	N/A	36.51	36.2	27.17	N/A	91.33
LEVEL 16	N/A	79.26	N/A	59.45	59.05	44.32	N/A	206.33
LEVEL 15	N/A	104.43	N/A	78.32	77.81	58.41	N/A	303.04
LEVEL 14	N/A	127.52	N/A	95.64	95.16	71.43	N/A	386.99
LEVEL 13	N/A	147.25	N/A	110.44	110.27	82.77	N/A	455
LEVEL 12	N/A	165.31	N/A	123.98	124.23	93.26	N/A	511.53
LEVEL 11	N/A	186.97	N/A	140.23	140.42	105.41	N/A	572.28
LEVEL 10	N/A	207.9	N/A	155.92	156.1	117.18	N/A	624.7
LEVEL 9	N/A	228.46	N/A	171.35	171.5	128.74	N/A	670.33
LEVEL 8	N/A	249	N/A	186.75	186.88	140.29	N/A	710.49
LEVEL 7	N/A	264.53	N/A	198.39	198.52	149.03	N/A	730.74
LEVEL 6	N/A	285.29	N/A	213.97	214.11	160.72	N/A	762.79
LEVEL 5	N/A	302.18	N/A	226.64	226.81	170.26	N/A	779.38
LEVEL 4	N/A	320.37	N/A	240.27	241.2	181.06	N/A	796.33
LEVEL 3	N/A	335.79	N/A	251.84	252.72	189.71	N/A	802.13
LEVEL 2	N/A	370.6	N/A	277.95	278.14	208.79	N/A	860.3

Shear Forces Wall C (kips)								
	Wind X	Wind Y	Case 2X	Case 2Y	Case 3	Case 4	Seismic X	Seismic Y
ROOF	5.52	0.98	4.14	0.74	4.87	3.66	12.17	-1.99
PENTHOUSE LEVEL	10.86	-0.24	8.14	-0.18	7.96	5.98	31.57	-3.59
LEVEL 16	15.17	2.46	11.38	1.85	13.23	9.93	45.02	6.97
LEVEL 15	17.85	4.9	13.39	3.67	17.06	12.81	53.86	16.15
LEVEL 14	20.17	6.66	15.13	5	20.13	15.11	60.76	23.09
LEVEL 13	22.57	8.15	16.93	6.11	23.04	17.29	67.03	28.47
LEVEL 12	24.99	10.1	18.75	7.58	26.32	19.76	72.56	34.24
LEVEL 11	27.13	12.34	20.35	9.26	29.61	22.23	76.6	40.59
LEVEL 10	29.08	14.43	21.81	10.82	32.63	24.5	79.45	45.91
LEVEL 9	30.63	16.47	22.98	12.35	35.33	26.52	80.69	50.56
LEVEL 8	30.93	13.93	23.2	10.44	33.64	25.25	77.76	41.67
LEVEL 7	30.79	14.95	23.09	11.21	34.3	25.75	74.02	42.27
LEVEL 6	32.36	20.82	24.27	15.61	39.88	29.94	75.06	56.93
LEVEL 5	30.26	22.94	22.7	17.21	39.9	29.95	66.11	60.18
LEVEL 4	30.31	24.86	22.74	18.64	41.38	31.06	62.65	62.69
LEVEL 3	32.61	26.04	24.46	19.53	43.99	33.02	63.88	63.23
LEVEL 2	52.25	13.73	39.19	10.29	49.48	37.14	99.36	38.88

Shear Forces Wall D (kips)								
	Wind X	Wind Y	Case 2X	Case 2Y	Case 3	Case 4	Seismic X	Seismic Y
ROOF	3.47	-1.06	2.6	-0.79	1.81	1.36	6.45	1.87
PENTHOUSE LEVEL	4.78	-2.24	3.59	-1.68	1.91	1.43	14.66	-3.46
LEVEL 16	8.75	-4.39	6.56	-3.29	3.27	2.45	27.19	-10.07
LEVEL 15	11.07	-6.21	8.31	-4.66	3.65	2.74	35.07	-16.66
LEVEL 14	13.28	-7.98	9.96	-5.98	3.98	2.98	41.68	-22.71
LEVEL 13	15.52	-10.24	11.64	-7.68	3.96	2.97	47.63	-29.5
LEVEL 12	17.72	-12.52	13.29	-9.39	3.91	2.93	52.79	-35.99
LEVEL 11	19.75	-14.18	14.81	-10.63	4.18	3.14	56.76	-40.13
LEVEL 10	21.69	-15.98	16.27	-11.98	4.28	3.21	59.88	-44.23
LEVEL 9	23.38	-17.64	17.54	-13.23	4.3	3.23	61.82	-47.53
LEVEL 8	24.56	-14.35	18.42	-10.76	7.66	5.75	61.59	-36.56
LEVEL 7	24.98	-15.09	18.74	-11.31	7.42	5.57	59.6	-37.03
LEVEL 6	26.68	-20.59	20.01	-15.44	4.57	3.43	61.1	-50.02
LEVEL 5	25.39	-22.24	19.04	-16.68	2.36	1.77	54.35	-52.2
LEVEL 4	26.57	-23.6	19.92	-17.7	2.22	1.67	53.75	-53.25
LEVEL 3	30.37	-24.44	22.78	-18.33	4.45	3.34	58.6	-53.42
LEVEL 2	51.28	-11.26	38.46	-8.45	30.02	22.53	97.15	-18.02

Shear Forces Wall E (kips)								
	Wind X	Wind Y	Case 2X	Case 2Y	Case 3	Case 4	Seismic X	Seismic Y
ROOF	N/A	11.35	N/A	8.52	8.73	6.55	N/A	-21.12
PENTHOUSE LEVEL	N/A	30.61	N/A	22.96	23.08	17.32	N/A	49.41
LEVEL 16	N/A	58.6	N/A	43.95	44.12	33.12	N/A	149.99
LEVEL 15	N/A	80.79	N/A	60.6	60.98	45.78	N/A	232.99
LEVEL 14	N/A	102.76	N/A	77.07	77.46	58.15	N/A	308.92
LEVEL 13	N/A	127.74	N/A	95.81	95.83	71.94	N/A	385.99
LEVEL 12	N/A	152.36	N/A	114.27	114.12	85.66	N/A	456.07
LEVEL 11	N/A	174.85	N/A	131.13	130.98	98.33	N/A	513.83
LEVEL 10	N/A	196.82	N/A	147.61	147.49	110.71	N/A	564.27
LEVEL 9	N/A	218.63	N/A	163.97	163.87	123.01	N/A	608.66
LEVEL 8	N/A	240.27	N/A	180.2	180.12	135.21	N/A	646.85
LEVEL 7	N/A	258.02	N/A	193.51	193.44	145.21	N/A	671.33
LEVEL 6	N/A	280.05	N/A	210.04	209.96	157.61	N/A	701.92
LEVEL 5	N/A	298.4	N/A	223.8	223.69	167.91	N/A	718.65
LEVEL 4	N/A	318.47	N/A	238.85	238.01	178.67	N/A	736.69
LEVEL 3	N/A	336.04	N/A	252.03	251.24	188.6	N/A	745.81
LEVEL 2	N/A	365.93	N/A	274.45	274.33	205.93	N/A	786.77

Shear Forces Wall F (kips)								
	Wind X	Wind Y	Case 2X	Case 2Y	Case 3	Case 4	Seismic X	Seismic Y
ROOF	3.55	1.04	2.66	0.78	3.44	2.59	6.69	-1.91
PENTHOUSE LEVEL	4.85	2.21	3.64	1.66	5.29	3.97	14.81	3.37
LEVEL 16	8.83	4.37	6.62	3.27	9.9	7.43	27.43	10
LEVEL 15	11.25	6.19	8.43	4.64	13.07	9.81	35.57	16.58
LEVEL 14	13.47	7.96	10.1	5.97	16.07	12.06	42.26	22.64
LEVEL 13	15.56	10.22	11.67	7.66	19.33	14.51	47.82	29.44
LEVEL 12	17.64	12.5	13.23	9.38	22.6	16.97	52.65	35.93
LEVEL 11	19.72	14.16	14.79	10.62	25.41	19.08	56.8	40.08
LEVEL 10	21.66	15.97	16.24	11.97	28.22	21.18	59.92	44.19
LEVEL 9	23.35	17.64	17.52	13.23	30.74	23.08	61.87	47.49
LEVEL 8	24.53	14.34	18.4	10.76	29.15	21.88	61.64	36.54
LEVEL 7	24.95	15.08	18.71	11.31	30.02	22.54	59.64	37
LEVEL 6	26.66	20.59	19.99	15.44	35.44	26.6	61.18	50.01
LEVEL 5	25.46	22.24	19.1	16.68	35.78	26.86	54.65	52.17
LEVEL 4	26.25	23.63	19.69	17.72	37.41	28.08	53.13	53.36
LEVEL 3	30.13	24.47	22.59	18.35	40.94	30.74	58.28	53.51
LEVEL 2	51.33	11.29	38.5	8.47	46.96	35.25	97.77	18.08

Shear Forces Wall G (kips)								
	Wind X	Wind Y	Case 2X	Case 2Y	Case 3	Case 4	Seismic X	Seismic Y
ROOF	-3.2	6.38	-2.4	4.78	2.38	1.79	-20.55	17.76
PENTHOUSE LEVEL	-4.84	11.64	-3.63	8.73	5.1	3.83	-8.99	33.42
LEVEL 16	6.11	12.82	4.58	9.62	14.2	10.66	30.84	34.96
LEVEL 15	16.16	12.71	12.12	9.54	21.66	16.26	65.47	34.13
LEVEL 14	26.37	12.42	19.78	9.31	29.09	21.84	96.86	32.99
LEVEL 13	36.38	13.22	27.29	9.92	37.2	27.93	124.23	34.81
LEVEL 12	46.57	13.88	34.93	10.41	45.33	34.03	148.78	36.58
LEVEL 11	57.03	12.9	42.77	9.67	52.45	39.37	170.91	33.46
LEVEL 10	67.59	12.2	50.69	9.15	59.84	44.92	190.4	31.21
LEVEL 9	78.66	11.63	59	8.72	67.72	50.84	208.76	29.25
LEVEL 8	92.09	11.44	69.07	8.58	77.65	58.29	231.13	28.07
LEVEL 7	102.57	10.69	76.93	8.02	84.94	63.76	243.03	26.32
LEVEL 6	114.85	8.72	86.14	6.54	92.68	69.57	257.03	20.08
LEVEL 5	131.53	7.85	98.65	5.88	104.53	78.47	280.95	16.85
LEVEL 4	143.79	6.03	107.84	4.52	112.36	84.35	292.87	10.76
LEVEL 3	147.75	3.31	110.81	2.48	113.29	85.05	286.05	1.32
LEVEL 2	140.97	-0.5	105.73	-0.38	105.35	79.08	266.03	-17.87

Shear Forces Wall H (kips)								
	Wind X	Wind Y	Case 2X	Case 2Y	Case 3	Case 4	Seismic X	Seismic Y
ROOF	-3.27	-6.4	-2.45	-4.8	-7.25	-5.44	-20.74	-17.85
PENTHOUSE LEVEL	-4.84	-11.7	-3.63	-8.78	-12.4	-9.31	-8.85	-33.62
LEVEL 16	6.05	-12.89	4.54	-9.66	-5.13	-3.85	30.74	-35.16
LEVEL 15	15.87	-12.78	11.9	-9.59	2.32	1.74	64.72	-34.34
LEVEL 14	26.01	-12.47	19.51	-9.36	10.15	7.62	95.87	-33.17
LEVEL 13	36.38	-13.28	27.29	-9.96	17.33	13.01	124.18	-34.99
LEVEL 12	46.86	-13.93	35.15	-10.44	24.7	18.54	149.5	-36.74
LEVEL 11	57.15	-12.94	42.86	-9.71	33.16	24.89	171.15	-33.6
LEVEL 10	67.66	-12.24	50.75	-9.18	41.57	31.2	190.52	-31.34
LEVEL 9	78.71	-11.66	59.04	-8.75	50.29	37.75	208.8	-29.37
LEVEL 8	92.12	-11.47	69.09	-8.61	60.48	45.4	231.08	-28.17
LEVEL 7	102.57	-10.72	76.92	-8.04	68.88	51.71	242.93	-26.42
LEVEL 6	114.79	-8.74	86.09	-6.56	79.54	59.7	256.77	-20.16
LEVEL 5	131.28	-7.88	98.46	-5.91	92.55	69.47	280.21	-16.97
LEVEL 4	144.64	-6.02	108.48	-4.51	103.97	78.04	294.68	-10.59
LEVEL 3	148.57	-3.32	111.43	-2.49	108.94	81.78	287.31	-1.23
LEVEL 2	140.97	0.45	105.73	0.34	106.06	79.62	264.83	17.73

Appendix E: Construction Management

MATERIAL QUANTITIES

Column Concrete Required (6000psi)								
Column Size	h (in)	d (in)	Area (ft^2)	Cubic Feet	Weight (lb)	Qty	Total Volume (ft^3)	
14 x 14	14	14	1.36	15.65	2348	24	376	
16 x 16	16	16	1.78	21.33	3200	48	1024	
18 x 18	18	18	2.25	27.00	4050	36	972	
20 x 20	20	20	2.78	33.33	5000	90	3000	
20 x 24	20	24	3.33	40.00	6000	24	960	
24 x 24	24	24	4.00	48.00	7200	84	4032	
28 x 28	28	28	5.44	65.33	9800	24	1568	
32 x 32	32	32	7.11	85.33	12800	12	1024	Vol. of Conc (CY)
							12956	480

Column Concrete Required (5000psi)								
Column Size	h (in)	d (in)	Area (ft^2)	Cubic Feet	Weight (lb)	Qty	Total Volume (ft^3)	
14 x 14	14	14	1.36	15.65	2348	64	1002	
18 x 18	18	18	2.25	27.00	4050	104	2808	
20 x 20	20	20	2.78	33.33	5000	102	3400	
24 x 24	24	24	4.00	48.00	7200	14	672	Vol. of Conc (CY)
							7882	292

Shear Wall Concrete Required (5000psi)								
Shear Wall	l (ft)	t (in)	Area (ft^2)	Cubic Feet	Weight (lb)	Qty	Total Volume (ft^3)	
1	9.33	12	9.33	111.96	16794	68	7613	
2	28	12	28.00	336.00	50400	34	11424	
3	20	12	20.00	240.00	36000	34	8160	Vol. of Conc (CY)
							19037	705

Slab Concrete Required (5000psi)								
Slab	l (ft)	t (in)	Area (ft^2)	Cubic Feet	Weight (lb)	Qty	Total Volume (ft^3)	
6" slab	-	6	21500	10750	1612500	1	10750	
							X 16 Floors	Vol. of Conc (CY)
							172000	6370

Column Reinforcing Steel								
Bar Size	**l (ft)**	**t (in)**	**Area (in^2)**	**Cubic Feet**	**Weight (lb)**	**Qty**	**Total Weight (lbs)**	
6	12	-	0.44	0.04	15.4	816	12566	
8	12	-	0.79	0.07	27.65	208	5751	
9	12	-	1.00	0.08	35	304	10640	
10	12	-	1.27	0.11	44.45	2536	112725	
11	12	-	1.56	0.13	54.6	778	42479	**Tons of Steel**
							184162	92

Beam Concrete Required (5000psi)								
Beam Size	**d (in)**	**w (in)**	**length (ft)**	**Cubic Feet**	**Weight (lb)**	**Qty**	**Total Volume (ft^3)**	
14 x 16	14	16	56.00	87.11	13067	2	174	
14 x 16	14	16	84.00	130.67	19600	2	261	
14 x 20	14	20	116.00	225.56	33833	10	2256	
14 x 20	14	20	140.00	272.22	40833	2	544	
14 x 22	14	22	196.00	419.22	62883	2	838	
							X 16 Floors	**Vol. of Conc (CY)**
							65184	2414
add 6" to depth of beam to get actual beam depth. Takes into account 6" slab already calculated above								

Beam Concrete Required (5000psi) for Post Tensioned Slab System								
Beam Size	**d (in)**	**w (in)**	**length (ft)**	**Cubic Feet**	**Weight (lb)**	**Qty**	**Total Volume (ft^3)**	
12 x 16	12	16	56.00	74.67	11200	2	149	
12 x 16	12	16	84.00	112.00	16800	2	224	
12 x 26	12	30	116.00	290.00	43500	6	1740	
12 x 20	12	20	140.00	233.33	35000	2	467	
12 x 22	12	22	196.00	359.33	53900	2	719	
							X 16 Floors	**Vol. of Conc (CY)**
							52779	1955
add 6" to depth of beam to get actually beam depth. Takes into account 6" slab already calculated above								

Slab Concrete Required for Steel Building (4000psi)								
Slab	**l (ft)**	**t (in)**	**Area (ft^2)**	**Cubic Feet**	**Weight (lb)**	**Qty**	**Total Volume (ft^3)**	
6" slab	-	3.25	21500	5823	576468.75	1	5823	
							X 16 Floors	**Vol. of Conc (CY)**
							93167	3451
The total volume of concrete was multiplie by 2/3 to account for the flutes of the metal decking								

Cost Esitmate for Concrete Structure- Post Tensioned Beams (Crane Placed)

Line Number	Item	QTY.	Unit	Crew	Daily Output	Labor Hours	Bare Material	Bare Labor	Bare Equipment	Bare Total	Total with O&P	Cost
03 310 200 0400	5000 psi Concrete											
	from Beams	2414	C.Y.				$90.00	-	-	-	$99.00	$238,986
	from Slab	6370	C.Y.				$90.00	-	-	-	$99.00	$630,630
	from Columns	292	C.Y.				$90.00	-	-	-	$99.00	$28,908
	from Shear Walls	990	C.Y.				$90.00	-	-	-	$99.00	$98,010
											TOTAL	$996,534
03 310 220 0411	6000 psi Concrete											
	from Columns	480	C.Y.				$103.00				$113.00	$54,240
											TOTAL	$54,240
03 310 700	Concrete Placing											
0650	Columns, 18", w/ crane	466	C.Y.	C7	55	1309	-	$38.00	$17.45	$55.45	$77.00	$35,882
0850	Columns, 24", w/ crane	306	C.Y.	C7	70	1029	-	$29.50	$13.70	$43.20	$60.50	$18,513
5200	12" walls, w/ crane	990	C.Y.	C7	90	0.8	-	$23.00	$10.65	$33.65	$47.50	$47,025
0250	Beams, w/ crane	2414	C.Y.	C7	65	1108	-	$32.00	$14.75	$46.75	$65.50	$158,117
1550	Slabs, 6", w/ crane	6370	C.Y.	C7	110	0.655	-	$18.90	$8.75	$27.65	$38.50	$245,245
3500	>5 stories, add per floor	8858	C.Y.	C7	2100	0.034	-	$0.99	$0.46	$1.45	$2.02	$17,893
												x 11stories
												$196,825
											BASE	$701,607
									Total w/Adjustment Factor, x 1.1			$771,767
03 110 410	Formwork											
6150	16"x16" column, 4 use	18000	SFCA	C1	235	0.136	$0.70	$4.41	-	$5.11	$7.60	$136,800
6500	24"x24" column, 4 use	29600	SFCA	C1	238	0.134	$0.80	$4.35	-	$5.15	$7.70	$227,920
7150	36"x36" column, 4 use	1500	SFCA	C1	250	0.128	$0.72	$4.14	-	$4.86	$7.25	$10,875
03 110 420 2150	Beam and Slab, 4 use	345136	SF	C2	545	0.088	-	$1.44	$2.94	$4.38	$6.15	$2,122,586
2440	Shear Walls, 4 use	51970	SFCA	C2	395	0.122	$1.40	$4.05	-	$5.45	$7.85	$407,965
												$2,906,146
												div by 4 uses
											BASE	$726,536
									Total w/Adjustment Factor, x 1.295			$940,865
03 210 600	Steel Reinforcement											
0100	Beams/Girders, #3-#7	83.7	TONS	4Rdmn	1.6	20	$800.00	$760.00	-	$1,560.00	$2,125.00	$177,863
0150	Beams/Girders, #8-#18	83.7	TONS	4Rdmn	2.7	11.85	$800.00	$450.00	-	$1,250.00	$1,625.00	$136,013
0250	Columns, #8-#18	92	TONS	4Rdmn	2.3	13.9	$800.00	$530.00	-	$1,330.00	$1,750.00	$161,000
0400	Elevated Slabs, #4-#7	335	TONS	4Rdmn	2.9	11.03	$850.00	$420.00	-	$1,270.00	$1,625.00	$544,375
											BASE	$1,019,250
										10% splice allowance		$1,121,175
									Total w/Adjustment Factor, x 1.2			$1,451,922
03 230 600	Stressing Tendons											
1450	100' span, 300 kip	14070	lbs	C4	1650	0.019	$0.46	$0.75	$0.02	$1.23	$1.77	$24,904
												x16 stories
											TOTAL	$398,462
03 350 300	Floor Finishing											
0250	floor, monoltic, machine	21500	SF	1 Cemfi	550	0.015	-	$0.48	-	$0.48	$0.70	$15,050
												x16 stories
											TOTAL	$240,800
03 150 600	Shoring											
1500	Reshoring	21500	SF Flr	2 Carp	1400	0.011	$0.38	$0.39	-	$0.77	$1.02	$21,930
												x16 stories
												$350,880
3060	rent, steel adjust. Per mo	21500	SF Flr	-	-	-	$1.50	-	-	$1.50	$1.65	$35,475
												x 7mos
											BASE	$599,205
									Total w/Adjustment Factor, x 1.295			$775,970
								TOTAL STRUCTURE ESTIMATE:				$5,630,561
								ESTIMATE IN 2001 DOLLARS:				$5,004,943
								COST PER SQUARE FOOT:				$14.51

Cost Esitmate for Concrete Structure- Post Tensioned Slab (Crane Placed)

Line Number	Item	QTY.	Unit	Crew	Daily Output	Labor Hours	Bare Material	Bare Labor	Bare Equipment	Bare Total	Total with O&P	Cost
03 310 200 0400	5000 psi Concrete											
	from Beams	1955	C.Y.	-	-	-	$90.00	-	-	-	$99.00	$193,545
	from Slab	6370	C.Y.	-	-	-	$90.00	-	-	-	$99.00	$630,630
	from Columns	292	C.Y.	-	-	-	$90.00	-	-	-	$99.00	$28,908
	from Shear Walls	990	C.Y.	-	-	-	$90.00	-	-	-	$99.00	$98,010
											TOTAL	$951,093
03 310 220 0411	6000 psi Concrete											
	from Columns	480	C.Y.	-	-	-	$103.00	-	-	-	$113.00	$54,240
											TOTAL	$54,240
03 310 700	Concrete Placing											
0600	Columns, 18", w/crane	466	C.Y.	C7	55	1309	-	$38.00	$17.45	$55.45	$77.00	$35,882
0800	Columns, 24", w/crane	306	C.Y.	C7	70	1029	-	$29.50	$13.70	$43.20	$60.50	$18,513
5100	12" walls, w/crane	990	C.Y.	C7	90	0.8	-	$23.00	$10.65	$33.65	$47.50	$47,025
0200	Beams, w/crane	1955	C.Y.	C7	65	1108	-	$32.00	$14.75	$46.75	$65.50	$128,053
1500	Slabs, 6", w/crane	6370	C.Y.	C7	110	0.655	-	$18.90	$8.75	$27.65	$38.50	$245,245
3500	>5 stories, add per floor	7067	C.Y.	C7	2100	0.034	-	$0.99	$0.46	$1.45	$2.02	$14,275
												x 11stories
												$157,029
											BASE	$631,746
									Total w/Adjustment Factor, x 1.1			$694,921
03 110 410	Formwork											
6150	16"x16" column, 4 use	18000	SFCA	C1	235	0.136	$0.70	$4.41	-	$5.11	$7.60	$136,800
6500	24"x24" column, 4 use	29600	SFCA	C1	238	0.134	$0.80	$4.35	-	$5.15	$7.70	$227,920
7150	36"x36" column, 4 use	1500	SFCA	C1	250	0.128	$0.72	$4.14	-	$4.86	$7.25	$10,875
03 110 420 2150	Beam and Slab, 4 use	345120	SF	C2	545	0.088	-	$1.44	$2.94	$4.38	$6.15	$2,122,488
2440	Shear Walls, 4 use	51970	SFCA	C2	395	0.122	$1.40	$4.05	-	$5.45	$7.85	$407,965
												$2,906,048
												div by 4 uses
											BASE	$726,512
									Total w/Adjustment Factor, x 1.295			$940,833
03 210 600	Steel Reinforcement											
0100	Beams/Girders, #3-#7	79.7	TONS	4Rdmn	1.6	20	$800.00	$760.00	-	$1,560.00	$2,125.00	$169,363
0150	Beams/Girders, #8-#18	79.7	TONS	4Rdmn	2.7	11.85	$800.00	$450.00	-	$1,250.00	$1,625.00	$129,513
0250	Columns, #8-#18	92	TONS	4Rdmn	2.3	13.9	$800.00	$530.00	-	$1,330.00	$1,750.00	$161,000
0400	Elevated Slabs, #4-#7	318.8	TONS	4Rdmn	2.9	11.03	$850.00	$420.00	-	$1,270.00	$1,625.00	$518,050
											BASE	$977,925
										10% splice allowance		$1,075,718
									Total w/Adjustment Factor, x 1.2			$1,393,054
03 230 600	Stressing Tendons											
1450	100' span, 300 kip	16446	lbs	C4	1650	0.019	$0.46	$0.75	$0.02	$1.23	$1.77	$29,109
												x16 stories
											TOTAL	$465,751
03 350 300	Floor Finishing											
0250	floor, monoltic, machine	21500	SF	1 Cemfi	550	0.015	-	$0.48	-	$0.48	$0.70	$15,050
												x16 stories
											TOTAL	$240,800
03 150 600	Shoring											
1500	Reshoring	21500	SF Flr	2 Carp	1400	0.011	$0.38	$0.39	-	$0.77	$1.02	$21,930
												x16 stories
												$350,880
3060	Rent, steel adjust. per mo	21500	SF Flr	-	-	-	$1.50	-	-	$1.50	$1.65	$35,475
												x 7mos
											BASE	$599,205
									Total w/Adjustment Factor, x 1.295			$775,970
								TOTAL STRUCTURE ESTIMATE:				$5,516,662
								ESTIMATE IN 2001 DOLLARS:				$4,903,700
								COST PER SQUARE FOOT:				$14.21

Cost Esitmate for Concrete Structure- Post Tensioned Beams (Pumped Concrete)											
Line Number	**Item**	**QTY.**	**Unit**	**Crew**	**Daily Output**	**Labor Hours**	**Bare Material**	**Bare Labor**	**Bare Equipment**	**Bare Total**	**Total with O&P**	**Cost**
03 310 200 0400	**5000 psi Concrete**											
	from Beams	2414	C.Y.				$90.00	-	-	-	$99.00	$238,986
	from Slab	6370	C.Y.				$90.00	-	-	-	$99.00	$630,630
	from Columns	292	C.Y.				$90.00	-	-	-	$99.00	$28,908
	from Shear Walls	990	C.Y.				$90.00	-	-	-	$99.00	$98,010
											TOTAL	**$996,534**
03 310 220 0411	**6000 psi Concrete**											
	from Columns	480	C.Y.				$103.00				$113.00	$54,240
											TOTAL	**$54,240**
03 310 700	**Concrete Placing**											
0600	Columns, 18", pumped	466	C.Y.	C20	90	0.711	-	$20.50	$8.35	$28.85	$40.50	$18,873
0800	Columns, 24", pumped	306	C.Y.	C20	92	0.696	-	$19.95	$8.15	$28.10	$39.50	$12,087
5100	12" walls, pumped	990	C.Y.	C20	110	0.582	-	$16.70	$6.85	$23.55	$33.00	$32,670
0200	Beams, pumped	2414	C.Y.	C20	90	0.711	-	$20.50	$8.35	$28.85	$40.50	$97,767
1500	Slabs, 6", pumped	6370	C.Y.	C20	160	0.4	-	$11.50	$4.70	$16.20	$23.00	$146,510
3500	>5 stories, add per floor	8858	C.Y.	C20	2100	0.03	-	$0.88	$0.36	$1.24	$1.74	$15,413
												x 11stories
												$169,542
											BASE	**$477,449**
									Total w/Adjustment Factor, x 1.1			**$525,194**
03 110 410	**Formwork**											
6150	16"x16" column, 4 use	18000	SFCA	C1	235	0.136	$0.70	$4.41	-	$5.11	$7.60	$136,800
6500	24"x24" column, 4 use	29600	SFCA	C1	238	0.134	$0.80	$4.35	-	$5.15	$7.70	$227,920
7150	36"x36" column, 4 use	1500	SFCA	C1	250	0.128	$0.72	$4.14	-	$4.86	$7.25	$10,875
03 110 420 2150	Beam and Slab, 4 use	345136	SF	C2	545	0.088	-	$1.44	$2.94	$4.38	$6.15	$2,122,586
2440	Shear Walls, 4 use	51970	SFCA	C2	395	0.122	$1.40	$4.05	-	$5.45	$7.85	$407,965
												$2,906,146
												div by 4 uses
											BASE	**$726,536**
									Total w/Adjustment Factor, x 1.295			**$940,865**
03 210 600	**Steel Reinforcement**											
0100	Beams/Girders, #3-#7	83.7	TONS	4Rdmn	1.6	20	$800.00	$760.00	-	$1,560.00	$2,125.00	$177,863
0150	Beams/Girders, #8-#18	83.7	TONS	4Rdmn	2.7	11.85	$800.00	$450.00	-	$1,250.00	$1,625.00	$136,013
0250	Columns, #8-#18	92	TONS	4Rdmn	2.3	13.9	$800.00	$530.00	-	$1,330.00	$1,750.00	$161,000
0400	Elevated Slabs, #4-#7	335	TONS	4Rdmn	2.9	11.03	$850.00	$420.00	-	$1,270.00	$1,625.00	$544,375
											BASE	**$1,019,250**
										10% splice allowance		**$1,121,175**
									Total w/Adjustment Factor, x 1.2			**$1,451,922**
03 230 600	**Stressing Tendons**											
1450	100' span, 300 kip	14070	lbs	C4	1650	0.019	$0.46	$0.75	$0.02	$1.23	$1.77	$24,904
												x16 stories
											TOTAL	**$398,462**
03 350 300	**Floor Finishing**											
0250	floor, monoltic, machine	21500	SF	1 Cemfi	550	0.015	-	$0.48	-	$0.48	$0.70	$15,050
												x16 stories
											TOTAL	**$240,800**
03 150 600	**Shoring**											
1500	Reshoring	21500	SF Flr	2 Carp	1400	0.011	$0.38	$0.39	-	$0.77	$1.02	$21,930
												x16 stories
												$350,880
3060	rent, steel adjust. Per mo	21500	SF Flr	-	-	-	$1.50	-	-	$1.50	$1.65	$35,475
												x 6mos
											BASE	**$563,730**
									Total w/Adjustment Factor, x 1.295			**$730,030**
								TOTAL STRUCTURE ESTIMATE:				**$5,338,047**
								ESTIMATE IN 2001 DOLLARS:				**$4,744,931**
								COST PER SQUARE FOOT				**$13.75**

Cost Esitmate for Concrete Structure- Post Tensioned Slab (Pumped Concrete)												
Line Number	**Item**	**QTY.**	**Unit**	**Crew**	**Daily Output**	**Labor Hours**	**Bare Material**	**Bare Labor**	**Bare Equipment**	**Bare Total**	**Total with O&P**	**Cost**
03 310 200 0400	**5000 psi Concrete**											
	from Beams	1955	C.Y.	-	-	-	$90.00	-	-	-	$99.00	$193,545
	from Slab	6370	C.Y.	-	-	-	$90.00	-	-	-	$99.00	$630,630
	from Columns	292	C.Y.	-	-	-	$90.00	-	-	-	$99.00	$28,908
	from Shear Walls	990	C.Y.	-	-	-	$90.00	-	-	-	$99.00	$98,010
											TOTAL	**$951,093**
03 310 220 0411	**6000 psi Concrete**											
	from Columns	480	C.Y.	-	-	-	$103.00	-	-	-	$113.00	$54,240
											TOTAL	**$54,240**
03 310 700	**Concrete Placing**											
0600	Columns, 18", pumped	466	C.Y.	C20	90	0.711	-	$20.50	$8.35	$28.85	$40.50	$18,873
0800	Columns, 24", pumped	306	C.Y.	C20	92	0.696	-	$19.95	$8.15	$28.10	$39.50	$12,087
5100	12" walls, pumped	990	C.Y.	C20	110	0.582	-	$16.70	$6.85	$23.55	$33.00	$32,670
0200	Beams, pumped	1955	C.Y.	C20	90	0.711	-	$20.50	$8.35	$28.85	$40.50	$79,178
1500	Slabs, 6", pumped	6370	C.Y.	C20	160	0.4	-	$11.50	$4.70	$16.20	$23.00	$146,510
3500	>5 stories, add per floor	7067	C.Y.	C20	2100	0.03	-	$0.88	$0.36	$1.24	$1.74	$12,297
												x 11stories
												$135,262
											BASE	**$424,580**
									Total w/Adjustment Factor, x 1.1			**$467,038**
03 110 410	**Formwork**											
6150	16"x16" column, 4 use	18000	SFCA	C1	235	0.136	$0.70	$4.41	-	$5.11	$7.60	$136,800
6500	24"x24" column, 4 use	29600	SFCA	C1	238	0.134	$0.80	$4.35	-	$5.15	$7.70	$227,920
7150	36"x36" column, 4 use	1500	SFCA	C1	250	0.128	$0.72	$4.14	-	$4.86	$7.25	$10,875
03 110 420 2150	Beam and Slab, 4 use	345120	SF	C2	545	0.088	-	$1.44	$2.94	$4.38	$6.15	$2,122,488
2440	Shear Walls, 4 use	51970	SFCA	C2	395	0.122	$1.40	$4.05	-	$5.45	$7.85	$407,965
												$2,906,048
												div by 4 uses
											BASE	**$726,512**
									Total w/Adjustment Factor, x 1.295			**$940,833**
03 210 600	**Steel Reinforcement**											
0100	Beams/Girders, #3-#7	79.7	TONS	4Rdmn	1.6	20	$800.00	$760.00	-	$1,560.00	$2,125.00	$169,363
0150	Beams/Girders, #8-#18	79.7	TONS	4Rdmn	2.7	11.85	$800.00	$450.00	-	$1,250.00	$1,625.00	$129,513
0250	Columns, #8-#18	92	TONS	4Rdmn	2.3	13.9	$800.00	$530.00	-	$1,330.00	$1,750.00	$161,000
0400	Elevated Slabs, #4-#7	318.8	TONS	4Rdmn	2.9	11.03	$850.00	$420.00	-	$1,270.00	$1,625.00	$518,050
											BASE	**$977,925**
										10% splice allowance		**$1,075,718**
									Total w/Adjustment Factor, x 1.2			**$1,393,054**
03 230 600	**Stressing Tendons**											
1450	100' span, 300 kip	16446	lbs	C4	1650	0.019	$0.46	$0.75	$0.02	$1.23	$1.77	$29,109
												x16 stories
											TOTAL	**$465,751**
03 350 300	**Floor Finishing**											
0250	floor, monoltic, machine	21500	SF	1 Cemfi	550	0.015	-	$0.48	-	$0.48	$0.70	$15,050
												x16 stories
											TOTAL	**$240,800**
03 150 600	**Shoring**											
1500	Reshoring	21500	SF Flr	2 Carp	1400	0.011	$0.38	$0.39	-	$0.77	$1.02	$21,930
												x16 stories
												$350,880
3060	Rent, steel adjust. per mo	21500	SF Flr	-	-	-	$1.50	-	-	$1.50	$1.65	$35,475
												x 6mos
											BASE	**$563,730**
									Total w/Adjustment Factor, x 1.295			**$730,030**
								TOTAL STRUCTURE ESTIMATE:				**$5,242,839**
								ESTIMATE IN 2001 DOLLARS:				**$4,660,301**
								COST PER SQUARE FOOT				**$13.51**

CRANE AND BUCKET CONCRETE CONSTRUCTION DURATIONS

Construction Duration/Floor					
Task	**Crew**	**QTY**	**# of crews**	**Output**	**Duration**
Shoring	C1	21000	5	1400	3
Formwork					
Beams/Slabs	C1	21570	8	545	4.95
Columns	C1	3070	3	240	4.26
Shear Walls	C2	2288	3	395	1.93
				Total	**11.14**
Reinforce				**MAX**	5
Beams/Slabs	4 Rdmn	10.5	3	2.2	1.59
Columns	4 Rdmn	5.75	2	2.3	1.25
walls	4 Rdmn	21	5	2.9	1.45
				Total	**4.29**
Placing Conc				**MAX**	2
Beams	C7	151	2	65	1.16
Slabs	C7	398	2	110	2
Shear Walls	C7	44	2	90	0.24
Columns	C7	48	2	63	0.38
				Total	**3.60**
				MAX	2
Post Tension	C4	14070	4	1650	2.13
Reshoring	2 CARP	21000	3	1400	5.00
				Total	**15.48**

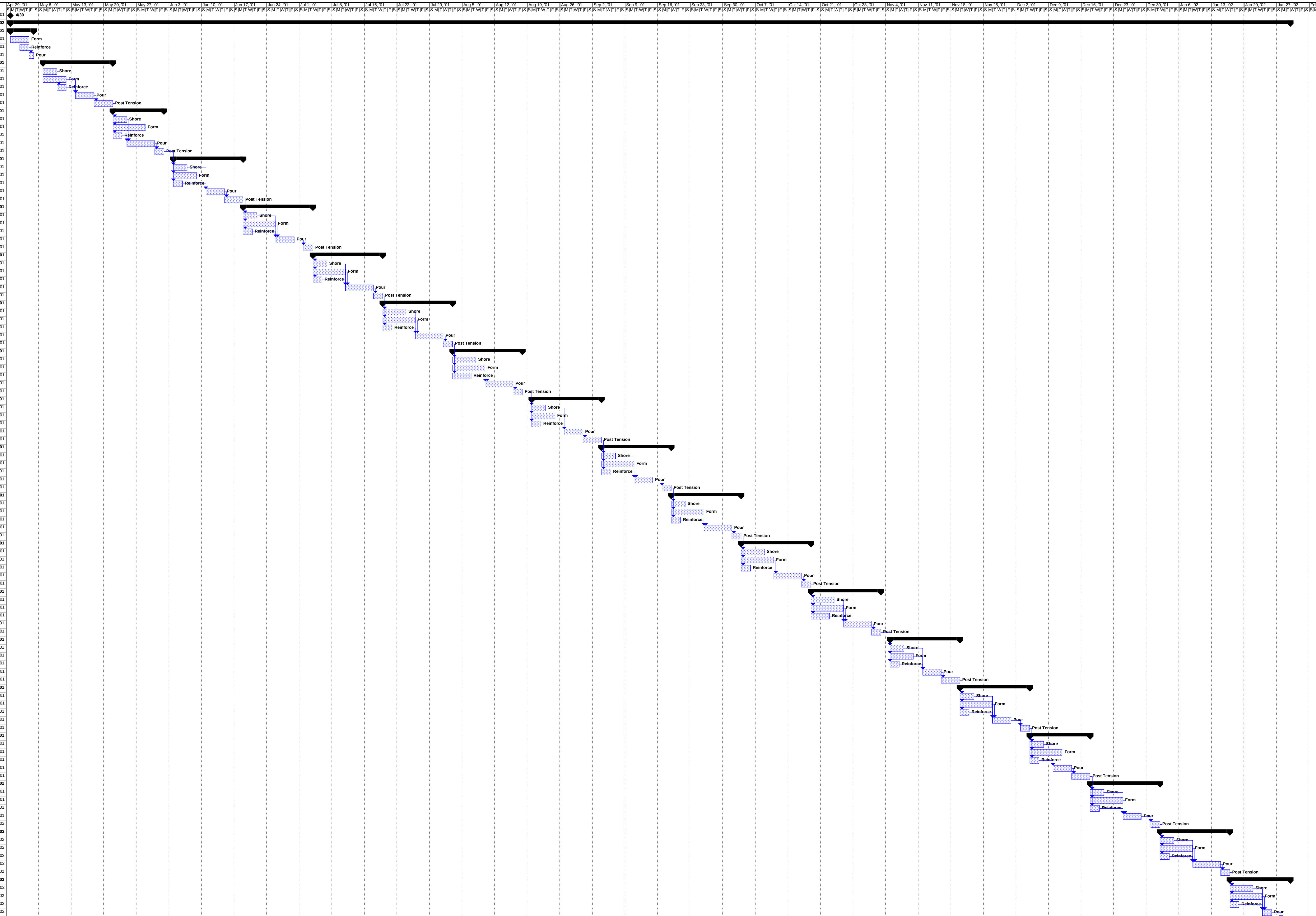
Construction Duration/Floor					
Task	**Crew**	**QTY**	**# of crews**	**Output**	**Duration**
Shoring	C1	21000	5	1400	3
Formwork					
Beams/Slabs	C1	21570	5	545	7.92
Columns	C1	3070	5	240	2.56
Shear Walls	C2	2288	4	395	1.45
				Total	**11.92**
Reinforce				**MAX**	8
Beams/Slabs	4 Rdmn	9.96	3	2.2	1.51
Columns	4 Rdmn	5.75	3	2.3	0.83
Slabs	4 Rdmn	19.9	4	2.9	1.72
				Total	**4.06**
Placing Conc				**MAX**	2
Beams	C7	114	5	65	0.35
Slabs	C7	398	5	110	0.72
Shear Walls	C7	44	5	90	0.10
Columns	C7	48	5	63	0.15
				Total	**1.32**
				MAX	1
Post Tensioning	C4	16100	4	1650	2.44

PUMPED CONCRETE CONSTRUCTION DURATIONS

Construction Duration/Floor System #1					
Task	**Crew**	**QTY**	**# of crews**	**Output**	**Duration**
Shoring	C1	21000	5	1400	3
Formwork					
Beams/Slabs	C1	21570	8	545	4.95
Columns	C1	3070	3	240	4.26
Shear Walls	C2	2288	2	395	2.90
				Total	**12.11**
Reinforce				**MAX**	5
Beams/Slabs	4 Rdmn	10.5	3	2.2	1.59
Columns	4 Rdmn	5.75	2	2.3	1.25
Slabs	4 Rdmn	21	4	2.9	1.81
				Total	**4.65**
Placing Conc				**MAX**	2
Beams	C20	151	3	90	0.56
Slabs	C20	398	3	160	1
Shear Walls	C20	44	2	110	0.20
Columns	C20	48	2	90	0.27
				Total	**1.86**
				MAX	1
Post Tension	C4	14070	5	1650	1.71
Reshoring	2 CARP	21000	5	1400	3.00
				Total	**15.29**

Construction Duration/Floor System #2					
Task	**Crew**	**QTY**	**# of crews**	**Output**	**Duration**
Shoring	C1	21000	5	1400	3
Formwork					
Beams/Slabs	C1	21570	8	545	4.95
Columns	C1	3070	3	240	4.26
Shear Walls	C2	2288	2	395	2.90
				Total	**12.11**
Reinforce				**MAX**	5
Beams/Slabs	4 Rdmn	9.96	3	2.2	1.51
Columns	4 Rdmn	5.75	2	2.3	1.25
Slabs	4 Rdmn	19.9	4	2.9	1.72
				Total	**4.47**
Placing Conc				**MAX**	2
Beams	C20	114	3	90	0.42
Slabs	C20	398	3	160	0.83
Shear Walls	C20	44	2	110	0.20
Columns	C20	48	2	90	0.27
				Total	**1.72**
				MAX	1
Post Tensioning	C4	16100	5	1650	1.95
Reshoring	2 CARP	21000	5	1400	3.00
				Total	**15.44**

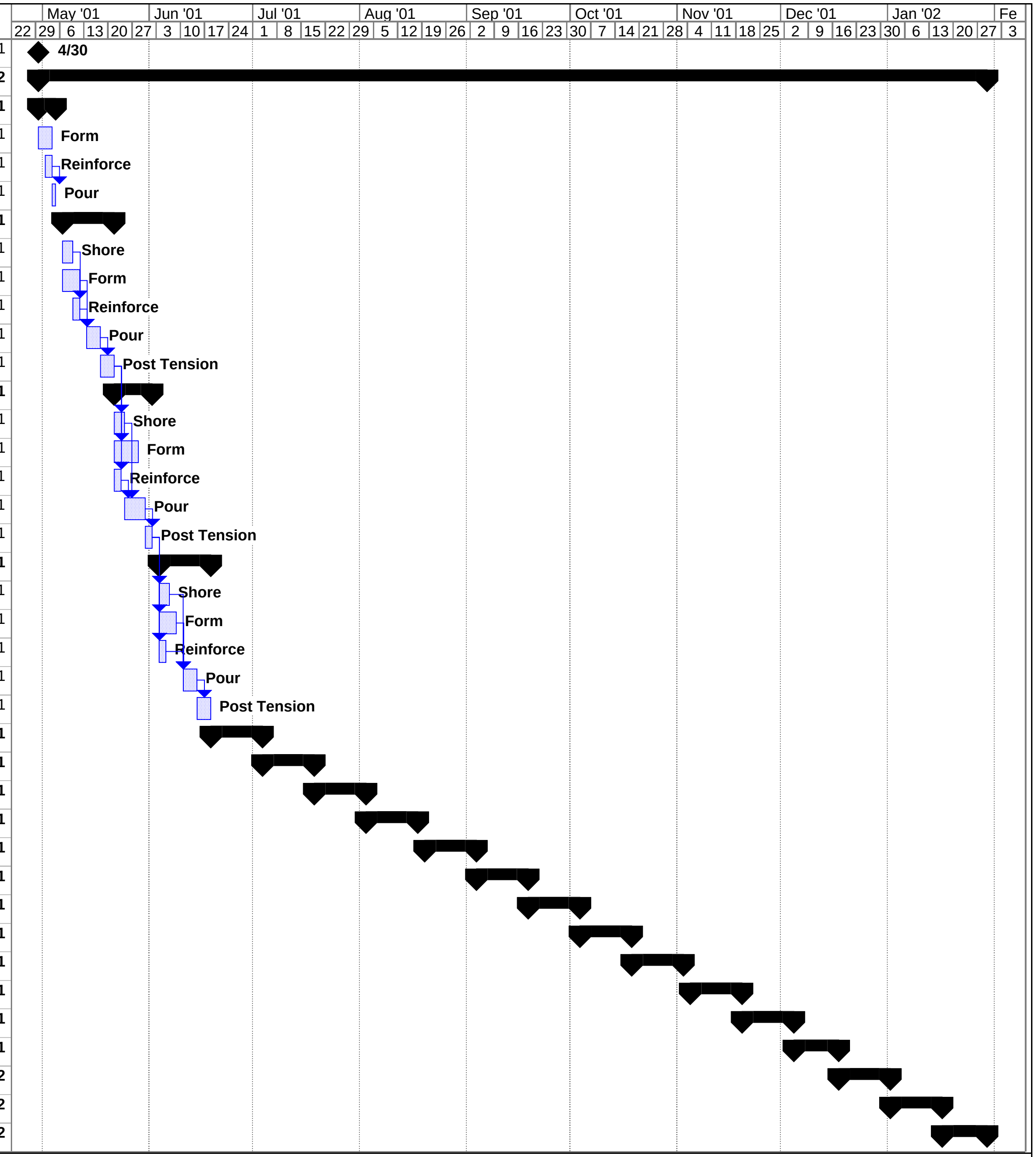
ID	Task Name	Duration	Start	Finish
1	Concrete Superstructure	0 days	Mon 4/30/01	Mon 4/30/01
2		**197 days**	**Mon 4/30/01**	**Tue 1/29/02**
3	**Level 2 Columns**	**5 days**	**Mon 4/30/01**	**Fri 5/4/01**
4	Form	4 days	Mon 4/30/01	Thu 5/3/01
5	Reinforce	2 days	Wed 5/2/01	Thu 5/3/01
6	Pour	1 day	Fri 5/4/01	Fri 5/4/01
7	**Level 2**	**11 days**	**Mon 5/7/01**	**Mon 5/21/01**
8	Shore	3 days	Mon 5/7/01	Wed 5/9/01
9	Form	5 days	Mon 5/7/01	Fri 5/11/01
10	Reinforce	2 days	Thu 5/10/01	Fri 5/11/01
11	Pour	4 days	Mon 5/14/01	Thu 5/17/01
12	Post Tension	2 days	Fri 5/18/01	Mon 5/21/01
13	**Level 3**	**9 days**	**Tue 5/22/01**	**Fri 6/1/01**
14	Shore	3 days	Tue 5/22/01	Thu 5/24/01
15	Form	5 days	Tue 5/22/01	Mon 5/28/01
16	Reinforce	2 days	Tue 5/22/01	Wed 5/23/01
17	Pour	4 days	Fri 5/25/01	Wed 5/30/01
18	Post Tension	2 days	Thu 5/31/01	Fri 6/1/01
19	**Level 4**	**11 days**	**Mon 6/4/01**	**Mon 6/18/01**
20	Shore	3 days	Mon 6/4/01	Wed 6/6/01
21	Form	5 days	Mon 6/4/01	Fri 6/8/01
22	Reinforce	2 days	Mon 6/4/01	Tue 6/5/01
23	Pour	4 days	Mon 6/11/01	Thu 6/14/01
24	Post Tension	2 days	Fri 6/15/01	Mon 6/18/01
25	**Level 5**	**11 days**	**Tue 6/19/01**	**Tue 7/3/01**
26	Shore	3 days	Tue 6/19/01	Thu 6/21/01
27	Form	5 days	Tue 6/19/01	Mon 6/25/01
28	Reinforce	2 days	Tue 6/19/01	Wed 6/20/01
29	Pour	4 days	Tue 6/26/01	Fri 6/29/01
30	Post Tension	2 days	Mon 7/2/01	Tue 7/3/01
31	**Level 6**	**11 days**	**Wed 7/4/01**	**Wed 7/18/01**
32	Shore	3 days	Wed 7/4/01	Fri 7/6/01
33	Form	5 days	Wed 7/4/01	Tue 7/10/01
34	Reinforce	2 days	Wed 7/4/01	Thu 7/5/01
35	Pour	4 days	Wed 7/11/01	Mon 7/16/01
36	Post Tension	2 days	Tue 7/17/01	Wed 7/18/01
37	**Level 7**	**11 days**	**Thu 7/19/01**	**Thu 8/2/01**
38	Shore	3 days	Thu 7/19/01	Mon 7/23/01
39	Form	5 days	Thu 7/19/01	Wed 7/25/01
40	Reinforce	2 days	Thu 7/19/01	Fri 7/20/01
41	Pour	4 days	Thu 7/26/01	Tue 7/31/01
42	Post Tension	2 days	Wed 8/1/01	Thu 8/2/01
43	**Level 8**	**11 days**	**Fri 8/3/01**	**Fri 8/17/01**
44	Shore	3 days	Fri 8/3/01	Tue 8/7/01
45	Form	5 days	Fri 8/3/01	Thu 8/9/01
46	Reinforce	2 days	Fri 8/3/01	Mon 8/6/01
47	Pour	4 days	Fri 8/10/01	Wed 8/15/01
48	Post Tension	2 days	Thu 8/16/01	Fri 8/17/01
49	**Level 9**	**11 days**	**Mon 8/20/01**	**Mon 9/3/01**
50	Shore	3 days	Mon 8/20/01	Wed 8/22/01
51	Form	5 days	Mon 8/20/01	Fri 8/24/01
52	Reinforce	2 days	Mon 8/20/01	Tue 8/21/01
53	Pour	4 days	Mon 8/27/01	Thu 8/30/01
54	Post Tension	2 days	Fri 8/31/01	Mon 9/3/01
55	**Level 10**	**11 days**	**Tue 9/4/01**	**Tue 9/18/01**
56	Shore	3 days	Tue 9/4/01	Thu 9/6/01
57	Form	5 days	Tue 9/4/01	Mon 9/10/01
58	Reinforce	2 days	Tue 9/4/01	Wed 9/5/01
59	Pour	4 days	Tue 9/11/01	Fri 9/14/01
60	Post Tension	2 days	Mon 9/17/01	Tue 9/18/01
61	**Level 11**	**11 days**	**Wed 9/19/01**	**Wed 10/3/01**
62	Shore	3 days	Wed 9/19/01	Fri 9/21/01
63	Form	5 days	Wed 9/19/01	Tue 9/25/01
64	Reinforce	2 days	Wed 9/19/01	Thu 9/20/01
65	Pour	4 days	Wed 9/26/01	Mon 10/1/01
66	Post Tension	2 days	Tue 10/2/01	Wed 10/3/01
67	**Level 11**	**11 days**	**Thu 10/4/01**	**Thu 10/18/01**
68	Shore	3 days	Thu 10/4/01	Mon 10/8/01
69	Form	5 days	Thu 10/4/01	Wed 10/10/01
70	Reinforce	2 days	Thu 10/4/01	Fri 10/5/01
71	Pour	4 days	Thu 10/11/01	Tue 10/16/01
72	Post Tension	2 days	Wed 10/17/01	Thu 10/18/01
73	**Level 12**	**11 days**	**Fri 10/19/01**	**Fri 11/2/01**
74	Shore	3 days	Fri 10/19/01	Tue 10/23/01
75	Form	5 days	Fri 10/19/01	Thu 10/25/01
76	Reinforce	2 days	Fri 10/19/01	Mon 10/22/01
77	Pour	4 days	Fri 10/26/01	Wed 10/31/01
78	Post Tension	2 days	Thu 11/1/01	Fri 11/2/01
79	**Level 13**	**11 days**	**Mon 11/5/01**	**Mon 11/19/01**
80	Shore	3 days	Mon 11/5/01	Wed 11/7/01
81	Form	5 days	Mon 11/5/01	Fri 11/9/01
82	Reinforce	2 days	Mon 11/5/01	Tue 11/6/01
83	Pour	4 days	Mon 11/12/01	Thu 11/15/01
84	Post Tension	2 days	Fri 11/16/01	Mon 11/19/01
85	**Level 14**	**11 days**	**Tue 11/20/01**	**Tue 12/4/01**
86	Shore	3 days	Tue 11/20/01	Thu 11/22/01
87	Form	5 days	Tue 11/20/01	Mon 11/26/01
88	Reinforce	2 days	Tue 11/20/01	Wed 11/21/01
89	Pour	4 days	Tue 11/27/01	Fri 11/30/01
90	Post Tension	2 days	Mon 12/3/01	Tue 12/4/01
91	**Level 14**	**9 days**	**Wed 12/5/01**	**Mon 12/17/01**
92	Shore	3 days	Wed 12/5/01	Fri 12/7/01
93	Form	5 days	Wed 12/5/01	Tue 12/11/01
94	Reinforce	2 days	Wed 12/5/01	Thu 12/6/01
95	Pour	4 days	Mon 12/10/01	Thu 12/13/01
96	Post Tension	2 days	Fri 12/14/01	Mon 12/17/01
97	**Level 15**	**11 days**	**Tue 12/18/01**	**Tue 1/1/02**
98	Shore	3 days	Tue 12/18/01	Thu 12/20/01
99	Form	5 days	Tue 12/18/01	Mon 12/24/01
100	Reinforce	2 days	Tue 12/18/01	Wed 12/19/01
101	Pour	4 days	Tue 12/25/01	Fri 12/28/01
102	Post Tension	2 days	Mon 12/31/01	Tue 1/1/02
103	**Level 16**	**11 days**	**Wed 1/2/02**	**Wed 1/16/02**
104	Shore	3 days	Wed 1/2/02	Fri 1/4/02
105	Form	5 days	Wed 1/2/02	Tue 1/8/02
106	Reinforce	2 days	Wed 1/2/02	Thu 1/3/02
107	Pour	4 days	Wed 1/9/02	Mon 1/14/02
108	Post Tension	2 days	Tue 1/15/02	Wed 1/16/02
109	**Rooftop**	**9 days**	**Thu 1/17/02**	**Tue 1/29/02**
110	Shore	3 days	Thu 1/17/02	Mon 1/21/02
111	Form	5 days	Thu 1/17/02	Wed 1/23/02
112	Reinforce	2 days	Thu 1/17/02	Fri 1/18/02
113	Pour	2 days	Thu 1/24/02	Fri 1/25/02
114	Post Tension	2 days	Mon 1/28/02	Tue 1/29/02



Project: Concrete-crane
Date: Thu 4/6/06

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

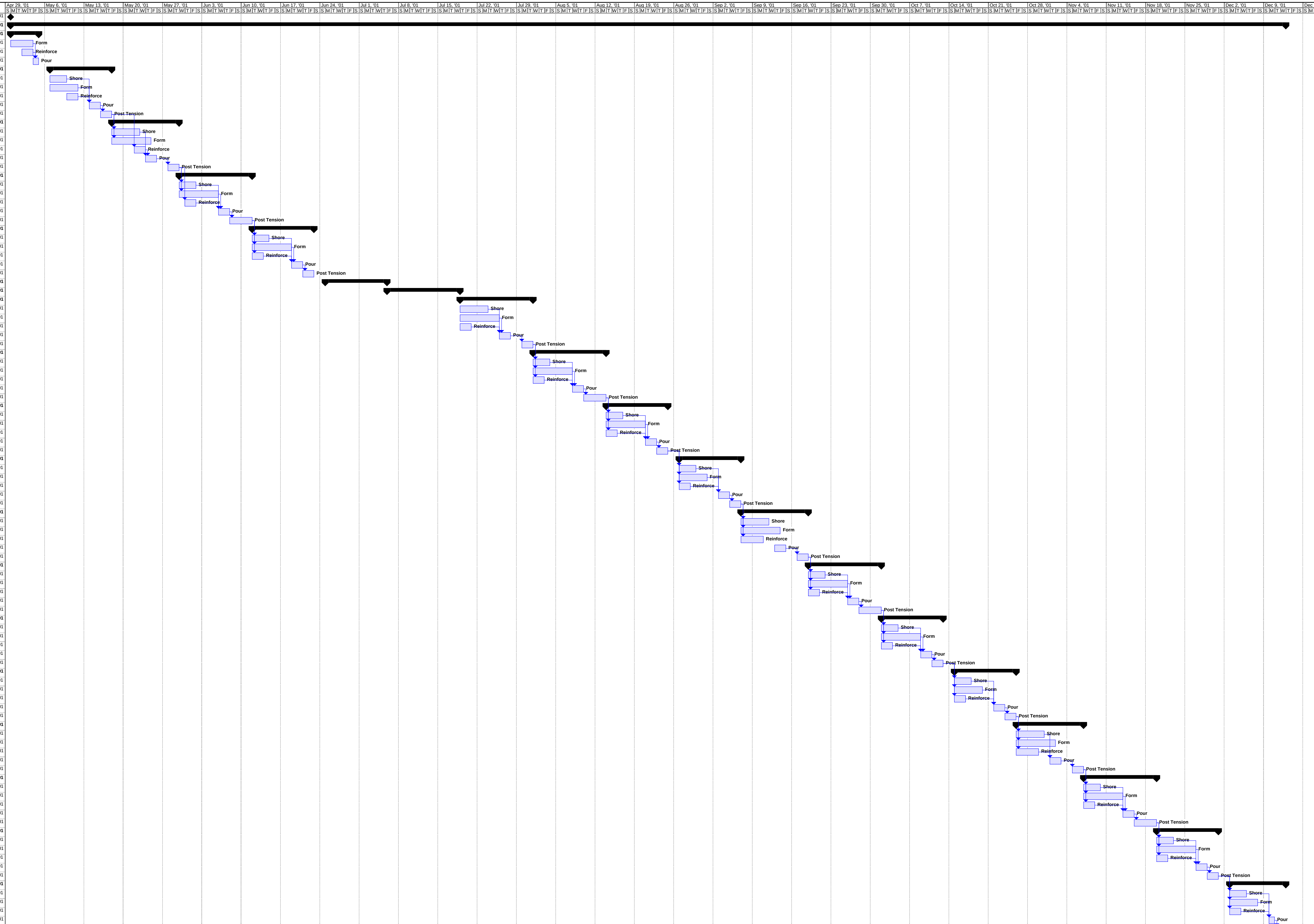
ID		Task Name	Duration	Start	Finish
1		Concrete Superstructure	0 days	Mon 4/30/01	Mon 4/30/01
2			**197 days**	**Mon 4/30/01**	**Tue 1/29/02**
3		**Level 2 Columns**	**5 days**	**Mon 4/30/01**	**Fri 5/4/01**
4		Form	4 days	Mon 4/30/01	Thu 5/3/01
5		Reinforce	2 days	Wed 5/2/01	Thu 5/3/01
6		Pour	1 day	Fri 5/4/01	Fri 5/4/01
7		**Level 2**	**11 days**	**Mon 5/7/01**	**Mon 5/21/01**
8		Shore	3 days	Mon 5/7/01	Wed 5/9/01
9		Form	5 days	Mon 5/7/01	Fri 5/11/01
10		Reinforce	2 days	Thu 5/10/01	Fri 5/11/01
11		Pour	4 days	Mon 5/14/01	Thu 5/17/01
12		Post Tension	2 days	Fri 5/18/01	Mon 5/21/01
13		**Level 3**	**9 days**	**Tue 5/22/01**	**Fri 6/1/01**
14		Shore	3 days	Tue 5/22/01	Thu 5/24/01
15		Form	5 days	Tue 5/22/01	Mon 5/28/01
16		Reinforce	2 days	Tue 5/22/01	Wed 5/23/01
17		Pour	4 days	Fri 5/25/01	Wed 5/30/01
18		Post Tension	2 days	Thu 5/31/01	Fri 6/1/01
19		**Level 4**	**11 days**	**Mon 6/4/01**	**Mon 6/18/01**
20		Shore	3 days	Mon 6/4/01	Wed 6/6/01
21		Form	5 days	Mon 6/4/01	Fri 6/8/01
22		Reinforce	2 days	Mon 6/4/01	Tue 6/5/01
23		Pour	4 days	Mon 6/11/01	Thu 6/14/01
24		Post Tension	2 days	Fri 6/15/01	Mon 6/18/01
25		**Level 5**	**11 days**	**Tue 6/19/01**	**Tue 7/3/01**
31		**Level 6**	**11 days**	**Wed 7/4/01**	**Wed 7/18/01**
37		**Level 7**	**11 days**	**Thu 7/19/01**	**Thu 8/2/01**
43		**Level 8**	**11 days**	**Fri 8/3/01**	**Fri 8/17/01**
49		**Level 9**	**11 days**	**Mon 8/20/01**	**Mon 9/3/01**
55		**Level 10**	**11 days**	**Tue 9/4/01**	**Tue 9/18/01**
61		**Level 11**	**11 days**	**Wed 9/19/01**	**Wed 10/3/01**
67		**Level 11**	**11 days**	**Thu 10/4/01**	**Thu 10/18/01**
73		**Level 12**	**11 days**	**Fri 10/19/01**	**Fri 11/2/01**
79		**Level 13**	**11 days**	**Mon 11/5/01**	**Mon 11/19/01**
85		**Level 14**	**11 days**	**Tue 11/20/01**	**Tue 12/4/01**
91		**Level 14**	**9 days**	**Wed 12/5/01**	**Mon 12/17/01**
97		**Level 15**	**11 days**	**Tue 12/18/01**	**Tue 1/1/02**
103		**Level 16**	**11 days**	**Wed 1/2/02**	**Wed 1/16/02**
109		**Rooftop**	**9 days**	**Thu 1/17/02**	**Tue 1/29/02**



Project: Concrete-crane
Date: Thu 4/6/06

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

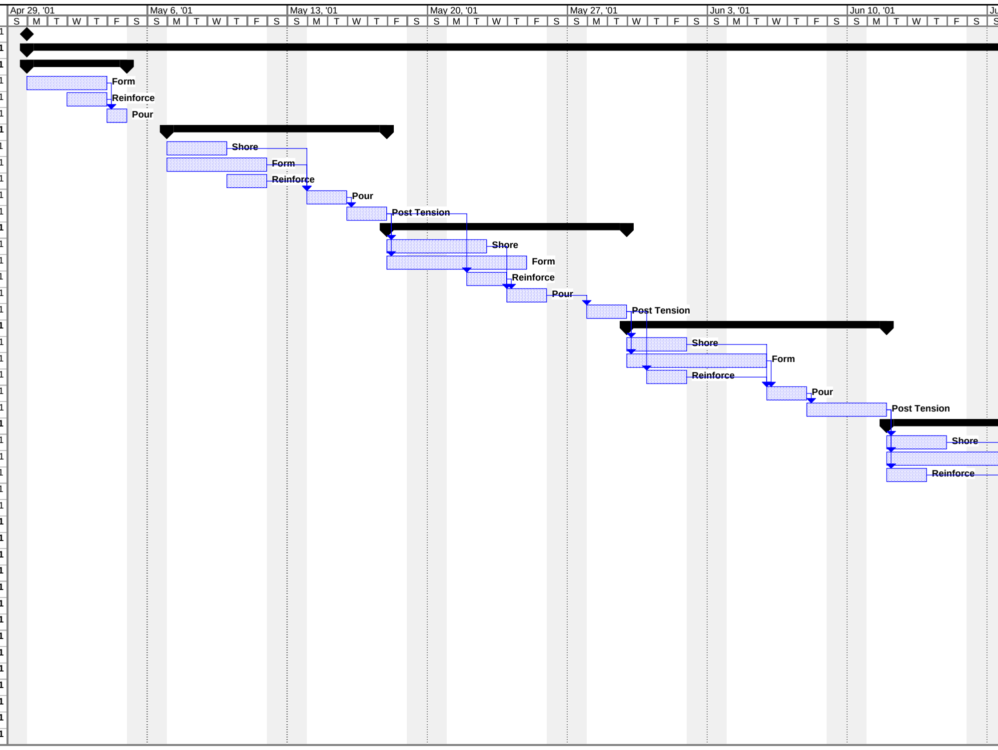
ID		Task Name	Duration	Start	Finish
1		Foundation Finished	0 days	Mon 4/30/01	Mon 4/30/01
2		**Concrete Superstructure**	**163 days**	**Mon 4/30/01**	**Wed 12/12/01**
3		**Level 2 Columns**	**5 days**	**Mon 4/30/01**	**Fri 5/4/01**
4		Form	4 days	Mon 4/30/01	Thu 5/3/01
5		Reinforce	2 days	Wed 5/2/01	Thu 5/3/01
6		Pour	1 day	Fri 5/4/01	Fri 5/4/01
7		**Level 2 Floor**	**9 days**	**Mon 5/7/01**	**Thu 5/17/01**
8		Shore	3 days	Mon 5/7/01	Wed 5/9/01
9		Form	5 days	Mon 5/7/01	Fri 5/11/01
10		Reinforce	2 days	Thu 5/10/01	Fri 5/11/01
11		Pour	2 days	Mon 5/14/01	Tue 5/15/01
12		Post Tension	2 days	Wed 5/16/01	Thu 5/17/01
13		**Level 3**	**8 days**	**Fri 5/18/01**	**Tue 5/29/01**
14		Shore	3 days	Fri 5/18/01	Tue 5/22/01
15		Form	5 days	Fri 5/18/01	Thu 5/24/01
16		Reinforce	2 days	Tue 5/22/01	Wed 5/23/01
17		Pour	2 days	Thu 5/24/01	Fri 5/25/01
18		Post Tension	2 days	Mon 5/28/01	Tue 5/29/01
19		**Level 4**	**9 days**	**Wed 5/30/01**	**Mon 6/11/01**
20		Shore	3 days	Wed 5/30/01	Fri 6/1/01
21		Form	5 days	Wed 5/30/01	Tue 6/5/01
22		Reinforce	2 days	Thu 5/31/01	Fri 6/1/01
23		Pour	2 days	Wed 6/6/01	Thu 6/7/01
24		Post Tension	2 days	Fri 6/8/01	Mon 6/11/01
25		**Level 5**	**9 days**	**Tue 6/12/01**	**Fri 6/22/01**
26		Shore	3 days	Tue 6/12/01	Thu 6/14/01
27		Form	5 days	Tue 6/12/01	Mon 6/18/01
28		Reinforce	2 days	Tue 6/12/01	Wed 6/13/01
29		Pour	2 days	Tue 6/19/01	Wed 6/20/01
30		Post Tension	2 days	Thu 6/21/01	Fri 6/22/01
31		**Level 6**	**9 days**	**Mon 6/25/01**	**Thu 7/5/01**
37		**Level 7**	**9 days**	**Fri 7/6/01**	**Wed 7/18/01**
43		**Level 8**	**9 days**	**Thu 7/19/01**	**Tue 7/31/01**
44		Shore	3 days	Thu 7/19/01	Mon 7/23/01
45		Form	5 days	Thu 7/19/01	Wed 7/25/01
46		Reinforce	2 days	Thu 7/19/01	Fri 7/20/01
47		Pour	2 days	Thu 7/26/01	Fri 7/27/01
48		Post Tension	2 days	Mon 7/30/01	Tue 7/31/01
49		**Level 9**	**9 days**	**Wed 8/1/01**	**Mon 8/13/01**
50		Shore	3 days	Wed 8/1/01	Fri 8/3/01
51		Form	5 days	Wed 8/1/01	Tue 8/7/01
52		Reinforce	2 days	Wed 8/1/01	Thu 8/2/01
53		Pour	2 days	Wed 8/8/01	Thu 8/9/01
54		Post Tension	2 days	Fri 8/10/01	Mon 8/13/01
55		**Level 10**	**9 days**	**Tue 8/14/01**	**Fri 8/24/01**
56		Shore	3 days	Tue 8/14/01	Thu 8/16/01
57		Form	5 days	Tue 8/14/01	Mon 8/20/01
58		Reinforce	2 days	Tue 8/14/01	Wed 8/15/01
59		Pour	2 days	Tue 8/21/01	Wed 8/22/01
60		Post Tension	2 days	Thu 8/23/01	Fri 8/24/01
61		**Level 11**	**9 days**	**Mon 8/27/01**	**Thu 9/6/01**
62		Shore	3 days	Mon 8/27/01	Wed 8/29/01
63		Form	5 days	Mon 8/27/01	Fri 8/31/01
64		Reinforce	2 days	Mon 8/27/01	Tue 8/28/01
65		Pour	2 days	Mon 9/3/01	Tue 9/4/01
66		Post Tension	2 days	Wed 9/5/01	Thu 9/6/01
67		**Level 11**	**8 days**	**Fri 9/7/01**	**Tue 9/18/01**
68		Shore	3 days	Fri 9/7/01	Tue 9/11/01
69		Form	5 days	Fri 9/7/01	Thu 9/13/01
70		Reinforce	2 days	Fri 9/7/01	Mon 9/10/01
71		Pour	2 days	Thu 9/13/01	Fri 9/14/01
72		Post Tension	2 days	Mon 9/17/01	Tue 9/18/01
73		**Level 12**	**9 days**	**Wed 9/19/01**	**Mon 10/1/01**
74		Shore	3 days	Wed 9/19/01	Fri 9/21/01
75		Form	5 days	Wed 9/19/01	Tue 9/25/01
76		Reinforce	2 days	Wed 9/19/01	Thu 9/20/01
77		Pour	2 days	Wed 9/26/01	Thu 9/27/01
78		Post Tension	2 days	Fri 9/28/01	Mon 10/1/01
79		**Level 13**	**9 days**	**Tue 10/2/01**	**Fri 10/12/01**
80		Shore	3 days	Tue 10/2/01	Thu 10/4/01
81		Form	5 days	Tue 10/2/01	Mon 10/8/01
82		Reinforce	2 days	Tue 10/2/01	Wed 10/3/01
83		Pour	2 days	Tue 10/9/01	Wed 10/10/01
84		Post Tension	2 days	Thu 10/11/01	Fri 10/12/01
85		**Level 14**	**9 days**	**Mon 10/15/01**	**Thu 10/25/01**
86		Shore	3 days	Mon 10/15/01	Wed 10/17/01
87		Form	5 days	Mon 10/15/01	Fri 10/19/01
88		Reinforce	2 days	Mon 10/15/01	Tue 10/16/01
89		Pour	2 days	Mon 10/22/01	Tue 10/23/01
90		Post Tension	2 days	Wed 10/24/01	Thu 10/25/01
91		**Level 14**	**8 days**	**Fri 10/26/01**	**Tue 11/6/01**
92		Shore	3 days	Fri 10/26/01	Tue 10/30/01
93		Form	5 days	Fri 10/26/01	Thu 11/1/01
94		Reinforce	2 days	Fri 10/26/01	Mon 10/29/01
95		Pour	2 days	Thu 11/1/01	Fri 11/2/01
96		Post Tension	2 days	Mon 11/5/01	Tue 11/6/01
97		**Level 15**	**9 days**	**Wed 11/7/01**	**Mon 11/19/01**
98		Shore	3 days	Wed 11/7/01	Fri 11/9/01
99		Form	5 days	Wed 11/7/01	Tue 11/13/01
100		Reinforce	2 days	Wed 11/7/01	Thu 11/8/01
101		Pour	2 days	Wed 11/14/01	Thu 11/15/01
102		Post Tension	2 days	Fri 11/16/01	Mon 11/19/01
103		**Level 16**	**9 days**	**Tue 11/20/01**	**Fri 11/30/01**
104		Shore	3 days	Tue 11/20/01	Thu 11/22/01
105		Form	5 days	Tue 11/20/01	Mon 11/26/01
106		Reinforce	2 days	Tue 11/20/01	Wed 11/21/01
107		Pour	2 days	Tue 11/27/01	Wed 11/28/01
108		Post Tension	2 days	Thu 11/29/01	Fri 11/30/01
109		**Rooftop**	**8 days**	**Mon 12/3/01**	**Wed 12/12/01**
110		Shore	3 days	Mon 12/3/01	Wed 12/5/01
111		Form	5 days	Mon 12/3/01	Fri 12/7/01
112		Reinforce	2 days	Mon 12/3/01	Tue 12/4/01
113		Pour	1 day	Mon 12/10/01	Mon 12/10/01
114		Post Tension	2 days	Tue 12/11/01	Wed 12/12/01



Project: Concrete-pumped
Date: Thu 4/6/06

Task | Progress | Milestone | Summary | Rolled Up Task | Rolled Up Milestone | Rolled Up Progress | Split | External Tasks | Project Summary | Group By Summary | Deadline

ID	Task Name	Duration	Start	Finish
1	Foundation Finished	0 days	Mon 4/30/01	Mon 4/30/01
2	**Concrete Superstructure**	**163 days**	**Mon 4/30/01**	**Wed 12/12/01**
3	**Level 2 Columns**	**5 days**	**Mon 4/30/01**	**Fri 5/4/01**
4	Form	4 days	Mon 4/30/01	Thu 5/3/01
5	Reinforce	2 days	Wed 5/2/01	Thu 5/3/01
6	Pour	1 day	Fri 5/4/01	Fri 5/4/01
7	**Level 2 Floor**	**9 days**	**Mon 5/7/01**	**Thu 5/17/01**
8	Shore	3 days	Mon 5/7/01	Wed 5/9/01
9	Form	5 days	Mon 5/7/01	Fri 5/11/01
10	Reinforce	2 days	Thu 5/10/01	Fri 5/11/01
11	Pour	2 days	Mon 5/14/01	Tue 5/15/01
12	Post Tension	2 days	Wed 5/16/01	Thu 5/17/01
13	**Level 3**	**8 days**	**Fri 5/18/01**	**Tue 5/29/01**
14	Shore	3 days	Fri 5/18/01	Tue 5/22/01
15	Form	5 days	Fri 5/18/01	Thu 5/24/01
16	Reinforce	2 days	Tue 5/22/01	Wed 5/23/01
17	Pour	2 days	Thu 5/24/01	Fri 5/25/01
18	Post Tension	2 days	Mon 5/28/01	Tue 5/29/01
19	**Level 4**	**9 days**	**Wed 5/30/01**	**Mon 6/11/01**
20	Shore	3 days	Wed 5/30/01	Fri 6/1/01
21	Form	5 days	Wed 5/30/01	Tue 6/5/01
22	Reinforce	2 days	Thu 5/31/01	Fri 6/1/01
23	Pour	2 days	Wed 6/6/01	Thu 6/7/01
24	Post Tension	2 days	Fri 6/8/01	Mon 6/11/01
25	**Level 5**	**9 days**	**Tue 6/12/01**	**Fri 6/22/01**
26	Shore	3 days	Tue 6/12/01	Thu 6/14/01
27	Form	5 days	Tue 6/12/01	Mon 6/18/01
28	Reinforce	2 days	Tue 6/12/01	Wed 6/13/01
29	Pour	2 days	Tue 6/19/01	Wed 6/20/01
30	Post Tension	2 days	Thu 6/21/01	Fri 6/22/01
31	**Level 6**	**9 days**	**Mon 6/25/01**	**Thu 7/5/01**
37	**Level 7**	**9 days**	**Fri 7/6/01**	**Wed 7/18/01**
43	**Level 8**	**9 days**	**Thu 7/19/01**	**Tue 7/31/01**
49	**Level 9**	**9 days**	**Wed 8/1/01**	**Mon 8/13/01**
55	**Level 10**	**9 days**	**Tue 8/14/01**	**Fri 8/24/01**
61	**Level 11**	**9 days**	**Mon 8/27/01**	**Thu 9/6/01**
67	**Level 11**	**8 days**	**Fri 9/7/01**	**Tue 9/18/01**
73	**Level 12**	**9 days**	**Wed 9/19/01**	**Mon 10/1/01**
79	**Level 13**	**9 days**	**Tue 10/2/01**	**Fri 10/12/01**
85	**Level 14**	**9 days**	**Mon 10/15/01**	**Thu 10/25/01**
91	**Level 14**	**8 days**	**Fri 10/26/01**	**Tue 11/6/01**
97	**Level 15**	**9 days**	**Wed 11/7/01**	**Mon 11/19/01**
103	**Level 16**	**9 days**	**Tue 11/20/01**	**Fri 11/30/01**
109	**Rooftop**	**8 days**	**Mon 12/3/01**	**Wed 12/12/01**



Project: Concrete-pumped Date: Thu 4/6/06	Task	Milestone	Rolled Up Task	Rolled Up Progress	External Tasks	Group By Summary
	Progress	Summary	Rolled Up Milestone	Split	Project Summary	Deadline

Appendix F: Mechanical System

RETScreen® Energy Model - Ground-Source Heat Pump Project

Training & Support

Site Conditions		Estimate	Notes/Range
Project name		**Eight Tower Bridge**	See Online Manual
Project location		**Conshohocken, PA**	
Available land area	m²	3,716	
Soil type	-	Heavy soil - damp	
Design heating load	kW	45.3	Complete H&CLC sheet
Design cooling load	kW	123.4	

System Characteristics		Estimate	Notes/Range
Base Case HVAC System			
Building has air-conditioning?	yes/no	Yes	
Heating fuel type	-	**Electricity**	
Heating system seasonal efficiency	%	85%	55% to 350%
Air-conditioner seasonal COP	-	3.0	2.4 to 5.0
Ground Heat Exchanger System			
System type	-	Vertical closed-loop	
Design criteria	-	Cooling	
Typical land area required	m²	876	
Ground heat exchanger layout	-	Standard	
Total borehole length	m	3,054	
Heat Pump System			
Average heat pump efficiency	-	User-defined	See Product Database
Heat pump manufacturer		Trane	
Heat pump model		WPVJ060	
Standard cooling COP	-	4.50	
Standard heating COP	-	3.30	
Total standard heating capacity	kW	93.3	
	million Btu/h	0.318	
Total standard cooling capacity	kW	121.3	
	ton (cooling)	34.5	
Supplemental Heating and Heat Rejection System			
Suggested supplemental heating capacity	kW	0.0	
	million Btu/h	0.000	
Suggested supplemental heat rejection	kW	0.0	
	million Btu/h	0.000	

Annual Energy Production		Estimate	Notes/Range
Heating			
Electricity used	MWh	34.9	
Supplemental energy delivered	MWh	0.0	
GSHP heating energy delivered	MWh	**88.4**	
	million Btu	301.5	
Seasonal heating COP	-	2.5	2.0 to 5.0
Cooling			
Electricity used	MWh	47.5	
GSHP cooling energy delivered	MWh	**205.0**	
	million Btu	699.3	
Seasonal cooling COP	-	4.3	2.0 to 5.5
Seasonal cooling EER	(Btu/h)/W	14.7	7.0 to 19.0
			Complete Cost Analysis sheet

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RETScreen® Heating and Cooling Load Calculation - Ground-Source Heat Pump Project

Site Conditions		Estimate	Notes/Range
Nearest location for weather data		Philadelphia, PA	See Weather Database
Heating design temperature	°C	-6.5	-40.0 to 15.0
Cooling design temperature	°C	27.3	10.0 to 40.0
Average summer daily temperature range	°C	7.3	5.0 to 15.0
Cooling humidity level	-	Medium	
Latitude of project location	°N	39.9	-90.0 to 90.0
Mean earth temperature	°C	11.7	Visit NASA satellite data site
Annual earth temperature amplitude	°C	18.4	5.0 to 20.0
Depth of measurement of earth temperature	m	0.0	0.0 to 3.0

Building Heating and Cooling Load		Estimate	Notes/Range
Type of building	-	Commercial	
Available information	-	Descriptive data	
Building floor area	m²	2,000	
Number of floors	floor	16	1 to 6
Window area	-	Standard	
Insulation level	-	Medium	
Occupancy type	-	Daytime	
Equipment and lighting usage	-	Moderate	
Building design heating load	kW	45.3	
	million Btu/h	0.155	
Building heating energy demand	MWh	88.4	
	million Btu	301.5	
Building design cooling load	kW	123.4	
	ton (cooling)	35.1	
Building cooling energy demand	MWh	205.0	
	million Btu	699.3	Return to Energy Model sheet

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RETScreen® Cost Analysis - Ground-Source Heat Pump Project

Type of analysis: Pre-feasibility | Currency: $ | Cost references: None

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
Feasibility Study							
Other - Feasibility Study	Cost	0	$ -	$ -		-	-
Sub-total:				**$ -**	0.0%		
Development							
Other - Development	Cost	0	$ -	$ -		-	-
Sub-total:				**$ -**	0.0%		
Engineering							
Other - Engineering	Cost	0	$ -	$ -		-	-
Sub-total:				**$ -**	0.0%		
Energy Equipment							
Heat pumps	kW cooling	121.3	$ 330	$ 40,029		-	-
Well pumps	kW	0.0	$ -	$ -		-	-
Circulating pumps	kW	2.1	$ 850	$ 1,753		-	-
Circulating fluid	m³	0.54	$ 2,600	$ 1,403		-	-
Plate heat exchangers	kW	0.0	$ -	$ -		-	-
Trenching and backfilling	m	0	$ -	$ -		-	-
Drilling and grouting	m	3,054	$ 12.00	$ 36,646		-	-
Ground HX loop pipes	m	6,108	$ 2.50	$ 15,269		-	-
Fittings and valves	kW cooling	121.3	$ 12.00	$ 1,456		-	-
Other - Energy Equipment	Cost	0	$ -	$ -		-	-
Electric central heating system	Credit	1	$ 20,000	$ (20,000)		-	-
Sub-total:				**$ 76,555**	79.4%		
Balance of System							
Supplemental heating system	kW	0.0	$ -	$ -		-	-
Supplemental heat rejection	kW	0.0	$ -	$ -		-	-
Internal piping and insulation	kW cooling	121.3	$ 60	$ 7,278		-	-
Other - Balance of System	Cost	0	$ -	$ -		-	-
Credit - Balance of System	Credit	1	$ 1,000	$ (1,000)		-	-
Sub-total:				**$ 6,278**	6.5%		
Miscellaneous							
Training	p-h	14	$ 70	$ 980		-	-
Contingencies	%	15%	$ 83,813	$ 12,572		-	-
Sub-total:				**$ 13,552**	14.1%		
Initial Costs - Total				**$ 96,385**	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
O&M							
Property taxes/Insurance	project	0	$ -	$ -		-	-
O&M labour	m²	1,000	$ 2.50	$ 2,500		-	-
Travel and accommodation	p-trip	0	$ -	$ -		-	-
Other - O&M	Cost	0	$ -	$ -		-	-
Credit - O&M	Credit	1	$ 3,500	$ (3,500)		-	-
Contingencies	%	5%	$ 82,833	$ 4,142		-	-
Sub-total:				**$ 3,142**	51.0%		
Fuel/Electricity							
Electricity	kWh	**82,338**	**$ 0.060**	$ 4,940		-	-
Incremental electricity load	kW	**-16.0**	**$ 120**	$ (1,923)		-	-
Sub-total:				**$ 3,018**	49.0%		
Annual Costs - Total				**$ 6,159**	100.0%		

Periodic Costs (Credits)		Period	Unit Cost	Amount		Interval Range	Unit Cost Range
Heat pump compressor	Cost	10 yr	$ 5,000	**$ 5,000**		-	-
Air-conditioner replacement	Credit	12 yr	$ 6,000	**$ (6,000)**		-	-
				$ -		-	-
End of project life	Credit	-	$ 2,000	**$ (2,000)**			

Go to GHG Analysis sheet

RETScreen® Financial Summary - Ground-Source Heat Pump Project

Annual Energy Balance

Project name		Eight Tower Bridge	Electricity required	MWh	82.3
Project location		Conshohocken, PA	Incremental electricity load	kW	(16.0)
Heating energy delivered	MWh	88.4			
Cooling energy delivered	MWh	205.0			
Heating fuel displaced	-	Electricity			

Financial Parameters

Avoided cost of heating energy	$/kWh	0.060	Debt ratio	%	0.0%
			Income tax analysis?	yes/no	No
Retail price of electricity	$/kWh	0.060			
Demand charge	$/kW	120			
Energy cost escalation rate	%	2.0%			
Inflation	%	2.0%			
Discount rate	%	10.0%			
Project life	yr	25			

Project Costs and Savings

Initial Costs				**Annual Costs and Debt**		
Feasibility study	0.0%	$	-	O&M	$	3,142
Development	0.0%	$	-	Fuel/Electricity	$	3,018
Engineering	0.0%	$	-			
Energy equipment	79.4%	$	76,555	**Annual Costs and Debt - Total**	**$**	**6,159**
Balance of system	6.5%	$	6,278			
Miscellaneous	14.1%	$	13,552	**Annual Savings or Income**		
Initial Costs - Total	100.0%	**$**	**96,385**	Heating energy savings/income	$	6,237
				Cooling energy savings/income	$	4,099
Incentives/Grants		$	-			
				Annual Savings - Total	**$**	**10,336**
Periodic Costs (Credits)						
Heat pump compressor		$	5,000	Schedule yr # 10,20		
Air-conditioner replacement		$	(6,000)	Schedule yr # 12,24		
		$	-			
End of project life - Credit		$	(2,000)	Schedule yr # 25		

Financial Feasibility

Pre-tax IRR and ROI	%	2.9%			
After-tax IRR and ROI	%	2.9%			
Simple Payback	yr	23.1	Project equity	$	96,385
Year-to-positive cash flow	yr	18.6			
Net Present Value - NPV	$	(50,942)			
Annual Life Cycle Savings	$	(5,612)			
Benefit-Cost (B-C) ratio	-	0.47			

Yearly Cash Flows

Year #	Pre-tax $	After-tax $	Cumulative $
0	(96,385)	(96,385)	(96,385)
1	4,260	4,260	(92,125)
2	4,346	4,346	(87,779)
3	4,432	4,432	(83,347)
4	4,521	4,521	(78,826)
5	4,612	4,612	(74,214)
6	4,704	4,704	(69,511)
7	4,798	4,798	(64,713)
8	4,894	4,894	(59,819)
9	4,992	4,992	(54,827)
10	(1,003)	(1,003)	(55,831)
11	5,193	5,193	(50,637)
12	12,907	12,907	(37,731)
13	5,403	5,403	(32,328)
14	5,511	5,511	(26,816)
15	5,621	5,621	(21,195)
16	5,734	5,734	(15,461)
17	5,849	5,849	(9,613)
18	5,966	5,966	(3,647)
19	6,085	6,085	2,438
20	(1,223)	(1,223)	1,214
21	6,331	6,331	7,545
22	6,457	6,457	14,002
23	6,586	6,586	20,589
24	16,369	16,369	36,957
25	10,134	10,134	47,091

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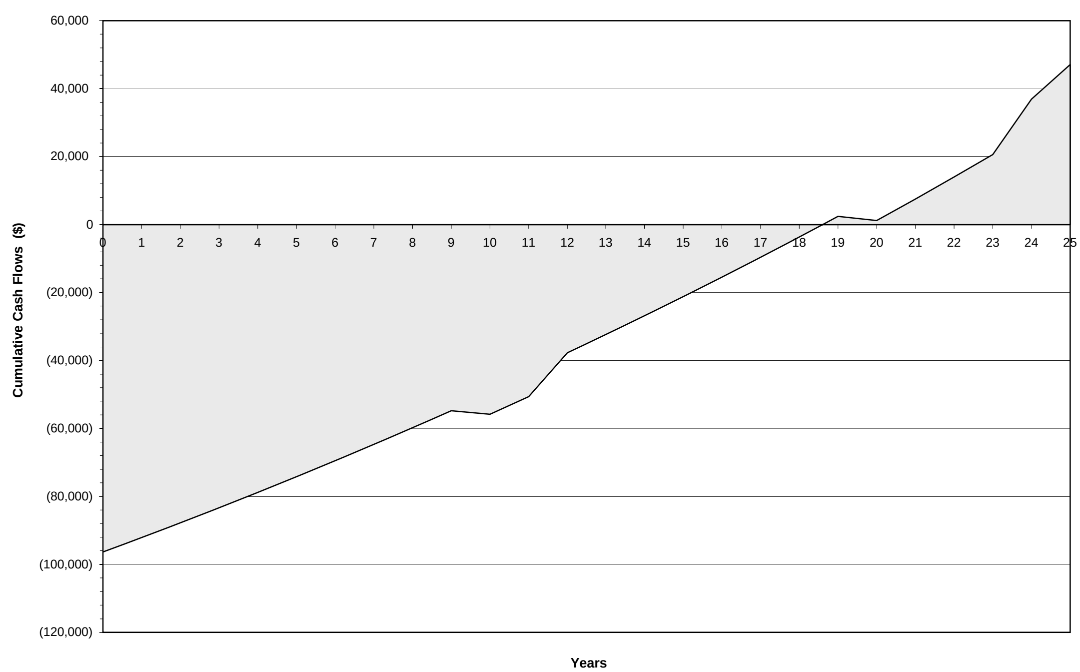
Cumulative Cash Flows Graph

GSHP Project Cumulative Cash Flows
Eight Tower Bridge, Conshohocken, PA

Total Initial Costs: $ 96,385



IRR and ROI: 2.9% **Year-to-positive cash flow: 18.6 yr** **Net Present Value: $ -50,942**

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RETScreen® Energy Model - Ground-Source Heat Pump Project

Training & Support

Site Conditions		Estimate	Notes/Range
Project name		**Eight Tower Bridge**	See Online Manual
Project location		**Conshohocken, PA**	
Available land area	m²	3,716	
Soil type	-	Heavy soil - damp	
Design heating load	kW	45.3	Complete H&CLC sheet
Design cooling load	kW	123.4	

System Characteristics		Estimate	Notes/Range
Base Case HVAC System			
Building has air-conditioning?	yes/no	Yes	
Heating fuel type	-	**Electricity**	
Heating system seasonal efficiency	%	85%	55% to 350%
Air-conditioner seasonal COP	-	3.0	2.4 to 5.0
Ground Heat Exchanger System			
System type	-	Vertical closed-loop	
Design criteria	-	Heating	
Typical land area required	m²	263	
Ground heat exchanger layout	-	Standard	
Total borehole length	m	938	
Heat Pump System			
Average heat pump efficiency	-	User-defined	See Product Database
Heat pump manufacturer		Trane	
Heat pump model		WPVJ060	
Standard cooling COP	-	4.50	
Standard heating COP	-	3.30	
Total standard heating capacity	kW	93.3	
	million Btu/h	0.318	
Total standard cooling capacity	kW	121.3	
	ton (cooling)	34.5	
Supplemental Heating and Heat Rejection System			
Suggested supplemental heating capacity	kW	0.0	
	million Btu/h	0.000	
Suggested supplemental heat rejection	kW	85.5	
	million Btu/h	0.292	

Annual Energy Production		Estimate	Notes/Range
Heating			
Electricity used	MWh	33.0	
Supplemental energy delivered	MWh	0.0	
GSHP heating energy delivered	MWh	**88.4**	
	million Btu	301.5	
Seasonal heating COP	-	2.7	2.0 to 5.0
Cooling			
Electricity used	MWh	46.3	
GSHP cooling energy delivered	MWh	**205.0**	
	million Btu	699.3	
Seasonal cooling COP	-	4.4	2.0 to 5.5
Seasonal cooling EER	(Btu/h)/W	15.1	7.0 to 19.0
			Complete Cost Analysis sheet

Version 3.1 NRCan/CETC - Varennes

RETScreen® Heating and Cooling Load Calculation - Ground-Source Heat Pump Project

Site Conditions		Estimate	Notes/Range
Nearest location for weather data		Philadelphia, PA	See Weather Database
Heating design temperature	°C	-6.5	-40.0 to 15.0
Cooling design temperature	°C	27.3	10.0 to 40.0
Average summer daily temperature range	°C	7.3	5.0 to 15.0
Cooling humidity level	-	Medium	
Latitude of project location	°N	39.9	-90.0 to 90.0
Mean earth temperature	°C	11.7	Visit NASA satellite data site
Annual earth temperature amplitude	°C	18.4	5.0 to 20.0
Depth of measurement of earth temperature	m	0.0	0.0 to 3.0

Building Heating and Cooling Load		Estimate	Notes/Range
Type of building	-	Commercial	
Available information	-	Descriptive data	
Building floor area	m²	2,000	
Number of floors	floor	16	1 to 6
Window area	-	Standard	
Insulation level	-	Medium	
Occupancy type	-	Daytime	
Equipment and lighting usage	-	Moderate	
Building design heating load	kW	45.3	
	million Btu/h	0.155	
Building heating energy demand	MWh	88.4	
	million Btu	301.5	
Building design cooling load	kW	123.4	
	ton (cooling)	35.1	
Building cooling energy demand	MWh	205.0	
	million Btu	699.3	Return to Energy Model sheet

Version 3.1 NRCan/CETC - Varennes

RETScreen® Cost Analysis - Ground-Source Heat Pump Project

Type of analysis: Pre-feasibility | Currency: $ | Cost references: None

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
Feasibility Study							
Other - Feasibility Study	Cost	0	$ -	$ -		-	-
Sub-total:				$ -	0.0%		
Development							
Other - Development	Cost	0	$ -	$ -		-	-
Sub-total:				$ -	0.0%		
Engineering							
Other - Engineering	Cost	0	$ -	$ -		-	-
Sub-total:				$ -	0.0%		
Energy Equipment							
Heat pumps	kW cooling	121.3	$ 330	$ 40,029		-	-
Well pumps	kW	0.0	$ -	$ -		-	-
Circulating pumps	kW	2.1	$ 850	$ 1,753		-	-
Circulating fluid	m³	0.17	$ 2,600	$ 431		-	-
Plate heat exchangers	kW	0.0	$ -	$ -		-	-
Trenching and backfilling	m	0	$ -	$ -		-	-
Drilling and grouting	m	938	$ 12.00	$ 11,257		-	-
Ground HX loop pipes	m	1,876	$ 2.50	$ 4,690		-	-
Fittings and valves	kW cooling	121.3	$ 12.00	$ 1,456		-	-
Other - Energy Equipment	Cost	0	$ -	$ -		-	-
Electric central heating system	Credit	1	$ 20,000	$ (20,000)		-	-
Sub-total:				**$ 39,616**	73.5%		
Balance of System							
Supplemental heating system	kW	0.0	$ -	$ -		-	-
Supplemental heat rejection	kW	85.5	$ -	$ -		-	-
Internal piping and insulation	kW cooling	121.3	$ 60	$ 7,278		-	-
Other - Balance of System	Cost	0	$ -	$ -		-	-
Credit - Balance of System	Credit	1	$ 1,000	$ (1,000)		-	-
Sub-total:				**$ 6,278**	11.6%		
Miscellaneous							
Training	p-h	14	$ 70	$ 980		-	-
Contingencies	%	15%	$ 46,873	$ 7,031		-	-
Sub-total:				**$ 8,011**	14.9%		
Initial Costs - Total				**$ 53,905**	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
O&M							
Property taxes/Insurance	project	0	$ -	$ -		-	-
O&M labour	m²	1,000	$ 2.50	$ 2,500		-	-
Travel and accommodation	p-trip	0	$ -	$ -		-	-
Other - O&M	Cost	0	$ -	$ -		-	-
Credit - O&M	Credit	1	$ 3,500	$ (3,500)		-	-
Contingencies	%	5%	$ 45,893	$ 2,295		-	-
Sub-total:				**$ 1,295**	30.7%		
Fuel/Electricity							
Electricity	kWh	**79,314**	**$ 0.060**	$ 4,759		-	-
Incremental electricity load	kW	**-15.3**	**$ 120**	$ (1,833)		-	-
Sub-total:				**$ 2,926**	69.3%		
Annual Costs - Total				**$ 4,220**	100.0%		

Periodic Costs (Credits)		Period	Unit Cost	Amount	Interval Range	Unit Cost Range
Heat pump compressor	Cost	10 yr	$ 5,000	**$ 5,000**	-	-
Air-conditioner replacement	Credit	12 yr	$ 6,000	**$ (6,000)**	-	-
				$ -	-	-
End of project life	Credit	-	$ 2,000	**$ (2,000)**		*Go to GHG Analysis sheet*

RETScreen® Financial Summary - Ground-Source Heat Pump Project

Annual Energy Balance

Project name		Eight Tower Bridge	Electricity required	MWh	79.3
Project location		Conshohocken, PA	Incremental electricity load	kW	(15.3)
Heating energy delivered	MWh	88.4			
Cooling energy delivered	MWh	205.0			
Heating fuel displaced	-	Electricity			

Financial Parameters

Avoided cost of heating energy	$/kWh	0.060	Debt ratio	%	0.0%
			Income tax analysis?	yes/no	No
Retail price of electricity	$/kWh	0.060			
Demand charge	$/kW	120			
Energy cost escalation rate	%	2.0%			
Inflation	%	2.0%			
Discount rate	%	10.0%			
Project life	yr	25			

Project Costs and Savings

Initial Costs				**Annual Costs and Debt**		
Feasibility study	0.0%	$	-	O&M	$	1,295
Development	0.0%	$	-	Fuel/Electricity	$	2,926
Engineering	0.0%	$	-			
Energy equipment	73.5%	$	39,616	**Annual Costs and Debt - Total**	**$**	**4,220**
Balance of system	11.6%	$	6,278			
Miscellaneous	14.9%	$	8,011	**Annual Savings or Income**		
Initial Costs - Total	100.0%	**$**	**53,905**	Heating energy savings/income	$	6,237
				Cooling energy savings/income	$	4,099
Incentives/Grants		$	-			
				Annual Savings - Total	**$**	**10,336**
Periodic Costs (Credits)						
Heat pump compressor		$	5,000	Schedule yr # 10,20		
Air-conditioner replacement		$	(6,000)	Schedule yr # 12,24		
		$	-			
End of project life - Credit		$	(2,000)	Schedule yr # 25		

Financial Feasibility

Pre-tax IRR and ROI	%	12.6%			
After-tax IRR and ROI	%	12.6%			
Simple Payback	yr	8.8	Project equity	$	53,905
Year-to-positive cash flow	yr	8.0			
Net Present Value - NPV	$	12,518			
Annual Life Cycle Savings	$	1,379			
Benefit-Cost (B-C) ratio	-	1.23			

Yearly Cash Flows

Year #	Pre-tax $	After-tax $	Cumulative $
0	(53,905)	(53,905)	(53,905)
1	6,238	6,238	(47,666)
2	6,363	6,363	(41,304)
3	6,490	6,490	(34,813)
4	6,620	6,620	(28,193)
5	6,752	6,752	(21,441)
6	6,887	6,887	(14,554)
7	7,025	7,025	(7,529)
8	7,166	7,166	(363)
9	7,309	7,309	6,946
10	1,360	1,360	8,306
11	7,604	7,604	15,910
12	15,366	15,366	31,276
13	7,911	7,911	39,188
14	8,070	8,070	47,257
15	8,231	8,231	55,488
16	8,396	8,396	63,884
17	8,564	8,564	72,448
18	8,735	8,735	81,182
19	8,910	8,910	90,092
20	1,658	1,658	91,750
21	9,270	9,270	101,020
22	9,455	9,455	110,474
23	9,644	9,644	120,118
24	19,488	19,488	139,606
25	13,315	13,315	152,921

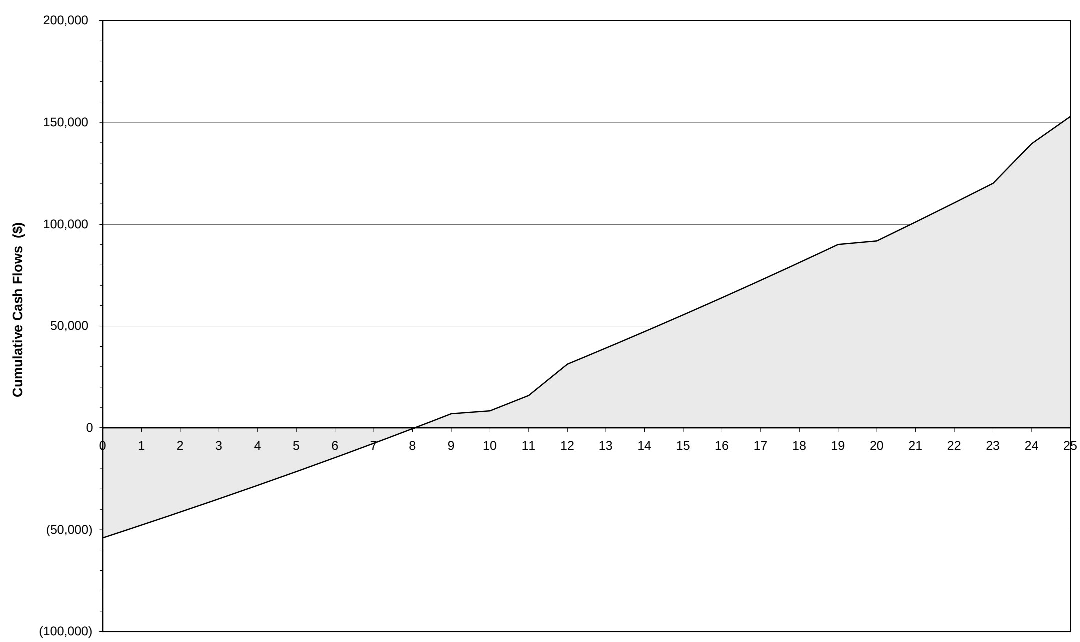
Version 3.1

NRCan/CETC - Varennes

Cumulative Cash Flows Graph

GSHP Project Cumulative Cash Flows
Eight Tower Bridge, Conshohocken, PA

Total Initial Costs: $ 53,905



IRR and ROI: 12.6% **Year-to-positive cash flow: 8 yr** **Net Present Value: $ 12,518**

Extra High Efficiency Vertical Water-Source Comfort System

1 1/2 -6 Tons – 60 HZ

February 2005 WSHP-PRC005-EN

E9

Introduction

A feature summary for the WPVJ unit includes:

1 High efficiency scroll Compressor

2 Co-axial Heat Exchanger *(copper or cupro-nickel)*

3 Right or Left Return-Air *Option*

4 75 VA Transformer *ZN510 Control Option*

5 Galvanized Finish

6 Thermal Expansion Metering designed for 25 to 120°F Range

7 1-inch FPT Connections

8 Acoutical Features

9 Choice of Standard Static or High Static Blower Motor

10 Removable, Cleanable Drain Pan

11 Integrated Controls

12 Factory Installed Desuperheater *Option*

13 Boilerless (external electric heat) Control *Option*

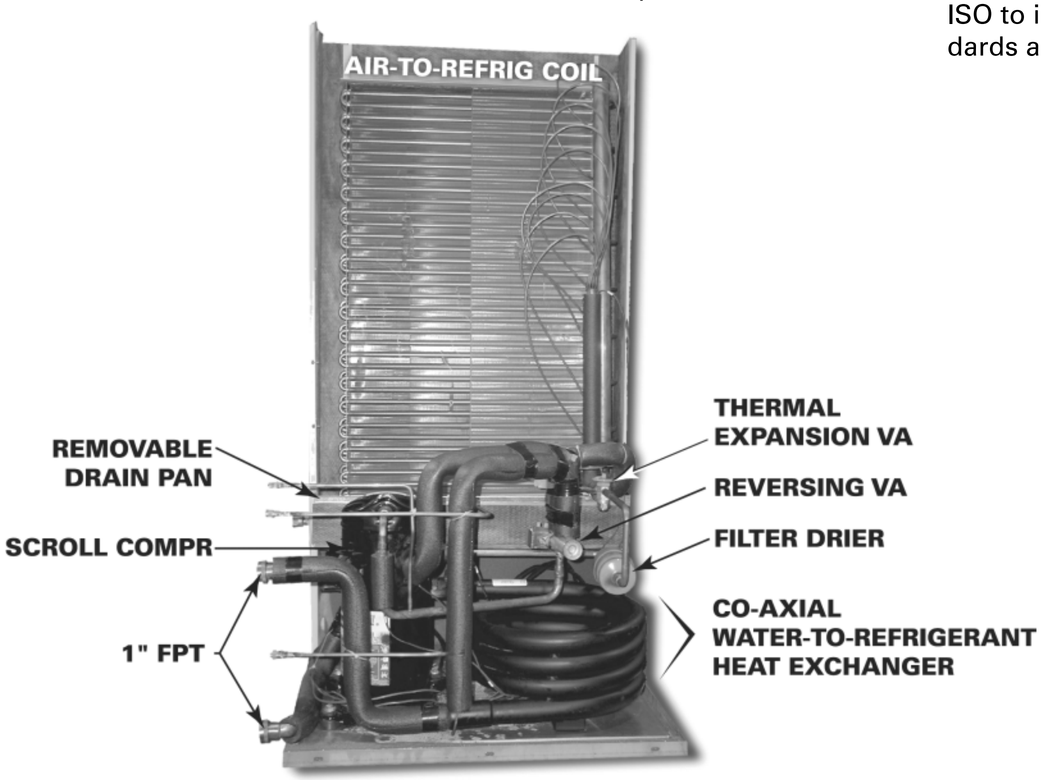
14 Leaving Water Freezestat 35° or 20° *Option*

The units are rated to ISO 13256-1 to provide an up-to-date configurations for today.

The units may be applied in a boiler/cooling tower setting, or in a geothermal closed or open loop application.

All units accommodate service access to the controls, blower motor and other major components to contribute to greater serviceability and maintainability of the unit.

Each unit is verified for total unit performance before shipping from the Waco Business Unit. Our equipment must meet the industry standards developed by ARI and ISO to insure global quality standards are inherent in every unit.



E10

TRANE

Features and Benefits

Unit Description

The cabinet design incorporates sturdy metal with a durable and corrosive resistive exterior galvanized finish. Before shipment, each unit is leak tested, dehydrated, charged with refrigerant and run tested for proper control operation.

The cabinet insulation meets UL 181 requirements. The air stream surface of the insulation is fabricated of a non-biodegradable source. The insulation in the wet section of the cabinet complies with ASHRAE standard 62 to accommodate indoor air quality (IAQ) standards.

Sound

The units operate quietly, with noise ratings of NC 40 to 45 in typical installations. All units have a thermal/acoustical insulated partition between the blower and compressor compartments to attenuate compressor noise and rumble.

Fan motors and compressors are internally isolated to reduce vibration. A compressor base plate and full-length channel stiffeners are installed to further reduce vibration.

Compressor

All units are equipped with a high efficiency scroll compressor to aid in the reduction of sound, increases reliability and provides a more efficient operation.

Condensate Pan

Each unit is equipped with a removable, cleanable condensate (drain) pan. It is removable from the unit to provide a means of cleaning the drain pan which is important to the improvement of indoor air quality. The condensate pan is designed to allow the condensate formed from the air-to-refrigerant coil to drain freely, discouraging condensate buildup and microbial growth in the pan.

Filter Rack and Filter

Each unit is equipped with an accessible filter rack to house a 1-inch or 2-inch *(option)* standard sized disposable fiberglass filter.

Filter Drier

Every unit is equipped with a bi-directional filter drier to dehydrate and clean the system, adding to the life of the unit.

Refrigeration Circuit

The 1-1/2 to 6-ton units incorporate a single circuit refrigeration design. All heat pump designs include a system reversing valve, thermal expansion valve, air-to-refrigerant coil, water-to-refrigerant coil, and compressor selected for the best optimization and efficiency of each circuit.

Air-to-Refrigerant Coil

The air-to-refrigerant coil is aluminum fin, mechanically bonded to the copper tubing.

Water-to-Refrigerant Coil

The water-to-refrigerant coil is a copper or cupro-nickel *(option)* coil within a coil (steel tube) design. It is leak tested to assure there is no cross leakage between the water tube (copper/cupro-nickel) and refrigerant gas (steel tube). The inner-tube of the coil is deeply fluted to enhance heat transfer, and to minimize fouling and scaling. *See Figure 1.*

Figure 1: Coaxial heat exchanger

Expansion Valve

The refrigerant flow metering is made through a thermal expansion valve (TXV). The TXV allows the unit to operate with an entering fluid temperature from 25 F to 120 F, and an entering air temperature from 55 F to 85 F. The valve precisely meters refrigerant flow through the circuitry to achieve desired heating or cooling. *See Figure 2.*

Unlike cap-tube assemblies, the TXV allows the exact amount of refrigerant required to meet the coil load demands. This precise metering increases the over-all efficiency of the unit.

Figure 2: Expansion valve

E11

Features and Benefits

Unit Safety

All unit safety devices are provided to prevent compressor damage. Low and high pressure switches are added to protect the compressor operation under a low charge or during high discharge pressures. The low pressure switch is set to activate at refrigerant pressures of 20 psig, and the high pressure switch de-energizes the compressor when discharge pressure exceeds 395 psig. A safety lockout relay is designed to turn off the compressor, and the desuperheater pump if a problem is detected.

Duct Collar

A return-air duct collar is provided with each unit for adequate connection of duct work to the unit. Using the duct collar, ductwork may be easily fastened to the unit, eliminating the need for extra sheet metal work. In many applications, when the ductwork is insulated, the performance of the unit is enhanced.

Blower and Motor

The blower motor may be ordered as either a standard static, or a high static option. The multi-speed blower motor contains internal thermal overload protection. The motor bearings are permanently lubricated and sealed. Standard motors are rated up to .85 ESP. Optional high static motors are rated up to 1.35 ESP. The multi-speed motor offers the flexibility of manually changing the speed of the blower to adapt to various duct designs. *See Figure 3*.

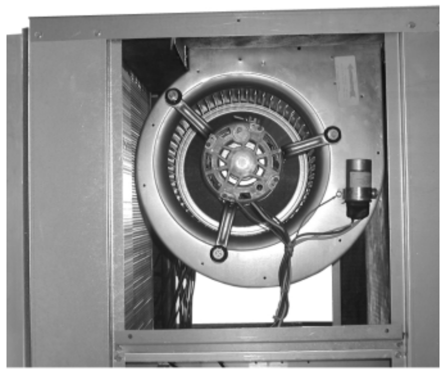


Figure 3: Blower and motor

Refrigerant and Service Ports

The unit includes high and low-side service ports and a water regulating valve connection external to the unit to provide quicker access during start-up and in a service situation.

Filters

The unit filters are removable from the front or back side of the unit, offering added flexibility for installation and replacing the standard, 1-inch or 2-inch disposable fiberglass filters. The hinged door feature of the filter rack allows the filter to be removed without detaching duct work.

Access Panels

The unit contains three, removable access panels (two front, one rear) for access to internal components. The majority of the unit's components may be readily reached through the two front access panels.

Water Connections

The water-in/water-out connections are constructed of copper material and include a National Female Pipe Thread (NFPT) junction.

Desuperheater and Pump

(Optional)

Through this desuperheater option, the high (hot) pressure energy that is rejected by the unit in cooling mode may be transfered to the facilities hot water heater through a water heater hook-up kit for virtually free hot water heating. This factory installed option provides higher efficiencies through the overall energy consumption by reducing the amount of time the hot water heater runs.

The desuperheater is controlled by two temperature control sensor. One sensor monitors the temperature of the compressor's discharge line. The desuperheater pump cannot operate until the compressor line reaches 145 F. The other sensor monitors the water temperature of the hot water heater. The desuperheater will automatically shut off if the water reaches 125 F to prevent scalding. For hook-up information pertaining to the desuperheater/hot water hook-up option see WSHPC-IN-4.

Leaving Water Freeze stat

(Optional)

A leaving water freeze stat may be provided with either a 35° or 20° trip point. The WPVJ model is standardly equipped with a low pressure switch to help detect water freeze-up. However, a leaving water freeze stat is an additional protection device to help protect the water coil from freezing.

Note: When the units leaving water falls below the designated trip point (35° or 20°), the unit will be placed in a lock-out (compressor off) mode.

E12

Selection Procedure

The performance standard ARI/ ISO 13256-1 became effective Jan. 1, 2000. It replaces ARI standards 320, 325 and 330. This new standard has three major categories: Water Loop (ARI 320), Ground Water (ARI 325), Ground Loop (ARI 330). Although these standards are similar there are some differences.

The cooling efficiency is measured in EER but includes a Watt-per-Watt unit of measure similar to the traditional COP measurement.

The entering water temperature has changed to reflect the centigrade temperature scale. For instance the water loop heating test is performed with 68-degree F (20-degree C) water instead of 70-degree F. The cooling tests are performed with 80.6-degree F (27-degree C) dry bulb and 66.2-degree F (19-degree C) wet bulb entering air instead of the traditional 80-degree F dry bulb, and 67-degree F wet bulb entering air temperatures. This data (80.6/66.2) may be converted to 80/67 by using the entering air correction table.

A pump power correction has been added onto the existing power consumption. Within each model, only one water flow rate is specified for each performance category, and pumping watts are calculated utilizing the pump power correction formula: (gpm x 0.0631) x press drop x 2990) / 300

Note: gpm relates to water flow, and press drop relates to the drop through the unit heat exchanger at rated water flow in feet of head. The fan power is corrected to zero external static pressure. The nominal airflow is rated at a specific external static pressure. This effectively reduces the power consumption of the unit, and increases cooling capacity but decreases heating capacity. These watts are significant enough in most cases to increase EER and COP over ARI 320, 325, and 330 ratings.

Cooling Dominated Applications

If humidity levels are moderate to high in a cooling dominated application, the heat pump should be selected to meet or exceed the calculated sensible load. Also, the unit's sensible capacity should be no more than 115% of the total cooling load (sensible + latent), unless the calculated latent load is less than the latent capacity of the unit.

The sensible-to-total cooling ratio can be adjusted with airflow. If the airflow is lowered, the unit latent capacity will increase. When less air is pulled across the DX coil, more moisture will condense from the air.

Heating Dominated Applications

Unit sizing in heating dominated applications is based upon humidity levels for the climate, and goals for operating cost and installation costs.

If humidity levels are moderate, the heat pump should be selected with the heating capacity equal to 125% of the cooling load.

If humidity levels are low in the application and low operating cost is important, the heat pump and ground loop should be sized for 90% to 100% of the heating load.

If humidity levels are low and lower initial cost is important, then the heat pump and ground loop should be sized for 70% to 85% of the heating load, with the remaining load to be treated with electric resistance heat.

Installation cost will be reduced in this approach because of the smaller heat pump selection and less loop materials.

In general, the system will not use enough electric heat to offset the higher installation costs associated with a fully sized or oversized system.

Finally, a unit sized for the entire heating load in a heating dominated application will be oversized in cooling. Comfort is reduced from increased room humidity caused by short-run times. Short cycling will also shorten the life expectancy of the equipment and increase power consumption and operating cost.

Many rebate incentives require the heat pump and ground loop to be sized for the entire heating load. Check with you local utility for their requirements.

TRANE

Model Number

Vertical Water-Source Heat Pump

W P V J 036 1 1 A 0 1 0 0 T L C 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 000

5 10 15 20 25 30

DIGITS 1-3: UNIT CONFIGURATION
WPV = Extra High Efficiency Upflow Heat Pump

DIGIT 4: DEVELOPMENT SEQUENCE J

DIGITS 5-7: NOMINAL SIZE (MBH)
018 = 18.0 MBH
024 = 24.0 MBH
030 = 30.0 MBH
036 = 36.0 MBH
042 = 42.0 MBH
048 = 48.0 MBH
060 = 60.0 MBH
072 = 72.0 MBH

DIGIT 8: VOLTAGE (Volts/Hz/Phase)
1 = 208/60/1 7 = 265/60/1
2 = 230/60/1 8 = 230/60/3
3 = 208/60/3
4 = 460/60/3
5 = 575/60/3

DIGITS 9: HEAT EXCHANGER
1 = Copper-Water Coil
2 = Cupro-Nickel Water Coil

DIGITS 10: DESIGN SEQUENCE A

DIGITS 11: REFRIGERATION CIRCUIT
0 = Heating and Cooling Circuit
1 = Heating and Cooling Circuit with Desuperheater

DIGITS 12: BLOWER CONFIGURATION
1 = Standard Blower Motor
2 = High Static Blower Motor

DIGIT 13: FREEZE PROTECTION
0 = No Freeze Control
A = 20°F Freeze Stat
B = 35°F Freeze Stat

DIGIT 14: OPEN DIGIT = 0

DIGIT 15: SUPPLY-AIR ARRANGEMENT
T = Top Supply Air Arrangement

DIGIT 16: RETURN-AIR ARRANGEMENT
L = Left Return-Air Arrangement
R = Right Return-Air Arrangement

DIGIT 17: CONTROL TYPES
0 = Basic 24 V Controls
1 = Basic 24 V with Random Start/ Time Delay
C = Tracer ZN510 Controls

DIGITS 18: TSTAT/SENSOR LOCATION
0 = Wall Mounted Location

DIGITS 19: FAULT SENSORS
0 = No Fault Sensor
1 = Condensate Overflow Sensor
2 = Filter Maintenance Timer
3 = Condensate Overflow and Filter Maintenance Timer

DIGITS 20: TEMPERATURE SENSOR
0 = No Additional Temperature Sensor
1 = Entering Water Sensor

DIGITS 21: NIGHT SETBACK CONTROL
0 = No Night Setback Relay
N = Night Setback Relay

DIGITS 22: ELECTRIC HEAT
0 = No Electric Heat
4 = Boilerless Control with External Electric Heat

DIGITS 23: UNIT MOUNTED DISCONNECT
0 = No Unit Mounted Disconnect

DIGITS 24: FILTER TYPE
1 = 1" Throwaway Filter
2 = 2" Throwaway Filter

DIGITS 25: ACOUSTIC ARRANGEMENT
0 = Standard Factory Configuration

DIGITS 26: FACTORY CONFIGURATION
0 = Standard Factory Configuration

DIGITS 27: PAINT COLOR
0 = No Paint Selection Available

DIGITS 28: OUTSIDE AIR
0 = No Outside Air Option Available

DIGITS 29: PIPING ARRANGEMENT
1 = Standard Piping with Schrader Connection for Water Regulating Valve

DIGITS 30-36: DOES NOT APPLY TO WPVJ
0000000 = Digits 30-36 are not applicable to the WPVJ product

E14

General Data

Table G1: General data about the units

Model		WPVJ 018	WPVJ 024	WPVJ 030	WPVJ 036
Unit Size	Depth (in)	21 1/2"	21 1/2"	27"	27"
	Height (in)	45"	45"	54 3/8"	54 3/8"
	Width (in) *includes filter*	22 1/4"	22 1/4"	23 3/4"	23 3/4"
Compressor Type		Scroll	Scroll	Scroll	Scroll
Approximate Weight	with Pallet (lb)	249	250	298	315
Approximate Weight	without Pallet (lb)	239	240	288	305
Air-to-Refrigerant Coil	no of rows	3	3	3	3
	Face Area (sq ft)	2.92	2.92	3.99	3.99
	Fins per inch	14	14	14	14
Filter Size	inches	16 x 20 x 1 (2)	16 x 20 x 1 (2)	20 x 25 x 1 (2)	20 x 25 x 1 (2)
Water in/out size (FPT)	inches	1	1	1	1
Condensate size (NPTI)	inches	3/4	3/4	3/4	3/4
Discharge-Air Collar	inches (L x H)	Not Provided			
Return-Air Collar	inches (L x H)	16 x 33	16 x 33	21 x 40 1/2	21 x 40 1/2
Refrigerant Charge	oz	58	62	73	66

Table G1: General data about the units *(continued)*

Model		WPVJ 042	WPVJ 048	WPVJ 060	WPVJ 072
Unit Size	Depth (in)	27"	31 1/2"	31 1/2"	31 1/2"
	Height (in)	54 3/8"	54 3/8"	54 3/8"	54 3/8"
	Width (in) *includes filter*	23 3/8"	26 1/4"	26 1/4"	26 1/4"
Compressor Type		Scroll	Scroll	Scroll	Scroll
Approximate Weight	with Pallet (lb)	324	398	439	440
Approximate Weight	without Pallet (lb)	314	388	429	430
Air-to-Refrigerant Coil	no of rows	3	3	3	3
	Face Area (sq ft)	5.13	5.56	6.94	6.94
	Fins per inch	14	14	14	14
Filter Size	inches	20 x 25 x 1 (2)	20 x 30 x 1 (2)	20 x 30 x 1 (2)	20 x 30 x 1 (2)
Water in/out size (FPT)	inches	1	1	1	1
Condensate size (NPTI)	inches	3/4	3/4	3/4	3/4
Discharge-Air Collar	inches (L x H)	Not Provided			
Return-Air Collar	inches (L x H)	21 x 40 1/2	26 x 40 1/2	26 x 40 1/2	26 x 40 1/2
Refrigerant Charge	oz	98	103	110	110

E15

TRANE

Performance Data
WPVJ 018-Cooling

Table P-2: 018 Cooling Performance

Performance data is tabulated for cooling at 80.6 F DB/66.2 F WB entering air at ARI/ISO 13256-1 rated CFM.

For conditions other than what is tabulated, multipliers must be used to correct performance. See the *fan correction factors table* for CFM other than rated and the *cooling correction factors* for variations in entering air temperature. WLHP data shown in **bold type** is performance data at ARI/ISO 13256-1. The **bold type** for GLHP is a rating point only. For ARI 13256-1 GLHP conditions, apply 15% methanol by volume per the antifreeze correction factors found on page 40.

Rated GPM 5.0 **Minimum CFM** 480
Rated CFM 600 **Maximum CFM** 720

EWT	GPM	Total Mbtuh	Sen Mbtuh	SHR	DSH Mbtuh	Power kW	Reject Mbtuh	LWT	Feet Head	PSID Head	CFM	ISO Cap Mbtuh	ISO Power kW	ISO EER
45	3.3	21.0	14.6	0.70	0.7	0.96	24.3	59.7	4.7	2.04	600	21.5	0.84	25.6
45	4.0	21.2	14.7	0.69	0.6	0.94	24.4	57.2	6.4	2.77	600	21.7	0.82	26.5
45	4.5	21.3	14.8	0.69	0.6	0.93	24.5	55.9	7.7	3.33	600	21.8	0.82	26.6
45	5.0	21.5	14.8	0.69	0.6	0.92	24.6	54.8	9.1	3.94	600	22.0	0.81	27.2
45	5.3	21.5	14.9	0.69	0.5	0.91	24.6	54.3	10.0	4.33	600	22.0	0.81	27.2
45	5.8	21.6	14.9	0.69	0.5	0.90	24.7	53.5	11.5	4.98	600	22.1	0.81	27.3
45	6.0	21.7	15.0	0.69	0.5	0.90	24.8	53.3	12.2	5.28	600	22.2	0.81	27.4
55	3.3	20.5	14.3	0.70	1.6	1.06	24.1	69.6	4.4	1.91	600	21.0	0.94	22.3
55	4.0	20.6	14.5	0.70	1.5	1.04	24.2	67.1	6.0	2.60	600	21.1	0.92	22.9
55	4.5	20.8	14.5	0.70	1.5	1.03	24.3	65.8	7.2	3.12	600	21.3	0.92	23.2
55	5.0	20.9	14.6	0.70	1.5	1.01	24.4	64.8	8.5	3.68	600	21.4	0.90	23.8
55	5.3	20.9	14.6	0.70	1.4	1.01	24.4	64.2	9.4	4.07	600	21.4	0.91	23.5
55	5.8	21.0	14.7	0.70	1.4	1.00	24.4	63.4	10.8	4.68	600	21.5	0.91	23.6
55	6.0	21.1	14.7	0.70	1.4	1.00	24.5	63.2	11.4	4.94	600	21.6	0.91	23.7
68	3.3	19.6	13.9	0.71	2.4	1.21	23.7	82.4	4.0	1.73	600	20.1	1.08	18.6
68	4.0	19.8	14.0	0.71	2.4	1.19	23.9	80.0	5.5	2.38	600	20.3	1.07	19.0
68	4.5	19.9	14.0	0.70	2.3	1.17	23.9	78.6	6.6	2.86	600	20.4	1.05	19.4
68	5.0	20.0	14.1	0.71	2.3	1.16	24.0	77.6	7.9	3.42	600	20.5	1.05	19.5
68	5.3	20.0	14.2	0.71	2.3	1.15	23.9	77.0	8.6	3.72	600	20.5	1.04	19.7
68	5.8	20.1	14.2	0.71	2.2	1.15	24.0	76.3	10.0	4.33	600	20.6	1.05	19.6
68	6.0	20.2	14.3	0.71	2.2	1.14	24.1	76.0	10.6	4.59	600	20.7	1.05	19.7
77	3.3	18.9	13.4	0.71	2.6	1.34	23.5	91.3	3.8	1.65	600	19.4	1.21	16.0
77	4.0	19.0	13.6	0.72	2.5	1.32	23.5	88.8	5.2	2.25	600	19.5	1.20	16.3
77	4.5	19.2	13.6	0.71	2.5	1.30	23.6	87.5	6.3	2.73	600	19.7	1.18	16.7
77	**5.0**	**19.3**	**13.7**	**0.71**	**2.5**	**1.28**	**23.7**	**86.5**	**7.5**	**3.25**	**600**	**19.8**	**1.17**	**16.9**
77	5.3	19.3	13.7	0.71	2.4	1.27	23.6	85.9	8.2	3.55	600	19.8	1.16	17.1
77	5.8	19.4	13.8	0.71	2.4	1.26	23.7	85.2	9.5	4.11	600	19.9	1.16	17.2
77	6.0	19.5	13.8	0.71	2.4	1.26	23.8	85.0	10.1	4.37	600	20.0	1.16	17.2
86	3.3	18.1	13.0	0.72	2.7	1.50	23.2	100.1	3.6	1.56	600	18.6	1.37	13.6
86	4.0	18.3	13.1	0.72	2.6	1.47	23.3	97.7	5.0	2.17	600	18.8	1.35	13.9
86	4.5	18.4	13.2	0.72	2.6	1.44	23.3	96.4	6.0	2.60	600	18.9	1.32	14.3
86	**5.0**	**18.5**	**13.2**	**0.71**	**2.5**	**1.42**	**23.4**	**95.4**	**7.2**	**3.12**	**600**	**19.0**	**1.31**	**14.5**
86	5.3	18.5	13.3	0.72	2.5	1.42	23.4	94.9	7.9	3.42	600	19.0	1.31	14.5
86	5.8	18.6	13.3	0.72	2.5	1.40	23.4	94.1	9.1	3.94	600	19.1	1.30	14.7
86	6.0	18.6	13.4	0.72	2.5	1.40	23.4	93.8	9.7	4.20	600	19.1	1.30	14.7
95	3.3	17.3	12.5	0.72	2.7	1.68	23.0	109.0	3.5	1.52	600	17.8	1.55	11.5
95	4.0	17.4	12.6	0.72	2.7	1.64	23.0	106.6	4.7	2.04	600	17.9	1.52	11.8
95	4.5	17.5	12.7	0.73	2.6	1.62	23.0	105.3	5.8	2.51	600	18.0	1.50	12.0
95	5.0	17.6	12.8	0.73	2.6	1.59	23.0	104.3	6.9	2.99	600	18.1	1.48	12.2
95	5.3	17.6	12.8	0.73	2.6	1.58	23.0	103.7	7.6	3.29	600	18.1	1.47	12.3
95	5.8	17.7	12.9	0.73	2.6	1.57	23.1	103.0	8.8	3.81	600	18.2	1.47	12.4
95	6.0	17.8	12.9	0.72	2.5	1.56	23.1	102.7	9.3	4.03	600	18.3	1.46	12.5
105	3.3	16.2	12.0	0.74	2.8	1.92	22.8	118.9	3.3	1.43	600	16.7	1.79	9.3
105	4.0	16.4	12.1	0.74	2.8	1.87	22.8	116.5	4.5	1.95	600	16.9	1.75	9.7
105	4.5	16.4	12.2	0.74	2.7	1.84	22.7	115.2	5.5	2.38	600	16.9	1.72	9.8
105	5.0	16.5	12.2	0.74	2.7	1.82	22.7	114.2	6.6	2.86	600	17.0	1.71	9.9
105	5.3	16.6	12.3	0.74	2.7	1.80	22.7	113.6	7.3	3.16	600	17.1	1.69	10.1
105	5.8	16.7	12.4	0.74	2.6	1.79	22.8	112.9	8.5	3.68	600	17.2	1.69	10.2
105	6.0	16.7	12.4	0.74	2.6	1.78	22.8	112.7	9.0	3.90	600	17.2	1.68	10.2
115	3.3	15.1	11.5	0.76	3.0	2.21	22.6	128.9	3.1	1.36	600	15.6	2.08	7.50
115	4.0	15.2	11.6	0.76	2.9	2.15	22.5	126.4	4.4	1.89	600	15.7	2.03	7.73
115	4.5	15.3	11.6	0.76	2.9	2.12	22.5	125.1	5.3	2.32	600	15.8	2.00	7.90
115	5.0	15.4	11.7	0.76	2.8	2.08	22.5	124.1	6.4	2.77	600	15.9	1.97	8.07
115	5.3	15.4	11.7	0.76	2.8	2.07	22.5	123.6	7.1	3.06	600	15.9	1.96	8.11
115	5.8	15.5	11.8	0.76	2.8	2.04	22.5	122.8	8.2	3.57	600	16.0	1.94	8.25
115	6.0	15.5	11.8	0.76	2.8	2.04	22.5	122.6	8.7	3.78	600	16.0	1.94	8.25
120	3.3	14.5	11.2	0.77	3.1	2.37	22.6	133.9	3.1	1.33	600	15.0	2.24	6.70
120	4.0	14.6	11.3	0.77	3.0	2.31	22.5	131.4	4.3	1.85	600	15.1	2.19	6.89
120	4.5	14.7	11.3	0.77	3.0	2.27	22.5	130.1	5.3	2.28	600	15.2	2.15	7.07
120	5.0	14.8	11.4	0.77	2.9	2.24	22.5	129.1	6.3	2.73	600	15.3	2.13	7.18
120	5.3	14.8	11.5	0.78	2.9	2.22	22.4	128.5	7.0	3.02	600	15.3	2.11	7.25
120	5.8	14.9	11.5	0.77	2.9	2.19	22.4	127.8	8.1	3.52	600	15.4	2.09	7.37
120	6.0	14.9	11.6	0.78	2.9	2.18	22.3	127.5	8.6	3.73	600	15.4	2.08	7.40

E16