The Helena

The Helena

New York, NY

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Structural Option
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The Helena 601 W. 57th Street, New York, NY 10019

DESIGN AND CONSTRUCTION TEAM

Owner – The Helena Associates, LLC
Owner's Representative – Rose Associates, Inc.
Architect – Fox & Fowle Architects, P.C.
Structural Engineer – Severud Associates
M.E.P. Engineer – Flack & Kurtz Inc.
Construction Manager – Kreisler Borg Florman

BUILDING OVERVIEW

Usage – Residential apartment building
Approximate cost – $160 Million
40 Stories – 38 above grade, 2 below
Size – 600,000 sq. ft.
Construction start – March 2003
Construction finish – Autumn 2004

ARCHITECTURAL FEATURES

Roof – 10,000 sq. ft. green roof
Maximize natural light – Floor-to-ceiling high performance glass
Solar power – Exterior metal panels have capability to collect solar energy
Going for the gold – Green designs for the building expected to receive gold LEED certification
What a view – Balconies protrude from the North façade as well as the NW and SE corners

STRUCTURAL FEATURES

Foundation – Monolithic and spread footings
Sub-Structure – Retaining Walls laterally braced by framed slabs and slabs-on-grade
Super-Structure:
Gravity System – 8" flat plate slabs and 12" one-way slabs supported by concrete columns
Lateral System – Shear walls supporting both directions

MECHANICAL FEATURES

One induced draft cooling tower with a total flow rate of 3300 GPM
Two 1350 GPM plate and frame heat exchangers
One rooftop air conditioning unit supplying 3500 CFM
All apartments furnished With a console water source heat pump for heating and cooling

ELEC./LTG. FEATURES

750 and 500 KVA step-up transformers
300 KW 277/480 V backup generator
120/208 V 1 phase typical apartment panel schedule
Power distributed through metering cabinets found on every third floor starting on the third floor
Mainly fluorescent lighting

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Executive Summary

This document was created to determine if moving the column placements within the building plan would make it more suitable by using a different floor system. The an analysis was started by taking the current column layout and altering it by keeping the position of some columns, moving the position of other, and adding a few where necessary. This was trying to accomplish the creation of typical bays that would make design much easier for a new floor system. With the columns in their current locations, the only viable floor system to use is a flat plate slab. By moving the columns to locations which create more of a grid layout, it becomes possible to run members between the columns and opens up other options for possible floor systems. Considering the architecture involved with the building, the use of high-performance glass and a shallow floor system gives the building a sense of seamlessness. To make sure the architecture was kept as a main focus, the use of a shallow replacement system was designed. Several different floor system alternatives were considered and a pre-cast concrete hollowcore plank system was chosen to be the best solution. The members were designed to rest upon steel beams which would then transfer the loads into the columns. As part of this re-design, the columns were re-located to make them more able to be connected by members. The pre-cast planks were then designed based on the loads outlined by the New York City Building Code. Once this was done, the columns were then re-designed considering the new loads. Comparing the two systems by serviceability, installation time, constructability, and other detail work shows that the pre-cast concrete plank floor system is a suitable if not preferable alternative. The use of a concrete plank system will give a more basic column layout which simplifies design and creates a grid for quick recognition of column locations. Using pre-cast planks eliminates the need for formwork and since they are created off-site, the quality of the members is very high. With all issues related to time of construction, the pre-cast system is much faster and this will also help with getting the other components of construction done faster, thus opening the building sooner leading to earlier occupancy which will help the owner begin making money much sooner on their investment. When all the conditions outlined in this document are taken into consideration, the new floor system is something which should seriously be considered as an option. Placing the columns in a more basic layout will open up several options for alternative floor systems and if this was given consideration, it would show that these possibilities could have proved to be better solutions.

Project Description

The Helena is a 40 story apartment building in the borough of Manhattan in New York City, New York. This 600,000 square foot building will house approximately 600 residential units on the above grade floors as well as a retail area on the ground floor and a 2 story parking deck below grade. Construction of The Helena began in late 2002 and is expected to be complete in mid 2005. The $160 million project is located at the corner of 57th Street and 11th Avenue and is only a few blocks from the Hudson River.

PROJECT TEAM:

Owner…………………………………………………….The Helena Associates, LLC
Owner's Representative………………………………………..Rose Associates, Inc.
Architect………………………………………………………...Fox & Fowle Architects
Lobby Architect…………………………………………………………B Five Studio
Apartment Consultants……………………………………..Harman Jablin Architects
Structural Engineer……………………………………………..Severud Associates
Construction Manager………………………………………….Kreisler Borg Florman
MEP Consultant………………………………………………………..Flack & Kurtz
Black Water Treatment Plant Consultants……………………..Dagher Engineering

Building Background

ARCHITECTURE

The Helena is a modern apartment building design of concrete, floor-to-ceiling glass, and wrap around windows. Perhaps the most interesting and striking aspect of The Helena is the green design that was put into the architecture and which anticipates to receive a gold Leadership in Energy and Environmental Design (LEED) rating. From bottom to top, The Helena is filled with green designs which will make it more environmentally friendly and self-sustaining. A 10,000 square foot green roof will top off the structure. The reasons for going with this design are to help lower energy costs by reducing heat gain as well as act as a rainwater retention system that will funnel water to the building's cooling system and also help reduce water runoff into the streets. Solar panels on the roof structure will help to draw sunlight and convert the solar heat to electricity which will be integrated into the electrical manufacturing plant in the building to lower overall energy costs. A black water treatment plant housed in the cellar helps re-use the water in the building and incorporates the water caught in the green roof. Part of the building's exterior skin, high-performance glass will be used to help reduce the amount of energy transmitted through the glass to help reduce energy costs and allow for more efficient air heating and cooling.

BUILDING ENVELOPE

The envelope of the building is supported by a reinforced concrete frame made up of a 45% furnace slag concrete mix. Attached to the outside of the frame are floor-to-ceiling windows featuring high performance glass. Atop the building, the mechanical equipment is housed inside of an area clad with solar collection panels. The building is a defiance of the typical building formula of exposed concrete slabs, masonry, and through-wall air conditioning units.

Building Systems

ELECTRICAL SYSTEM

The Helena is powered by one 750 KVA - 208Y/120V and one 500 KVA - 208Y/120V transformer. The transformers power two service switchboards located in the cellar. The switchboards are rated for 6000 A each and supply power to 20 metering cabinets in the east and west sides of the building on floors 3,6,9,12,15,18,21,24,27,30,33, and 36. Each cabinet serves up to 9 apartment units. The distribution panel also runs on the 208Y/120V system and is rated at 800 A. The typical apartment panel schedule runs on a 208Y/120V 1 phase system. Also included in the electrical system is a 480Y/277V system running transformers from 15 KVA to 225 KVA. This power is distributed through a 600 A rated distribution panel.

FIRE PROTECTION SYSTEM

Each floor is fitted with a floor control valve assembly and fire hose valve in the staircase area. The ground floor staircase houses a fire hose storage cabinet and key box. The typical floor plan is supplied water by a 2.5" diamter main pipe which branches off into smaller pipes of diameters ranging from 1" to 2" in diameter. A 6" fire service pipe enters into the building to supply water for the system. This water is sent through a manual fire pump in the cellar. This pipe is accessible from a 3"x3"x6" fire department connection at 57th street. The sprinkler flow control valve assemblies are connected to a 2" diameter sprinkler drain spill which leads to a service sink. Sprinklers are also supplied in the trash chutes, fed by 2" diameter piping. The roof contains a jockey pump and a special service fire pump which lead to a 25,000 gallon capacity water storage tank, which holds 15,000 gallons for fire reserve and 10,000 gallons for domestic building use.

LIGHTING SYSTEM

The main portion of the lighting in the building is composed of flourescent lighting. 2'x2' surface mounted parabolic troffers are used in the conference room and office areas. Among the lighting used in the rest of the building are 6" recessed compact flourescent down lights and 1'x4' surface mounted 2 lamp

wraparound flourescent fixtures. The lighting on the first floor retail areas includes metal halide track lighting, recessed adjustable low voltage lighting, metal halide wall wash, and penadant mounted downlighting.

MECHANICAL SYSTEM

An induced draft cooling tower highlights the mechanical system putting out 3300 GPM. Cooling is provided with one rooftop airconditioning unit supplying 3500 CFM. Heating is aided by two 1350 GPM plate and frame heat exchangers. All apartments are furnished with a console water source heat pump for heating and cooling needs. The cooling tower is hooked up to 3 water pumps which create pressure for the water flow. The cooling tower consists of two tanks located on the roof. The fuel oil storage tank is located in the sub-cellar along with two low pressure steam boilers and the heat exchangers.

SPECIAL SYSTEMS

The Helena is fitted with a roof lightning protection plan. On the roof is a copper down conductor which runs down through the building by way of 1" fiberglass conduit. The largest part of the design of this building was put into the green design. The building is capped by a 10,000 square foot green roof. The architecture incorporates solar collection panels and high performance glass. Internally, the building also has green components. A black water treatment plant housed in the cellar helps re-use the water in the building and incorporates the water caught in the green roof. Recycling is also made easy with chutes designed at each floor which can be used to dispose of recyclable materials.

STRUCTURAL SYSTEM

The foundation of the building is composed of monolithic and spread footings, some of which are anchored with 20-ton rock anchors. Retaining walls laterally braced by framed slabs and slabs-on-grade make up the sub-structure of the building. The superstructure is composed of a gravity and lateral load resisting systems. The gravity system is composed of 8" flat plate slabs and 12" one-way slabs supported by reinforced concrete columns. Shear walls which provide support in both directions creates the lateral resisting system of the building. Materials consist of reinforced concrete with a 45% furnace slag concrete mix.

The exterior of the building is made up of mostly high-performance glass and solar collecting metal panels.

TELECOMMUNICATIONS SYSTEM

The telecommunications for The Helena enters into a telephone room in the cellar floor from 11th Avenue and 57th Street. The telephone room has a telecommunications main grounding busbar, 20" long x 4" wide x 1/4" thick newton, which is connected to the stranded continuous copper telecommunications bonding backbone (TBB). This wiring is run vertically through the building using (8) - 4" diameter conduits. Starting on the second floor, each third floor houses a main grounding busbar, 10" long x 4" wide x 1/4" thick newton. A typical one bedroom apartment has a network interface device (ICC compace distribution center or equivalent) which branches out to allow for one voice only connection, one voice/data, one voice/data/cable tv, and one cable tv only connection. All connections are CAT5E.

TRANSPORTATION SYSTEM

There are two staircases located in the building, one in the East wing and one in the West wing. Approximately in the middle of the building are 5 elevators, 1 combination elevator and 4 passenger elevators. Horizontal movement through the building is done through a corridor which is the point of access for the apartment units. Floors 12-23 have access to the roof on the north side from a door at the end of a hallway that branches off of the main corridor. Balconies are located on the 14th through 38th floors on the West side of the Northwest corner, also on the 30th through 38th floors on the East side of the Southeast corner, and finally on the 33rd through 38th floor on the North side of the building.

Building Systems to be Altered

STRUCTURAL SYSTEM

The Helena is composed of two different load resisting systems, gravity and lateral. For the purpose of this analysis, only the components of the gravity load resisting system will be considered.

The main component of the gravity load resisting system consists of reinforced concrete columns placed around the perimeter of the building as well as throughout the floor plan. The columns are to be made up of normal weight concrete with a 28-day ultimate strength of 8000 psi from the sub-cellar up to and including the 18^{th} floor, 5950 psi from the 19^{th} floor through up to and including the 28^{th} floor, and 5000 psi for all columns at and above the 29^{th} floor.

Supported by the columns in the system is a flat plate slab which makes up the existing floor system for The Helena. The cellar and ground floor are made up of a 12” flat plate slab and all the residential floors are supported by 8” flat plate slabs. Compressive strength for the slabs is to be 5950 psi up to and including the 20^{th} floor and 5000 psi for the 21^{st} floor and above.

Currently, the foundation is designed with spread and monolithic footings. The footings are to bear on undisturbed rock with a capacity of 40 tons per square foot. Some of the footings are also further reinforced with 100-ton rock anchors.

MECHANICAL SYSTEM

The current set up of the mechanical ducts is based on the location of the reinforcement in the flat plate slab. Sizing for the ducts is also based on the ability for the ducts to vertically pass between the bars of reinforcement traveling horizontally in the slab to provide support.

Proposal

PROBLEM STATEMENT

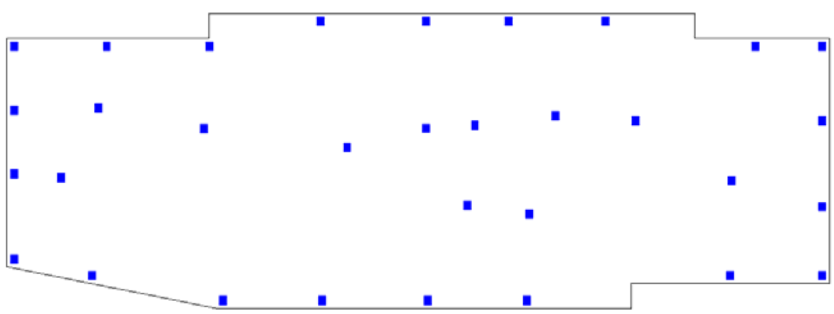
From the analysis of The Helena's structural floor system which was conducted in Technical Assignment 2, it was apparent that the column locations were such that the only viable solution for a floor system was to use a flat plate slab. It is the purpose of this report to conduct an investigation to determine whether a re-positioning of the column locations will be beneficial to opening up new solutions for flooring systems. The new floor system will be required to carry all the superimposed loads that the existing floor system does as well as its own self-weight. The most important issue with the re-location of the columns is to make sure the new locations work within the limits of the designed architecture. After the columns have been placed, the design for the floor system can take place. Once the floor system has been designed, the columns must then be re-designed to make sure they can withstand the new loads which will be placed on them. Moving the column locations will also mean having to move the locations of the footings in the foundation. Also, the new loads in the columns will mean there are new loads being transferred into the footings. This will create the need to re-design the footings to make sure they will be able to carry these new loads. Other building systems will also be affected by the change in location of the columns and the design of the new floor system. The current routing of the mechanical ductwork is based on the current locations of the columns to ensure optimum horizontal flow and it is also governed vertically by the placement of the rebar which runs through the flat plate slab of the existing floor system. Sizing and placement for the ductwork is done to ensure the movement through the slabs will create a minimum disturbance to the floor system. To determine if the new floor system is an option which requires consideration, a cost analysis will be conducted to compare the existing floor system with the new system. This and other governing factors will be used to provide a conclusion as to whether these changes are something which would be a better option for a design for this building.

PROPOSED SOLUTION

Working off of the current column layout and within the boundaries of the architectural drawings, a new column layout will be created to produce a typical bay. The new locations will create more of a grid layout for ease and repetition of design. A pre-cast concrete plank floor system will be designed as the new floor system. From the use of a flat plate slab and the floor-to-ceiling glass used for the building's skin, it is apparent that the plenum space and overall building height are important factors to consider during the re-design. To keep on-site fabrication time to a minimum, the planks will be designed to rest upon W-shape steel beams. After the planks are designed, the new loads that will be transmitted to the columns will be used to re-size the columns. The loads will then be followed down the columns and at the bottom of the columns, the loads will then be transferred into the footings. The footings will also need to be re-designed, not only for the new loads, but also for the new locations as determine by the new column placements. Other structural considerations will be addressed but not taken into detail as with the main components of this analysis. As for the mechanical ductwork, the designed paths for the ductwork will be reviewed to determine if the new column locations will interfere with the current placements. Also, the locations where the ductwork will travel vertically through the slab will be checked to make sure they will fit through the spaces between the reinforcement in the new pre-cast concrete plank system.

Column Re-locations

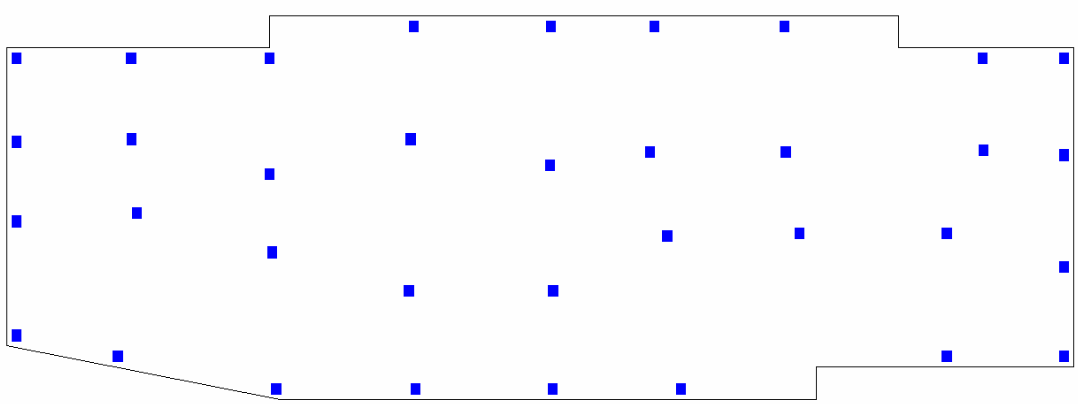
Currently, the columns are located around the perimeter of the building as well as scattered throughout the floor plan. This layout is not conducive for the formation of a grid layout to be able to create a typical bay for design. The formation of typical bays is helpful for the design of many floor systems. However, The Helena features the only viable floor system solution for the current column layout, a flat plate slab. The most important governing aspect of the current column layout is the need for the columns to integrate with the architectural layout of the floor plan. The new column layout uses many of the existing column locations as well as adjusting some of the existing column locations and adding columns where needed. A diagram of the existing column layout is shown below.



Column layout for the 12th through 38th floor

This diagram illustrates the fact that the columns are not arranged in a repetitive manner making it impossible to establish a typical bay. The architecture of the building seems to take precedent over the simplicity of design for this building. Along with the scattered arrangement of the columns, the shear walls are also placed in spots where they will have a minimum affect on the floor plan layout. Because of the importance paid to design, it was critical to work within the boundaries of the architecture and try to establish a grid pattern that would be integrated with the floor layout. All of the columns around the perimeter of the building were kept in place to ensure to exterior look of the building would stay the same. Almost all of the columns in the interior of the floor plan were simply moved to a different location to accommodate the grid pattern, but the addition of a few columns was necessary to complete the grid and ensure the new floor system would be properly supported. In total, three columns were added to the floor layout and the total was brought from 32 columns to 35. The affect this will have on the overall building structure will have advantages as well as disadvantages. The added weight of the columns will have a greater bearing on the foundation and will require greater support from the footings. Also, the added space required for the columns will take away space which may be needed for the building's other systems. There are more advantages to disadvantages however. The added weight from the additional columns will increase the overall building weight and thus make it less susceptible to overturning from lateral loads. Also, adding a few extra columns will help to lighten the load that will be distributed to each column. In turn, the lighter loads will allow for the design of smaller columns which will open up more space for the floor plan, lessening the impact the columns will have on the architectural layout. The columns were designed to make sure all of the locations were integrated among the floor plan throughout all floors of the building.

Below is the diagram for the new column layout. The columns are set up in a grid layout which provides the ability to create typical bays for ease of construction.



New column layout for the 12th through 38th floor

Keeping the columns in a grid layout is important because it will allow for square or rectangular bays which make it easier and more suitable for floor system design. The pre-cast concrete plank floor system, which will be supported by members that will rest on the columns, will span in the East-West direction. This leaves the members to span in the North-South direction to create the support the planks will need. This made it especially important to try to keep the columns in line with each other in the North-South direction. The members will then span between the columns, giving the planks a place to rest upon and designating their span length. Having the columns arranged in a way that is conducive to design is the most important part of the structure. It is what will designate which types of floor systems are possible which has an impact on the dimensional layout of the building as well as the overall building height. The columns create the structural base from which the building will be created around and that makes it that much more important for the layout of the columns to be open to different design possibilities. Other floor plan diagrams can be referenced in Appendix A at the end of this document.

Floor System Re-design

Currently, the floor system in place for The Helena is a flat plate slab. The slab is 12" for the ground and sub-grade floors and 8" for all residential floors. This floor system was chosen to be the best solution for the column layout which was designed by the engineers. A flat plate slab also seems to be the only viable solution for such a layout. The concept for this re-design was based off of the ability to be able to move the column placements within the building's layout and design a new layout which would make it possible for the design of other floor systems which could be more beneficial or accommodating for the owner and residents.

In the previous section, the columns were re-designed into a grid pattern in an attempt to create typical bays and open up the ability to design for different floor systems which could be better solutions for the floor system design. In Technical Assignment #2, a structural floor system analysis was done and a flat plate slab was determined to be the best solution for the existing column layout. It was because of this lack of options for alternative floor systems that initiated this proposal for an analysis of alternative floor systems which would be possible solutions given the column placements conditions required for them to be functional.

ALTERNATIVE FLOOR SYSTEMS CONSIDERED

Since the columns were designed to be made from concrete, only concrete alternative floor systems were considered. The first of these was the one-way slab system. This system works best for rectangular shaped bays. It consists of a slab reinforced with rebar spanning in only one direction. The slab then rests on beams which will transfer the loads into girders and those girders will send the load into the columns. The rebar spans in the short direction because that is the way the load path will naturally take. It is not beneficial to place rebar in the long direction because the loads will want to transfer themselves through the shortest possible distance and the rebar will have no effect on helping the loads follow the long bay direction. A disadvantage to this system is the formwork will take more time to erect since the beams are poured integrally with the slab. One advantage to this, however, is the conduit can be placed below the slab between the beams, taking less time to pour the slab. Not as much time is needed to place the conduit in the slab, so the slab can be poured quicker because of this. Since the conduit can be placed after the pouring of the slab, the forms will not be needed

and can be used to get the next pour set up, decreasing the amount of time it takes to pour the floor system. The use of a slab plus beams and girders will make this system too deep for the parameters of this building. A flat plate slab system will be much shallower than a one-way slab system and have less of an effect on the overall building height. The use of floor-to-ceiling glass gives the building a sense of seamlessness and the look would not be expressed as well if the floor system was deeper.

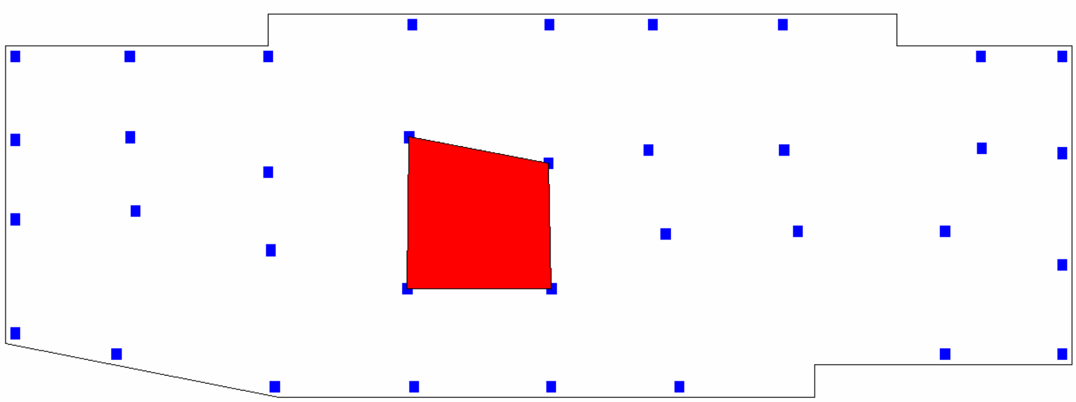
A post-tensioned slab was another floor system which was considered. Post-tensioning is accomplished by adding tendons inside of the concrete slab which are then tightened to give the slab added support. The tendons will span across the slab and the force from the tendons will be great enough to cause the slab to act as a one-way system. This system is not a bad alternative considering the length of the building is 2.5 times the depth which could make it easy for the system to be made into a one-way slab. Keeping the system in the form of a slab will help to minimize the depth of the system as well as the overall building height and also maximize plenum space. There are disadvantages to using a post-tensioned slab however. The cost and time for the project will be greater. It will take more time to have to add the tension into the slab after it has been poured than to just have a slab that needs to be poured and move to the next one. It is also more involved to make any alterations to the slab. If any holes need to be cut into the slab for mechanical ductwork or conduit to pass through, the locations of the tendons must be carefully documented to ensure they are not ruptured.

Finally, a pre-cast concrete plank floor system was analyzed and, along with the re-location of columns, considered to be the best viable solution for an alternative floor system. The planks are not very deep members and they will rest upon members which will rest on the columns, making for less transfer of loads and a shorter load path than the one-way slab system. There are many benefits to using a pre-cast concrete plank system. It is well suited to carry large loads across long spans because of the pre-stressed reinforcement designed into the member. The members are made from the same ultimate strength concrete as other systems are molded in. The material is strong, durable and does not require much maintenance. It is created off-site in factories where optimal conditions are created and the pieces can be precision made to adjust to the sizes and special details required. Once brought on-site, it only needs to be put into place and connected. This means much faster construction and also helps to make it more favorable to any weather conditions as opposed to having to cover a building to heat it or using admixtures in concrete to help it cure faster.

The planks also meet the required fire resistance rating and do not require any additional fireproofing saving time and money. This pre-cast system is also recognized by the Leadership in Energy and Environmental Design (LEED) rating system. With the building trying to achieve a gold LEED rating, this system just seems to fit the overall theme of the building very well.

PRE-CAST CONCRETE PLANK DESIGN

The largest bay within the floor plan was selected to designate the design of the floor plank size. Even if the design would allow for smaller plank sizes at a different bay of the floor, it would not be worth designating a different plank size because of the care that would need to be taken during the construction process. The planks are designed with two different depths, 8 and 12 inch. It would not be hard to tell these different planks apart, however, it would be extremely hard to differentiate between the planks which have 4 bars of reinforcement as opposed to those having 6 bars. Trying to keep track of which plank to place at which area would be tedious on-site and would slow down construction. It is much easier to take the planks to the site in one stack in the order they need to be placed in and just let the workers be able to put them in place without having to worry about which is the correct plank for the position.



Design bay used for plank sizing for 12th through 38th floor

The planks were designed to run in the East-West direction to cover the balconies which are found on the Northwest corner, Southeast corner, and north façade of the building. A diagram is provided below to illustrate the balcony locations.

Balcony locations for residential floors

This diagram shows the layout of the 32nd through 38th floor plan which contains all three balcony areas. The balcony on the Northwest corner starts at the 14th floor and continues to the top floor, the Southeast balcony begins at the 30th floor to the top floor and the North façade balcony is in place for floors 30 through 38. Spanning the planks in the East-West direction allows for a much easier design of the balcony area; the planks will simply extend across the member and be cantilevered to the edge.

The loads used for the design of the floor system were taken from Technical Assignment #1 and are as follows:

Dead Loads

<u>Residential Floors:</u>

MEP/Light	5 psf
Sprinklers	5 psf
Finishes	15 psf
Partitions	20 psf

<u>Ground Floor:</u>

Partitions	20 psf
MEP/Light	5 psf
Sprinklers	5 psf
Finishes	15 psf

<u>Parking Floors:</u>

MEP/Light	5 psf
Sprinklers	5 psf

<u>Roof:</u>

MEP/Light	5 psf
Sprinklers	5 psf
Finishes	15 psf

Live Loads – As designated by the New York City Building Code

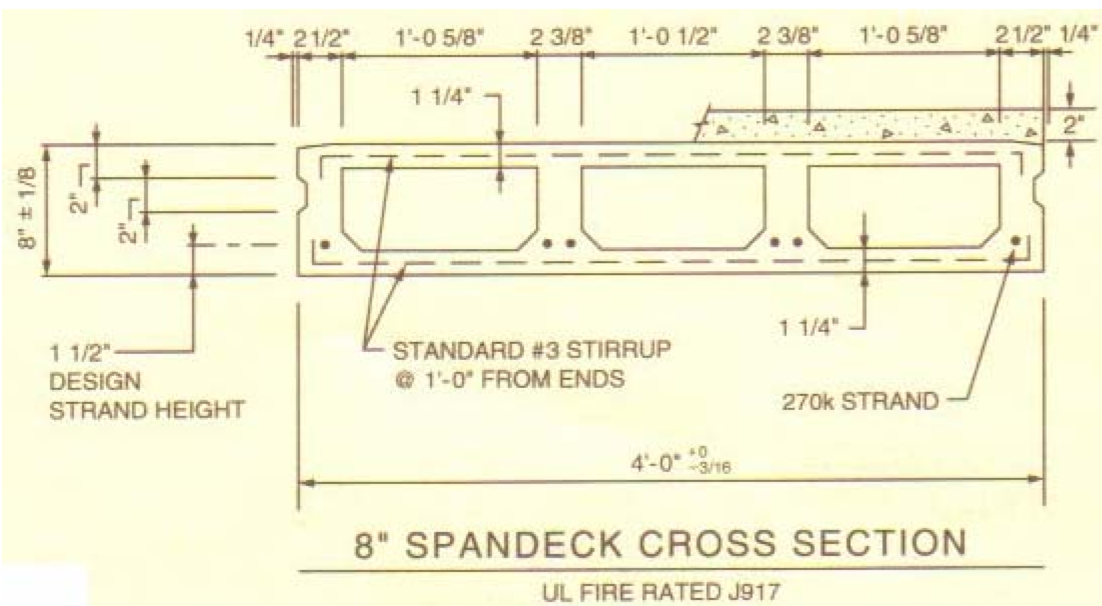
Residential Areas	40 psf
Offices	50 psf
Lobbies	100 psf
Corridors	100 psf
Mechanical Equipment Rooms	75 psf
Stairs	100 psf
Assembly Spaces	100 psf
Parking Areas	50 psf
Retail	100 psf

The plank was designed using materials from Nitterhouse Concrete Products, Inc. The typical bay size measures approximately 25’-8” x 25’-8”. Using the loads given by the New York City Building Code and the plank span, a plank depth size and reinforcement strand pattern can be established. A diagram of the load table is shown below.

8" SPANDECK W/2" TOPPING				ALLOWABLE SUPERIMPOSED LOAD (PSF)																				
STRAND PATTERN	SPAN (FEET)																							
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Flexure 4 – 1/2"ø	795	718	650	590	500	426	366	317	275	240	210	184	162	142	125	110	96	84	73	60	49	39	X
Shear 4 – 1/2"ø	571	509	458	415	378	347	320	296	275	257	240	222	199	178	160	145	133	126	115	103	93	84	X
Flexure 6 – 1/2"ø	1155	1040	945	859	732	629	544	474	416	366	324	287	256	228	204	183	164	147	132	118	103	90	77
Shear 6 – 1/2"ø	589	525	472	428	391	360	331	308	286	266	249	235	220	207	195	184	175	160	145	132	120	110	100

Allowable superimposed load table for 8” plank with 2” topping

The 6 strand pattern was chosen with an allowable superimposed load, at 26’, of 133 psf. Each strand is a 270K, one-half inch in diameter and sets 1.25 inches above the bottom of the plank. Additional dead load from the self-weight of the system will be 330 plf. All other information for the plank can be found in the Appendix. The following diagram shows a cross-section of the plank that is to be used for the residential floors.

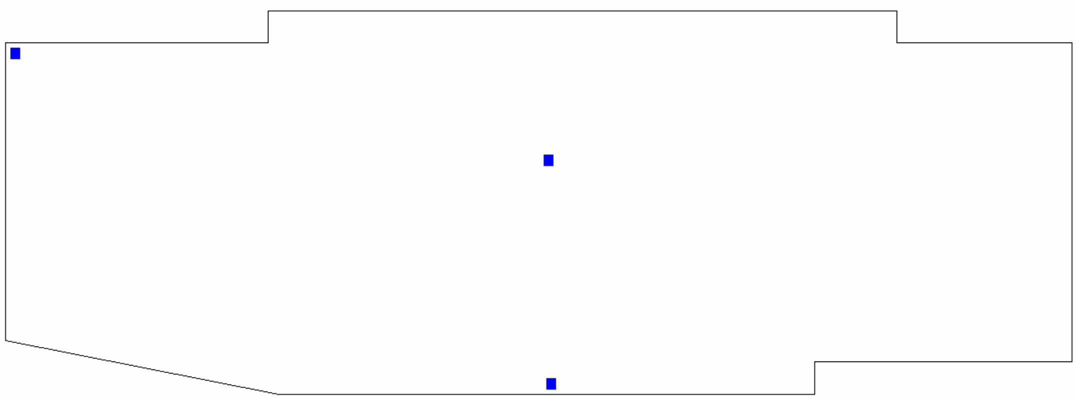


Cross-section of 8” plank used for residential floors

Once the floor system was designed, the steel members which would support the planks were designed. The 3rd edition Load and Resistance Factor Design (LRFD) steel manual was used for the design. Using the beam tables in the steel manual, it was determined that a W10x49 member is the optimal member and would be sufficient to carry up to 150'K at an un-braced length of up to 30 feet. Because this was found to be among the largest bay in the floor plan and with the support of up to 30 feet of un-braced length, a W10x49 will be the largest member needed to support the pre-cast planks. This will mean that the overall building height will not be affected very much if at all. It is possible to rest the beams on the columns at a little lower height and simply frame around the beam as an interior finish. This would allow for the new floor system to have no impact on a building height change thus making it a more than suitable alternative floor system.

Column Re-design

With the column locations being moved and the floor system re-designed, the column for the building will also have to be re-designed to compensate for the new loads to be supported. The diagram below outlines which columns will be considered for this section of the report.

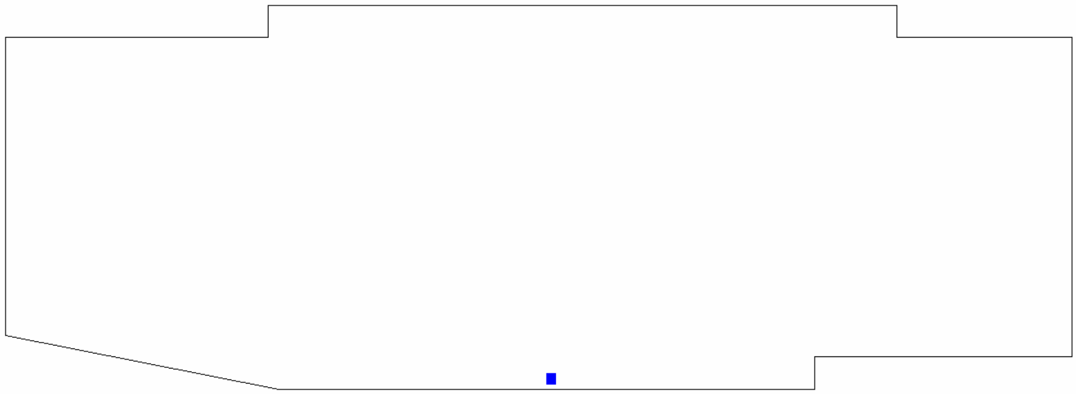


Columns considered for example calculations

The columns will be designed from reinforced concrete using the Concrete Reinforcing Steel Institute (CRSI) Design Handbook 2002. The re-locating of columns means a more typical layout making design more consistent throughout the floor plan. Because the columns around the perimeter and at corners have different influence areas, several different columns in the floor plan were considered. First, the loads from the re-designed floor system were used and then transferred into the columns. These loads were used for the axial compression load placed onto the column for design. These loads as well as the moment put onto the column by the un-balanced area of floor system around the column are taken into the column tables in the CRSI Design Handbook and a size and reinforcing is determined from these loads. The columns were designed using the design handbook for rectangular and round tied columns, with concrete compression strength of 4000 psi instead of the 5000 psi used in the existing building. The axial compressive loads and moments were found and then taken into the tables to determine the new sizes for the members. The sizes of the members were found to be comparable to those of the existing members. The use of the typical bay system as well as adding a few columns where necessary to complete the grid spread out the load better to each column thus reducing the size required. Also, if the designed compressive strength of the concrete used in the existing building was taken into account for the new column design, the sizes would then be taken to be even smaller. This design will not only help with the distribution of the loads on each column but it will keep each column size to a minimum allowing for the freeing up of more interior space for architectural use. Below is a comparison of sizes between two columns used for example design calculations.

Corner column used for design example

	Existing column	New column
Floors 24-38	16” Φ	12” Φ
Floors 11-23	20” Φ	12” Φ
Floors 8-10	24” Φ	12” Φ
Floors 2-7	24” Φ	12” Φ



Edge column used for design example

	Existing column	New column
Floors 24-38	16”x16”	14”x16”
Floors 11-23	20”x28”	18”x20”
Floors 8-10	20”x28”	18”x20”
Floors 2-7	20”x32”	18”x20”

The use of the grid column layout distributed the load much better to each column meaning less load on each column leading to a smaller size. This will allow the utilization of more architectural space. The impact of the re-location of the columns can be seen through this design example stating another reason why this proposal deserves serious consideration. Calculations for these examples can be found in the Appendix.

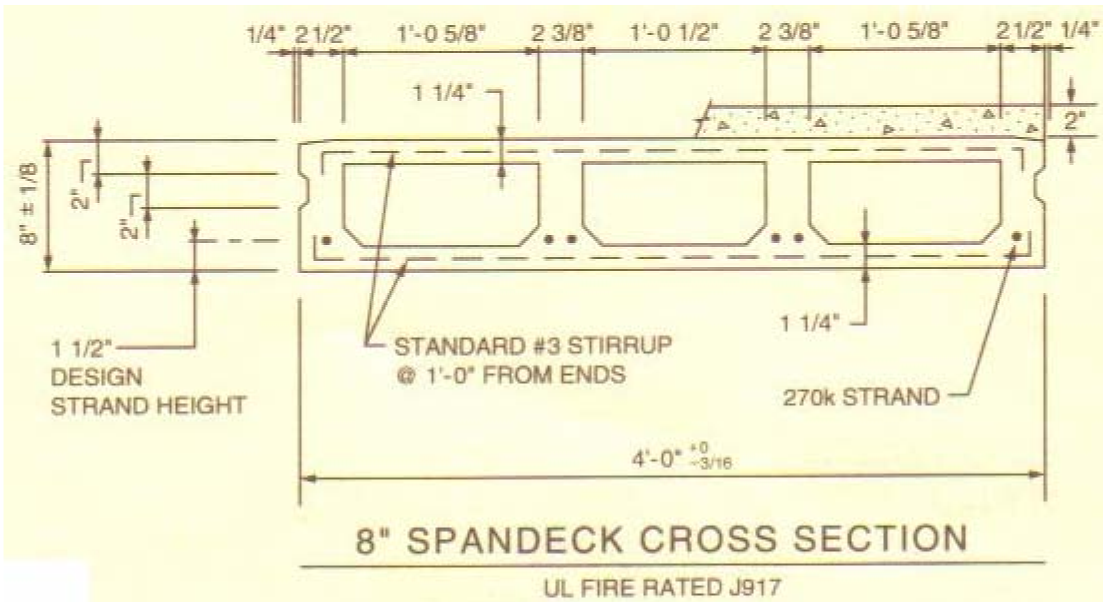
Other Design Considerations

There are many other design factors that need to be taken into consideration in the design of the building components which were suggested in this report. The first of these is a vibration analysis which should be conducted to determine if the new floor system will be sufficient enough to keep vibrations down to a minimum and be tolerable by tenants as well as any kind of mechanical and electrical equipment housed within the building. Acoustics should also be a topic of discussion. With a new floor system being installed, it should be checked whether or not the thickness and composition of the pre-cast concrete floor planks will be sufficient to meet acoustic sound criteria. If this is not the case, a ceiling assembly may be required with acoustic ceiling tiles to further prohibit the sound from traveling through the floor planks. Another consideration to take into account is the connections which will be required to connect the planks to the beams and the beams to the columns. The intricacy of the connections would need to be considered to see if they would take too much time to create or if they would be so expensive as to not be a possibility. For the building envelope, the overall building height increase must be taken into consideration to account for the extra cladding which will be required. Also, the high performance glass might require an analysis if it is deemed a change to its design and sizing is found to be necessary. With the re-locating of the columns, the positions of the footings for the foundation must also change. After the footings are moved they must be re-designed for the new loads which will be transferred from the newly designed columns. There is not expected to be much of an impact created from the re-design of the footings because they are still going to bear on 40 ton per square foot, undisturbed rock.

Breadth Analysis

MECHANICAL DUCTWORK LAYOUT

With the column locations being changed, the mechanical ductwork layout and paths were taken into consideration for changes. Originally, the ductwork followed the paths of the existing column layout and the flat plate slab dictated where the ductwork would pass vertically through the floor system. The purpose of this analysis is to determine whether or not the ductwork would need to be re-routed to accommodate the new column locations. After analyzing the layout of the ductwork, it was determined that there would not be a need to have to re-route the path of the ductwork across the floor plan. However, the layout for the exhaust ducts that move vertically throughout the system would have to be examined to adjust the size the make sure they will be able to pass between the strands in the planks. With the existing system, the ductwork passes between the locations of the rebar in the slab. The locations of the rebar and not mapped out in any particular grid setup, they are designed to support the areas of the slab where it is needed most. In some spots, the reinforcement is very close and in other spots it is spaced farther apart. It is within these more open, un-reinforced areas that the ducts are designed to pass vertically through the floor system. Since the pre-cast concrete planks will have a uniform rebar design throughout the system, it is important to make sure the location of the ducts will coincide with the gaps in the planks to make sure the floor system is not weakened to the point where it will fail. It is allowable to remove only a small length of one set of strands along a plank. It is not suggested that many of these cuts be made in each plank; only one or two openings per plank would still allow for enough bearing capacity while allowing the space needed to accommodate the ductwork openings. The diagram below illustrates the distance between reinforcing strands that the ducts will have allowable clearance.



Section view of an 8" pre-cast concrete plank showing reinforcing strand locations

The design of these planks does, however, allow for the removal of the open spaces between the reinforcing strands with little consequence. Overlaying the floor plan with the locations of the pre-cast planks showed that the exhaust ducts were spread out far enough that only one duct that needed strands removed would be required to pass through any given plank. Any other ductwork was placed where it would be able to pass through the voids in the planks.

CONSTRUCTION MANAGEMENT TIME ANALYSIS

A schedule or cost breakdown was not able to be acquired, but this analysis will be done given the known relative costs and times associated with each system. The first and most important factor when considering a floor system as it relates to the construction process is installation time. The pre-cast concrete planks will come straight from the factory where they are produced in an optimal environment and can be installed as soon as they arrive at the site. There is no installation is that the planks can be cut to shape any architectural features. This will cut down on even more forming time which would be required to lay out a more intricately shaped floor plan. Because the planks can be installed so quickly, they can be grouted, sealed, and topped with a cast-in-place topping to

help stiffen the system. These things will help the pre-cast system set up quickly and allow for fast floor system erection time. An issue that goes along with the system setting up quickly is the fact that after the topping is applied, the planks are ready for finish work. The floor can simply be covered with padding and carpeting and the ceiling can be painted or sprayed with texture coating which can also help the acoustics of the system. While the existing system requires taking time to place conduit into the slab before pouring it, the pre-cast plank system provides built-in channels where conduit can be placed. Another secondary system which places an effect on the pour time for the flat plate slab is any kind of hangers which will be placed in the slab for placement of mechanical ductwork. The pre-cast plank system allows for drilling into the plank to place hangers which will go much quicker during installation.

Summary and Conclusions

Taking all design considerations into account, this re-design of the spatial layout of the columns opened up the opportunity for the use of alternative floor systems. After considering several different alternative floor systems, a pre-cast concrete hollowcore plank system was chosen. This system was chosen for its exemplary load carrying capacity over longer spans, quick constructability, quality and custom forming, and the shallow depth of the system. The floor system was designed to the same depth as the current floor system so there will be no impact on the overall building height. This means there will not be the need to do any kind of further analysis done on the lateral building system. Once the columns were re-located, the floor system was then designed using the new bay sizes and spans. The columns were then re-designed to carry the new loads from the planks. After designing the columns for the new loads, it was shown that the new layout led to a lesser amount of load distributed to the columns allowing for smaller columns which opened up more architectural space. Even though more columns were required within the floor plan to create the grid pattern that was being designed, the smaller sizes per column make up for the loss of architectural space throughout the other areas of the building. The breadth analysis for the mechanical system showed that the new column layout coupled with the pre-cast concrete plank floor system will not have a detrimental effect on the design layout for the ductwork. In addition to the pre-cast system having the same depth as the existing flat plate slab system, other means of determining the value of using an alternative system were needed. This was carried out in the form of the construction management breadth analysis. Through this analysis, it was discovered that the newly designed pre-cast plank system would prove to be quicker to install, allow for faster finishing work, and provide easier placement for supplementary systems such as conduit and mechanical ductwork hangers. From the comparisons made throughout this report, it is apparent that all the changes made to the structural design of the building would only allow for faster construction and better constructability conditions. It has been shown that the systems chosen to be altered were designed in such a way as to only benefit the design and construction of the building.

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Reinforced Concrete Column Design

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Foundation Design

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Acknowledgements

SPECIAL THANKS MUST BE GIVEN TO:

Dr. Linda Hanagan for her help not only this past year, but also for all the classes of her I have taken

The owners of The Helena for allowing me use their building for this project

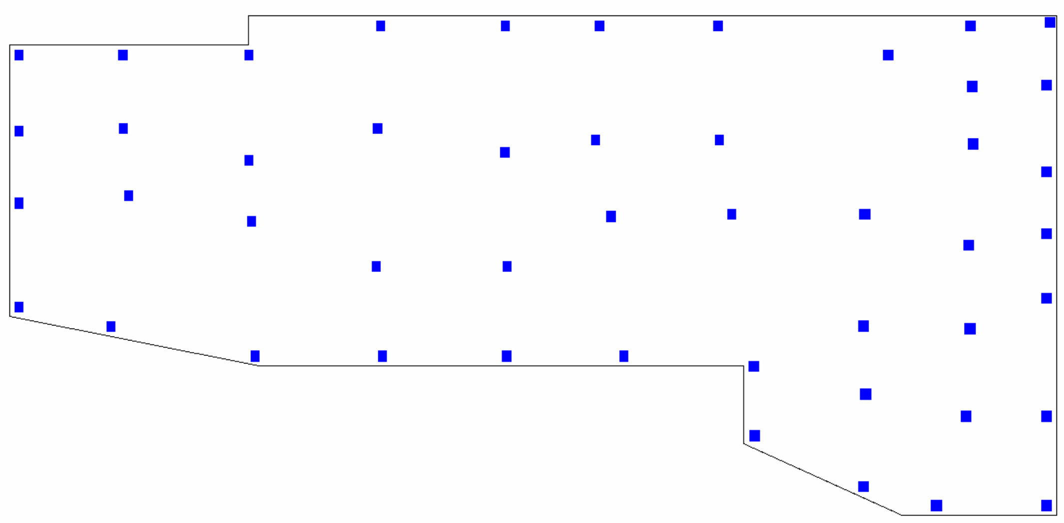
Severud Associates for their help with attaining the drawings and specifications for this building

My family for all of their love and support in helping make my dreams come true

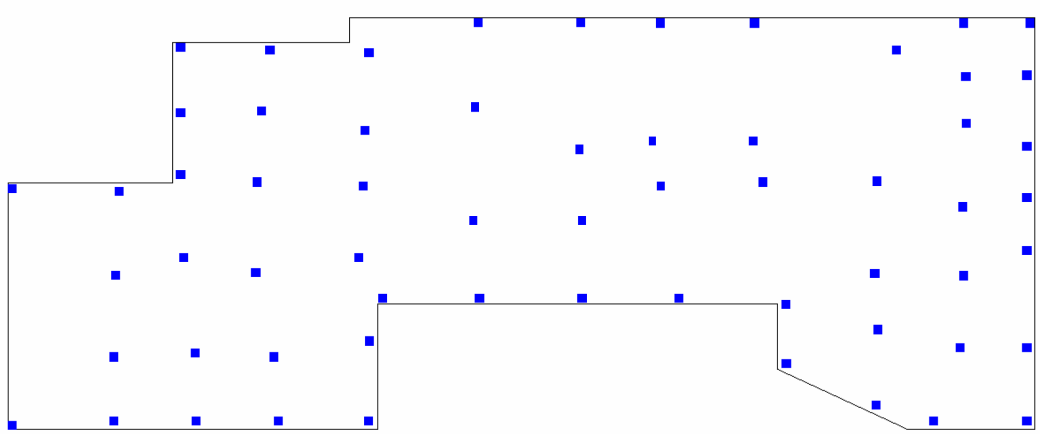
Jodi for being there for me always

Appendix I

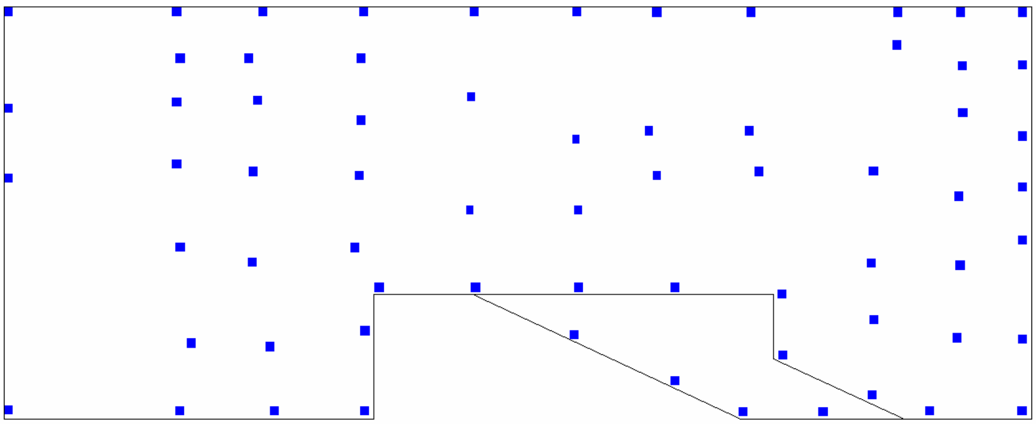
This appendix includes the remaining column re-location diagrams.



New column layout for floors 9-11



New column layout for floors 2-8



New column layout for ground floor

Appendix II

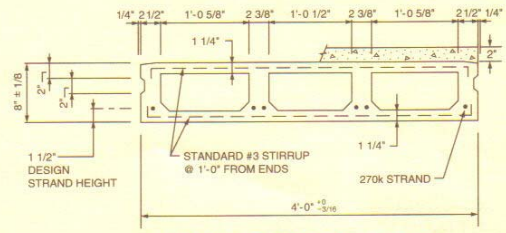
Prestressed Concrete
8" x 4' SpanDeck – U.L. – J917

(2" C.I.P. TOPPING)

PHYSICAL PROPERTIES

Composite

A' = 254 in.^{2}	S'_b = 547 in.^{3}
I' = 2944 in.^{4}	S'_t = 1124 in.^{3} (At Top of SpanDeck)
$Y_{b'}$ = 5.38 in.	S'_{tt} = 637 in.^{3} (At Top of Topping)
Y_t' = 2.62 in. (To Top of SpanDeck)	Wt.' = 330 PLF
Y'_{tt} = 4.62 in. (To Top of Topping)	Wt.' = 82.5 PSF



8" SPANDECK CROSS SECTION

UL FIRE RATED J917

DESIGN DATA

1. Precast Strength @ 28 days = 5000 PSI.
2. Precast Density = 150 PCF
3. Strand = 1/2"ø, 270K Lo-Relaxation.
4. Composite Strength = 3000 PSI.
5. Composite Density = 150 PCF.
6. Strand Height = 1.5 in.
7. Ultimate moment capacities (when fully developed) . . .
   4 – 1/2"ø, 270K = 94.6'K
   6 – 1/2"ø, 270K = 133.3'K
8. Maximum bottom tensile stress is $6\sqrt{f'c}$ = 424 PSI.
9. All superimposed load is treated as live load in the strength analysis of flexure and shear.
10. Flexural strength capacity is based on stress/strain strand relationships.
11. Load values to the left of the solid line are controlled by ultimate strength. Load values to the right are controlled by service stress.
12. Shear values are the maximum allowable before shear reinforcement is required.
13. Deflection limits were not considered when determining allowable loads in this table.
14. All loads shown refer to allowable loads applied after topping has hardened.

8" SPANDECK W/2" TOPPING — ALLOWABLE SUPERIMPOSED LOAD (PSF)

STRAND PATTERN	SPAN (FEET) 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Flexure 4 – 1/2"ø	795	718	650	590	500	426	366	317	275	240	210	184	162	142	125	110	96	84	73	60	49	39	
Shear 4 – 1/2"ø	571	509	458	415	378	347	320	296	275	257	240	222	199	178	160	145	133	126	115	103	93	84	
Flexure 6 – 1/2"ø	1155	1040	945	859	732	629	544	474	416	366	324	287	256	228	204	183	164	147	132	118	103	90	77
Shear 6 – 1/2"ø	589	525	472	428	391	360	331	308	286	266	249	235	220	207	195	184	175	160	145	132	120	110	100

NITTERHOUSE
CONCRETE PRODUCTS

This table is for simple spans and uniform loads. Design data for any of these span-load conditions is available on request. Individual designs may be furnished to satisfy unusual conditions of heavy loads, concentrated loads, cantilevers, flange or stem openings and narrow widths.

2655 Molly Pitcher Hwy. South, Box N
Chambersburg, PA 17201-0813
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REVISED 12/93

Prestressed Concrete

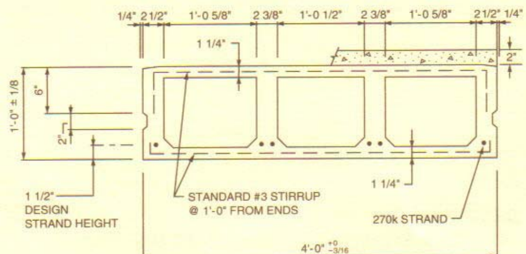
12" x 4' SpanDeck – U.L. – J917

(2" C.I.P. TOPPING)

PHYSICAL PROPERTIES

Composite

$A' = 293$ in.^{2}	$S'_b = 936$ in.^{3}
$I' = 7164$ in.^{4}	$S'_t = 1649$ in.^{3} (At Top of SpanDeck)
$Y'_b = 7.65$ in.	$S'_{tt} = 1129$ in.^{3} (At Top of Topping)
$Y'_t = 4.35$ in. (To Top of SpanDeck)	Wt. = 410 PLF
$Y'_{tt} = 6.35$ in. (To Top of Topping)	Wt. = 102.5 PSF



12" SPANDECK CROSS SECTION

UL FIRE RATED J917

DESIGN DATA

1. Precast Strength @ 28 days = 5000 PSI.
2. Precast Density = 150 PCF.
3. Strand = 1/2"ø, 270K Lo-Relaxation.
4. Composite Strength = 3000 PSI.
5. Composite Density = 150 PCF.
6. Strand Height = 1.5 in.
7. Ultimate moment capacities (when fully developed) . . .
   4 – 1/2"ø, 270K = 146.2'K
   6 – 1/2"ø, 270K = 208.1'K
8. Maximum bottom tensile stress is $6\sqrt{f'c} = 424$ PSI.
9. All superimposed load is treated as live load in the strength analysis of flexure and shear.
10. Flexural strength capacity is based on stress/strain strand relationships.
11. Load values to the left of the solid line are controlled by ultimate strength. Load values to the right are controlled by service stress.
12. Shear values are the maximum allowable before shear reinforcement is required.
13. Deflection limits were not considered when determining allowable loads in this table.
14. All loads shown refer to allowable loads applied after the topping has hardened.

12" SPANDECK W/2" TOPPING	ALLOWABLE SUPERIMPOSED LOAD (PSF)																						
STRAND PATTERN	SPAN (FEET)																						
	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Flexure 4 – 1/2"ø	446	392	345	305	271	240	214	190	170	151	134	120	106	94	83	73	64						
Shear 4 – 1/2"ø	436	408	379	357	335	309	281	257	234	214	195	181	172	162	149	136	125						
Flexure 6 – 1/2"ø	671	593	527	470	421	378	340	307	277	251	227	206	187	170	154	140	127	115	104	94	85	76	66
Shear 6 – 1/2"ø	453	423	397	373	351	331	313	297	282	268	255	237	218	201	186	171	158	146	136	124	118	113	108

This table is for simple spans and uniform loads. Design data for any of these span-load conditions is available on request. Individual designs may be furnished to satisfy unusual conditions of heavy loads, concentrated loads, cantilevers, flange or stem openings and narrow widths.

NITTERHOUSE CONCRETE PRODUCTS

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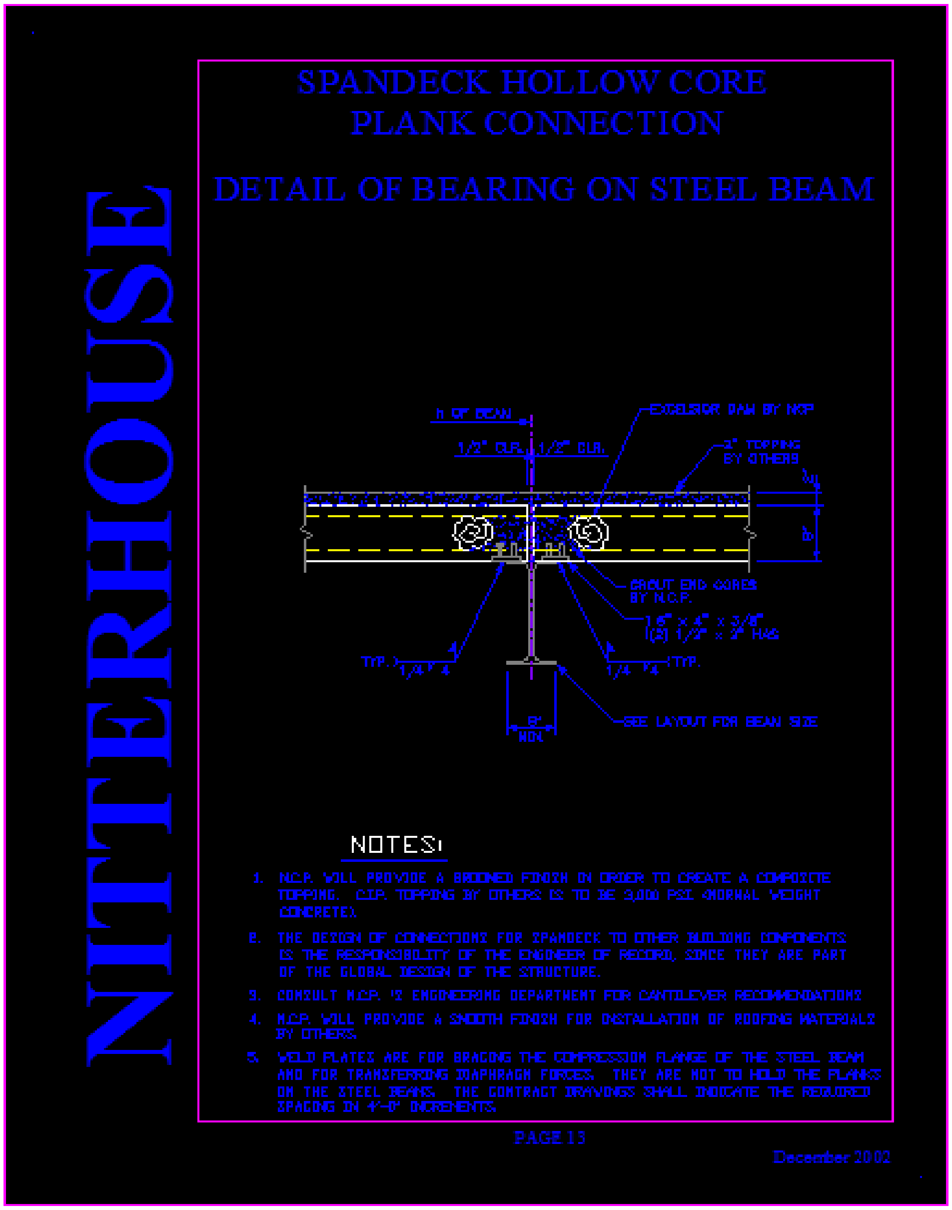
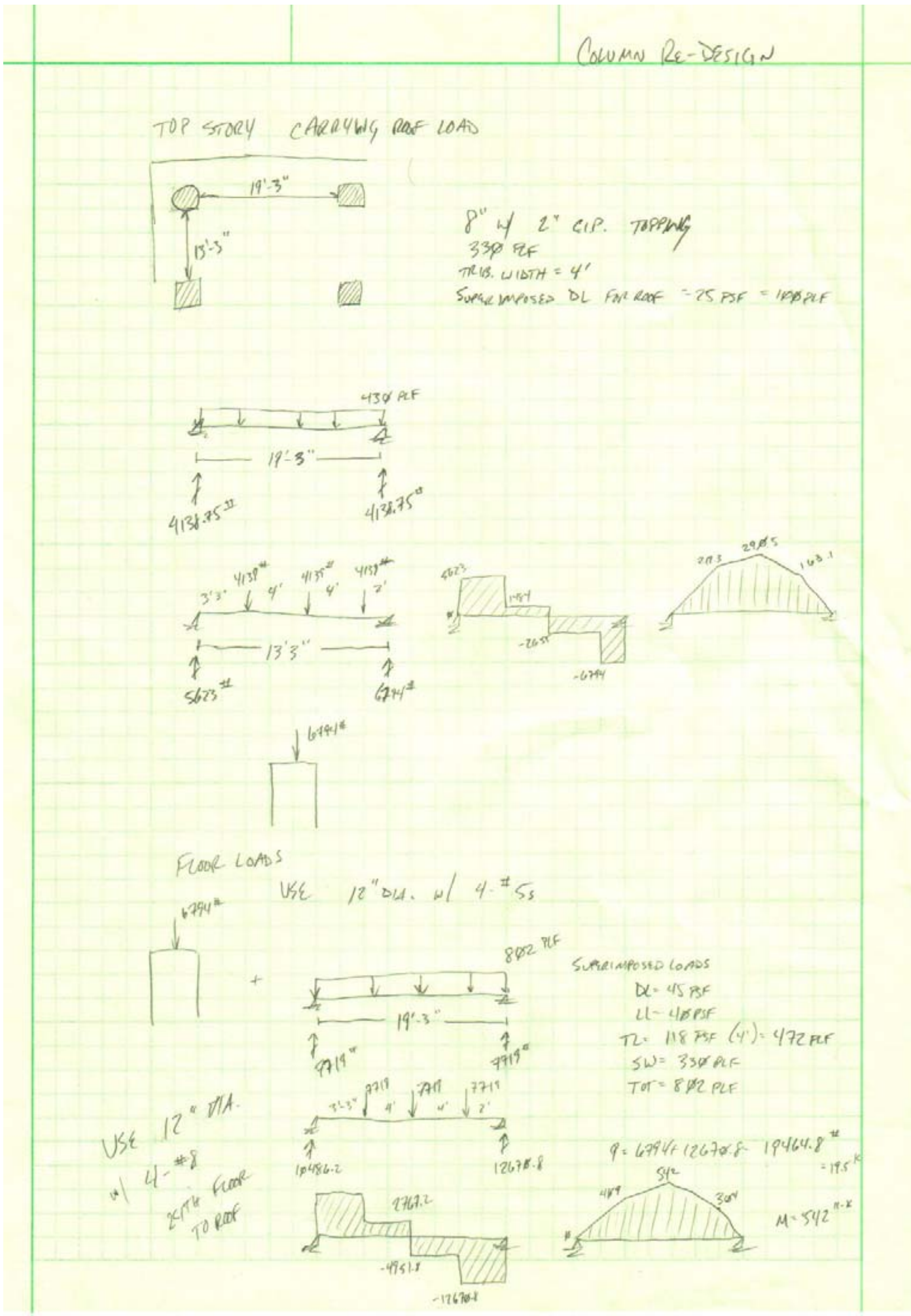

NITTERHOUSE
SPANDECK HOLLOW CORE
PLANK CONNECTION
DETAIL OF BEARING ON STEEL BEAM
℄ OF BEAM
1/2" CLR.
1/2" CLR.
EXCELSIOR DAM BY NCP
2" TOPPING
BY OTHERS
GROUT END CORES
BY N.C.P.
6" x 4" x 3/8"
(2) 1/2" x 3" HAS
TYP.
1/4
TYP.
1/4
SEE LAYOUT FOR BEAM SIZE
8"
MIN.
NOTES:
1. N.C.P. WILL PROVIDE A BROOMED FINISH IN ORDER TO CREATE A COMPOSITE TOPPING. C.I.P. TOPPING BY OTHERS IS TO BE 3,000 PSI (NORMAL WEIGHT CONCRETE).
2. THE DESIGN OF CONNECTIONS FOR SPANDECK TO OTHER BUILDING COMPONENTS IS THE RESPONSIBILITY OF THE ENGINEER OF RECORD, SINCE THEY ARE PART OF THE GLOBAL DESIGN OF THE STRUCTURE.
3. CONSULT N.C.P. 'S ENGINEERING DEPARTMENT FOR CANTILEVER RECOMMENDATIONS
4. N.C.P. WILL PROVIDE A SMOOTH FINISH FOR INSTALLATION OF ROOFING MATERIALS BY OTHERS.
5. WELD PLATES ARE FOR BRACING THE COMPRESSION FLANGE OF THE STEEL BEAM AND FOR TRANSFERRING DIAPHRAGM FORCES. THEY ARE NOT TO HOLD THE PLANKS ON THE STEEL BEAMS. THE CONTRACT DRAWINGS SHALL INDICATE THE REQUIRED SPACING IN 4'-0" INCREMENTS.
PAGE 13
December 2002

Appendix III



$M = 542^{'k}$ FOR REST OF RESIDENTIAL FLOORS

KEEP RE-CALCULATING P

SAME LAYOUT & LOADS FOR THIS COLUMN THROUGHOUT FLOORS 2-38

∴ KEEP ADDING ADDING 12.7^k ONTO P LOAD CAPACITY

19.5^k @ 37TH FLOOR

$19.5^k + 12.7(x) = 259^k$

$x = 18.8 \sim 19$ FLOORS

@ 18TH FLOOR COLUMN MUST BE RE-SIZED

LAYOUT CHANGES @ 10TH FLOOR SO DESIGN COLUMN FOR 11TH FLOOR LOAD

$19.5^k + 12.7^k(26 \text{ FLOORS}) = 349.7^k$

USE 12" DIA w/ 5-#9's 11TH FLOOR TO 23RD FLOOR

LAYOUT CHANGES AGAIN @ 7TH FLOOR ∴ DESIGN @ 8TH FLOOR

$349.7^k + 12.7(3) = 387.8^k$

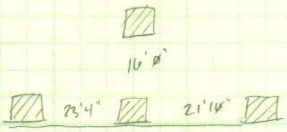
USE 12" DIA. w/ 6-#9's FROM 8TH TO 10TH FLOOR

LAYOUT CHANGE @ GROUND FLOOR ∴ DESIGN @ 2ND FLOOR

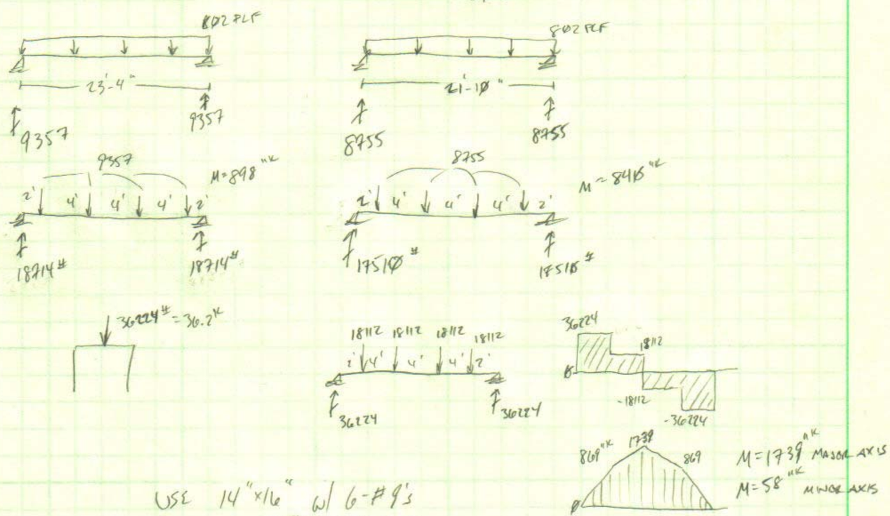
$387.8 + 12.7(6) = 464^k$

USE 12" DIA w/ 4-#14's FROM 2ND - 7TH FLOOR

COLUMN RE-DESIGN



DL = 45 PSF
LL = 40 PSF
TL = 118 PSF (4') = 472 PLF
SW = 330 PLF
TOT = 802 PLF



USE 14"×16" w/ 6-#9's
24TH FLOOR TO ROOF

MAX COLUMN CAPACITY

$36.2 + 36.2(x) = 617$
$x \Rightarrow 17$ FLOORS

DESIGN @ 11TH FLOOR

$36.2 + 36.2(26) = 977.4^K$

USE 18"×20" w/ 6-#11 P = 982K FROM 11TH TO 23RD FLOOR

DESIGN @ 8TH FLOOR

$977.4 + 36.2(3) = 1086^K$

USE 18"×20" w/ 10-#10 P = 1088K

DESIGN @ 2ND FLOOR

$1086 + 36.2(6) = 1303.2^K$

USE 18"×20" w/ 16-#10's P = 1330K

RECTANGULAR TIED COLUMNS 18" × 20"

Short columns – no sidesway
Bending on major or minor axis

f'_c = 4,000 psi f_y = 60,000 psi
ϕM in inch-kips ϕP in kips

BARS	RHO	AXIS	Max Cap ϕM	Max Cap ϕP	0% fy ϕM	0% fy ϕP	25% fy ϕM	25% fy ϕP	50% fy ϕM	50% fy ϕP	100% fy ϕM	100% fy ϕP	$.1f'_c$ Ag ϕM	$.1f'_c$ Ag ϕP	Zero Axial Load ϕM
4-# 9	1.11	MA	1650	812	2221	719	2740	604	3033	513	3347	374	2431	144	1792
2E		MI	1468	812	2022	709	2462	595	2707	505	2966	368	2148	144	1591
4-#10	1.41	MA	1714	846	2388	738	2942	617	3271	521	3664	371	2749	144	2226
2E		MI	1522	846	2168	727	2636	609	2912	513	3239	365	2422	144	1969
4-#11	1.73	MA	1767	883	2570	753	3145	628	3503	526	3964	365	3054	144	2659
2E		MI	1563	883	2325	742	2808	619	3108	518	3490	359	2680	144	2343
4-#14	2.50	MA	1905	971	2968	803	3628	664	4078	548	4729	359	3823	144	3697
2E		MI	1676	971	2667	791	3222	654	3598	540	4131	350	3337	144	3237
4-#18	4.44	MA	2209	1193	3916	931	4791	757	5465	606	6570	343	5682	144	6176
2E		MI	1926	1193	3473	919	4206	746	4771	596	5578	315	4907	144	5348
6-# 8	1.32	MA	1703	836	2326	736	2882	616	3210	521	3589	374	2672	144	2105
2L - 3S		MI	1386	836	1906	732	2323	613	2544	517	2751	373	2254	144	1866
6-# 9	1.67	MA	1778	876	2521	758	3119	633	3491	531	3964	371	3049	144	2613
2L - 3S		MI	1422	876	2022	755	2462	630	2707	528	2966	371	2502	144	2301
6-#10	2.12	MA	1870	927	2765	788	3418	654	3848	545	4440	368	3528	144	3254
2L - 3S		MI	1466	927	2168	786	2636	652	2912	541	3239	368	2806	144	2839
6-#11	2.60	MA	1944	982	3021	815	3715	673	4193	555	4892	362	3984	144	3884
2L - 3S		MI	1503	982	2325	813	2808	670	3108	550	3490	360	3074	144	3356
6-#14	3.75	MA	2141	1113	3606	892	4435	729	5054	590	6043	354	5140	144	5418
2L - 3S		MI	1605	1113	2667	892	3222	727	3598	584	4131	349	3754	144	4419
6-#18	6.67	MA	2589	1446	5005	1090	6168	873	7131	680	8808	333	7932	144	9097
2L - 3S		MI	1854	1446	3473	1092	4206	869	4771	668	5578	304	5309	144	6476
6-# 8	1.32	MA	1555	836	2088	742	2581	622	2844	526	3098	380	2554	144	2105
3L - 2S		MI	1514	836	2114	726	2586	608	2861	514	3178	369	2358	144	1865
6-# 9	1.67	MA	1598	876	2221	766	2740	639	3033	537	3347	378	2844	144	2602
3L - 2S		MI	1577	876	2282	748	2790	624	3104	524	3502	365	2683	144	2307
6-#10	2.12	MA	1653	927	2388	798	2942	662	3271	551	3664	376	3201	144	3220
3L - 2S		MI	1653	927	2494	778	3049	646	3412	537	3911	362	3094	144	2863
6-#11	2.60	MA	1701	982	2570	826	3145	682	3503	561	3964	370	3523	144	3822
3L - 2S		MI	1711	982	2714	804	3301	664	3703	547	4292	355	3481	144	3403
6-#14	3.75	MA	1828	1113	2968	906	3628	740	4078	597	4729	363	4333	144	5121
3L - 2S		MI	1874	1113	3215	881	3916	720	4438	582	5255	344	4465	144	4719
6-#18	6.67	MA	2138	1446	3916	1111	4791	887	5465	686	6570	342	6206	144	7592
3L - 2S		MI	2244	1446	4404	1077	5384	863	6195	671	7430	295	6821	144	7839
8-# 8	1.76	MA	1805	886	2565	767	3184	639	3575	536	4081	372	3166	144	2757
2L - 4S		MI	1403	886	1966	769	2394	640	2617	539	2844	372	2455	144	2398
8-# 9	2.22	MA	1902	939	2820	798	3498	662	3949	550	4581	369	3669	144	3427
2L - 4S		MI	1444	939	2097	802	2549	664	2797	555	3082	369	2773	144	2845
8-#10	2.82	MA	2018	1007	3142	838	3895	691	4425	568	5217	365	4308	144	4274
2L - 4S		MI	1502	1007	2261	845	2745	695	3025	575	3383	364	3158	144	3394
8-#11	3.47	MA	2113	1081	3472	877	4285	719	4883	584	5821	358	4916	144	5101
2L - 4S		MI	1542	1081	2434	884	2921	729	3239	590	3660	354	3446	144	3905
8-# 8	1.76	MA	1664	886	2326	774	2882	645	3210	540	3589	378	3035	144	2748
3E		MI	1478	886	2114	763	2586	636	2861	532	3178	371	2666	144	2428
8-# 9	2.22	MA	1732	939	2521	806	3119	669	3491	555	3964	376	3449	144	3404
3E		MI	1535	939	2282	795	2790	659	3104	546	3502	368	3019	144	2998
8-#10	2.82	MA	1822	1007	2765	848	3418	699	3848	574	4440	373	3963	144	4226
3E		MI	1608	1007	2494	836	3049	689	3412	565	3911	365	3456	144	3709
8-#11	3.47	MA	1892	1081	3021	888	3715	727	4193	590	4892	366	4429	144	5020
3E		MI	1663	1081	2714	875	3301	716	3703	580	4292	356	3843	144	4386
8-#14	5.00	MA	2089	1256	3606	996	4435	805	5054	639	6043	358	5616	144	6713
3E		MI	1825	1256	3215	981	3916	792	4438	626	5255	343	4840	144	5766
8-# 8	1.76	MA	1578	886	2158	780	2663	650	2930	548	3207	380	2775	144	2708
4L - 2S		MI	1600	886	2321	757	2848	631	3179	529	3606	367	2785	144	2433
8-# 9	2.22	MA	1629	939	2309	814	2843	675	3139	565	3484	378	3144	144	3229
4L - 2S		MI	1681	939	2542	788	3119	653	3502	543	4037	363	3219	144	3015

RECTANGULAR TIED COLUMNS 18" × 20"

Short columns – no sidesway
Bending on major or minor axis

f'_c = 4,000 psi f_y = 60,000 psi
ϕM in inch-kips ϕP in kips

BARS	RHO	AXIS	Max Cap ϕM	Max Cap ϕP	0% fy ϕM	0% fy ϕP	25% fy ϕM	25% fy ϕP	50% fy ϕM	50% fy ϕP	100% fy ϕM	100% fy ϕP	$.1f'_c$ Ag ϕM	$.1f'_c$ Ag ϕP	Zero Axial Load ϕM
8-#10	2.82	MA	1695	1007	2499	858	3071	707	3405	586	3835	375	3604	144	3864
4L - 2S		MI	1778	1007	2821	828	3462	682	3912	561	4584	359	3768	144	3747
8-#11	3.47	MA	1754	1081	2700	899	3297	736	3660	603	4165	367	3968	144	4465
4L - 2S		MI	1854	1081	3103	866	3793	710	4298	576	5093	351	4282	144	4454
8-#14	5.00	MA	1915	1256	3150	1010	3841	816	4297	656	5011	356	4865	144	5920
4L - 2S		MI	2068	1256	3764	970	4610	785	5277	623	6379	338	5596	144	6192
10-#10	3.53	MA	2161	1088	3519	888	4372	728	5001	592	5993	362	5089	144	5291
2L - 5S		MI	1559	1088	2378	904	2863	744	3175	603	3574	367	3428	144	3927
10-#10	3.53	MA	1979	1088	3142	898	3895	736	4425	598	5217	370	4728	144	5231
3L - 4S		MI	1646	1088	2588	895	3158	732	3524	599	4056	361	3810	144	4228
10-#11	4.33	MA	2074	1180	3472	950	4285	773	4883	619	5821	362	5340	144	6219
3L - 4S		MI	1710	1180	2823	946	3413	775	3835	619	4461	350	4217	144	4900
10-#10	3.53	MA	1872	1088	2876	908	3548	744	3981	610	4611	372	4384	144	4836
4L - 3S		MI	1741	1088	2821	887	3462	726	3912	588	4584	362	4110	144	4578
10-#11	4.33	MA	1953	1180	3151	961	3867	781	4350	633	5094	363	4879	144	5630
4L - 3S		MI	1817	1180	3103	937	3793	761	4298	609	5093	352	4619	144	5402
10-#14	6.25	MA	2191	1399	3787	1099	4648	881	5273	698	6324	351	6154	144	7583
4L - 3S		MI	2036	1399	3764	1070	4610	858	5277	668	6379	337	5936	144	7133
10-#10	3.53	MA	1757	1088	2637	918	3210	758	3582	616	4060	381	3912	144	4492
5L - 2S		MI	1899	1088	3147	878	3875	719	4411	584	5257	356	4443	144	4629
10-#11	4.33	MA	1831	1180	2863	972	3460	797	3869	638	4430	371	4358	144	5111
5L - 2S		MI	1994	1180	3492	928	4285	755	4894	605	5895	348	5085	144	5501
12-#10	4.23	MA	2130	1168	3519	949	4372	773	5001	622	5993	367	5496	144	6238
3L - 5S		MI	1701	1168	2705	954	3276	781	3675	626	4247	364	4095	144	4756
12-#10	4.23	MA	2035	1168	3252	959	4024	781	4558	634	5388	369	5155	144	5815
4E		MI	1785	1168	2914	946	3571	769	4024	622	4729	358	4465	144	5069
12-#11	5.20	MA	2144	1279	3602	1022	4438	826	5040	662	6023	359	5794	144	6802
4E		MI	1871	1279	3213	1008	3905	820	4430	648	5263	346	4992	144	5904
12-#10	4.23	MA	1929	1168	3013	968	3687	795	4159	640	4837	378	4692	144	5462
5L - 3S		MI	1870	1168	3147	937	3875	763	4411	612	5257	359	4768	144	5448
12-#11	5.20	MA	2024	1279	3314	1033	4031	842	4559	667	5359	367	5276	144	6271
5L - 3S		MI	1966	1279	3492	999	4285	806	4894	638	5895	349	5399	144	6374
14-#10	4.94	MA	2193	1249	3629	1009	4501	818	5135	657	6164	366	5926	144	6799
4L - 4S		MI	1836	1249	3031	1004	3689	818	4175	650	4920	361	4763	144	5589
14-#10	4.94	MA	2088	1249	3390	1019	4163	832	4736	663	5613	375	5473	144	6437
5L - 4S		MI	1919	1249	3241	996	3985	806	4524	646	5402	355	5123	144	5915
14-#11	6.07	MA	2211	1378	3765	1095	4601	888	5249	696	6288	364	6196	144	7437
5L - 4S		MI	2027	1378	3602	1069	4398	865	5025	677	6064	342	5770	144	6913
16-#10	5.64	MA	2243	1330	3767	1069	4640	869	5312	687	6390	372	6256	144	7416
5E		MI	1968	1329	3358	1055	4102	855	4674	674	5593	358	5434	144	6427

(1) "0% f_y" indicates zero tension in bars on the tension side, "50% f_y" indicates 50% f_y stress in bars on the tension side, and "100% f_y" indicates 100% f_y stress (i.e., balance point) in bars on the tension side.
(2) L = long face, S = short face, E = each face; 3E = 3 bars each face; 2L-3S = 2 bars each long face and 3 short face.