North Mountain IMS Medical Office Building

Phoenix, Arizona

Michael Hopple

Final Report -
Integration of Sustainable Structural Elements
and Evaluating Mechanical System Effects

April 9th, 2008

AE 482W-Senior Thesis

The Pennsylvania State University

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North Mountain
Integarted Medical Services
Office Building

Phoenix, Arizona
123, 400 Square Feet
$ 10 Million

Design and Construction Team

Owner: Advanced Real Estate Resources
Developer: Thomas Speer L.L.C.
Architect: DFD CornoyerHedrick
Contractor: IBC Southwest
Precast Contractor: Coreslab Structures (Ariz) Inc.
Structural Engineer: Paul Koehler
Precast Detailer: TRC Worldwide Engineering
Mechanical Engineer: Tri-City Mechanical
Electrical Engineer: Arkibis Engineering L.L.C.

Architectural Features

Design-build project with construction starting June 2007 and expecting completion February 2008
State-of-the-art outpatient diagnostic imaging center and ambulatory surgery center on ground floor
Large open floor plan provides over 92,000 square feet of rentable office space on three floors
Precast concrete wall panels provide building envelope and lateral load stability

Design Features

Structure:

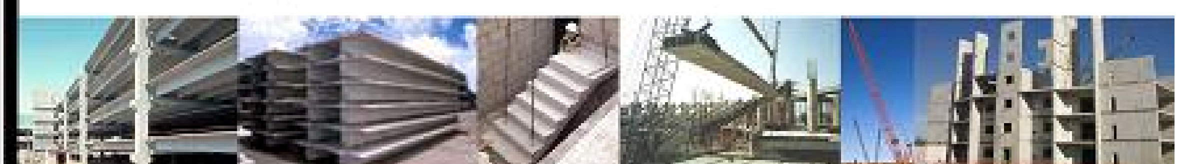
- Precast concrete double tees and inverted tee girders provide interior floor framing
- Precast concrete shear walls provide lateral load resistance
- Interior columns supported by 6'-0" diameter caissons drilled to a depth of 30'-0"
- Exterior wall panels bear on grade beams which span between caissons drilled to 20'-0"

Mechanical:

- Water Source Heat Pump with roof mounted cooling tower and boiler provides cooling and heating to office floors
- Units sized on ambient temperatures of 115 degrees summer and 40 degrees winter
- Calculated cooling load: 341 tons, calculated heating load: 188 kw

Lighting/Electrical:

- Both 120/208V and 277/408V service is supplied to the building
- Total electrical demand for the imaging and surgical center is 1000 kVA, while the rentable space demand is 1754 kVA
- Interior lighting is built to suit future tenants
- Lighting load calculations are based on 3.5 Watts per square foot



Michael Hopple
Structural Option
http://www.engr.psu.edu/ae/thesis/portfolios/2008/mrh260

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Credits/Acknowledgements

Penn State

- Dr. Ali Memari – Penn State AE Faculty
- Kevin Parfitt – Penn State AE Faculty
- Robert Holland – Penn State AE Faculty
- All other Penn State AE faculty and staff

Industry Professionals

- Jeff Antolick – TRC Worldwide Engineering
- AE message board mentors

Design Firms

- Thomas Speer LLC
- Coreslab Structures
- DFD CornoyerHedrick
- Paul Koehler
- Heliodyne

Executive Summary

As climate change continues to become more prevalent in the public eye, it is the responsibility of every person to make small changes in their life to combat this global problem. This senior thesis project is aimed to research and design various elements of the building that can be implemented immediately, meaning that all technologies are currently used. This report will investigate the use of vegetative roofing, insulated concrete sandwich panels, radiant solar collectors, as well as the structural elements as green building materials.

North Mountain IMS Medical Office Building is a 123,000 square foot medical office building located in Phoenix, Arizona. The building reaches a height of 56' and consists of three supported office floors and a surgical center on the ground floor. The structural system is entirely precast concrete, featuring shear walls as the lateral load resisting system.

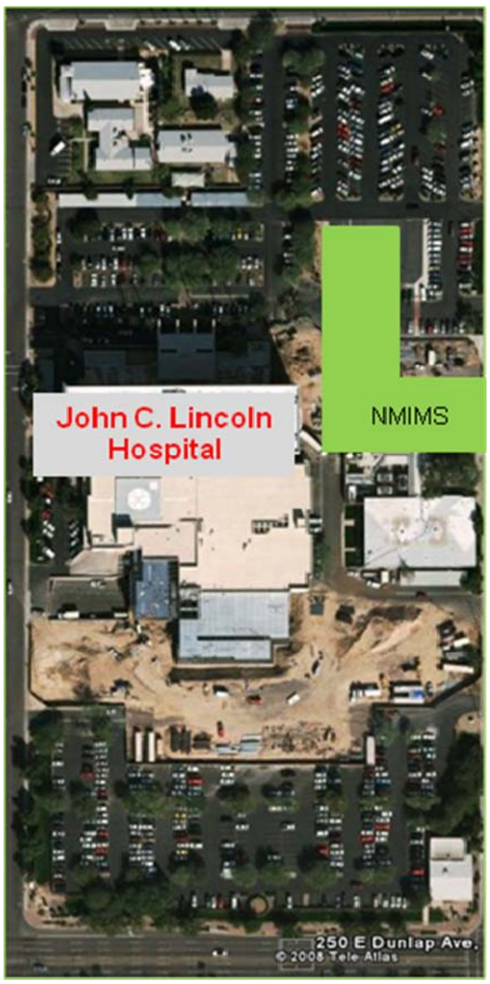
All redesign considerations for this project have the underlying theme of sustainability. The building was redesigned as ordinary steel moment frames which greatly reduced the structure weight. A vegetative roof is proposed as well as increasing thermal efficiency of the building enclosure. Impacts to the mechanical system because of these design changes are discussed.

The resulting research shows that small changes can have a significant impact on the overall environmental footprint of the building. However, making these changes require certain sacrifices to be made to other aspects of the building design and construction.

North Mountain As Designed Conditions

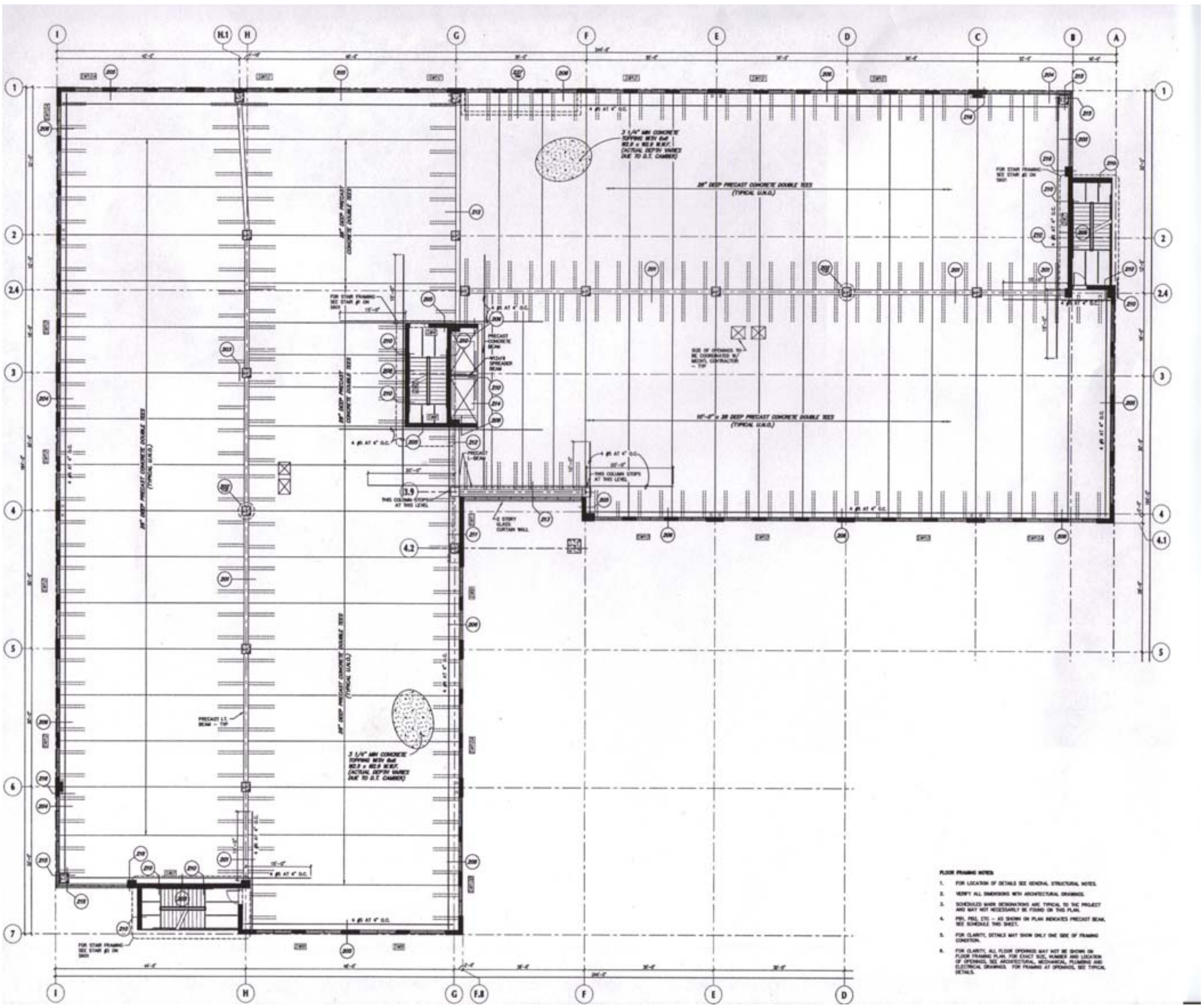
Building and Site Overview

North Mountain IMS Medical Office Building is a 123,400 square feet precast concrete office building located in Phoenix, Arizona. This $10 million design-build project started construction in June of 2007 and was completed February 2008. As part of the North Mountain medical complex, the building features a state-of-the-art outpatient diagnostic imaging center and ambulatory surgery center on the ground floor. The three remaining floors feature over 92,000 square feet of open, rentable office space. The total building height is 60 feet, with a mechanical parapet wall that reaches 70 feet above ground level.



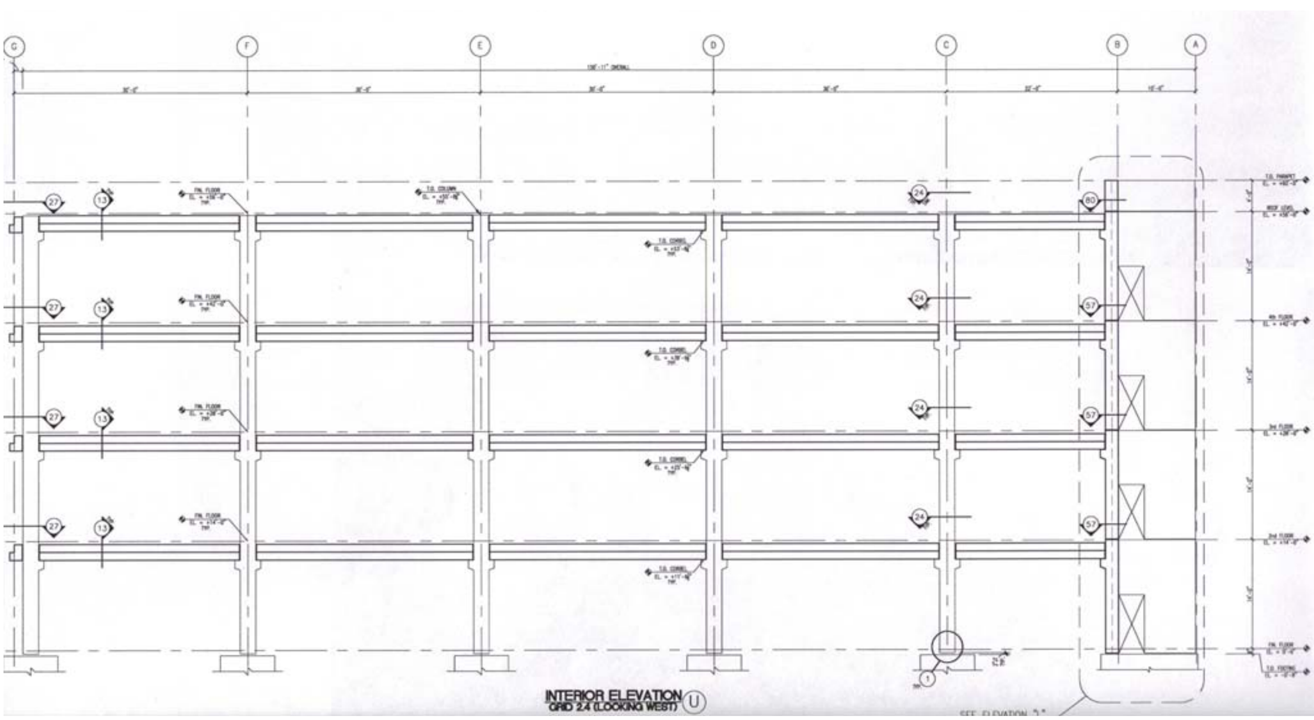
Typical Framing Plans and Details

North Mountain IMS Office Building floor framing consists of 24" deep, 10' wide double tees with a minimum of 3-1/4" concrete topping. The tees are normal-weight concrete and have a 28-day compressive strength of 6,000 psi. The minimum prestress release strength is 4,200 psi. The prestressing strand is 7 wire, ½" diameter 270 ksi low relaxation strand. Each strand is pulled to 72.5% capacity, which results in a 30 kip force. The strand is held down at one point in the middle of the tee. Depressed strand provides greater flexural strength while reducing the stresses in the concrete during prestress release. Typical spans are 44', 48', and 54'. A typical floor plan is shown below.



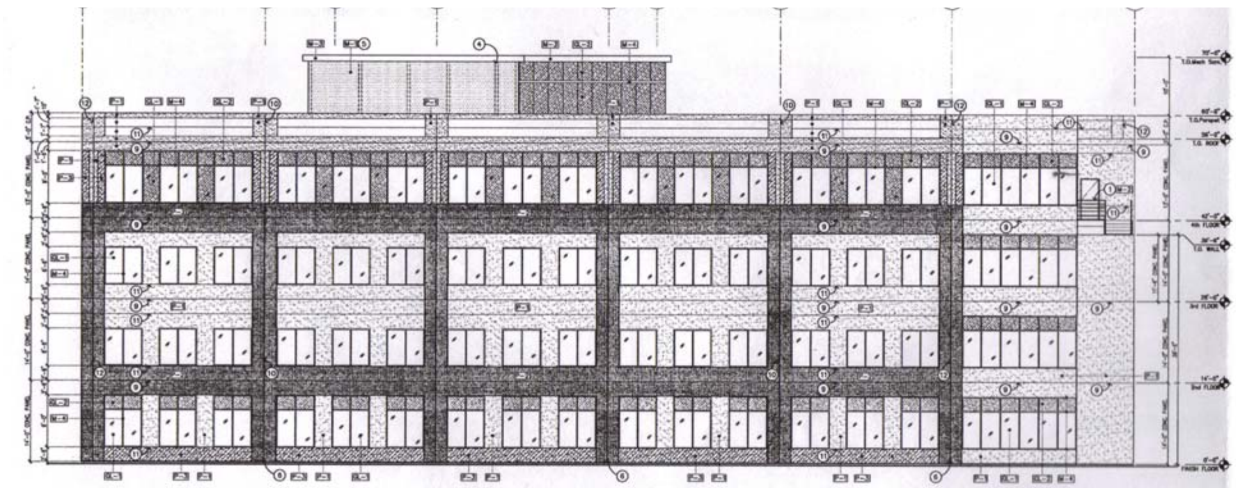
The 24” deep double tees are supported on the interior by 24” deep by 32” wide inverted tee girders. 28-day strength is 7,500 psi and minimum release strength is 3,750 psi. Typical inverted tee girders use 22 ½” diameter stand for tensile reinforcement. Span length for a 30’ bay is 28’ due to the columns on each end. Dapped ends on the double tees allow the top of the tee to line flush with the top of the girder. The topping is then poured over the tee and the girder at the same time, interlocking them. This construction technique is known as emulation. Emulation design creates construction that is either monolithic at critical joints, or provides connections that act as if they are monolithic at those locations. This is a great way to connect precast pieces in high seismic zones.

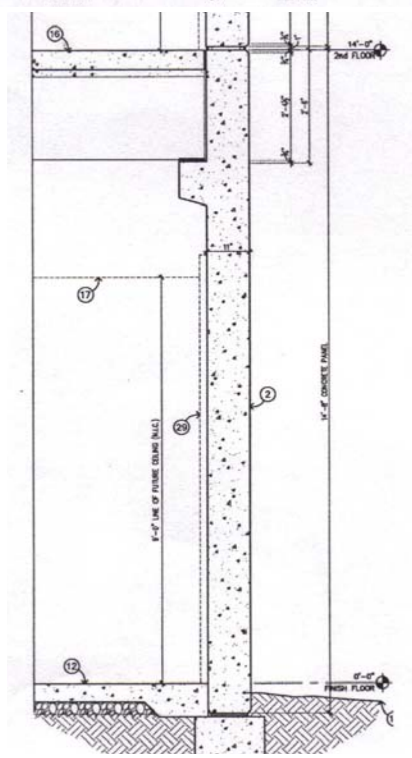
Interior spans of inverted tee girders bear on 24” x 24” columns. Concrete strength is 6,000 psi. There is no need for prestressing strand in columns, because there is no large tensile zone. Any tension in the columns is addressed with traditional reinforcing bars. These columns are 56’ tall and arrive on site in one piece. These columns showcase precast concrete’s advantages over other structural systems. The columns only need one connection, to the foundation. This ease of construction makes North Mountain’s erection duration much shorter compared to other systems. However, long lead times may be an issue due to cure time and storage at the precast fabrication plant. A typical interior elevation is shown below to demonstrate the bearing conditions for inverted tee girders and columns.



The exterior walls for North Mountain IMS Office Building fulfill many different structural requirements. First, and most importantly, they provide the building enclosure. Second, they support gravity load from double tees. Third, the walls are detailed to provide a pleasant architectural aesthetic. Last, but also extremely important, they resist the lateral forces due to wind and earthquakes. These walls give the structure its rigidity and structural integrity. Without shear walls, a moment-resisting frame system would have to be used. This structure utilizes interior and exterior shear walls. The interior shear walls are located in the center of the building around the elevator shaft and a stair tower. Shear wall design will be discussed at length in the Lateral Load Resisting System section of this report.

Below is an exterior elevation. It is easy to notice the different textures applied to the exterior of these walls. These finishes are applied when the panels are cast, which makes for no further work when they arrive on site. Also, the exterior wall sections depict the bearing condition for double tees.





Structural System

Design Loads:

Live Loads:
- Roof Live Load……………………………………………..20 psf
- Floor Live Load…………………………………………….80 psf
- Stair Live Load……………………………………………100 psf
- Partition Live Load………………………………………20 psf

Dead Loads:
- Superimposed Roof Dead Load……………………………..15 psf
- Superimposed Floor Dead Load……………………………15 psf

Wind Load:
- Total Wind Force (North-South Direction)………………218 kips
- Total Wind Force (East-West Direction)…………….…….285 kips

Seismic Load:
- Design Base Shear………………..…………………...1627 kips

Gravity Loads:

The floor live loads for North Mountain are typical office loads. The second, third, and forth floors all feature an open floor plan with no set dimensions for walls or corridors. Because of the open floor plan, the floor live load is 80 psf. By code, corridor loading above the first floor is 80 psf. However, 50 psf is the minimum recommended live load for office space above the first floor. For design, the corridor value was used as the live load over the entire floor; it is much easier to assume a uniform load over the entire floor compared to breaking the loads down between office and corridors. Also, a partition live load of 20 psf is used over the entire floor.

The floor dead load only accounts for 15 psf of superimposed load which includes mechanical, electrical, and pluming equipment. The nature of precast concrete structures makes it very simple to calculate the actual weight of the structure; a dead load in pounds per square foot is not needed because each piece of precast is detailed and the exact weight calculated. Tabulated structure weights can be found on pages 12-15 in the Appendix.

In Phoenix, there is no snow load. However, a roof live load is still required. This live load accounts for potential ponding of rain water and construction loads.

Wind Load:

Wind Load Factors:
Basic Wind Speed, V = 90 mph

Importance Factor, I = 1.15
Occupancy Category, IV
Exposure Category, B
Topographic Factor, Kzt = 1.0
Gust Factor, G = 0.803 (E-W) 0.814 (N-S)
Exposure Classification, Enclosed
Internal Pressure Coefficient, GCpi = +-0.18
External Pressure Coefficient, Cp = 0.8 (Windward) -0.5 (Leeward) -0.7 (Side)

Wind load was not expected to control the lateral design due to the overall dimensions of North Mountain. The building is fairly short and it is not located in a high wind zone. Also, there are no abnormal site features, such as hills or valleys, which would increase the wind speed. Wind load calculations are based on ASCE 7 Method 1. The resulting calculations gave a base shear value of 218 kips in the North-South direction and 285 kips in the East-West direction. Complete wind load calculations are provided in the Appendix on page 16.

Seismic Load:

Seismic Load Factors:
Seismic Response Coefficient, Cs = 0.0769
Total Dead Load, W = 21,153 kips
Spectral Response Accelerations, Ss = 0.256, S1 = 0.075
Site Classification, C
Response Accelerations, Sms = 0.307, Sm1 = 0.128
5% Damped Design Spectral Response Accelerations, Sds = 0.205, Sd1 = 0.085
Approximate Fundamental Period, Ta = 0.409 s

Seismic loading controls the lateral design. The design base shear for seismic loads is actually over five times higher than the shear load due to wind. The precast structure is very heavy, which is the main cause for such a high seismic load. The calculated design base shear is 1627 kips. Complete seismic load calculations can be found on page 19 in the Appendix.

Mechanical System

North Mountain IMS Medical Office Building features a split air conditioning system for cooling and a. The split a/c system uses multiple water loop heat pumps and water cooled condensers. The condensers are sized for a summer ambient temperature of 115 degrees and a low of 40 degrees. Due to the preliminary nature of the mechanical drawings used for this project, these units were not yet specified by the mechanical engineer.

Outside air enters the building through one of two air handling units. When cooling, the units cool the air down to 55 degrees. This air is sent throughout the building by means of (2) 30”x24” vertical duct runs. These ducts are reduced to 16”x12” horizontal ducts to supply each area of the floor. The cooled air is then reheated by hydronic heat pumps based on the needs of the space. Hot water for the heat pumps is supplied by a 60 gallon electric water heater with an 85 gallon per minute capacity. Return air is completely exhausted; there is no recirculation of return air. The used water is routed back to the electric boiler.

Project Objective

As climate change continues to become more prevalent in the public eye, it is the responsibility of every person to make small changes in their life to combat this global problem. It is also the responsibility of industry leaders and politicians to make sound choices concerning the environment. The construction industry is no exception. In the United States, 54% of energy consumption is directly or indirectly related to buildings and their construction; commercial buildings represent a major share in energy consumption. In the past, this industry has been slow to change as code documents are approved years after they are published. However, technologies needed to stop global climate change currently exist. The construction industry should be the leader in the green movement, because public opinion holds "green" as fashionable and we can provide our future generations with sustainable, environmentally friendly buildings.

This senior thesis project is aimed to design various elements of the building that can be implemented immediately, meaning that all technologies are currently used, to produce a more sustainable building. This report will investigate the use of green roofing, insulated concrete sandwich panels, radiant solar collectors, as well as the structural elements as green building materials. When all of these technologies are combined, the result is a sustainable product which will last for many generations and be an example of industry leadership for all parties involved.

Structural Depth

North Mountain's precast concrete structure is efficient and provides a safe environment for all occupants. However, the heavy concrete structure raises the design seismic load to more than five times the wind load. Considering the building's dimensions, wind load should not control the lateral load resisting system in this region of the United States, but reducing the seismic loads could result in a more efficient structure. In general, there are two ways to reduce the seismic load on a building. The first is to change the lateral load resisting system itself. Different systems have different Response Modification Factors, R, which is a multiplier used to determine the magnitude of seismic loads. A smaller R value will result in a larger seismic load. The other way to reduce the seismic load is to reduce the weight. This can be accomplished by choosing different materials for the floor framing and lateral load resisting system.

This project incorporates both techniques. However, using steel ordinary moment frames will change the R value from 4 to 3.5 resulting in a slightly higher seismic load. However, seismic loads will still be reduced by a dramatic drop in weight. A different facade could also be used to reduce weight, but this may drastically alter the exterior appearance of the building. So, the exterior precast concrete walls will remain. However, they will not act as part of the lateral load resisting system. This allows them to be thin which, once again, reduces the structure weight.

Sustainable Architecture Breadth

Reducing electricity use and limiting green house gases will help to create a more sustainable Earth. A sustainable building incorporates many different green technologies throughout all aspects of construction. For this breadth, a few main components will be investigated to produce a more environmentally friendly building. Such components will include a vegetative roof and insulation techniques for precast concrete wall panels. Also, the effects of changing the framing system from concrete to steel will be discussed.

Mechanical Breadth

In conjunction with sustainable architecture, the means and methods of providing heating and cooling for a building must also be investigated. With the addition of a green roof and increased exterior insulation, new heating and cooling loads will have to be calculated. Also, by utilizing Phoenix's 200 plus days of full sunshine a year, energy to generate hot water can be greatly reduced. A system of panelized radiant solar collectors on the roof will provide hot water for the building's heating demand. Even though the Phoenix climate does not require a high demand for heating, the goal is to utilize nature as much as possible to provide heating for the building.

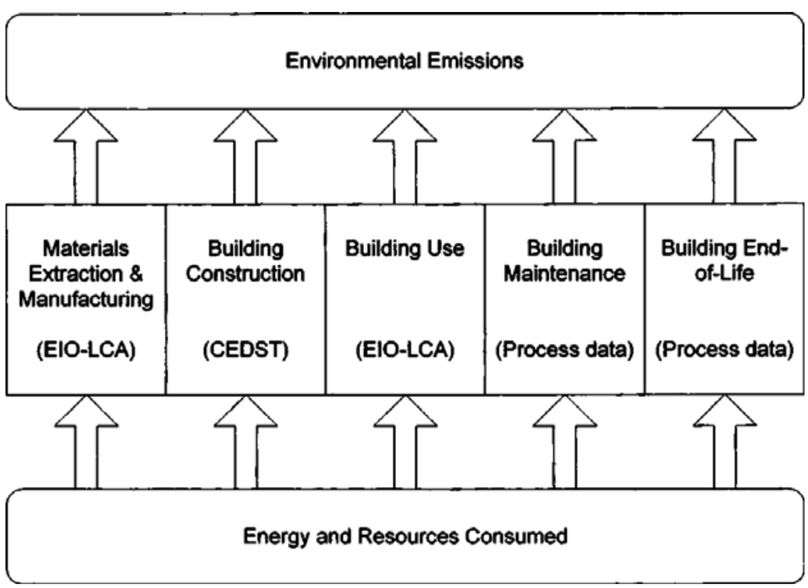
Sustainable Architecture Breadth

Environmental Effects of Steel vs. Concrete Building Frames

www.shalomrav.wordpress.com

www.healylongjevin.com

When considering the environmental effects of buildings, all stages of a building's life-cycle must be considered. These stages include material extraction and manufacturing, building construction, building use, building maintenance and building end-of-life. Life-cycle assessment (LCA) is commonly used to measure the overall environmental impact of buildings. LCA accounts for energy use and emission generation for every life-cycle stage. Simple LCA is used in this report to compare the environmental impacts of the existing precast concrete framing system with the redesigned steel frame. The figure below shows the basic principles of LCA, breaking down the building into phases and measuring each part's environmental impact. Using this type of approach, it is easy to determine specific areas for improvement.



Life-cycle phases of an office building

The largest difference between concrete and steel frames is noticed in the materials extraction and manufacturing and building construction phases. The following sections will discuss and compare the environmental impacts of both concrete and steel relating to building frames.

Material Extraction and Manufacturing

Steel is an exceptional performer with respect to recycled content. The amount of recycled content in steel products varies over time, both as a function of the cost of steel scrap and its availability. The only manufacturing method used domestically for the production of structural shapes contains about 95% recycled content. Since steel is made to exact specifications, on-site waste is minimized. Steel is the worlds, as well as North America's, most recycled material.

Recycling of concrete is a relatively simple process. It involves breaking, removing, and crushing existing concrete into a material with a specified size and quality. The quality of concrete with recycled concrete aggregates is very dependent on the quality of the recycled material used. Reinforcing steel and other embedded items, if any, must be removed, and care must be taken to prevent contamination by other materials. The crushing characteristics of hardened concrete are similar to those of natural rock and are not significantly affected by the grade or quality of the original concrete.

Fly ash, slag cement, and silica fume are industrial by-products that are used as a partial replacement for portland cement in concrete. These supplementary cementitious materials (SCMs) are pre-consumer materials. If not used in concrete, these materials would use valuable landfill space. Fly ash is commonly used at replacement levels up to 25%; slag cement up to 60%; and silica fume up to 5% to 7%. Because the cementitious content of concrete is about 7 to 15%, these SCMs typically account for only 2% to 8% of the overall concrete material in buildings.

Building Construction

For either frame system, materials must be shipped to the site from the fabricator's shop. North Mountain has a steel fabricator and precast manufacturer within 20 miles of the site. This is an important variable to take into account; the trucks used and distance traveled to transport the material can considerably effect emissions. Trucks carrying concrete pieces can potentially have higher emissions and lower fuel efficiencies than trucks carrying steel pieces due to the heavier loads on each truck.

Waste and temporary materials used at the fabrication shop are also a large contributor of negative environmental effects. A few examples are oils and lubricants used in steel shops and wood forms used in precast concrete production. Precast concrete, however, has many advantages over cast-in-place concrete. Since each precast manufacturer produces standard size pieces, formwork is typically used more than once. Also, controlled shop settings reduce the amount of waste concrete used. Steel shapes are manufactured to exact specifications, so steel waste is limited.

Building Use and Maintenance

Building use and maintenance includes all impacts of functions, renovations, materials and related activities to the use phase of a building. This phase is the most energy intensive within LCA; it includes all the energy required to heat, cool and power the building. Energy consumption during the use phase is typically the main topic of discussion when considering sustainable design. However, the structure represents little environmental impact during this phase. For a typical office building, such as North Mountain with a 50 year lifespan, the building use and building maintenance phase is comparable for either a concrete or steel frame. The best way to limit negative environmental effects caused by the building frame during this phase is to ensure efficient and practical construction practices.

Building End-of-life

The end-of-life phase includes demolition of the building and removal of debris. Typically, concrete buildings take longer to demolish than steel buildings. Also concrete frames are much heavier than steel frames which will require more trucks to remove debris off site. Nearly 100% of structural steel is recycled into new steel products at the end of their useful life. Concrete is a relatively heavy construction material and is frequently recycled into aggregate for road bases or construction fill. Concrete can be especially difficult to recycle because all other materials must be removed, such as rebar. Once separated, rebar can be recycled.

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Concrete frames have more embodied energy due to the use of temporary materials such as formwork and extra transportation impacts due to its larger mass. However, construction of steel frames produces more volatile organic compounds (VOCs) and heavy metal emissions due to touch cutting and welding. Referring to page 37 in the Appendix, typical construction process diagrams of steel and concrete buildings show where waste and various emissions are generated. Studying these diagrams proves to be inconclusive when trying to determine the worst environmental offender. There is not a prominent difference between concrete and steel frames. Also, building frame construction only represents up to 10% of energy use during a building's life cycle.

Relating LCA to North Mountain will create more efficient building structure and systems design. In terms of this project, many sustainable items have been implemented in the redesign. A green roof will significantly reduce roof maintenance costs and energy use for heating and cooling systems. Insulated concrete panels will further reduce energy use. Including specifications to include recycled content into construction materials will reduce manufacturing emissions. Since the redesigned structure will feature mostly steel and concrete produced in fabrication shops, on site construction waste will be kept to a minimum. The structural frame for North Mountain, whether steel or concrete, will not have near the environmental impact as the mechanical and electrical systems.

Green Roof

Green roofs provide many benefits for the environment, building occupants, and building owners. These advantages range from ecological to aesthetic to economic. The ecological benefits stem from replacing an unnatural surface with a mini ecosystem. Also, the green roof replaces the land that the building footprint occupies. Aesthetically, a green roof is a drastic improvement from an ordinary roofing system. Adding a green roof will add another level of aesthetic interest to a building. Economic benefits are not realized until the long term. Green roof installation is more expensive than a traditional system, but investing the extra initial capital can return by reduced maintenance costs and energy savings.

(Arizona green roofs, from left: Riverfront Residence, Yazzie Residence, Optima Camel View Village)

Green roofs can provide an inviting outdoor space while serving as a functional way to limit the heat island effect, control water runoff, and help to reduce energy requirements for the building. The proposed green roof for North Mountain will fulfill two of the above beneficial aspects; it will reduce both the heat island effect and building energy consumption.

According to the National Weather Service, Phoenix averaged 6.7 days of 110 degree heat a year in the 1950's. Now, that number averages 21.9 days. Unfortunately, this extreme heat does not dissipate at night; it is stored in the cities' buildings and paved surfaces. Outlining rural areas of Phoenix have an average night time low that is 14 degrees cooler than the city. Higher night time temperatures result in more energy and water use. This was the main factor when choosing to add a green roof to North Mountain.

Evaluating a green roof's insulation properties and determining exactly how much energy can be saved is a difficult task. Depending on water within the soil, the R-value will change dramatically. However, since there is little rain in Phoenix, the R-value of the roof will remain fairly constant. This R-value is not the most beneficial thermal aspect of a green roof. Since the green roof will have vegetation, the sun's rays are reflected away from the roof. This will reduce the actual temperature on the roof. Also, when it does rain, the process of evaporation will dissipate heat. Even though an exact R-value cannot be determined, there are many ways that the green roof will reduce stored thermal energy. These energy saving aspects will be discussed further in the mechanical breadth.

Selecting vegetation for a green roof in Phoenix Arizona is a challenging task. It is so challenging, in fact, that some landscape architects consider such information proprietary. The main challenges are the desert heat and little rainfall. However, many native plants will thrive in this environment. Most desert plants have long root systems. The plants use the long roots to search for water deep below the surface. Here in the Northeast, it is common to have a growing medium of only a few inches. In the Arizona sun, this is impossible without extensive irrigation. Irrigation should be avoided in most cases; the plants used for this project do not require irrigation. Water in this area is scarce and should be used only for necessity.

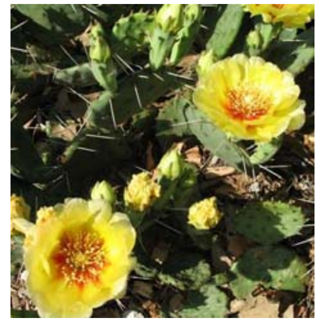
Using a variety of flowering plants and shrubs, the growing medium should be at least 10 inches deep for this area. Twelve inches ensures that root systems have ample room to develop. If large shrubs or small trees are desired, a soil depth of 24 inches is recommended. However, using this amount of soil can strain the structural system. Larger gravity beams are needed to provide the strength required due to the extra dead load. Also, placing this load on the roof causes a significant earthquake load to be applied at that story. As a goal of this project, lateral loads are to be kept to a minimum. Effects of this additional weight will be addressed in the structural depth portion of this report.

For North Mountain, a soil depth of 10 inches was chosen. With this depth, only small shrubs can be used. Again, no irrigation is necessary with the vegetation selected. Using many online landscaping guides for the Phoenix region, the following plants were selected.

Trailing Rosemary: As one of the best and toughest plants for arid growing zones, trailing rosemary does well in poor or shallow soils. It tolerates great heat and blazing sun as well as cold climates. Pale flowers appear along branches in spring and throughout the year. The low-growing form is used as a ground cover. The upright form makes a nice shrub or hedge. Grows to 2 feet high and spreads 3 to 6 feet or wider. (www.horticultureunlimited.com)

Damianita: This ground cover is a star performer in the arid Southwest. Damianita has a long blooming season and fragrant foliage. Golden yellow, daisy-like flowers are small - about 1/2 inch across. Bright green, needle-like leaves create a nice contrast to the flowers. This plant has a long bloom period, but flowers are most profuse in the spring and fall. Damianita grows at a moderate rate to 2 feet high and 2 feet wide. (www.horticultureunlimited.com)

Prickly Pear: Easily grown in dry, sandy or gravelly, well-drained soils in full sun. May be grown in clay soils as long as drainage is good and soils do not remain wet. Plants often spread in the wild to form colonies as pads break off and root nearby. (www.mobog.org)



Hedgehog Cactus: A small barrel-shaped cactus. Flowers are scarlet red, with many petals, and are cup-shaped. The flowers are one to two inches long and grow below the stem's apex. Flowers bloom April through June, from low to higher elevations. This is the first cactus to bloom in the spring. The flowers bloom three to five days. (www.desertusa.com)

Precast Concrete Sandwich Panels

Architectural precast cladding provides an efficient building enclosure while offering a variety of finishes that can provide almost any desired aesthetic. Since the product is manufactured in a factory setting, there is high flexibility of architectural finishes. Manufactures must satisfy strict dimensional tolerances and offer superior performance. These panels are thermally efficient and use a minimal amount of material.

Examples of Architectural Precast (from left): Gateprecast.com, acps.com, Ravacast.com

Precast concrete sandwich panels were chosen as the building envelope for this redesign project mainly to ensure that the architectural aesthetic of the new system resembled the architect's original design. This was achieved by casting the panels with the same dimensions as the original shear walls. Precast sandwich panels were also selected due to its high thermal and strength efficiency. The strength aspects will be discussed in the structural depth portion of this report.

The panels used for this project provide all necessary insulation for the building's exterior wall. This is a great feature, because no further insulation is required once the building is erected saving interior construction time and cost. Higher R-values result in lower heat loss through the insulation. This is a very important part about sustainability; more insulation means less energy use. The insulation selected is called ISOCAST R and is a type of Polyisocyanurate insulation manufactured by Dow Building Solutions. The product works very well for concrete sandwich panels. It provides excellent insulation with an R-value of 6.5 per inch and will not corrode or react chemically with the concrete. Also, it is manufactured into 4'x8' sheets which can easily be cut to fit any desired shape.

Despite a high insulation value through most of the sandwich panel, large windows will subtract from the overall facade insulation value. North Mountain has many large windows which must be considered when determining insulation value. The existing windows consist of a single pane ¼" low E glass. To significantly increase the overall insulation value of the wall panel, a significant change must be made to the windows as well. Using double or triple pane windows can make that significant change. Also, using a variety of different coating films, solar heat gain can also be reduced. Reducing solar heat gain is an important part of cutting cooling costs especially in a city that averages over 200 full sun days a year.

The new glazing selected for North Mountain is a double pane system featuring 2 ¼” low E panes separated by ½” air space. Both panes are designed to limit solar heat gain while allowing visible to be transmitted. Below is the product description and specifications.

Oldcastle Glass®

Product Comparison Chart

Configuration	Nominal Thickness	Visible Light Trans %	Visible Light Reflectance Outside %	Visible Light Reflectance Inside %	Ultraviolet Trans %	Solar Trans %	Solar Reflectance Outside %	U-factor / U-Value Winter Nightime	U-factor / U-Value Summer Daytime	Shading Coefficient	Solar Heat Gain Coefficient	Relative Heat Gain	Light to Solar Gain
OB: 1/4" Pilkington Gold Eclipse Advantage™ Radiant Low-E #2 AS: 1/2" (Air Fill) IB: 1/4" Oldcastle Glass® SunGlass™ Low-E #3													
IGU	0.956	23	32	18	1	9	40	0.29	0.27	0.23	0.20	51	1.15

Using a layup of 2” concrete on the exterior face, 3” insulation, and 3” concrete on the inside face, an R-value of 21.8 can be obtained. Combine this with the new window R-value (4.63), and the overall panel R-value reaches 10.3. This is a 247% increase in thermal efficiency compared to the existing system. Refer to page 40 in the Appendix to see R-value calculations for the existing and redesigned building envelope. Energy savings due to this added insulation are discussed in the Mechanical Breadth portion of this report.

Mechanical Breadth

Heating and Cooling Load Reduction

According to the 2003 Commercial Building Energy Consumption Survey, space conditioning in U.S. commercial buildings is responsible for 3,037 trillion Btus per year of site energy use. This is a staggering number showing no signs of decreasing. For this breadth only the mechanical loads will be calculated. The existing structure is compared with the redesigned structure.

Heat loss is divided into two groups: transmission losses and infiltration losses. Transmission heat loss by conduction and convection occurs through confining walls, floors and ceilings. Infiltration heat loss is caused by outdoor air infiltration through cracks, openings and natural ventilation. Limiting each type of heat loss is important to reduce the overall energy consumption of a building. Higher R-values for building enclosures and roofing systems will reduce the amount of transmission heat loss. This is a relatively easy aspect of the building that can be redesigned. For this report, air infiltration and natural ventilation is assumed to be the same for both the original and redesigned building.

Trane Trace 700 was used to compute heating and cooling loads for both the existing building and the redesigned building. Based on occupancy and function, the program determines the requirements for heating and cooling in BTU/hr and tons, respectfully. The purpose of using this program is to see what effect the precast concrete sandwich panels and green roof would have on heating and cooling loads. As stated previously, the R-value for the existing façade is 4.2, and the new system is 10.3. The percentage of glass area on each wall of the building ranges from 27% to 37%. So, a large part of the increased efficiency is a function of selecting insulating glass instead of single pane.

Since North Mountain is a general office building, the space on the upper floors will be divided based on tenant demands. Modeling these floors with rooms would be impossible because there is no way to know how the floor space will be divided. Instead, each floor was modeled as an individual room, making a total of 4 rooms. Heating and cooling loads were first determined by modeling the existing building. The model produced similar results to those calculated by the design professional. The design and calculated loads are shown on the next page.

Design and Calculated Loads

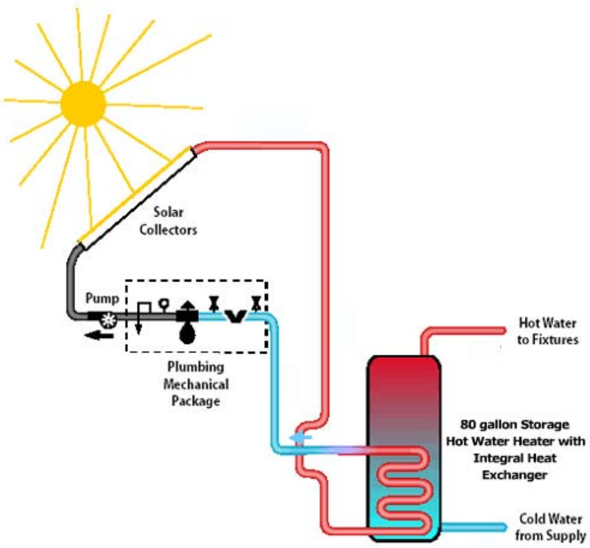
	Heating (Btu/h)	Cooling (tons)
Design Professional	641,650	341
Calculated Exisiting	670,678	394
Calculated Redesign	681,226	256

Since the model was considered accurate, a new model was created representing the façade changes and green roof. The program accounted for these changes by adjusting the U-value of the roof and walls. Also, the reflectance of the new windows was also taken into account. However, the reflectance of the roof was not considered for the redesigned model; there is no way to enter that information into the program. The green roof would have a lower reflectance than then existing system, which would result in further decreased cooling loads.

The calculated results show that the increased insulation reduced the cooling load by 138 tons, or 35%. However, the heating load increased by 10,000 Btu/hr or 1%. This can be accounted for the fact that the new windows have a higher reflectance which will limit solar gain in the cooler months. Smaller air handling units can be sized based off the new cooling load requirements.

Radiant Solar Collectors

Radiant solar water heating panels work by capturing the suns radiant energy and converting it into heat. Tubes inside the panel either directly heat the water flowing through them or a transfer fluid that warms a heat exchanger. This exchanger heats water in a storage tank. Solar systems must be used in conjunction with a conventional system in case of extended periods of cloudy weather. Utilizing Phoenix's 200 plus days a year of full sun, radiant solar collectors are an efficient way to reduce the overall energy use within North Mountain IMS Office Building.



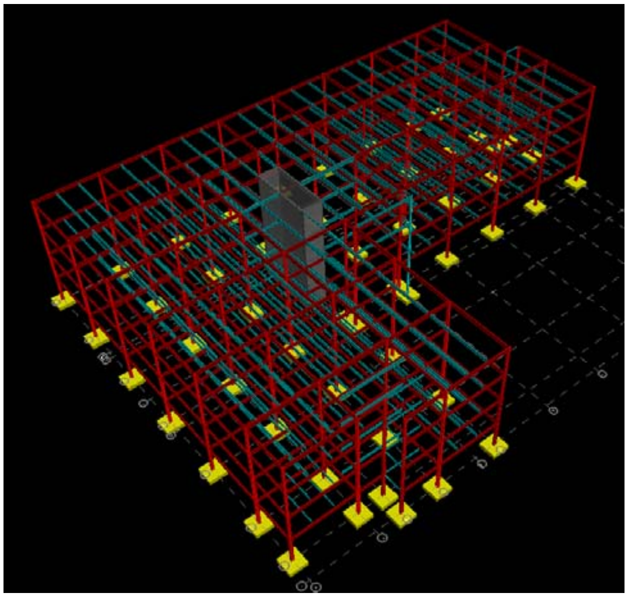

University of South Carolina (www.thermomax.com)

The solar water heating system was sized using RETScreen Clean Energy Project Analysis Software. This software allows input of the project location as well as many different solar products. Heliodyne Gobi 410 glazed panels were selected. These panels are very efficient for the Phoenix region. Evacuated tubes were also considered, but they tend to be more efficient for colder climates. Also, glazed panels have much cheaper upfront costs. Based on the RETScreen software, 25 panels are required provide roughly 320,000 Btu. This is approximately half of the required load. However, if 50 panels are used, the energy provided does not double. Inefficiencies in the system do not allow for a linear relationship. To combat this issue, two separate systems will be used; 25 panels and one storage tank for each system. This will provide a total of 640,000 Btu of energy, enough to generate almost the entire heating requirement for the building. The output of this program can be seen in the Appendix on page 42.

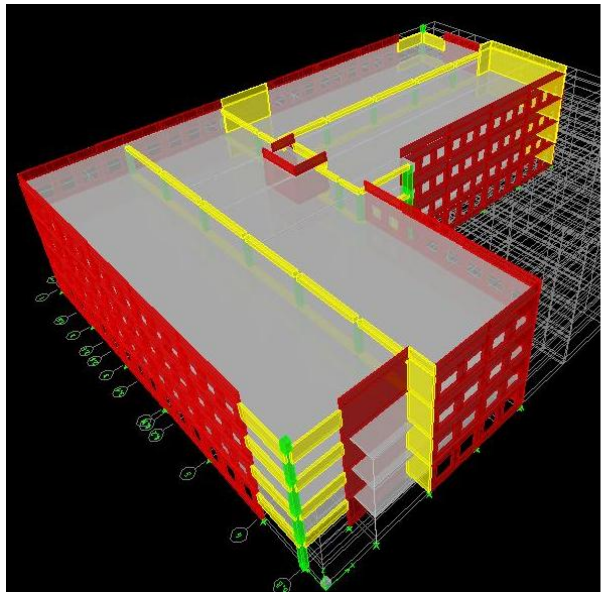
The storage tanks will rest of the roof, which minimizes the distance hot water travels to the tanks. The Gobi 410 panels are 4'x8'. Using 50 panels gives a total panel area of 1,600 $ft.^2$. This could potentially reduce the size of the green roof, but the panels are installed on a 25 degree incline which reduces their projected area by 10%. This incline will also allow plants to grow underneath. The shading form the panels will also be beneficial, reducing the temperature on the roof. The southern face of the building is 180' long, so two rows of panels facing due south can easily be adapted into the roof structure.

Structural Depth

Precast to Steel Framing



RAM Structural System



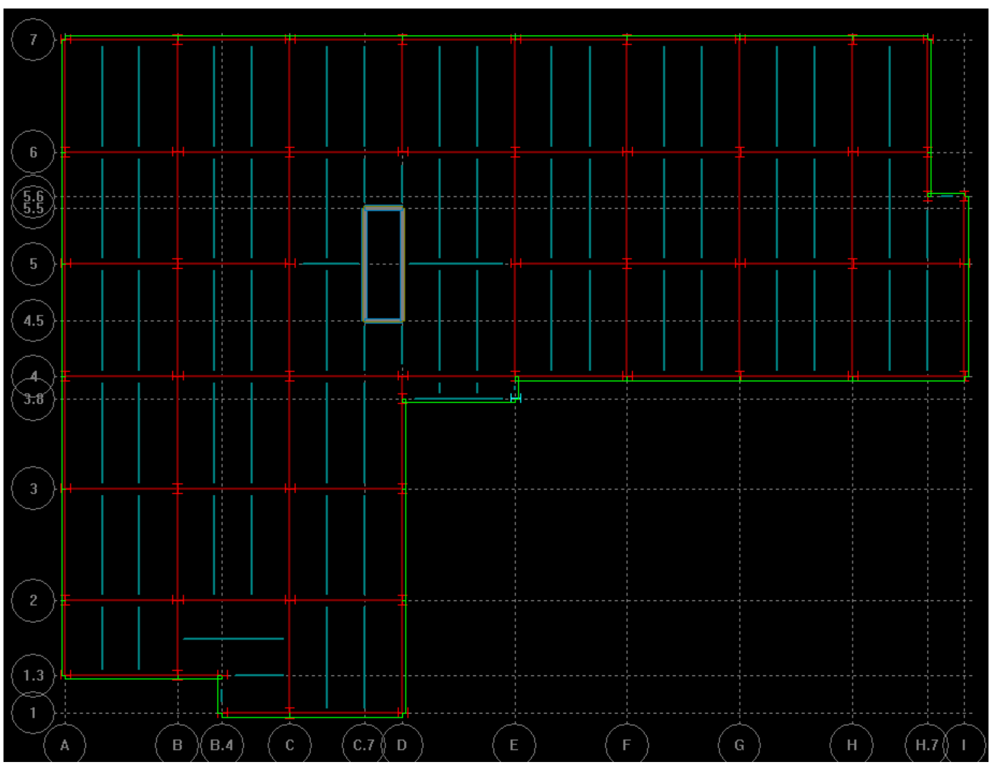
ETABS

The main reason for changing the structural system from precast concrete to steel was to reduce the weight of the structure. The massive precast concrete system had seismic forces which are five times more than the wind forces. Steel frames are much lighter than concrete frames, and changing the system for North Mountain proved to significantly reduce the design seismic forces. Complete framing plans, which will be discussed in detail throughout this section, are provided in the Appendix on page 43.

Ordinary steel moment frames were selected as the lateral load resisting system. The building structure is designed as a space frame, meaning that the structural system composed of columns, girders and connections resist the applied loads by flexural stiffness, strength and ductility of its members and connections. For the redesigned building, all girder-to-column connections are designed as rigid. Braced frames are unpractical in an office building with rentable space, as it is desirable to keep the floor plan as open as possible. However, by deviating from the long spans capable of prestressed concrete, more internal columns had to be added. Future tenants will have to work around and within the column grid. A potential major pit fall of adding more columns is the effect on the layout of the first floor surgical center. Without the layout of this floor, it was impossible to determine appropriate column locations. Lacking this information, square 30’-0” structural bays were designed. This size bay works perfectly in the 180’-0” by 240’-0” building footprint.

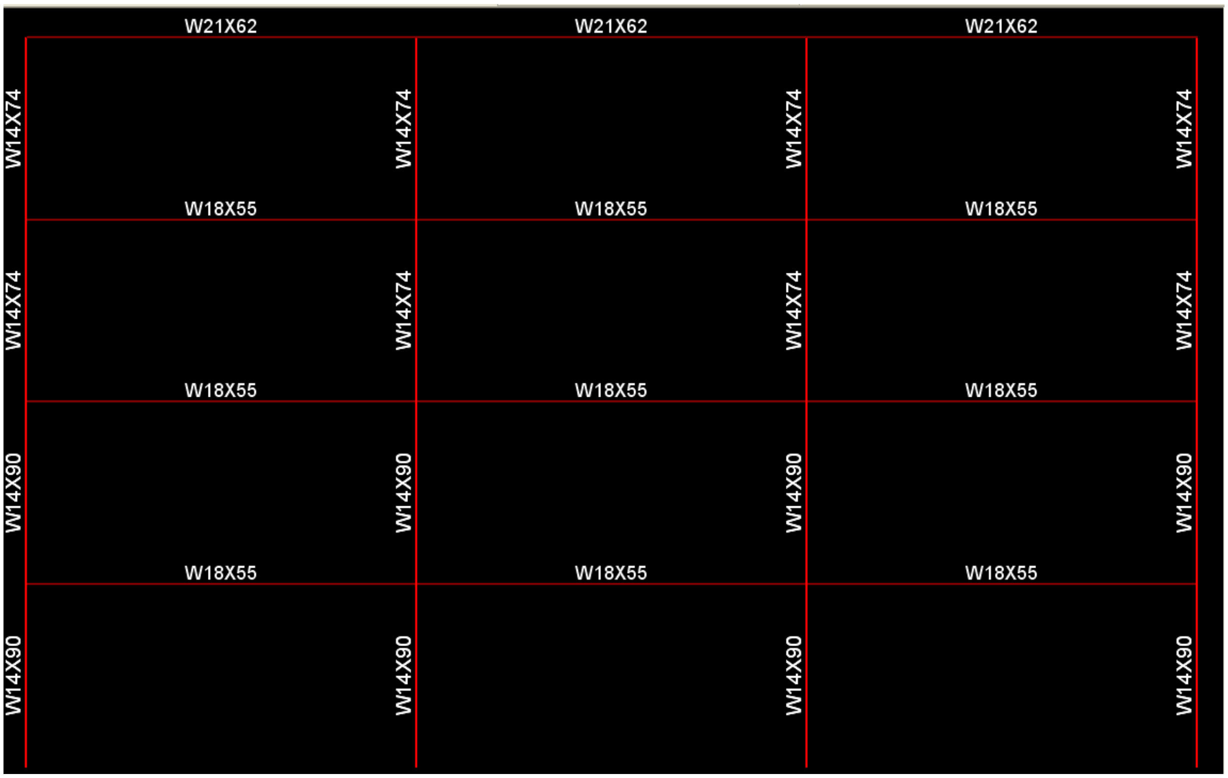
Gravity loads remain the same on the office floors, however the addition of the green roof adds significant load to the roof framing. If needed, reference “loading analysis” in the North Mountain as Designed Conditions of this report for loading information. The ten inches of soil is considered dead load and analyzed at 100 psf. Also, building code requires an additional 20 psf live load for green roofs. Slab and deck design were based on ten feet spans. Vulcraft 2.0 VLI 17 composite floor decking was selected. The deck load table used can be found on page 47 in the Appendix. This deck and slab selection can withstand loads from both the roof and office floors. Using composite beams, the typical gravity beam size for office floors is W16x31 with 18 studs. These beams span 30’-0” and have a tributary width of 10’-0”. W18x35 beams with 22 studs are required on the roof.

Seismic loads were drastically reduced due to the lighter structure and the decreased response modification factor, as mentioned earlier. As designed, the seismic base shear is 1627 kips. The steel framed base shear is 730 kips, which is 45% of the concrete frame seismic load. Seismic calculations are provided on page 48 in the Appendix. To compare how this would relate to material savings, concrete shear walls similar to those used in North Mountain would have to be designed for the steel frame system using this new base shear value. However, in an effort to reduce the amount of concrete in the building, steel moment frames were selected to act as the lateral load resisting system. As shown below, all bays act as moment frames in each direction. The elevator shaft in the middle of the building does not provide any resistance to lateral load.



(Red beams and columns indicate moment frames)

Using RAM Structural System, the typical frame beams are W18x55 on the first three floors, and W21x62 on the roof. W14x74 columns support the roof and the fourth floor. These columns carry their loads to W14x90 columns which support the third and second floor. RAM designed the frames based on user inputs for story forces. Story force calculations are provided on page 50 of the Appendix. A typical frame is shown below.



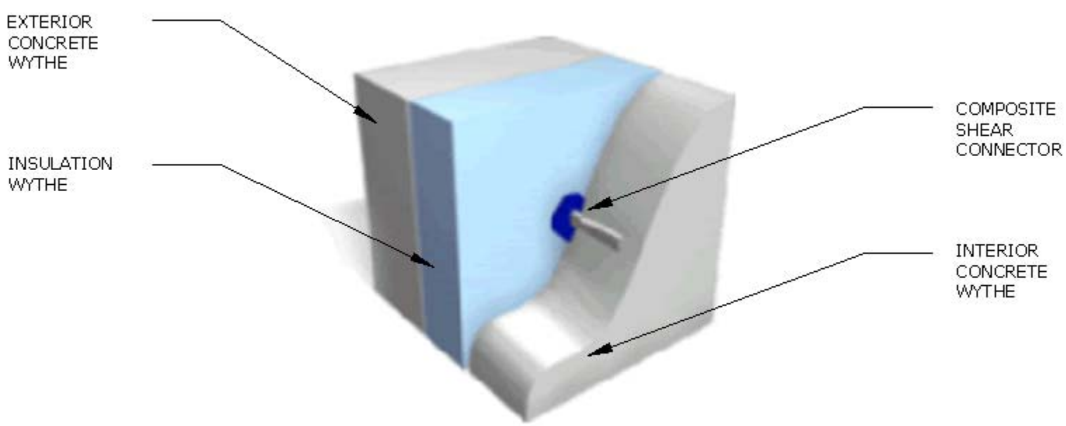
The precast concrete frame performed very well under seismic and wind loading conditions, with a total building drift of less than half and inch. This is a number that can not be matched be the steel frame. However, based on the size of members in the moment frame described above, total building drift is within code requirements. Refer to page 52 in the Appendix for story drift calculations and code comparisons. RAM Structural System was used to calculate building drift magnitudes.

Adding columns to the frame and reducing the gravity load also has a positive impact on the foundation system. The as designed system utilizes a series of drilled concrete piers. In some locations these concrete piers are drilled to a depth of 30 feet and have a diameter of six feet. With lighter column loads, deep foundations are no longer necessary. Even though soil bearing capacity is only 3,000 psf, standard spread footings can be used. Changing to the shallow foundation system will save approximately 170 cubic yards of concrete, which constitutes a 10% material savings. Material take offs are shown in the Appendix on page 54.

Precast Concrete Sandwich Panels

Load bearing concrete panels can support floor or roof gravity loads and can also be utilized as shear walls for the lateral load resisting system. Non-load bearing panels do not carry gravity loads, but can act as shear walls. However, non-load bearing panels must resist wind and earthquake forces acting on the panel itself. By using insulated concrete sandwich panels, a majority of the required insulation value for a particular building can be provided by the panel alone. Insulated panels can be load bearing or non-load bearing.

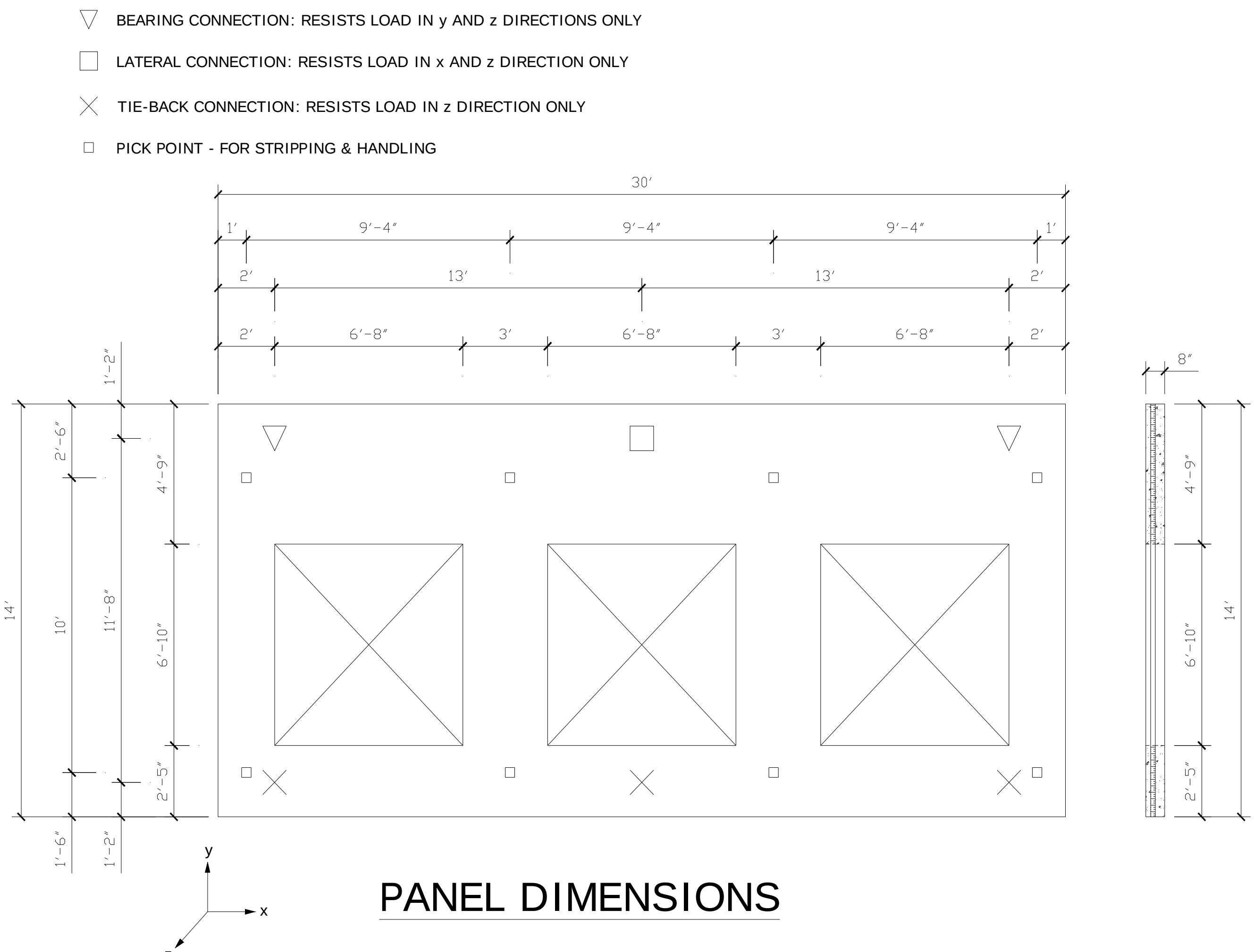
Concrete sandwich panels can be designed as either composite or non-composite. Composite panels use both concrete wythes to resist design loads. The figure below is an example of a composite panel. The shear connecter transfers load so that the two concrete wythes act as one. Panel thickness can be limited by allowing the two concrete wythes to act together. Shear connectors are typically steel, but for this project, fiber reinforced shear connectors were selected. These connectors are superior to steel connectors because of their low thermal conductivity, high strength, and resistance to corrosion.



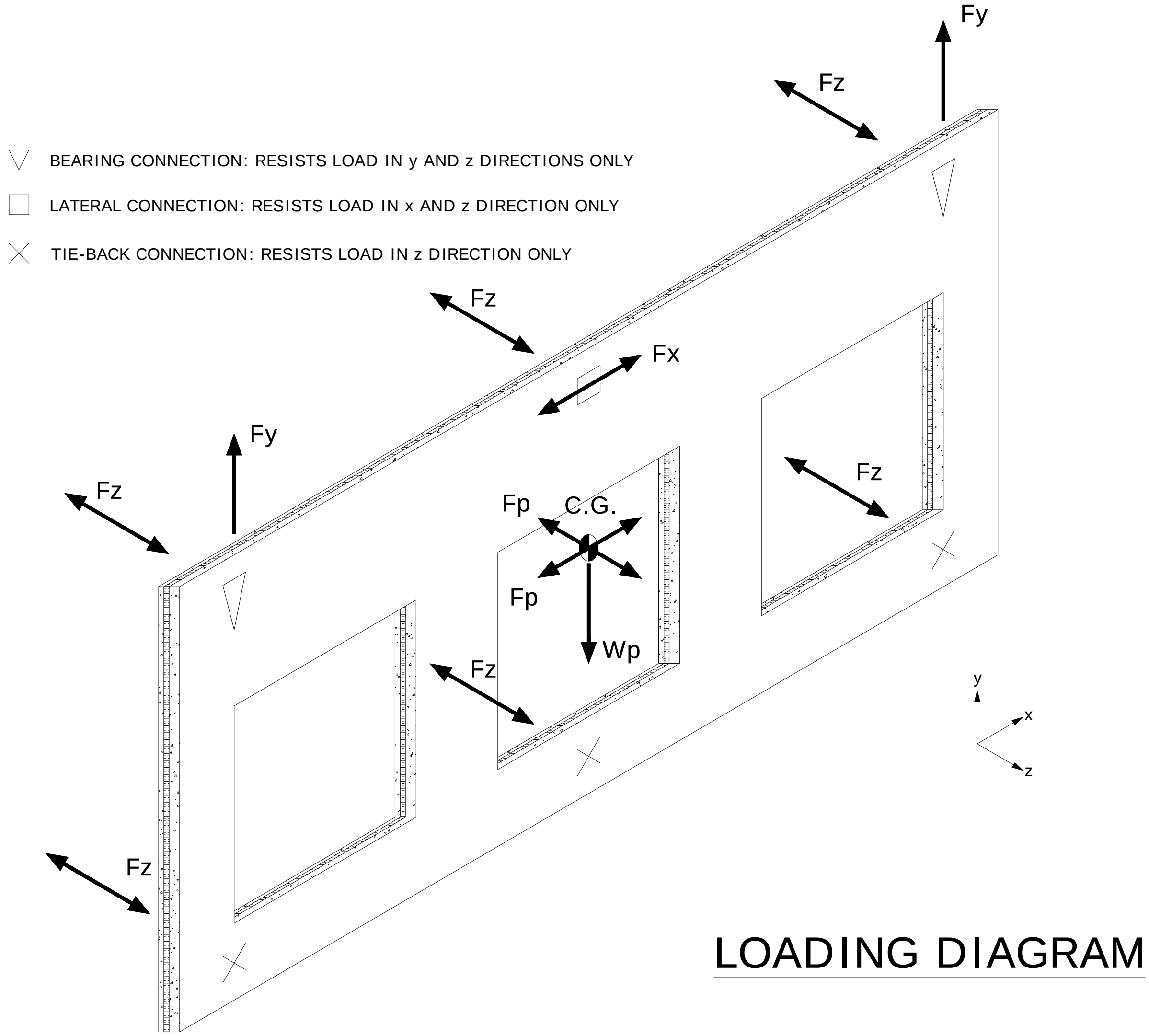
(www.thermomass.com)

Since the panels for the redesign are non-load bearing and are not self supporting, the only design loads to be considered are stripping and handling, wind, and seismic forces. Resulting calculations have shown that wind is the controlling service load. However, stripping and handling forces cannot be neglected. Panel load calculations can be found in the Appendix on page 55 Moments due to self weight and wind load were calculated using STAAD beam 2.0. Minimum reinforcement controlled the design of both the exterior and interior wythe. The panels were designed as composite panels; this was achieved by using fiber composite connectors.

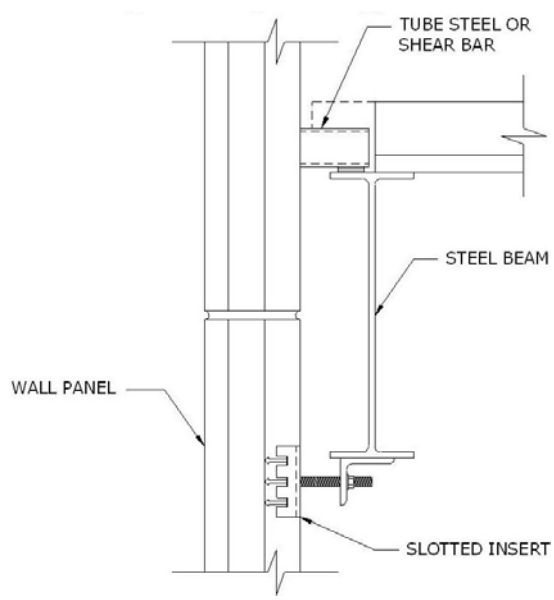
Connections must be properly detailed and designed to transfer panel loads to the steel framing system. Two bearing connections are provided near the end of each panel transferring the panel's self weight to the framing system. These connections also resist lateral load against the face of the panel. One lateral connection is provided to resist the lateral force acting in-plane with the panel. Tie-back connections must also be provided to give the panel stability. These connections as well as panel dimensions and stripping pick points can be seen in the following diagrams. Also, a simple wall section is provided to show typical connection details.



PANEL DIMENSIONS



Fy
Fz
BEARING CONNECTION: RESISTS LOAD IN y AND z DIRECTIONS ONLY
LATERAL CONNECTION: RESISTS LOAD IN x AND z DIRECTION ONLY
TIE-BACK CONNECTION: RESISTS LOAD IN z DIRECTION ONLY
Fz
Fx
Fy
Fz
Fz
Fp
C.G.
Fp
Wp
Fz
Fz
y
x
z
LOADING DIAGRAM



TUBE STEEL OR SHEAR BAR
STEEL BEAM
WALL PANEL
SLOTTED INSERT

The figure on the bottom of the previous page shows basic connection details for simple bearing and tie-back connections. This connection combination allows for fast erection. The panel is supported near its base with tubular steel or a shear bar. Once the panel is resting securely on the beam, the top is bolted through a steel angle that has been previously welded. The panel can be released as soon as the panel has been bolted down. This is an important safety feature, because no welding is necessary to initially secure the panel.

Considering various structural and architectural design criteria, the use of precast concrete sandwich wall panels has achieved the project objective. The panels use much less concrete than the original concrete shear walls, which reduces the overall structure weight. The total building enclosure weight was reduced by 55%. Due to the three inches of insulation in the wall panel, no further insulation is required in the interior of the building. Overall, precast concrete sandwich panels are an efficient, high quality product that should be considered for many different building types early in the design phase.

Conclusions and Recommendations

Overall, North Mountain IMS Medical Office Building is a safe and efficient building. The building meets all the owner's requirements and was delivered on schedule and on budget. Analyzing the success of a building can be measured on the following items, aesthetics, energy efficiency, total cost, quality of materials and swift construction. North Mountain is a successful building because it meets all of the owner's requirements. The most important aspects for the owner concerning the construction of North Mountain were time and cost. The owner wanted a building that could be completed quickly and at a competitive cost. The design provided certainly hits these marks while also providing a quality medical office building.

Changing a few aspects of the building will certainly effect both construction time and cost. Precast concrete is one of the fastest structural systems to construct as well as cost efficient. Changing to steel framing will add cost and time to the construction schedule. For the educational purposes of this report, the owner's needs were slightly ignored. However, the structural system redesigned within this report is a realistic effort of designing to specific goals set forth in the Project Objective. All design elements were carefully considered based on structural integrity, serviceability, cost efficiency and sustainability. No structure should be designed without constraints.

The use of space moment frames may not be the most efficient way of resisting lateral loads. A system of perimeter moment frames could have been explored. This would result in fewer moment connections resulting in a cheaper structure. However, the use of moment frames throughout the floor plan does provide a certain factor of safety because more elements are used to resist the lateral loads.

The redesigned structure met the goals outlined in the Project Objective section of this report. Structure weight was significantly reduced which saves on material. An added benefit of this is that the transportation requirement of materials is also reduced. The steel frame was originally proposed because it was thought that the recyclability of steel would make it a more sustainable construction material. However, upon further research, both steel and concrete frames have relatively equal environmental footprints.

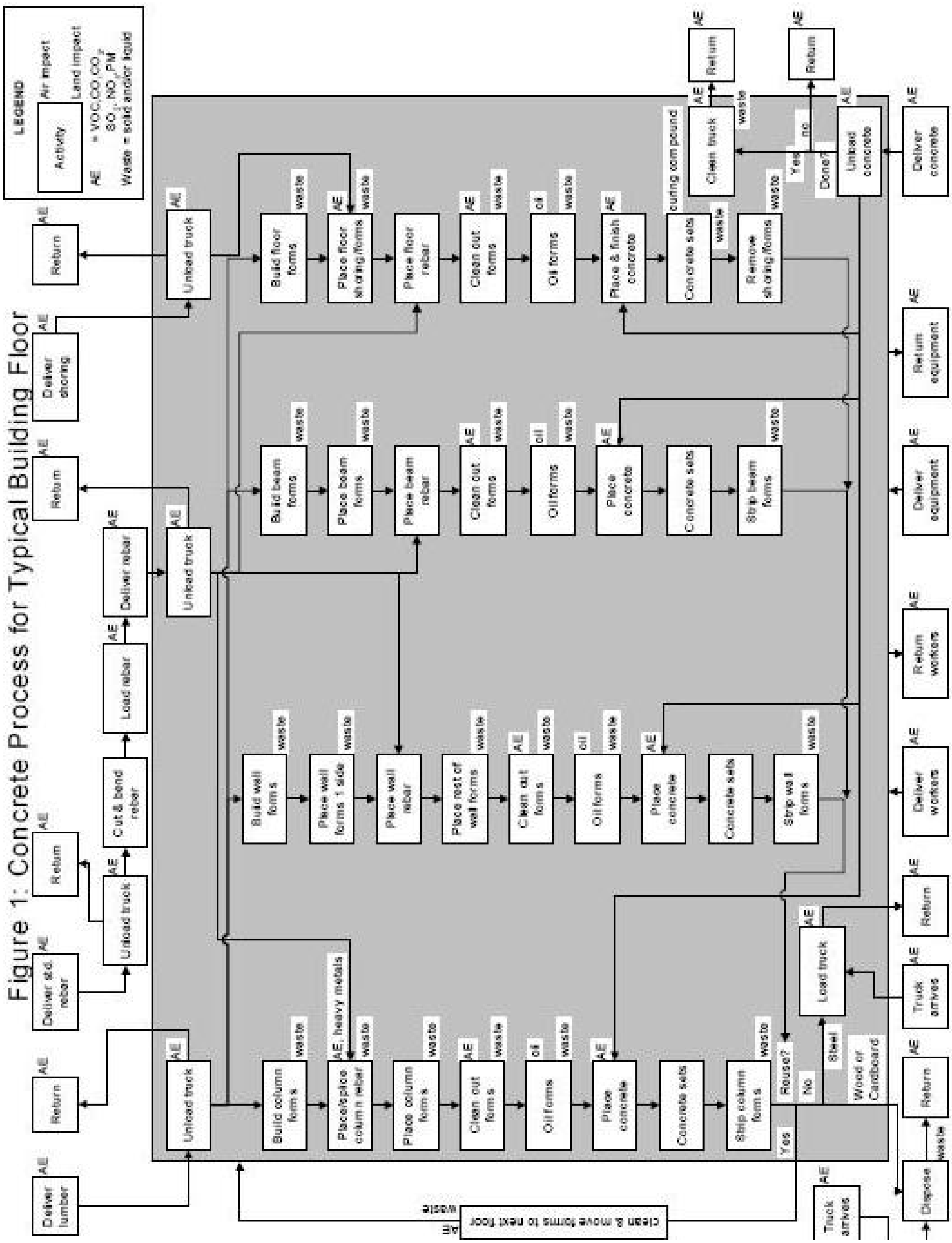
Reducing the environmental impact of this building was a large part of the design elements. Reducing the cooling load on the building will cause a significant drop in energy consumption. However, the changes required to facilitate a sustainable building are not cheap. The green roof, radiant solar panels, and insulated concrete panels will add significant cost to the building. Here is another example of where the owner's needs were skewed. These added costs are not in vein; the new heating system combined with the green roof will quickly recoup its upfront cost by an overall reduction in building energy consumption. Also, North Mountain could be a leader in sustainable design for the region; it would certainly have the largest green roof in the southwest.

The objective of this report was to investigate various techniques to reduce the environmental impact of the building. This was accomplished by vegetative roofing and increased thermal efficiency of the building enclosure. From the findings of this report, it is a general recommendation that all buildings should go through a “green engineering” design phase before construction documents are finalized. This would be a similar step as “value engineering”. Instead of finding ways to reduce costs in a building, green engineering would find ways to reduce energy consumption. Obviously, there are many ways to reduce energy consumption. The green engineering phase would concentrate on small changes throughout the building that would result in a significant reduction in energy consumption.

Certainly, more improvements could be made to reduce the environmental impact all buildings. One could argue that a more sustainable material exists for every aspect of design. However, ignoring the problem is far more perilous to the planet than choosing to do something, no matter how small. In this election year, I am inspired to quote two presidential contenders. From John McCain, “Our nation has both an obligation and self-interest in facing head-on the serious environmental, economic and national security threat posed by global warming.” And from Barack Obama, “Change does not happen from the top down, it happens from the bottom up.” The construction industry must be a part of the solution.

Appendix

Concrete Process Diagram



Steel Process Diagram

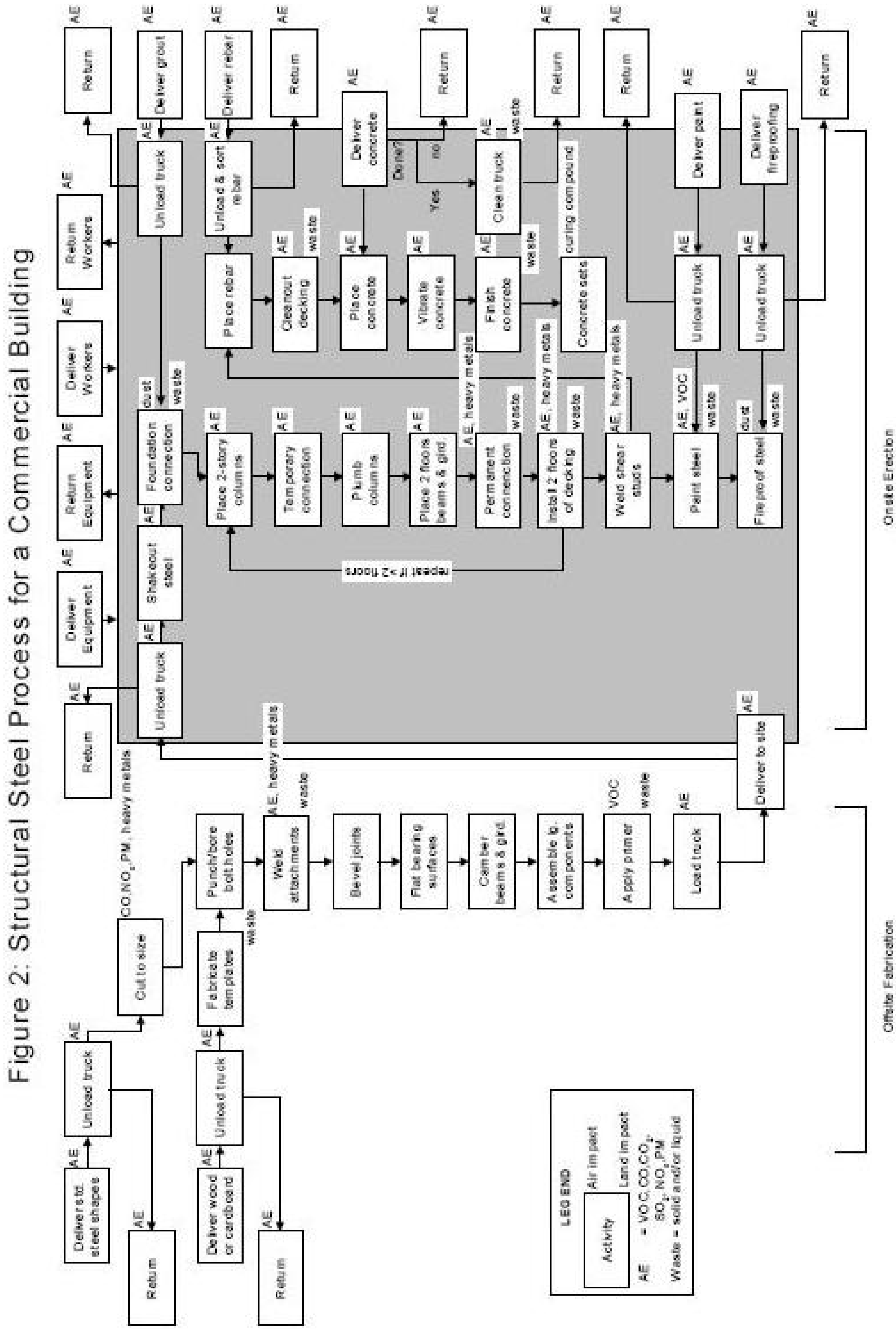


Figure 2: Structural Steel Process for a Commercial Building

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Roof R-value

EXISTING:

	WINTER	SUMMER
A. OUTSIDE SURFACE	0.17	0.25
B. ROOF MEMBRANE	0.33	0.33
C. POLYSTYRENE 4"	16.0	16.0
D. 5¼" CONCRETE (150)	0.53	0.53
E. BATT INSUL. 3.5"	11.38	11.38
F. ½ GYP. BOARD	0.44	0.44
G. INSIDE SURFACE	0.61	0.92
TOTAL R	29.5	29.9
U	0.034	0.034

REDESIGN:

	WINTER	SUMMER
A. OUTSIDE SURFACE	0.17	0.25
B. 10" SOIL	N/A	N/A
C. ROOF MEMBRANE	0.33	0.33
D. DRAINAGE	N/A	N/A
E. POLYSTYRENE 4"	16.0	16.0
F. 6" CONC. (110)	1.08	1.08
G. METAL DECK	0.0	0.0
H. BATT INSUL. 3.5"	11.38	11.38
I. ½" GYP. BOARD	0.44	0.44
J. INSIDE SURFACE	0.61	0.92
TOTAL R	30.0	30.4
U	0.033	0.033

Wall R-value

EXISTING CONCRETE SHEAR WALLS:

(REFER TO STRUCTURAL DEPTH FOR PANEL DIMENSIONS)

AREA INSULATED PATH = 293 ft.^{2} A_I/A_T = 0.698

AREA WINDOW PATH = 127 ft.^{2} A_W/A_T = 0.302

TOTAL AREA = 420 ft.^{2}

SUMMER:

$$\frac{1}{R} = \frac{0.698}{9.25} + \frac{0.302}{1.84} = 0.24$$

R = 4.17

WINTER:

$$\frac{1}{R} = \frac{0.698}{9.17} + \frac{0.302}{1.76} = 0.25$$

R = 4.0

INSULATED PATH

		K	THICKNESS (in.)	U = K/t	R = 1/U SUMMER	R = 1/U WINTER
A	OUTSIDE SURFACE	–	–	–	0.25	0.17
B	CONCRETE	10	11	0.91	1.10	1.10
C	BATT INSULATION	0.25	1-5/8	0.15	6.67	6.67
D	5/8" GYP. BOARD	1.14	5/8	1.82	0.55	0.55
E	INSIDE SURFACE	–	–	–	0.68	0.68
	TOTALS				9.25	9.17

WINDOW PATH

		K	THICKNESS (in.)	U = K/t	R = 1/U SUMMER	R = 1/U WINTER
A	OUTSIDE SURFACE	–	–	–	0.25	0.17
B	GLASS	0.28	1/4	1.10	0.91	0.91
C	INSIDE SURFACE	–	–	–	0.68	0.68
	TOTALS				1.84	1.76

REDESIGNED WALL PANELS:

AREA RATIOS SAME AS PREVIOUS

INSULATED PATH

		K	THICKNESS (in.)	$U = k/t$	$R = 1/U$ SUMMER	$R = 1/U$ WINTER
A	OUTSIDE SURFACE	-	-	-	0.25	0.17
B	2" CONC. (110 pcf)	5.55	2	2.78	0.36	0.36
C	3" INSULATION	0.15	3	0.051	19.5	19.5
D	3" CONC. (110 pcf)	5.55	3	1.85	0.54	0.54
E	5/8" GYP. BOARD	1.14	5/8	1.82	0.55	0.55
F	INSIDE SURFACE	-	-	-	0.68	0.68
	TOTALS				21.88	21.80

WINDOW PATH

		K	THICKNESS (in)	$U = k/t$	$R = 1/U$ SUMMER	$R = 1/U$ WINTER
A	OUTSIDE SURFACE	-	-	-	0.25	0.17
B	OLDCASTLE GLASS	-	-	-	3.70	3.45
C	INSIDE SURFACE	-	-	-	0.68	0.68
	TOTALS				4.63	4.30

SUMMER:

$$\frac{1}{R} = \frac{0.698}{21.88} + \frac{0.302}{4.63} = 0.097$$

$R = 10.3$

$$\frac{10.3}{4.17} \times 100 = 247\%$$

INCREASE

WINTER:

$$\frac{1}{R} = \frac{0.698}{21.8} + \frac{0.302}{4.30} = 0.102$$

$R = 9.80$

$$\frac{9.80}{4.0} \times 100 = 245\%$$

INCREASE

Energy Model Output

RETScreen® Energy Model - Solar Water Heating Project

Training & Support

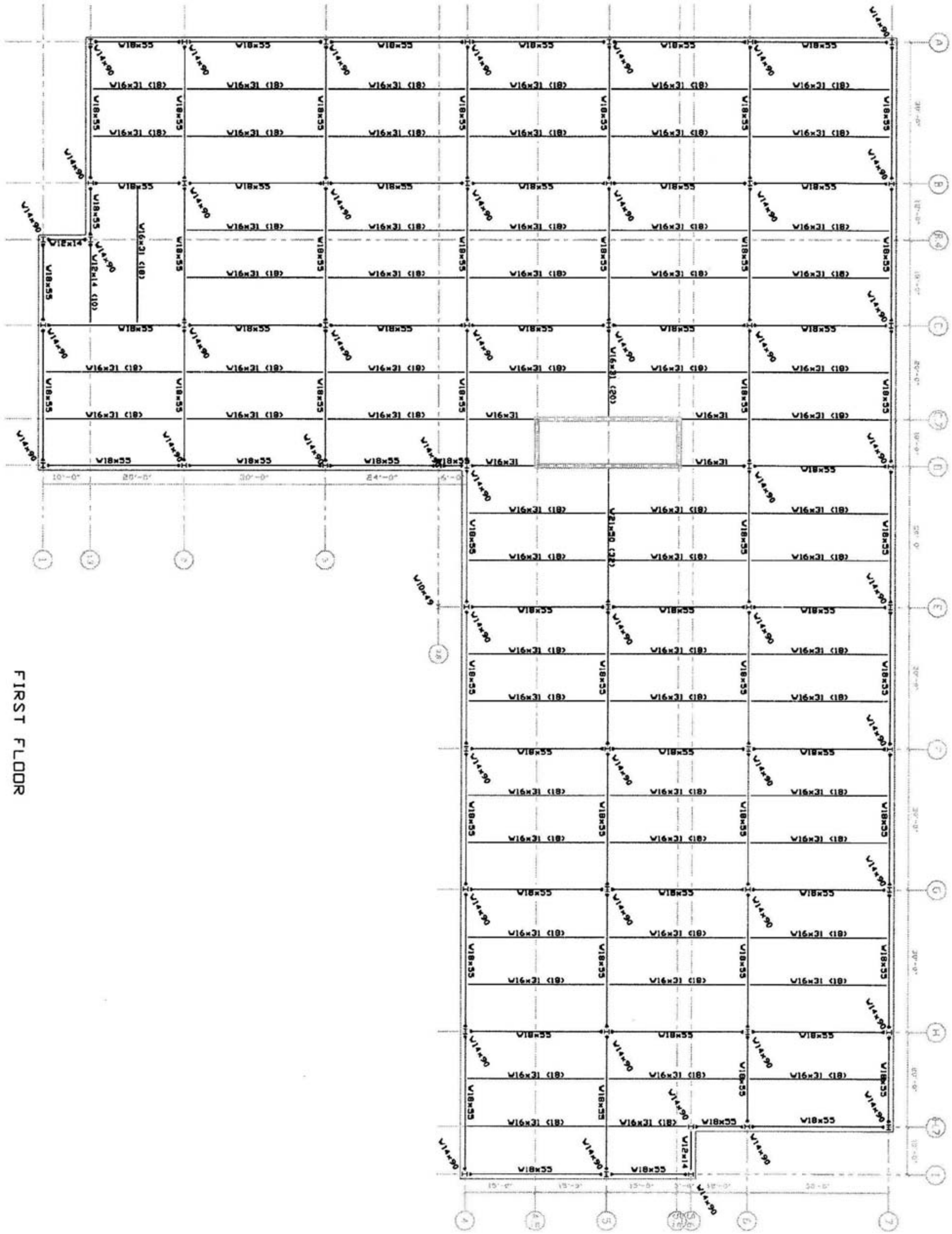
Site Conditions		Estimate	Notes/Range
Project name		Radiant Heating	See Online Manual
Project location		Phoenix, Arizona	
Nearest location for weather data		Phoenix/Sky Harbor, AZ	Complete SR&HL sheet
Annual solar radiation (tilted surface)	MWh/m²	2.31	
Annual average temperature	°C	22.7	-20.0 to 30.0
Annual average wind speed	m/s	3.0	
Desired load temperature	°C	60	
Hot water use	L/d	12,000	
Number of months analysed	month	12.00	
Energy demand for months analysed	MWh	190.57	

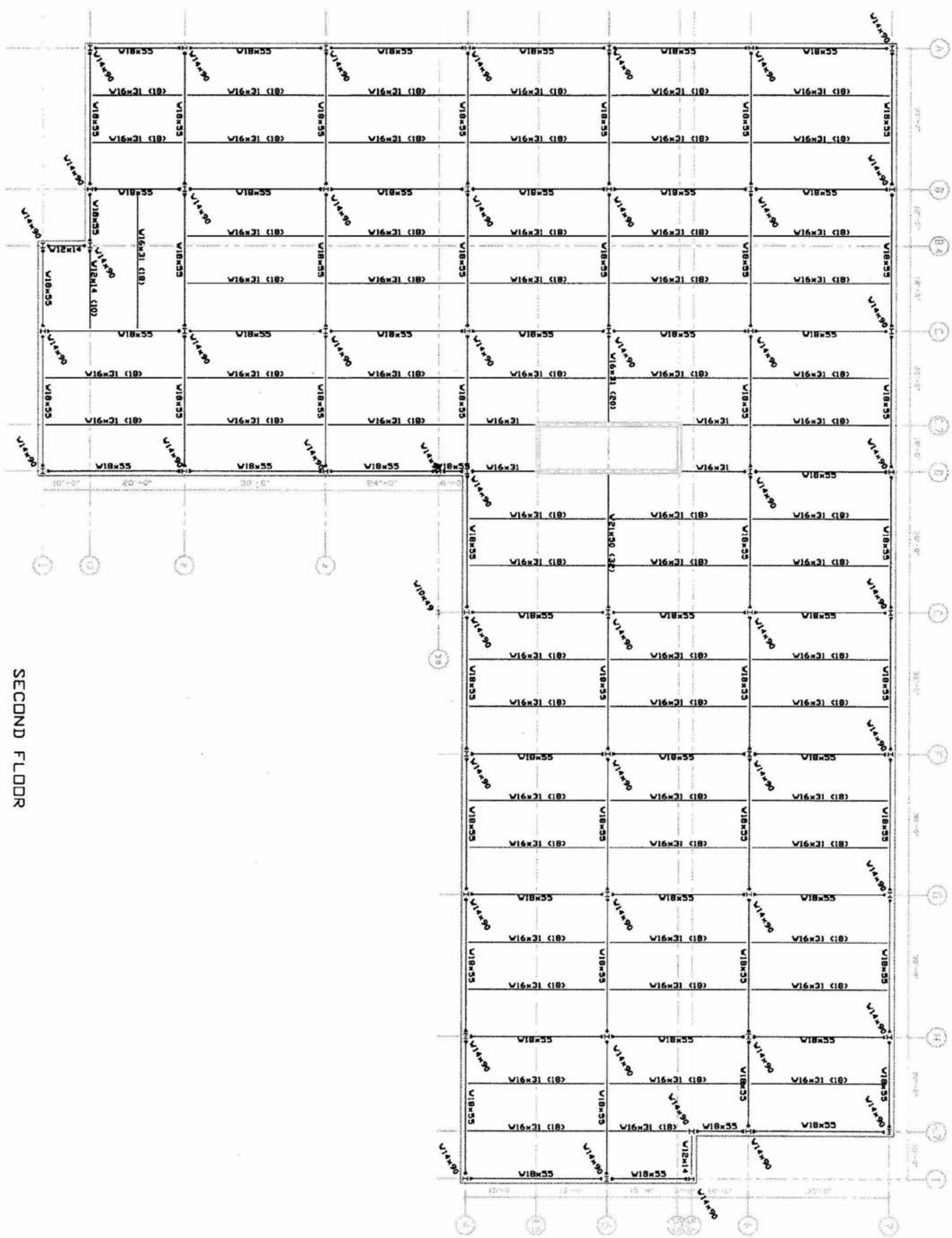
System Characteristics		Estimate	Notes/Range
Application type		Service hot water (with storage)	
Base Case Water Heating System			
Heating fuel type	-	Electricity	
Water heating system seasonal efficiency	%	150%	50% to 190%
Solar Collector			
Collector type	-	Glazed	See Technical Note 1
Solar water heating collector manufacturer		Heliodyne	See Product Database
Solar water heating collector model		Heliodyne Gobi 410	
Gross area of one collector	m²	3.74	1.00 to 5.00
Aperture area of one collector	m²	3.56	1.00 to 5.00
Fr (tau alpha) coefficient	-	0.74	0.50 to 0.90
Fr UL coefficient	(W/m²)/°C	4.57	1.50 to 8.00
Temperature coefficient for Fr UL	(W/(m·°C)²)	0.00	0.000 to 0.010
Suggested number of collectors		27	
Number of collectors		25	
Total gross collector area	m²	93.5	
Storage			
Ratio of storage capacity to coll. area	L/m²	45.9	37.5 to 100.0
Storage capacity	L	4,085	
Balance of System			
Heat exchanger/antifreeze protection	yes/no	No	
Suggested pipe diameter	mm	N/A	8 to 25 or PVC 35 to 50
Pipe diameter	mm	38	8 to 25 or PVC 35 to 50
Pumping power per collector area	W/m²	0	3 to 22, or 0
Piping and solar tank losses	%	1%	1% to 10%
Losses due to snow and/or dirt	%	3%	2% to 10%
Horz. dist. from mech. room to collector	m	5	5 to 20
# of floors from mech. room to collector	-	2	0 to 20

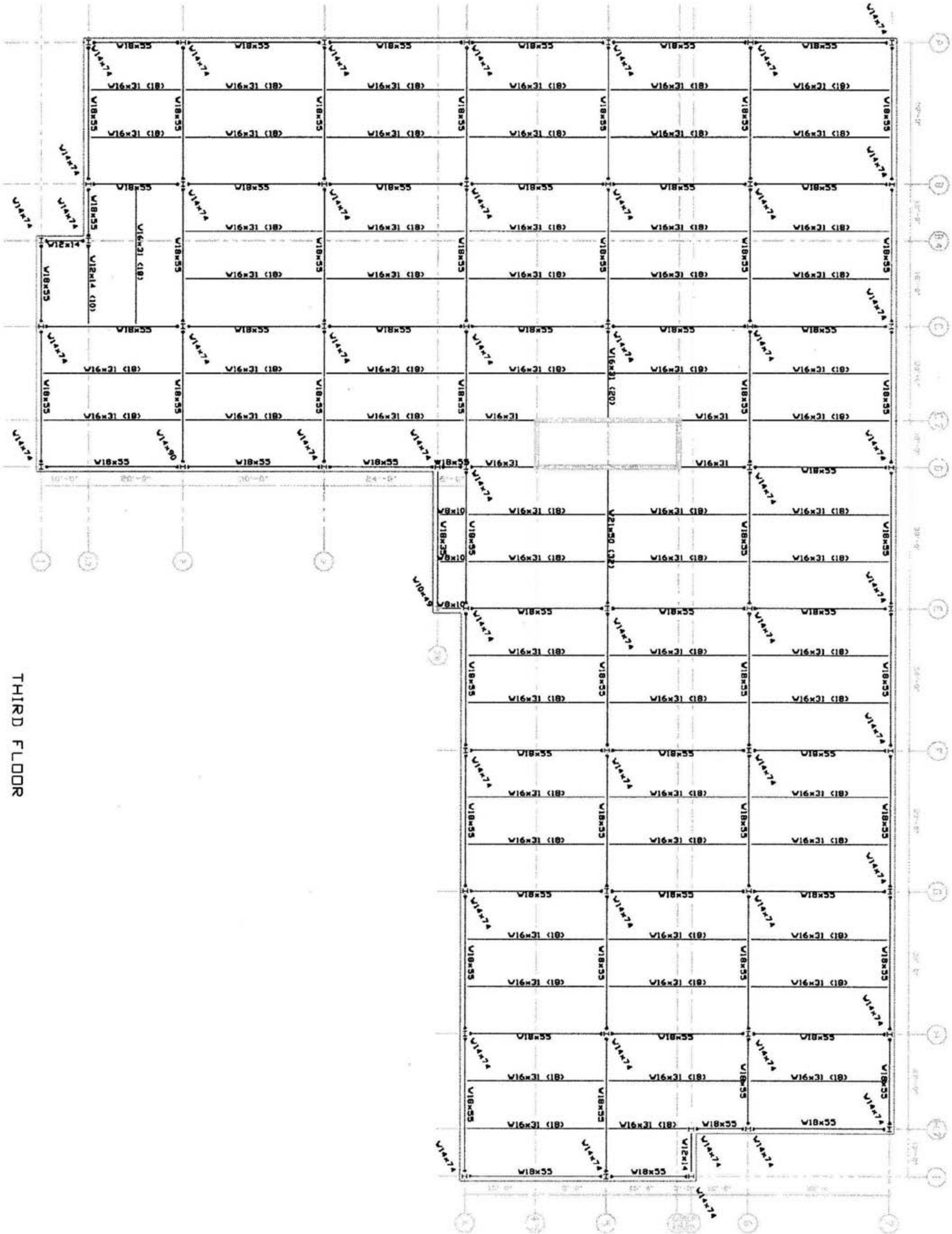
Annual Energy Production (12.00 months analysed)		Estimate	Notes/Range
SWH system capacity	kW_{th}	62	
	MW$_{th}$	0.062	
Pumping energy (electricity)	MWh	0.00	
Specific yield	kWh/m²	1,004	
System efficiency	%	43%	
Solar fraction	%	49%	
Renewable energy delivered	MWh	93.87	
	million Btu	320.31	

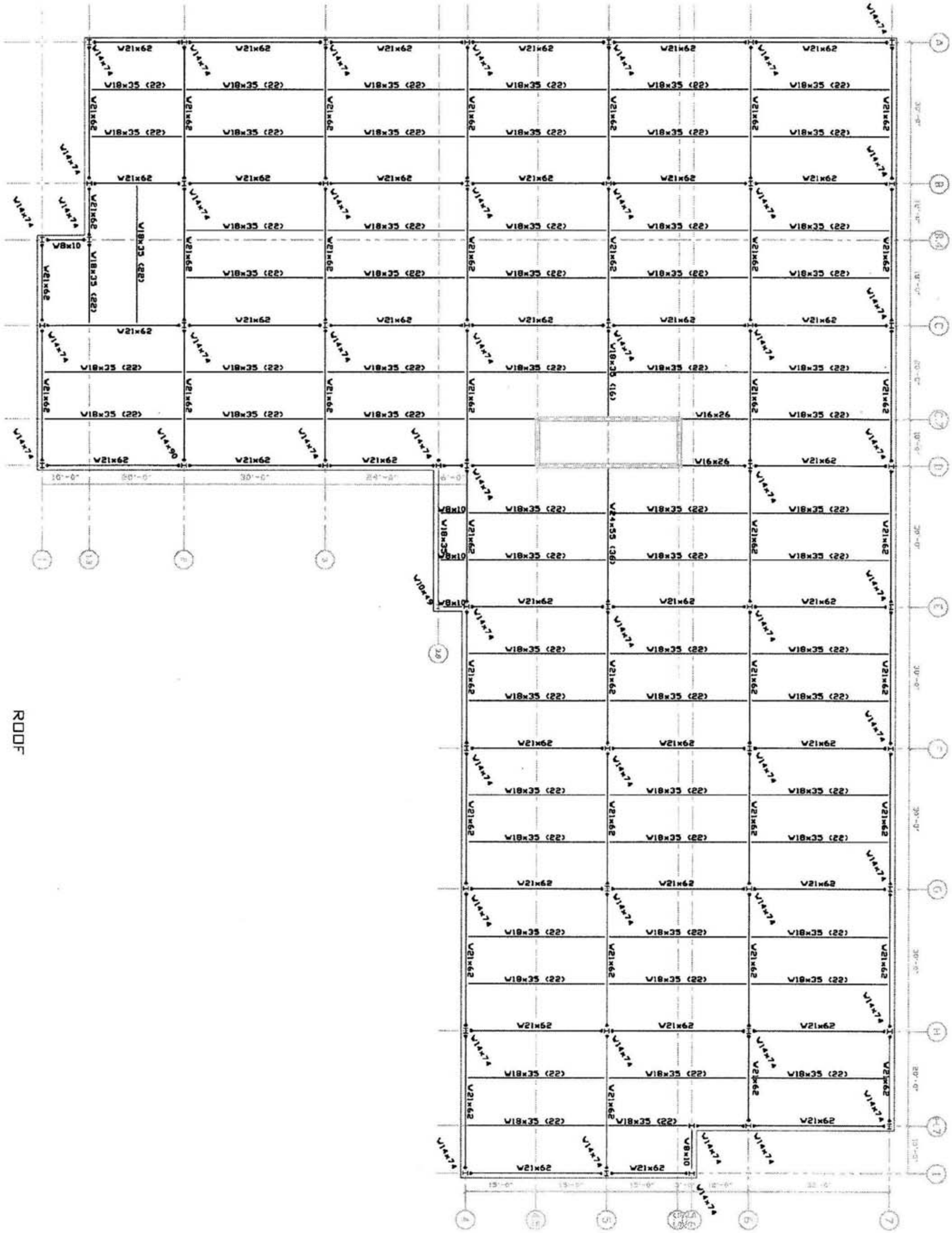
Complete Cost Analysis sheet

Framing Plans




SECOND FLOOR
W18x55
W16x31 (18)
W14x90
W12x14
W12x14 (10)
W16x31 (20)
W16x31
W21x50 (32)
W10x49


THIRD FLOOR
W18x55
W16x31 (18)
W14x74
W14x90
W12x14
W12x14 (10)
W16x31
W16x31 (20)
W21x50 (32)
W8x10
W18x35
W10x49


ROOF
W21x62
W18x35 (22)
W14x74
W14x90
W8x10
W16x26
W24x55 (36)
W18x35 (16)
W10x49

Vulcraft Deck Table

(N=14) LIGHTWEIGHT CONCRETE (110 PCF)

Total Slab Depth	Deck Type	SDI Max. Unshored Clear Span			Superimposed Live Load, PSF Clear Span (ft.-in.)														
		1 Span	2 Span	3 Span	6'-0	6'-6	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6	11'-0	11'-6	12'-0	12'-6	13'-0
	2VLI22	7'-2	9'-6	9'-8	238	209	186	149	133	120	108	98	90	82	75	69	64	59	55
4"	2VLI21	7'-10	10'-2	10'-6	254	223	198	178	142	128	115	105	96	87	80	74	68	63	58
	2VLI20	8'-5	10'-9	11'-1	268	235	209	187	169	135	122	110	101	92	84	78	72	66	61
(t=2")	2VLI19	9'-6	11'-11	12'-4	297	260	230	206	185	168	153	141	111	101	93	86	79	73	68
	2VLI18	10'-6	12'-10	13'-3	324	285	253	227	205	187	171	158	146	136	107	99	92	86	80
30 PSF	2VLI17	11'-5	13'-8	14'-0	352	308	273	245	221	201	184	169	156	145	135	107	99	92	86
	2VLI16	12'-1	14'-4	14'-4	377	330	292	261	235	214	195	179	165	153	143	133	118	98	91
	2VLI22	6'-9	9'-1	9'-3	276	243	195	173	155	139	126	114	104	96	88	81	75	69	64
4 1/2"	2VLI21	7'-5	9'-9	10'-1	295	259	231	185	165	149	134	122	111	102	93	86	79	73	68
	2VLI20	8'-0	10'-4	10'-8	312	273	243	217	196	157	141	128	117	107	98	90	84	77	72
(t=2 1/2")	2VLI19	9'-0	11'-5	11'-9	346	302	268	239	215	195	178	142	129	118	108	100	92	85	79
	2VLI18	10'-0	12'-3	12'-8	376	331	294	264	238	217	199	183	170	136	125	116	107	100	93
35 PSF	2VLI17	10'-10	13'-1	13'-6	400	358	318	284	256	233	213	196	181	168	134	124	115	107	100
	2VLI16	11'-5	13'-8	13'-10	400	384	340	303	273	248	227	208	192	178	166	132	123	114	106
	2VLI22	6'-6	8'-8	8'-10	315	277	222	197	176	159	144	130	119	109	100	92	85	79	73
5"	2VLI21	7'-1	9'-4	9'-8	337	296	263	211	189	169	153	139	127	116	107	98	91	84	78
	2VLI20	7'-7	9'-11	10'-3	355	312	276	248	199	179	161	146	133	122	112	103	95	88	82
(t=3")	2VLI19	8'-7	10'-11	11'-4	394	345	305	272	245	223	178	162	147	135	124	114	105	97	90
	2VLI18	9'-6	11'-10	12'-2	400	377	335	300	272	247	227	209	168	155	143	132	122	114	106
40 PSF	2VLI17	10'-3	12'-7	13'-0	400	400	362	324	292	266	243	223	207	166	153	142	131	122	114
	2VLI16	10'-11	13'-2	13'-5	400	400	387	346	311	283	258	237	219	203	163	151	140	130	121
	2VLI22	6'-4	8'-6	8'-8	334	268	236	209	187	168	152	138	126	116	106	98	90	84	78
5 1/4"	2VLI21	7'-0	9'-2	9'-6	357	314	279	224	200	180	163	148	135	123	113	104	96	89	83

Seismic Base Shear

SEISMIC BASE SHEAR CALCULATION (REDESIGN)

- TOTAL DEAD LOAD OF BUILDING:
  - PARTITION LOAD
    $20\,psf \times 30{,}000\,ft^2 \times 3\,floors = 1{,}800^k$
  - SUPERIMPOSED FLOOR DEAD LOAD
    $15\,psf \times 30{,}000\,ft^2 \times 3\,floors = 1{,}350^k$
  - SUPERIMPOSED ROOF DEAD LOAD
    $115\,psf \times 30{,}000\,ft^2 = 3{,}450^k$
  - SLAB SELF WEIGHT
    $40\,psf \times 30{,}000\,ft^2 \times 4\,floors = 4{,}800^k$
  - FRAMING LOAD
    $5\,psf \times 30{,}000\,ft^2 \times 4\,floors = 600^k$
  - COLUMN LOAD
    $50\,plf \times 56' \cdot 53\,columns \approx 150^k$
  - EXTERIOR WALL PANEL WEIGHT
    [illegible] / PANEL × 116 PANELS = 1740^k
  - PARAPET WALL PANEL WEIGHT
    $110\,pcf \cdot 4' \cdot \frac{5}{12} \cdot 30' = 5.5^k/panel \times 28\,panels = 154^k$

  TOTAL BUILDING WEIGHT: $14{,}044^k$

- DETERMINE C_s:
  1. SPECTRAL RESPONSE ACCELERATION
     $S_s = 0.256 \quad S_1 = 0.075$
  2. SITE CLASSIFICATION: SITE CLASS C
  3. RESPONSE ACCELERATIONS
     $S_{MS} = F_a S_s \qquad S_{M1} = F_v S_1$
     $S_{MS} = 1.2(0.256) \qquad S_{M1} = 1.7(0.075)$
     $S_{MS} = 0.307 \qquad S_{M1} = 0.128$

4. 5% DAMPED DESIGN SPECTRAL RESPONSE ACCELERATIONS

$S_{DS} = 2/3\, S_{MS}$ $S_{D1} = 2/3\, S_{M1}$

$S_{DS} = 2/3\,(0.307)$ $S_{D1} = 2/3\,(0.128)$

$S_{DS} = 0.205$ $S_{D1} = 0.085$

5. APPROXIMATE FUNDAMENTAL PERIOD:

$T_a = C_t \cdot h_n^x$ $C_t = 0.028$ } STEEL MOMENT FRAMES

$T_a = 0.028(56)^{0.8}$ $x = 0.8$

$T_a = 0.701s$ $h_n = 56'$

6. DETERMINE C_S FROM LESSER OF 2 EQN'S

$R = 3.5$

$I = 1.5$

$C_S = \frac{S_{DS}}{(R/I)}$ OR $C_S = \frac{S_{D1}}{(R/I)T}$

$C_S = \frac{0.205}{(3.5/1.5)}$ OR $C_S = \frac{0.085}{(3.5/1.5)(0.701)}$

$C_S = 0.0879$ OR $C_S = 0.0520$

BUT CAN NOT BE LESS THAN

$C_S \geq 0.044\, S_{DS} I$

$C_S \geq 0.044(0.205)(1.5)$

$C_S \geq 0.0135 < 0.0520 \therefore C_S = 0.052$

7. DESIGN BASE SHEAR

$V = C_S \cdot W$

$V = 0.0520(14,044)$

$V = 730^k$

Story Forces

SEISMIC LOAD DISTRIBUTION (STORY FORCES)

LEVEL 1,2,3 DEAD LOAD:

PARTITION: 600^k

SUPER. DEAD LOAD = 450^k

FLOOR SELF WEIGHT = 1200^k

FRAMING = 150^k

COLUMN = 37.5^k

WALL PANEL = 435

2873^k

ROOF LEVEL DEAD LOAD:

SUPER. DEAD LOAD = 3,450^k

FLOOR SELF WEIGHT = 1200^k

FRAMING = 150^k

COLUMN = 37.5^k

WALL PANEL 435

PARAPET = 154

5427^k

LATERAL FORCE AT EACH LEVEL

$F_x = C_{vx} \cdot V$ WHERE $C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$ $k = 1.1$ BY INTERP.

$\sum w_i h_i^k = 2873(14')^{1.1} + 2873(28)^{1.1} + 2873(42')^{1.1} + 5427(56')^{1.1}$

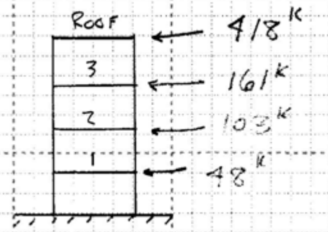
$\sum w_i h_i^k = 794511$

$C_{v1} = \frac{2873(14)^{1.1}}{794511} = 0.066$ $F_1 = 0.066(730) = 48.18^k$

$C_{v2} = \frac{2873(28)^{1.1}}{794511} = 0.141$ $F_2 = 0.141(730) = 102.93^k$

$$C_{V3} = \frac{2873(42)^{1.1}}{79451} = 0.221 \qquad F_3 = 0.221(730) = 161.33^K$$

$$C_{VR} = \frac{5427(56)^{1.1}}{79451} = 0.572 \qquad F_R = 0.572(730) = 417.56^K$$



Story Drift

ALLOWABLE STORY DRIFT: $C_d = 3, I = 1.5$

$$\Delta_a = 0.015(14' \times 12) = 2.52''$$

STORY 1 ALLOWABLE DRIFT:

$$\frac{C_d \cdot \delta_{e1}}{I} \le \Delta_a \;;\; \frac{3 \cdot \delta_{e1}}{1.5} \le 2.52'' \Rightarrow \delta_{e1} \le 1.26''$$

STORY 1 ACTUAL DRIFT:

LdC	Disp X in	Disp Y in	Theta Z rad
D	0.00331	0.00186	-0.00000
Lp	0.00506	0.00162	-0.00000
Rfp	-0.00003	0.00006	-0.00000
E1	-0.00522	0.60262	0.00007
E2	0.60037	-0.02145	0.00024
W1	-0.00213	0.23875	0.00003
W2	0.17720	-0.00657	0.00007

STORY 2 ALLOWABLE DRIFT:

$$(\delta_{e2} - \delta_{e1}) \cdot \frac{C_d}{I} \le \Delta_a \;;\; (\delta_{e2} - 1.26)\frac{3}{1.5} \le 2.52 \Rightarrow \delta_{e2} \le 2.52''$$

STORY 2 ACTUAL DRIFT:

LdC	Disp X in	Disp Y in	Theta Z rad
D	0.01810	0.01586	-0.00000
Lp	0.02446	0.01317	-0.00001
Rfp	-0.00004	0.00060	0.00000
E1	-0.02008	2.46263	0.00030
E2	2.47365	-0.08534	0.00097
W1	-0.00613	0.74027	0.00009
W2	0.55268	-0.01922	0.00022

STORY 3 ALLOWABLE DRIFT:

$$(\delta_{e3} - \delta_{e2}) \cdot \frac{c_d}{I} \leq \Delta_a \; ; \; (\delta_{e3} - 2.52)\frac{3}{1.5} \leq 2.52 \Rightarrow \delta_{e3} = 3.78$$

STORY 3 ACTUAL DRIFT:

LdC	Disp X in	Disp Y in	Theta Z rad
D	0.01032	0.00664	-0.00000
Lp	0.01553	0.00567	-0.00000
Rfp	-0.00009	0.00024	-0.00000
E1	-0.01236	1.48711	0.00019
E2	1.49050	-0.05009	0.00059
W1	-0.00438	0.51152	0.00006
W2	0.38143	-0.01324	0.00015

STORY 4 ALLOWABLE DRIFT:

$$(\delta_{e4} - \delta_{e3}) \cdot \frac{c_d}{I} \leq \Delta_a \; ; \; (\delta_{e3} - 3.78)\frac{3}{1.5} \leq 2.52 \Rightarrow \delta_{e4} = 5.04$$

STORY 4 ACTUAL DRIFT:

LdC	Disp X in	Disp Y in	Theta Z rad
D	0.04145	0.02814	0.00000
Lp	0.03143	0.01876	-0.00001
Rfp	0.00225	0.00151	-0.00000
E1	-0.02418	3.14295	0.00039
E2	3.16345	-0.10338	0.00124
W1	-0.00666	0.85559	0.00011
W2	0.63941	-0.02067	0.00025

Foundation Comparison Takeoffs

Redesigned:

SPREAD FOOTINGS TAKEOFF:

Concrete Strength, f'c (ksi): 3.00 Unit Wt (pcf): 150.00

Size (ft)	Quantity	Volume (yds³)	Weight (kips)
4.00x 4.00x 1.50	1	0.89	3.60
10.00x10.00x 2.00	2	14.81	60.00
10.00x11.00x 1.50	1	6.11	24.75
11.00x11.00x 2.00	5	44.81	181.50
12.00x12.00x 2.00	18	192.00	777.60
13.00x13.00x 2.00	3	37.56	152.10
13.00x13.00x 2.50	2	31.30	126.75
14.00x14.00x 2.50	14	254.07	1029.00
14.00x17.00x 2.50	1	22.04	89.25
20.00x16.00x 3.00	1	35.56	144.00
20.00x17.00x 3.00	1	37.78	153.00
20.00x18.00x 3.00	1	40.00	162.00
20.00x20.00x 3.00	1	44.44	180.00
20.00x20.00x 3.50	1	51.85	210.00
20.00x20.00x 4.00	1	59.26	240.00
	53	**872.48**	**3533.55**

Existing:

Grade Beams						
Mark	Dimensions		Area	Length	Volume	
	Width	Height	in.²	ft.	yd.³	
GB1	18	40	720	830	153.7	
Caisson Footings						
Mark	Shaft	Depth	Area	Volume	Number	Total
	Diameter		ft.²	yd.³		Volume
CF1	6'-0"	30'-0"	28.26	31.4	9	282.6
CF2	4'-0"	20'-0"	12.56	9.3	39	362.7
CF3	4'-0"	15'-0"	12.56	7.0	3	21.0
CF4	5'-0"	25'-0"	19.63	18.2	10	182.0
CF5	4'-0"	30'-0"	12.56	14.0	3	42.0
Total Amount of Concrete:				1044	yd.³	

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STRIPPING:

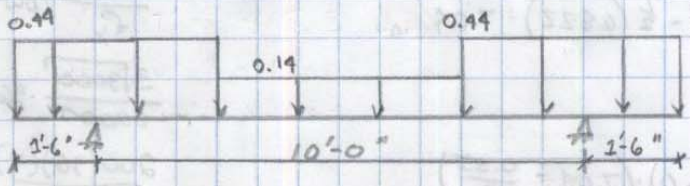
$f'_{ci} = 3000psi$

USE DYNAMIC LOADING FACTOR = 1.4

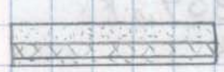
TRANSVERSE BENDING

$W_1 = 110\ lbs/ft^3 \cdot 5/12' \cdot 9.67' = 443\ lbs/ft.$ (CONC.)

$W_2 = 110\ lbs/ft^3 \cdot 5/12' \cdot 3' = 137.5\ lbs/ft.$ (OPENINGS)



SECTION PROPERTIES



$A_c = 36(2+3) = 180\ in^2$

$\bar{y} = \frac{\Sigma A \cdot d}{\Sigma A} = \frac{(36 \times 2)(1) + (36 \times 3)(6.5)}{180} = 4.3"$

$I = \bar{I} + Ad^2$

$I_1 = bh^3/12 = 36(2)^3/12 = 24\ in^4$

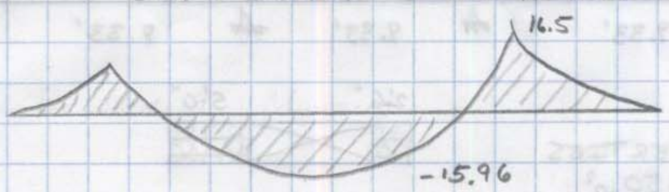
$I_2 = bh^3/12 = 36(3)^3/12 = 81\ in^4$

$I = [24 + (36 \times 2)(3.3)^2] + [81 + (36 \times 2)(2.2)^2] = 1238\ in^4$

$S_b = I/c = 1238/4.3 = 288\ in^3$

$S_T = I/c = 1238/3.7 = 335\ in^3$

MOMENT: (FROM STAAD BEAM) $M = 16\ k \cdot in$



ALLOWABLE TENSILE STRESS = F_t

$F_t = 5\lambda\sqrt{f'_{ci}} = 5(0.75)\sqrt{3000} = 0.205\ ksi$

ACTUAL TENSILE STRESS = f_t

$f_t = M/S_b = \frac{1.4(16)}{288} = 0.078 < 0.205\ ksi \therefore O.K.$

EXTERIOR WYTHE REINF. 2/5

USE 12x12 W6.5x6.5 MESH

$\phi M_n = A_s \cdot f_y (d - a/2)$; $a = \frac{A_s \cdot f_y}{0.85 \cdot f'_c \cdot b} = \frac{0.84 \cdot (60)}{0.85(3)(36)} = 0.55''$

$A_s = 0.84$
$f_y = 60\ ksi$
$d = 8'' - 0.75'' - \frac{1}{2}(6.422) = 7.04\ in$
$f'_c = 3000\ psi$
$b = 36\ in$

$A_{s,min} = \frac{3\sqrt{f'_c}}{f_y} \cdot b_w \cdot d \geq \frac{200 b_w d}{f_y}$

$\frac{3\sqrt{3000}}{60000} \cdot 36 \cdot 7 = 0.69\ in^2$

$\frac{200(36)(7)}{60{,}000} = \boxed{0.84\ in^2}$ CONTROLS

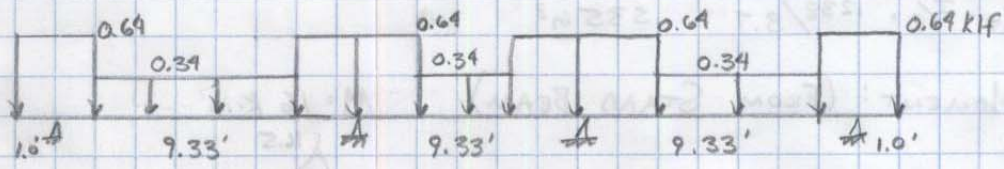
USE 6x6 W14xW14 MESH (BOTH WAYS)

$\phi M_n = 0.84(60) \cdot (7.04 - \frac{0.55}{2})$
$\phi M_n = 341\ in \cdot k\ (0.9) = 307\ in \cdot k$
$M_u = 1.4(16) = 22.4\ in \cdot k$

$\phi M_n = 307 \gg 22.4 = M_u \therefore$ O.K.

LONGITUDINAL BENDING

$w_1 = 110\ lbs/ft^3 \cdot 5/12' \cdot 14' = 642\ lbs/ft$ (CONC.)
$w_2 = 110\ lbs/ft^3 \cdot 5/12' \cdot 7.5' = 344\ lbs/ft$ (OPENINGS)



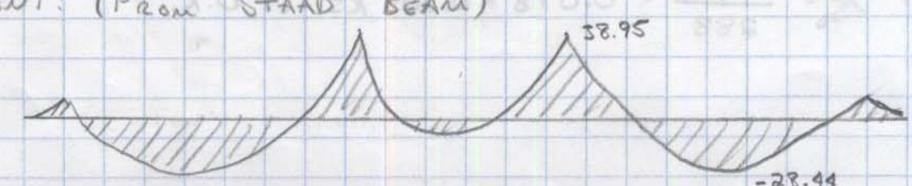
SECTION PROPERTIES

$A = 90(2+3) = 450\ in^2$
$\bar{y} = 4.3''$
$I_x = \bar{I} + Ad^2$

$I_1 = \frac{90(2)^3}{12} = 60\ in^4$
$I_2 = 90(3)^3/12 = 202.5\ in^4$

$I_x = [60 + (90 \times 2)(3.3)^2] + [202.5 + (90 \times 3)(2.2)^2] = 3{,}530\ in^4$
$S_b = I/c = 3530/4.3 = 821\ in^3$
$S_T = I/c = 3530/3.7 = 954\ in^3$

MOMENT: (FROM STAAD BEAM)



ACTUAL TENSILE STRESS = f_t

$f_t = M/S_b = \frac{1.4(28.4)}{821} = 0.048 < 0.205$ ksi ∴ O.K.

SERVICE LOADS:

$f'_c = 5{,}000$ psi

L.C. = $1.2D + 1.6W$, $1.2D + 1.0E$

EARTHQUAKE LOADING

$$F_p = \frac{0.4\, a_p \cdot S_{DS} \cdot W_p}{R_p}\left(1 + 2\frac{z}{h}\right)$$

$a_p = 1.0$ (PCI 3.10.10)

$S_{DS} = 0.205$

$R_p = 2.5$ (PCI 3.10.10)

$W_p = 282\,ft^2 \cdot 110\,lbs/ft^3 \cdot 5/12' + 5\,lbs/ft^2 \cdot 282\,ft^2 = 14{,}335$ lbs

$z = 56'$

$h = 56'$

$$F_p = \frac{0.4(1.0)(0.205)(14{,}335)}{2.5}\left(1 + 2\left(\frac{56}{56}\right)\right) = 1{,}410 \text{ lbs}$$

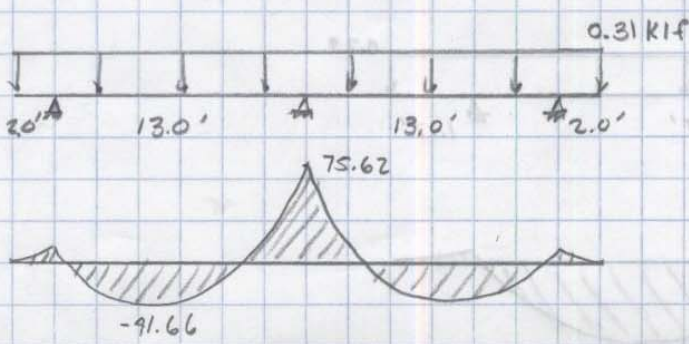
WIND LOADING

$W = 14\,psf \cdot (14' \times 30') = 5{,}880$ lbs $> 1{,}410$ lbs ∴ WIND CONTROLS

LONGITUDINAL BENDING

$w_u = 14\,lbs/ft^2 \cdot 14' = 196\,lbs/ft \cdot 1.6 = 314\,lbs/ft$

MOMENT: (FROM STAAD BEAM) $M_u = 42$ in·k



4/5

$A_{s,min} = \frac{3\sqrt{f'_c}}{f_y} \cdot b_w \cdot d \geq \frac{200 \cdot b_w \cdot d}{f_y}$

$\frac{3\sqrt{5000}}{60000} \cdot 90 \cdot 7 = \boxed{2.23\ in^2}$ CONTROLS

$\frac{200 \cdot 90 \cdot 7}{60000} = 2.1\ in^2$

USE #5 @ 12" o.c. $A_s = 0.31(7.5') = 2.33\ in^2$

$\phi M_n = 2.33(60)(6.94 - \frac{0.365}{2})$ $a = \frac{2.33(60)}{0.85(5)(90)} = 0.365$

$\phi M_n = 944\ in \cdot k \cdot (0.9)$

$\phi M_n = 850\ in \cdot k$ $d = 8 - 0.75 - \frac{0.625}{2} = 6.94\ in$

$\phi M_n = 850 \gg 42 = M_u \therefore$ O.K.

TRANSVERSE BENDING

$w_u = 1.6(14\ lbs/ft^2 \cdot 13ft) = 291\ lbs/ft$

MOMENT (FROM STAAD BEAM) $M = 57\ in \cdot k$

$A_{s,min} = \frac{3\sqrt{5000}}{60000} \cdot 36 \cdot 7 = \boxed{0.891\ in^2}$ CONTROLS

$\frac{200(36)(7)}{60000} = 0.84\ in^2$

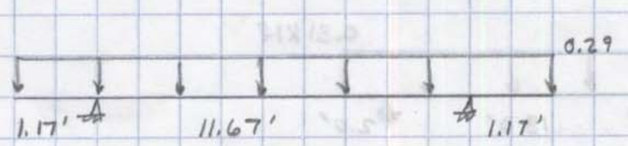
USE #5 @ 12" o.c. $A_s = 0.31(3') = 0.93\ in^2$

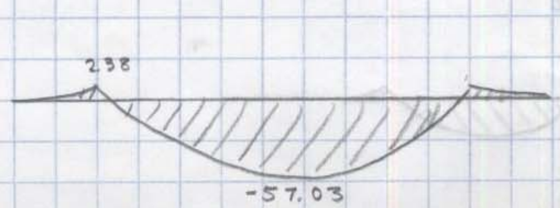
$\phi M_n = 0.93(60)(6.94 - \frac{0.365}{2})$ $a = \frac{0.93(60)}{0.85(5)(36)} = 0.365$

$\phi M_u = 377(0.9) =$

$\phi M_n = 339\ in \cdot k$

$\phi M_n = 850 \gg 57 = M_u \therefore$ O.K.





THERMAL BOWING: (PCI 4.8.5) 5/5

ASSUME COEFFICIENT OF THERMAL EXPANSION, $C = 6 \times 10^{-6}$ in/in/°F

TEMP. DIFFERENTIAL

OUTSIDE: 110° F

INSIDE: 70° F

$T_2 - T_1 = 110 - 70 = 40°F$

$\Delta = \alpha \frac{\ell^2}{8 \cdot h}$

$\alpha = C(T_2 - T_1) = 6 \times 10^{-6}(40) = 2.4 \times 10^{-4}$

$\ell = 11'\text{-}8"$

$h = 8"$

$$\Delta = \frac{2.4 \times 10^{-4}(11.67 \times 12)^2}{8(8)}$$

$\Delta = 0.074$ in ∴ THERMAL BOWING CAN BE NEGLECTED